Electronic Filing: Received, Clerk's Office 11/22/2021 **AS 2021-05**

Exhibit
A

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-005
Petition of Electric Energy, Inc.	)	(Adjusted Standard)
For a Finding of Inapplicability or, in the	)	
Alternative, an Adjusted Standard from	)	
35 Ill. Adm. Code Part 845	)	

AFFIDAVIT OF LAUREN HUNT MARTIN

I, Lauren Martin, certify under penalty of perjury pursuant to Section 1-109 of the Illinois Code of Civil Procedure, 735 ILCS 5/1-109, that the statements set forth in this affidavit are true and correct, and further state that if called upon to testify in this matter, I would competently testify as follows:

1. I am employed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency") as an Environmental Protection Geologist II in the Hydrogeology and Compliance Unit ("HCU") within the Groundwater Section of the Bureau of Water, and I am located in Springfield, Illinois. I have been employed by the Illinois EPA since February of 2020.

2. I have a Bachelor of Science degree in geology from Western Illinois University and a Master of Science in hydrogeology from Illinois State University. My curriculum vitae is attached (Attachment 1) for further detail about my training and experience.

3. As a Geologist in the HCU, my duties include: providing review of hydrogeologic assessments and reports, and providing technical input on the same as well as special projects requiring hydrogeologic and engineering geology expertise; providing construction, engineering geology, and hydrogeologic expertise to Bureau of Water permit programs (industrial, mines and municipal) and Public Water Supply permits; responding to questions from the regulated community, public and other governmental agencies about the provisions of the Illinois Environmental Protection Act ("Act"), Illinois Groundwater Protection Act (ILGPA), and Illinois

Pollution Control Board ("Board") rules adopted thereunder; project management of sites subject to corrective actions under the Act or Board rules; testifying before the Board on proposed rules and in various proceedings; and assisting in the implementation of source water protection programs.. As part of these duties, I served as a witness on behalf of the Groundwater Section in support of Illinois EPA's proposed Part 845 throughout the Illinois Pollution Control Board's rulemaking proceedings in R2020-019.

4. I have reviewed the Petition of Electric Energy, Inc. for a Finding of Inapplicability or, in the Alternative, an Adjusted Standard from 35 Ill. Adm. Code Part 845 ("Petition"), along with its supporting documents.

5. I have personal knowledge of the facts set forth in Illinois EPA's Recommendation to the Board as stated below.

6. Figure 2-5 of Petitioner's Exhibit 2 displays drawings illustrating that the Joppa West Ash Pond ("JWAP") was created using embankments in conjunction with a natural topographic depression. Figure 2-3 of Petitioner's Exhibit 2 shows that the design holds CCR and liquids. The embankments have not been removed and the natural topographic depression still exists under the CCR fill.

7. The JWAP (including the settling basin and the larger CCR surface impoundment collectively known as the Joppa West Ash Pond) allows the collection and holding of storm water and CCR material, and the intermingling of storm water and groundwater, within the CCR surface impoundment.

8. Field verification of the compressive strength of materials that are encountered during test pitting and soil sampling assist in the verification of the compaction of the fill materials *in situ* and provide insight on the manner of placement. Materials that are placed by wet sluicing

would not have been compacted as a part of placement. Materials that are dry placed will necessarily compact to some extent due to material handling equipment and may be intentionally compacted to allow for more capacity to store the material and will not be expanded for water saturation.

9. Appendix D of Petitioner's Exhibit 2 contains test pit logs. Test Pit Log 13 documents flowable ash at 2.5 feet. Several other test pit locations were either terminated at 2.5 to 3 feet below ground surface, with "wet" (saturated) conditions or increased moisture conditions encountered. Flowable ash represents saturated, very soft ash (very loose or uncompacted ash) below the water table. Test pit logs did not provide compressive strength field testing results.

10. Attachment 3 of Petitioner's Exhibit 3 contains boring logs, well diagrams, well development, and abandonment forms. Boring logs provide field compressive strength testing for clays and silts. The results of field compressive strength testing of the materials that were tested confirmed the lack of compaction within the JWAP.

11. According to the boring logs from XTPW01 and XSB02, the JWAP contains ash at 0.8 to 35 feet below ground surface ("bgs") and 2.5 to 40 feet bgs, respectively. Groundwater level during drilling was 1.5 feet bgs at XTPW01: moist to wet was logged for XTPW01 at 1.5 to 10 feet bgs, with "wet" being logged after that, signifying that saturated conditions were encountered during drilling. Sonic drilling was performed at the location making notation of other saturation indications not possible. No water level is indicated at XSB02 due to the drilling method (also sonic) and smaller diameter of the drilling rods causing soil samples retrieved to be dried out. XTPW01 was drilled through the middle of the JWAP, XSB02 was drilled on the south side of the JWAP, and no borings were available for review of the material within the settling basin on the

south end of the JWAP. No other borings presented in Petitioner's Exhibit 3 were logged and investigated within the JWAP (including its settling basin).

12. Attached to the Recommendation as Exhibit B ("Rec. Ex. B") is a Phase I Hydrogeological Assessment Report for the Coal Combustion Product Impoundments at the Joppa Generating Station in Joppa, Illinois, dated July 23, 2013 and submitted to Illinois EPA on July 30, 2013. This report is kept by the Illinois EPA in the regular course of business, and it is the regular course of business of the Illinois EPA to transmit the information thereof to be included in this record. The 2013 Hydrogeological Assessment Report, submitted to Illinois EPA on July 30, 2013 and attached to the Recommendation as Exhibit B, is an exact duplicate of the original.

13. My review of the boring logs of the wells surrounding the JWAP confirm that the JWAP is surrounded by clay material. The 2013 Hydrogeologic Assessment Report for the Joppa Station provides site-specific hydraulic conductivity of the clay materials (5.9×10^{-6} centimeters per second ("cm/s"). *See* Rec. Ex. B at ES-1. Additionally, the blow count values collected during drilling of wells G101, G111, G112B, G112C and G113 reveal that the clay materials encountered at 0 to 50 feet just outside of the JWAP have greater compaction than the materials in the JWAP. *See* Ex. B, App. B The compaction and the hydraulic conductivity indicate that most of the groundwater recharge comes from precipitation and infiltration.

14. Though vegetation exists and has formed an organic layer, it has not prevented erosion of the berms or the surface of the JWAP. CCR material eroded from erosional pathways over uncompacted materials enables the CCR material to travel from the JWAP to Outfall 011 by way of the storm water runoff at the JWAP. Erosion pathways are not always mature enough to be visible from an aerial photograph. Erosional pathways are preferential flow paths for stormwater runoff within the CCR surface impoundment. In many areas, erosional pathways are likely exposed

CCR due to the lack of thickness in the overlying organic sediments that have developed naturally since sluicing of CCR stopped. Though CCR is no longer sluiced to the JWAP, liquids that enter the JWAP flow to low areas, likely carrying eroded CCR material, where they are decanted for discharge. *See* Pet. Ex. 2, Fig. 2-4. Decanting of water from within the impoundment is the same process that was taking place when CCR was being sluiced to the impoundment. Due to the inadequate vegetative cover, transport of CCR necessarily occurs during the erosional processes, likely resulting in its discharge during the decanting process.

15. Table 3.1 of Petitioner's Exhibit 4 identifies monitoring well TPZ117D as the only monitoring well finished in the upper aquifer ("UA"). Figure 3.5 displays TPZ117D as not being directly down gradient of the JWAP, although TPZ117D is nested with TPZ117,. TPZ117 is installed in the upper confining unit (UCU) and does have exceedances. Because TPZ117D is not installed in the same hydrogeologic unit as the rest of the monitoring wells at the JWAP, at least an upgradient well, near G-101 and another downgradient well, near G112C, are required for adequate hydrogeologic characterization of the UA.

16. Groundwater flow direction must be based on a minimum of three wells in the same geologic formation. To have a potentially approvable GMZ under Part 620, the owner or operator would have to conduct additional site investigation and assessment of the UA to assure that contaminants from the JWAP are not migrating through the UCU into the UA, in addition to any other required activities.

17. A sufficient soil cover at the JWAP should provide a barrier to groundwater infiltration at the JWAP. The barrier then reduces or eliminates the influx of water with higher amounts or varied amounts of dissolved oxygen. The dissolved oxygen changes the groundwater geochemistry potentially spurring microbial and geochemical processes. The microbial and/or

geochemical processes may enable the potential release of additional metals from the JWAP CCR material to the groundwater downgradient.

18. Topsoil is produced from vegetation, composed of partially decomposed organic materials and thus is not a clay material with a hydraulic conductivity that would prevent infiltration. The JWAP is fully saturated with static groundwater recharged directly through the CCR material in the JWAP, and the JWAP cover is not sufficient to prevent infiltration. However, the mass of heavy metals and other constituents listed in Section 845.600 may have reduced because of mass transport and geochemical processes over the last 45 years. The extent of constituents listed in Section 845.600 remaining above GWPS should be fully investigated. Total metals, as opposed to dissolved metals, in accordance with Section 845.640(i) should be used to compare with Section 845.600 GWPS.

19. Table 3 of Petitioner's Exhibit 3 presents data collected during the 2010 to 2013 Hydrogeologic Assessment and groundwater analytical from samples collected during March 2021. Data from the March 2021 sampling event exhibits what would be GWPS exceedances for pH, arsenic, boron, lithium, molybdenum, and selenium at the source well, XTPW01. What would be exceedances of antimony, arsenic, boron, lead, cobalt, beryllium, and sulfate are present at downgradient wells, TPZ114, G112C, TPZ116, and TPZ117. There are no exceedances in TPZ117D, exhibiting that there is no direct downward vertical hydraulic gradient carrying contamination vertically downward. Alternatively, geochemical reactions and/or microbial processes within the source material and source groundwater may be resulting in the exceedances of several heavy metals in downgradient wells. The reactive transport of metals at the JWAP has not been investigated fully, as the full extent of the total metals has not been characterized.

20. The basic requirements for geochemical monitoring, or groundwater stabilization parameters, have been a part of the Part 620 standards since its inception. The additional field stabilization parameters, dissolved oxygen and oxidation-reduction potential, are required for adequate determination of collection of a representative sample at each individual monitoring well and adequate characterization of geochemical conditions. The additional field stabilization parameters are required for groundwater sampling under Part 257. The necessity for reporting of groundwater stabilization parameters are imperative now that the published materials on geochemistry and metals transport has definitively determined that the existence of reactive transport of metals. I have provided two such published works as Recommendation Exhibits E and F in support of the Agency's Recommendation and the necessity of reporting groundwater stabilization parameters.

21. The Human Health Risk Assessment ("HHRA") presented in Petitioner's Exhibit 4 uses mostly dissolved data collected between 2010 and 2013 and does not accurately present the data collected at the JWAP, omitting G112B and XPTW01 and not addressing what would be exceedances of the GWPS. Table 3.2, which is based on detections and not exceedances of the GWQS or GWPS, summarizes the mostly dissolved metals groundwater data, while omitting the majority of downgradient data from the groundwater results and providing an outsized proportion of cross gradient and upgradient data from outside of the groundwater plume. The arsenic detection limit is above the GWPS and GWQS for the samples collected from 2010 to 2013. G112B was replaced by G112C at the beginning of 2013, skipping one sampling event in the fourth quarter of 2012. The arsenic analytical samples at G112B are above the GWPS and GWQS in six out of nine dissolved samples collected from 2010 to 2012. In the remaining three samples, the laboratory reporting limit exceeded the GWPS, meaning effectively no sample was collected and analyzed

for arsenic during those quarters. The samples collected at TPZ117D should not be compared to other samples, as the samples were collected from a different aquifer. Because the majority of sample analytical data that is used for the evaluation is based on dissolved parameters and not total analytical parameters, the data cannot be used to accurately predict whether precipitation of cobalt is occurring or whether there is a source material that is not adequately characterized at the JWAP, primarily because cobalt is not appearing in dissolved form.

22. The HHRA was based mostly on dissolved metals concentrations and general chemical parameters listed in Section 620.410 and excluded data for monitoring well G112B, which has been abandoned and replaced with well G112C. The abandonment of G112B and installation of G112C was completed with Agency approval for the purpose of the hydrogeologic assessment. G112C still has what would be Section 845.600 GWPS exceedances for cobalt and boron, and also exceeds for boron, cobalt and other parameters monitored under Section 620.420. The use of limited groundwater data, and four quarters of sampling data at G112C compared to twelve quarters of data at upgradient and cross gradient wells (G111, G101, G113), does not accurately weigh the risk associated with the direct downgradient exceedance of multiple GWQS and GWPS.

23. Only one round of sampling for total metals concentrations has been conducted at JWAP. The total metals and general chemical constituents were collected in March 2021. There is an extreme change in pH between the JWAP source well and the downgradient wells indicating a potential for a corrosive environment. The source well is not exceeding all the same constituents as the down gradient wells. Thus, the results of the analyses provided an initial characterization of the potential geochemical complexities that need further investigation.

24. Attached to the Recommendation as Exhibit Y is a draft representation and geospatial configuration I created, utilizing the February 2020 Google Earth image, EEI's March 2021 sampling data and estimated boring locations. Exhibit Y is a fair and accurate depiction of the March 2021 data set and the corresponding sampling locations at the Joppa Station.

25. Exhibit Y is a geospatial configuration of what would be exceedances of Section 845.600 at the JWAP. The pH at the source, XTPW01, was 11.1, whereas the pH at the other wells were 7+-0.3, signifying an acidic groundwater environment that is changing the pH in the source to as low as 6.7 at TPZ117. Exhibit Y also shows that the JWAP groundwater at the source and downgradient is either actively changing due to unknown geochemical parameters and/or the source material has not been adequately characterized. Geochemistry must be understood to eliminate reactive transport of the metals constituents at the West Ash Pond.

26. Attached to the Recommendation as Exhibits N through V are aerial photographs of the Joppa Station from October 1971 through February 2020 that I obtained from Google Earth and Illinois Department of Transportation. I utilized the publicly available resource to create demonstrative exhibits identifying the Joppa West Ash Pond ("JWAP"). Other than the identification markers I added to the images, Recommendation Exhibits N through V provide exact duplicate images of those obtained from Google Earth or Illinois Department of Transportation.

27. Exhibit N shows the Joppa Station in operation in October 1971. The JWAP is evident with wet CCR material being placed through wet placement methods. The plant is operating with emissions flowing out of the stack at the plant. There is a pond to the northeast of the JWAP that is in the same location as the pond associated with the discharge from Outfall 011 that NPDES Permit IL0004171 was modified to include in 1993. The pond functions to collect stormwater runoff from the JWAP and discharges to the Ohio River ("discharge pond").

28. Exhibit O shows the Joppa Station in operation in August 1980. The settling basin on the south side of the JWAP still has water in it. There is erosional surface scarring apparent in the aerial photograph depicting the surface water drainage throughout the JWAP to the low areas. The JWAP is still exposed on the north side with evidence remaining of wet placement of CCR material placement. The northeast pond identified in Exhibit N remains present in the 1980 aerial photo.

29. Exhibit P shows the Joppa Station in operation in March 1993. The settling basin on the south side of the JWAP still has water in it. There is erosional surface scarring apparent in the aerial photograph depicting the surface water drainage throughout the JWAP to the low areas. The JWAP has ponding in several locations but also has vegetation growing on the north and south sides. Just northeast of the JWAP is a discharge pond for draining of the remaining water in the JWAP on the north side. The pond is in relatively the same location as the previously mentioned pond to the northeast of the JWAP but has been modified to encompass a smaller area and a road separates it from the JWAP.

30. Exhibit Q shows the Joppa Station in operation in November 1998. The erosional surface scarring apparent in Exhibit P remains present and leads to low points of ponding at the JWAP. The settling basin on the south side of the JWAP still has water in it. The JWAP has become fully overgrown and has two utility corridor landscaping strips evident crossing it from southeast to northwest. The discharge pond and discharge from the JWAP is still present.

31. Exhibit R shows the Joppa Station in operation in March 2005. The erosional surface scarring apparent in Exhibits P and Q remains present and leads to low points of ponding at the JWAP. The settling basin on the south side of the JWAP still has water in it. The JWAP has become fully overgrown and has two utility corridor landscaping strips evident crossing it from

southeast to northwest and connecting with a third. The discharge pond and discharge from the JWAP is still present.

32. Exhibit S shows the Joppa Station in operation in May 2015. The erosional surface scarring apparent in Exhibits P, Q and R remains present but heavily vegetated and leads to the discharge pond just northeast of the JWAP. The settling basin on the south side of the JWAP is overgrown with vegetation and no water is evident. The JWAP has become fully overgrown and has two utility corridor landscaping strips evident crossing it from southeast to northwest and connecting with a third. The discharge pond and discharge from the JWAP is still present.

33. Exhibit T shows the Joppa Station in operation in March 2017. The erosional surface scarring apparent in the earlier aerial photographs remains present but heavily vegetated and leads to the discharge pond just northeast of the JWAP. The settling basin on the south side of the JWAP is overgrown with vegetation and no water is evident. The JWAP has become fully overgrown and has two utility corridor landscaping strips evident crossing it from southeast to northwest and connecting with a third. There is an exposed spot on the northwest corner. The discharge pond and discharge from the JWAP is still present.

34. Exhibit U shows the Joppa Station in operation in September 2018 and Exhibit V shows the Joppa Station in operation in February 2020. The erosional surface scarring apparent in the earlier aerial photographs remains present but heavily vegetated in both aerials and leads to the discharge pond just northeast of the JWAP. The settling basin on the south side of the JWAP is overgrown with vegetation and no water is evident. The JWAP has become fully overgrown and has two utility corridor landscaping strips evident crossing it from southeast to northwest and connecting with a third. The exposed spot on the northwest corner is covered with low lying vegetation. The discharge pond and discharge from the JWAP is still present.

35. Petitioner's Exhibit 2, an Expert Engineering Evaluation for Adjusted Standard for Part 845, also performs an aerial photography review of the site. Illinois EPA does not necessarily agree with the aerial findings that the JWAP has not received ash or CCR materials since October 15, 2015. The sediments discussed in Petitioner's Exhibit 2 correlate with the exposed area shown in Exhibit T. *See* Pet. Ex. 2 at 4. The material was dredged "from the Ohio River near the original discharge structure" and placed within the JWAP. Petitioner's Exhibit 2 does not provide a date for this dredging and placement of material in the JWAP. However, Exhibits S and T indicate that the vegetation was cleared to provide space for the dredged sediments to be placed within the JWAP after October 15 or November 15,2015 and before April 2016 or between October 15/November 15, 2016 and March 2017 due to US Fish and Wildlife Service vegetation clearing guidance for locations where the endangered species use the trees present as habitat. This sediment, which likely contains CCR material, was likely placed after the enactment of Part 257 and has likely been covered with an undetermined amount of fill material as seen in Exhibit T. *See* Rec. Ex. T, U, and V. Additionally, NPDES Permit No. IL0004171 currently authorizes discharge from the "former ash pond," indicating that the sediments include materials from the former ash pond, JWAP.

36. When the Joppa Station ceased operation of the JWAP in 1973, the whole of the JWAP was not graded; portions were graded leaving low areas with standing water on both ends of the JWAP. While portions of the JWAP were graded for the utility corridor, the ponding of water is still apparent in Exhibits O (1980), P (1993), Q (1998), and R (2005). Upon close inspection, Exhibits O through V show erosional pathways leading to low areas. As the JWAP becomes more vegetated, the erosional surfaces are covered from view by trees, but still have greener and heavier vegetation following the relative same paths easily seen in earlier aerial photographs. Petitioner's Exhibit 2 shows storm water flow paths to the permitted outfall for

stormwater and other water from the JWAP. With the lack of cover and exposed CCR sediments, CCR is likely travelling out of the JWAP and into the outfall or streams leading to the outfall.

37. During the course of the Hydrogeologic Assessment, EEI did not evaluate the JWAP CCR material for leaching, geochemical changes to the groundwater over distance or for exposed sediments.

38. The cost estimate in Petitioner's Exhibit 2 assumes that the infiltration from precipitation through the surface of the CCR surface impoundment is not significant and that the groundwater chemistry is homogeneous and stable, which is contradictory to the data collected in March 2021. The March 2021 data shows an acidic groundwater environment with potential leaching of heavy metals occurring. Cobalt, lead, beryllium, antimony, and sulfate occur downgradient of the source well which may be indicating that leaching of the aforementioned metals and general chemistry parameters is occurring. Those heavy metals and general chemistry parameters occurred downgradient above GWPS. Arsenic is also above GWPS both within the CCR surface impoundment and down gradient of the JWAP. At best, the JWAP CCR surface impoundment has not been fully characterized to understand where the cobalt, lead, beryllium, antimony and sulfate are originating.

39. I reviewed the Source Water Assessment Protection Program ("SWAP") website that identifies surface water intakes and potable wells in the state. Attached to the Recommendation as Exhibit Z is a screenshot of the SWAP website, which is a fair and accurate depiction of the SWAP website and the distance from the Joppa Station to the CWS River Intake Zone 1 Protection Area.

40. According to the SWAP website. The Ohio River at the JWAP flows northwest to the Mississippi River entering a Community Supply Well River Intake Zone 1 Protection Area

within 5 miles of the JWAP. *See* Rec. Ex. Z. The JWAP is discharging to the Ohio River upstream of the protected area. The potential for discharge constituents associated with CCR material from the JWAP to be present in the Ohio River from Outfall 011 is not included in the Conceptual Site Model or Section 3.2 of Petitioner's Exhibit 4. Surface water sampling included mercury only at Outfall 011 and sampling was ceased prior to 2015. Thus, the exposure pathway has not been fully examined.

41. Groundwater has not been fully investigated at this time to substantiate the conclusions of the HHRA or compliance with regulatory limits presented in the Petition. Until March 2021, groundwater samples were filtered, and reported as dissolved, and are not representative of the total metals and general chemistry constituents. Additionally, characterization of the geochemistry of the groundwater has not been completed. Geochemistry must be understood to eliminate reactive transport of the metals constituents at the JWAP.

42. A sufficient evaluation of the organic clay cover and/or remaining heavy metals within the CCR materials of the JWAP and groundwater would require sufficient groundwater results exhibiting the efficacy of the cover or lack of remaining heavy metals for transport in the groundwater. The evaluation should include five years of quarterly analytical data for total metals and general chemical parameters in accordance with Section 845.600. Sufficient data would typically be a minimum of 10 data points for each groundwater season (low season and high season) to properly characterize the effects of precipitation, infiltration, potential flooding, and other potential groundwater recharge impacts at the JWAP.

FURTHER AFFIANT SAYETH NOT

Lauren Hunt Martin
LAUREN HUNT MARTIN

11/22/21
DATE

State of Illinois
County of Sangamon

Subscribed and Sworn to before
me this 22nd day of November 2021.

Dawn A. Hollis
Notary Public

DAWN A. HOLLIS
MY COMMISSION EXPIRES 03-21-2025

Attachment

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CURRICULUM VITAE

LAUREN HUNT MARTIN, M.S.

1021 N Grand Avenue East
Springfield, Illinois 62704
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
Springfield, Illinois
Environmental Protection Geologist II
February 2020 to Present

Ms. Martin has been employed as an engineering geologist in the construction materials testing and geotechnical engineering consulting since 2001 and has been employed as a geologist and hydrogeologist in the environmental consulting industry since 2005. Ms. Martin started at the Illinois EPA in February 2020. During the short time that Ms. Martin has been at the Illinois EPA, Ms. Martin assisted in updates to the Part 845 regulations, implementation of Part 845, implementation of Part 620, and amendments to Part 620. Ms. Martin is involved as project manager for mines, industrial and municipal sites for ongoing support and decision making.

Professional History

Jacobs Engineering (Formerly CH2M)
Chicago, Illinois
Geologist
August 2005 to January 2020

Subject Matter Expert, Bedrock Geology, Confidential Federal Client, Iowa, August 2016 to January 2020. Jacobs Engineering is performing the site investigation for a Remedial Investigation for a large active military installation. Ms. Martin was subject matter expert for the investigation into bedrock. Ms. Martin also assisted in implementation of vegetation clearing, site safety management, site investigation management.

Task Coordinator and Technical Expert, Confidential State Client, Wisconsin, January 2017 to January 2020. Phase I Update for ongoing transportation design project. Ms. Martin wrote and consulted on the proposal and Phase I Update for the client deliverable.

Task Coordinator and Assistant Project Manager, LUST Site, Confidential Federal Client, Illinois, August 2017 to January 2020. Jacobs Engineering is performing the site investigation and corrective action for a LUST site in western Illinois at a former large active military installation. Ms. Martin was the task coordinator and assistant project manager. In a technical role Ms. Martin assisted in providing guidance in closing with monitored natural attenuation coupled with other possible closure alternatives.

Task Coordinator and Project Manager for H&S, Confidential Private Client, Cook and DuPage Counties, Illinois, 2012 to January 2020. Jacobs Engineering is the Design Corridor Manager for a premier transportation project for a confidential private client. Ms. Martin was the Task Coordinator various tasks including serving as the Project Manager for Safety, coordinated the combined geotechnical and environmental field investigation at O'Hare International Airport in 2014 and the follow up environmental field investigation in 2016 including evaluations of soils pursuant to 35 Ill. Admin. Code 1100. Ms. Martin was the task manager for combining the geotechnical and environmental field investigation for the borrow source material along and near the project right of way including identifying design needs and environmental testing needs to comply with 35 Ill. Admin. Code 1100. Coordination consisted of logistics for implementation of field work, work planning, and reporting including coordinating with the client and guiding internal team to ensure design needs were met. Logistics included meeting with Chicago Department of Aviation, FAA, Illinois Tollway, Illinois Department of Transportation, and coordination of access and runway closures for the purpose of field events.

Project Manager and Task Manager, Confidential Private Client, Illinois, February 2008-December 2016. Project site is a liquids terminal near Chicago, Illinois. Site has had many spills of various chemicals over the years around loading racks for railcars and semi-trucks and docks for loading barges. Ms. Martin managed tasks and projects including proposals, emergency environmental compliance response, site remediation, and site characterization. Emergency compliance response included overseeing emergency soil removal actions and subsequent reporting and regulatory agency coordination. Site remediation included emergency spill clean-up, construction of a geomembrane, and mentoring of junior staff on implementing construction plans. Site characterization included installing wells, drilling boreholes, gauging NAPL, and collecting groundwater data requiring mitigation of a multitude of gases, chemicals and subsequent safety hazards associated with chlorinated solvents, petroleum products and proprietary chemicals.

Assistant Project Manager, Site Superintendent, Construction Quality Manager, and Site Safety and Health Officer, Confidential Federal Client, Illinois, September 2014 to September 2016. The Project included the remediation of a railyard within a former military base for coal containing arsenic. Ms. Martin was the assistant project manager during work planning and reporting. During the construction phase, Ms. Martin was the site superintendent, construction quality manager, and site safety and health officer managing all site operations and contractors.

Technical Hydrogeology Lead, Confidential Federal Client, Illinois, August 2010 to July 2014. Project was a former Radar School for the military during WWII. Ms. Martin designed and implemented the technical approach for closure of the site. Ms. Martin wrote and presented environmental data findings and proposed plan to the public in the public meeting. The Site went to a No Further Action Record of Decision in 2013/2014.

Site Characterization Site Manager, Confidential Private Client, Middle East, January to July 2009. The Project involved the design of four new nuclear reactors and surrounding support structures at two proposed sites. Ms. Martin provided oversight and review of project documents for the site characterization during the field investigation and work planning for four new nuclear reactors at two proposed sites. The field investigation included geotechnical, hydrogeologic, geologic, biologic, geophysical and meteorological data collection and analyses.

Geotechnical Field Investigation Lead, Confidential Private Client, Abu Dhabi, UAE, August to November 2008. The Programme was a $2+ billion Design/Build Tunneling Project for the City of Abu Dhabi in the United Arab Emirates. Ms. Martin led the field investigation including management of contractors from various countries of origin for the first one third section of the 25 mile long tunnel design on behalf of the programme ensuring that the field documentation and laboratory testing was completed as per the tunneling and geotechnical engineer's specifications.

Field Team Member, Field Team Leader, and Task Lead Assistant, Confidential Power Plant, Confidential Location, May-August 2006 and December 2006 to February 2007. The Project involved the design of two new nuclear reactors and surrounding support structures at an existing nuclear power plant. Ms. Martin actively participated in and led various tasks during the Final Safety Analysis Report field work and report construction. Tasks included data collection, data validation, software validation, data analyses and task management.

Various other Geotechnical and Environmental projects. 2005 to 2019. Ms. Martin provided project support, field investigation leadership and implementation to a variety of geotechnical and environmental projects aside from the aforementioned, performing groundwater sampling, geotechnical field sampling and drilling, well installations, quality control and quality assurance field oversight.

Nicor 2004
Hudson Gas Storage Field, Hudson, Illinois
Reservoir Engineering Intern

Ms. Martin worked as a Reservoir Engineering Intern for the Summer of 2004 for Nicor. Ms. Martin’s work tasks included supervising the seismic survey crew for her thesis, learning Geographix Software, reducing and analyzing data from the well logs for the various gas storage fields.

Whitney and Associates, Inc.
Peoria, Illinois
Engineering Geologist and Construction Inspector

Ms. Martin performed various concrete, soils, and asphalt quality assurance and quality control inspections at commercial and federal construction sites. Ms. Martin operated an IDOT and ASTM certified soils and concrete laboratory.

Education

Bachelor of Science, Geology, Western Illinois University

Master of Science, Hydrogeology, Illinois State University

Publications

Peterson, Eric, Lauren I. Martin, and David Malone. Identification of Potential Vertical Gas Migration Pathways Above Gas Storage Reservoirs, World of Engineering, 2015.

Certifications

OSHA 10-hour Construction Safety Awareness, 2005

OSHA 30-hour Construction Safety, 2015

USACE Construction Quality Manager, 2015-2020

WHMIS Certification (safety certification required for environmental site work in Canada), 2010

Additional Training

OSHA HAZWOPER 40-hour Training, 2005; 8-hour Refresher Training, Annually 2006 to 2019

First Aid/CPR Training, Annually or Biannually 2005 to 2019

Munitions Safety Awareness, 2011

Bloodborne Pathogens, 2018

Dangerous Goods Shipping, 2017

Fire Extinguisher Use Training, 2018

Arsenic, 2018

Asbestos, 2005

Behavior Based loss Prevention Systems Training, 2007

Benzene, 2013

Electrical Safety, 2017

Ergonomics Training, 2005

Excavation Safety Training, 2005

Fall Protection Safety Training, 2005

Field Awareness Safety Training, 2005

Global Harmonization Training, 2013

Hand Safety, 2018

Hazard Communication Training, 2005

Ladder Safety, 2005

Lead Safety, 2016

Manual Lifting Safety, 2016

Military Munitions Rule Training, 2018

Noise/Hearing Conservation, 2014

Personal Protective Equipment Training, 2018

Project Manager Health, Safety and Environment Training, 2013

Railroad Contractor Orientation Training, 2010

Railroad Education for Contractors (On-Track), 2010

Railroad Safety Online Training, 2013

Remediation Waste Management Training, 2018

Respirators-Level C, 2018

Various Site Safety Coordinator Trainings in accordance with 29 CFR 1920, every 3 years 2005-2018

Smith System Small Vehicle Backing and Forward Motion Trainings, 2012

Subcontractor Management Training, 2010

Traffic Control Training, 2013

Waste Management Training, 2018

Exhibit
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IEPA - DIVISION OF RECORDS MANAGEMENT
RELEASABLE

MAY 25 2017

REVIEWER: JMR

PHASE I HYDROGEOLOGICAL ASSESSMENT REPORT

Coal Combustion Product Impoundments
Joppa Generating Station
Joppa, Illinois

Project No: 2126

July 23, 2013

RECEIVED

JUL 30 2013

DIVISION OF PUBLIC WATER SUPPLIES
ENVIRONMENTAL PROTECTION AGENCY
STATE OF ILLINOIS

NATURAL
RESOURCE
TECHNOLOGY
ENVIRONMENTAL CONSULTANTS

234 W FLORIDA ST.
MILWAUKEE, WI 53204
(P) 414.837.3607
(F) 414.837.3608

PHASE 1 HYDROGEOLOGICAL ASSESSMENT REPORT

COAL COMBUSTION PRODUCT IMPOUNDMENTS
JOPPA GENERATING STATION
JOPPA, ILLINOIS

Project No. 2126

Prepared For:

ELECTRIC ENERGY INC
and
AMEREN ENERGY GENERATING COMPANY

Prepared By:

Natural Resource Technology, Inc.
234 W Florida St
Milwaukee, WI 53204

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Bruce R. Hensel, PG
Principal Hydrogeologist

EXECUTIVE SUMMARY

Background and Objectives

Electric Energy Incorporated (EEI) and Ameren Energy Generating Company own and operate the Joppa Generating Station in Joppa, Illinois. The coal-fired power station currently operates one impoundment for coal combustion product (CCP) management purposes, and has another impoundment that is no longer in service. To assess the potential for constituent migration from the impoundments as requested by the Agency in their correspondence dated April 10, 2009 and a follow-up letter on January 25, 2013, EEI commissioned a hydrogeologic study, water well survey, development of a groundwater monitoring plan, and an initial groundwater quality assessment. This report reviews 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.

Hydrogeology

Site-specific data were supplemented with geologic data from EEI's nearby landfill facility and published regional data to develop a conceptual model of geology and groundwater flow at the CCP impoundments. Site specific data were collected at seven monitoring wells (G101, G111, G112B, G113, G151, G152, and G153) installed in June 2010. Groundwater samples were collected from these monitoring wells for nine consecutive quarters from August 2010 through August 2012 to establish a statistical baseline for groundwater quality. Monitoring wells G112B and G153 were subsequently determined to be returning groundwater samples that were not representative of the uppermost water bearing formation beneath the CCP impoundments, and were abandoned and replaced with G112C and G152B in January 2013. Two additional quarters of groundwater quality samples were collected from the remaining original and new replacement monitoring wells in March and May 2013.

Three hydrostratigraphic units have been identified in the vicinity of the CCP impoundments:

- The uppermost hydrostratigraphic unit is approximately 50 or more feet thick and is composed of the Equality Formation and the underlying Metropolis Formation. These units consist of predominantly clay and silty clay with some minor intervals of sandy clay. This surficial groundwater unit extends downward to the McNairy Formation, which was not intercepted by any of the borings advanced around the CCP impoundments. The geometric mean hydraulic conductivity of this hydrostratigraphic unit is 5.9×10^{-6} cm/s, suggesting that it is a confining unit.

- The McNairy Formation is the lowest unlithified unit identified in the vicinity of the CCP impoundments and rests on top bedrock. Based on regional data, the McNairy Formation is typically more permeable than the overlying Equality and Metropolis Formations owing to the larger amount of sand and gravel in that unit. This hydrostratigraphic unit is approximately 85 feet thick in the vicinity of the CCP impoundments.

- The third hydrostratigraphic unit is defined by the uppermost bedrock unit, the Salem Limestone, which is the uppermost bedrock unit underlying the Station, and has a reported thickness of 200 to 500 feet.

Groundwater occurs within the uppermost hydrostratigraphic unit at depths of 2.6 to 42.7 feet, depending on monitoring well location. Groundwater flow beneath the CCP impoundments is conceptually south toward the Ohio River, a regional groundwater sink. The CCP impoundments, particularly the east impoundment, are close to the Station property boundary and given expected east-west variations in groundwater flow direction, there may be potential for off-site migration in the event of a release.

Potential for Groundwater Receptors

A search of water well records on file with the Illinois State Geological Survey, Illinois State Water Survey, and Illinois Environmental Protection Agency identified 25 water well records within 2,500 feet of the CCP impoundments. Locations were field verified and no buildings or other evidence of water wells were identified at six of these locations, one location on property recently purchased by EEI where the well will soon be abandoned, and nine wells that are not used for potable water supply, leaving nine wells within the search radius that are may be active and used for potable water supply. In addition, the Ft. Massac and Joppa Water Districts were consulted to verify areas surrounding the impoundments serviced by municipal water; LaFarge Corporation, which owns the water wells west of the impoundments, was consulted to identify the location of potable wells on their property; and Trunkline Gas Pumping Station was consulted to verify the status of wells on their property.

The well search identified no potable water supply wells within 2,500 feet of either CCP impoundment in a position likely to be downgradient. The closest active water supply wells to the CCP impoundments are non-potable, belong to EEI, and are used for plant process water. The closest community water supply well is in the village of Joppa, approximately 3,000 feet to the southeast. Water quality data for this well shows no evidence of impacts from the CCP impoundments.

Groundwater Chemistry

Groundwater monitored in the uppermost hydrostratigraphic unit at the CCP impoundments is classified as Class II because these materials are composed of silt and clay with hydraulic conductivity lower than 1×10^{-4} cm/s. Excluding the August 2010 sample event, which was bailed and produced anomalous samples that were not representative of groundwater quality as indicated by all subsequent samples, exceedances of Class II groundwater quality standards were identified for two constituents at three monitoring wells:

- pH: G113 (1 of 10 samples) and G151 (8 of 8 samples)
- Boron: G112C (3 of 3 samples)

The only Class II groundwater quality standard exceedance potentially related to the CCP impoundments is boron. Boron had three exceedances at well G112C, which is downgradient of the inactive west impoundment, with concentrations of 3.1 to 3.3 mg/L versus a Class II groundwater quality standard of 2 mg/L. In addition, manganese at G112C was high relative to background, although lower than its Class II groundwater quality standard, and may be associated with coal ash leachate. No other constituent at G112C had a concentration that was high relative to background.

The pH values lower than the 6.5 SU standard are not associated with coal ash leachate, which tends to be alkaline. Additionally, boron concentrations at these monitoring wells were at background concentrations (relative to G101), indicating no correlation between pH and the primary coal ash indicator parameter, boron.

Conclusions

The primary conclusion from voluntary monitoring of groundwater at the Joppa Generating Station CCP impoundments is that past operation of the west ash pond has caused a localized exceedance of Class II groundwater quality standards for boron. The west ash pond is no longer in service. There are no exceedances attributed to the east ash pond, which is currently in service. Exceedances of the Class II standard for pH were also observed, but those exceedances are not related to CCP impoundment operation. Furthermore:

- The impoundments are underlain by more than 50 feet of clay-rich deposits. These clays restrict migration of leachate from the impoundment to surrounding groundwater.
- Groundwater beneath the impoundments is conceptually interpreted to flow south toward the Ohio River.
- The exceedances attributed to former operation of the west ash pond were only observed in monitoring well G112C, immediately south and downgradient of the impoundment.
- Manganese concentrations in G112C are elevated relative to background, although less than 2 percent of the Class II groundwater quality standard, and while these concentrations may be naturally occurring due to a reduced hydrogeologic environment, the west ash pond cannot be ruled out as a source of this manganese.
- A search of water well records indicates that there are no potential receptors downgradient, and potential receptors are unlikely within 2,500 feet sidegradient of the east impoundment. Drinking water in this area is provided by the Joppa and Ft. Massac Water Districts.
- There are no potential receptors directly downgradient of the west impoundment. There are active potable wells sidegradient, and within 2,500 feet of the west impoundment. These wells are used for sinks and showers, but not drinking water supply. The property owner brings in bottled drinking water.
- The Station's non-potable water supply wells are the closest water wells downgradient of the CCP impoundments. Water quality data for the Station wells and the closest community water supply well (3,000 feet sidegradient of the east impoundment) indicate very low boron and sulfate concentrations, indicating no evidence of impacts from the CCP impoundments after more than 50 years of service.

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1 INTRODUCTION

1.1 Purpose

Electric Energy Incorporated (EEI) and Ameren Energy Generating Company own and operate the Joppa Generating Station in Joppa, Illinois (Figure 1). The coal-fired plant currently operates one impoundment for coal combustion product (CCP) management purposes, and has another impoundment that is no longer in service. To assess the potential for constituent migration from the impoundments as requested by the Agency in their correspondence dated April 10, 2009 and a follow-up letter on January 25, 2013, EEI commissioned a hydrogeologic study, water well survey, development of a groundwater monitoring plan, and an initial groundwater quality assessment.

The objectives of this report are to:

- Summarize hydrogeologic information pertinent to the site.
- Evaluate groundwater quality data to determine whether or not operation of the impoundment has adversely affected groundwater.
- Determine the potential for off-site migration and whether or not there are potential groundwater receptors in the event of a release.

2 SETTING

Portions of the information in this section were previously presented and have been modified from the CCP impoundment hydrogeologic assessment plan (October 2009) and the hydrogeologic report for the Station's CCP landfill (June 2009) prepared by Hanson Professional Services, Inc. (Hanson).

2.1 Power Plant and CCP Impoundments

The Joppa Generating Station (Station) is located west of the Village of Joppa and northeast of the Ohio River in Massac County, Illinois. The Station lies in Section 14, Township 15 North, Range 3 East of the 3rd Principal Meridian. The Station has two CCP impoundments, the West Ash Pond located in the east half of Section 15 and the East Ash Pond located in the west half of Section 14 directly north of the power plant (Figure 2)

During initial operation of the plant, coal ash was impounded within the levees formed by the construction of the Station railroad loop. The East Ash Pond was later constructed inside the railroad loop.

The West Ash Pond (WAP), encompassing approximately 84 acres, was used from the early 1950's until it was removed from service in the 1970's. The base elevation of the WAP is reportedly 320 feet above mean sea level (amsl). The elevation of the top of the CCP within the impoundment ranges from approximately 362 feet amsl towards the south end to 370 feet amsl at the northern tip, although most of the WAP lies at an elevation of 362 feet amsl. The height of the WAP is approximately 22 feet relative to surrounding grade.

The East Ash Pond (EAP), encompassing approximately 103 acres, was built in two stages. The northern portion (Phase I) was placed into service in late 1973. The southern portion (Phase II) was permitted in May 1985 with completion of construction activities in late 1985. The elevation of the top of the CCP within Phase I of the impoundment ranges from approximately 372 to 380 feet amsl, although most of the CCP lies between 372 and 374 feet amsl. The elevation of CCP within Phase II of the impoundment ranges from approximately 351 to 363 feet amsl, with most of the CCP between 352 and 356 feet amsl. The height of the EAP is approximately 55 feet relative to surrounding grade. The EAP is currently operated in accordance with IEPA NPDES Permit No. IL0004171.

2.2 Regional Geology

The Station 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 (Figure 3)

(Leighton, 1948). Based on stack-unit maps prepared by the Illinois State Geological Survey (Berg and Kempton, 1987) the vicinity of the Station generally has less than 6 meters (<19.7 feet) of silty and clayey diamictons overlying Cretaceous age sediments, silts, sands, etc. between depths of 6 to 15 meters (19 to 50 feet). However, in some areas along the Ohio River, the predominant unlithified materials are Quaternary age sand and gravel outwash deposits belonging to the Henry Formation. The unlithified materials rest on Mississippian age bedrock.

2.2.1 Unlithified Materials

Regionally, unlithified materials consist of diamictons and lacustrine/alluvial deposits. These deposits may exceed 100 feet in thickness. Several deep boring logs within the property boundary of the Station have thicknesses of unlithified materials ranging from 135 to 142 feet. Four principal unlithified deposits exist in the vicinity of the Station: (1) the Equality Formation; (2) Peoria Silt / Roxana Silt / Loveland Silt; (3) Metropolis Formation; and (4) McNairy Formation (Figure 4).

The Equality Formation is the uppermost material encountered in the vicinity of the Station. The Equality Formation consists of silt, clay, and minor amounts of 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 for the landfill approximately ¼ to 1 mile northwest of the WAP (Hanson, 2009a), the thickness of the Equality Formation ranges from 14 to 32 feet.

Contiguous with the Equality Formation are the Peoria Silt, Roxana Silt, and Loveland Silt (these silts are not shown on regional maps of this area, but have been encountered in soil borings in the vicinity of the Station). 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 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, 1999b). The lower contact is unconformable on the McNairy Formation in most places. Age is Pleistocene, Illinoian, and older. Based on thirteen borings advanced approximately ¼ to 1 mile northwest of the WAP (Hanson, 2009a) the thickness of the Metropolis Formation ranges from 25 to 40 feet. 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 CCP impoundments.

The lowermost unlithified unit encountered in the vicinity of the Station is the McNairy Formation, which consists of sands, silts, and clays. The McNairy is Upper Cretaceous in age and consists of very fine- to medium-grained sand, mostly highly micaceous, and ranges 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 a boring advanced to bedrock by Hanson (2009a) approximately 0.7 miles mile northwest of the WAP, the thickness of the McNairy is approximately 76 feet. The drillers log for plant well 4 indicates sand from a depth of 50 to 135 feet, suggesting that the McNairy formation is 85 feet thick south of the CCP impoundments.

Thick outwash deposits of the Wisconsinan aged Henry Formation may be encountered within the Ohio River Valley. These deposits, which are not present beneath the CCP impoundments, consist of sorted and stratified water-laid material that is predominantly sand and gravel.

2.2.2 Bedrock

Bedrock in the region surrounding the Station 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 upper-most bedrock unit near the Station generally consists of limestone. The total thickness of the Mississippian System in southern Illinois is greater than 3,200 ft (Willman et al., 1975).

The uppermost unit encountered in the vicinity of the Station is the Salem Limestone. 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 Station 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).

2.3 Water Resources

2.3.1 Surface Water

The major surface water body in the vicinity of the Station is the Ohio River, which borders the entire Station property to the south. The southern edges of the WAP and EAP are approximately 1,500 and 2,100 feet from the north bank of the Ohio River, respectively, during normal flow. The primary drainage in the area of the WAP is an intermittent stream that runs parallel to the east side of the impoundment and runs south initially and then south-southwest to the Ohio River. The primary drainage in the vicinity of the EAP is a stream that begins between the east portion of impoundment and the railroad loop and runs approximately 1,000 feet south from a culvert beneath the railroad loop before turning to the south-southwest to the Ohio River. This stream conveys discharge water from the EAP.

2.3.2 Groundwater

No surficial aquifers, i.e., aquifers that are present or exposed at the ground surface, are present in the vicinity of the ash impoundments. Berg, Kempton and Cartwright (1984) classified the area as D2 - uniform, relatively impermeable silty or clayey till at least 20 feet thick with no evidence of interbedded sand and gravel. Aquifers in the area of the Station generally fall into two broad categories: (1) intermittent sand and gravel deposits within the McNairy Formation; and, (2) bedrock consisting of limestone and fractured limestone, which vary widely in transmissivity.

No known wells in the area utilize the deposits of the Equality or Metropolis Formation for groundwater. These formations predominantly consist of silt and clay with isolated lenses of sand and gravel, which do not yield large amounts of water. Most wells in the area obtain groundwater from the McNairy sand and gravels or Mississippian limestone, principally the Salem or Ullin Limestones.

2.3.3 Well Search

Public records were searched to identify water wells located within 2,500 feet of the CCP impoundments. The Station Property is located in Township 15 South, Range 3 East, and the CCP impoundments are located within Sections 14 and 15. The 2,500 foot search radius spans across Sections 10, 11, 14, 15, 22, and 23. All water supply wells within these sections are shown on Figure 5 and tabulated in Appendix A.

