

Preliminary Hydrogeologic Investigation of the FutureGen 2 Site in Morgan County, Illinois

William S. Dey, Randall A. Locke, Ivan G. Krapac, Christopher G. Patterson, and Jacquelyn L. Hurry



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ILLINOIS STATE GEOLOGICAL SURVEY
Prairie Research Institute
University of Illinois at Urbana-Champaign

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Final Report

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Principal Investigator: Robert J. Finley

Illinois State Geological Survey

Prairie Research Institute

University of Illinois

(217) 244-8389

finley@illinois.edu

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The Board of Trustees of the University of Illinois

Sandy Moulton, Director

c/o Grants & Contracts Office

1901 S. First Street, Suite A

Champaign, IL 61820

Illinois State Geological Survey

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ILLINOIS STATE GEOLOGICAL SURVEY
Prairie Research Institute
University of Illinois at Urbana-Champaign
615 E. Peabody Drive
Champaign, Illinois 61820-6964
<http://www.isgs.illinois.edu>

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EXECUTIVE SUMMARY

In anticipation of the FutureGen 2 carbon sequestration activities in Morgan County (Section 25, Township 16 North, Range 9 West), field work was conducted to describe shallow geologic conditions and characterize shallow groundwater quality at the site. The Illinois State Geological Survey (ISGS) drilled one shallow stratigraphic boring to 230 feet. Bedrock was encountered at 123.5 feet below the land surface. No aquifer material was encountered in the Quaternary material or in the bedrock. A shallow groundwater monitoring well was installed at a depth of 20 feet and developed to ensure water levels and water quality within the well were representative of *in situ* conditions. A surficial 2-D seismic survey and an electrical earth resistivity (EER) survey were conducted at the site. The seismic survey was conducted before drilling primarily to assess the presence of shallow natural gas. None was detected. An EER survey was conducted following installation of the shallow monitoring well to assess whether aquifer materials were present at other locations in the vicinity of the shallow well. Results from the EER survey indicated a slight increase in resistivity to the southwest and southeast. The higher resistivity may indicate a slight increase in the occurrence of shallow sand in those directions. Water from 10 private water supply wells and the shallow groundwater monitoring well were sampled between October 25 and November 17, 2011. Most constituent concentrations were less than the drinking water standards. Iron (Fe), manganese (Mn), nitrate (NO₃), and total dissolved solids (TDS) were the only constituents whose concentrations exceeded USEPA primary or secondary standards in some of the groundwater samples. Groundwater samples from two wells contained nitrate concentrations above the EPA Maximum Contaminant Level (MCL), 10 mg NO₃-N/L. The concentrations of nitrate in the samples from these wells were also significantly greater than those detected in other samples.

This report summarizes results from the stratigraphic bore hole, the geophysical surveys, and analytical results from groundwater sampling.

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INTRODUCTION

In anticipation of the FutureGen 2 carbon sequestration activities in Morgan County, Illinois (Section 25, Township 16 North, Range 9 West), the Illinois State Geological Survey (ISGS) was contracted by Pacific Northwest National Laboratory (PNNL) to conduct preliminary field work to describe shallow geologic conditions and characterize shallow groundwater quality at the site (Figure 1). The ISGS (1) drilled one stratigraphic boring to 230 feet, (2) installed and monitored a shallow groundwater monitoring well, (3) performed a surficial seismic survey and a 1-D electrical earth resistivity (EER) survey, and (4) sampled 10 private water supply wells and the shallow groundwater monitoring well between October 25 and November 17, 2011. This report summarizes results from the stratigraphic bore hole and the geophysical surveys, and analytical results from groundwater sampling.

Geologic Setting

The FutureGen 2 site is located on the Springfield Till Plain in Morgan County, Illinois. The site consists of approximately 600 acres, near the center of which are 2.4 acres of a constructed and compacted gravel drilling pad.

The ground elevation is approximately 620 feet above mean sea level (MSL) in Section 25. Surface drainage is to the north-northeast toward the Illinois River via Indian Creek. The unconsolidated deposits range in thickness from 50 feet to over 123 feet and the surficial materials are mapped as glacial deposits of the Illinois Episode. These Illinois Episode deposits are predominantly fine-textured material of the Glasford Formation (Lineback, 1979). The uppermost bedrock is mapped as Pennsylvanian Shelburn Patoka Formation, which is regionally recognized as being composed of thinly bedded shale, siltstone, sandstone, limestone, and coal (Willman et al., 1975).