The following sources of information were queried to identify water well locations and locations near the Station serviced by public water supplies:

- Illinois State Geological Survey's Illinois Water Well (ILWATER) Internet Map Service
- Illinois State Water Survey Domestic Well Database (ISWS)
- Illinois EPA's web-based Geographic Information System (GIS) files
- Illinois Department of Public Health
- Massac County Health Department
- The Joppa Water District
- The Ft. Massac Water District
- LaFarge Corporation, located immediately west of the Station
- Trunkline Gas Pumping Station, located north of the west ash pond

Records were identified for 68 wells within the six sections surrounding the unlined ash ponds. Twenty of the 68 wells were identified as monitoring wells associated with the Station's landfill. In addition, 9 wells on the LaFarge property west of the power plant were identified as test holes rather than water wells. These 29 wells are not shown on Figure 5 but are listed in Appendix A, Table A-1. The remaining wells are current or former water wells listed for industrial/commercial use or farm/domestic use.

A follow-up field survey was performed to visually verify the locations of water wells within the search radius (Appendix A). During this survey, personnel from the Joppa and Ft. Massac Water Districts were consulted to identify locations served by these districts. This survey identified:

- Eight records with incorrect coordinates. New coordinates were obtained using a hand-held GPS unit, and the locations on Figure 5 reflect the corrected coordinates.
- One well (79) that did not appear in the well records search. This well was added to Table A-1 and Figure 5.
- Six locations where no building and no wells could be located. These locations either represent water well records that have incorrect locations listed in the database or were associated with buildings that were abandoned and torn down. These locations are shown in grey on Figure 5.
- One well on property recently purchased by EEI where the building has been removed and the well will be abandoned. This location is also shown in grey on Figure 5.

In addition, the Station wells (including Midwest Electric Power) and Trunkline Gas Pumping Station wells are shown in grey on Figure 5 because they were verified to be non-potable. The Station wells are used only for production water, and the Trunkline Gas Pumping Station wells are not active. Both facilities obtain potable water from the Ft. Massac Water District.

Based on information derived from the well search, there are 25 water wells within a 2,500 foot radius of the two CCP impoundments, nine of which may be active and used for potable water (Figure 5). The water wells range from 52 to 451 feet in depth, with an average depth of 189 feet and a median depth of 158 feet. Of the eight water wells within the search radius with sufficient data to indicate the primary water-bearing zone supplying the well, three are in sand and gravel deposits and five are in limestone.

The closest active water supply wells to the EAP are wells 7 and 8, which are Station wells completed at depths of 350 and 403 feet. These wells supply production water, but are not used for potable water supply. The four active Station wells were sampled in February 2013 for analysis of coal ash indicator constituents, boron and sulfate. Boron concentrations in all four wells were <0.10 mg/L and sulfate concentrations were 6 mg/L (Appendix A). These low concentrations demonstrate that groundwater withdrawn from the Station's water wells is not affected by any release from the CCP impoundments.

There are no active potable wells downgradient of the EAP. The only potentially active potable well within 2,500 feet of the EAP that is not upgradient is well 3, which is sidegradient. This well is not considered a potential receptor because it is sidegradient, rather than downgradient of the EAP and is in an area served by the Joppa Water District.

There are no water wells directly downgradient of the WAP. The closest wells to the WAP are wells 49 and 50. These wells are non-potable and supply production water to the combustion gas turbines at the Station. There are two industrial wells (wells 20 and 75) associated with the LaFarge cement plant immediately west of the Station that are sidegradient of the WAP. The cement plant uses bottled drinking water, while well water is used in sinks and shower facilities as well as for production. The closest of these wells is more than 2,400 feet from the WAP.

Based on state records, there is one community water supply (CWS) well in the sections surrounding the CCP impoundments, but outside the 2,500 foot search radius. Well number 51 on Figure 5 and in Appendix A, Table A-1 is located in the village of Joppa in Section 23, 3,000 feet east of the Station property boundary. According to the IEPA database, CWS well 51 has a minimum setback zone of 200 feet, and a Phase I Wellhead Protection Area (WHPA) of 1,000 ft. The western edge of the WHPA falls within the 2,500 foot search radius. On-line water quality data available for this well[1] indicate low boron (<0.010 to 0.044 mg/L) and sulfate (<10 to 25 mg/L) concentrations, demonstrating that groundwater withdrawn by these wells has not been affected by any release from the CCP impoundments.

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[1] http://163.191.83.31/dww/JSP/WaterSystemDetail.jsp?tinwsys_is_number=717415&tinwsys_st_code=IL&wsnumber=IL1270100

3 MONITORING WELL INSTALLATION, DEVELOPMENT, AND SAMPLING

3.1 Monitoring Well Installation and Development

Seven monitoring wells (G101, G111, G112B, G113, G151, G152, and G153) were installed between June 1 and 25, 2010 (Table 1, Figure 1) by Geotechnology, Inc. (Geotechnology, 2010). At each well location, subsurface borings were advanced with a rotary drill rig equipped with hollow-stem augers to facilitate soil classification. Soil was continuously sampled through the center of the hollow stem auger. Monitoring wells, constructed of 2" inside diameter schedule 40 PVC riser and screen, with steel above-ground well covers, were installed at each location to monitor groundwater within the uppermost water-bearing unit adjacent to the impoundments. All of the monitoring wells were screened within one or more of the following unlithified materials: silty clay, silty/sandy clay, clay or silt. The wells were constructed consistent with monitoring well construction standards per 35 IAC 811.318. Drilling and sampling equipment was decontaminated before sampling and between sample locations to prevent cross contamination. The monitoring wells were surveyed by a licensed surveyor.

In a November 7, 2012 meeting between the Illinois Environmental Protection Agency (IEPA) and EEI, it was proposed by EEI that monitoring wells G112B and G152 be relocated because they were installed beneath fill materials that appeared to be impacting analytical results. Subsequent to that meeting and with the IEPA's approval, wells G112B and G152 were replaced by new monitoring wells G112C and G152B in January 2013 by Natural Resource Technology, Inc. (NRT). The original monitoring wells, G112B and G152 were properly sealed and abandoned at that time.

Monitoring well construction, survey data, and screened formation are summarized in Table 1. Boring logs and well diagrams are included in Appendix B. In addition, copies of the monitoring well sealing forms submitted to the Illinois Department of Public Health are also in Appendix B. Boring depths for the original seven monitoring wells and two replacement wells were between 25 and 50 feet bgs.
A cross-sectional view of the seven current monitoring wells showing ground surface and well screen elevations is provided in Figure 6.

Following installation, the initial seven monitoring wells were developed in June 2010 by surging and pumping a minimum of five well volumes and until specific conductivity stabilized. The depth to groundwater was measured in each monitoring well using an electronic water level indicator. The two replacement wells (i.e., G112C and G152B) were developed on February 7, 2013. Groundwater levels and elevations at all of the monitoring wells at the EAP and WAP impoundments from August 2010 through May 2013 are provided in Table 2.

3.2 Groundwater Sampling and Chemical Analysis

The seven monitoring wells installed in June 2010 were sampled during nine consecutive quarterly monitoring events from August 2010 through August 2012 to establish a statistical baseline for groundwater quality. The monitoring wells were purged and sampled for the first quarterly sampling event on August 17, 2010 using disposable bailers; purging and sampling of wells in subsequent events was through low-flow sampling methods with dedicated bladder pumps. Groundwater levels measured in the seven wells for the first monitoring event ranged from 5.46 to 42.68 feet bgs (Table 2).

During the first monitoring event each well was purged until three well volumes were removed. Water quality parameters including pH, specific conductivity, and temperature were monitored in the field. In subsequent monitoring events, starting with the 4th Quarter event in November 2010, the wells were purged until the field parameters stabilized.

Following the completion of baseline sampling in the 3rd Quarter 2012, evaluation of the initial groundwater quality, and approval of the revised monitoring plan by IEPA, monitoring wells G112B and G152 were abandoned and replaced by wells G112C and G152B. Groundwater sampling of the modified monitoring well network was conducted in the 1st and 2nd Quarters of 2013 for inclusion with this hydrogeologic assessment.

Water samples were field filtered for dissolved constituents, unfiltered for totals, and preserved as required for each constituent. Sample containers were labeled, placed in an ice-filled cooler, and transported using standard chain-of-custody procedures. All groundwater sampling events from August 2010 through May 2013 were conducted by Geotechnology, Inc. and sample analyses conducted by Teklab, Inc., located in Collinsville, Illinois. The initial groundwater sampling information and laboratory analytical reports are provided in the Geotechnology, Inc. monitoring report dated October 19, 2010 (Geotechnology, 2010). The groundwater sampling reports for the 1st and 2nd Quarters of 2013 are found in the groundwater monitoring reports by Geotechnology dated March 25 and May 23, 2013, respectively.

All eleven quarters of groundwater samples were analyzed for the inorganic parameters listed under 35 IAC 620.410 with the exception of radium 226/228.[2] Table 3 lists the field, general chemistry, and metal parameters monitored along with the analytical methods.

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[2] Perchlorate and vanadium were added to 35 IAC 620.410 on October 5, 2012, after the groundwater monitoring plan for this site was approved, and therefore were not monitored.

4 SITE HYDROGEOLOGY

4.1 Lithology

The information used to describe site hydrogeology is based on the local geology obtained from published sources as presented in Section 2, supplemented with the boring data collected at the seven current monitoring well locations G101, G111, G112C, G113, G151, G152B, and G153. These seven borings ranged from 25 to 50 feet bgs. The upper portion of two other borings (G112B and G152) were determined to be through fill materials that included some coal and an unknown amount of fly ash. The monitoring wells installed within these two borings were abandoned in January 2013 and replaced by nearby wells G112C and G152B, so the lithology data from the earlier well locations is not included in the following discussion.

Other than an 8.5 foot thick silt layer intercepted at boring G152B at a depth of 4 to 12.5 feet bgs, all geologic materials below the top few feet were logged as clay, silty clay, clayey silt, and sandy clay. Out of a total of 296 feet of unlithified materials logged in the seven borings, the following percentages of materials were described:

- 1.0% fill material at the surface, described generically as "Fill" or gravel, and intercepted at well locations G113 and G151
- 3.5% silt or clayey silt, intercepted at depths of 4.5 to 12.5 feet at well G152B and 38 to 40 feet at well G153
- 5.0% sandy clay, intercepted at depths of 32 to 36 feet at well G113, 36 to 42 feet at well G151, and 32 to 38 feet at well G153
- 90.5% clay and silty clay, intercepted through most of the logged depths of all monitoring well locations at both the EAP and WAP

Bedrock was not encountered in the borings for any of the monitoring wells installed around the EAP or WAP, but limestone bedrock was intercepted as part of another study, approximately 3,500 feet northwest of the WAP, at 142 feet bgs (227 feet amsl), and at a depth of 135 feet bgs (~210 feet amsl) at plant well 4, which is 900 feet south of the EAP. The lowest elevation drilled during the hydrogeologic characterization around the two impoundments was at well G112C, which extended to 299 feet amsl.

The uppermost hydrostratigraphic unit encountered by the monitoring wells installed around the two impoundments is composed of the Equality Formation and the underlying Metropolis Formation (Figure 4), which both consist of predominantly clay and silty clay with some minor intervals of sandy clay. This Surficial Groundwater Unit (i.e., Upper Groundwater Unit) extends downward to the McNairy Formation, which was not intercepted by any of the borings advanced around the EAP and WAP.

The McNairy Formation (i.e., Lower Groundwater Unit) is the lowest unlithified unit identified in the vicinity of the Station and rests on top bedrock. Based on regional data, the McNairy Formation is typically more permeable than the overlying Equality and Metropolis Formations owing to the larger amount of sand and gravel in that unit. The McNairy Formation would be considered the second hydrostratigraphic unit at the Station. The third hydrostratigraphic unit is defined by the uppermost bedrock unit, the Salem Limestone, which is the uppermost bedrock unit underlying the Station.

4.2 Groundwater Flow

Groundwater elevation data (potentiometric levels) were collected from the monitoring wells installed within the uppermost water-bearing unit surrounding the CCP impoundments. Groundwater depths and elevations for the eleven quarterly monitoring events are provided on Table 2 and graphically illustrated in time-series plots on Figure 7 (note: only three and two sample events have been recorded for replacement monitoring wells G112C and G152B, respectively). Groundwater levels were the closest to ground surface at the three wells adjacent to the WAP (G111, G112C, and G113), with water levels for the period of August 2010 through May 2013 ranging from 2.64 to 16.65 feet bgs. Groundwater levels were deepest at the three wells adjacent to the EAP (G151, G152B, and G153), with water levels ranging from 17.08 to 42.70 feet bgs.

Groundwater conceptually flows north to south from topographically higher areas at the north end of the site toward the Ohio River which is topographically lower than the rest of the site and a regional discharge point for groundwater. Topographically upgradient from both the EAP and WAP is monitoring well G101, which is conceptually upgradient of the CCP impoundments. However, groundwater elevations in well G101 were lower than all other monitoring wells during two quarters (February 2012 and May 2013) and were the second lowest of all the wells in the remaining nine quarters (Figure 7). Similarly, G151 and G153 have lower groundwater elevations than G152B which is topographically lower than those wells. This appears to be counter-intuitive given that well G152B is further south and conceptually downgradient from the rest of the wells at the EAP. There are no known high capacity wells north of the station that could explain the groundwater elevations observed in G101 (Section 2.3.3).

Based on the lack of correlation between topography and groundwater elevations, and given that the wells are all screened clay that has very low hydraulic conductivity, it is apparent that the measured groundwater elevations are not reflective of groundwater flow patterns in the upper hydrostratigraphic unit in the vicinity of the EAP. Therefore, groundwater elevation measurements from wells G101, G151, and G153 were not included in the development of the potentiometric surface map in the area of the EAP (Figure 8).

Conversely, the three wells adjacent to the WAP (G111, G113, and G112C) appear to have a consistent correlation between topographic and groundwater elevations. Groundwater elevations are highest in the topographically upgradient well G111, which is located west of the central portion of the WAP, and lowest at the topographically downgradient well G112C, located to the south of the impoundment. Therefore, a potentiometric surface map was prepared for the 2nd Quarter 2013 utilizing the three monitoring wells adjacent to the WAP and well G152B south of the EAP (Figure 8) but excluding the non-representative groundwater elevations at background well G101 and the EAP wells G151 and G153. As seen on the map, groundwater flow in the vicinity of the WAP is south-southwest at a gradient of approximately 0.014 ft/ft.

The conceptual model for groundwater flow beneath both impoundments is southwest towards the Ohio River, with baseflow discharge from the unlithified deposits to the river during most of the year, as conceptualized in Figure 9. Given the close proximity of the CCP impoundments, particularly the EAP, to the Station property boundary and expected east-west variations in groundwater flow direction, there may be potential for off-site migration in the event of a release.

4.3 Potential for Groundwater Receptors

A potential groundwater receptor is a potable water supply well located in a position that can be interpreted as downgradient from the CCP impoundment, and screened within a geologic formation that can reasonably be expected to be a groundwater migration pathway in the event of a release.

As described in Section 2.3.3, Figure 5 shows water wells located within the vicinity of the CCP impoundments. The Station and areas within 2,500 feet both east and west of the CCP impoundments obtain drinking water from the Joppa or Ft. Massac Water Districts; although, the LaFarge cement plant to the west reportedly uses well water for sinks and showering, so these wells would be considered potable. The closest cement plant well is slightly less than 2,500 feet west of the WAP. The only downgradient water supply wells are on the Station property; however, these wells are not potable. Water quality data from these wells shows no evidence of impacts from the CCP impoundments. The closest CWS well is in the village of Joppa, approximately 3,000 feet southeast of the EAP. Water quality data for this well shows no evidence of impacts from the CCP impoundment.

5 GROUNDWATER CHEMISTRY

5.1 Overview

The purpose of the sampling and inorganic analysis of groundwater from monitoring wells at the Station was to assess background and downgradient groundwater quality; to evaluate elevated concentrations and those exceeding groundwater standards; and to identify primary factors potentially influencing groundwater quality changes spatially and temporally.

All of the groundwater quality data collected and analyzed for both field and laboratory parameters, including the full list of inorganic constituents listed in 35 IAC 620.410 except for radium 224/226,[3] are listed in Appendix C for the 11 quarters of monitoring conducted from August 2010 through May 2013. A statistical summary of all of the water quality data at each active monitoring well, including the mean, median, maximum, minimum, standard deviation, and percent non-detects, is provided in Table 4 for the period of November 2010 through May 2013. The first quarterly monitoring event (conducted in August 2010) is not included in the statistical analysis since the wells were purged and sampled using bailers, as opposed to low-flow sampling methods with dedicated bladder pumps in the subsequent 10 events. In addition, monitoring wells G112B and G152 were not included in the statistical analysis or the discussion that follows because groundwater quality in these monitoring wells was affected by the overlying fill materials, and they were subsequently replaced by G112C and G152B.

5.2 Groundwater Classification

As set forth in 35 IAC 620, any geologic material with a hydraulic conductivity of less than $1\text{x}10^{-4}$ cm/sec, and which does not meet the provisions of Section 620.210 (Class I), Section 620.230 (Class III), or Section 620.240 (Class IV), meets the definition of a Class II – General Resource Groundwater. Based on the hydrogeologic information provided below, groundwater within the shallow (<50 feet bgs) unlithified materials in which the monitoring wells are screened is classified as Class II groundwater and the groundwater quality standards set forth in 35 IAC 620.420 are the applicable groundwater quality standards.

Specifically, groundwater monitored at the CCP impoundments is from the clay, silt, and silty clay of the Equality Formation, Peoria/Roxana/Loveland Silts, or the Metropolis Formation, and does not qualify as Class I groundwater because:

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[3] Perchlorate and vanadium were added to 35 IAC 620.410 on October 5, 2012, after the groundwater monitoring plan for this site was approved, and therefore were not monitored.

- The CCP impoundments are not within the minimum setback zone of a well which serves as a potable water supply.
- The monitoring wells are screened in clay and silty clay rather than unconsolidated sand, gravel, or sand and gravel which is 5 feet or more in thickness and that contains 12 percent or less of fines.
- The monitoring wells are not screened in a sandstone which is 10 feet or more in thickness, nor are they screened in fractured carbonate which is 15 feet or more in thickness.
- Hydraulic conductivity was tested in 2010 (Geotechnology, 2010), and ranges from $1.1\text{x}10^{-6}$ to $7.6\text{x}10^{-5}$ cm/s (see table below). The geometric mean hydraulic conductivity for the screened intervals of the monitoring wells is $5.9\text{x}10^{-6}$ cm/s.

Monitoring Well	**Hydraulic Conductivity (cm/sec)**
G101	5.6E-06
G111	1.5E-05
G112B	1.1E-06
G113	6.1E-06
G151	3.1E-06
G152	7.6E-05
G153	1.9E-06
Geometric Mean	*5.9E-06*

Since shallow groundwater in the uppermost water-bearing unit meets the classification criteria of a Class II (General Resource) groundwater, groundwater quality monitored at the EAP and WAP was compared to the Class II groundwater standards.

5.3 Comparison of Groundwater Quality to Class II Standards

Constituents with exceedances of Class II groundwater quality standards between November 2010 and May 2013 are:

- pH: G113 (1 of 10 samples) and G151 (8 of 8 samples); and
- Boron: G112C (3 of 3 samples).

The only exceedance potentially related to the CCP impoundments is boron. Boron had three exceedances at well G112C during the three monitoring events conducted in the first two quarters of 2013, with concentrations of 3.1 to 3.3 mg/L versus a Class II groundwater quality standard of 2 mg/L.

The pH values lower than the 6.5 SU standard at wells G113 and G151 are not associated with coal ash leachate, which tends to be alkaline. Additionally, the boron concentrations at both these wells were at background concentrations (relative to G101), indicating no correlation between pH and the primary coal ash indicator parameter, boron.

5.4 Groundwater Quality Analysis

5.4.1 Primary Coal Ash Leachate Indicators

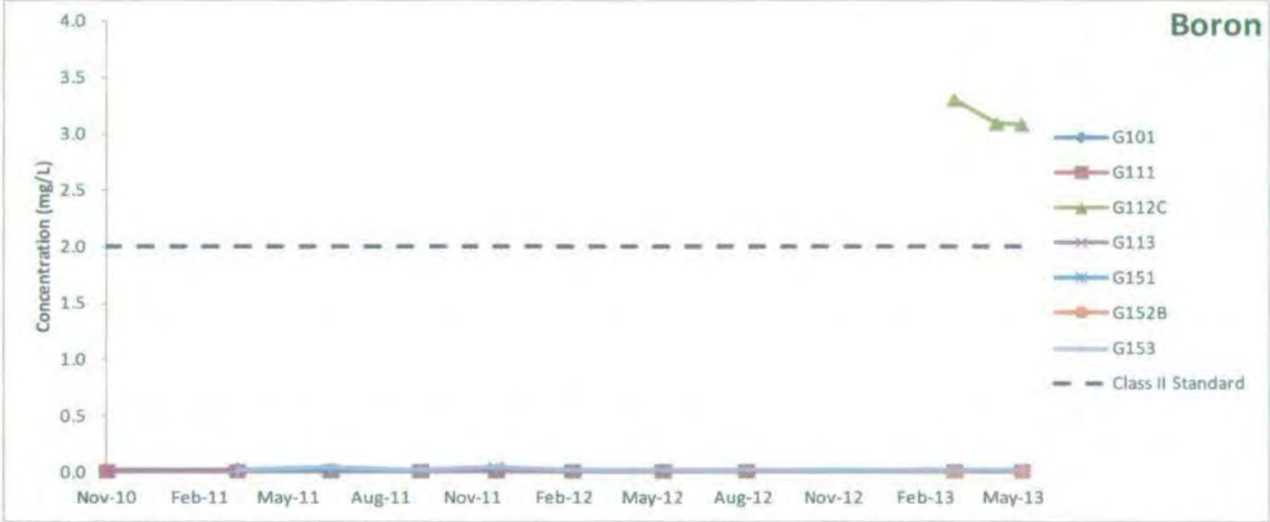
Boron and sulfate are the primary indicator constituents for coal ash leachate. Median boron concentrations in groundwater at the CCP impoundments were mostly lower than the laboratory reporting limit of 0.02 mg/L at all monitoring wells except G112C, located south of the WAP. Only 3 of 46 samples contained boron concentrations above the laboratory reporting limit at the six monitoring wells (other than G112C) collected during ten quarterly monitoring events from November 2010 through May 2013. Those three boron concentrations reported by the laboratory were less than 3 percent of the Class II groundwater quality standard of 2 mg/L.

Median sulfate concentrations were similar to background (as monitored at G101) at G111, G113, and G152B. The highest median sulfate concentrations of 103 and 104 mg/L were observed at wells G151 and G153, respectively, and the highest individual sulfate concentrations (111 mg/L in both instances) were also observed at these wells. All sulfate concentrations observed in groundwater were less than one-third of the Class II groundwater standard.

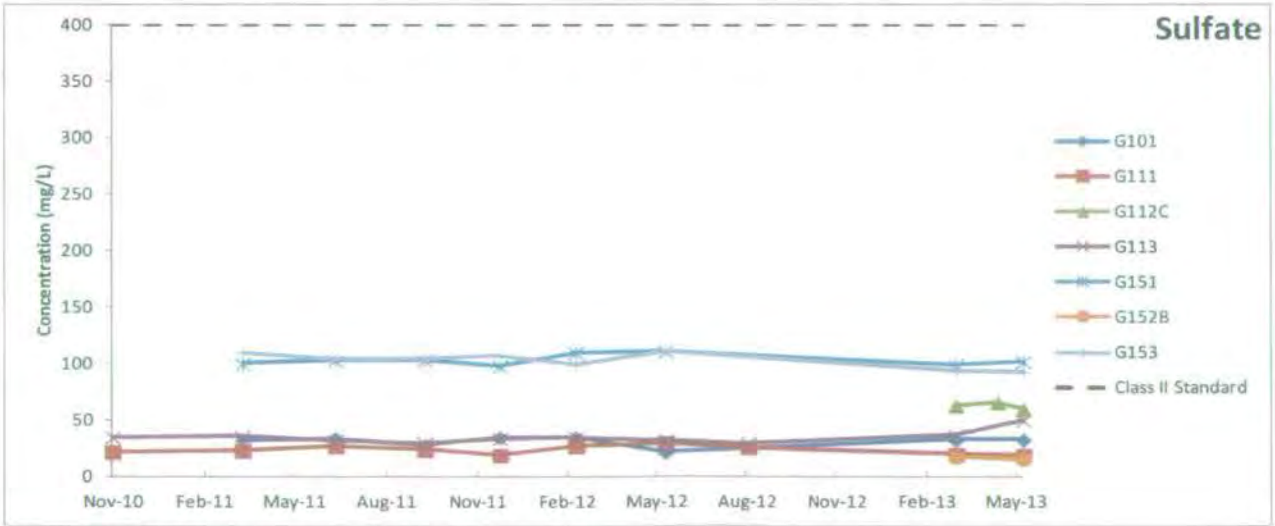
Well No.	**Median Concentration**	
	Boron mg/L	**Sulfate mg/L**
G101	<0.02	33
G111	<0.02	24
G112C	3.1	63
G113	<0.02	35
G151	<0.02	103
G152B	<0.02	17
G153	<0.02	104
IL Class II Standard	*2.0*	*400*

There is no correlation between boron and sulfate concentrations, suggesting that the sulfate concentrations are not related to the boron concentrations. The CCP impoundments are the only likely source of boron in the area, while sulfate has other potential sources. This lack of correlation suggests that boron is the better indicator constituent for the Station's CCP impoundments than sulfate.

Boron and sulfate concentrations were stable during the 2½ year monitoring period, with neither parameter increasing or decreasing significantly. Graphs of boron and sulfate trends are shown below. Most boron concentrations were below the detection limit, with the exception of well G112C where the three samples had similar concentration and no discernible increasing or decreasing trend. Sulfate concentration trends were flat for all monitoring wells.



Graph showing boron concentration versus time. Non-detects are plotted as zero values.



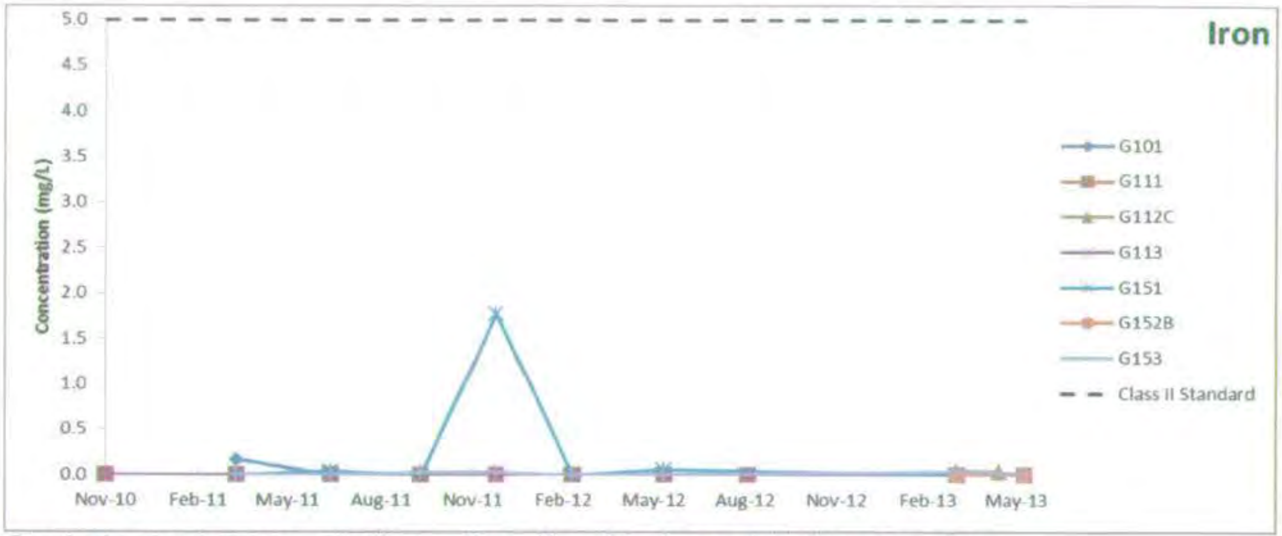
Graph showing sulfate concentrations versus time.

5.4.2 Other Constituents Potentially Impacted by Coal Ash Leachate

Median iron and manganese concentrations were higher in samples from monitoring well G112C than in samples from the other monitoring wells at the Station. G112C also had relatively high boron concentrations that suggest potential for a release from the WAP. However, iron and manganese are sensitive to redox conditions, and exhibit a tendency to have relatively high naturally occurring concentration in reduced hydrogeologic environments.

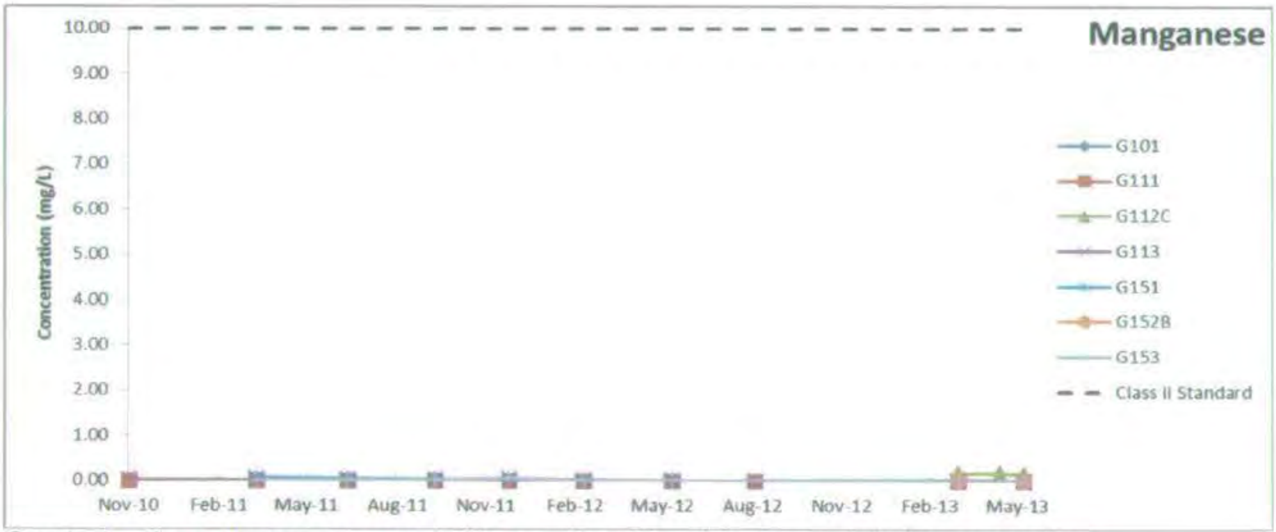
Well No.	Median Concentration	
	Iron mg/L	Manganese mg/L
G101	0.020	<0.005
G111	<0.020	<0.005
G112C	0.039	0.17
G113	<0.020	<0.005
G151	<0.020	0.027
G152B	<0.020	0.010
G153	0.021	<0.005
IL Class II Standard	*5.0*	*10*

Iron concentrations from individual samples in G112C were not high relative to iron concentrations detected in other monitoring wells (see graph below). The median concentration appears relatively high because iron was detected in two of the three samples from G112C, while it was detected in half or fewer of the samples from the other monitoring wells—causing the median value for the other wells to be the reporting limit. The low boron concentrations at the other monitoring wells indicate that iron observed in those wells is not associated with a release from the CCP impoundments, meaning it is likely naturally occurring. Therefore, the iron concentrations at G112C, which are lower than naturally occurring iron concentrations in the other monitoring wells and less than 1 percent of the Class II standard, may also be naturally occurring.



Graph showing iron concentrations vs time. Non-detects are plotted as zero values.

Manganese concentrations in G112C were higher than in the other wells. Given the close proximity of this monitoring well to the Ohio River, where reducing conditions are expected, it is possible that the manganese is naturally occurring; however, the WAP cannot be ruled out as a potential source for the manganese observed in this monitoring well because the concentrations are higher than observed in any other monitoring well, although less than 2 percent of the Class II groundwater quality standard.

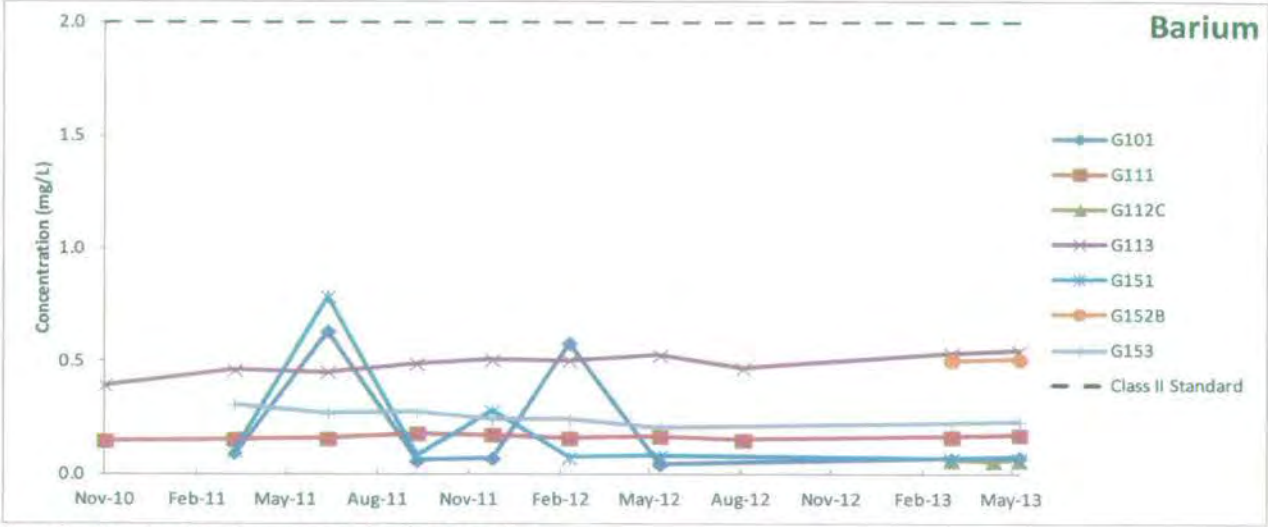


Graph showing manganese concentrations vs time. Non-detects are plotted as zero values.

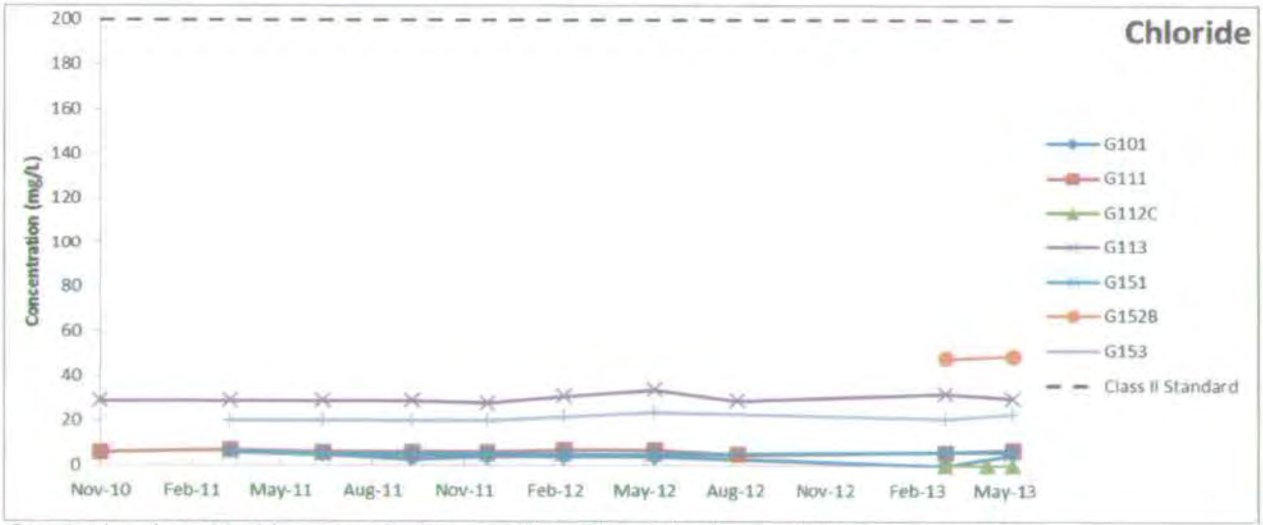
5.4.3 Constituents with Elevated Concentrations Due to Causes Other than Coal Ash Leachate

Barium, chloride, fluoride, and TDS had median concentrations in some downgradient monitoring wells that were higher than the median concentrations in background monitoring well G101. In addition, pH in G151 was low relative to the other monitoring wells. There were no exceedances of Class II groundwater quality standards for barium, chloride, fluoride, and TDS; while pH in G151 (and one sample from G113) was lower than the Class II range. Concentrations in G111, G113, G151, G152B, and G153 are not attributed to coal ash leachate because coal ash indicator concentrations in these monitoring wells are low. The concentrations of barium, chloride, fluoride, TDS, and pH in G112C are not attributed to coal ash leachate because they fall within the range of concentrations observed in the other wells, which are not attributed to a coal ash leachate source.

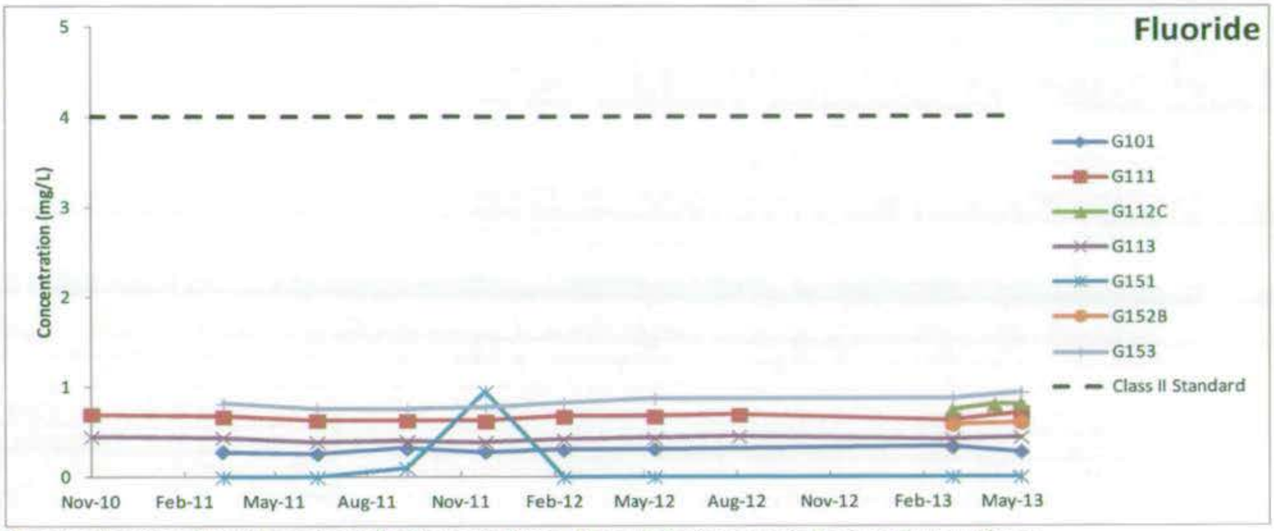
Well No.		**Median Concentration**			
	Barium mg/L	**Chloride mg/L**	**Fluoride mg/L**	**TDS mg/L**	**pH SU**
G101	0.074	4.5	0.29	245	6.97
G111	0.16	6.0	0.67	363	7.09
G112C	0.062	<5.0	0.80	432	6.79
G113	0.50	29	0.43	590	6.57
G151	0.083	5.0	<0.10	248	6.01
G152B	0.51	49	0.59	483	6.81
G153	0.24	21	0.82	433	6.93
IL Class II Standard	*2.0*	*200*	*4.0*	*1,200*	*6.5 / 9.0*



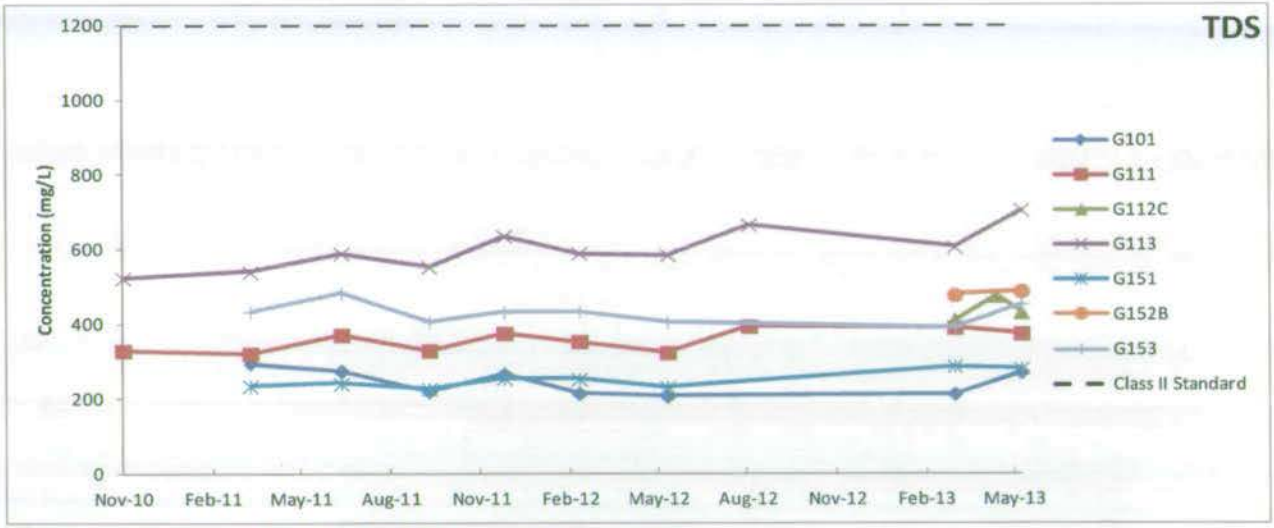
Graph showing barium concentrations vs time.



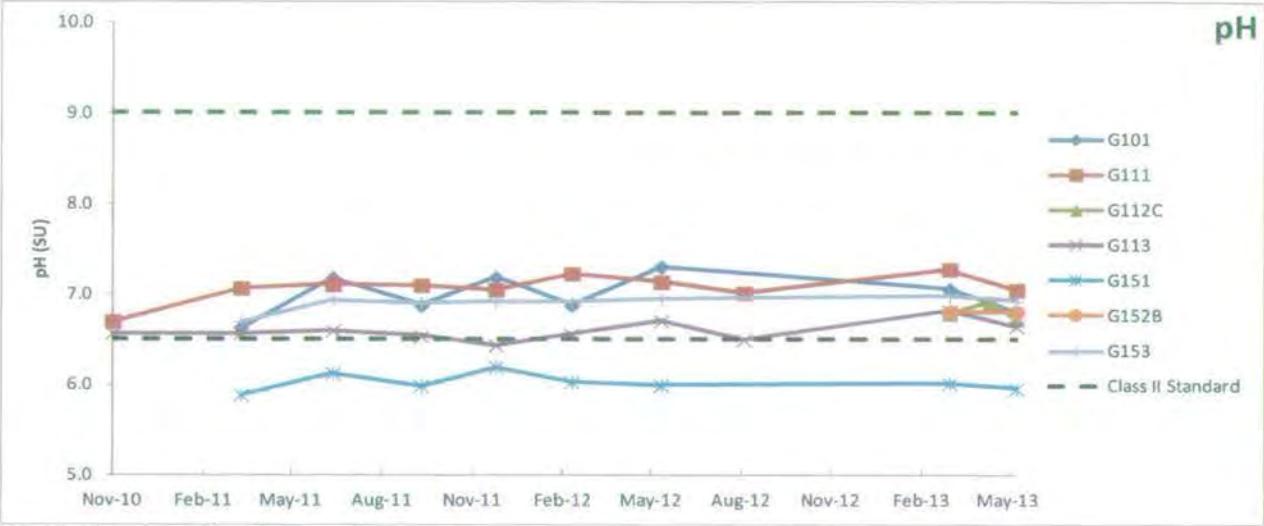
Graph showing chloride concentrations vs time. Non-detects are plotted as zero values.



Graph showing fluoride concentrations vs time. Non-detects are plotted as zero values.



Graph showing total dissolved solids concentrations vs time.

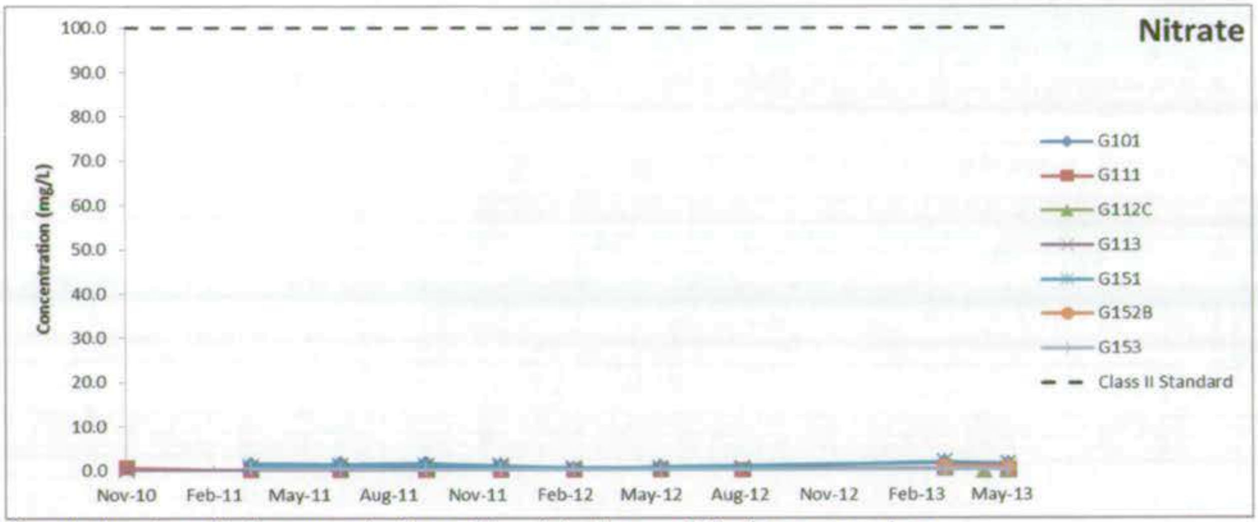


Graph showing pH values vs time.

5.4.4 Constituents with Concentrations Near or Below Background

The median nitrate concentration in background monitoring well G101 was higher than the other monitoring wells, indicating that observed nitrate concentrations are due to a source other than the CCP impoundments. The likely nitrate source is agricultural activity immediately north of this monitoring location.

Well No.	Median Concentration
	Nitrate mg/L
G101	1.5
G111	0.12
G112C	<0.05
G113	0.44
G151	1.1
G152B	0.84
G153	0.28
IL Class II Standard	*100*



Graph showing nitrate concentrations. Non-detects are plotted as zero values.

5.4.5 Constituents That Were Infrequently or Not Detected

Antimony, arsenic, beryllium, cadmium, chromium, cobalt, cyanide, lead, mercury, nickel, selenium, silver, and thallium were below their respective reporting limits in all seven monitoring wells during all ten quarterly monitoring events conducted from November 2010 through May 2013.