Bedrock as a Source of Drinking Water

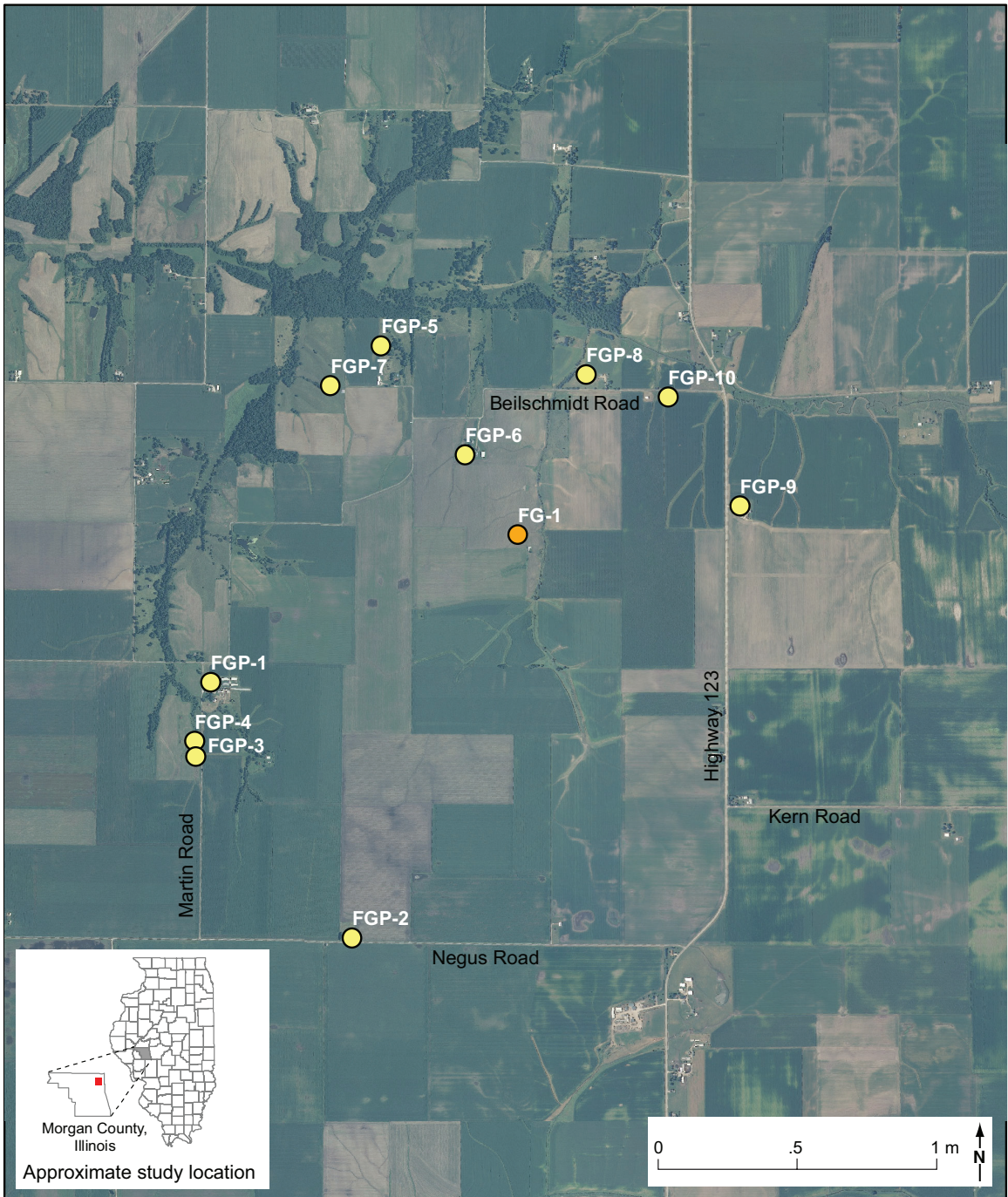
A search of the literature and water well records was conducted to identify public and domestic water supplies using bedrock aquifers for drinking water. We could find no evidence of bedrock aquifers currently in use as municipal water supplies within a 10 mile radius of the study site. As of 1978 there was no pumpage of water for public supplies from the bedrock aquifers in Morgan County (Woller et al., 1979). Upper bedrock units are reported as water supplies for domestic use in Morgan County and adjacent counties.