		Copper mg/L	Zinc mg/L
G101	Max	n/a	n/a
	% BDL	100%	100%
G111	Max	n/a	0.018
	% BDL	100%	80%
G112C	Max	n/a	n/a
	% BDL	100%	100%
G113	Max	n/a	n/a
	% BDL	100%	100%
G151	Max	0.011	0.017
	% BDL	87.5%	62.5
G152B	Max	n/a	n/a
	% BDL	100%	100%
G153	Max	n/a	n/a
	% BDL	100%	100%
Illinois Class II Standard		*0.65*	*10.*

Copper and zinc had reportable concentrations in one and five samples, respectively, out of 49 possible samples. However, the maximum concentrations of these constituents was more than an order of magnitude lower than the Class II standard.

6 CONCLUSIONS

6.1 Conclusions

The primary conclusion from voluntary monitoring of groundwater at the Joppa Generating Station CCP impoundments is that past operation of the west ash pond has caused a localized exceedance of Class II groundwater quality standards for boron. The west ash pond is no longer in service. There are no exceedances attributed to the east ash pond, which is currently in service. Exceedances of the Class II standard for pH were also observed, but those exceedances are not related to CCP impoundment operation. Furthermore:

- The impoundments are underlain by more than 50 feet of clay-rich deposits. These clays restrict migration of leachate from the impoundment to surrounding groundwater.
- Groundwater beneath the impoundments is conceptually interpreted to flow south toward the Ohio River.
- The exceedances attributed to former operation of the west ash pond were only observed in monitoring well G112C, immediately south and downgradient of the impoundment.
- Manganese concentrations in G112C are elevated relative to background, although less than 2 percent of the Class II groundwater quality standard, and while these concentrations may be naturally occurring due to a reduced hydrogeologic environment, the west ash pond cannot be ruled out as a source of this manganese.
- A search of water well records indicates that there are no potential receptors downgradient, and potential receptors are unlikely within 2,500 feet sidegradient of the east impoundment. Drinking water in this area is provided by the Joppa and Ft. Massac Water Districts.
- There are no potential receptors directly downgradient of the west impoundment. There are active potable wells sidegradient, and within 2,500 feet of the west impoundment. These wells are used for sinks and showers, but not drinking water supply. The property owner brings in bottled drinking water.
- The Station's non-potable water supply wells are the closest water wells downgradient of the CCP impoundments. Water quality data for the Station wells and the closest community water supply well (3,000 feet sidegradient of the east impoundment) indicate very low boron and sulfate concentrations, indicating no evidence of impacts from the CCP impoundments after more than 50 years of service.

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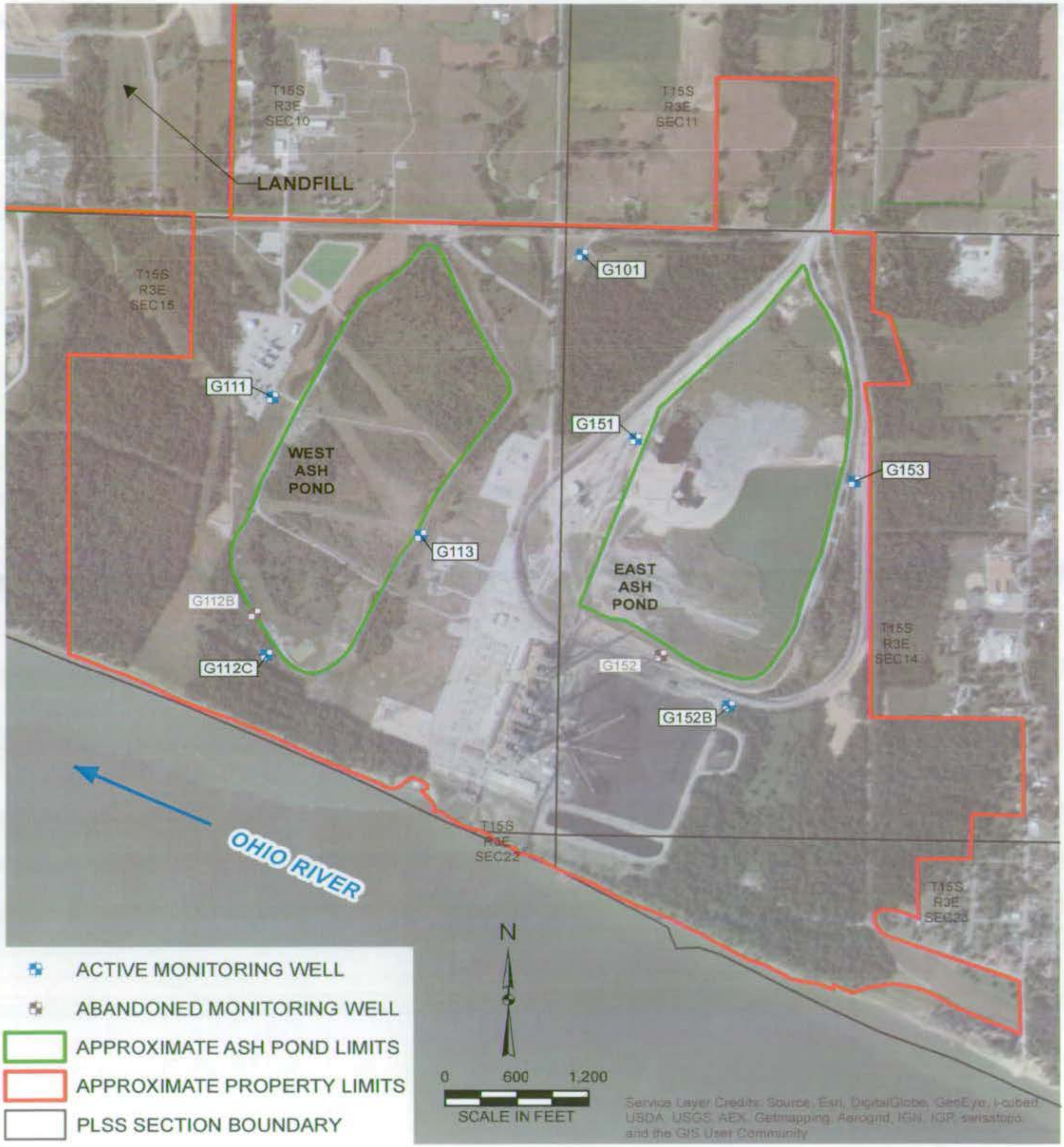

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REVIEWED BY/DATE:
BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

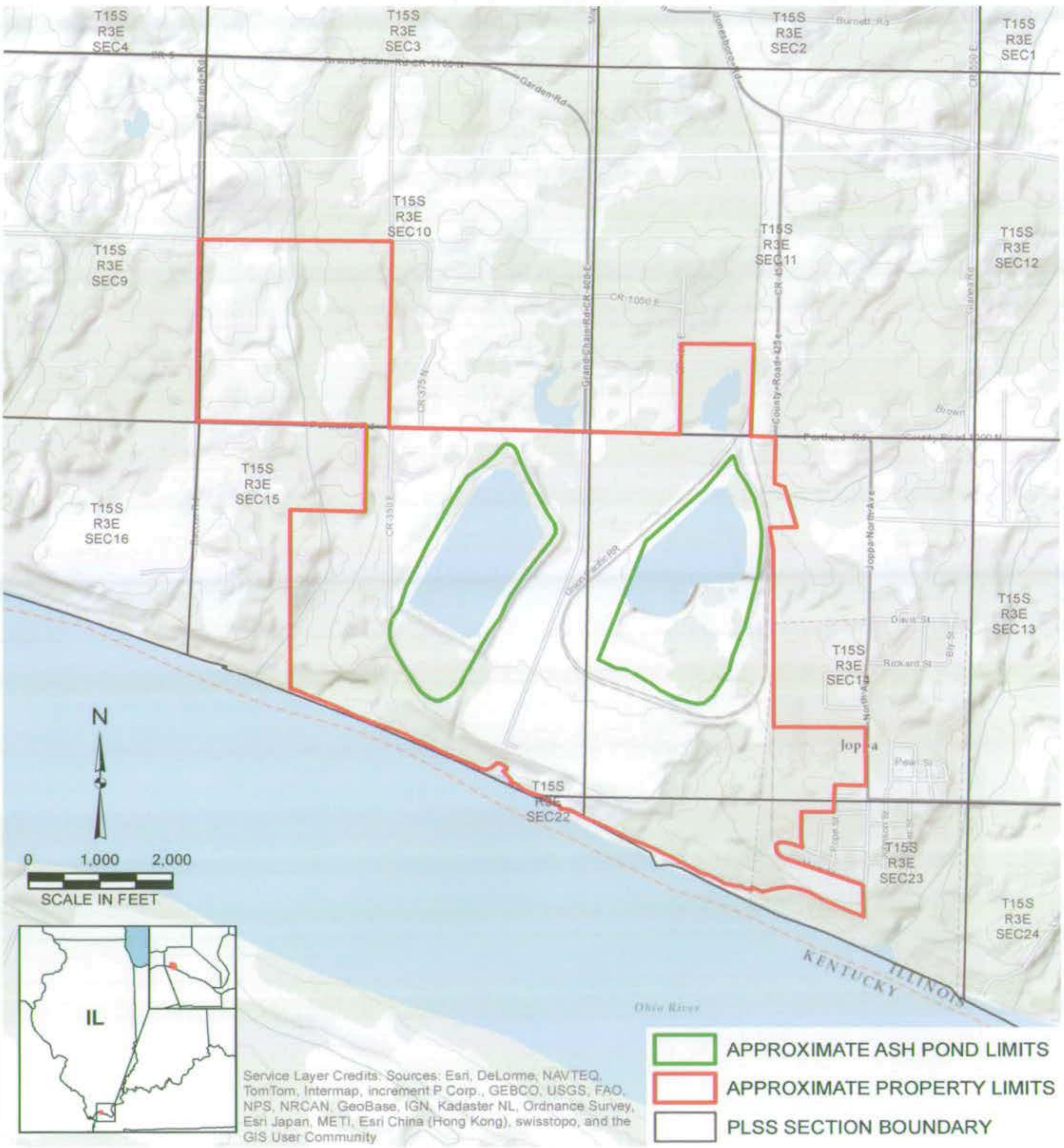
SITE OVERVIEW MAP

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 1

NATURAL RESOURCE TECHNOLOGY



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🟩 APPROXIMATE ASH POND LIMITS
🟥 APPROXIMATE PROPERTY LIMITS
☐ PLSS SECTION BOUNDARY

DRAWN BY/DATE:
TDC 6/18/13
REVIEWED BY/DATE:
BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

SITE LOCATION MAP

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, MASSAC COUNTY, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 2

NATURAL RESOURCE TECHNOLOGY

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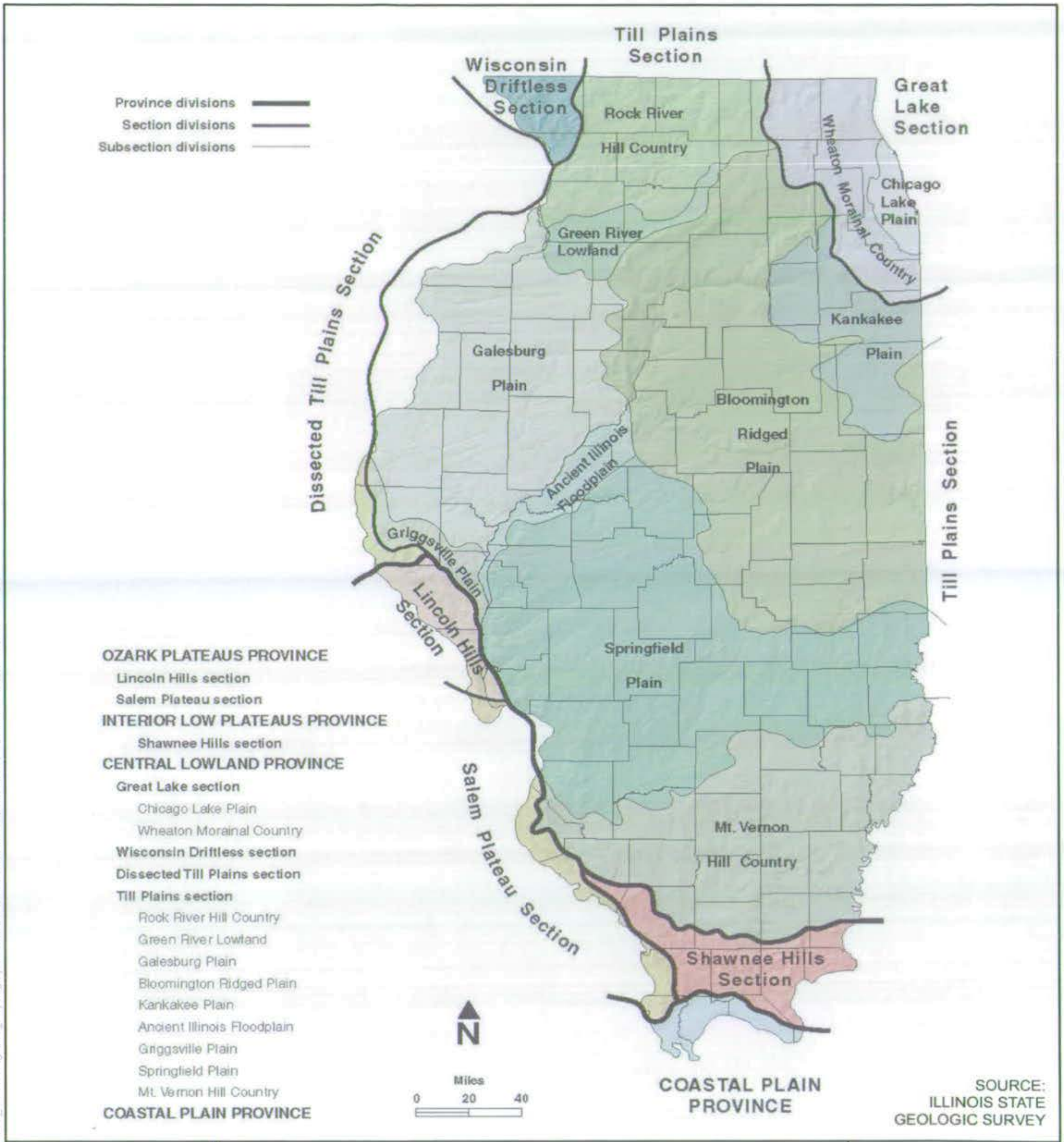

SOURCE:
ILLINOIS STATE
GEOLOGIC SURVEY

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BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

PHYSIOGRAPHIC DIVISIONS OF ILLINOIS

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 3

NATURAL RESOURCE TECHNOLOGY

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GEOLOGIC UNITS			Groundwater Hydrologic Units	Lithology in Vicinity of Impoundments
System	Series / Stage	Formation		
Quaternary	Pleistocene (Wisconsinan, Illinoian, and Pre-Illinoian Glacial Stages)	Equality or Henry *Peoria Silt* *Roxana Silt* *Loveland Silt*	(Upper) Surficial Groundwater Unit	**Equality Fm:** Clay, Silt, minor Sand (14 to 32 feet *Henry Fm (not intercepted at Impoundments): Sand and Gravel Outwash*
		Metropolis		**Metropolis Fm:** Primarily Clay (Diamicton), Some Silty Sand and Sandy Silt, Occasional Gravel Lenses (25 to 40 feet thick)
Tertiary	Pliocene Miocene	McNairy	Lower Groundwater Unit	**McNairy Fm:** Sands, Silts, and Clays (not intercepted at Impoundments): up to 76 feet thick 3/4 miles northwest of West Ash Pond
Cretaceous	Maastrichtian Campanian			
Mississippian	Valmeyeran	Salem Limestone	Bedrock Groundwater Unit	Limestone

DRAWN BY/DATE:
TDC 6/18/13
REVIEWED BY/DATE:
BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

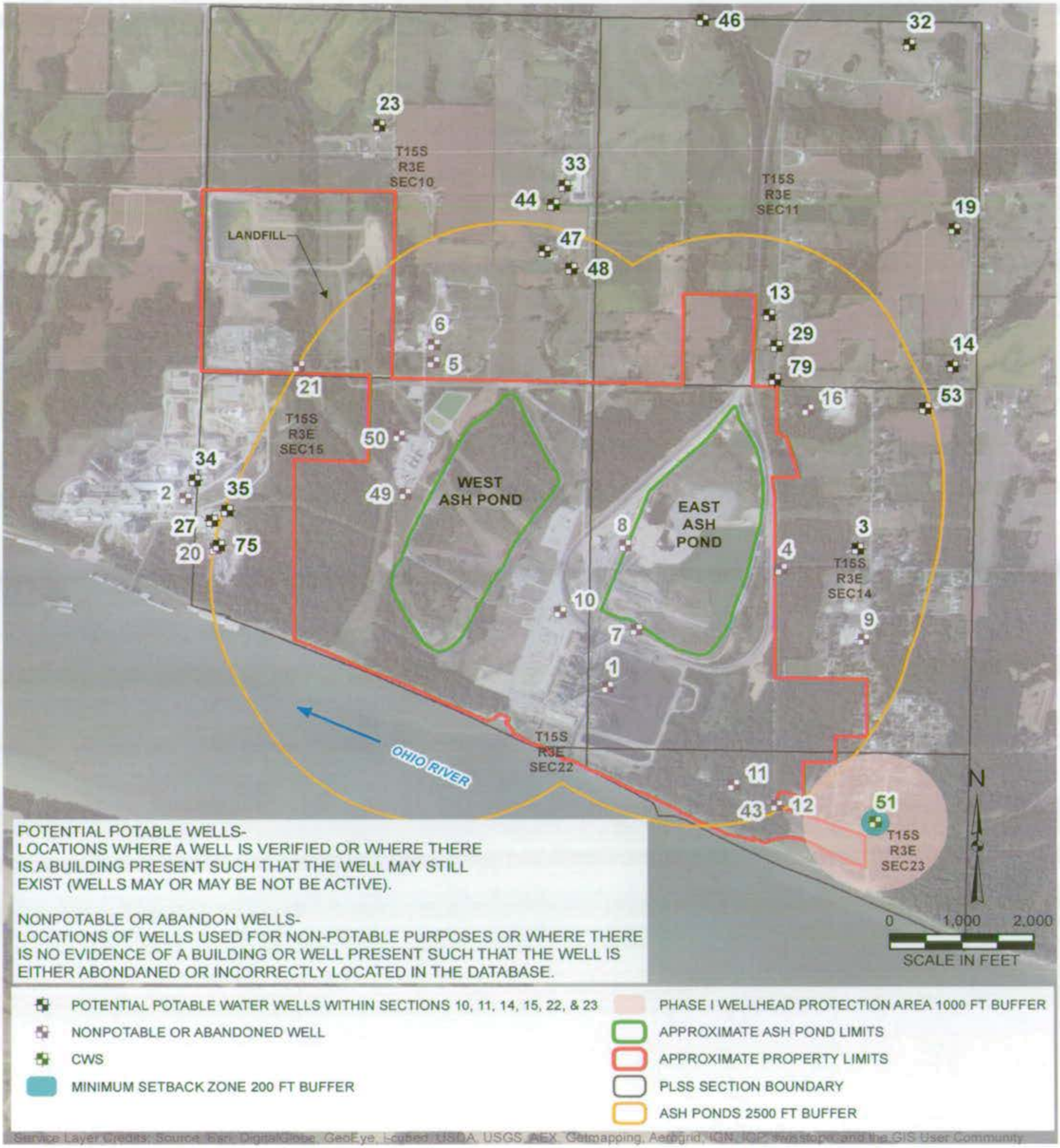
GENERALIZED STRATIGRAPHIC COLUMN

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 4

NATURAL RESOURCE TECHNOLOGY



POTENTIAL POTABLE WELLS-
LOCATIONS WHERE A WELL IS VERIFIED OR WHERE THERE IS A BUILDING PRESENT SUCH THAT THE WELL MAY STILL EXIST (WELLS MAY OR MAY BE NOT BE ACTIVE).

NONPOTABLE OR ABANDON WELLS-
LOCATIONS OF WELLS USED FOR NON-POTABLE PURPOSES OR WHERE THERE IS NO EVIDENCE OF A BUILDING OR WELL PRESENT SUCH THAT THE WELL IS EITHER ABONDANED OR INCORRECTLY LOCATED IN THE DATABASE.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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NDK 7/15/13
REVIEWED BY/DATE:
BRH 7/19/13
APPROVED BY/DATE:
BRH 7/22/13

WELL SEARCH RESULTS

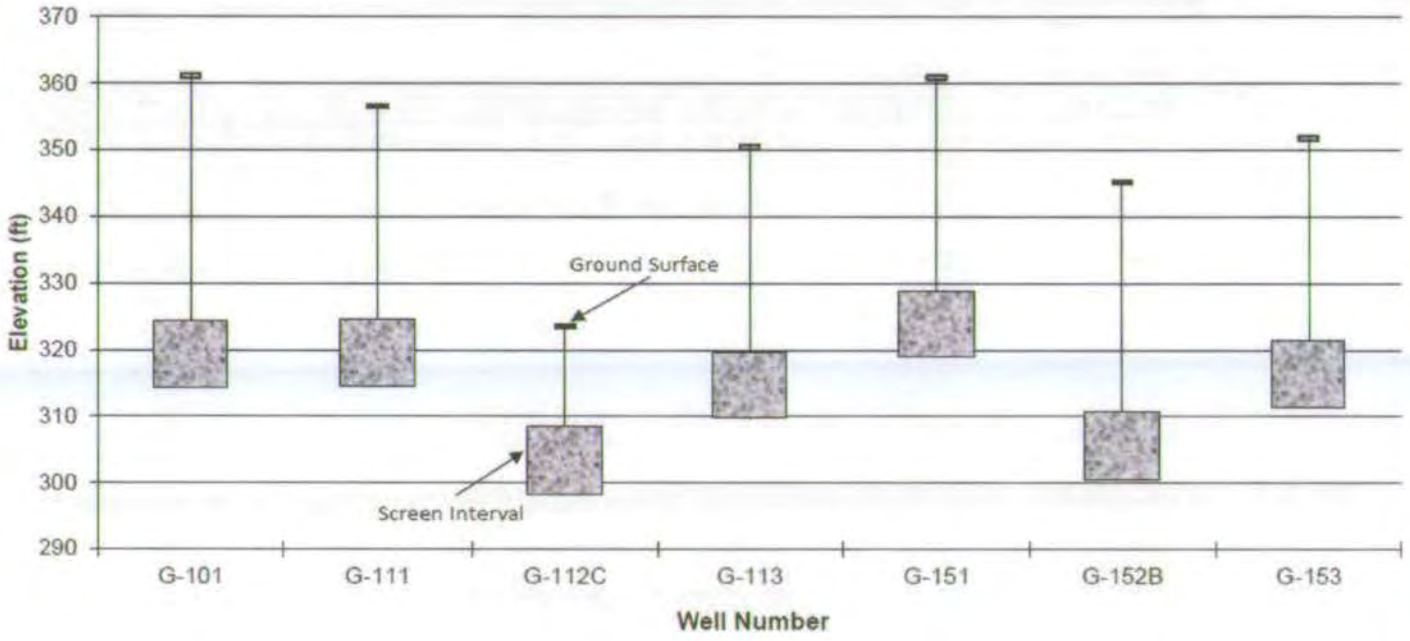
PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 5

NATURAL
RESOURCE
TECHNOLOGY

Y:\Mapping\Projects\21\2126\MXD\HydroGeo_Assmnt\Figure 5_Potable Well Search Results_NDK.mxd; Author: nkron; DateTime: 7/22/2013, 11:17:17 AM



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BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

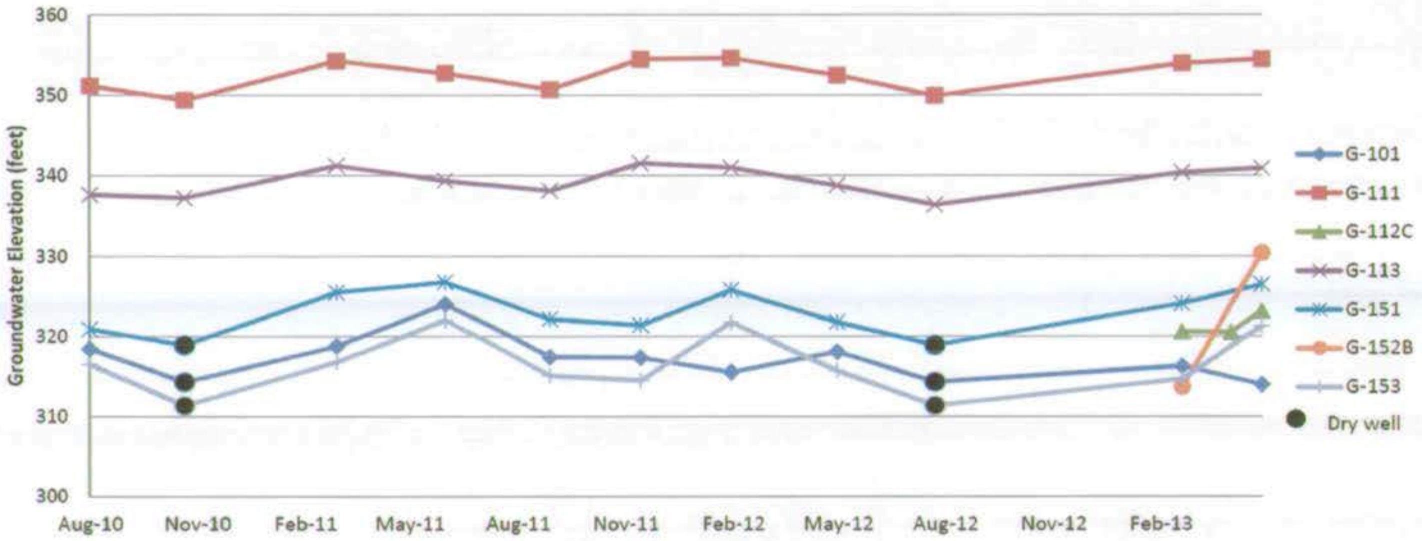
MONITORING WELL SCREEN ELEVATIONS

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 6

NATURAL RESOURCE TECHNOLOGY



NOTE: DRY WELLS NOTED WITH DIFFERENT MARKER

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REVIEWED BY/DATE:
BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

GROUNDWATER ELEVATION TIME SERIES

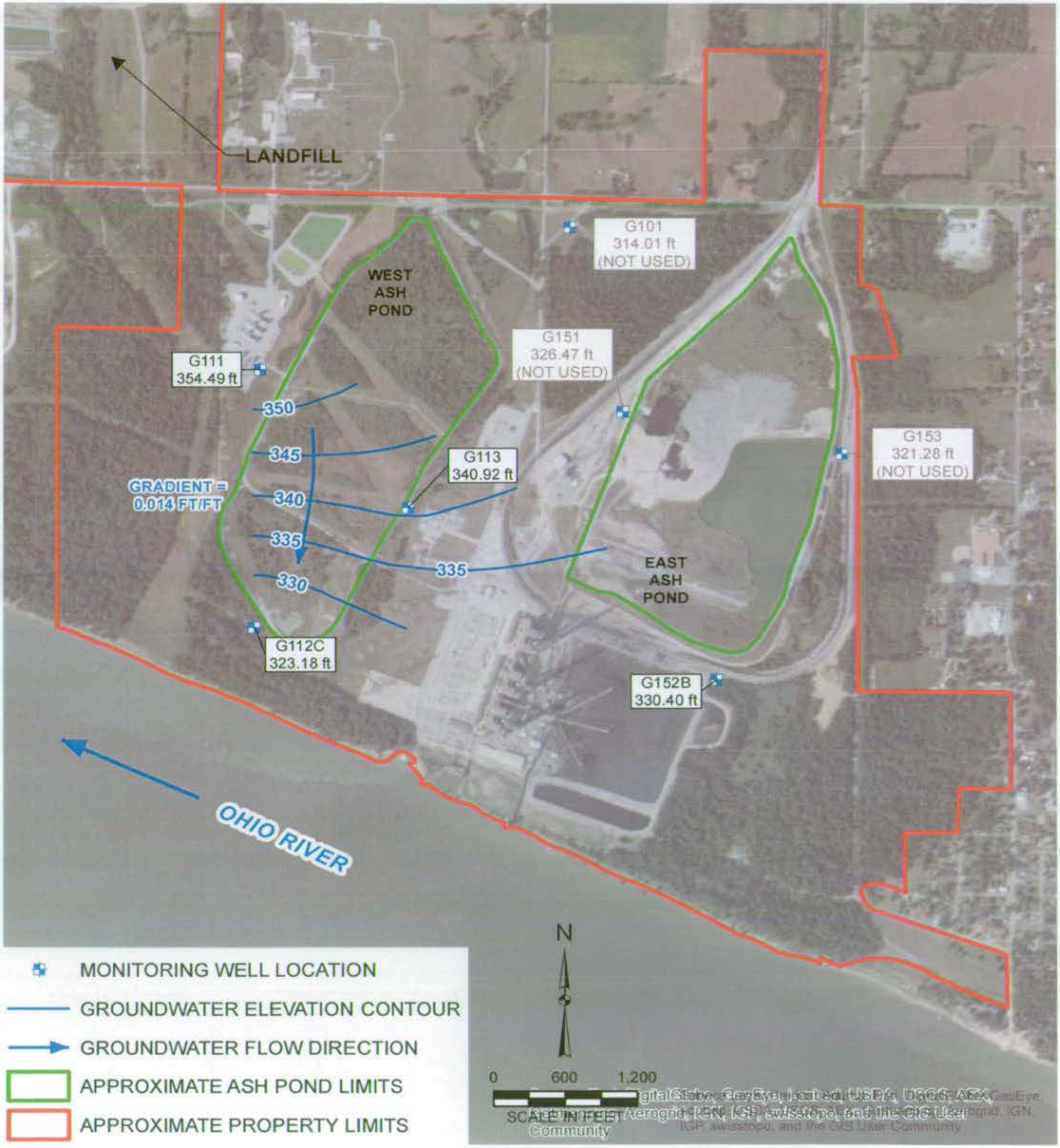
PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 7

NATURAL RESOURCE TECHNOLOGY

Y:\Mapping\Projects\21\2126\MXD\HydroGeo_Assmnt\Figure 7_Groundwater Elevation Time Series.mxd Author: nkoch; Date/Time: 7/22/2013, 11:18:26 AM



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BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

GROUNDWATER ELEVATIONS AND CONTOURS
MAY 2013

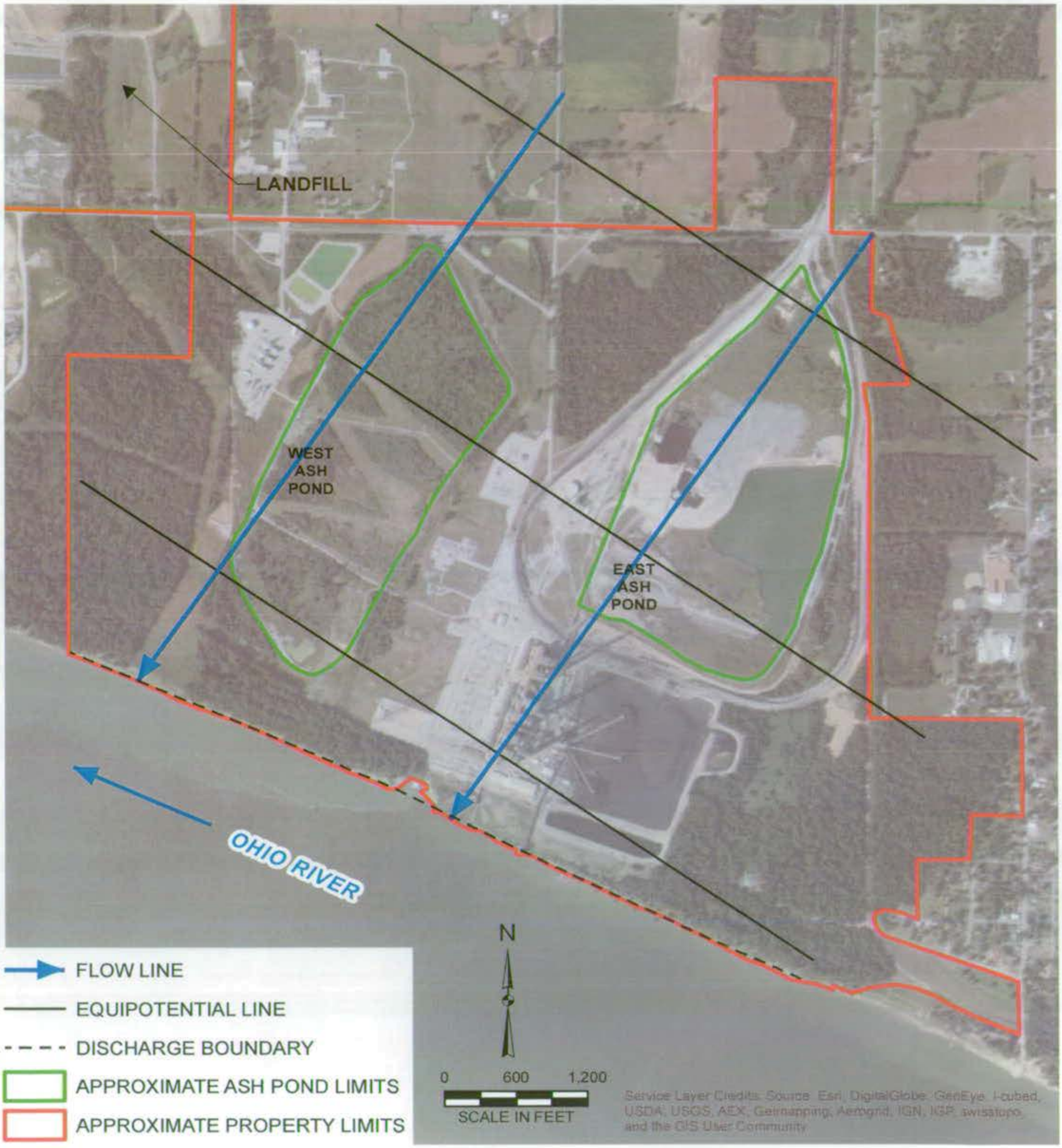
PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 8

NATURAL RESOURCE TECHNOLOGY

Y:\Mapping\Projects\21\2126\MXD\HydroGeo_Assmt\Figure 8_Groundwater Elevations and Contours_May 2013.mxd Author: nkron, Date/Time: 7/22/2013, 11:19:19 AM



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Y:\Mapping\Projects\21\2126\MXD\Hydro\Geo_Assmnt\Figure 9_Conceptual Groundwater Flow System.mxd Author: nkron; Date/Time: 7/22/2013, 11:20:04 AM

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REVIEWED BY/DATE:
BGH 6/21/13
APPROVED BY/DATE:
BRH 6/26/13

CONCEPTUAL GROUNDWATER FLOW SYSTEM

PHASE I HYDROGEOLOGIC ASSESSMENT
JOPPA GENERATING STATION
ELECTRIC ENERGY INC.
JOPPA, ILLINOIS

PROJECT NO: 2126

FIGURE NO: 9

NATURAL RESOURCE TECHNOLOGY

Table 1. Monitoring Well Construction Details

Phase I Hydrogeologic Assessment
Joppa Generating Station
Electric Energy Inc.
Joppa, IL

Monitoring Well Number	Installation Date	Top of Well Riser Elevation	Ground Elevation	Screen Top Depth (BGS)	Screen Bottom Depth (BGS)	Slotted Screen Length	Screen Top Elevation	Screen Bottom Elevation	Bottom of Boring Elevation	Total Boring Depth	Screened Formation
G101 [1]	06/01/10	363.69	361.12	36.80	46.80	10.00	324.32	314.32	309.1	52.0	Silty Clay
G111 [1]	06/24/10	359.17	356.63	32.13	42.13	10.00	324.50	314.50	311.6	45.0	Silty Clay
G112C [2]	01/29/13	325.82	323.60	15.00	25.00	10.00	298.30	308.60	298.6	25.0	Silty Clay
G113 [1]	06/25/10	353.04	350.46	30.69	40.69	10.00	319.77	309.77	306.9	43.6	Silty/Sandy Clay
G151 [1]	06/19/10	363.60	360.90	31.97	41.97	10.00	328.93	318.93	315.9	45.0	Silty/Sandy Clay
G152B [2]	01/30/13	347.48	345.20	34.40	44.40	10.00	300.60	310.80	300.7	44.5	Silty Clay
G153 [1]	06/18/10	354.65	351.73	30.35	40.35	10.00	321.38	311.38	308.1	43.6	Silty/Sandy Clay & Silt
G112B [1A]	06/20/10	347.62	345.16	32.41	42.41	10.00	312.75	302.75	300.0	45.2	Silty Clay
G152 [1B]	06/21/10	351.18	348.55	13.94	23.94	10.00	334.61	324.61	321.7	26.9	Silty Clay

Monitoring Well Number	Northing[3]	Easting[3]
G101	202,050.25	831,716.43
G111	200,806.11	829,139.79
G112C	198,552.26	829,088.33
G113	199,599.53	830,364.44
G151	200,437.41	832,154.25
G152B	198,547.23	832,358.44
G153	200,067.47	833,979.90
G112B	198,913.55	828,988.60
G152	198,547.23	832,358.44

Notes:

BGS = below ground surface.

All depths are in feet. All elevation measurements are in feet relative to NAVD 1988.

All wells constructed with 2-inch diameter, 10-slot, Schedule 40 PVC screens.

[1] Drilling and well installation by Geotechnology, Inc.

[2] Drilling and well installation by Natural Resource Technology, Inc.

[3] Coordinates are referenced to Illinois State Plane Coordinates, East Zone - NAD 1983.

A	Well sealed and abandoned on 1/28/13.
B	Well sealed and abandoned on 1/29/13.

Table 3. Field and Laboratory Groundwater Monitoring Parameters

Phase I Hydrogeologic Assessment
Joppa Generating Station
Electric Energy Inc.
Joppa, IL

Field Parameters			**Analysis Method**
Groundwater Elevation		in-situ	
pH (field)	[1]	in-situ	SM 21st ed. 4500-H$^+$
Specific Conductance		in-situ	SM 21st ed. 2520-B
Temperature		in-situ	SM 21st ed. 2550
General Chemistry Parameters			**Analysis Method**
Chloride	[1]	dissolved	SW846 9251
Cyanide	[1]	total	SW846 9012A
Fluoride	[1]	total	SW846 9214
Nitrogen, Nitrate (as N)	[1]	dissolved	SM4500-NO3
Sulfate	[1]	dissolved	ASTM516-90,02
Total Dissolved Solids	[1]	dissolved	SM21 2540 C
METALS			**Analysis Method**
Antimony	[1]	dissolved	SW846 3005A, 7041 (by GFAA)
Arsenic	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Barium	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Beryllium	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Boron	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Cadmium	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Chromium	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Cobalt	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Copper	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Iron	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Lead	[1]	dissolved	SW846 3005A, 7421 (by GFAA)
Manganese	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Mercury	[1]	dissolved	SW846 7470A
Nickel	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Selenium	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Silver	[1]	dissolved	SW846 3005A, 6010B (by ICP)
Thallium	[1]	dissolved	SW846 3005A, 7841 (by GFAA)
Zinc	[1]	dissolved	SW846 3005A, 6010B (by ICP)

Notes:

[1] Groundwater quality parameters for Class I: Potable Resource Groundwater (IAC 35 Part 620 Section 410).

Samples filtered and preserved in field.

Table 4. Statistical Summary of Groundwater Quality Data for Period of November 2010 - May 2013

Phase I Hydrogeologic Assessment
Joppa Generating Station
Electric Energy Inc.
Joppa, IL

Parameter, Unit	Class II GW Standard	Monitoring Well G101 (N = 8)						Monitoring Well G111 (N = 10)						Monitoring Well G112C (N = 3)						Monitoring Well G113 (N = 10)					
		Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects
Field Parameters																									
pH, Std Units	6.5 / 9.0*	6.99	6.97	7.31	6.63	0.23	N/A	7.08	7.09	7.28	6.70	0.155	N/A	6.81	6.79	6.92	6.73	0.097	N/A	6.60	6.57	6.82	6.44	0.11	N/A
General Chemistry Parameters																									
Chloride (diss), mg/L	200	4.5	4.5	6.0	3.0	0.93	0	6.3	6.0	7.0	5.0	0.67	0	nc	nc	nc	nc	nc	100	30	29	34	28	1.8	0
Cyanide (total), mg/L	0.6	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Fluoride (total), mg/L	4.0	0.29	0.29	0.33	0.26	0.025	0	0.66	0.67	0.71	0.62	0.033	0	0.78	0.80	0.81	0.74	0.038	0	0.42	0.43	0.45	0.39	0.023	0
Nitrate (diss), mg/L	100	1.3	1.5	1.7	0.28	0.51	0	0.19	0.12	0.72	<0.050	0.21	10	0.15	0.050	0.34	<0.050	0.17	67	0.43	0.44	0.68	0.14	0.15	0
Sulfate (diss), mg/L	400	32	33	35	22	4.4	0	24	24	30	19	3.8	0	63	63	66	60	3.0	0	35	35	50	30	5.8	0
Total Dissolved Solids, mg/L	1,200	246	245	294	208	34	0	357	363	394	322	28	0	440	432	476	412	33	0	600	590	706	524	57	0
Metals (dissolved)																									
Antimony, mg/L .006 mcl	0.024	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Arsenic, mg/L 0.010	0.20	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Barium, mg./L	2.0	0.20	0.074	0.64	0.044	0.25	0	0.16	0.16	0.18	0.15	0.011	0	0.061	0.062	0.062	0.059	0.0	0	0.49	0.50	0.55	0.40	0.046	0
Beryllium, mg/L	0.5	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Boron, mg/L	2.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	3.2	3.1	3.3	3.1	0.12	0	nc	nc	nc	nc	nc	100
Cadmium, mg/L	0.05	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Chromium, mg/L	1.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Cobalt, mg/L	1.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Copper, mg/L	0.65	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Iron, mg/L	5.0	0.039	0.020	0.17	<0.020	0.054	12.5	nc	nc	nc	nc	nc	100	0.036	0.039	0.048	<0.020	0.015	33.3	nc	nc	nc	nc	nc	100
Lead, mg/L	0.1	0.0030	0.0020	<0.0070	<0.0020	0.0023	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Manganese, mg/L	10	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	0.17	0.17	0.18	0.15	0.013	0	0.0074	0.0050	0.025	<0.0050	0.0063	70
Mercury, mg/L	0.010	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Nickel, mg/L	2.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Selenium, mg/L	0.05	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Silver, mg/L	ns	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Thallium, mg/L	0.020	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Zinc, mg/L	10	nc	nc	nc	nc	nc	100	0.011	0.010	0.018	<0.010	0.0026	80	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100

Notes:
N = number of observations (does not include August 2010 sampling event, which was not representative due to bailing of monitoring wells; all other events used low-flow sampling methods with dedicated bladder pumps).
ns = no Class II Groundwater Quality Standard for Parameter.
* Lower and Upper limits for pH is the Class I groundwater quality standard of 6.5 and 9.0 Standard Units.
Groundwater quality standards for Class II: Potable Resource Groundwater (IAC 35 Part 620 Section 420).
Statistics calculated with replacement of non-detect concentrations at 1X reported non-detect concentration: nc indicates that statistics were not calculated because all values were below reporting levels.
Exceeds Class II Groundwater Quality Standard.
Parameter is 100% Non-Detect in all 7 monitoring wells.

Table 4. Statistical Summary of Groundwater Quality Data for Period of November 2010 - May 2013

Phase I Hydrogeologic Assessment
Joppa Generating Station
Electric Energy Inc.
Joppa, IL

		Monitoring Well G151 (N = 8)						Monitoring Well G152B (N = 2)						Monitoring Well G153 (N = 8)					
Parameter, Unit	Class II GW Standard	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects	Mean	Median	Maximum	Minimum	Std Dev	% of Non-Detects
Field Parameters																			
pH, Std Units	6.5 / 9.0*	6.03	6.01	6.20	5.89	0.10	N/A	6.81	6.81	6.81	6.81	0.00	N/A	6.91	6.93	6.98	6.70	0.086	N/A
General Chemistry Parameters																			
Chloride (diss), mg/L	200	5.4	5.0	6.0	5.0	0.52	0	49	49	49	48	0.71	0	21	21	24	20	1.6	0
Cyanide (total), mg/L	0.6	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Fluoride (total), mg/L	4.0	0.21	0.10	0.95	<0.10	0.30	75	0.59	0.59	0.60	0.58	0.014	0	0.83	0.82	0.94	0.75	0.066	0
Nitrate (diss), mg/L	100	1.2	1.1	2.0	0.62	0.45	0	0.84	0.84	0.87	0.82	0.032	0	0.31	0.28	0.46	0.21	0.075	0
Sulfate (diss), mg/L	400	103	103	111	98	4.8	0	17	17	18	16	1.4	0	103	104	111	93	6.8	0
Total Dissolved Solids, mg/L	1,200	252	248	288	228	23	0	483	483	488	478	7.1	0	431	433	484	392	29	0
Metals (dissolved)																			
Antimony, mg/L	0.024	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Arsenic, mg/L	0.20	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Barium, mg./L	2.0	0.19	0.083	0.79	0.068	0.25	0	0.51	0.51	0.51	0.51	0.0028	0	0.25	0.24	0.31	0.21	0.032	0
Beryllium, mg/L	0.5	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Boron, mg/L	2.0	0.024	0.020	0.052	<0.020	0.011	87.5	nc	nc	nc	nc	nc	100	0.028	0.020	<0.020	<0.020	0.014	75
Cadmium, mg/L	0.05	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Chromium, mg/L	1.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Cobalt, mg/L	1.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Copper, mg/L	0.65	0.010	0.010	0.011	<0.010	0	87.5	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Iron, mg/L	5.0	0.25	0.020	1.8	<0.020	0.62	62.5	nc	nc	nc	nc	nc	100	0.025	0.021	0.040	<0.020	0.0072	50
Lead, mg/L	0.10	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Manganese, mg/L	10	0.029	0.027	0.062	0.011	0.018	0	0.010	0.010	0.015	<0.0050	0.0072	50	0.011	0.0050	0.056	<0.0050	0.018	87.5
Mercury, mg/L	0.010	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Nickel, mg/L	2.0	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Selenium, mg/L	0.05	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Silver, mg/L	ns	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Thallium, mg/L	0.020	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100
Zinc, mg/L	10	0.012	0.010	0.017	<0.010	0.0030	62.5	nc	nc	nc	nc	nc	100	nc	nc	nc	nc	nc	100

Notes:
N = number of observations (does not include August 2010 sampling event, which was not representative due to bailing of monitoring wells; all other events used low-flow sampling methods with dedicated bladder pumps).
ns = no Class II Groundwater Quality Standard for Parameter.
* Lower and Upper limits for pH is the Class I groundwater quality standard of 6.5 and 9.0 Standard Units.
Groundwater quality standards for Class II: Potable Resource Groundwater (IAC 35 Part 620 Section 420).
Statistics calculated with replacement of non-detect concentrations at 1X reported non-detect concentration: nc indicates that statistics were not calculated because all values were below reporting levels.
Exceeds Class II Groundwater Quality Standard.
Parameter is 100% Non-Detect in all 7 monitoring wells.

APPENDIX A WELL SEARCH

A.1 Well Search Overview

The following sources of information were utilized in order to determine community water source and water well locations:

- Illinois State Geological Survey's Illinois Water Well (ILWATER) Internet Map Service
- Illinois State Water Survey Domestic Well Database
- Illinois EPA web-based Geographic Information System (GIS) files
- Illinois Department of Public Health
- Massac County Health Department

A.2 Illinois State Geological Survey (ISGS)

The ISGS website provided an ArcIMS View Map as well as a database query for water wells. ISGS database information including any boring logs and well construction information is provided in this Appendix.

A.3 Illinois State Water Survey (ISWS)

All of the wells found through the ISWS database, also known as the Domestic Well Database, were previously identified on the ISGS website except for three locations, see Table A-1, (well numbers: 75-77). Records contained within the ISWS database, consisting of public, industrial, and commercial water wells, were not all received as of the date of this report. Since the ISWS database generally contains the same well information as the ISGS and Illinois EPA databases, some ISWS well entries on the Appendix A-1 Table were marked as pending. Should any new information be acquired from the ISWS including additional water wells not previously identified from the other sources of the well information, it will be provided as an addendum to this report.

A.4 Illinois Environmental Protection Agency (IEPA)

The Illinois EPA database website provided ArcIMS Viewer Maps showing information on community, non-community, and public water supply wells as defined on the Illinois EPA website:

- Community Water Supply (CWS): a public water supply that serves or is intended to serve at least 15 service connections used by residents or regularly serves at least 25 residents.

Based on the IEPA maps, there are two CWS wells in the vicinity of the Station. One CWS well is located in Section 24, east of the Station, and east of Joppa. This CWS well is not within the 2500 foot search radius from the impoundments. The second CWS well, listed on Figure 5 as well number 51, is located directly east of the Station, in Section 23 and the village of Joppa. CWS well no. 51 has a Minimum Setback Zone (MSZ) of 200 feet and a Phase I Wellhead protection area (WHPA) of 1000 ft. A MSZ is an area of 200 or 400 radial feet surrounding a water well supplying public water system through which contaminants from a source are theoretically likely to move and reach the well. The Phase I WHPA extends the surface and subsurface area surrounding the water well to 1,000 radial feet. The two CWS wells were not identified on the ISGS website.

Twenty-eight water wells owned by the Station were identified in the IEPA database, located within Sections 10, 14, 15, and 23. The IEPA database noted 20 wells owned by the Station as monitoring wells. These 20 monitoring wells can be seen in Table A-1 and are located on the Station property in Section 10.

A.5 Massac County Health Department

Attempts were made to contact the Massac County Health Department to confirm the CWS well systems located in the area. No personnel from the county health department have responded at the date of this report. Should any new information be acquired from the county health department including additional water well information not previously identified from the other sources, it will be provided as an addendum to this report.

A.6 Field Survey

A field survey was conducted on July 11, 2013 to verify selected well locations listed in the ISGS, ISWS, and IEPA databases and to locate wells not identified within the databases. Eight wells listed within State databases, and originally located based on the original boring and/or well logs, were re-located on the well location map based on the visual survey. In addition, six wells could not be located and there was no evidence of any house or building at those locations; therefore it was assumed that there was no active potable supply or receptor at that location. Finally, one well that was not identified in the state records was located and added to the Figure and Table. Meetings were held with the Joppa and Ft. Massic Water Districts to determine whether buildings with well records were serviced by the water districts.

The LaFarge Corporation and Trunkline Gas Pumping Station were consulted to review well locations on their properties, which are immediately west and north of the WAP, respectively. LaFarge personnel indicated that they had four active wells and two inactive wells, and that the remaining borings were likely "test holes". LaFarge also revised and refined the locations for these wells. Trunkline indicated that their wells are no longer active.

Illinois EPA FOIA Exemption Reference Sheet

SID: 37

Agency ID: 170000128298
Media File Type: WATER
Bureau ID: W1270100004
Site Name: Dynegy Joppa Plant
Site Address1: 2100 Portland Rd
Site Address2:
Site City: Joppa
State: IL
Zip: 62953-

This record has been determined to be partially or wholly exempt from public disclosure

Exemption Type:

Redaction

Exempt Doc #: 12
Document Date: 7 /30/2013
Staff: JMR

Document Description: PHASE 1 HYDROGEOLOGICAL ASSESSMENT REPORT - APPENDIX A WELL SURVEY REPORTS

Category ID: 06I
Category Description: GROUNDWATER HYDROGEOLOGIC RPTS
Exempt Type: Redaction
Permit ID:
Date of Determination: 5 /25/2017

Table A-1. Well Search Results
Phase I Hydrogeologic Assessment
Joppa Generating Station

Map Well#	Source of Well Information			Location Name at time of completion	Well Depth	Location					Year Drilled	Aquifer Type	Formation	Well Use	Corrected Location (visual survey)		converted coordinates (Decimal Degrees)		CWS Metered Location	Verified Water Well	Current Well Status
	ISGS (API)	ISWS	IEPA			County	Township	Range	Section	SubSection					Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)			
1	121270000100	--	1	Bechtel Corp	304	Massac	15S	3E	14	--	1955	--	--	IC					Yes (FM)	Yes	A (NP)
2	121270002300	--	23	Missouri Portland Cemt	140	Massac	15S	3E	15	NW SW	1961	--	--	IC							
3	121270003000	366704	30	[redacted]	153	Massac	15S	3E	14	SW SW NE	1941	--	--	FD	37° 12.873'	88° 50.699'	37.214550	-88.844983	Yes (J)	No	U
4	121270003100	366705	31	[redacted]	156	Massac	15S	3E	14	--	1941	--	--	FD					No	No (NS)	U
5	121270004800	--	48	Joppa Compressor Station #7	150	Massac	15S	3E	10	--	1950	--	--	IC					Yes (FM)		NA(NP)
6	121270004900	--	49	Joppa Compressor Station #7	166	Massac	15S	3E	10	--	1950	--	--	IC					Yes (FM)		NA(NP)
7	121270005000	--	50	Electric Energy Inc	350	Massac	15S	3E	14	--	1951	--	--	IC					Yes (FM)	Yes	A (NP)
8	121270005100	--	51	Electric Energy Inc	403	Massac	15S	3E	14	--	1951	--	--	IC	37° 12.879'	88° 51.365'	37.214650	-88.856083	Yes (FM)	Yes	A (NP)
9	121270005200	--	52	Joppa Grade School	138	Massac	15S	3E	14	--	1940	--	--	FD					Yes (J)	No (NS)	NA*
10	121270005300	--	53	Electric Energy Inc	235	Massac	15S	3E	15	--	1951	--	--	IC					Yes (FM)		NA(NP)
11	121270005400	--	54	Joppa Colored Schl	137	Massac	15S	3E	23	--	1940	--	--	FD					No	No (NS)	NA
12	121270005500	--	55	[redacted]	65	Massac	15S	3E	23	--	1941	--	--	FD					No	No (NS)	NA
13	121270011100	275092	111	[redacted]	78	Massac	15S	3E	11	--	1969	Unconsolidated	gravel & sand	FD	37° 13.433'	88° 50.956'	37.223883	-88.849267	Yes (FM)	Yes	U
14	121270014600	275090	146	[redacted]	150	Massac	15S	3E	11	SE SE SE	--	Unconsolidated	sand gravel	FD							
16	121270015800	275097	158	[redacted]	160	Massac	15S	3E	14	NW NW NE	1971	--	--	FD					No	No (NS)	U
19	121270019800	275091	198	[redacted]	283	Massac	15S	3E	11	NE NE SE	1973	Bedrock	broken lime	FD							
20	121272022000	--	20220	Mo Portland Cement	110	Massac	15S	3E	15	--	1974	--	--	IC							
21	121272025500	275089	20255	[redacted]	52	Massac	15S	3E	10	SW SE SW	1976	--	--	FD	37° 13.305'	88° 52.297'	37.221750	-88.871617	No	Yes	NA (PSA)
23	121272047100	275088	20471	[redacted]	175	Massac	15S	3E	10	NE SE NW	1987	Bedrock	chert	FD							
26	121272051900	--	20519	Missouri Portland Cement Co.	110	Massac	15S	3E	15	--	1985	--	--	IC							
27	121272052000	--	20520	Missouri Portland Cmt Co.	110	Massac	15S	3E	15	--	1985	Unconsolidated	alluvial	IC							
29	121272067500	265617	20675	[redacted]	94	Massac	15S	3E	11	NE SE SW	1994	Unconsolidated	gravel	FD	37° 13.359'	88° 50.934'	37.222650	-88.848900	Yes (FM)	Yes	NA
32	121272069900	286483	20699	[redacted]	280	Massac	15S	3E	11	NW NE NE	1995	Bedrock	chert	FD							
33	121272085100	--	23716.08871	Maple Grove School	76	Massac	15S	3E	10	--	1997	--	--	IC							
34	121272085600	--	24645.42174	Lafarge Corp.	98	Massac	15S	3E	15	NE NW SW	1997	Unconsolidated	sand & gravel	IC							
35	121272091900	--	--	Missouri Portland Cement Co	451	Massac	15S	3E	15	--	1961	--	--	IC							
36	121272092600	--	--	Missouri Portland Cement Co	136	Massac	15S	3E	15	NW	1961	--	--	IC							
37	121272092700	--	25574.75477	Missouri Portland Cement Co	110	Massac	15S	3E	15	NW	1961	--	--	IC							
38	121272092800	--	26504.08779	Missouri Portland Cement T.H.	130	Massac	15S	3E	15	NW	1962	--	--	IC							
39	121272092900	--	27433.42082	Missouri Portland Cement T.H.	138	Massac	15S	3E	15	NW	1962	--	--	IC							
40	121272093000	--	28362.75385	Missouri Portland Cement T.H.	105	Massac	15S	3E	15	NW	1962	--	--	IC							
41	121272093300	--	29292.08688	Missouri Portland Cement T.H.	105	Massac	15S	3E	15	NW	1962	--	--	IC							
42	121272093400	--	30221.4199	Missouri Portland Cement T.H.	169	Massac	15S	3E	15	NW	1962	--	--	IC							
43	121272094200	--	31150.75293	Electrical Energy Corp (Joppa)	90	Massac	15S	3E	23	--	1952	--	--	IC					No	No (NS)	NA
44	121272096300	--	32080.08596	Maple Grove School	362	Massac	15S	3E	10	--	1999	--	--	IC							
47	121272100900	322429	34868.08504	[redacted]	202	Massac	15S	3E	10	--	2000	Bedrock	limestone	FD					Yes (FM)	No	U
48	121272103000	--	35797.41807	[redacted]	202	Massac	15S	3E	10	SE NE SE	2000	Bedrock	limestone	FD					Yes (FM)	No	U
49	121272103900	--	36726.7511	Midwest Electric Power Co.	238	Massac	15S	3E	15	SW NW NE	2000	Bedrock	limestone	IC	37° 13.000'	88° 51.992'	37.216667	-88.866533	No	Yes	A (NP)
50	121272104000	--	37656.08413	Midwest Electric Power, Inc	277	Massac	15S	3E	15	NW NW NE	1999	Bedrock	limestone	IC	37° 13.140'	88° 52.010'	37.21900000	-88.86683333	No	Yes	A (NP)
51	121272105600	--	70900	--	--	Massac	15S	3E	23	--	--	--	--	CWS							
52	121272105700	--	70901	--	--	Massac	15S	3E	24	--	--	--	--	CWS							
53	121272106100	362229	39514.75018	[redacted]	92	Massac	15S	3E	14	NW NE NE	2001	Unconsolidated	gravel	FD	37° 13.211'	88° 50.508'	37.220183	-88.841800	No	No	A
54	121272109500	--	40444.08321	La Farge Corp.	1472	Massac	15S	3E	15	--	--	--	--	FD							
55	121272110900	--	--	Electric Energy, Inc.	73	Massac	15S	3E	10	NW NW SW	2006	Unconsolidated	sand	MONIT							
56	121272111000	--	--	Electric Energy, Inc.	60	Massac	15S	3E	10	NE NW SW	2006	Unconsolidated	sand	MONIT							
57	121272111100	--	--	Electric Energy, Inc.	66	Massac	15S	3E	10	SE NW SW	2006	Unconsolidated	sand	MONIT							
58	121272111200	--	--	Electric Energy, Inc.	61	Massac	15S	3E	10	SE SW SW	2006	Unconsolidated	sand	MONIT							
59	121272111300	--	--	Electric Energy, Inc.	73	Massac	15S	3E	10	NE SW SW	2006	Unconsolidated	sand	MONIT							
60	121272111400	--	--	Electric Energy, Inc.	81	Massac	15S	3E	10	SW NW SW	2006	Unconsolidated	sand	MONIT							
61	121272111500	--	--	Electric Energy, Inc.	68	Massac	15S	3E	10	SE SW SW	2006	Unconsolidated	sand	MONIT							
62	121272111600	--	--	Electric Energy, Inc.	71	Massac	15S	3E	10	NW NW SW	2006	Unconsolidated	sand	MONIT							
63	121272111700	--	--	Electric Energy, Inc.	81	Massac	15S	3E	10	NE SW SW	2006	Unconsolidated	sand	MONIT							
64	121272111800	--	--	Electric Energy, Inc.	68	Massac	15S	3E	10	SW SW SW	2006	Unconsolidated	sand	MONIT							
65	121272111900	--	--	Electric Energy, Inc.	29	Massac	15S	3E	10	NW NW SW	2006	Unconsolidated	silt	MONIT							
66	121272112000	--	--	Electric Energy, Inc.	12	Massac	15S	3E	10	NE NW SW	2006	Unconsolidated	silt	MONIT							
67	121272112100	--	--	Electric Energy, Inc.	20	Massac	15S	3E	10	SE NW SW	2006	Unconsolidated	clayey sand	MONIT							
68	121272112200	--	--	Electric Energy, Inc.	13	Massac	15S	3E	10	SE SW SW	2006	Unconsolidated	clayey sand	MONIT							

Table A-1. Well Search Results
Phase I Hydrogeologic Assessment
Joppa Generating Station

Map Well#	Source of Well Information			Location Name at time of completion	Well Depth	Location					Year Drilled	Aquifer Type	Formation	Well Use	Corrected Location (visual survey)		converted coordinates (Decimal Degrees)		CWS Metered Location	Verified Water Well	Current Well Status
	ISGS (API)	ISWS	IEPA			County	Township	Range	Section	SubSection					Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)			
69	121272112300	--	--	Electric Energy, Inc.	18	Massac	15S	3E	10	NE SW SW	2006	Unconsolidated	silt	MONIT							
70	121272112400	--	--	Electric Energy, Inc.	27	Massac	15S	3E	10	SW NW SW	2006	Unconsolidated	silt	MONIT							
71	121272112500	--	--	Electric Energy, Inc.	16	Massac	15S	3E	10	SE SW SW	2006	Unconsolidated	silt	MONIT							
72	121272112600	--	--	Electric Energy, Inc.	23	Massac	15S	3E	10	NW NW SW	2006	Unconsolidated	silt & sand	MONIT							
73	121272112700	--	--	Electric Energy, Inc.	24	Massac	15S	3E	10	NE SW SW	2006	Unconsolidated	silty sand	MONIT							
74	121272112800	--	--	Electric Energy, Inc.	20	Massac	15S	3E	10	SW SW SW	2006	Unconsolidated	silt	MONIT							
75	121272117200	--	--	LaFarge N.A., Midwest River	227	Massac	15S	3E	15	NW NE SW	2010	Bedrock	limestone	IC							
76	--	275094	--	[redacted]	162	Massac	15S	3E	--	--	1961	--	--	FD							
77	--	366703	--	[redacted]	--	Massac	15S	3E	--	--	1896	--	--	FD							
78	--	366706	--	[redacted]	65	Massac	15S	3E	--	--	1941	--	--	FD							
79	--	--	--	--	--	Massac	15S	3E	11		--	--	--	FD	37° 13.278'	88° 50.938'	37.22130000	-88.84896667	No	Yes	A

Source of Information

IEPA	Illinois Environmental Protection Agency
ISGS	Illinois State Geological Survey
ISWS	Illinois State Water Survey
SWAP	IEPA Source Water Assessment

Well Use

CWS	Community Water Supply Well
MONIT	Joppa Power Station Monitoring Well
FD	Farm and/or Domestic Water Well
IC	Industrial/Commercial Water Well

Notes

--	Not Applicable or no information available
A	Active
NA	Not Active
U	Unknown
NP	Non-potable / industrial use only
J	Village of Joppa CWS metered location
FM	Fort Massac Water District CWS metered location
NS	No structure and/or well at location based on visual survey
PSA	Pending seal and abandonent of well
*	Reported sealed but no record

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well for Commercial Operation	Top	Bottom
clay	0	42
gravel & sand	42	83
gray clay	83	154
broken up limestone	154	158
gray limestone	158	227
Total Depth		227

Casing: 10" STEEL from -1' to 157'

Water from limestone at 160' to 222'.

Static level 56' below casing top which is 3' above GL

Pumping level 67' when pumping at 700 gpm for 3 hours

Permanent pump installed at 147' on December 22, 2010, with a capacity of 500 gpm

Remarks: Driller's Estimated Well Yield 3000 gpm

Additional location info: Lot: Subdivision: Joppa Plant

Address of well: same as above

Location source: Global Positioning System verified

Permit Date: November 9, 2010 **Permit #:** 127-12-

COMPANY Beanland, Glen

FARM LaFarge N.A., Midwest River

DATE DRILLED December 3, 2010 **NO.**

ELEVATION 367GL **COUNTY NO.** 21172

LOCATION NW NE SW

LATITUDE 37.216133 **LONGITUDE** -88.873433

COUNTY **Massac** **API 121272117200** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	19
silty clay	19	20
Total Depth		20

Casing: 2" PVC from -3' to 15'
2" PVC SCREEN from 15' to 20'
2" PVC from 20' to 20'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 13.

Grout: BENTONITE CHIPS from 13 to 14.

Grout: QUARTZ SAND from 14 to 20.

Water from silt at 14' to 20'.

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED December 1, 2006 **NO.** MW10S
ELEVATION 371 **COUNTY NO.** 21128
LOCATION SW SW SW
LATITUDE 37.222365 **LONGITUDE** -88.874989
COUNTY **Massac** **API** **121272112800** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	17
silty sand	17	20
silty clay	20	24
Total Depth		**24**

Casing: 2" PVC from -3' to 19'
2" PVC SCREEN from 19' to 23'
2" PVC from 23' to 24'

Screen: 4' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 16.

Grout: QUARTZ SAND from 16 to 24.

Water from silty sand at 17' to 20'.
Static level 13' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 10, 2006 **NO.** MW09S
ELEVATION 364 **COUNTY NO.** 21127
LOCATION NE SW SW
LATITUDE 37.22415 **LONGITUDE** -88.872644
COUNTY **Massac** **API** **121272112700** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	22
clayey sand	22	23
Total Depth		**23**

Casing: 2" PVC from -3' to 18'
2" PVC SCREEN from 18' to 23'
2" PVC from 23' to 23'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 17.

Grout: QUARTZ SAND from 17 to 23.

Water from silt & sand at 17' to 23'.
Static level 22' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 17, 2006 **NO.** MW08S
ELEVATION 378 **COUNTY NO.** 21126
LOCATION NW NW SW
LATITUDE 37.227853 **LONGITUDE** -88.874897
COUNTY **Massac** **API** **121272112600** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	14
silty clay	14	16
Total Depth		16

Casing: 2" PVC from -3' to 10'
2" PVC SCREEN from 10' to 15'
2" PVC from 15' to 16'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 9.

Grout: QUARTZ SAND from 9 to 16.

Water from silt at 9' to 14'.
Static level 16' below casing top which is 3' above GL

Address of well: Portland Rd & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 29, 2006 **NO.** MW07S
ELEVATION 360 **COUNTY NO.** 21125
LOCATION SE SW SW
LATITUDE 37.222321 **LONGITUDE** -88.872675
COUNTY Massac **API** 121272112500 10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	27
Total Depth		27

Casing: 2" PVC from -3' to 21'
2" PVC SCREEN from 21' to 26'
2" PVC from 26' to 27'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 19.

Grout: QUARTZ SAND from 19 to 27.

Water from silt at 19' to 27'.
Static level 25' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date:

Permit #:

COMPANY Holcomb Foundation Eng.

FARM Electric Energy, Inc.

DATE DRILLED November 14, 2006

NO. MW06S

ELEVATION 373

COUNTY NO. 21124

LOCATION SW NW SW

LATITUDE 37.226024

LONGITUDE -88.874927

COUNTY **Massac**

API **121272112400**

10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	16
silty clay	16	18
Total Depth		18

Casing: 2" PVC from -3' to 12'
2" PVC SCREEN from 12' to 17'
2" PVC from 17' to 18'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 6.

Grout: BENTONITE CHIPS from 7 to 11.

Grout: QUARTZ SAND from 11 to 18.

Water from silt at 12' to 16'.

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.

FARM Electric Energy, Inc.

DATE DRILLED December 6, 2006 **NO.** MW05S

ELEVATION 364 **COUNTY NO.** 21123

LOCATION NE SW SW

LATITUDE 37.22415 **LONGITUDE** -88.872644

COUNTY Massac **API 121272112300** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	7
clayey sand	7	12
silty clay	12	13
Total Depth		13

Casing: 2" PVC from -3' to 7'
2" PVC SCREEN from 7' to 12'
2" PVC from 12' to 13'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 6.

Grout: QUARTZ SAND from 6 to 12.

Water from clayey sand at 7' to 12'.
Static level 15' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED December 5, 2006 **NO.** MW04S
ELEVATION 351 **COUNTY NO.** 21122
LOCATION SE SW SW
LATITUDE 37.222321 **LONGITUDE** -88.872675
COUNTY **Massac** **API** **121272112200** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	16
clayey sand to 19.5', silty clay to 19.7	16	20
Total Depth		**20**

Casing: 2" PVC from -3' to 15'
2" PVC SCREEN from 15' to 19'
2" PVC from 19' to 20'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 3 to 12.

Grout: BENTONITE CHIPS from 12 to 13.

Grout: QUARTZ SAND from 13 to 20.

Water from clayey sand at 16' to 20'.

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.

FARM Electric Energy, Inc.

DATE DRILLED December 4, 2006 **NO.** MW03S

ELEVATION 367 **COUNTY NO.** 21121

LOCATION SE NW SW

LATITUDE 37.225979 **LONGITUDE** -88.872612

COUNTY **Massac** **API** **121272112100** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	11
silty clay	11	12
Total Depth		12

Casing: 2" PVC from 12' to 12'
2" PVC from -3' to 7'
2" PVC SCREEN from 7' to 12'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 7.

Grout: QUARTZ SAND from 7 to 12.

Water from silt at 7' to 11'.
Static level 9' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 27, 2006 **NO.** MW02S
ELEVATION 360 **COUNTY NO.** 21120
LOCATION NE NW SW
LATITUDE 37.227808 **LONGITUDE** -88.872581
COUNTY Massac **API** 121272112000 **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	24
clay sand	24	28
silty clay	28	29
Total Depth		29

Casing: 2" PVC from -3' to 24'
2" PVC SCREEN from 24' to 28'
2" PVC from 28' to 28'

Screen: 4' of 2" diameter 10 slot

Grout: BENTONITE CHIPS from 0 to 23.

Grout: QUARTZ SAND from 23 to 29.

Water from silt at 24' to 28'.
Static level 28' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 28, 2006 **NO.** MW01S
ELEVATION 384 **COUNTY NO.** 21119
LOCATION NW NW SW
LATITUDE 37.227853 **LONGITUDE** -88.874897
COUNTY Massac **API** 121272111900 10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	19
silty clay	19	26
silty sand	26	28
silty clay	28	34
clayey sand	34	51
silty sand	51	63
sand	63	68
Total Depth		68

Casing: 2" PVC from -3' to 63'
2" PVC SCREEN from 63' to 67'
2" PVC from 67' to 68'

Screen: 4' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 58.

Grout: BENTONITE CHIPS from 58 to 61.

Water from sand at 63' to 68'.
Static level 56' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED December 1, 2006 **NO.** MW10D
ELEVATION 371 **COUNTY NO.** 21118
LOCATION SW SW SW
LATITUDE 37.222365 **LONGITUDE** -88.874989
COUNTY **Massac** **API** **121272111800** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	17
silty sand	17	20
silty clay	20	52
clayey sand	52	61
silty sand	61	71
sand	71	81
Total Depth		81

Casing: 2" PVC from -3' to 76'
2" PVC SCREEN from 76' to 81'
2" PVC from 81' to 81'

Screen: 5' of 2" diameter 20 slot

Grout: BENTONITE from 0 to 69.

Grout: BENTONITE CHIPS from 69 to 73.

Grout: QUARTZ SAND from 73 to 81.

Water from sand at 73' to 81'.
Static level 48' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.

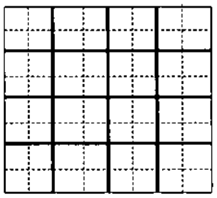
FARM Electric Energy, Inc.

DATE DRILLED November 10, 2006 **NO.** MW09D

ELEVATION 364 **COUNTY NO.** 21117

LOCATION NE SW SW

LATITUDE 37.22415 **LONGITUDE** -88.872644



COUNTY **Massac** **API** **121272111700** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	22
clayey sand	22	24
silty clay	24	37
clayey sand	37	50
silty sand	50	66
sand	66	71
Total Depth		71

Casing: 2" PVC from -3' to 66'
2" PVC SCREEN from 66' to 71'
2" PVC from 71' to 71'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 62.

Grout: BENTONITE CHIPS from 62 to 64.

Grout: QUARTZ SAND from 64 to 71.

Water from sand at 66' to 71'.
Static level 60' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 17, 2006 **NO.** MW08D
ELEVATION 378 **COUNTY NO.** 21116
LOCATION NW NW SW
LATITUDE 37.227853 **LONGITUDE** -88.874897
COUNTY **Massac** **API 121272111600** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	14
silty clay	14	33
clayey sand	33	48
silty sand	48	62
sand	62	68
Total Depth		68

Casing: 2" PVC from -3' to 62'
2" PVC SCREEN from 62' to 67'
2" PVC from 67' to 68'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 57.

Grout: BENTONITE CHIPS from 57 to 58.

Grout: QUARTZ SAND from 58 to 68.

Water from sand at 58' to 68'.
Static level 43' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 29, 2006 **NO.** MW07D
ELEVATION 360 **COUNTY NO.** 21115
LOCATION SE SW SW
LATITUDE 37.222321 **LONGITUDE** -88.872675
COUNTY Massac **API 121272111500** **10 - 15S - 3E**

Page 1 **ILLINOIS STATE GEOLOGICAL SURVEY**

Monitoring	Top	Bottom
clayey silt	0	28
silty clay	28	40
clayey sand	40	48
silty sand	48	77
sand	77	81
Total Depth		81

Casing: 2" PVC from -3' to 76'
2" PVC SCREEN from 76' to 81'
2" PVC from 81' to 81'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 69.

Grout: BENTONITE CHIPS from 69 to 74.

Grout: FORMATION SAND from 74 to 81.

Water from sand at 63' to 73'.
Static level 57' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 14, 2006 **NO.** MW06D
ELEVATION 373 **COUNTY NO.** 21114
LOCATION SW NW SW
LATITUDE 37.226024 **LONGITUDE** -88.874927
COUNTY Massac **API** 121272111400 10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	16
silty clay	16	24
clayey sand	24	31
silty sand	31	51
sand	51	73
Total Depth		73

Casing: 2" PVC from -3' to 68'
2" PVC SCREEN from 68' to 73'
2" PVC from 73' to 73'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 60.

Grout: BENTONITE CHIPS from 60 to 63.

Grout: FORMATION SAND from 63 to 73.

Water from sand at 63' to 73'.
Static level 44' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.

FARM Electric Energy, Inc.

DATE DRILLED December 6, 2006 **NO.** MW05D

ELEVATION 364 **COUNTY NO.** 21113

LOCATION NE SW SW

LATITUDE 37.22415 **LONGITUDE** -88.872644

COUNTY Massac **API 121272111300** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	7
clayey sand	7	12
silty clay	12	27
clayey sand	27	40
silty sand	40	54
sand	54	61
Total Depth		61

Casing: 2" PVC from -3' to 56'
2" PVC SCREEN from 56' to 60'
2" PVC from 60' to 61'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 0 to 52.

Grout: BENTONITE CHIPS from 52 to 54.

Grout: QUARTZ SAND from 54 to 61.

Water from sand at 54' to 61'.
Static level 34' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED December 5, 2006 **NO.** MW04D
ELEVATION 351 **COUNTY NO.** 21112
LOCATION SE SW SW
LATITUDE 37.222321 **LONGITUDE** -88.872675
COUNTY **Massac** **API** **121272111200** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	Top	Bottom
clayey silt	0	16
clayey sand	16	20
silty clay	20	25
clayey sand	25	44
silty sand	44	50
sand	50	66
Total Depth		66

Casing: 2" PVC from -3' to 61'
2" PVC SCREEN from 61' to 66'
2" PVC from 66' to 66'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 6 to 54.

Grout: BENTONITE CHIPS from 54 to 58.

Grout: QUARTZ SAND from 58 to 66.

Water from sand at 61' to 66'.
Static level 50' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED December 4, 2006 **NO.** MW03D
ELEVATION 367 **COUNTY NO.** 21111
LOCATION SE NW SW
LATITUDE 37.225979 **LONGITUDE** -88.872612
COUNTY Massac **API** 121272111100 **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	11
silty clay	11	14
clayey sand	14	26
silty clay	26	29
clayey sand	29	40
silty sand	40	52
sand	52	60
Total Depth		60

Casing: 2" PVC from -3' to 55'
2" PVC SCREEN from 55' to 60'
2" PVC from 60' to 60'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 11 to 52.

Grout: BENTONITE CHIPS from 52 to 53.

Grout: QUARTZ SAND from 58 to 66.

Water from sand at 52' to 60'.
Static level 36' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 27, 2006 **NO.** MW02D
ELEVATION 360 **COUNTY NO.** 21110
LOCATION NE NW SW
LATITUDE 37.227808 **LONGITUDE** -88.872581
COUNTY Massac **API 121272111000** **10 - 15S - 3E**

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ILLINOIS STATE GEOLOGICAL SURVEY

Monitoring	**Top**	**Bottom**
clayey silt	0	24
clayey sand	24	28
silty clay	28	41
clayey sand	41	49
silty sand	49	64
sand	64	73
Total Depth		73

Casing: 2" PVC SCREEN from 67' to 72'
2" PVC from -3' to 67'
2" PVC from 72' to 73'

Screen: 5' of 2" diameter 10 slot

Grout: BENTONITE from 12 to 63.

Grout: BENTONITE CHIPS from 63 to 65.

Grout: QUARTZ SAND from 65 to 72.

Water from sand at 67' to 73'.
Static level 62' below casing top which is 3' above GL

Address of well: Portland Rd. & Baccus Rd.
Joppa, IL

Location source: Location from the driller

Permit Date: **Permit #:**

COMPANY Holcomb Foundation Eng.
FARM Electric Energy, Inc.
DATE DRILLED November 28, 2006 **NO.** MW01D
ELEVATION 384 **COUNTY NO.** 21109
LOCATION NW NW SW
LATITUDE 37.227853 **LONGITUDE** -88.874897
COUNTY **Massac** **API** **121272110900** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

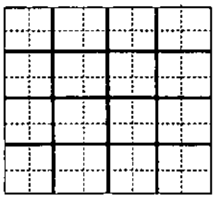
Test Hole	Top	Bottom
Total Depth		1472

Gamma Ray Log filed

Location source: Field verified

Permit Date: **Permit #:**

COMPANY IL State Geological Survey
FARM La Farge Corp.
DATE DRILLED **NO.** J2-04
ELEVATION 0 **COUNTY NO.** 21095
LOCATION 1098'N line, 1226'W line of section
LATITUDE 37.218362 **LONGITUDE** -88.872106
COUNTY **Massac** **API** **121272109500**



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
Address of well: same as above

Location source: Location from permit

Permit Date: September 17, 2001 **Permit #:**

COMPANY Beanland, Leonard Ralph
FARM [redacted]
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**

ILLINOIS STATE GEOLOGICAL SURVEY

Municipal Water Supply	**Top**	**Bottom**
no record	0	448
Total Depth		448

Casing: 10" OUTER CASING from 0' to 0'
6" CASING from 0' to 75'

Static level 32' below casing top which is 0' above GL
Pumping level 175' when pumping at 141 gpm for 3 hours

Permit Date: **Permit #:**

COMPANY
FARM Joppa, Village
DATE DRILLED January 1, 1952 **NO.** 1
ELEVATION 0 **COUNTY NO.** 21057
LOCATION 500'S 500'E NW/c
LATITUDE 37.20493 **LONGITUDE** -88.837921
COUNTY Massac **API** 121272105700 24 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Non Potable Water Well	Top	Bottom
topsoil clay & gray silty sand	0	28
clay & silty sand w/trace of gravel	28	160
limestone shelf followed by f sy clay	160	263
sandy & silty clay/weather limestone	263	273
fractured limestone	273	277
Total Depth		277

Casing: 12" STAINLESS 49.56FT from -2' to 160'
10" STAINLESS 40.48FT from -2' to 273'

Grout: CEMENT from 0 to 273.

Size hole below casing: 10"

Water from limestone at 273' to 277'.
Static level 45' below casing top which is 2' above GL
Pumping level 50' when pumping at 600 gpm for 12 hours

Permanent pump installed at 150' on , with a capacity of 600 gpm

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, Inc
DATE DRILLED January 19, 2000 **NO.** 5
ELEVATION 0 **COUNTY NO.** 21040
LOCATION NW NW NE
LATITUDE 37.220361 **LONGITUDE** -88.865779
COUNTY **Massac** **API** **121272104000** **15 - 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

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

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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

Address of well: same as above

Location source: Location from permit

Permit Date: February 8, 2000 **Permit #:**

COMPANY Beanland, Ronald D.
FARM [redacted]
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

Irrigation Well	Top	Bottom
yellow clay	0	27
gravel	27	28
white clay	28	36
yellow sandy clay with gravel	36	58
yellow sandy clay with coarse yl sand	58	65
yellow sandy clay with white streaks	65	105
fine yellow sand with clay streaks	105	118
chert	118	142
chert with yellow to white clay streaks	142	160
chert with gray clay streaks	160	178
weathered limestone	178	180
chert with gray clay	180	191
fractured gray limestone	191	202
Interpretation by: John Nelson on 07-APR-00 samples are wet and disaggregated		
Loess: silt, medium yellowish brown; less than 1% sand grains.	0	10
Loess: sandy silt, medium yellowish-brown, 5% to 10% fine to medium sand.	10	25
Metropolis Formation: sandy silt, light gray to yellowish-gray, 10 to 20% very fine to fine sand. note on bag says "little gravel at 27 ft."	25	30
Metropolis Formation: sand, light brownish gray, very fine grained (to coarse silt), fluid.	30	35
Metropolis Formation: sandy silt, yellowish-orange to yellowish-brown, a little gray (mottled?), sand fraction very fine to fine, sand increasing downward.	35	45

Permit Date: **Permit #:**

COMPANY Beanland, John R.

FARM [redacted]

DATE DRILLED March 28, 2000 **NO.** 1

ELEVATION 0 **COUNTY NO.** 21009

LOCATION 1900'S line, 700'E line of section

LATITUDE 37.226406 **LONGITUDE** -88.859969

COUNTY Massac **API** 121272100900 **10 - 15S - 3E**

Metropolis Formation: silty sand, dark yellowish brown, some lighter yellow mottling, very fine to fine, clay present.	45	60
Metropolis Formation: silty sand, mottled light gray, yellowish gray, yellowish orange; otherwise similar to above. mica appears at 75 feet.	60	80
McNairy Formation: sand, light yellowish to brownish gray, vey fine grained, clean, dominantly quartz with a little mica.	80	105
McNairy Formation: sand, medium yellowish brown, very fine to fine-grained, otherwise as above. scattered coarse sand to small granules, mostly dark brown chert (?) appear at 115 feet. clay present at 120-125 feet.	105	125
McNairy Formation: sand, brownish gray, poorly sorted, fine to very coarse, composed fo quartz and dull, opaque gray to brown chert. some clay present.	125	130
Post Creek Formation: sand and fine gravel, a washed sample consists of fine to medium quartz sand and angular fragments of dull, opaque, light to medium gray and brownish-gray chert. matrix is yellowish-brown silt.	130	135
Post Creek Formation: gravel, composed of broken chert pebbles, fragments of rounded pebbles common. mostly dull, opaque gray to brown chert as above, some light gray and tripolitic, some sand matrix partially cemented with gravel.	135	140
Total Depth		202

Sample set # 68834 (0' - 140') Received: April 4, 2000
Location source: Field verified Verified by: WJN on April 7, 2000

ILLINOIS STATE GEOLOGICAL SURVEY

Stratigraphic Test	**Top**	**Bottom**
Loess	0	10
Metropolis formation	10	59
Unidentified	59	127
McNairy formation	127	328
Post Creek formation	328	359
Salem limestone	359	362

Interpretation by: W. John Nelson on 27-JUL-99
Drilled with USGS Mobile B-61 wireline coring rig.
Driller: Gene Cobbs.

Silt, yellowish brown with orange and gray mottling, massive, slightly clayey, roots at top, scattered organic matter throughout.	.5	5
Silt, similar to above. Only 1' recovered for 5' run.	5	10
Gap (recovered about 6' for the run from 10' to 20').	10	20
Silt and sand, yellowish orange and light to medium gray, strongly mottled, contains scattered chert granules. This silty sand to sandy silt with a clay matrix. Sand consists of fine to very coarse quartz, common red grains, and brown chert granules with Mounds patina. Massive to laminated, laminated, laminations dip 10 to 30 degrees. Gradational contact:	20	26.7
Sandy silt, light gray and yellowish orange, strongly streaked and mottled. Clay-rich, granules rare. No layering, appears brecciated. Irregular contact:	26.7	33.8
Silty sand, gray, brown, and yellowish-orange mottled, much coarse sand to small grainules in a silty clay matrix, granules are largerly well-rounded	33.8	48.2

Permit Date: **Permit #:**

COMPANY IL State Geological Survey
FARM Maple Grove School
DATE DRILLED **NO.** 2
ELEVATION 0GL **COUNTY NO.** 20963
LOCATION 2575'S line, 600'E line of section
LATITUDE 37.228262 **LONGITUDE** -88.85959
COUNTY Massac **API** 121272096300 10 - 15S - 3E

brown chert, reworked Mounds Gravel. Massive to weakly laminated, laminae gently inclined. Sharp contact:		
Gravel, reworked Mounds-type chert pebbles to 1" across supported in matrix of silty sand, as above. Sharp contact:	48.2	48.5
Sand, reddish orange with a little gray mottling, dominantly fine to medium grained but contains scattered coarse sand grains and small brown chert pebbles. No layering. Barely coherent, a little silt and clay matrix. Black laminae in lower part are probably iron/manganese oxides. Grades to:	48.5	50.8
Sand, colors vary, mostly yellowish gray, some layers light gray and reddish gray. Fine grained, well sorted, subrounded to rounded quarts sand, barely coherent, has irregular nearly horizontal silty lamination. Black layers (common at 54' - 55') proably iron/manganese oxide. Thin gravelly layer at 59', rounded quarts granules and small pebbles, also brown chert pebbles that appear to be reworked Mounds. Grades to:	50.8	60
Sand, light gray with small yellowish-orange and black patches, mainly in upper part of unit. Very fine to fine grained, slightly silty, nearly all quartz with a trace of heavy minerals. Slightly coherent, no lamination noted in upper 10'. Below 70' sand has faint planar laminations that dip about 30 degrees. Quartz grains largely rounded to well-rounded. Grades to:	60	79
Sand, light grayish orange, fine grained, otherwise as above. Sharp contact:	79	82.5
Silty sand, light gray with small yellowish orange patches, sand very fine and quartzose, massive, a	82.5	87.5

little clay matrix makes the sediment coherent. Grades to:		
Silty clay, light gray, massive, moderately stiff, can be formed into balls. Grades to:	87.5	89
Silty sand, like next-to-last unit. Less silt and clay downward, grades to:	89	94.1
Sand, light orange to yellowish gray, very fine to medium, coarser near base, like that at 60' at 82.5'. Grain size and colors vary, some intervals are silty. Rare quartz granules, near base. No mica or caly laminae as would be typical for McNairy. Sharp contact:	94.1	109.7
Gravel, composed of subangular to well rounded pebbles to at least 1" across in a sand matrix, with a little clay binder. Pebbles largely light gray, opaque, tripolitic chert. Dark gray chert and silicified limestone (some oolitic), white to red quartz pebbles less than 10% of total. Sand medium to coarse, dominantly rounded quartz grains. Mostly gravel-supported. No bedding evident. Only partial recovery; 6' recovered from 110' to 119'.	109.7	119
Gravel, as above? Drilled 9' but recovered only about 1' of gravel, as above. Last 2' was easier drilling, like sand or clay.	119	127
Sand; as below? Not sampled, but drilled like next 11'.	127	129
Sand, light gray to light yellowish gray, fine-grained, dominantly quartz with less than 1% very fine black grains and a few mica flakes. Massive to faintly laminated, weakly coherent (a little clay and silt binder). Basically the same as sands above the gravel. Recovered only 2.5' from 129' to 140', but easy drilling indicates consistent material. Nearly	129	179.7

complete recovery 140' - 150'; several thin white clay laminae in this interval dip 30-40 degrees. Near-vertical clay laminae or veinlets at 150' - 155'. Sharp contact:		
Clayey sand, light to medium gray, very fine grained, silty, laminated; as before the sand is dominantly quartz with less than 1% dark grains and a few mica flakes. Grades to:	179.7	180.9
Sand, upper 2' light gray, changing back to light yellowish or orange-gray, fine-grained, like next-to-last unit. Occasional clay laminae dipping 20-30 degrees. Grades to:	180.9	201
Sand, light gray, very fine to fine grained. As before, dominantly quartz with less than 1% black grains and sparse mica. many laminae and stringers (veinlets) of light gray plastic clay crisscross the core at various angles. The clay contains only scattered mica flakes and is unlike typical McNairy.	201	210.5
Sand, mostly yellowish-orange, some light gray, fine-grained, light gray clay laminae inclined 40-50 degrees.	210.5	213.5
Sand, light gray, fine grained, well sorted, dominantly quartz with silt-sized black grains, barely coherent (slightly silty), uniform, massive.	213.5	237
Sand, light orange to light gray, fine-grained, contains a few steeply dipping light gray clay veinlets, otherwise, as above. Small-scales faulting was visible on freshly extracted sample at about 275' and steeply dipping clay laminae or veins at 300' - 305'. Mica becomes more common downward, but still sparse.	237	304.7
Silty sand, light gray, very fine grained, clayey, slightly micaceous. Dominantly quartz as above.	304.7	320

Appears to be riddled with a network of light gray clay laminae. Gradational contact:		
Sandy clay, light gray and yellowish orange, mixture of fine quartz sand and plastic clay, yellowish orange color increases downward. Chert granules in lower 2'.	320	327
Pebbly sand and clay, yellowish orange to brownish orange, mostly granule-size, but some pebbles to 1" of dark gray to brown chert. Indistinct and irregular layering in places.	327	334
Chert, a few large angular fragments of bluish gray slightly translucent chert that is silicified, coarse-grained crinoidal grainstone, probably from bedrock. No sample from about 334' to 340'.	334	340
Pebbly sand and clay, like next-to-last unit. No large chunks of chert recovered. Only about 3' of sample recovered.	340	350
Pebbly sand and clay, as above, about 1.5' recovered for 9' run.	350	359
Limestone, medium to dark gray, coarse crinoid-bryozoan packstone with shaly partings and chert nodules; bryozoan fronds parallel with bedding. Bedding horizontal, probably Salem Limestone.	359	362

Interpretation by: Jack Masters & John Nelson on 04-AUG-99

Silt, light yellowish brown, uniform color, clayey, sand-size iron-manganese pellets common. Soft, massive.	.5	2
Silt, similar to above but has dinstinct light gray mottling,. pellets as above have orange rims. Gray zones are silty clay and appear to be steeply inclined fractures and/or burrows.	2	4.7

Silt, medium yellowish brown, faintly mottled, slightly sandy with fine to medium white to pink quartz grains. Faint distorted grayish laminations, darker laminations more clayey. A few chert granules.	4.7	6.1
No sample - recovered 1.1 feet of core between 5' and 10'.	6.1	10
Sandy silt, strongly mottled in gray, brown and yellowish orange, gray zones are clay-rich. Scattered granules and small pebbles of brown chert probably derived from Mounds Gravel. Gradational contact:	10	11.5
Sany silt, strongly mottled in light orange-brown, yellowish gray, and gray. Intermixed silty clay, some of which is clay skins. Irregular lamination in lower part of interval. A few chert granules, as above.	11.5	13.5
Sandy silt and clay, darker than above; clay yellowish brown to gray, silt medium to dark orange-brown, all mottled. Two layers of chert granules and pebbles, as above. No lamination. Large chert pebbles at base.	13.5	15.1
No sample. core loss believed to be in lower 4.9' of interval from 10' to 20', because chert pebbles at base of sample may have plugged core barrel.	15.1	20
Silty sand, mottled orange-brown, sand is medium to coarse, several gray silty clay layers. Weakly layered, chert granules and pebbles (as above) common. Gradational contact:	20	21.4
Sandy silt, colors as above, clay-rich, clayey zones lighter gray to yellowish brown. Thick clay skins abundant. Massive to weakly laminated, stiff. Gradational contact:	21.4	23.4

Sandy silt, mottled light brownish-gray to light brown, coarse silt to fine sand, scattered chert pebbles as above. Massive to weakly layered.	23.4	26.5
Clayey and sandy silt, strongly mottled in light gray and yellowish to brownish orange, sand content increases downward. Gray patches are clay-rich. Probably bioturbated, lower 3' appears brecciated but colors less distinct. Scattered chert granules. Sharp contact:	26.5	33.7
Pebbly sand, coarse to very coarse, dominantly quartz sand with pink grains common, pebbles a mixture of Mounds-type chert and quartz, subrounded to well rounded (quartz pebbles well rounded). Sand has a clay matrix. Sharp contact:	33.7	34.1
Silty sand, light orange-brown with yellowish gray mottling, clayey, contains iron oxide nodules (dark brown) and manganese (black). Pink to rose-colored quartz grains common. Largely bioturbated, a few silty clay laminations. Lower contact sharp.	34.1	39.9
Silty and clay, silt orange to brown, clay light to medium gray, clay and silt intermixed and mottled, no layering. Concentrated black iron/manganese stains near top, along with scattered pebbles (but this could be slop at top of core run). Material appears bioturbated. A hint of lamination. Scattered white to pink, fine to medium quartz sand grains and rare granules. Black iron/manganese stains and pellets common. Sand increases downward. Possible small fault dipping 40-50 degrees at 45.3'. Sharp contact:	39.9	48.2
Sand, pebbly, grayish to orange brown, fine to very coarse sand, dominantly quartz, with clay matrix, abundant shiny brown clay-skins; gravel dominantly reworked Mounds-type chert pebbles, some have patina,	48.2	48.6

but many are bleached, sharp lower contact.		
Sand, red to orange with gray mottling, dominantly fine grain with scattered coarse grains, subrounded to well rounded, trace of muscovite mica, lower 0.5' has distorted banding (maybe liesegang) black iron manganese stains abundant, scattered granules and pebbles of reworked Mounds gravel. Sharp contact:	48.6	50.8
Sand, light gray to light yellowish and reddish orange, fine to medium grain-size, almost entirely quartz, slightly silty, more silty at top, some sand nearly loose and water saturated when drilled, faint disturbed laminations, spots and patches of black iron manganese oxide, rare well-rounded quartz granules throughout, basal 0.1' is a concentration of well-rounded granules and small pebbles, of mostly quartz, with some reworked iron oxide and Mounds-type chert.	50.8	58.8
Sand, light gray, yellowish orange stains at top diminish below upper 1', to nearly all light gray, nearly 100% quartz, rare pink to red quartz grains, few very fine grain black heavy minerals, upper part is silty, decreses downward to loose, clean sand, grades to fine to medium at base (fining upward interval), gradational contat.	58.8	79
Sand, light grayish orange, fine to medium grain-size, subrounded to rounded quartz, maybe 1% chert and black heavy mineral grains, less well sorted than above, loose (water saturated), contact gradational, possibly smeared out by sampling.	79	83
Sand, silty, light gray, coarse silt to very fine sand intermixed, massive, angular to hackly fractures and clay concentrations suggest paleosol, interval looks bleached, lower contact indistinct.	83	88

Silt, clayey, medium light gray, massive, fractures more even than above, less paleosol-like than above, very fine sand in lower part and increases downward.	88	90
Silt and sand interbedded, silt is medium light gray, sand is light gray, very fine grain, all quartz except for few heavies, faint laminations to thin beds inclined 40-60 degrees, gradational contact.	90	93
Sand, light wellowish gray to grayish orange, very fine to fine grain size, becomes coarser downward with some medium sand in lower 2', mineralogy as above, except maybe 1% chert and heavies in lower 2', sand mostly clean and loose, but contains several silty intervals. Sharp contact:	93	109.7
Gravel, light gray, composed mainly of chert pebbles, largest nearly 2" across, subrounded to rounded, light gray, tripolitic chert, few medium to dark gray chert (vitreous to bioclastic texture) granules to small pebbles of white to pink or rose colored chert, matrix fine to very coarse quartz sand with common pink grains, gravel largely grain supported, but some matrix supported intervals. Only 1' of loose gravel in 10' core run. Lower contact based on drilling rate with no recovery, but probably like underlying sand.	109.7	127
Sand, light gray and light brownish gray very fine grain, dominantly quartz, but conspicuous mica and silt-size heavies (black), silt and clay lamination is common and coated with mica flakes, sand loose to weakly indurated, less than 3' recovery in 14' or coring (126'-140'), contact with gravel lost.	127	140
Sand, light yellowish gray, light gray to yellowish orange, fine grain, subrounded to rounded, less than 1% black heavies, scattered mica flakes, loose to	140	179.6

wekaly indurated, some intervals slightly silty, scattered black spots of manganese oxide, local concentrated clay laminations (especially between 150'-153') are steeply inclined.		
Sand, light to medium gray, upper part contains several thin interbeds of light to medium gray plastic clay, otherwise similar to above.	179.6	182.8
Sand, light to medium grayish orange with few light gray streaks. Fine grained like next to last unit, concentrations of black iron-manganese oxides at base.	182.8	201
Sand, light gray and light brownish gray, very fine to fine grain, laminae and veins or stringers of light gray clay at various angles, possible microfault at top of unit, slightly micaceous (more mica than in clean fine-grain sands). Sharp contact:	201	210.8
Sand, yellowish orange with gray layers and veins that are more clayey, probable core loss through this unit, some black iron manganese stained spots.	210.8	215
Sand, light gray, fine grained, sugary texture, loose, well sorted, subround to rounded, +99% quartz, some siltsize black heavies and mica flakes.	215	237.1
Sand, light gray and light grayish orange, colors intermixed, near vertical color and textural boundaries (veins and possible Ophiomorphia).	237.1	239.5
Sand, medium grayish orange, fine to medium grain-size, otherwise like next to last unit.	239.5	251
Sand, light gray to light grayish orange, color intermixed, fine to medium grained, orange portions tend to be a little coarser grained, slightly micaceous, few steeply inclined light gray stringers or veinlets, loose to weakly indurated, gradational	251	280

contact.		
Sand, medium light gray and light brownish grain, fine grained, more than 99% quartz, many grains sparkly, silt size heavies, mica flakes as above, mostly loose, liquified in core box, possibly little faint laminations in places, fairly sharp contact.	280	304.6
Sand, very light gray to gray, very fine laminae of silty clay, same color as sand, bedding planes lined with mica flakes, inclined 40 degrees plus/minus, gradiation contact.	304.6	320
Sand, clayey to sandy clay, light gray and dark yellowish brown mottling, more brown toward base, upper half of unit is contorted and broken laminations with blebs of sand cemented by limonite, lower part, structureless mix of sand, silt and clay, with few fragments broken chert, gradational contact.	320	328
Sand, clay and gravel mixture, dark yellowish to orange brown, with a little gray mottling in places, gravel fraction is rounded small pebbles, larger chunks of chert, largely bluish gray, at 334' was very large chunk of such chert, overall look of highly weathered and oxidized, all matrix supported (mud-like), poor core recovery.	328	359
Limestone, medium to dark gray, coarse bryozoan and crinoid wackestone, large fronds of fennestrate bryozoans define bedding, horizontal to gently dipping, numerous partings of dark gray, slightly silty shale, in lower part are nodules of dark gray chert.	359	362

Interpretation by: John Nelson & Jack Masters on 05-AUG-99
This hole was drilled to investigate an apparent graben indicated by long of school water well and previous shallow ISGS boring (ISGS #1 Maple Grove

School).