The Village of Ashland in Cass County is about 6 miles northeast of the FutureGen 2 site. The village has used shallow groundwater from sand and gravel aquifers for its primary water supply. Village well number one, drilled in 1935, is 21 feet deep and 3 feet in diameter. Two wells of similar depth and design were drilled in the same vicinity in 1937. The wells are in Morgan County Township 16N, Range 8W, Section 16 (Hanson, 1950). As of 1979 the wells were considered supplemental to a surface water reservoir and “available for emergency use” (Woller and Sanderson, 1979).

The city of Jacksonville in Morgan County historically supplemented its water supply with bedrock wells, but has discontinued that practice:

“From 1871 until about 1921, water for the city was obtained from Morgan Lake, which is presently used for recreation purposes. At times part of the public water supply has been obtained from wells. The city purchased a well from the Gas and Oil Syndicate, which had been drilled in 1885 to a depth of 1,600 feet. The well, located near the Wabash RR in Jacksonville, was deepened to a reported depth of 2,343 feet in about 1886. This well was abandoned in 1895 because of insufficient production and was sold to J. Capps and Son. Three wells were drilled between 1888 and 1895 on the pumping station grounds in the south part of the city to depths of 3,110, 3,100, and 3,118 feet, respectively. These wells were abandoned in 1914” (Woller and Sanderson, 1979).

The wells, completed at depths of near 3,000 feet, would have likely penetrated and been open to St. Peter Sandstone and penetrated into the Cambrian sandstone at a depth of around 2,000 feet. Tests of water quality from these wells showed a chloride content of 1,000 ppm, iron of 2.6 ppm, and total mineral content of 2,431 ppm. It was also reported the water contained “considerable hydrogen sulphide” (Habermeyer, 1925).



Data Source: Midwest Geological Sequestration Consortium, February 13, 2012

2010 NAIP Digital Ortho Photo Imagery

● Shallow monitoring well ● Private well

Figure 1 Map of FutureGen 2 area.

From the abandonment of these deeper wells until present, Jacksonville has obtained its water supply from a combination of shallow wells, less than 90 feet deep, finished in sand and gravel deposits, and different surface water sources. From the 1950s to present, the primary source of water has been from radial wells constructed under the Illinois River floodplain several miles west of Jacksonville (Woller and Sanderson, 1979).

Other municipal water supplies in the area include Pleasant Plains in Sangamon County. The town is about 10 miles east-northeast of the study site. The town was reported as having used a 32-foot-deep radial well as a water supply (Hanson, 1958). New Berlin in Sangamon County is about 11 miles southeast of the FutureGen 2 site. The town depends on surface water for their municipal water supply (<http://newberlin.il.us/WaterSewer.htm>). Virginia in Cass County uses a surface water supply supplemented by shallow groundwater wells (Bogner, 1983). Virginia is about 12 miles northwest of the FutureGen 2 site.

Bergstrom and Zeizel (1957) noted domestic wells being finished in Pennsylvanian formations and in the Mississippian Salem Limestone in Morgan County. No mention is made in the report of water quality from these units.

In “Geology for Planning for the Springfield-Decatur Region, Illinois” (Bergstrom et al., 1976) it was reported that groundwater in the lower Pennsylvanian and deeper bedrock units would be too highly mineralized to be suitable for drinking water. Selkregg and Kempton (1958) identified the upper Pennsylvanian sandstones as a potentially favorable source of water for domestic supplies in Sangamon County. They did not recommend drilling more than 150 feet into bedrock because of the increasing likelihood of highly mineralized water with depth.

In northern Macoupin County, shallow Pennsylvanian sandstones are considered the primary source of water for farm and domestic supplies (Selkregg et al., 1957). In portions of Cass County, Pennsylvanian or Keokuk-Burlington bedrock is used for domestic water supplies (Bergstrom and Zeizel, 1957). In Menard County to the northeast of the study site, the upper Pennsylvanian bedrock is used throughout the county as a water source for domestic use (Selkregg and Kempton, 1958).