Peoria silt	0	4.7
Roxana silt	4.7	6.1
Core loss, may include Loveland silt	6.1	10
Metropolis Formation, silt and sand with much clay and reworked Mounds-type gravel. Laminations appear to dip 10 to 30 degrees in places.	10	58.8
Unidentified strata, about 51' and and minor silt overlying 17' of gravel. Two upward-fining sequences are present. These materials could be as young as Quarternary or as old as Cretaceous, but Eocene to Miocene age appears most likely based on absence of mica in sands (as would be tuypical for Cretaceous) and absence of brown Mounds-type chert pebbles.	58.8	127
McNairy Formation, clean quartz sand, minor silt and clay laminae and interbeds, some of which contain considerable mica. An unusually sandy McNairy section.	127	328
Post Creek Formation, clay and sand mixture, oxidized and weathered, mixed with chert gravel and fragments.	328	359
Salem Limestone, the lithology is fairly typical of this unit.	359	362
Total Depth		362

Core #C 14730 (0' - 10') Received: August 2, 1999
Core #C 14730 (10' - 59') Received: August 2, 1999
Core #C 14730 (59' - 127') Received: August 2, 1999
Core #C 14730 (127' - 328') Received: August 2, 1999
Core #C 14730 (328' - 359') Received: August 2, 1999
Core #C 14730 (359' - 362') Received: August 2, 1999

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		90
Sample set # 23753 (5' - 90') Received: January 9, 1952		

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

	Top	Bottom
Total Depth		169
Core #C 4292 (145.5' - 149') Received: March 5, 1962		
Core #C 4292 (154' - 169') Received: March 5, 1962		

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Missouri Portland Cement T.H.

DATE DRILLED **NO.** 61-9(62)

ELEVATION 0 **COUNTY NO.** 20934

LOCATION 825'N 325'E SW/c NW

LATITUDE 37.216334 **LONGITUDE** -88.875329

COUNTY Massac **API 121272093400** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		105
Sample set # 41920 (0' - 105') Received: March 5, 1962		

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Missouri Portland Cement T.H.

DATE DRILLED **NO.** 61-9(62)

ELEVATION 0 **COUNTY NO.** 20933

LOCATION 825'N 325'E SW/c NW

LATITUDE 37.216334 **LONGITUDE** -88.875329

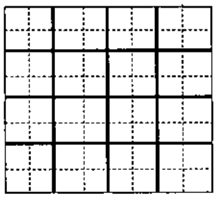
COUNTY Massac **API** 121272093300 **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		105
Sample set # 41919 (0' - 105') Received: March 5, 1962		

Permit Date: **Permit #:**

COMPANY Layne Western
FARM Missouri Portland Cement T.H.
DATE DRILLED **NO.** 61-6(62)
ELEVATION 0 **COUNTY NO.** 20930
LOCATION 335'N 500'E SW/c NW
LATITUDE 37.214973 **LONGITUDE** -88.874799
COUNTY **Massac** **API 121272093000** **15 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		138
Sample set # 41921 (0' - 138') Received: March 5, 1962		

Permit Date: **Permit #:**

COMPANY Layne Western
FARM Missouri Portland Cement T.H.
DATE DRILLED **NO.** 61-7(62)
ELEVATION 0 **COUNTY NO.** 20929
LOCATION 570'N 740'E SW/c NW
LATITUDE 37.215609 **LONGITUDE** -88.873938
COUNTY **Massac** **API** **121272092900** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		130
Sample set # 41922 (0' - 130') Received: March 5, 1962		

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Missouri Portland Cement T.H.

DATE DRILLED **NO.** 61-4

ELEVATION 0 **COUNTY NO.** 20928

LOCATION 442'N 395'E SW/c NW

LATITUDE 37.215273 **LONGITUDE** -88.875145

COUNTY **Massac** **API** **121272092800** **15 - 15S - 3E**

Page 1

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		110

Sample set # 41685 (0' - 110') Received: December 20, 1961

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Missouri Portland Cement Co

DATE DRILLED **NO.** 5

ELEVATION 0 **COUNTY NO.** 20927

LOCATION 173'N 288'E SW/c NW

LATITUDE 37.214536 **LONGITUDE** -88.875555

COUNTY **Massac** **API** **121272092700** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		136
Sample set # 41556 (0' - 136') Received: November 22, 1961		

Permit Date: **Permit #:**

COMPANY Layne Western
FARM Missouri Portland Cement Co
DATE DRILLED **NO.** 2
ELEVATION 0 **COUNTY NO.** 20926
LOCATION 512'N 40'E SW/c NW
LATITUDE 37.215484 **LONGITUDE** -88.876362
COUNTY Massac **API** 121272092600 15 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		451
Sample set # 41557 (160' - 451') Received: November 22, 1961		

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Missouri Portland Cement Co

DATE DRILLED **NO.** 1

ELEVATION 0 **COUNTY NO.** 20919

LOCATION 489'N 143'E SW/c NW

LATITUDE 37.215416 **LONGITUDE** -88.876007

COUNTY Massac **API** 121272091900 15 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Industrial Water Well	**Top**	**Bottom**
topsoil	0	5
brown clay	5	35
fine sand with gray clay	35	65
sand & gravel	65	98
Total Depth		98

Casing: 16" STEEL 62.58#/FT from -2' to 72'
16" STNLESS STL SCREEN from 72' to 97'

Screen: 2' of 16" diameter 80 slot

Grout: CEMENT from 2 to 20.

Size hole below casing: 48"

Water from sand & gravel at 72' to 97'.
Static level 48' below casing top which is 2' above GL
Pumping level 71' when pumping at 0 gpm for 8 hours

Permanent pump installed at 90' on August 12, 1997, with a capacity of 325 gpm

Address of well: same as above

Location source: Location from permit

Permit Date: July 8, 1997 **Permit #:**

COMPANY Stollhans, Jeff
FARM Lafarge Corp.
DATE DRILLED July 21, 1997 **NO.** 5
ELEVATION 0 **COUNTY NO.** 20856
LOCATION NE NW SW
LATITUDE 37.213209 **LONGITUDE** -88.873085
COUNTY **Massac** **API 121272085600** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Stratigraphic Test	Top	Bottom
Total Depth		76
Core #C 14531 (0' - 6.2') Received: August 25, 1997		
Core #C 14531 (6.2' - 11') Received: August 25, 1997		
Core #C 14531 (11' - 16') Received: August 25, 1997		
Core #C 14531 (16' - 38.1') Received: August 25, 1997		
Core #C 14531 (38.1' - 76') Received: August 25, 1997		

Permit Date:

Permit #:

COMPANY IL State Geological Survey

FARM Maple Grove School

DATE DRILLED

NO. J-1

ELEVATION 0

COUNTY NO. 20851

LOCATION 2450'N line, 450'E line of section

LATITUDE 37.229018

LONGITUDE -88.859059

COUNTY **Massac**

API **121272085100**

10 - 15S - 3E

Page 1 **ILLINOIS STATE GEOLOGICAL SURVEY**

Private Water Well	**Top**	**Bottom**
clay	0	76
sandy clay & yellow sand	76	120
gray clay	120	145
gray clay & sand	145	210
chert	210	280
Total Depth		280

Casing: 6" PVC SDR 21 from -1' to 235'

Grout: BENTONITE from 0 to 230.

Water from chert at 265' to 280'.
Static level 120' below casing top which is 1' above GL
Pumping level 160' when pumping at 12 gpm for 72 hours
Permanent pump installed at 200' on February 10, 1996, with a capacity of 7 gpm
Remarks: Well not completed at this time
Location source: Location from permit

Permit Date: October 12, 1995 **Permit #:**

COMPANY Beanland, Ronald D.
FARM [redacted]
DATE DRILLED November 10, 1995 **NO.**
ELEVATION 0 **COUNTY NO.** 20699
LOCATION NW NE NE
LATITUDE 37.234715 **LONGITUDE** -88.842652
COUNTY **Massac** **API** **121272069900** **11 - 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

Address of well:
Joppa, IL

Location source: Location from permit

Permit Date: October 7, 1994 **Permit #:**

COMPANY Beanland, Leonard Ralph
FARM [redacted]
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

Industrial Water Well	**Top**	**Bottom**
SS #64975 (0'-105')	0	0
light brown clay	0	10
dark brown clay	10	25
gray clay	25	40
gray & brown clay	40	55
brown fine sdy till	55	60
coarse sand & gravel	60	92
Total Depth		**110**

Casing: 42" STEEL 166.71 LB from 0' to 20'
16" STEEL 62.58 LB from -3' to 71'

Screen: 25' of 16" diameter 5 slot

Grout: READY MIX from 0 to 20.

Size hole below casing: 42"

Water from alluvial at 71' to 94'.
Static level 52' below casing top which is 3' above GL
Pumping level 62' when pumping at 300 gpm for 4 hours

Permanent pump installed at 65' on April 4, 1985, with a capacity of 300 gpm

Sample set # 64975 (0' - 105')

Location source: Location from permit

Permit Date: December 21, 1984 **Permit #:** 116253

COMPANY Ruester, John T.
FARM Missouri Portland Cmt Co.
DATE DRILLED February 22, 1985 **NO.** 4
ELEVATION 0 **COUNTY NO.** 20520
LOCATION 1980'S 800'E NW/c
LATITUDE 37.215958 **LONGITUDE** -88.873711
COUNTY Massac **API 121272052000** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Test Hole	**Top**	**Bottom**
SS #64976 (0'-95')	0	0
light brown clay	0	5
brown clay	5	25
gray clay	25	40
drk brn cl w/fine s	40	50
brn fine sand & gvl	50	65
coarse sand & gravel	65	75
fine to medium sand	75	80
coarse sand & gravel	80	95
fine sand	95	110
Total Depth		**110**

Size hole below casing: 0"

Remarks: test hole for fm spls.sealed w/bentonite

Sample set # 64976 (0' - 95') Received: March 5, 1985

Location source: Location from permit

Permit Date: December 21, 1984 **Permit #:** 116252

COMPANY Ruester, John T.

FARM Missouri Portland Cement Co.

DATE DRILLED January 3, 1985 **NO.**

ELEVATION 0 **COUNTY NO.** 20519

LOCATION 1800'N line, 700'W line of section

LATITUDE 37.216462 **LONGITUDE** -88.874027

COUNTY Massac **API 121272051900** **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Household - Livestock Watering Well	**Top**	**Bottom**
clay	0	21
clay & fine sand	21	150
chert	150	175
Total Depth		175

Casing: 6" PVC SDR-21 from -1' to 174'

Grout: BENTONITE/SAND from 0 to 160.

Size hole below casing: 0"

Water from chert at 165' to 174'.
Static level 50' below casing top which is 1' above GL
Pumping level 90' when pumping at 20 gpm for 2 hours

Permanent pump installed at 120' on May 16, 1987, with a capacity of 20 gpm

Address of well: R.R.
Joppa, IL

Location source: Location from permit

Permit Date: April 23, 1987 **Permit #:** 131156

COMPANY Beanland, Ronald D.
FARM [redacted]
DATE DRILLED May 15, 1987 **NO.**
ELEVATION 0 **COUNTY NO.** 20471
LOCATION NE SE NW
LATITUDE 37.231377 **LONGITUDE** -88.867889
COUNTY Massac **API** 121272047100 10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		52
Driller's Log filed		

Permit Date: **Permit #:**

COMPANY Horman, Paul

FARM [redacted]

DATE DRILLED October 1, 1976 **NO.** 1

ELEVATION 0 **COUNTY NO.** 20255

LOCATION SW SE SW

LATITUDE 37.222274 **LONGITUDE** -88.870363

COUNTY Massac **API** 121272025500 10 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		110
Driller's Log filed		

Permit Date: **Permit #:**

COMPANY Luhr Brothers, Inc.
FARM Mo Portland Cement
DATE DRILLED September 1, 1974 **NO.** 3
ELEVATION 355GL **COUNTY NO.** 20220
LOCATION 2220'N line, 500'W line of NW
LATITUDE 37.215316 **LONGITUDE** -88.874782
COUNTY Massac **API** 121272022000 15 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	**Top**	**Bottom**
surface red clay	0	20
big, red gravel	20	70
sandy clay	70	120
dry sand	120	135
blue clay, dark	135	270
broken limerock	270	280
limerock	280	283
Total Depth		283

Casing: 6" STEEL 20# from 0' to 280'

Grout: DRILL CUTTINGS from 0 to 40.

Size hole below casing: 6"

Water from broken lime at 280' to 283'.
Static level 135' below casing top which is 1' above GL
Pumping level 160' when pumping at 15 gpm for 4 hours

Driller's Log filed
Location source: Location from permit

Permit Date: January 24, 1973 **Permit #:** NF17726

COMPANY Horman, Paul
FARM [redacted]
DATE DRILLED February 7, 1973 **NO.** 1
ELEVATION 0 **COUNTY NO.** 00198
LOCATION NE NE SE
LATITUDE 37.22736 **LONGITUDE** -88.840461
COUNTY Massac **API** 121270019800 **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 [redacted]
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

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
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**
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
Location source: Location from permit

Permit Date: August 11, 1969 **Permit #:** 06803

COMPANY Jennings, James E.
FARM [redacted]
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
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 [redacted]

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
Total Depth		137
Driller's Log filed		
Survey Sample Study filed		
Sample set # 4671 (0' - 137') Received: June 20, 1940		

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

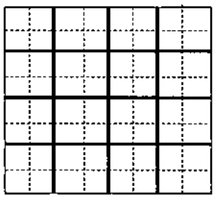
API 121270005400

23 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	**Top**	**Bottom**
Total Depth		235
Driller's Log filed		
Sample set # 21218 (0' - 235') Received: July 11, 1951		

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		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		403
Driller's Log filed		
Survey Sample Study filed		
Sample set # 21445 (0' - 405') Received: January 9, 1951		

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**

Page 1

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		

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		166
Driller's Log filed		
Survey Sample Study filed		
Sample set # 20885 (0' - 166') Received: July 11, 1950		

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Joppa Compressor Station #7
DATE DRILLED October 1, 1950 **NO.** 2
ELEVATION 360GL **COUNTY NO.** 00049
LOCATION 500'S line, 2200'E line of SE
LATITUDE 37.222643 **LONGITUDE** -88.865214
COUNTY **Massac** **API** **121270004900** **10 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		150
Survey Sample Study filed		
Driller's Log filed		
Sample set # 20884 (0' - 150') Received: July 11, 1950		

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.

FARM Joppa Compressor Station #7

DATE DRILLED November 1, 1950 **NO.** 1

ELEVATION 360GL **COUNTY NO.** 00048

LOCATION 250'S line, 2200'E line of SE

LATITUDE 37.221953 **LONGITUDE** -88.865227

COUNTY Massac **API 121270004800** **10 - 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		

Permit Date:

Permit #:

COMPANY Smith & Cunningham

FARM [redacted]

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		153
Driller's Log filed		

Permit Date: Permit #:

COMPANY Smith & Cunningham

FARM [redacted]

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

Page 1

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		140
Driller's Log filed		

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Missouri Prtlnd Cemt
DATE DRILLED November 1, 1961 **NO.** 1A
ELEVATION 355GL **COUNTY NO.** 00023
LOCATION NW SW
LATITUDE 37.21218 **LONGITUDE** -88.874319
COUNTY Massac **API** 121270002300 15 - 15S - 3E

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		

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**

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LABORATORIES, Inc.

P.O. Box 907, 825 Industrial Road
Madisonville, KY 42431
270.821.7375
www.mccoylabs.com

Lexington, KY
859.299.7775

Pikeville, KY
606.432.3104

Louisville, KY
502.961.0001

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"Providing Tomorrow's Analytical Capabilites Today"

Certificate of Analysis

Chris Skates
Electric Energy Inc
P O Box 165
Joppa IL, 62953

Report Printed: 02/26/2013 15:34

Project Name:	Process Control	Workorder:	3022088

Dear Chris Skates

Enclosed are the analytical results for samples received at the lab on 02/14/2013 15:15.

McCoy & McCoy Laboratories, Inc located in Madisonville, Kentucky is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and as such, certifies that all applicable test results meet the requirements of NELAP.

If you have any questions regarding this certificate of analysis, please contact us at (270) 821-7375.

Please visit us at www.mccoylabs.com for a listing of NELAP accreditations and Scope of Work, as well as other links to Water Quality documentation on the internet.

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60 YEARS
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This page is included as part of the Analytical Report and must be retained as a permanent record thereof.

Brett Davis

Brett Davis, Project Manager

McCOY & McCOY
LABORATORIES, Inc.

P.O. Box 907, 825 Industrial Road
Madisonville, KY 42431
270.821.7375
www.mccoylabs.com

Lexington, KY
859.299.7775

Pikeville, KY
606.432.3104

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SAMPLE SUMMARY

Lab ID	Client Sample ID/Alias	Matrix	Date Collected	Date Received	Sampled By
3022088-01	Groundwater/Well #1	Wastewater	02/12/2013 12:25	02/14/2013 15:15	Chris Skates
3022088-02	Groundwater/Well #2	Wastewater	02/12/2013 12:40	02/14/2013 15:15	Chris Skates
3022088-03	Groundwater/Well #3	Wastewater	02/12/2013 14:20	02/14/2013 15:15	Chris Skates
3022088-04	Groundwater/Well #4	Wastewater	02/12/2013 13:10	02/14/2013 15:15	Chris Skates

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Madisonville, KY 42431
270.821.7375
www.mccoylabs.com

Lexington, KY
859.299.7775

Pikeville, KY
606.432.3104

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ANALYTICAL RESULTS

Lab Sample ID: **3022088-01**
Description: **Groundwater Well #1**

Sample Collection Date Time: 02/12/2013 12:25
Sample Received Date Time: 02/14/2013 15:15

Metals by EPA 200 Series Methods

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Boron	ND	L1, U	mg/L	0.10	0.10	EPA 200.7	02/18/2013 08:14	02/18/2013 21:31	MLC

Conventional Chemistry Analyses_01

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Sulfate	6		mg/L	1	0.2	EPA 300.0	02/25/2013 18:03	02/25/2013 18:03	DMH

ANALYTICAL RESULTS

Lab Sample ID: **3022088-02**
Description: **Groundwater Well #2**

Sample Collection Date Time: 02/12/2013 12:40
Sample Received Date Time: 02/14/2013 15:15

Metals by EPA 200 Series Methods

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Boron	ND	L1, U	mg/L	0.10	0.10	EPA 200.7	02/18/2013 08:14	02/18/2013 21:42	MLC

Conventional Chemistry Analyses_01

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Sulfate	6		mg/L	1	0.2	EPA 300.0	02/25/2013 18:26	02/25/2013 18:26	DMH

ANALYTICAL RESULTS

Lab Sample ID: **3022088-03**
Description: **Groundwater Well #3**

Sample Collection Date Time: 02/12/2013 14:20
Sample Received Date Time: 02/14/2013 15:15

Metals by EPA 200 Series Methods

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Boron	ND	L1, U	mg/L	0.10	0.10	EPA 200.7	02/18/2013 08:14	02/18/2013 21:46	MLC

Conventional Chemistry Analyses_01

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Sulfate	6		mg/L	1	0.2	EPA 300.0	02/25/2013 18:49	02/25/2013 18:49	DMH

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Madisonville, KY 42431
270.821.7375
www.mccoylabs.com

Lexington, KY 859.299.7775
Pikeville, KY 606.432.3104
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ANALYTICAL RESULTS

Lab Sample ID: **3022088-04**
Description: **Groundwater Well #4**

Sample Collection Date Time: 02/12/2013 13:10
Sample Received Date Time: 02/14/2013 15:15

Metals by EPA 200 Series Methods

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Boron	ND	L1, U	mg/L	0.10	0.10	EPA 200.7	02/18/2013 08:14	02/21/2013 14:09	MLC

Conventional Chemistry Analyses_01

Analyte	Result	Flag	Units	MRL	MDL	Method	Prepared	Analyzed	Analyst
Sulfate	6		mg/L	1	0.2	EPA 300.0	02/25/2013 19:11	02/25/2013 19:11	DMH

Notes for work order 3022088

- Samples collected by MMLI personnel are done so in accordance with procedures set forth in MMLI field services SOPs.
- All Waste Water analyses comply with methodology requirements of 40 CFR Part 136.
- All Drinking Water analyses comply with methodology requirements of 40 CFR Part 141.
- Unless otherwise noted, all quantitative results for soils are reported on a dry weight basis.
- The Chain of Custody document is included as part of this report.
- All Library Search analytes should be regarded as tentative identification based on the presumptive evidence of the mass spectra.

U	Target analyte was analyzed for, but was below detection limit (the value associated with the qualifier is the laboratory method detection limit in our LIMS system).
L1	The associated blank spike recovery was above method acceptance limits.
J	Estimated value.

Standard Quallifiers/Acronymns

MDL	Method Detection Limit
MRL	Minimum Reporting Limit
ND	Not Detected
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
DUP	Sample Duplicate
% Rec	Percent Recovery
RPD	Relative Percent Difference
>	Greater than permit limits
<	Less than permit limits

Analyses performed at the Madisonville KY location unless specified with the following location codes.

02	Pikeville, KY
03	Paducah, KY
04	Lexington, KY
05	Louisville, KY

Certified Analyses included in this Report

Analyte	Certifications
EPA 200.7 in Water	
Boron	VA NELAC (460210)
EPA 300.0 in Water	
Sulfate	KY Drinking Water (00030) VA NELAC (460210)

Surface Elevation: 361.12

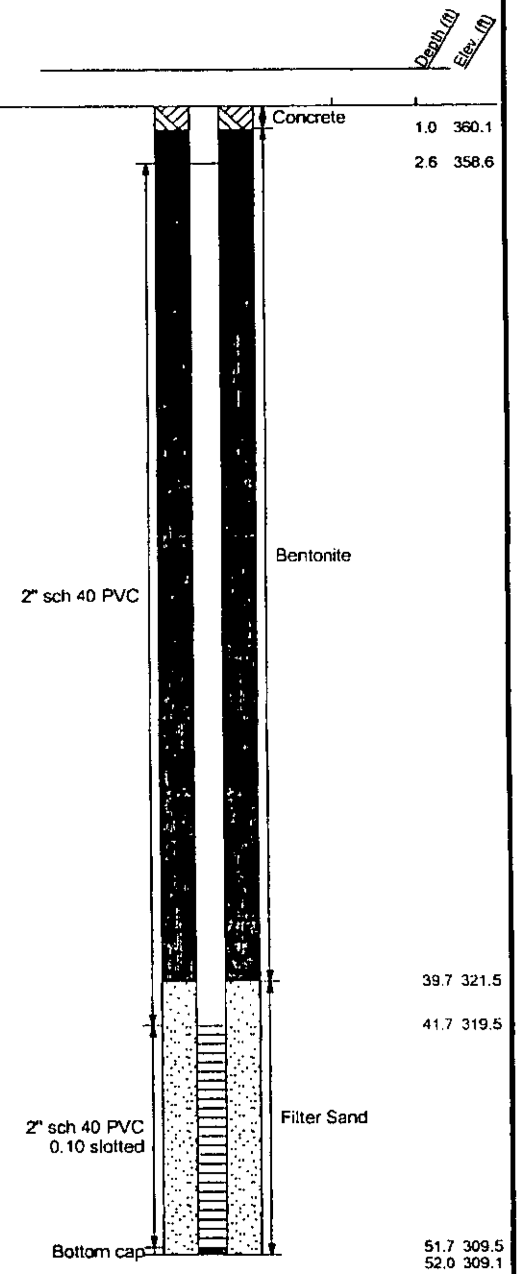
Datum msl

Completion Date: ______

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff to stiff, brown and gray, silty CLAY - (CL)		2-4-4-5	SS1
	k = 2.8 x 10^{-8}cm/s		2-2-3-4	SS2
5			2-3-4-5	SS3
			5-4-5-6	SS4
			3-5-6-7	SS5
10			3-5-7-9	SS6
			3-4-4-5	SS7
15			2-2-4-5	SS8
			2-4-5-5	SS9
			2-4-6-7	SS10
20			2-4-7-5	SS11
			2-3-4-4	SS12
25	trace sand		3-4-6-6	SS13
			2-4-5-8	SS14
			2-3-4-6	SS15
30	trace gravel and weathered limestone		2-4-8-18	SS16
	Weathered LIMESTONE with silty clay		15-18-22 -22	SS17
35	Stiff, brown and gray, silty CLAY with sand - CL		7-7-6-6	SS18
	Medium stiff, brown and gray, silty CLAY, trace sand - CL		2-3-4-4	SS19
			3-3-4-4	SS20
40	soft		1-2-2-1	SS21
			1-4-6-7	SS22
45	very stiff, with weathered limestone		4-10-12-6	SS23
			3-4-4-4	SS24
		∇	1-2-3-3	SS25
50			2-3-4-6	SS26
	Boring terminated at 52 feet.			

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 48 FEET ∇

DRILLING DATA

__ AUGER __ HOLLOW STEM

WASHBORING FROM __ FEET

PH DRILLER BGF LOGGER

__ DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: ROP	App'vd. by: KBP
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-101

Project No. J017150.02

Surface Elevation: 356.63

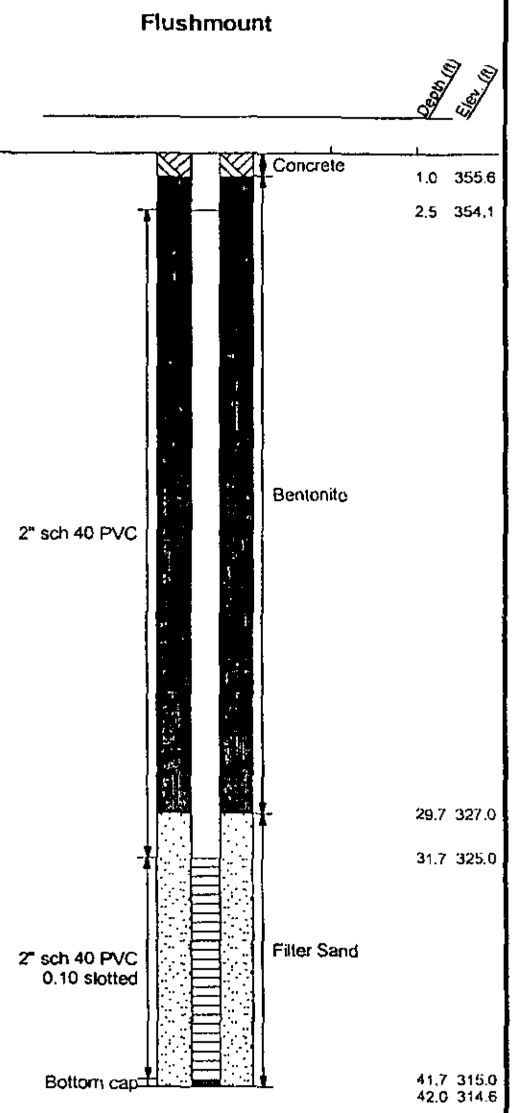
Datum msl

Completion Date: 6/24/10

DEPTH IN FEET: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50

DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
Medium stiff to stiff, brown, silty CLAY - (CL)	▨	2-2-3-4	SS1
	▨	2-3-4-5	SS2
	▨	1-3-4-5	SS3
	▨	1-3-4-4	SS4
	▨	1-4-4-4	SS5
	▨	2-3-5-6	SS6
	▨	2-3-5-7	SS7
	▨	2-4-4-4	SS8
	▨	3-6-7-9	SS9
	▨	5-6-7-8	SS10
	▨	1-5-5-10	SS11
	▨	3-5-6-8	SS12
k = 4.6 x 10^{-9}cm/s	▨	3-5-7-9	SS13
brown and gray	▨	2-4-6-6	SS14
	▨	3-6-10-11	SS15
	▨	3-4-7-8	SS16
Stiff, brown and gray, silty CLAY, trace sand - CL	▨	2-3-6-7	SS17
	▨	6-5-5-8	SS18
	▨	3-5-6-7	SS19
	▨	1-3-5-6	SS20
	▨	3-4-5-7	SS21
Boring terminated at 42 feet.			

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

__ AUGER __ HOLLOW STEM

WASHBORING FROM __ FEET

PH DRILLER JPC LOGGER

CME 550X DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: Kgp	App'vd. by: KBP
Date: 7/14/10	Date: 9/21/10	Date: 9/21/10

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ash Pond Evaluation
EEI Facility
Joppa, Illinois

LOG OF BORING: G-111

Project No. J017150.02

Surface Elevation: 345.16

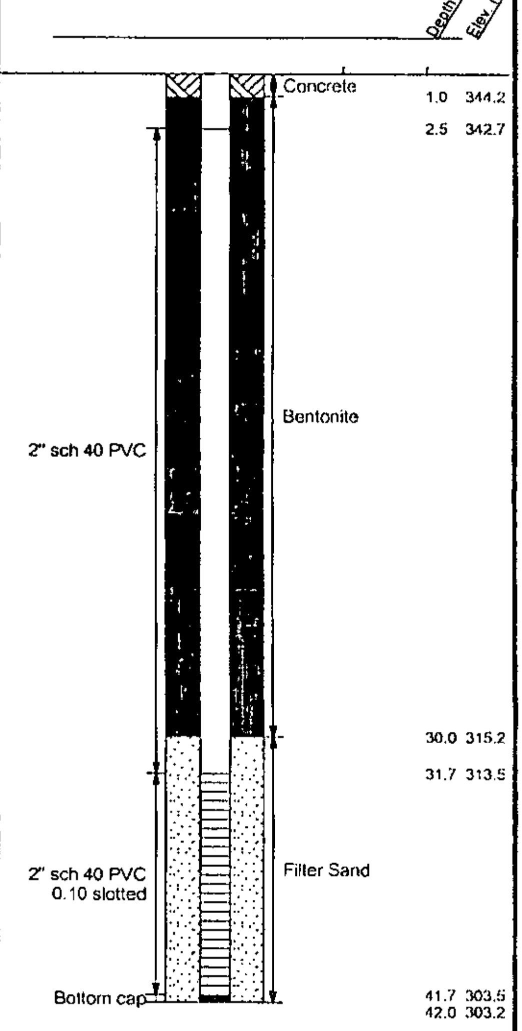
Datum msl

Completion Date: 6/20/10

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff to very stiff, brown silty CLAY - (CL)	▨	2-3-5-6	SS1
		▨	3-5-9-11	SS2
5		▨	3-6-11-11	SS3
		▨	4-11-14-15	SS4
10		▨	6-8-9-10	SS5
		▨	2-5-5-6	SS6
		▨	2-5-5-7	SS7
15		▨	2-5-6-7	SS8
	k = 9.2×10^{-9}cm/s	▨	2-3-4-5	SS9
20	with coal	▨	2-4-5-4	SS10
		▨	2-3-4-4	SS11
		▨	1-2-3-4	SS12
25		▨	1-3-4-4	SS13
		▨	1-3-4-5	SS14
30		▨	1-2-3-4	SS15
		▨	2-3-4-5	SS16
	Soft to medium stiff, brown silty CLAY - CL	▨	1-2-2-4	SS17
35		▨	2-2-4-5	SS18
		▨	0-1-1-2	SS19
40		▨	2-2-2-2	SS20
		▨	2-4-4-8	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.

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

__ AUGER __ HOLLOW STEM

WASHBORING FROM __ FEET

PH DRILLER JPC LOGGER

__ DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RBP	App'vd. by: RBY
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

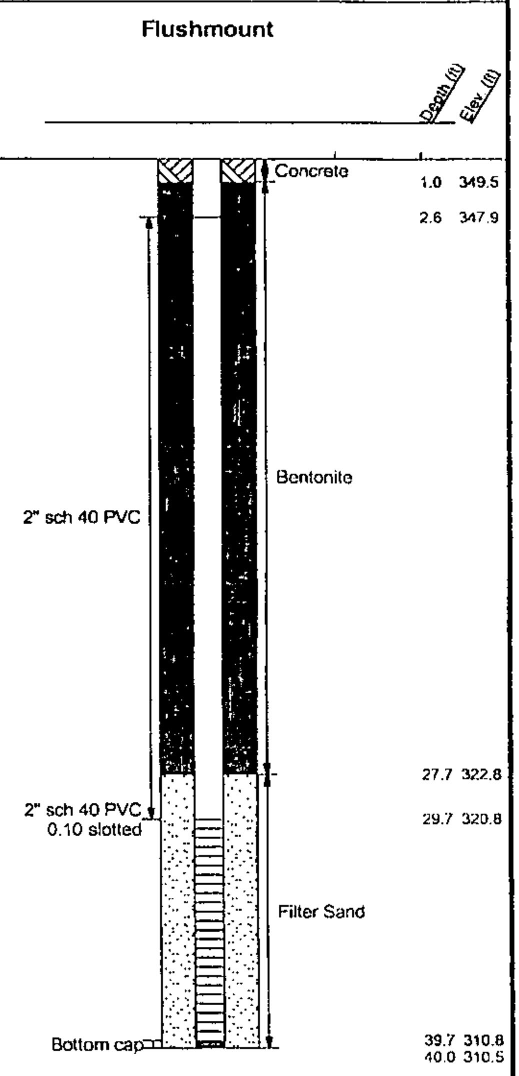
LOG OF BORING: G-112b

Project No. J017150.02

Surface Elevation: 350.46
Datum msl
Completion Date: 6/25/10

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	FILL		2-2-3-4	SS1
	Medium stiff to stiff, brown CLAY - CH		2-5-6-7	SS2
5			2-2-4-3	SS3
	Soft, brown to brown and gray CLAY - CH		2-1-2-3	SS4
			1-1-1-3	SS5
10	Medium stiff to stiff, brown and gray CLAY - CH		3-3-4-5	SS6
			2-3-4-6	SS7
15			2-3-4-5	SS8
			2-2-4-5	SS9
			4-5-7-8	SS10
20			4-5-7-7	SS11
			2-5-6-10	SS12
25			2-8-10-10	SS13
	Stiff, gray and brown, silty CLAY - CL k = 3.7 x 10^{-9}cm/s		3-6-8-9	SS14
			4-6-8-11	SS15
30			4-4-7-19	SS16
	Hard to very stiff, gray and brown, sandy CLAY - CL		8-17-16 -20	SS17
35			6-8-9-9	SS18
	Stiff, brown and gray, silty CLAY, trace sand - (CL)		3-4-6-8	SS19
40	Boring terminated at 40 feet.		4-4-6-9	SS20
45				
50				

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

__ AUGER __ HOLLOW STEM
WASHBORING FROM __ FEET
PH DRILLER JPC LOGGER
CME 550X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: KOP	App'vd. by: KOP
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-113

Project No. J017150.02

LOG OF BORING 2002 WL J017150.02ENV - EEI JOPPA.GPJ GTINC 0636301.GPJ 9/22/10

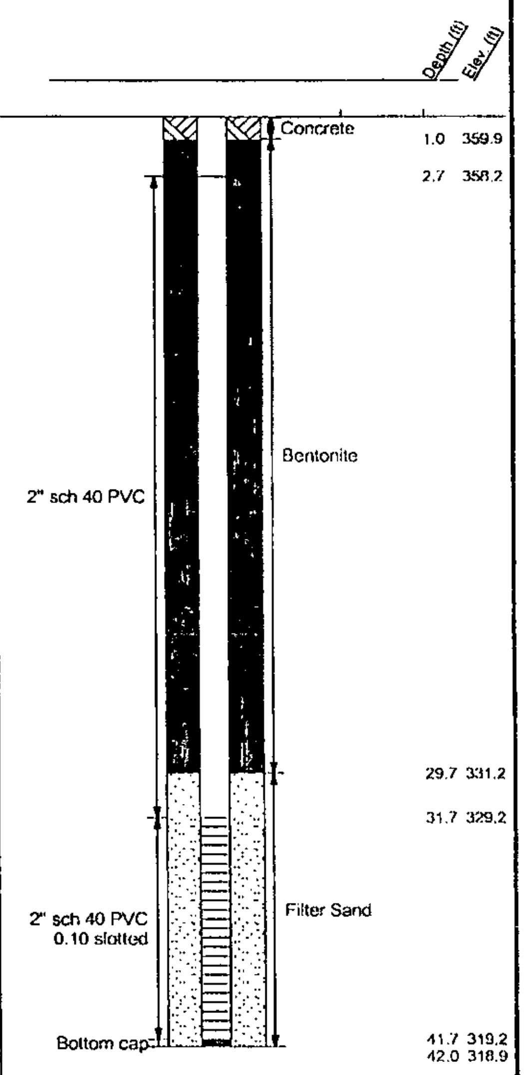
Surface Elevation: 360.9 Completion Date: 6/19/10

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 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
__ DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RDF	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

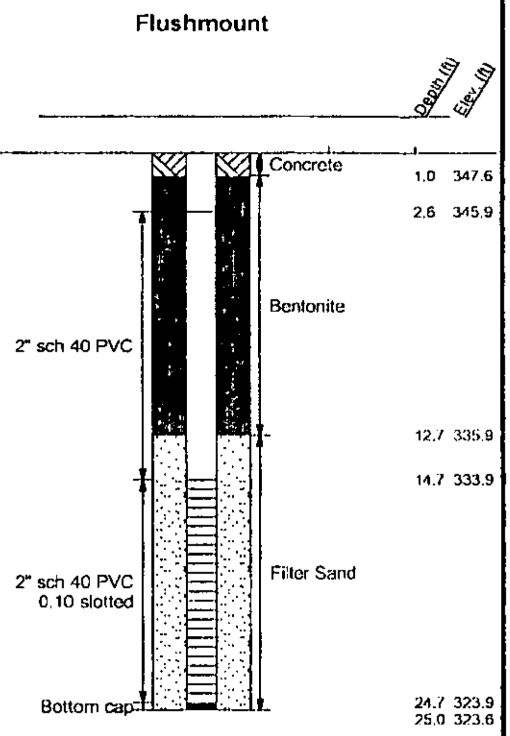
Surface Elevation: 348.56

Datum msl

Completion Date: ___

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



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: KBP	App'vd. by: KBP
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

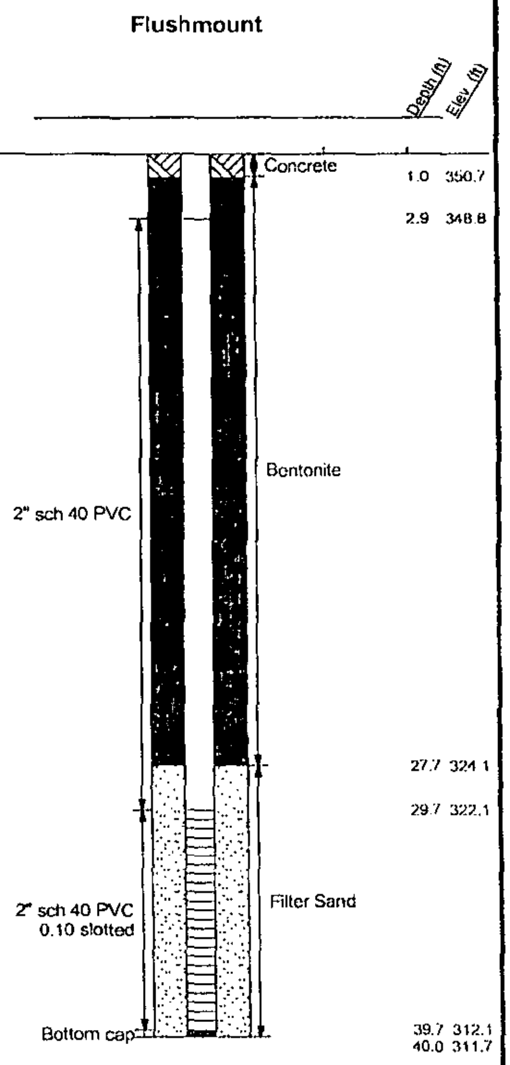
Datum msl

Completion Date: 6/18/10

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
			2-3-6-6	SS5
10				
			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
			3-5-7-7	SS10
20				
			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
35			3-4-6-8	SS18
			5-5-7-7	SS19
	Stiff, brown clayey SILT - ML		2-3-6-7	SS20
40	Boring terminated at 40 feet.			
45				
50				

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

WELL DIAGRAM



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: KOP	App'vd. by: KOP
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

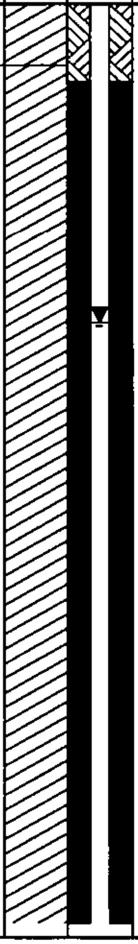
LOG OF BORING 2002 WL J017150.02ENV - EEI JOPPA.GPJ GTINC 0638301.GPJ 9/22/10

SOIL BORING LOG INFORMATION

NATURAL
RESOURCE
TECHNOLOGY

Page 1 of 2

Facility/Project Name Joppa Power Station (EEI)	License/Permit/Monitoring Number	Boring Number G112C	
Boring Drilled By: Name of crew chief (first, last) and Firm Matt Cooper Bulldog Drilling, Inc.	Date Drilling Started 1/28/2013	Date Drilling Completed 1/28/2013	Drilling Method hollow stem auger
Common Well Name G112C	Final Static Water Level 319.4 Feet (NAVD88)	Surface Elevation 323.6 Feet (NAVD88)	Borehole Diameter 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 ☐ S 198552.26 Feet	☒ E ☐ W 829088.33 Feet
Facility ID	County Massac	State Illinois	Civil Town/City/ or Village 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	U S C S	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
1	48 20			0 - 0.8' **SILTY CLAY** CL, LOAM, dark brown, high plasticity, soft, moist.	CL									soil samples collected with 1.5" diameter macro core sampler with liners
			1	0.8 - 24' **SILTY CLAY** CL, light yellowish brown (10YR 6/4), high plasticity, very soft to soft.					1.25					
			2											
			3											
2	60 46		4				▼							
			5	4.5' stiff to very stiff, low to medium plasticity, light gray (10YR 7/1) with 10-25 % yellowish brown (10YR6/8) mottling..					4					
									3.5					
			6		CL				3.5					
			7						3.5					
			8	8' light gray with <10% mottling, hard, dry.					4					
									4					
3	60 51		9	9.5' stiff, medium plasticity, moist.					2					
			10						2.5					
			11						2.25					
			12											

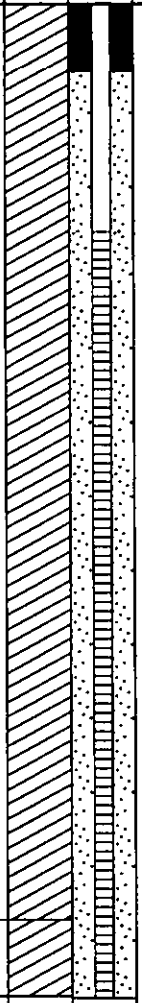
I hereby certify that the information on this form is true and correct to the best of my knowledge.

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 G112C



Sample		Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	
				0.8 - 24' **SILTY CLAY** CL, light yellowish brown (10YR 6/4), high plasticity, very soft to soft. *(continued)*					3					
			13	12.5' gray (10YR 5/1), no mottling.										
				13.5' very stiff silty clay.					3.25					
4	60 52		14	14' medium to stiff, medium to high plasticity, gray (10YR 6/1) with trace mottling.					2.5					
			15						3.25					
			16	16' no mottling.					1.75					
			17	17.5' light gray (10YR 7/1), no mottling.					1.5					
			18		CL									
				18.5' very stiff silty clay.					4					
5	60 50		19	19' wet, soft to very soft, high plasticity.										
			20						1					
			21						2					
			22						2.5					
			23	22.5' very stiff to hard, low plasticity, light gray (10YR 7/1), no mottling.					3					
														PP 3.5 - 4.0
NR	12 0		24	24 - 25' CL.	CL									Auger and Clean hole 24' to 25'
			25	25' End of Boring.										

SOIL BORING LOG INFORMATION

NATURAL
RESOURCE
TECHNOLOGY

Page 1 of 3

Facility/Project Name Joppa Power Station (EEI)	License/Permit/Monitoring Number	Boring Number G152B

Boring Drilled By: Name of crew chief (first, last) and Firm Matt Cooper Bulldog Drilling, Inc.	Date Drilling Started 1/28/2013	Date Drilling Completed 1/30/2013	Drilling Method hollow stem auger
Common Well Name G152B	Final Static Water Level 312.3 Feet (NAVD88)	Surface Elevation 345.2 Feet (NAVD88)	Borehole Diameter 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
198094.58 Feet ☒ N ☐ S 832931.61 Feet ☒ E ☐ W

Facility ID	County Massac	State Illinois	Civil Town/City/ or Village 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	U S C S	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 - 0.75' **SILTY CLAY** CL, disturbed with gravel, tree limbs, wood from clearing activities; dark brown, wet.	CL									PP 2 - 2.25
			1 2 3	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									
2	60 56		4	4' Silty Clay grading to a Clayey Silt, low plasticity, stiff, light gray (10YR 7/1), with 50% reddish brown mottling, moist.					3.25					
			5 6 7	4.5 - 12.5' **SILT**: ML, non plastic, stiff, very pale brown (10YR 8/2), dry.					3 3 2					
			8	7.3' soil horizon with small rootlets, 50% reddish brown mottling. 7.5' very pale brown (10YR 8/2), non plastic, stiff, dry.	ML				1.75					
3	60 58		9 10 11 12	9' silt with clay, very stiff, non plastic, very pale brown (10YR 7/3) with 10-25% reddish brown mottling.					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

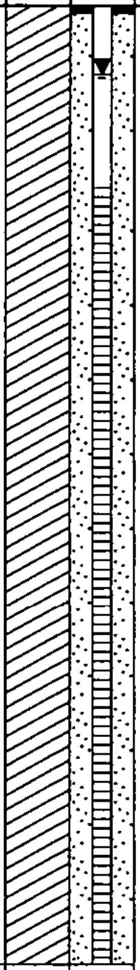
Boring Number G152B

Sample		Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	
									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			13.5' 10-50% reddish brown mottling.										
			14						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		CL				2.5					
			21						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.	CL				2.75					
			31						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	U S C S	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
				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	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			34.5' stiff to very stiff, high plasticity.										
			35						3.5					
			36						2.5					
			37						4.25					
			38	38' hard, < 10% mottling.	CL				2.5					
			39											PP is >4.5
9	60 55			39.5' very stiff to hard, high plasticity, gray (10YR 6/1) with < 10% yellowish brown (10YR 5/6) mottling, moist.										
			40						3					
			41						3					
			42						3					
			43						4.5					
			44						3.75					
				44.5' End of Boring.										

NATURAL RESOURCE TECHNOLOGY

MONITORING WELL CONSTRUCTION

Facility/Project Name Joppa Power Station (EEI)	Local Grid Location of Well 198552.26 ft. ☒ N. ☐ S. 829088.33 ft. ☒ E. ☐ W.	Well Name
Facility License, Permit or Monitoring No.	Local Grid Origin ☒ (estimated: ☐) or Well Location ☐ Lat. ___ ° ___ ' ___ " Long. ___ ° ___ ' ___ " or	G112C
Facility ID	St. Plane Illinois East Zone ft. N, ________ ft. E. S / C / [✓ N]	Date Well Installed 01/29/2013
Type of Well Well Code 11/mw	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
Distance from Waste/ Source ft. | State Illinois	Location of Well Relative to Waste/Source u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known | Gov. Lot Number	

A. Protective pipe, top elevation ________ ft. (NAVD88)

B. Well casing, top elevation 325.82 ft. (NAVD88)

C. Land surface elevation 323.6 ft. (NAVD88)

D. Surface seal, bottom 322.6 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 322.6 ft. (NAVD88) or 1.0 ft.

F. Fine sand, top ________ ft. (NAVD88) or ____ ft.

G. Filter pack, top 310.7 ft. (NAVD88) or 12.9 ft.

H. Screen joint, top 308.6 ft. (NAVD88) or 15.0 ft.

I. Well bottom 298.3 ft. (NAVD88) or 25.3 ft.

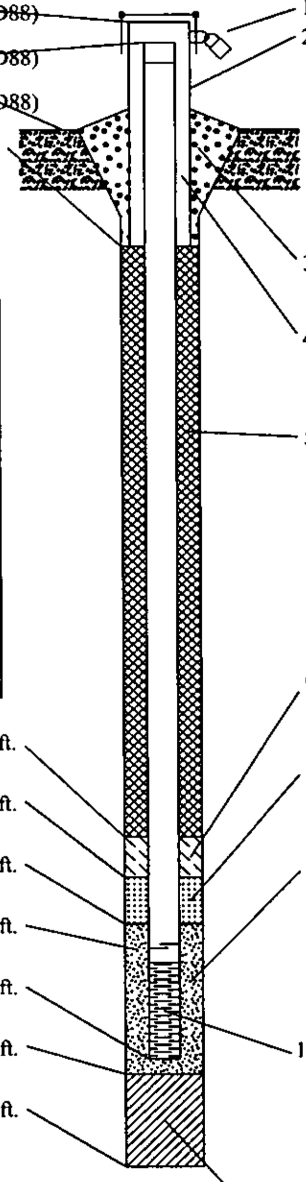
J. Filter pack, bottom 298.6 ft. (NAVD88) or 25.0 ft.

K. Borehole, bottom 298.6 ft. (NAVD88) or 25.0 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. 3.5 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 6 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.

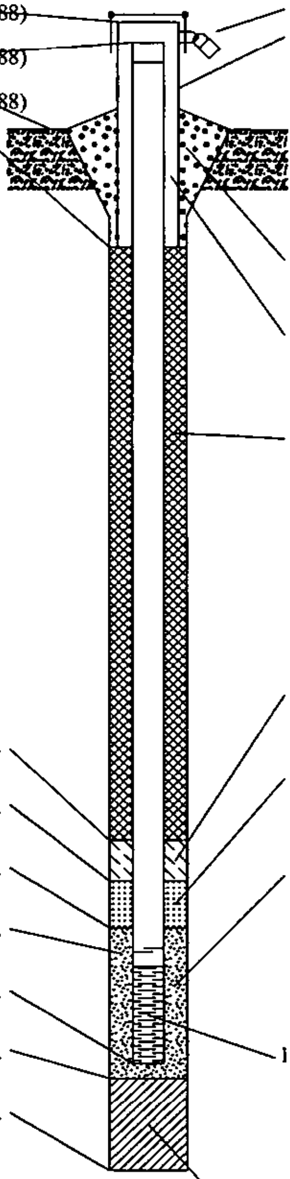
Date Modified: 2/19/2013

Signature	Firm Natural Resource Technology 23713 W. Paul Road Suite D, Pewaukee, WI 53072	Tel: (262) 523-9000 Fax: (262) 523-9001

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
Facility License, Permit or Monitoring No.	Local Grid Origin ☒ (estimated: ☐) or Well Location ☐ Lat. ____ ° ____ ' ____ " Long. ____ ° ____ ' ____ " or	G152B
Facility ID	St. Plane Illinois East Zone ft. N, ________ ft. E. S/C/[✓ N]	Date Well Installed 01/30/2013
Type of Well Well Code 11/mw	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
Distance from Waste/ Source ft. / State Illinois	Location of Well Relative to Waste/Source u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known / Gov. Lot Number	



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

Print Form

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 W. JEFFERSON ST.
SPRINGFIELD, IL 62761

WATER WELL SEALING FORM

PDF FILLABLE/SAVABLE

RETURN ALL COPIES TO IDPH OR LOCAL HEALTH DEPARTMENT

This form shall be submitted to this Department or the local health department not more than 30 days after a water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Illinois Water Well Construction Code. THE LOCAL HEALTH DEPARTMENT OR REGIONAL PUBLIC HEALTH DEPARTMENT MUST BE NOTIFIED AT LEAST 48 HOURS PRIOR TO SEALING.

1. Ownership (Name of Controlling Party): Electric Energy, Inc.

2. Well Location: Well Site Address: 2100 Portland Rd City: Joppa Zip: 62953

Lot #: Land I.D.#: County: Massac Township: 15S

Range: 3E Section: Quarter of the Quarter of the Quarter

GPS: North Degrees: 37 Minutes: 12 Seconds: 42.4 West Degrees: 88 Minutes: 51 Seconds: 59.3

Report decimal minutes to minutes and seconds by multiplying the decimal part of the minutes by 60, e.g. latitude 38 degrees 46.07 minutes N would be latitude 38 degrees 46 minutes 4.2 seconds (0.07 x 60 = 4.2) N. Report GPS coordinates to the nearest 0.1 second.

3. Year Drilled: 6/2010 4. Drilling Permit Number (and date, if known: G-112B

5. Type of Well: Monitoring 6. Total Depth (ft.): 42 Diameter (in.): 2

7. Formation clear of obstruction: Yes

8. Detains of Plugging (bentonite, neat cement or other materials)

Filled with	Chip Bentonite	From (ft.)	42	to (ft.)	3
Kind of plug	Soil	From (ft.)	3	to (ft.)	0
Filled with		From (ft.)		to (ft.)	
Kind of plug		From (ft.)		to (ft.)	
Filled with		From (ft.)		to (ft.)	
Kind of plug		From (ft.)		to (ft.)	

9. CASING RECORD Upper 2 feet of casing removed: Yes 10. Date well was sealed: Jan 28, 2013

11. Licensed water well driller or other person approved by the Department performing well sealing

Name: John Thomas Marlo Complete License Number: 092-006857

Address: 411 Transpoint Dr, Suite A City: Dupo State: Illinois Zip Code: 62239

This state agency is requesting discolsure of information that is necessary to accomplish the statutory purpose as outlined under Public Act-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center. IL 482-0631- Revised 5/09

Questions regarding the completion of this form should be directed to the local health department or the Illinois Department of Public Health 217-782-5830, TTY (for hearing impaired only) 800-547-0466.

Print Form

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 W. JEFFERSON ST.
SPRINGFIELD, IL 62761

WATER WELL SEALING FORM

PDF FILLABLE/SAVABLE

RETURN ALL COPIES TO IDPH OR LOCAL HEALTH DEPARTMENT

This form shall be submitted to this Department or the local health department not more than 30 days after a water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Illinois Water Well Construction Code. THE LOCAL HEALTH DEPARTMENT OR REGIONAL PUBLIC HEALTH DEPARTMENT MUST BE NOTIFIED AT LEAST 48 HOURS PRIOR TO SEALING.

1. Ownership (Name of Controlling Party) Electric Energy, Inc.
2. Well Location: Well Site Address 2100 Portland Rd City Joppa Zip 62953

Lot # Land I.D.# County Massac Township 15S

Range 3E Section Quarter of the Quarter of the Quarter

GPS: North Degrees 37 Minutes 12 Seconds 39 West Degrees 88 Minutes 51 Seconds 17.7

Report decimal minutes to minutes and seconds by multiplying the decimal part of the minutes by 60, e.g. latitude 38 degrees 46.07 minutes N would be latitude 38 degrees 46 minutes 4.2 seconds (0.07 x 60 = 4.2) N. Report GPS coordinates to the nearest 0.1 second.

3. Year Drilled 6/21/2010 4. Drilling Permit Number (and date, if known G-152

5. Type of Well Monitoring 6. Total Depth (ft.) 25 Diameter (in.) 2

7. Formation clear of obstruction Yes

8. Detains of Plugging (bentonite, neat cement or other materials)

Filled with	Chip Bentonite	From (ft.)	25	to (ft.)	3
Kind of plug	Soil	From (ft.)	3	to (ft.)	0
Filled with		From (ft.)		to (ft.)	
Kind of plug		From (ft.)		to (ft.)	
Filled with		From (ft.)		to (ft.)	
Kind of plug		From (ft.)		to (ft.)	

9. CASING RECORD Upper 2 feet of casing removed Yes 10. Date well was sealed Jan 29, 2013

11. Licensed water well driller or other person approved by the Department performing well sealing

Name John Thomas Marlo Complete License Number 092-006857

Address 411 Transpoint Dr, Suite A City Dupo State Illinois Zip Code 62239

This state agency is requesting discolsure of information that is necessary to accomplish the statutory purpose as outlined under Public Act-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center. IL 482-0631- Revised 5/09

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Appendix C. Groundwater Quality Results for August 2010 to May 2013

Hydrogeologic Assessment
Joppa Generating Station, Joppa, IL
Electric Energy Inc. and Ameren Energy Generating Company

Monitoring Well	Date	Depth to GW^2 (ft)	35 IAC 620 Standard^1	pH (SU)	TDS	Nitrogen, Nitrate	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Nickel	Selenium	Silver	Zinc	Antimony	Lead	Thallium	Mercury	Cyanide	Sulfate	Fluoride	Chloride
				6.5-9.0	1200	100	0.20	2.0	0.5	2.0	0.050	1.0	1.0	0.65	5.0	10.0	2.0	0.05	ns	10.0	0.024	0.10	0.020	0.010	0.60	400	4.0	200
G101	8/17/2010	45.25		7.13	344	2.1	<0.0250	0.103	<0.0010	<0.0200	<0.00200	<0.0100	<0.0100	<0.0100	1.34	0.0556	<0.010	<0.050	<0.010	<0.010	<0.0050	0.0026	<0.0020	<0.00020	<0.0070	32	0.26	7.0
G101	11/5/2010	dry																										
G101	03/15/11	44.88		6.63	294	1.72	<0.0250	0.09	<0.0010	<0.020	<0.0020	<0.0100	<0.0100	<0.0100	0.172	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	32	0.27	6.0
G101	06/16/11	39.64		7.18	276	1.6	<0.025	0.64	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	34	0.26	5.0
G101	09/13/11	46.24		6.88	222	1.6	<0.025	0.061	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	28	0.32	3.0
G101	11/29/11	46.32		7.19	268	1.1	<0.025	0.072	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	35	0.28	4.0
G101	02/14/12	48.12		6.88	216	0.28	<0.025	0.58	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	35	0.30	4.0
G101	05/15/12	45.59		7.31	208	0.82	<0.025	0.044	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	22	0.31	4.0
G101	08/07/12	dry																										
G101	03/06/13	47.40		7.06	214	1.7	<0.010	0.069	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	33	0.33	<5.0
G101	05/13/13	49.68		6.81	272	1.4	<0.010	0.076	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0060	<0.0070	<0.0020	<0.00020	<0.0070	33	0.28	5.0
G111	8/17/2010	8.00		7.30	342	0.092	<0.025	0.15	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.45	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	25	0.62	8.0
G111	11/5/2010	9.77		6.70	330	0.72	<0.025	0.15	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	0.013	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	22	0.70	6.0
G111	03/15/11	4.90		7.07	322	0.10	<0.025	0.16	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	0.018	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	23	0.67	7.0
G111	06/16/11	6.42		7.11	372	0.17	<0.025	0.16	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	27	0.63	6.0
G111	09/13/11	8.45		7.10	330	0.13	<0.025	0.18	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	24	0.63	6.0
G111	11/29/11	4.68		7.05	376	0.15	<0.025	0.18	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	19	0.62	6.0
G111	02/14/12	4.55		7.23	354	0.093	<0.025	0.16	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	27	0.67	7.0
G111	05/15/12	6.68		7.14	324	0.12	<0.025	0.17	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	30	0.67	7.0
G111	08/07/12	9.22		7.02	394	0.052	<0.025	0.15	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	26	0.69	5.0
G111	03/07/13	5.20		7.28	390	0.37	<0.010	0.17	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	20	0.63	6.0
G111	05/14/13	4.68		7.05	374	<0.050	<0.010	0.17	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0060	<0.0070	<0.0020	<0.00020	<0.0070	19	0.71	7.0
G112C	03/07/13	5.25		6.79	412	0.34	<0.010	0.062	<0.0010	3.3	<0.0020	<0.010	<0.010	<0.010	0.048	0.18	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	63	0.74	<5.0
G112C	04/17/13	5.31		6.92	476	<0.050	<0.010	0.059	<0.0010	3.1	<0.0020	<0.010	<0.010	<0.010	0.039	0.17	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.040	<0.0020	<0.00020	<0.0070	66	0.80	<5.0
G112C	05/14/13	2.64		6.73	432	<0.050	<0.010	0.062	<0.0010	3.1	<0.0020	<0.010	<0.010	<0.010	<0.020	0.15	<0.010	<0.050	<0.010	<0.010	<0.0060	<0.0070	<0.0020	<0.00020	<0.0070	60	0.81	<5.0
G113	8/17/2010	15.40		6.89	542	0.84	<0.025	0.35	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.040	0.092	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	61	0.43	27
G113	11/5/2010	15.80		6.57	524	0.14	<0.025	0.40	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.025	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	35	0.45	29
G113	03/15/11	11.80		6.57	540	0.33	<0.025	0.46	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.0064	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	36	0.44	29
G113	06/16/11	13.66		6.60	590	0.35	<0.025	0.45	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	32	0.39	29
G113	09/13/11	14.90		6.54	554	0.40	<0.025	0.49	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	30	0.40	29
G113	11/29/11	11.50		6.44	636	0.68	<0.025	0.51	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	34	0.39	28
G113	02/14/12	12.05		6.56	590	0.48	<0.025	0.50	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	35	0.42	31
G113	05/15/12	14.25		6.71	586	0.57	<0.025	0.53	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	32	0.43	34
G113	08/07/12	16.65		6.50	666	0.48	<0.025	0.47	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	30	0.45	29
G113	03/07/13	12.65		6.82	606	0.53	<0.010	0.54	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.0076	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	37	0.42	32
G113	05/14/13	12.12		6.65	706	0.38	<0.010	0.55	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	50	0.44	30
G151	8/17/2010	42.70		6.70	348	1.0	<0.025	0.52	0.0025	8.3	<0.0020	0.023	0.033	0.028	18	0.47	0.021	<0.050	<0.010	0.061	<0.0050	0.027	<0.0020	<0.00020	<0.0070	93	0.17	16
G151	11/5/2010	dry																										
G151	03/16/11	38.10		5.89	236	1.1	<0.025	0.11	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.062	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	100	<0.10	6.0
G151	06/17/11	36.83		6.13	242	1.1	<0.025	0.79	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.038	0.036	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	103	<0.10	5.0
G151	09/13/11	41.45		5.99	228	1.2	<0.025	0.086	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.032	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	103	0.10	5.0
G151	11/29/11	42.20		6.20	256	1.1	<0.025	0.28	<0.0010	0.052	<0.0020	<0.010	<0.010	0.011	1.8	0.045	<0.010	<0.050	<0.010	0.017	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	98	0.95	5.0
G151	02/14/12	37.80		6.03	254	0.62	<0.025	0.074	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.022	<0.010	<0.050	<0.010	0.017	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	110	<0.10	5.0
G151	05/15/12	41.82		6.00	232	0.63	<0.025	0.081	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.060	0.011	<0.010	<0.050	<0.010	0.014	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	111	<0.10	5.0
G151	08/07/12	dry																										
G151	03/06/13	39.49		6.02	288	2.0	<0.010	0.069	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.015	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	99	<0.10	6.0
G151	05/13/13	37.13		5.96	282	1.6	<0.010	0.068	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.011	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	102	<0.10	6.0
G152B	03/07/13	33.80		6.81	478	0.87	<0.010	0.51	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	0.015	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	18	0.58	48
G152B	05/14/13	17.08		6.81	488	0.82	<0.010	0.51	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	16	0.60	49
G153	8/17/2010	38.13		6.90	462	0.30	<0.025	0.63	0.0024	0.034	<0.0020	0.025	0.025	0.019	13	0.22	0.012	<0.050	<0.010	0.025	<0.0050	0.019	<0.0020	<0.00020	<0.0070	102	0.64	18
G153	11/5/2010	dry																										
G153	03/16/11	37.82		6.70	434	0.46	<0.025	0.31	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	110	0.82	20
G153	06/17/11	32.62		6.94	484	0.37	<0.025	0.27	<0.0010	0.047	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	104	0.76	20
G153	09/13/11	39.55		6.91	408	0.31	<0.025	0.28	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.029	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	104	0.75	20
G153	11/29/11	40.17		6.92	432	0.27	<0.025	0.24	<0.0010	0.055	<0.0020	<0.010	<0.010	<0.010	0.029	0.056	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	107	0.77	20
G153	02/14/12	32.9		6.92	434	0.29	<0.025	0.24	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	99	0.82	22
G153	05/15/12	38.92		6.95	406	0.21	<0.025	0.21	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	111	0.87	24
G153	08/07/12	dry																										
G153	03/06/13	39.95		6.98	392	0.28	<0.010	0.23	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.040	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	94	0.87	21
G153	05/13/13	33.37		6.93	454	0.28	<0.010	0.23	<0.0010	<0.020	<0.0020	<0.010	<0.010	<0.010	0.022	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0070	<0.0020	<0.00020	<0.0070	93	0.94	23

Notes:
Unless otherwise noted, all results are in mg/L.

[1] 35 IAC 620.420 Groundwater Quality Standards for Class II Potable Resource Groundwater.

ns indicates no standard for the listed parameter

[2] Depth to water as measured from top of well casing (in feet).

Yellow highlighted cells represent results exceeding 35 IAC 620.420 Groundwater Quality Standards for Class II General Resource Groundwater.

Appendix C. Groundwater Quality Results for August 2010 to May 2013

Hydrogeologic Assessment
Joppa Generating Station, Joppa, IL
Electric Energy Inc. and Ameren Energy Generating Company

Monitoring Well	Date	Depth to GW[2] (ft)	35 IAC 620 Standard[1]	pH (SU) ns*	TDS ns*	Nitrogen, Nitrate 100	Arsenic 0.20	Barium ns*	Beryllium 0.5	Boron ns*	Cadmium 0.05	Chromium 1.0	Cobalt 1.0	Copper ns*	Iron ns*	Manganese ns*	Nickel ns*	Selenium ns*	Silver ns	Zinc ns*	Antimony 0.024	Lead 0.1	Thallium 0.020	Mercury 0.010	Cyanide 0.60	Sulfate ns*	Fluoride 4.0	Chloride ns*
G112B	8/17/2010	26.42		6.05	744	0.95	<0.025	0.086	<0.0010	3.5	<0.0020	<0.010	0.065	<0.010	13	4.3	0.035	<0.050	<0.010	0.055	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	298	0.29	56
G112B	11/5/2010	26.18		6.33	754	<0.050	<0.025	0.12	<0.0010	1.6	<0.0020	<0.010	0.032	<0.010	22	4.1	0.020	<0.050	<0.010	0.015	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	129	0.49	49
G112B	03/15/11	15.50		5.80	856	0.055	0.037	0.082	<0.0010	4.4	<0.0020	<0.010	0.081	<0.010	53	5.5	0.043	<0.050	<0.010	0.043	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	352	0.29	56
G112B	06/16/11	22.03		6.60	776	0.12	<0.025	0.10	<0.0010	3.5	<0.0020	<0.010	0.067	<0.010	45	5.1	0.037	<0.050	<0.010	0.022	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	302	0.28	55
G112B	09/13/11	26.05		6.51	778	0.15	0.058	0.20	<0.0010	0.44	<0.0020	<0.010	0.020	<0.010	75	4.6	0.013	<0.050	<0.010	0.022	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	37	0.63	40
G112B	11/29/11	20.80		6.35	804	<0.050	0.054	0.17	<0.0010	2.0	<0.0020	<0.010	0.037	<0.010	68	4.3	0.024	<0.050	<0.010	0.014	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	176	0.46	56
G112B	02/14/12	9.72		6.33	860	<0.050	0.058	0.17	<0.0010	1.9	<0.0020	<0.010	0.042	<0.010	71	4.7	0.025	<0.050	<0.010	0.020	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	147	0.52	50
G112B	05/15/12	24.01		6.64	778	<0.050	0.066	0.21	<0.0010	0.35	<0.0020	<0.010	0.016	<0.010	77	4.5	<0.010	<0.050	<0.010	0.020	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	21	0.78	52
G112B	08/07/12	28.45		6.50	860	<0.050	0.060	0.20	<0.0010	0.051	<0.0020	<0.010	0.010	<0.010	62	4.2	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	15	0.83	67
G152	8/17/2010	9.21		6.41	1110	0.92	<0.025	0.019	<0.0010	12	<0.0020	<0.010	<0.010	<0.010	0.045	0.19	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	768	0.12	21
G152	11/5/2010	5.42		6.03	1090	0.070	<0.025	0.017	<0.0010	12	<0.0020	<0.010	<0.010	<0.010	<0.020	0.17	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	692	0.16	22
G152	03/16/11	2.20		5.98	1080	<0.050	<0.025	0.015	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	731	0.12	22
G152	06/17/11	3.92		5.97	1020	<0.050	<0.025	0.012	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	0.0068	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	593	0.11	21
G152	09/13/11	5.34		5.91	922	<0.050	<0.025	0.013	<0.0010	12	<0.0020	<0.010	<0.010	<0.010	<0.020	0.014	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	570	0.14	21
G152	11/29/11	22.50		6.04	910	0.10	<0.025	0.016	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	0.0083	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	565	0.12	20
G152	02/14/12	18.20		6.25	878	<0.050	<0.025	0.012	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	605	0.14	24
G152	05/15/12	5.07		6.03	866	0.14	<0.025	0.012	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	<0.0050	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	572	0.13	25
G152	08/07/12	8.03		5.81	956	<0.050	<0.025	0.011	<0.0010	11	<0.0020	<0.010	<0.010	<0.010	<0.020	0.014	<0.010	<0.050	<0.010	<0.010	<0.0050	<0.0020	<0.0020	<0.00020	<0.0070	451	0.15	21

Notes:

Unless otherwise noted, all results are in milligrams per Liter (mg/L).

[1] 35 IAC 620.420 Groundwater Quality Standards for Class II Potable Resource Groundwater.

[2] Depth to water as measured from top of well casing (in feet).

ns indicates no standard for the listed parameter

ns* indicates no standard for monitored points meeting criteria of 35 IAC 620.420(a)(3): applies to G112B and G152

Yellow highlighted cells represent results exceeding 35 IAC 620.420 Groundwater Quality Standards for Class II General Resource Groundwater.

Exhibit
C

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004
ILD001979350	IL0004171	Electric Energy, Inc.	

Form 2F NPDES

U.S Environmental Protection Agency
Application for NPDES Permit to Discharge Wastewater

STORMWATER DISCHARGES ASSOCIATED WITH INDUSTRIAL ACTIVITY

SECTION 1. OUTFALL LOCATION (40 CFR 122.21(g)(1))

Outfall Location

1.1 Provide information on each of the facility's outfalls in the table below

Outfall Number	Receiving Water Name	Latitude			Longitude		
011	UnName Trib to Ohio River	37.00°	12.00′	40.00″	-88.00°	52.00′	5.00″
012	UnName Trib to Ohio River	37.00°	12.00′	37.00″	-88.00°	51.00′	7.00″
013	UnName Trib to Ohio River	37.00°	12.00′	37.00″	-88.00°	51.00′	7.00″
		°	′	″	°	′	″
		°	′	″	°	′	″
		°	′	″	°	′	″

SECTION 2. IMPROVEMENTS (40 CFR 122.21(g)(6))

Improvements

2.1 Are you presently required by any federal, state, or local authority to meet an implementation schedule for constructing, upgrading, or operating wastewater treatment equipment or practices or any other environmental programs that could affect the discharges described in this application?

☐ Yes ☑ No → SKIP to Section 3.

2.2 Briefly identify each applicable project in the table below.

Brief Identification and Description of Project	Affected Outfalls (list outfall numbers)	Source(s) of Discharge	Final Compliance Dates	
			Required	Projected

2.3 Have you attached sheets describing any additional water pollution control programs (or other environmental projects that may affect your discharges) that you now have underway or planned? (Optional Item)

☐ Yes ☐ No

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19
ILD001979350	IL0004171	Electric Energy, Inc.	OMB No. 2040-0004

SECTION 3. SITE DRAINAGE MAP (40 CFR 122.26(c)(1)(i)(A))

Site Drainage Map

3.1 Have you attached a site drainage map containing all required information to this application? (See instructions for specific guidance.)

☑ Yes ☐ No

SECTION 4. POLLUTANT SOURCES (40 CFR 122.26(c)(1)(i)(B))

Pollutant Sources

4.1 Provide information on the facility's pollutant sources in the table below.

Outfall Number	Impervious Surface Area (within a mile radius of the facility)		Total Surface Area Drained (within a mile radius of the facility)	
011	0	*specify units* acres	160	*specify units* acres
012	0.01	*specify units* acres	3	*specify units* acres
013	0.1	*specify units* acres	37	*specify units* acres
		specify units		*specify units*
		specify units		*specify units*
		specify units		*specify units*

4.2 Provide a narrative description of the facility's significant material in the space below. (See instructions for content requirements.)

All outfalls have contact with or potential exposure to coal and coal combustion byproducts. Outfalls have exposure to herbicides which are used sparingly to control weeds. EEI uses s Spill Control and Countermeasure Plan to minimize storm water exposure to spills. EEI uses a Storm Water Pollution Prevention Plan to minimize storm water exposure to materials, by products, and chemicals.

4.3 Provide the location and a description of existing structural and non-structural control measures to reduce pollutants in stormwater runoff. (See instructions for specific guidance.)

Stormwater Treatment

Outfall Number	Control Measures and Treatment	Codes from Exhibit 2F–1 (list)
011	NaturalVegetation&GravelUsed forStormWaterMgmt(SeeRef Infomation forOutfallLocation)	
012	NaturalVegetation&GravelUsed forStormWaterMgmt(SeeRef Infomation forOutfallLocation)	
013	NaturalVegetation&GravelUsed forStormWaterMgmt(SeeRef Infomation forOutfallLocation)	

EPA Identification Number	NPDES Permit Number	Facility Name
ILD001979350	IL0004171	Electric Energy, Inc.

Form Approved 03/05/19
OMB No. 2040-0004

SECTION 5. NON STORMWATER DISCHARGES (40 CFR 122.26(c)(1)(i)(C))

Non-Stormwater Discharges

5.1 *I certify under penalty of law that the outfall(s) covered by this application have been tested or evaluated for the presence of non-stormwater discharges. Moreover, I certify that the outfalls identified as having non-stormwater discharges are described in either an accompanying NPDES Form 2C, 2D, or 2E application.*

Name (print or type first and last name)	Official title
Signature	Date signed

5.2 Provide the testing information requested in the table below.

Outfall Number	Description of Testing Method Used	Date(s) of Testing	Onsite Drainage Points Directly Observed During Test

SECTION 6. SIGNIFICANT LEAKS OR SPILLS (40 CFR 122.26(c)(1)(i)(D))

Significant Leaks or Spills

6.1 Describe any significant leaks or spills of toxic or hazardous pollutants in the last three years.

SECTION 7. DISCHARGE INFORMATION (40 CFR 122.26(c)(1)(i)(E))

Discharge Information

See the instructions to determine the pollutants and parameters you are required to monitor and, in turn, the tables you must complete. Not all applicants need to complete each table.

7.1 Is this a new source or new discharge?

☐ Yes → See instructions regarding submission of *estimated* data.

☑ No → See instructions regarding submission of *actual* data.

Tables A, B, C, and D

7.2 Have you completed Table A for each outfall?

☑ Yes

☐ No

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004
ILD001979350	IL0004171	Electric Energy, Inc.	

Discharge Information Continued

7.3	Is the facility subject to an effluent limitation guideline (ELG) or effluent limitations in an NPDES permit for its process wastewater?	☐ Yes	☑ No → SKIP to Item 7.5.
7.4	Have you completed Table B by providing quantitative data for those pollutants that are (1) limited either directly or indirectly in an ELG and/or (2) subject to effluent limitations in an NPDES permit for the facility's process wastewater?	☐ Yes	☐ No
7.5	Do you know or have reason to believe any pollutants in Exhibit 2F–2 are present in the discharge?	☑ Yes	☐ No → SKIP to Item 7.7.
7.6	Have you listed all pollutants in Exhibit 2F–2 that you know or have reason to believe are present in the discharge and provided quantitative data or an explanation for those pollutants in Table C?	☑ Yes	☐ No
7.7	Do you qualify for a small business exemption under the criteria specified in the Instructions?	☐ Yes → SKIP to Item 7.18.	☑ No
7.8	Do you know or have reason to believe any pollutants in Exhibit 2F–3 are present in the discharge?	☑ Yes	☐ No → SKIP to Item 7.10.
7.9	Have you listed all pollutants in Exhibit 2F–3 that you know or have reason to believe are present in the discharge in Table C?	☑ Yes	☐ No
7.10	Do you expect any of the pollutants in Exhibit 2F–3 to be discharged in concentrations of 10 ppb or greater?	☑ Yes	☐ No → SKIP to Item 7.12.
7.11	Have you provided quantitative data in Table C for those pollutants in Exhibit 2F–3 that you expect to be discharged in concentrations of 10 ppb or greater?	☑ Yes	☐ No
7.12	Do you expect acrolein, acrylonitrile, 2,4-dinitrophenol, or 2-methyl-4,6-dinitrophenol to be discharged in concentrations of 100 ppb or greater?	☐ Yes	☑ No → SKIP to Item 7.14.
7.13	Have you provided quantitative data in Table C for the pollutants identified in Item 7.12 that you expect to be discharged in concentrations of 100 ppb or greater?	☐ Yes	☐ No
7.14	Have you provided quantitative data or an explanation in Table C for pollutants you expect to be present in the discharge at concentrations less than 10 ppb (or less than 100 ppb for the pollutants identified in Item 7.12)?	☑ Yes	☐ No
7.15	Do you know or have reason to believe any pollutants in Exhibit 2F–4 are present in the discharge?	☐ Yes	☑ No → SKIP to Item 7.17.
7.16	Have you listed pollutants in Exhibit 2F–4 that you know or believe to be present in the discharge and provided an explanation in Table C?	☐ Yes	☐ No
7.17	Have you provided information for the storm event(s) sampled in Table D?	☑ Yes	☐ No

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004
ILD001979350	IL0004171	Electric Energy, Inc.	

Discharge Information Continued

Used or Manufactured Toxics

7.18 Is any pollutant listed on Exhibits 2F–2 through 2F–4 a substance or a component of a substance used or manufactured as an intermediate or final product or byproduct?

☐ Yes ☑ No ➔ SKIP to Section 8.

7.19 List the pollutants below, including TCDD if applicable.

1.	4.	7.
2.	5.	8.
3.	6.	9.

SECTION 8. BIOLOGICAL TOXICITY TESTING DATA (40 CFR 122.21(g)(11))

Biological Toxicity Testing Data

8.1 Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last three years?

☐ Yes ☑ No ➔ SKIP to Section 9.

8.2 Identify the tests and their purposes below.

Test(s)	Purpose of Test(s)	Submitted to NPDES Permitting Authority?	Date Submitted
		☐ Yes ☐ No	
		☐ Yes ☐ No	
		☐ Yes ☐ No	

SECTION 9. CONTRACT ANALYSIS INFORMATION (40 CFR 122.21(g)(12))

Contract Analysis Information

9.1 Were any of the analyses reported in Section 7 (on Tables A through C) performed by a contract laboratory or consulting firm?

☑ Yes ☐ No ➔ SKIP to Section 10.

9.2 Provide information for each contract laboratory or consulting firm below.

	Laboratory Number 1	Laboratory Number 2	Laboratory Number 3
Name of laboratory/firm	TekLab		
Laboratory address	5445 Horseshoe Lake Road Collinsville, IL 62234		
Phone number	(618) 344-1004		
Pollutant(s) analyzed	All Samples analyzed by Lab		

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004
ILD001979350	IL0004171	Electric Energy, Inc.	

SECTION 10. CHECKLIST AND CERTIFICATION STATEMENT (40 CFR 122.22(a) and (d))

Checklist and Certification Statement

10.1 In Column 1 below, mark the sections of Form 2F that you have completed and are submitting with your application. For each section, specify in Column 2 any attachments that you are enclosing to alert the permitting authority. Note that not all applicants are required to complete all sections or provide attachments.

Column 1	Column 2	
☑ Section 1	☐ w/ attachments (e.g., responses for additional outfalls)	
☐ Section 2	☐ w/ attachments	
☑ Section 3	☑ w/ site drainage map	
☑ Section 4	☐ w/ attachments	
☐ Section 5	☐ w/ attachments	
☐ Section 6	☐ w/ attachments	
☑ Section 7	☑ Table A	☐ w/ small business exemption request
	☑ Table B	☐ w/ analytical results as an attachment
	☑ Table C	☑ Table D
☐ Section 8	☐ w/attachments	
☑ Section 9	☐ w/attachments (e.g., responses for additional contact laboratories or firms)	
☑ Section 10	☐	

10.2 **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) Stephen Wait	Official title Plant Manager, Electric Energy, Inc.
Signature Stephen Wait	Date signed 1/29/2020

Exhibit
D

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-005
Petition of Electric Energy, Inc.	)	(Adjusted Standard)
For a Finding of Inapplicability or, in the	)	
Alternative, an Adjusted Standard from	)	
35 Ill. Adm. Code Part 845	)	

AFFIDAVIT OF LYNN E. DUNAWAY

I, Lynn E. Dunaway, certify under penalty of perjury pursuant to Section 1-109 of the Illinois Code of Civil Procedure, 735 ILCS 5/1-109, that the statements set forth in this affidavit are true and correct, and further state that if called upon to testify in this matter, I would competently testify as follows:

1. I am an Illinois Licensed Professional Geologist employed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency") as an Environmental Protection Specialist IV in the Hydrogeology and Compliance Unit ("HCU") within the Groundwater Section of the Bureau of Water, and I am located in Springfield, Illinois. I have been employed by the Illinois EPA since February of 1988.

2. As a Geologist in the HCU, I work on the development and implementation of rules and regulations related to protecting, monitoring, and restoring groundwater in Illinois, and I provide technical expertise to the Bureau of Water Permit Section on groundwater issues. As part of these duties, I served as a witness on behalf of the Groundwater Section in support of Illinois EPA's proposed Part 845 throughout the Illinois Pollution Control Board's rulemaking proceedings in R2020-019.

3. I have reviewed the Petition of Electric Energy, Inc. for a Finding of Inapplicability or, in the Alternative, an Adjusted Standard from 35 Ill. Adm. Code Part 845 ("Petition").

4. I have personal knowledge of the facts set forth in Illinois EPA's Recommendation to the Board as stated below.

5. Petitioner cites my testimony in support of its Petition. *See* Pet. Ex. 18. At hearing in R2020-019, when questioned whether Part 845 was intended to apply to the same ponds that are subject to requirements under Part 257, I responded: "In the Agency's opinion, they will be the same ones." Pet Ex. 18 at lines 17-24. To further explain my testimony, Part 257 is a self-implementing program, so the United States Environmental Protection Agency ("USEPA") neither selected nor approved which CCR surface impoundments should appropriately be regulated – that decision was left entirely to owners and operators of CCR surface impoundments, based on their interpretation of Part 257 and its Preamble. Therefore, Illinois EPA has maintained that the universe of regulated CCR surface impoundments is the same in both Part 845 and Part 257, but the Agency's interpretation of Part 257 and its Preamble may be different than some owners and operators.

6. I assisted in the drafting and review of Illinois EPA's comments submitted to USEPA on its proposed definition of "legacy ponds" in February 2021, provided as Petitioner's Exhibit 10. The in-depth review of aerial photos presented in Paragraphs 36 through 44 of the Recommendation and Petitioner's Exhibit 2 demonstrate that the Joppa West Ash Pond ("JWAP") does contain CCR and liquids and should be regulated by Part 257, by Petitioner's own interpretation of the Part 257 requirements. We used Petitioner's interpretation and application of the Part 257 requirements to the JWAP, which has been echoed by other owners and operators in Illinois, to demonstrate the number of CCR surface impoundments that may never be properly closed if the United States Environmental Protection Agency required legacy ponds to have obviously impounded water within them. The information contained in Petitioner's Exhibit 2, as

well as the extensive review of aerial photography and other documents discussed in Illinois EPA's Recommendation, showing areas of ponded water, sediment disposal within the JWAP and continued saturation of CCR, was not available at the time the Agency submitted its comments. That information demonstrates that the JWAP does contain CCR and liquids and should be considered regulated by Part 257 under Petitioner's own interpretation of the federal rules, contrary to the Agency's statements made at the time it submitted its comments to USEPA.

FURTHER AFFIANT SAYETH NOT

Lynn E. Dunaway
LYNN E. DUNAWAY

11/19/2021
DATE

State of Illinois
County of Sangamon

Subscribed and Sworn to before
me this 19th day of November 2021.

Dawn A. Hollis
Notary Public

DAWN A. HOLLIS
03-21-2025

Exhibit
E

Geochemistry and Reactive Transport of Metal Contaminants in Ground Water, Pinal Creek Basin, Arizona

James G. Brown, Pierre D. Glynn, and R.L. Bassett

ABSTRACT

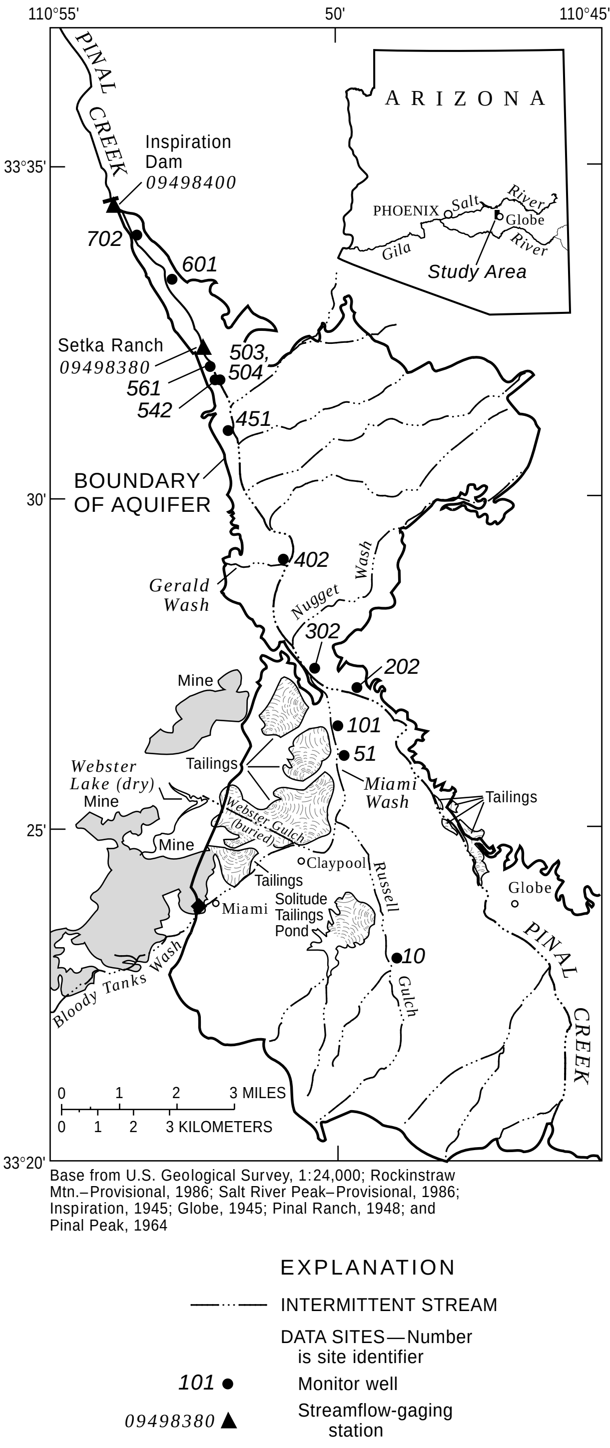
Activities related to more than a century of large-scale copper mining in the Pinal Creek Basin in central Arizona have contaminated the regional alluvial aquifer and perennial streamflow with acidity and metals. Water-chemistry and solid-phase analyses and computer-aided geochemical modeling were used to understand the evolution of the ground-water plume between 1984 and 1998. The ground-water plume consists of three hydrochemical zones: (1) an acidic zone, which contains large concentrations of metals and has a pH that ranges from 3.6 to about 5; (2) a transition zone where carbonate-mineral dissolution causes pH to increase to above 5, which results in the precipitation of iron hydroxide and the adsorption of trace metals such as nickel and zinc; and (3) a neutralized zone, which contains large concentrations of manganese, calcium, and sulfate, and has a pH of about 6 to 7. Inverse geochemical modeling using NETPATH revealed that, in addition to calcite dissolution, silicate dissolution was required to account for the mass transfers of calcium and magnesium across the transition zone. Analysis of the measured changes in plume geochemistry was aided by PHREEQC reactive-transport modeling, which helped determine that oxidation-reduction reactions were significant in the acidic zone of the plume through the late 1980's. The local equilibrium assumption required by reactive-transport modeling probably was invalid for oxidation-reduction reactions that involved manganese and, to a lesser extent, neutralization reactions that involved calcite. Sensitivity analyses indicated that the rate of advance of the pH front was highly sensitive to the initial calcite concentration, and that ground water along a flow path near the base of the alluvium was in partial or indirect contact with the atmosphere, possibly through mixing with shallower water.

INTRODUCTION

Activities related to more than a century of large-scale copper mining in the Pinal Creek Basin in central Arizona (fig. 1) have contaminated the regional aquifer and perennial streamflow. Potential contaminant sources include mine tailings, unlined surface-water impoundments of mine-process water, heap-leach areas, and occasional spills of contaminated water into streambeds. Acidic ground-water contamination has a pH of about 3.6 to 5, and neutralized-contaminated water has a pH that ranges from about 6 in the aquifer to 8 in perennial streamflow. Contaminants that occur in large concentrations are iron (Fe), sulfate (SO_4), manganese (Mn), copper (Cu), cobalt (Co), nickel (Ni), zinc (Zn), and other metals. Investigations by the U.S. Geological Survey (USGS) at the site have been ongoing since 1984 and are a collaborative effort among USGS scientists and investigators at several universities.

The purpose of this paper is to give an overview of recent and ongoing ground-water investigations at the site with a focus on the results of inverse modeling and reactive-transport geochemical modeling that were used to help understand the important processes that control the movement and distribution of contaminants in ground water. Information gained from these investigations should provide insight into processes that occur at other sites similarly contaminated.

The regional aquifer includes two distinct lithologic units. The older of the two is semiconsolidated to consolidated basin fill that is Tertiary in age. The unit has a maximum thickness of more than 1,000 meters (m) and consists of conglomerates, sand, silt, and fine-grained lakebed sediments. Incised into the basin fill in the major drainages is an unconsolidated alluvium that is less



Base from U.S. Geological Survey, 1:24,000; Rockinstraw Mtn.–Provisional, 1986; Salt River Peak–Provisional, 1986; Inspiration, 1945; Globe, 1945; Pinal Ranch, 1948; and Pinal Peak, 1964

Figure 1. Pinal Creek Basin, Arizona

than 50 m thick and contains more than 90 percent sand and gravel. Detailed discussions of the geology and hydrogeology of the basin have been published in Peterson (1962), Brown and Eychaner (1996), and Neaville and Brown (1994).

METHODS

From 1984 to 1996, 37 monitor wells and 6 test holes were drilled into the alluvium and shallow basin fill at 12 locations in or near contaminated areas. Aquifer materials collected at the time of drilling were analyzed by particle-size analysis, macroscopic- and microscopic-mineralogical identification (Eychaner and others, 1989), x-ray diffraction (Lind and Stollenwerk, 1996), sequential extractions (Ficklin and others, 1991a, b), column and batch experiments (Stollenwerk, 1994, 1996), and other methods. Water samples were collected from most monitor wells one or two times a year and analyzed for major ions and trace elements to characterize the distribution and movement of contaminants. Less frequently, ground water from selected wells was analyzed for stable isotopes, tritium, chlorofluorocarbons, and dissolved gases. Ongoing investigations include the examination of changes in aquifer materials that have been exposed to contaminated water in wells for periods ranging from 6 to18 months. The purpose of these investigations is to examine changes in mineralogy and the rates of selected geochemical reactions in acidic and neutralized ground water.

Several computer geochemical models have been used in the analysis of contaminant movement at the site. Stollenwerk (1994) used PHREEQE (Parkhurst and others, 1980) and MINTQA2 (Allison and others, 1980) to analyze the important reactions that controlled the evolution of the plume through the mid-1980's using laboratory batch and column experiments, and geochemical modeling. Glynn and Brown (1996) used NETPATH (Plummer and others, 1991) and PHREEQC (Parkhurst, 1995) to refine Stollenwerk's findings and examine the possible effects of reactions not considered by Stollenwerk. Brown and others (1998) used PHREEQC's transport capabilities to help examine the changes observed in the ground-water plume from 1984–94. This paper provides an overview of the analysis of Glynn and Brown (1996), extends the model of Brown and others (1998) through 1998, and summarizes the major findings.

DISTRIBUTION OF HYDROCHEMICAL ZONES IN THE AQUIFER

The ground-water plume in the Pinal Creek Basin can be separated into three major zones (fig. 2) on the basis of aqueous and solid-phase geochemistry. An acidic zone in which the pH of the ground water was between 4 and 5 in 1998 extends from Miami Wash to well 561.

The acidic zone contains large concentrations of dissolved metals and other contaminants. In 1984, concentrations of dissolved Fe, Mn, and aluminum (Al) at well 51 were 57, 1.3, and 11.1 mmol/L, respectively (table 1). Metals, such as Cu, Co, Ni, and Zn, occurred in the acidic zone at concentrations that ranged from 0.02 to more than 2 mmol/L.

Downgradient from the acidic zone is a transition zone characterized by steep pH and redox gradients and the precipitation and adsorption of metals. In 1984, this zone was about 1.5 km south of the future location of well 451. In this zone, calcite ($CaCO_3$) and, to a lesser extent, dolomite ($CaMg(CO_3)_2$), react with and partially neutralize acidic ground water according to the reactions:

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^-,$$

and

$$CaMg(CO_3)_2 + 2H^+ = Ca^{2+} + Mg^{2+} + 2HCO_3^-.$$

Oxidation and reduction reactions are important as well. The reductive dissolution of Mn oxide is coupled to the oxidation and precipitation of Fe hydroxide (Stollenwerk, 1994). The overall reaction can be written as:

$$MnO_{2(s)} + 2Fe^{2+} + 4H_2O \longrightarrow 2Fe(OH)_{3(a)} + 2H^+ + Mn^{2+}.$$

Although this last reaction produces protons, the net result of reactions in the transition zone was to raise the pH from about 5 to about 6. Metals, such as Cu, Co, Ni, and Zn, are adsorbed to Fe hydroxide and possibly other surfaces in the transition zone because of the increase in pH (Stollenwerk, 1994).

Advective flow moves through the alluvium at an average velocity of 5 meters per day (m/d), which is about 7 times the rate of movement of the acidic front (Eychaner, 1991). As a result, contaminants that remain in solution as the pH increases move beyond the transition zone into the neutralized zone (fig. 2), and eventually surface in the perennial reach of Pinal Creek. Neutralized water generally contains large concentrations of calcium (Ca), Mn, and SO_4; other contaminants, including Fe, Cu, Co, Ni, and Zn, occur at concentrations less than 1 mmol/L (table 1).

Mineral species and other solid phases in the regional aquifer were characterized by the examination and analysis of drill cores and cuttings. Calcite and Mn oxide are present in uncontaminated alluvium, the basin fill, and the neutralized zone of the plume. Sequential extractions of aquifer material and the measured water chemistry indicate that in the acidic zone of the plume most if not all the Mn oxide and carbonate minerals have been dissolved by reaction with the acidic ground-water plume. Minerals present throughout the aquifer include Fe hydroxide and the silicate minerals orthoclase and plagioclase feldspar, muscovite, biotite, and tremolite. The degree to which each reacts with contaminated ground water varies.

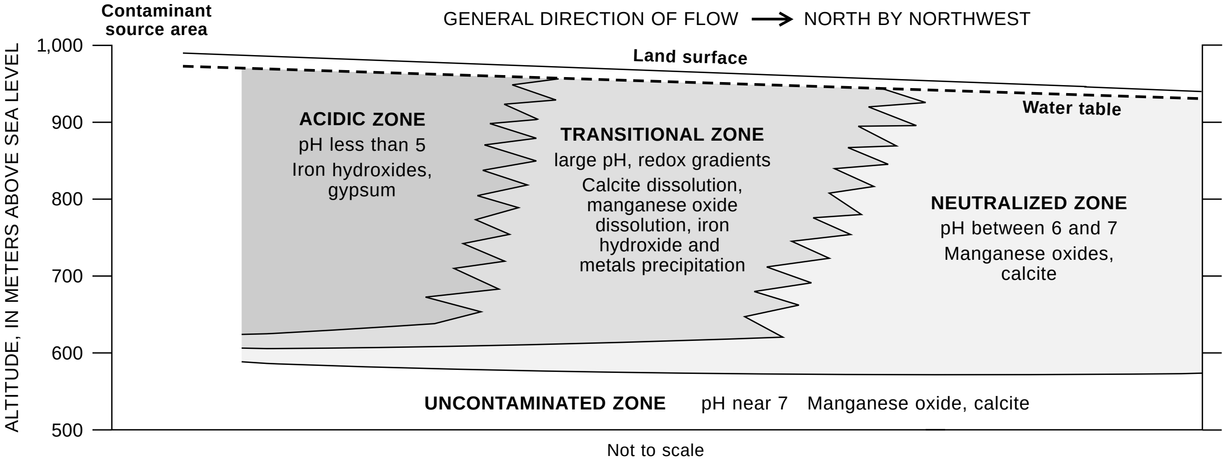


Figure 2. Generalized longitudinal section indicating hydrochemical zones in aquifer.

Table 1. Measured water chemistry and related data for water in selected wells and in streamflow, Pinal Creek Basin, 1984–97

[Values are in millimoles per liter (mmol/L) except for pH. At most locations, earliest available analysis is shown. Dashes indicate no data; km, kilometer; m, meter; <, less than; PCID, Pinal Creek at Inspiration Dam; Depth, depth of well below land surface]

Well number	Distance along flow path (km)	Date of sample	Well depth (m)	pH	Dissolved oxygen (DO as O)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity	Total inorganic carbon (TIC)	Sulfate (SO_4)
51	0	11–84	33.4	3.6	<0.02	12	16	10	0.24	---	---	100
101	.7	11–84	36.1	3.6	<.02	12	12	8.3	.25	---	---	74
202[1]	---	03–85	12.3	7.2	.46	1.2	.37	.96	.036	2.3	---	.7
302	2.1	11–84	35.8	3.5	---	17	12	7.0	.21	---	---	72
402	5.8	11–84	20.9	4.2	<.02	13	5.8	3.5	.19	---	---	27
451	10.1	03–89	24.4	4.9	<.006	15	5.5	3.6	.28	---	4.7	25
503	11.4	07–86	25.3	6.2	.01	15	5.8	3.4	.11	2.0	---	21
542	11.4	05–97	19.8	4.3	.01	7.7	3.3	2.4	.16	---	1.3	14
561	11.8	05–97	15.3	5.0	.01	7.6	3.1	2.5	.17	---	1.7	13
601	14.2	11–92	8.6	6.4	.04	13	4.5	3.3	.11	2.9	---	18
702	16.3	05–90	7.3	7.0	.006	14	5.1	3.0	.16	3.5	---	18
PCID[1]	---	01–93	---	7.7	.64	1.4	.31	.33	.087	.93	---	1.5

Well number	Distance along flow path (km)	Chloride (Cl)	Fluoride (F)	Silica (Si)	Iron (Fe)	Manganese (Mn)	Aluminum (Al)	Copper (Cu)	Cobalt (Co)	Nickel (Ni)	Strontium (Sr)	Zinc (Zn)
51	0	11	---	1.7	57	1.3	11.1	2.4	0.18	0.065	0.017	0.29
101	.7	10	---	1.6	39	1.0	8.54	1.7	.14	.054	.018	.18
202[1]	---	.48	---	.36	.00072	<.0006	<.003	.00016	<.00034	<.0085	.0023	<.00023
302	2.1	8.7	---	1.8	32	1.1	6.69	1.5	.12	.051	.034	.14
402	5.8	4.0	---	1.4	6.3	.91	.409	.30	.030	.019	.020	.046
451	10.1	5.1	.53	1.1	2.5	1.9	1.53	.18	.031	.020	.018	.53
503	11.4	3.7	.021	1.0	.0032	.82	.0007	.0005	<.0007	.007	.240	.0029
542	11.4	1.3	.19	1.1	1.1	.81	.213	.075	---	.005	.013	.037
561	11.8	1.3	.25	1.1	.00016	1.0	.13	.076	.020	.012	.013	.039
601	14.2	2.4	.01	.72	.00072	.031	<.0004	<.0005	<.0002	<.0005	.024	.00038
702	16.3	2.3	.013	.46	.019	.052	.186	<.002	<.003	<.008	.027	.00026
PCID[1]	---	.11	.02	---	.0001	.00098	---	.00047	---	---	---	<.00005

[1] Not on simulated flow path.

INVERSE GEOCHEMICAL MODELING

Inverse geochemical modeling has been used at Pinal Creek to help identify and understand the important chemical reactions and physical processes that controlled the evolution of the contaminant plume. Glynn and Brown (1996) used the geochemical codes NETPATH and PHREEQC to examine some plausible reaction models that might have been responsible for the changes in ground-water chemistry that have been measured across the transition zone.

Inverse modeling uses a mass-balance approach to determine the reactions responsible for observed changes in water chemistry between two wells along a flow path. Inverse modeling requires that the system be in a chemically steady-state condition if the wells are sampled at the same time. Because contaminated ground water at the study site was not at steady state, Glynn and Brown (1998) considered the chemical changes between wells that occurred over a period of time equal to the estimated ground-water travel time between the two wells. The inverse-modeling approach also assumes that all potentially important reactions were considered and that the important existing and potential solid phases in the aquifer were known. The assumption of a steady-state flow field also is required. The computer codes do not require that the postulated reactions be thermodynamically feasible, although the thermodynamics of any postulated reaction should be considered when evaluating potential models.

Required input for inverse modeling includes chemical analyses for the selected wells, the chemical composition of solid phases (minerals or amorphous solids) and dissolved gases in the aquifer, and some knowledge about which minerals and gases have the potential to react with the ground water. NETPATH and PHREEQC allow for the initial water to be mixed with one or more waters along the flow path to produce the final water.

Glynn and Brown (1996) examined dozens of models using different combinations of plausible and not so plausible solid- and gas-phase reactants and different assumptions concerning the degree to which the flow path was in contact with gases in the unsaturated zone. Space limitations here preclude a detailed discussion of particular models. Instead, this paper focuses on the common characteristics shared by the more plausible models and will summarize major conclusions.

The analysis of Glynn and Brown (1996) considered a flow path across the transition zone from well 402 (sampled on January 12, 1989) to well 503 (sampled on November 22, 1991). Mixing with uncontaminated water along the flow path was represented by water from well 504 (sampled on November 22, 1991), which is perforated in uncontaminated basin fill. The chemical composition of water from these wells during 1989–91 was similar to that during 1984–89 (table 1); although contaminant concentrations generally decreased from 1984–89. Three minerals were required to be included in all models: calcite, geothite (FeOOH), and gypsum ($CaSO_4$).

For most models, the system was considered closed to atmospheric oxygen because the flow path across the transition zone was more than 7 m below the water table during 1989–91. Dissolved-oxygen concentrations of water from shallow wells at both sites indicated that essentially all the oxygen moving downward from the unsaturated zone into the plume was consumed near the water table. Although the well openings were not in contact with the unsaturated zone, the degassing of carbon dioxide (CO_2) was allowed in some models because CO_2 had the potential of leaving the flow path through diffusion or mixing processes.

The NETPATH models considered to be most plausible shared several characteristics—the dissolution of calcite and dolomite ($CaMg(CO_3)_2$), and the precipitation of rhodochrosite ($MnCO_3$) and gypsum. The results of the PHREEQC simulations were similar, except that accounting for analytical uncertainty (a feature unavailable in NETPATH) resulted in some significantly different results. When a 5-percent relative uncertainty was assumed for SO_4, the precipitation of gypsum was not necessary. This was because SO_4 occurred at concentrations more than 5 times that of Ca, and the uncertainties in the SO_4 concentrations were large in relation to the measured mass transfer of Ca between wells 402 and 503.

A significant conclusion from the NETPATH and PHREEQC inverse modeling was that in order to satisfy the mass-balance constraints on Ca and Mg, the dissolution of Ca-Mg silicates was required. The measured increase in dissolved strontium (Sr) along the flow path was additional evidence of silicate dissolution along the flow path (Glynn, 1991). Solid-phase mass transfers of rhodochrosite and Al were significant particularly in models that allowed no CO_2 exsolution.

GROUND-WATER REACTIVE TRANSPORT, 1984–98

From 1984 to 1998, the concentrations of most contaminants in the acidic zone decreased primarily because of the drainage of an unlined surface-water impoundment that contained acidic mine-process water, other source control measures, remedial pumping that began in the mid-1980's, and recharge of uncontaminated ground water from record high streamflow in 1993. This paper focuses on the most contaminated well at each monitor well group. At each site, this generally was the well perforated closest to the contact with the alluvium and the underlying basin fill. The wells were located along, or reasonably close to, an assumed flow path near the base of the alluvium. Lithologic evidence of a boulder zone near the base of the alluvium was additional evidence that the zone near the base of the alluvium was a preferred pathway for contaminants.

A one-dimensional reactive-transport model was developed using PHREEQC (Parkhurst, 1995) to help characterize the reactions and processes that were responsible for the measured changes in plume geochemistry from 1984 to 1994 (Brown and others, 1998). Equilibrium reactive-transport modeling requires some of the same assumptions as inverse modeling. One such assumption was that the wells in the model were located along a flow path; another was that all important reactions were accounted for. Unlike inverse modeling, equilibrium reactive-transport modeling assumes that water along the flow path reacts to a local equilibrium with selected solid phases in the aquifer. As a result, some of the reactions considered for inverse modeling (silicate dissolution, for example) were not included in the reactive-transport model because these reactions were known to be slow in relation to the travel time of water through contaminated alluvium.

PHREEQC uses a mixing-cell approach (Appelo and Postma, 1993) to simulate contaminant transport. In this approach, a series of mixing cells is set up in which geochemical reactions are calculated. In this simulation, these reactions involve water, minerals, and surfaces to which selected constituents may adsorb or desorb. Before each transport step, the aqueous and solid-phase equilibrium condition is calculated. Water is then shifted to the next adjacent cell where equilibrium is then re-established through the precipitation or dissolution (if the solid phase is present) of the required solid phases. For this analysis, dispersion was simulated using the mixing option. A dispersivity of 30 m was used for this analysis on the basis of a review of field estimates of dispersivities made by Gelhar and others (1992). Glynn and Brown (1996) found that varying the dispersivity from 0 to 10 percent of the length of the flow path had little effect on movement of the acidic front except where the initial calcite concentration was <0.03 mol/kg H_2O. This concentration was less than half the initial calcite concentration used in the neutralized zone of the present model.

For this report, the reactive-transport model of Brown and others (1998) was extended to June 1998. Water from well 51, the monitor well closest to upgradient contaminant sources, was used as inflow to the model. The flow path from well 51 to well 702 (fig. 1) was divided into 82 cells, which were each 200 m long. The earliest available water-chemistry analysis for each well (table 1) along the flow path was used to define the initial conditions for the model. Simulated input for missing constituents were estimated from the earliest available analysis. For example, total inorganic carbon (TIC) was first measured in 1987 and was used to represent 1984 conditions in the model. Between wells, initial water chemistry in each cell consisted of water from a nearby well, or a mixture of water from the nearest upgradient and downgradient wells, as appropriate. The minerals included in the model (table 2) in each cell were determined on the basis of solid-phase analyses. Gypsum and Fe hydroxide were assumed to be initially present along the entire flow path. Adsorption along the flow path was assumed to occur on the Fe hydroxide that is present throughout the aquifer (Stollenwerk, 1994). Calcite was assumed to be initially present in the neutralized zone and absent in the acidic zone where calcite would have been substantially depleted or completely consumed by acidic ground water. Sequential extractions by Ficklin and others (1991a, b) indicated that extractable Mn was present at much lower concentrations

Table 2. Mineral reactions and solubility-product constants used in simulation of reactive transport

[*logKsp*, log of the solubility- product constant]

Mineral	Reaction	***LogKsp***
Calcite	$CaCO_{3(c)} = Ca^{2+} + CO_3{}^{2-}$	-8.48
Gypsum	$CaSO_{4(c)} *2H_2O = Ca^{2+} + SO_4{}^{2-} + 2H_2O$	-4.58
Iron hydroxide	$Fe(OH)_{3(a)} + 3H^+ = Fe^{3+} + 3H_2O$	4.89
Manganese oxide	$MnO_{2(c)} + 4H^+ + e^- = Mn^{2+} + 2H_2O$	41.38
Aluminum-mineral equilibria:		
$Al(OH)_{3(a)}$	$Al(OH)_{3(a)} + 3H^+ = Al^{3+} + 3H_2O$	10.8
$AlOHSO_4$	$AlOHSO_{4(s)} + H^+ = Al^{3+} + SO_4{}^{2-} + H_2O$	-3.23
Rhodochrosite	$MnCO_{3(c)} = Mn^{2+} + CO_3{}^{2-}$	-11.13

in the acidic zone than in the neutralized zone. Because of this, most if not all of the reactive Mn oxide in aquifer material was assumed to be reductively dissolved with the passage of the transition zone, and the simulated concentration of Mn oxide in the acidic zone was set to 0 in the model. Under these conditions, simulated Fe behaved as a conservative constituent in the acidic zone and reacted with Mn only in cells where Mn oxide was present.

Conservative Transport

Chloride (Cl) is a conservative constituent at Pinal Creek (Stollenwerk, 1994) and was used to measure the degree to which contaminated water was diluted by uncontaminated water along the flow path. Uncontaminated ground water from the underlying basin fill and tributary alluvium was represented in the model by water from well 202, which is in Pinal Creek alluvium about 1 km upstream from the mouth of Miami Wash. Dilution from flood-related recharge was represented in the model by a sample of water from Pinal Creek at Inspiration Dam obtained during a flood in January 1993. Both sources of uncontaminated inflow were mixed with contaminated ground water in each cell in amounts necessary to match measured Cl concentrations in wells along the flow path.

In 1984, the Cl concentration of water decreased from 11.0 mmol/L at km 0 to 3.95 mmol/L at km 5.8 (fig. 3). From km 5.8 to the end of the flow path (km 16.3), Cl decreased only slightly to 2.34 mmol/L in 1990. Because of contaminant-source removal, remedial pumping, and significant ground-water recharge in the early 1990's, Cl concentrations decreased along the entire flow path from 1984 to 1998. By 1998, the trend observed in 1984 had disappeared, and Cl concentrations were about equal along the flow path. Distribution of Cl simulated with PHREEQC matched measured concentrations reasonably well using mixing fractions that ranged from 0.06 at the upstream end of the model to 0.01 at the downstream end. (Water resulting from a mixing fraction of 0.06 consisted of 94-percent contaminated water and 6-percent uncontaminated water.) For 1993, the fraction of water mixed with contaminated water in each cell was increased slightly from km 3 to 11.4 to account for recharge of uncontaminated water from the 1993 flood.

Acidity and Related Equilibria

Unlike Cl, pH and other species, including Al, Ca, inorganic carbon, SO_4, Mn, and Fe, were affected by chemical reactions with solids in the aquifer or gases in the unsaturated zone. The pH along the flow path defined the acidic, transition, and neutralized zones in the aquifer. In 1984, the pH in the acidic zone was about 3.8, and by 1998, the pH had risen slightly to about 4 (fig. 4). Stollenwerk (1994) attributed the persistence of low pH in the aquifer to the gradual desorption of protons from Fe hydroxide surfaces in the aquifer. Several reactions acting in combination controlled the pH in the plume. The dissolution of calcite and mixing of contaminated ground water with uncontaminated ground water increased the pH. The

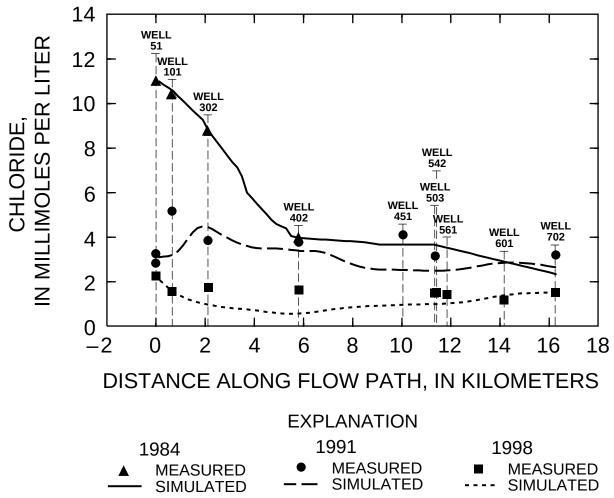


Figure 3. Measured and simulated concentrations of chloride along the flow path in the aquifer, 1984, 1991, and 1998, and locations of wells.

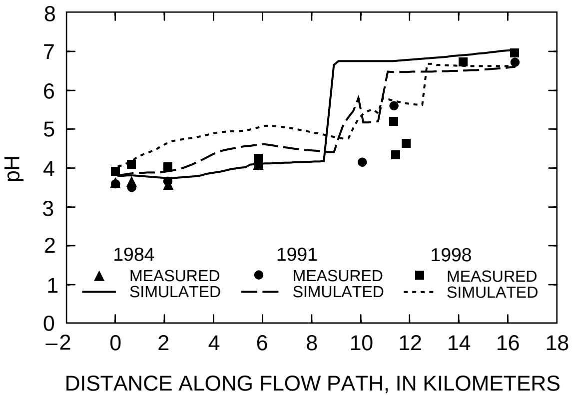


Figure 4. Measured and simulated ph along the flow path in the aquifer, 1984, 1991, and 1998.

reductive dissolution of Mn oxide and the consequent oxidation and precipitation of Fe hydroxide decreased the pH, as did the gradual desorption of protons from Fe hydroxide surfaces.

Concentrations of Ca in the aquifer were controlled by equilibrium with calcite and gypsum, and by mixing of contaminated ground water with uncontaminated ground water. Calculations using PHREEQC indicated that water in the acidic part of the flow path was slightly supersaturated or in equilibrium with gypsum from 1984 until 1991 and was increasingly undersaturated from 1992 to 1998 (fig. 5). Gypsum equilibria can be expressed by the following reaction:

$$Ca^{2+} + SO_4^{2-} + 2H_2O = CaSO_4{\bullet}2H_2O.$$

Although this reaction does not directly affect the pH, the increase in dissolved Ca that results from the redissolution of precipitated gypsum increases the calcite saturation index and indirectly plays a role in acidity equilibria.

Concentrations of Ca in water at km 0 decreased slightly from 12 mmol/L in 1984 to 11 mmol/L in 1992 and then decreased abruptly to 3.9 mmol/L in 1994 after the aquifer received recharge from flooding in 1993. Ca increased to 7.8 mmol/L by 1998 (fig. 6). During the same period, Cl decreased by a factor of 3.6, which indicates that dissolution of gypsum was responsible for the small decreases in measured Ca concentrations relative to Cl concentrations.

As previously mentioned, carbonate mineral dissolution in the transition zone increased the pH from about 4 to greater than 6. Calcite saturation indices were between –0.2 and –1.0 at km 14.2 in the neutralized zone (fig. 7), which indicated that calcite dissolution in the transition zone was not sufficient to bring partially neutralized water into equilibrium with calcite. Ground water was undersaturated with calcite at km 14.2, and equilibrium with calcite was established by km 16.3. The saturation indices indicate that calcite dissolution in the neutralized zone was responsible for the measured increase in Ca along the flow path from km 10 to km 16 through 1998.

From 1984 to 1998, simulated concentrations of Ca generally were larger than measured concentrations (fig. 6). The measured decreases in Ca from 1991 to 1998 were not reflected in the model, probably because simulated gypsum dissolution was greater than that in the aquifer. Beginning in 1991 (figs. 5 and 6), acidic water became undersaturated with respect to gypsum; however, the model maintained equilibrium through dissolu-

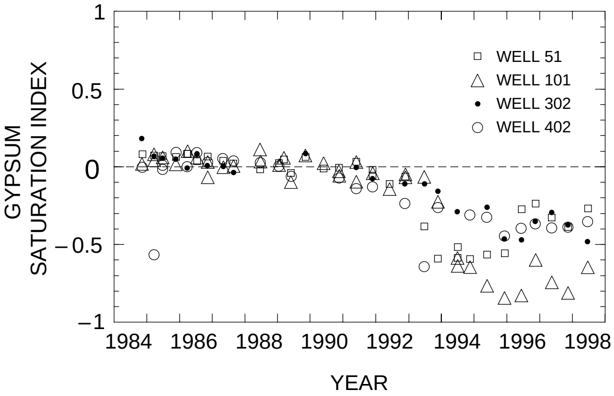


Figure 5. Saturation indices for gypsum in water from wells in the acidic part of the flow path, 1984–1998.

tion with gypsum. The simulated concentration of gypsum initially in the acidic part of the aquifer estimated from sequential extractions done by Ficklin (1991a, b) probably was unreasonably large.

Iron, Manganese, and Oxidation-Reduction Reactions

As previously mentioned, concentrations of Fe and Mn were controlled in part by oxidation-reduction reactions in the transition zone and mixing of contaminated ground water with uncontaminated ground water along the flow path. Mn also may sorb to Fe hydroxide surfaces under certain conditions. In 1984, concentrations of dissolved Fe decreased from 57 mmol/L at km 0 to less than 10 mmol/L at km 5.8 (fig. 8), which is a factor of about 6. Over the same interval, Cl decreased by a factor of 3 (fig. 3) and Mn decreased by less than half, from 1.3 mmol/L to 0.9 mmol/L (fig. 9). These differences suggest that oxidation-reduction reactions in part controlled the concentrations of Fe and Mn more than 2 km upgradient from the transition zone. In addition, the simulated and measured concentrations of dissolved Fe and Mn at km 6 differed significantly in the late 1980’s. In 1987 at km 5.8, the simulated concentration of Fe was greater than the measured concentration, and the simulated concentration of Mn was less than the measured concentration. Because the initial modeled concentration of Mn oxide was 0 in the acidic zone, simulated Fe moved conservatively through the acidic zone to the transition zone where reaction with Mn oxides occurred. The differences between measured and simulated concentrations of Mn and Fe at km 5.8 provided additional evidence for the continued reductive dissolution of Mn oxides and oxidation and precipitation of Fe in the acidic zone.

In the transition zone, simulated Mn concentrations were unreasonably large (fig. 9) probably because the reductive dissolution of Mn is kinetically controlled. The simulated attainment of equilibrium with each transport step caused excessive Mn dissolution in the transition zone. Although Stollenwerk (1994) observed a peak of similar magnitude in a column experiment using acidic ground water and alluvium from the site, such a peak has not been observed in the field. The slight decrease in concentrations of dissolved Mn between km 12.1 and km 16.2 was attributed to rhodochrosite precipitation on the basis of measured saturation indices near 0 at km 16.2 (Brown and others, 1998).

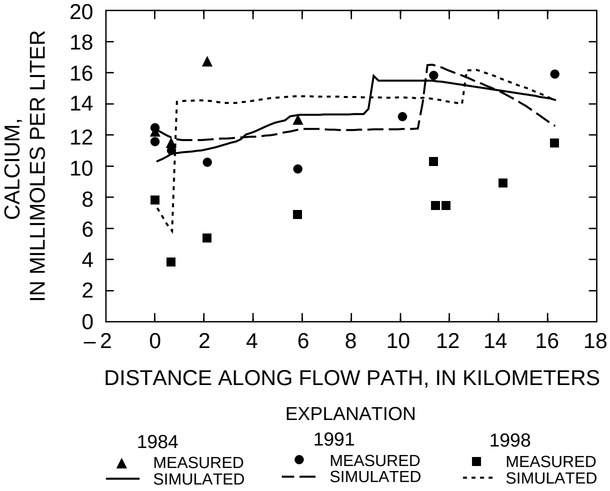


Figure 6. Measured and simulated concentrations of dissolved calcium along the flow path in the aquifer, 1984, 1991, and 1998.

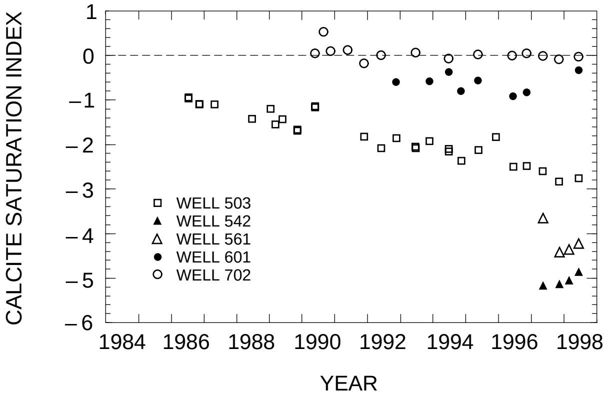


Figure 7. Saturation indices for calcite in the transition and neutralized zones of the plume, 1984–98.

Aluminum Equilibria

Inverse modeling indicated that the measured attenuation of Al across the transition zone was in part controlled by mineral reactions. The determination of the solubility controls on dissolved Al over the range in pH measured in the plume, however, remains problematic. Stollenwerk (1994) used amorphous aluminum hydroxide ($Al(OH)_{3(a)}$; table 2) as the solubility control above a pH of 4.5, and a mineral with the formula

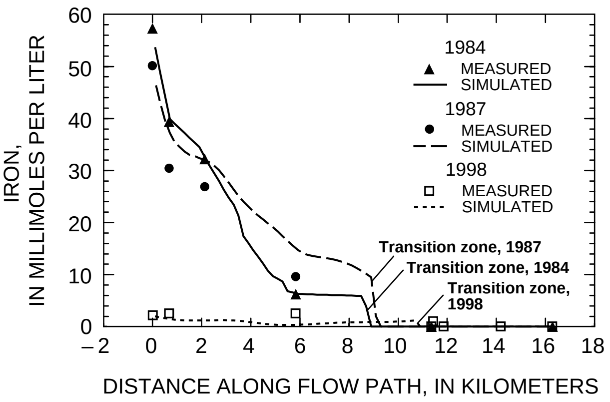


Figure 8. Measured and simulated concentrations of dissolved iron along the flow path in the aquifer, 1984, 1987, and 1998.

AlOHSO$_4$ below a pH of 4.5, but changed the equilibrium constant by more than an order of magnitude to obtain a reasonable fit between his simulation and measured concentrations of dissolved Al.

Because the precipitation of each mineral releases protons to solution, Al mineral reactions could have a significant effect on pH in the plume. Because of the uncertainties related to the control on dissolved Al concentrations below a pH of 4.5, however, no controls were placed on Al solubility in the present simulation.

SENSITIVITY ANALYSES

As is the case with many field studies, the physical and chemical characteristics of the ground-water flow system in the Pinal Creek Basin were determined on the basis of sparse or incomplete data. Similarly, the reactions that control the movement and transformation of the plume have not been determined with absolute certainty. Sensitivity analyses are useful, therefore, to examine the effects of uncertainty on reactive transport in the plume. Uncertainties considered below are the calcite content, the nature of reactions with gases in the unsaturated zone, and Al-mineral equilibria. Not discussed here because of space limitations are the uncertainties in initial solid-phase concentrations, other than calcite, and slow reactions that may nonetheless be significant.

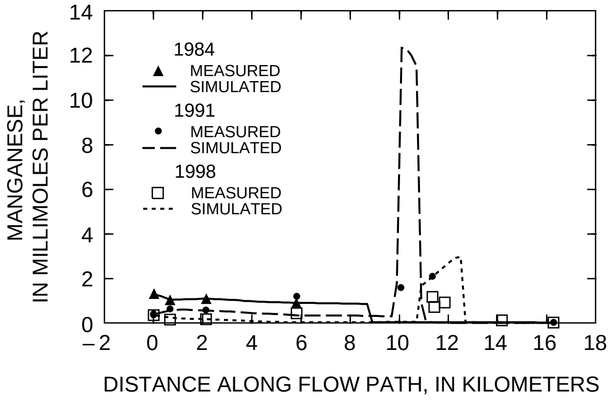


Figure 9. Measured and simulated concentrations of dissolved manganese along the flow path in the aquifer, 1984, 1991, and 1998.

Calcite Content

The calcite content of 0.075 mol/kg H_2O used to simulate transport from 1984 to 1998 was estimated on the basis of a mass balance of Ca done on Stollenwerk's (1994) column experiment. At this concentration, the movement of the simulated pH front had a retardation factor of 7. A calcite concentration of 0.038 mmol/kg H_2O was used as the lower limit in this sensitivity analysis. Other measurements have yielded larger concentrations. Stollenwerk (1994) measured 0.17 mol/kg H_2O of calcite in the uncontaminated alluvium used in his experiment. Buffer-capacity measurements done by Hydro Geo Chem, Inc. (1989) yielded carbonate content estimates that ranged from 0.125 mol/kg H_2O in sand and gravel to 0.76 mol/kg H_2O in calcareous clay. Adjusting these values for the average particle size of sediments at monitor well group 500 yielded a value of 0.29 mol/kg H_2O, which was used as the upper limit in this sensitivity analysis.

Increasing the calcite content in the neutralized zone from 0.075 to 0.29 mol/kg H_2O reduced the rate of movement of the acidic front from by a factor of 9 (fig. 10). Decreasing the calcite content to 0.038 mol/kg H_2O increased the rate of movement by a factor of 1.7 and created a zone from km 11 to km 12 where Mn oxide dissolution occurred in the absence of calcite dissolution. Such a zone (and pH's associated with those conditions) has not been observed in the field. Glynn and Brown (1996) noted a similar zone when the initial carbonate-mineral to Mn oxide ratio was greater than 3:2.

Carbon Dioxide Exchange

The simulation of the plume at Pinal Creek was made with the assumption that the plume was closed to the in-gassing of oxygen from the unsaturated zone and the out-gassing of CO_2 to the unsaturated zone. Field values of dissolved oxygen suggest that the system is closed, but the extent to which CO_2 does or does not decrease along the flow path through mixing or diffusion cannot be known with complete certainty. Opening the system to CO_2 at a constant pCO_2 of $10^{-1.33}$ atmospheres (calculated from measured concentrations of total inorganic carbon, TIC) decreased by less than 0.25 km the distance traveled by the pH front from 1984 to 1998. For both simulations, the 1993 decrease in simulated TIC marked the point at which carbonate dissolution was complete upgradient from km 11.4). The simulations indicate that when carbonate dissolution is ongoing, keeping the system closed allowed for unreasonable buildup of TIC in the neutralized zone (fig. 11). After all the simulated calcite had dissolved, the closed system simulated that the TIC concentrations were in good agreement. These results indicate that the water along the flow path was in partial or indirect contact with the atmosphere possibly through mixing with shallower water that is in direct contact with the unsaturated zone. More realistic simulation of this (and other gas-exchange processes) will require the use of a two-dimensional model.

Aluminum Equilibria

Because of the uncertainty regarding the solid-phase controls on Al solubility, no controls were placed on dissolved Al in the model. The effects of Al solid phases on the movement of the pH front were explored by a sensitivity analysis that allowed for the control of dissolved Al concentrations by $Al(OH)_{3(a)}$ and $AlOHSO_4$. Initial concentrations of these minerals were set to 0. By allowing for the precipitation and redissolution of these minerals, the simulated pH from km 0 to km 10 was as much as one unit less in 1998. Between km 9 and km 10, the pH decreased by as much as one unit. These changes had little effect on the rate of movement of the simulated acidic front of the plume. Glynn and Brown (1996) simulated flow between wells 402 and 503 and found that allowing $AlOHSO_4$ to precipitate rather than $Al(OH)_{3(a)}$ increased the retardation factors of the rhodochrosite and Al solid-phase dissolution fronts, which are associated with the breakthrough of the low pH front.

CONCLUSIONS

From 1984 to 1998, concentrations of contaminants in the alluvial aquifer in Pinal Creek Basin, Arizona, decreased as a result of mixing, recharge, source removal, remedial pumping, and chemical reactions. Inverse and reactive-transport geochemical modeling were used to help understand the important reactions and processes that controlled the measured changes in chemistry. The major conclusions of this analysis are as follows.

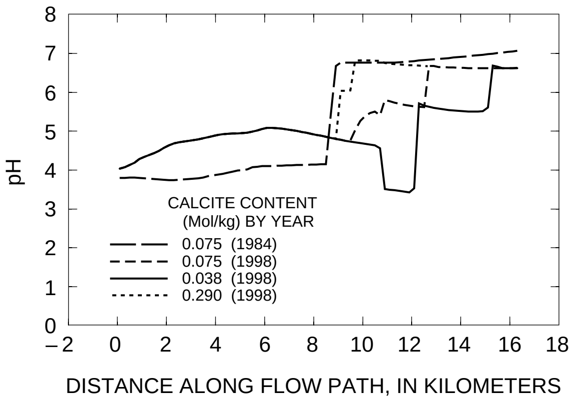


Figure 10. Simulated pH for selected concentrations of calcite in aquifer material, 1984 and 1998.

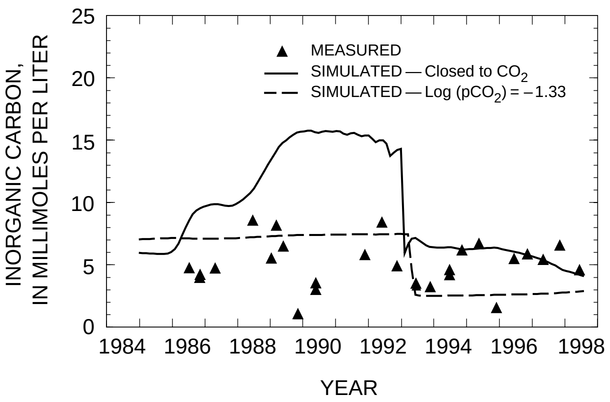


Figure 11. Measured and simulated concentrations of total inorganic carbon in water at km 11.4, 1984–98.

NETPATH and PHREEQC inverse modeling indicated that in order to satisfy the mass-balance constraints on Ca and Mg, the dissolution of Ca-Mg silicates were required. Rhodochrosite and Al solid-phase mass transfers were significant, particularly in models that allowed no CO_2 exsolution.

Simulated and measured concentrations of Fe, Mn, and Ca differed mainly because water along the flow path appeared not to be in a state of local equilibrium. The lack of equilibrium is related at least in part to slow reaction kinetics, but an apparent lack of equilibrium also could result from diffusion processes that limit the interaction of solid-phase surfaces with solutes in the aquifer. Distinguishing reaction kinetics from diffusion limitations in the subsurface is difficult if not impossible at the present time.

Because of the apparent lack of equilibrium, the primary usefulness of the model was as a means of comparing the system at Pinal Creek with a system in local equilibrium. Although the equilibrium approach provided insight as to which processes at the site were kinetically controlled and which were not, future work will require a kinetic modeling approach to more thoroughly characterize selected reactions between the plume and aquifer materials and will require the use of a two- or three-dimensional reactive-transport model.

From 1984 to 1990, water along the flow path was supersaturated or in equilibrium with gypsum, and gypsum equilibria controlled dissolved concentrations of Ca and SO_4. Beginning in 1991, water in the acidic part of the plume became increasingly undersaturated with gypsum indicating that the gypsum available for dissolution in the aquifer became limited beginning in about 1991.

Rhodochrosite precipitation probably was responsible for the measured attenuation in dissolved Mn in the neutralized zone. For reactions involving gypsum and rhodochrosite, the assumption of a local geochemical equilibrium generally was valid.

For oxidation-reduction reactions, the local equilibrium assumption generally was not valid. Reaction kinetics appear to control the measured concentrations of dissolved Fe and Mn in the acidic and transition zones.

For reactions involving calcite, the local equilibrium assumption did not appear valid. Although dissolution of calcite in the transition zone was not sufficient to establish equilibrium, calcite undersaturation decreased along the flow path in the neutralized zone, and equilibrium was reached by the end of the flow path.

Sensitivity analysis indicated that the rate of advance of the pH front was highly sensitive to the initial calcite concentration. Increasing the calcite content from 0.075 to 0.29 mol/kg H_2O reduced the calculated rate of advance of the pH front by a factor of 9. Decreasing the calcite content to 0.038 mol/kg H_2O increased the rate of the pH front advance by a factor of 1.7.

Opening the system to CO_2 at a constant pCO_2 of $10^{-1.33}$ atmospheres produced a better agreement between measured and simulated concentrations of dissolved TIC when calcite dissolution was occurring. After simulated calcite was completely consumed, better agreement between measured and simulated concentrations of dissolved TIC was achieved when the exsolution of CO_2 was not allowed. The simulations indicate that when calcite dissolution is ongoing, keeping the system closed allowed for unreasonable buildup of dissolved carbon in the neutralized zone. After all the simulated calcite had dissolved, the simulated carbon concentrations in the closed system were in good agreement. Water along the flow path was in partial or indirect contact with the atmosphere possibly through mixing with shallower water that is in direct contact with the unsaturated zone. More realistic simulation of this (and other gas-exchange processes) will require the use of a two-dimensional model.

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Exhibit

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Heavy Metals Toxicity and the Environment

Paul B Tchounwou, Clement G Yedjou, [...], and Dwayne J Sutton

Abstract

Heavy metals are naturally occurring elements that have a high atomic weight and a density at least 5 times greater than that of water. Their multiple industrial, domestic, agricultural, medical and technological applications have led to their wide distribution in the environment; raising concerns over their potential effects on human health and the environment. Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure. They are also classified as human carcinogens (known or probable) according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer. This review provides an analysis of their environmental occurrence, production and use, potential for human exposure, and molecular mechanisms of toxicity, genotoxicity, and carcinogenicity.

Keywords: Heavy metals, production and use, human exposure, toxicity, genotoxicity, carcinogenicity

Introduction

Heavy metals are defined as metallic elements that have a relatively high density compared to water [1]. With the assumption that heaviness and toxicity are inter-related, heavy metals also include metalloids, such as arsenic, that are able to induce toxicity at low level of exposure [2]. In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by these metals. Also, human exposure has risen dramatically as a result of an exponential increase of their use in several industrial, agricultural, domestic and technological applications [3]. Reported sources of heavy metals in the environment include geogenic, industrial, agricultural, pharmaceutical, domestic effluents, and atmospheric sources [4]. Environmental pollution is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operations [1, 3, 4].

Although heavy metals are naturally occurring elements that are found throughout the earth's crust, most environmental contamination and human exposure result from anthropogenic activities such as mining and smelting operations, industrial production and use, and domestic and agricultural use of metals and metal-containing compounds [4–7]. Environmental contamination can also occur through metal corrosion, atmospheric deposition, soil erosion of metal ions and leaching of heavy metals, sediment re-suspension and metal evaporation from water resources to soil and ground water [8]. Natural phenomena such as weathering and volcanic eruptions have also been reported to significantly contribute to heavy metal pollution [1, 3, 4, 7, 8]. Industrial sources include metal processing in refineries, coal burning in power plants, petroleum combustion, nuclear power stations and high tension lines, plastics, textiles, microelectronics, wood preservation and paper processing plants [9–11].

It has been reported that metals such as cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Zn) are essential nutrients that are required for various biochemical and physiological functions [12]. Inadequate supply of these micro-nutrients results in a variety of deficiency diseases or syndromes [12].

Heavy metals are also considered as trace elements because of their presence in trace concentrations (ppb range to less than 10ppm) in various environmental matrices [13]. Their bioavailability is influenced by physical factors such as temperature, phase association, adsorption and sequestration. It is also affected by chemical factors that influence speciation at thermodynamic equilibrium, complexation kinetics, lipid solubility and octanol/water partition coefficients [14]. Biological factors such as species characteristics, trophic interactions, and biochemical/physiological adaptation, also play an important role [15].

The essential heavy metals exert biochemical and physiological functions in plants and animals. They are important constituents of several key enzymes and play important roles in various oxidation-reduction reactions [12]. Copper for example serves as an essential co-factor for several oxidative stress-related enzymes including catalase, superoxide dismutase, peroxidase, cytochrome c oxidases, ferroxidases, monoamine oxidase, and dopamine β-monooxygenase [16–18]. Hence, it is an essential nutrient that is incorporated into a number of metalloenzymes involved in hemoglobin formation, carbohydrate metabolism, catecholamine biosynthesis, and cross-linking of collagen, elastin, and hair keratin. The ability of copper to cycle between an oxidized state, Cu(II), and reduced state, Cu(I), is used by cuproenzymes involved in redox reactions [16–18]. However, it is this property of copper that also makes it potentially toxic because the transitions between Cu(II) and Cu(I) can result in the generation of superoxide and hydroxyl radicals [16–19]. Also, excessive exposure to copper has been linked to cellular damage leading to Wilson disease in humans [18, 19]. Similar to copper, several other essential elements are required for biologic functioning, however, an excess amount of such metals produces cellular and tissue damage leading to a variety of adverse effects and human diseases. For some including chromium and copper, there is a very narrow range of concentrations between beneficial and toxic effects [19, 20]. Other metals such as aluminium (Al), antinomy (Sb), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), gallium (Ga), germanium (Ge), gold (Au), indium (In), lead (Pb), lithium (Li), mercury (Hg), nickel (Ni), platinum (Pt), silver (Ag), strontium (Sr), tellurium (Te), thallium (Tl), tin (Sn), titanium (Ti), vanadium (V) and uranium (U) have no established biological functions and are considered as non-essential metals [20].

In biological systems, heavy metals have been reported to affect cellular organelles and components such as cell membrane, mitochondrial, lysosome, endoplasmic reticulum, nuclei, and some enzymes involved in metabolism, detoxification, and damage repair [21]. Metal ions have been found to interact with cell components such as DNA and nuclear proteins, causing DNA damage and conformational changes that may lead to cell cycle modulation, carcinogenesis or apoptosis [20–22]. Several studies from our laboratory have demonstrated that reactive oxygen species (ROS) production and oxidative stress play a key role in the toxicity and carcinogenicity of metals such as arsenic [23, 24, 25], cadmium [26], chromium [27, 28], lead [29, 30], and mercury [31, 32]. Because of their high degree of toxicity, these five elements rank among the priority metals that are of great public health significance. They are all systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure. According to the United States Environmental Protection Agency (U.S. EPA), and the International Agency for Research on Cancer (IARC), these metals are also classified as either “known” or “probable” human carcinogens based on epidemiological and experimental studies showing an association between exposure and cancer incidence in humans and animals.

Heavy metal-induced toxicity and carcinogenicity involves many mechanistic aspects, some of which are not clearly elucidated or understood. However, each metal is known to have unique features and physic-chemical properties that confer to its specific toxicological mechanisms of action. This review provides an analysis of the environmental occurrence, production and use, potential for human exposure, and molecular mechanisms of toxicity, genotoxicity, and carcinogenicity of arsenic, cadmium, chromium, lead, and mercury.

Arsenic

Environmental Occurrence, Industrial Production and Use

Arsenic is a ubiquitous element that is detected at low concentrations in virtually all environmental matrices [33]. The major inorganic forms of arsenic include the trivalent arsenite and the pentavalent arsenate. The organic forms are the methylated metabolites – monomethylarsonic acid (MMA), dimethylarsinic acid (DMA) and trimethylarsine oxide. Environmental pollution by arsenic occurs as a result of natural phenomena such as volcanic eruptions and soil erosion, and anthropogenic activities [33]. Several arsenic-containing compounds are produced industrially, and have been used to manufacture products with agricultural applications such as insecticides, herbicides, fungicides, algicides, sheep dips, wood preservatives, and dye-stuffs. They have also been used in veterinary medicine for the eradication of tapeworms in sheep and cattle [34]. Arsenic compounds have also been used in the medical field for at least a century in the treatment of syphilis, yaws, amoebic dysentery, and trypanosomaiasis [34,35]. Arsenic-based drugs are still used in treating certain tropical diseases such as African sleeping sickness and amoebic dysentery, and in veterinary medicine to treat parasitic diseases, including filariasis in dogs and black head in turkeys and chickens [35]. Recently, arsenic trioxide has been approved by the Food and Drug Administration as an anticancer agent in the treatment of acute promeylocytic leukemia [36]. Its therapeutic action has been attributed to the induction of programmed cell death (apoptosis) in leukemia cells [24].

Potential for Human Exposure

It is estimated that several million people are exposed to arsenic chronically throughout the world, especially in countries like Bangladesh, India, Chile, Uruguay, Mexico, Taiwan, where the ground water is contaminated with high concentrations of arsenic. Exposure to arsenic occurs via the oral route (ingestion), inhalation, dermal contact, and the parenteral route to some extent [33,34,37]. Arsenic concentrations in air range from 1 to 3 ng/m^3 in remote locations (away from human releases), and from 20 to 100 ng/m^3 in cities. Its water concentration is usually less than 10µg/L, although higher levels can occur near natural mineral deposits or mining sites. Its concentration in various foods ranges from 20 to 140 ng/kg [38]. Natural levels of arsenic in soil usually range from 1 to 40 mg/kg, but pesticide application or waste disposal can produce much higher values [25].

Diet, for most individuals, is the largest source of exposure, with an average intake of about 50 µg per day. Intake from air, water and soil are usually much smaller, but exposure from these media may become significant in areas of arsenic contamination. Workers who produce or use arsenic compounds in such occupations as vineyards, ceramics, glass-making, smelting, refining of metallic ores, pesticide manufacturing and application, wood preservation, semiconductor manufacturing can be exposed to substantially higher levels of arsenic [39]. Arsenic has also been identified at 781 sites of the 1,300 hazardous waste sites that have been proposed by the U.S. EPA for inclusion on the national priority list [33,39]. Human exposure at these sites may occur by a variety of pathways, including inhalation of dusts in air, ingestion of contaminated water or soil, or through the food chain [40].

Contamination with high levels of arsenic is of concern because arsenic can cause a number of human health effects. Several epidemiological studies have reported a strong association between arsenic exposure and increased risks of both carcinogenic and systemic health effects [41]. Interest in the toxicity of arsenic has been heightened by recent reports of large populations in West Bengal, Bangladesh, Thailand, Inner Mongolia, Taiwan, China, Mexico, Argentina, Chile, Finland and Hungary that have been exposed to high concentrations of arsenic in their drinking water and are displaying various clinico-pathological conditions including cardiovascular and peripheral vascular disease, developmental anomalies, neurologic and neurobehavioural disorders, diabetes, hearing loss, portal fibrosis, hematologic disorders (anemia, leukopenia and eosinophilia) and carcinoma [25, 33, 35, 39]. Arsenic exposure affects virtually all organ systems including the cardiovascular, dermatologic, nervous, hepatobilliary, renal, gastro-intestinal, and respiratory systems [41]. Research has also pointed to significantly higher standardized mortality rates for cancers of the bladder, kidney, skin, and liver in many areas of arsenic pollution. The severity of adverse health effects is related to the chemical form of arsenic, and is also time- and dose-dependent [42,43]. Although the evidence of carcinogenicity of arsenic in humans seems strong, the mechanism by which it produces tumors in humans is not completely understood [44].

Mechanisms of Toxicity and Carcinogenicity

Analyzing the toxic effects of arsenic is complicated because the toxicity is highly influenced by its oxidation state and solubility, as well as many other intrinsic and extrinsic factors [45]. Several studies have indicated that the toxicity of arsenic depends on the exposure dose, frequency and duration, the biological species, age, and gender, as well as on individual susceptibilities, genetic and nutritional factors [46]. Most cases of human toxicity from arsenic have been associated with exposure to inorganic arsenic. Inorganic trivalent arsenite (As^{III}) is 2–10 times more toxic than pentavalent arsenate (As^{V}) [5]. By binding to thiol or sulfhydryl groups on proteins, As (III) can inactivate over 200 enzymes. This is the likely mechanism responsible for arsenic's widespread effects on different organ systems. As (V) can replace phosphate, which is involved in many biochemical pathways [5, 47].

One of the mechanisms by which arsenic exerts its toxic effect is through impairment of cellular respiration by the inhibition of various mitochondrial enzymes, and the uncoupling of oxidative phosphorylation. Most toxicity of arsenic results from its ability to interact with sulfhydryl groups of proteins and enzymes, and to substitute phosphorous in a variety of biochemical reactions [48]. Arsenic *in vitro* reacts with protein sulfhydryl groups to inactivate enzymes, such as dihydrolipoyl dehydrogenase and thiolase, thereby producing inhibited oxidation of pyruvate and betaoxidation of fatty acids [49]. The major metabolic pathway for inorganic arsenic in humans is methylation. Arsenic trioxide is methylated to two major metabolites via a non-enzymatic process to monomethylarsonic acid (MMA), which is further methylated enzymatically to dimethyl arsenic acid (DMA) before excretion in the urine [40, 47]. It was previously thought that this methylation process is a pathway of arsenic detoxification, however, recent studies have pointed out that some methylated metabolites may be more toxic than arsenite if they contain trivalent forms of arsenic [41].

Tests for genotoxicity have indicated that arsenic compounds inhibit DNA repair, and induce chromosomal aberrations, sister-chromatid exchanges, and micronuclei formation in both human and rodent cells in culture [50–52] and in cells of exposed humans [53]. Reversion assays with *Salmonella typhimurium* fail to detect mutations that are induced by arsenic compounds. Although arsenic compounds are generally perceived as weak mutagens in bacterial and animal cells, they exhibit clastogenic properties in many cell types *in vivo* and *in vitro* [54]. In the absence of animal models, *in vitro* cell transformation studies become a useful means of obtaining information on the carcinogenic mechanisms of arsenic toxicity. Arsenic and arsenical compounds are cytotoxic and induce morphological transformations of Syrian hamster embryo (SHE) cells as well as mouse C3H10T1/2 cells and BALB/3T3 cells [55, 56].

Based on the comet assay, it has been reported that arsenic trioxide induces DNA damage in human lymphophytes [57] and also in mice leukocytes [58]. Arsenic compounds have also been shown to induce gene amplification, arrest cells in mitosis, inhibit DNA repair, and induce expression of the *c-fos* gene and the oxidative stress protein heme oxygenase in mammalian cells [58, 59]. They have been implicated as promoters and comutagens for a variety of toxic agents [60]. Recent studies in our laboratory have demonstrated that arsenic trioxide is cytotoxic and able to transcriptionally induce a significant number of stress genes and related proteins in human liver carcinoma cells [61].

Epidemiological investigations have indicated that long-term arsenic exposure results in promotion of carcinogenesis. Several hypotheses have been proposed to describe the mechanism of arsenic-induced carcinogenesis. Zhao et al. [62] reported that arsenic may act as a carcinogen by inducing DNA hypomethylation, which in turn facilitates aberrant gene expression. Additionally, it was found that arsenic is a potent stimulator of extracellular signal-regulated protein kinase Erk1 and AP-1 transactivational activity, and an efficient inducer of *c-fos* and *c-jun* gene expression [63]. Induction of *c-jun* and *c-fos* by arsenic is associated with activation of JNK [64]. However, the role of JNK activation by arsenite in cell transformation or tumor promotion is unclear.

In another study, Trouba et al. [65] concluded that long-term exposure to high levels of arsenic might make cells more susceptible to mitogenic stimulation and that alterations in mitogenic signaling proteins might contribute to the carcinogenic action of arsenic. Collectively, several recent studies have demonstrated that arsenic can interfere with cell signaling pathways (e.g., the p53 signaling pathway) that are frequently implicated in the promotion and progression of a variety of tumor types in experimental animal models, and of some human tumors [66, 68]. However, the specific alterations in signal transduction pathways or the actual targets that contribute to the development of arsenic-induced tumors in humans following chronic consumption of arsenic remains uncertain.

Recent clinical trials have found that arsenic trioxide has therapeutic value in the treatment of acute promyelocytic leukemia, and there is interest in exploring its effectiveness in the treatment of a variety of other cancers [69,70]. In acute promyelocytic leukemia, the specific molecular event critical to the formation of malignant cells is known. A study by Puccetti et al. [71] found that forced overexpression of BCR-ABL susceptibility in human lymphoblasts cells resulted in greatly enhanced sensitivity to arsenic-induced apoptosis. They also concluded that arsenic trioxide is a tumor specific agent capable of inducing apoptosis selectively in acute promyelocytic leukemia cells. Several recent studies have shown that arsenic can induce apoptosis through alterations in other cell signaling pathways [72,73]. In addition to acute peomyelocytic leukemia, arsenic is thought to have therapeutic potential for myeloma [74]. In summary, numerous cancer chemotherapy studies in cell cultures and in patients with acute promyelocytic leukemia demonstrate that arsenic trioxide administration can lead to cell-cycle arrest and apoptosis in malignant cells.

Previous studies have also examined p53 gene expression and mutation in tumors obtained from subjects with a history of arsenic ingestion. p53 participates in many cellular functions, cell-cycle control, DNA repair, differentiation, genomic plasticity and programmed cell death. Additional support for the hypothesis that arsenic can modulate gene expression has been provided by several different studies [75,76]. Collectively, these studies provide further evidence that various forms of arsenic can alter gene expression and that such changes could contribute substantially to the toxic and carcinogenic actions of arsenic treatment in human populations [77].

Several *in vitro* studies in our laboratory have demonstrated that arsenic modulates DNA synthesis, gene and protein expression, genotoxicity, mitosis and/or apoptotic mechanisms in various cell lines including keratinocytes, melanocytes, dendritic cells, dermal fibroblasts, microvascular endothelial cells, monocytes, and T-cells [78], colon cancer cells [79], lung cancer cells [80], human leukemia cells [81], Jurkat-T lymphocytes [82], and human liver carcinoma cells [83]. We have also shown that oxidative stress plays a key role in arsenic induced cytotoxicity, a process that is modulated by pro- and/or anti-oxidants such as ascorbic acid and n-acetyl cysteine [84–86]. We have further demonstrated that the toxicity of arsenic depends on its chemical form, the inorganic form being more toxic than the organic one [42].

Various hypotheses have been proposed to explain the carcinogenicity of inorganic arsenic. Nevertheless, the molecular mechanisms by which this arsenical induces cancer are still poorly understood. Results of previous studies have indicated that inorganic arsenic does not act through classic genotoxic and mutagenic mechanisms, but rather may be a tumor promoter that modifies signal transduction pathways involved in cell growth and proliferation [68]. Although much progress has been recently made in the area of arsenic's possible mode(s) of carcinogenic action, a scientific consensus has not yet reached. A recent review discusses nine different possible modes of action of arsenic carcinogenesis: induced chromosomal abnormalities, oxidative stress, altered DNA repair, altered DNA methylation patterns, altered growth factors, enhanced cell proliferation, promotion/progression, suppression of p53, and gene amplification [87]. Presently, three modes (chromosomal abnormality, oxidative stress, and altered growth factors) of arsenic carcinogenesis have shown a degree of positive evidence, both in experimental systems (animal and human cells) and in human tissues. The remaining possible modes of carcinogenic action (progression of carcinogenesis, altered DNA repair, p53 suppression, altered DNA methylation patterns and gene amplification) do not have as much evidence, particularly from *in vivo* studies with laboratory animals, *in vitro* studies with cultured human cells, or human data from case or population studies. Thus, the mode-of-action studies suggest that arsenic might be acting as a cocarcinogen, a promoter, or a progressor of carcinogenesis.

Cadmium

Environmental Occurrence, Industrial Production and Use

Cadmium is a heavy metal of considerable environmental and occupational concern. It is widely distributed in the earth's crust at an average concentration of about 0.1 mg/kg. The highest level of cadmium compounds in the environment is accumulated in sedimentary rocks, and marine phosphates contain about 15 mg cadmium/kg [88].

Cadmium is frequently used in various industrial activities. The major industrial applications of cadmium include the production of alloys, pigments, and batteries [89]. Although the use of cadmium in batteries has shown considerable growth in recent years, its commercial use has declined in developed countries in response to environmental concerns. In the United States for example, the daily cadmium intake is about 0.4μg/kg/day, less than half of the U.S. EPA's oral reference dose [90]. This decline has been linked to the introduction of stringent effluent limits from plating works and, more recently, to the introduction of general restrictions on cadmium consumption in certain countries.

Potential for Human Exposure

The main routes of exposure to cadmium are via inhalation or cigarette smoke, and ingestion of food. Skin absorption is rare. Human exposure to cadmium is possible through a number of several sources including employment in primary metal industries, eating contaminated food, smoking cigarettes, and working in cadmium-contaminated work places, with smoking being a major contributor [91, 92]. Other sources of cadmium include emissions from industrial activities, including mining, smelting, and manufacturing of batteries, pigments, stabilizers, and alloys [93]. Cadmium is also present in trace amounts in certain foods such as leafy vegetables, potatoes, grains and seeds, liver and kidney, and crustaceans and mollusks [94]. In addition, foodstuffs that are rich in cadmium can greatly increase the cadmium concentration in human bodies. Examples are liver, mushrooms, shellfish, mussels, cocoa powder and dried seaweed. An important distribution route is the circulatory system whereas blood vessels are considered to be main stream organs of cadmium toxicity. Chronic inhalation exposure to cadmium particulates is generally associated with changes in pulmonary function and chest radiographs that are consistent with emphysema [95]. Workplace exposure to airborne cadmium particulates has been associated with decreases in olfactory function [96]. Several epidemiologic studies have documented an association of chronic low-level cadmium exposure with decreases in bone mineral density and osteoporosis [97–99].

Exposure to cadmium is commonly determined by measuring cadmium levels in blood or urine. Blood cadmium reflects recent cadmium exposure (from smoking, for example). Cadmium in urine (usually adjusted for dilution by calculating the cadmium/creatinine ratio) indicates accumulation, or kidney burden of cadmium [100, 101]. It is estimated that about 2.3% of the U.S. population has elevated levels of urine cadmium (>2μg/g creatinine), a marker of chronic exposure and body burden [102]. Blood and urine cadmium levels are typically higher in cigarette smokers, intermediate in former smokers and lower in nonsmokers [102, 103]. Because of continuing use of cadmium in industrial applications, the environmental contamination and human exposure to cadmium have dramatically increased during the past century [104].

Molecular Mechanisms of Toxicity and Carcinogenicity

Cadmium is a severe pulmonary and gastrointestinal irritant, which can be fatal if inhaled or ingested. After acute ingestion, symptoms such as abdominal pain, burning sensation, nausea, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness and convulsions usually appear within 15 to 30 min [105]. Acute cadmium ingestion can also cause gastrointestinal tract erosion, pulmonary, hepatic or renal injury and coma, depending on the route of poisoning [105, 106]. Chronic exposure to cadmium has a depressive effect on levels of norepinephrine, serotonin, and acetylcholine [107]. Rodent studies have shown that chronic inhalation of cadmium causes pulmonary adenocarcinomas [108, 109]. It can also cause prostatic proliferative lesions including adenocarcinomas, after systemic or direct exposure [110].

Although the mechanisms of cadmium toxicity are poorly understood, it has been speculated that cadmium causes damage to cells primarily through the generation of ROS [111], which causes single-strand DNA damage and disrupts the synthesis of nucleic acids and proteins [112]. Studies using two-dimensional gel electrophoresis have shown that several stress response systems are expressed in response to cadmium exposure, including those for heat shock, oxidative stress, stringent response, cold shock, and SOS [113– 115]. *In vitro* studies indicate that cadmium induces cytotoxic effects at the concentrations 0.1 to 10 mM and free radical-dependent DNA damage [116, 117]. *In vivo* studies have shown that cadmium modulates male reproduction in mice model at a concentration of 1 mg/kg body weight [118]. However, cadmium is a weak mutagen when compared with other carcinogenic metals [119]. Previous reports have indicated that cadmium affects signal transduction pathways; inducing inositol polyphosphate formation, increasing cytosolic free calcium levels in various cell types [120], and blocking calcium channels [121, 122]. At lower concentrations (1–100 μM), cadmium binds to proteins, decreases DNA repair [123], activates protein degradation, up-regulates cytokines and proto-oncogenes such as c-*fos*, c-*jun*, and c-*myc* [124], and induces expression of several genes including metallothioneins [125], heme oxygenases, glutathione transferases, heat-shock proteins, acute-phase reactants, and DNA polymerase β [126].

Cadmium compounds are classified as human carcinogens by several regulatory agencies. The International Agency for Research on Cancer [91] and the U.S. National Toxicology Program have concluded that there is adequate evidence that cadmium is a human carcinogen. This designation as a human carcinogen is based primarily on repeated findings of an association between occupational cadmium exposure and lung cancer, as well as on very strong rodent data showing the pulmonary system as a target site [91]. Thus, the lung is the most definitively established site of human carcinogenesis from cadmium exposure. Other target tissues of cadmium carcinogenesis in animals include injection sites, adrenals, testes, and the hemopoietic system [91, 108, 109]. In some studies, occupational or environmental cadmium exposure has also been associated with development of cancers of the prostate, kidney, liver, hematopoietic system and stomach [108, 109]. Carcinogenic metals including arsenic, cadmium, chromium, and nickel have all been associated with DNA damage through base pair mutation, deletion, or oxygen radical attack on DNA [126]. Animal studies have demonstrated reproductive and teratogenic effects. Small epidemiologic studies have noted an inverse relationship between cadmium in cord blood, maternal blood or maternal urine and birth weight and length at birth [127, 128].

Chromium

Environmental Occurrence, Industrial Production and Use

Chromium (Cr) is a naturally occurring element present in the earth’s crust, with oxidation states (or valence states) ranging from chromium (II) to chromium (VI) [129]. Chromium compounds are stable in the trivalent [Cr(III)] form and occur in nature in this state in ores, such as ferrochromite. The hexavalent [Cr(VI)] form is the second-most stable state [28]. Elemental chromium [Cr(0)] does not occur naturally. Chromium enters into various environmental matrices (air, water, and soil) from a wide variety of natural and anthropogenic sources with the largest release coming from industrial establishments. Industries with the largest contribution to chromium release include metal processing, tannery facilities, chromate production, stainless steel welding, and ferrochrome and chrome pigment production. The increase in the environmental concentrations of chromium has been linked to air and wastewater release of chromium, mainly from metallurgical, refractory, and chemical industries. Chromium released into the environment from anthropogenic activity occurs mainly in the hexavalent form [Cr(VI)] [130]. Hexavalent chromium [Cr(VI)] is a toxic industrial pollutant that is classified as human carcinogen by several regulatory and non-regulatory agencies [130–132]. The health hazard associated with exposure to chromium depends on its oxidation state, ranging from the low toxicity of the metal form to the high toxicity of the hexavalent form. All Cr(VI)-containing compounds were once thought to be man-made, with only Cr(III) naturally ubiquitous in air, water, soil and biological materials. Recently, however, naturally occurring Cr(VI) has been found in ground and surface waters at values exceeding the World Health Organization limit for drinking water of 50 μg of Cr(VI) per liter [133]. Chromium is widely used in numerous industrial processes and as a result, is a contaminant of many environmental systems [134]. Commercially chromium compounds are used in industrial welding, chrome plating, dyes and pigments, leather tanning and wood preservation. Chromium is also used as anticorrosive in cooking systems and boilers [135, 136].

Potential for Human Exposure

It is estimated that more than 300,000 workers are exposed annually to chromium and chromium-containing compounds in the workplace. In humans and animals, [Cr(III)] is an essential nutrient that plays a role in glucose, fat and protein metabolism by potentiating the action of insulin [5]. However, occupational exposure has been a major concern because of the high risk of Cr-induced diseases in industrial workers occupationally exposed to Cr(VI) [137]. Also, the general human population and some wildlife may also be at risk. It is estimated that 33 tons of total Cr are released annually into the environment [130]. The U.S. Occupational Safety and Health Administration (OSHA) recently set a “safe” level of 5μg/m^3, for an 8-hr time-weighted average, even though this revised level may still pose a carcinogenic risk [138]. For the general human population, atmospheric levels range from 1 to 100 ng/cm^3 [139], but can exceed this range in areas that are close to Cr manufacturing.

Non-occupational exposure occurs via ingestion of chromium containing food and water whereas occupational exposure occurs via inhalation [140]. Chromium concentrations range between 1 and 3000 mg/kg in soil, 5 to 800 μg/L in sea water, and 26 μg/L to 5.2 mg/L in rivers and lakes [129]. Chromium content in foods varies greatly and depends on the processing and preparation. In general, most fresh foods typically contain chromium levels ranging from <10 to 1,300 μg/kg. Present day workers in chromium-related industries can be exposed to chromium concentrations two orders of magnitude higher than the general population [141]. Even though the principal route of human exposure to chromium is through inhalation, and the lung is the primary target organ, significant human exposure to chromium has also been reported to take place through the skin [142, 143]. For example, the widespread incidence of dermatitis noticed among construction workers is attributed to their exposure to chromium present in cement [143]. Occupational and environmental exposure to Cr(VI)-containing compounds is known to cause multiorgan toxicity such as renal damage, allergy and asthma, and cancer of the respiratory tract in humans [5, 144].

Breathing high levels of chromium (VI) can cause irritation to the lining of the nose, and nose ulcers. The main health problems seen in animals following ingestion of chromium (VI) compounds are irritation and ulcers in the stomach and small intestine, anemia, sperm damage and male reproductive system damage. Chromium (III) compounds are much less toxic and do not appear to cause these problems. Some individuals are extremely sensitive to chromium(VI) or chromium(III), allergic reactions consisting of severe redness and swelling of the skin have been noted. An increase in stomach tumors was observed in humans and animals exposed to chromium(VI) in drinking water. Accidental or intentional ingestion of extremely high doses of chromium (VI) compounds by humans has resulted in severe respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological effects as part of the sequelae leading to death or in patients who survived because of medical treatment [141]. Although the evidence of carcinogenicity of chromium in humans and terrestrial mammals seems strong, the mechanism by which it causes cancer is not completely understood [145].

Mechanisms of Toxicity and Carcinogenicity

Major factors governing the toxicity of chromium compounds are oxidation state and solubility. Cr(VI) compounds, which are powerful oxidizing agents and thus tend to be irritating and corrosive, appear to be much more toxic systemically than Cr(III) compounds, given similar amount and solubility [146, 147]. Although the mechanisms of biological interaction are uncertain, the variation in toxicity may be related to the ease with which Cr(VI) can pass through cell membranes and its subsequent intracellular reduction to reactive intermediates. Since Cr(III) is poorly absorbed by any route, the toxicity of chromium is mainly attributable to the Cr(VI) form. It can be absorbed by the lung and gastrointestinal tract, and even to a certain extent by intact skin. The reduction of Cr(VI) is considered as being a detoxification process when it occurs at a distance from the target site for toxic or genotoxic effect while reduction of Cr(VI) may serve to activate chromium toxicity if it takes place in or near the cell nucleus of target organs [148]. If Cr(VI) is reduced to Cr(III) extracellularly, this form of the metal is not readily transported into cells and so toxicity is not observed. The balance that exists between extracellular Cr(VI) and intracellular Cr(III) is what ultimately dictates the amount and rate at which Cr(VI) can enter cells and impart its toxic effects [134].

Cr(VI) enters many types of cells and under physiological conditions can be reduced by hydrogen peroxide (H_2O_2), glutathione (GSH) reductase, ascorbic acid, and GSH to produce reactive intermediates, including Cr(V), Cr(IV), thiylradicals, hydroxyl radicals, and ultimately, Cr(III). Any of these species could attack DNA, proteins, and membrane lipids, thereby disrupting cellular integrity and functions [149, 150].

Studies with animal models have also reported many harmful effects of Cr (VI) on mammals. Subcutaneous administration of Cr (VI) to rats caused severe progressive proteinuria, urea nitrogen and creatinine, as well as elevation in serum alanine aminotransferase activity and hepatic lipid peroxide formation [151]. Similar studies reported by Gumbleton and Nicholls [152] found that Cr (VI) induced renal damage in rats when administered by single sub-cutaneous injections. Bagchi et al. demonstrated that rats received Cr (VI) orally in water induced hepatic mitochondrial and microsomal lipid peroxidation, as well as enhanced excretion of urinary lipid metabolites including malondialdehyde [153, 154].

Adverse health effects induced by Cr (VI) have also been reported in humans. Epidemiological investigations have reported respiratory cancers in workers occupationally exposed to Cr (VI)-containing compounds [142, 148]. DNA strand breaks in peripheral lymphocytes and lipid peroxidation products in urine observed in chromium-exposed workers also support the evidence of Cr (VI)-induced toxicity to humans [155, 156]. Oxidative damage is considered to be the underlying cause of these genotoxic effects including chromosomal abnormalities [157, 158], and DNA strand breaks [159]. Nevertheless, recent studies indicate a biological relevance of non-oxidative mechanisms in Cr(VI) carcinogenesis [160].

Carcinogenicity appears to be associated with the inhalation of the less soluble/insoluble Cr(VI) compounds. The toxicology of Cr(VI) does not reside with the elemental form. It varies greatly among a wide variety of very different Cr(VI) compounds [161]. Epidemiological evidence strongly points to Cr(VI) as the agent in carcinogenesis. Solubility and other characteristics of chromium, such as size, crystal modification, surface charge, and the ability to be phagocytized might be important in determining cancer risk [135].

Studies in our laboratory have indicated that chromium (VI) is cytotoxic and able to induce DNA damaging effects such as chromosomal abnormalities [162], DNA strand breaks, DNA fragmentation and oxidative stress in Sprague-Dawley rats and human liver carcinoma cells [27, 28]. Recently, our laboratory has also demonstrated that chromium (VI) induces biochemical, genotoxic and histopathologic effects in liver and kidney of goldfish, *carassius auratus* [163].

Various hypotheses have been proposed to explain the carcinogenicity of chromium and its salts, however some inherent difficulties exist when discussing metal carcinogenesis. A metal cannot be classified as carcinogenic per se since its different compounds may have different potencies. Because of the multiple chemical exposure in industrial establishments, it is difficult from an epidemiological standpoint to relate the carcinogenic effect to a single compound. Thus, the carcinogenic risk must often be related to a process or to a group of metal compounds rather than to a single substance. Differences in carcinogenic potential are related not only to different chemical forms of the same metal but also to the particle size of the inhaled aerosol and to physical characteristics of the particle such as surface charge and crystal modification [164].

Lead

Environmental Occurrence, Industrial Production and Use

Lead is a naturally occurring bluish-gray metal present in small amounts in the earth’s crust. Although lead occurs naturally in the environment, anthropogenic activities such as fossil fuels burning, mining, and manufacturing contribute to the release of high concentrations. Lead has many different industrial, agricultural and domestic applications. It is currently used in the production of lead-acid batteries, ammunitions, metal products (solder and pipes), and devices to shield X-rays. An estimated 1.52 million metric tons of lead were used for various industrial applications in the United Stated in 2004. Of that amount, lead-acid batteries production accounted for 83 percent, and the remaining usage covered a range of products such as ammunitions (3.5 percent), oxides for paint, glass, pigments and chemicals (2.6 percent), and sheet lead (1.7 percent) [165, 166].

In recent years, the industrial use of lead has been significantly reduced from paints and ceramic products, caulking, and pipe solder [167]. Despite this progress, it has been reported that among 16.4 million United States homes with more than one child younger than 6 years per household, 25% of homes still had significant amounts of lead-contaminated deteriorated paint, dust, or adjacent bare soil [168]. Lead in dust and soil often re-contaminates cleaned houses [169] and contributes to elevating blood lead concentrations in children who play on bare, contaminated soil [170]. Today, the largest source of lead poisoning in children comes from dust and chips from deteriorating lead paint on interior surfaces [171]. Children who live in homes with deteriorating lead paint can achieve blood lead concentrations of 20µg/dL or greater [172].

Potential for Human Exposure

Exposure to lead occurs mainly via inhalation of lead-contaminated dust particles or aerosols, and ingestion of lead-contaminated food, water, and paints [173, 174]. Adults absorb 35 to 50% of lead through drinking water and the absorption rate for children may be greater than 50%. Lead absorption is influenced by factors such as age and physiological status. In the human body, the greatest percentage of lead is taken into the kidney, followed by the liver and the other soft tissues such as heart and brain, however, the lead in the skeleton represents the major body fraction [175]. The nervous system is the most vulnerable target of lead poisoning. Headache, poor attention spam, irritability, loss of memory and dullness are the early symptoms of the effects of lead exposure on the central nervous system [170, 173].

Since the late 1970's, lead exposure has decreased significantly as a result of multiple efforts including the elimination of lead in gasoline, and the reduction of lead levels in residential paints, food and drink cans, and plumbing systems [173, 174]. Several federal programs implemented by state and local health governments have not only focused on banning lead in gasoline, paint and soldered cans, but have also supported screening programs for lead poisoning in children and lead abatement in housing [167]. Despite the progress in these programs, human exposure to lead remains a serious health problem [176, 177]. Lead is the most systemic toxicant that affects several organs in the body including the kidneys, liver, central nervous system, hematopoetic system, endocrine system, and reproductive system [173].

Lead exposure usually results from lead in deteriorating household paints, lead in the work place, lead in crystals and ceramic containers that leaches into water and food, lead use in hobbies, and lead use in some traditional medicines and cosmetics [167, 174]. Several studies conducted by the National Health and Nutrition Examination surveys (NHANES) have measured blood lead levels in the U.S. populations and have assessed the magnitude of lead exposure by age, gender, race, income and degree of urbanization [176]. Although the results of these surveys have demonstrated a general decline in blood lead levels since the 1970s, they have also shown that large populations of children continue to have elevated blood lead levels (> 10µg/dL). Hence, lead poisoning remains one of the most common pediatric health problems in the United States today [167, 173, 174, 176–179]. Exposure to lead is of special concern among women particularly during pregnancy. Lead absorbed by the pregnant mother is readily transferred to the developing fetus [180]. Human evidence corroborates animal findings [181], linking prenatal exposure to lead with reduced birth weight and preterm delivery [182], and with neuro-developmental abnormalities in offspring [183].

Molecular Mechanisms of Toxicity and Carcinogenicity

There are many published studies that have documented the adverse effects of lead in children and the adult population. In children, these studies have shown an association between blood level poisoning and diminished intelligence, lower intelligence quotient-IQ, delayed or impaired neurobehavioral development, decreased hearing acuity, speech and language handicaps, growth retardation, poor attention span, and anti social and diligent behaviors [178, 179, 184, 185]. In the adult population, reproductive effects, such as decreased sperm count in men and spontaneous abortions in women have been associated with high lead exposure

[186, 187]. Acute exposure to lead induces brain damage, kidney damage, and gastrointestinal diseases, while chronic exposure may cause adverse effects on the blood, central nervous system, blood pressure, kidneys, and vitamin D metabolism [173, 174, 178, 179, 184–187].

One of the major mechanisms by which lead exerts its toxic effect is through biochemical processes that include lead's ability to inhibit or mimic the actions of calcium and to interact with proteins [173]. Within the skeleton, lead is incorporated into the mineral in place of calcium. Lead binds to biological molecules and thereby interfering with their function by a number of mechanisms. Lead binds to sulfhydryl and amide groups of enzymes, altering their configuration and diminishing their activities. Lead may also compete with essential metallic cations for binding sites, inhibiting enzyme activity, or altering the transport of essential cations such as calcium [188]. Many investigators have demonstrated that lead intoxication induces a cellular damage mediated by the formation of reactive oxygen species (ROS) [189]. In addition, Jiun and Hseien [190] demonstrated that the levels of malondialdehyde (MDA) in blood strongly correlate with lead concentration in the blood of exposed workers. Other studies showed that the activities of antioxidant enzymes, including superoxide dismutase (SOD), and glutathione peroxidase in erythrocytes of workers exposed to lead are remarkably higher than that in non-exposed workers [191]. A series of recent studies in our laboratory demonstrated that lead-induced toxicity and apoptosis in human cancer cells involved several cellular and molecular processes including induction of cell death and oxidative stress [29, 192], transcriptional activation of stress genes [30], DNA damage [29], externalization of phosphatidylserine and activation of caspase-3 [193].

A large body of research has indicated that lead acts by interfering with calcium-dependent processes related to neuronal signaling and intracellular signal transduction. Lead perturbs intracellular calcium cycling, altering releasability of organelle stores, such as endoplasmic reticulum and mitochondria [194, 195]. In some cases lead inhibits calcium-dependent events, including calcium-dependent release of several neurotransmitters and receptor-coupled ionophores in glutamatergic neurons [196]. In other cases lead appears to augment calcium-dependent events, such as protein kinase C and calmodulin [194, 197].

Experimental studies have indicated that lead is potentially carcinogenic, inducing renal tumors in rats and mice [198, 199], and is therefore considered by the IARC as a probable human carcinogen [200]. Lead exposure is also known to induce gene mutations and sister chromatid exchanges [201, 202], morphological transformations in cultured rodent cells [203], and to enhance anchorage independence in diploid human fibroblasts [204]. *In vitro* and *in vivo* studies indicated that lead compounds cause genetic damage through various indirect mechanisms that include inhibition of DNA synthesis and repair, oxidative damage, and interaction with DNA-binding proteins and tumor suppressor proteins. Studies by Roy and his group showed that lead acetate induced mutagenicity at a toxic dose at the *E. coli gpt* locus transfected to V79 cells [205]. They also reported that toxic doses of lead acetate and lead nitrate induced DNA breaks at the *E. coli gpt* locus transfected to V79 cells [205]. Another study by Wise and his collaborators found no evidence for direct genotoxic or DNA-damaging effects of lead except for lead chromate. They pointed out that the genotoxicity may be due to hexavalent chromate rather than lead [206].

Mercury

Environmental Occurrence, Industrial Production and Use

Mercury is a heavy metal belonging to the transition element series of the periodic table. It is unique in that it exists or is found in nature in three forms (elemental, inorganic, and organic), with each having its own profile of toxicity [207]. At room temperature elemental mercury exists as a liquid which has a high vapor pressure and is released into the environment as mercury vapor. Mercury also exists as a cation with oxidation states of +1 (mercurous) or +2 (mercuric) [208]. Methylmercury is the most frequently encountered compound of the organic form found in the environment, and is formed as a result of the methylation of inorganic (mercuric) forms of mercury by microorganisms found in soil and water [209].

Mercury is a widespread environmental toxicant and pollutant which induces severe alterations in the body tissues and causes a wide range of adverse health effects [210]. Both humans and animals are exposed to various chemical forms of mercury in the environment. These include elemental mercury vapor (Hg^0), inorganic mercurous (Hg^{+1}), mercuric (Hg^{+2}), and the organic mercury compounds [211]. Because mercury is ubiquitous in the environment, humans, plants and animals are all unable to avoid exposure to some form of mercury [212].

Mercury is utilized in the electrical industry (switches, thermostats, batteries), dentistry (dental amalgams), and numerous industrial processes including the production of caustic soda, in nuclear reactors, as antifungal agents for wood processing, as a solvent for reactive and precious metal, and as a preservative of pharmaceutical products [213]. The industrial demand for mercury peaked in 1964 and began to sharply decline between 1980 and 1994 as a result of federal bans on mercury additives in paints, pesticides, and the reduction of its use in batteries [214].

Potential for Human Exposure

Humans are exposed to all forms of mercury through accidents, environmental pollution, food contamination, dental care, preventive medical practices, industrial and agricultural operations, and occupational operations [215]. The major sources of chronic, low level mercury exposure are dental amalgams and fish consumption. Mercury enters water as a natural process of off-gassing from the earth’s crust and also through industrial pollution [216]. Algae and bacteria methylate the mercury entering the waterways. Methyl mercury then makes its way through the food chain into fish, shellfish, and eventually into humans [217].

The two most highly absorbed species are elemental mercury (Hg^0) and methyl mercury (MeHg). Dental amalgams contain over 50% elemental mercury [218]. The elemental vapor is highly lipophilic and is effectively absorbed through the lungs and tissues lining the mouth. After Hg^0 enters the blood, it rapidly passes through cell membranes, which include both the blood-brain barrier and the placental barrier [219]. Once it gains entry into the cell, Hg^0 is oxidized and becomes highly reactive Hg^{2+}. Methyl mercury derived from eating fish is readily absorbed in the gastrointestinal tract and because of its lipid solubility, can easily cross both the placental and blood-brain barriers. Once mercury is absorbed it has a very low excretion rate. A major proportion of what is absorbed accumulates in the kidneys, neurological tissue and the liver. All forms of mercury are toxic and their effects include gastrointestinal toxicity, neurotoxicity, and nephrotoxicity [213].

Molecular Mechanisms of Mercury Toxicity and Carcingenicity

The molecular mechanisms of toxicity of mercury are based on its chemical activity and biological features which suggest that oxidative stress is involved in its toxicity [220]. Through oxidative stress mercury has shown mechanisms of sulfhydryl reactivity. Once in the cell both Hg^{2+} and MeHg form covalent bonds with cysteine residues of proteins and deplete cellular antioxidants. Antioxidant enzymes serve as a line of cellular defense against mercury compounds [221]. The interaction of mercury compounds suggests the production of oxidative damage through the accumulation of reactive oxygen species (ROS) which would normally be eliminated by cellular antioxidants.

In eukaryotic organisms the primary site for the production of reactive oxygen species (ROS) occurs in the mitochondria through normal metabolism [222]. Inorganic mercury has been reported to increase the production of these ROS by causing defects in oxidative phosphorylation and electron transport at the ubiquinone-cytochrome b5 step [223]. Through the acceleration of the rate of electron transfer in the electron transport chain in the mitochondria, mercury induces the premature shedding of electrons to molecular oxygen which causes an increase in the generation of reactive oxygen species [224].

Oxidative stress appears to also have an effect on calcium homeostasis. The role of calcium in the activation of proteases, endonucleases and phospholipases is well established. The activation of phospholipase A_2 has been shown to result in an increase in reactive oxygen species through the increase generation of arachidonic acid. Arachidonic acid has also been shown to be an important target of reactive oxygen species [225]. Both organic and inorganic mercury have been shown to alter calcium homeostasis but through different mechanisms. Organic mercury compounds (MeHg) are believed to increase intracellular calcium by accelerating the influx of calcium from the extracellular medium and mobilizing intracellular stores, while inorganic mercury ($Hg^{2+)}$ compounds increase intracellular calcium stores only through the influx of calcium from the extracellular medium [226]. Mercury compounds have also been shown to induce increased levels of MDA in both the livers, kidneys, lungs and testes of rats treated with $HgCl_2$ [227]. This increase in concentration was shown to correlate with the severity of hepatotoxicity and nephrotoxicity [228]. $HgCl_2$-induced lipid peroxidation was shown to be significantly reduced by antioxidant pretreatment with selenium. Selenium has been shown to achieve this protective effect through direct binding to mercury or serving as a cofactor for glutathione peroxidase and facilitating its ability to scavenge ROS [229]. Vitamin E has also been reported to protect against $HgCl_2$-induced lipid peroxidation in the liver [230].

Metal-induced carcinogenicity has been a research subject of great public health interest. Generally, carcinogenesis is considered to have three stages including initiation, promotion, and progression and metastasis. Although mutations of DNA, which can activate oncogenesis or inhibit tumor suppression, were traditionally thought to be crucial factors for the initiation of carcinogenesis, recent studies have demonstrated that other molecular events such as transcription activation, signal transduction, oncogene amplification, and recombination, also constitute significant contributing factors [231, 232]. Studies have shown that mercury and other toxic metals effect cellular organelles and adversely affect their biologic functions [231, 233]. Accumulating evidence also suggests that ROS play a major role in the mediation of metal-induced cellular responses and carcinogenesis [234–236].

The connection between mercury exposure and carcinogenesis is very controversial. While some studies have confirmed its genotoxic potential, others have not shown an association between mercury exposure and genotoxic damage [237]. In studies implicating mercury as a genotoxic agent, oxidative stress has been described has the molecular mechanism of toxicity. Hence, mercury has been shown to induce the formation of ROS known to cause DNA damage in cells, a process which can lead to the initiation of carcinogenic processes [238, 239]. The direct action of these free radicals on nucleic acids may generate genetic mutations. Although mercury-containing compounds are not mutagenic in bacterial assays, inorganic mercury has been shown to induce mutational events in eukaryotic cell lines with doses as low as 0.5 μM [240]. These free radicals may also induce conformational changes in proteins that are responsible for DNA repair, mitotic spindle, and chromosomal segregation [241]. To combat these effects, cells have antioxidant mechanisms that work to correct and avoid the formation of ROS (free radicals) in excess. These antioxidant mechanisms involve low molecular weight compounds such as vitamins C and E, melatonin, glutathione, superoxide dismutase, catalase, glutathione peroxidase and glutathione reductase that protect the cells by chelating mercury and reducing its oxidative stress potential [242].

Glutathione levels in human populations exposed to methylmercury intoxication by eating contaminated fish have been shown to be higher than normal [243]. These studies were also able to confirm a direct and positive correlation between mercury and glutathione levels in blood. They also confirmed an increased mitotic index and polyploidal aberrations associated with mercury exposure [243]. Epidemiological studies have demonstrated that enzymatic activity was altered in populations exposed to mercury; producing genotoxic alterations, and suggesting that both chronic and relatively low level mercury exposures may inhibit enzyme activity and induce oxidative stress in the cells [244]. There is no doubt that the connection between mercury exposure and carcinogenesis is very controversial. However, *in-vitro* studies suggest that the susceptibility to DNA damage exists as a result of cellular exposure to mercury. These studies also indicate that mercury-induced toxicity and carcinogenicity may be cell-, organ- and/or species- specific.

Prospects

A comprehensive analysis of published data indicates that heavy metals such as arsenic cadmium, chromium, lead, and mercury, occur naturally. However, anthropogenic activities contribute significantly to environmental contamination. These metals are systemic toxicants known to induce adverse health effects in humans, including cardiovascular diseases, developmental abnormalities, neurologic and neurobehavioral disorders, diabetes, hearing loss, hematologic and immunologic disorders, and various types of cancer. The main pathways of exposure include ingestion, inhalation, and dermal contact. The severity of adverse health effects is related to the type of heavy metal and its chemical form, and is also time- and dose-dependent. Among many other factors, speciation plays a key role in metal toxicokinetics and toxicodynamics, and is highly influenced by factors such as valence state, particle size, solubility, biotransformation, and chemical form. Several studies have shown that toxic metals exposure causes long term health problems in human populations. Although the acute and chronic effects are known for some metals, little is known about the health impact of mixtures of toxic elements. Recent reports have pointed out that these toxic elements may interfere metabolically with nutritionally essential metals such as iron, calcium, copper, and zinc [245, 246]. However, the literature is scarce regarding the combined toxicity of heavy metals. Simultaneous exposure to multiple heavy metals may produce a toxic effect that is either additive, antagonistic or synergistic.

A recent review of a number of individual studies that addressed metals interactions reported that co-exposure to metal/metalloid mixtures of arsenic, lead and cadmium produced more severe effects at both relatively high dose and low dose levels in a biomarker-specific manner [247]. These effects were found to be mediated by dose, duration of exposure and genetic factors. Also, human co-exposure to cadmium and inorganic arsenic resulted in a more pronounced renal damage than exposure to each of the elements alone [248]. In many areas of metal pollution, chronic low dose exposure to multiple elements is a major public health concern. Elucidating the mechanistic basis of heavy metal interactions is essential for health risk assessment and management of chemical mixtures. Hence, research is needed to further elucidate the molecular mechanisms and public health impact associated with human exposure to mixtures of toxic metals.

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Paul B Tchounwou,[*] Clement G Yedjou, Anita K Patlolla, and Dwayne J Sutton

NIH-RCMI Center for Environmental Health, College of Science, Engineering and Technology, Jackson State University, 1400 Lynch Street, Box 18750, Jackson, MS 39217, USA

[*]Correspondence to Paul B. Tchounwou. paul.b.tchounwou@jsums.edu, Tel: 601-979-0777 Fax: 601-979-0570

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