Reporting on groundwater quality of Pennsylvanian aquifers, Gibbs and O’Hearn (1980) wrote,

“Very little data exists for these aquifers in western Illinois. Total dissolved solids content of the water from these aquifers can be extremely variable regionally and with depth. Two wells in the same area tapping limestone or sandstone units at different depths often produce water of significantly different quality.”

The literature indicates that the upper Pennsylvanian is a potentially potable source of drinking water in the vicinity of the study site. The difficulty is finding geologic material that has enough primary or secondary porosity to generate an economical yield from a well completed in this bedrock. We encountered no such material in the upper 100 feet of bedrock at the site.

SITE INVESTIGATIONS

The scope of the ISGS investigation included two main tasks. The first task was to drill a stratigraphic test hole at the Morgan County site, install up to two monitoring wells, and sample groundwater to evaluate the ambient water quality. The second task was to inventory and sample a subset of private/domestic water supply wells within 1.5 miles of Section 25.

Stratigraphic Drilling and Geophysical Investigations

A preliminary review of water well and oil and gas well records indicated the likely presence of shallow natural gas deposits in the vicinity of the FutureGen 2 Site. A 2-D seismic reflection survey (Pugin et al., 2006) was conducted at the site on August 12, 2011, to examine whether natural gas might be observed at the site. The survey covered a line 1,115 feet long crossing the FutureGen 2 drill pad and the proposed ISGS drilling location. Under certain geologic scenarios, the seismic survey can be useful in identifying gas deposits. Positive results of gas deposits are very reliable; however, due to the complexities of seismic data processing, negative results are inconclusive and cannot rule out the presence of gas. Results from the sur-

Table 1 Generalized geologic description of drilling core.

Depth (feet)	Material
0.0-2.8	Fill
2.8-4.2	Silty clay loam
4.2-9.5	Silty clay to clay loam
9.5-22.8	Silt to silt loam
22.8-46.5	Loam diamicton
46.5-92	Silt loam diamicton
92-123.5	Clayey silt to silty clay, some organic rich zones
123.5-164	Shale, with intrbedded siltstone and limestone
164-167	Shale, organic rich
167-190	Sandy shale, very dense
190-200	Shale, organic rich, thinly bedded limestone
200-203	Coal
203-210	Shale, paleosol
210-220	Limestone
220-230	Shale, silty

vey indicated that no significant deposits of shallow natural gas were identified at the site. Results from the survey are presented in Appendix A.

A shallow stratigraphic bore hole was drilled at the site on August 23 and 24, 2011 (Figure 1). Continuous core was collected during drilling. Bedrock was encountered at 123.5 feet. Coring continued into bedrock to a depth of 230 feet. No aquifer or aquifer material was identified from the core, either in the Quaternary material or in the bedrock. The lack of an aquifer at the drill site was also strongly indicated by the minimal loss of drilling fluid during drilling operations. Table 1 contains a summary of the field description of core collected during drilling. Summaries of a more detailed laboratory description of the drilling core are included in Appendix B.

Downhole geophysical logs were collected on August 25, 2011. Results from the geophysical logging also suggest an absence of aquifer material at the drill site. Results from the downhole geophysical logging are summarized in Appendix C. Following the downhole geophysical logging, the bore hole was back filled with bentonite grout to a depth of 20.1 feet. A monitoring well was constructed to a depth of 20 feet (FG-1), with a screened interval from 5 to 20 feet below land surface (Figures 2 and 3).

An electrical earth resistivity (EER) survey was conducted at the site on August 31, 2011, with the goal of identifying areas near the site that would have a greater potential for containing aquifer material. Results from the survey indicated the area southwest of the FutureGen 2 drill pad as having slightly higher resistivity, indicating a higher potential for coarser-textured deposits in that area, which may be aquifer materials. Results from the survey are summarized in Appendix D.

Private Water Well Inventory and Selection

ISGS well records contain logs of 13 private/domestic wells within 1.5 miles of the FutureGen 2 site (Table 2). Most of the wells are shallow (<50 feet in depth) and are large diameter or bored wells (Figure 3). This type of well is indicative of areas without an aquifer. Of the four wells greater than 50 feet in depth, one was listed as dry in the database (API Number: 1213700189). Another (API Number: 1213700285) was

API: 12-137-22131001
 Well name: FG-1
 Date installed: 08/29/2011

Total depth
 Well depth from top of Riser: 22.2'
 Screened interval: 5–15'

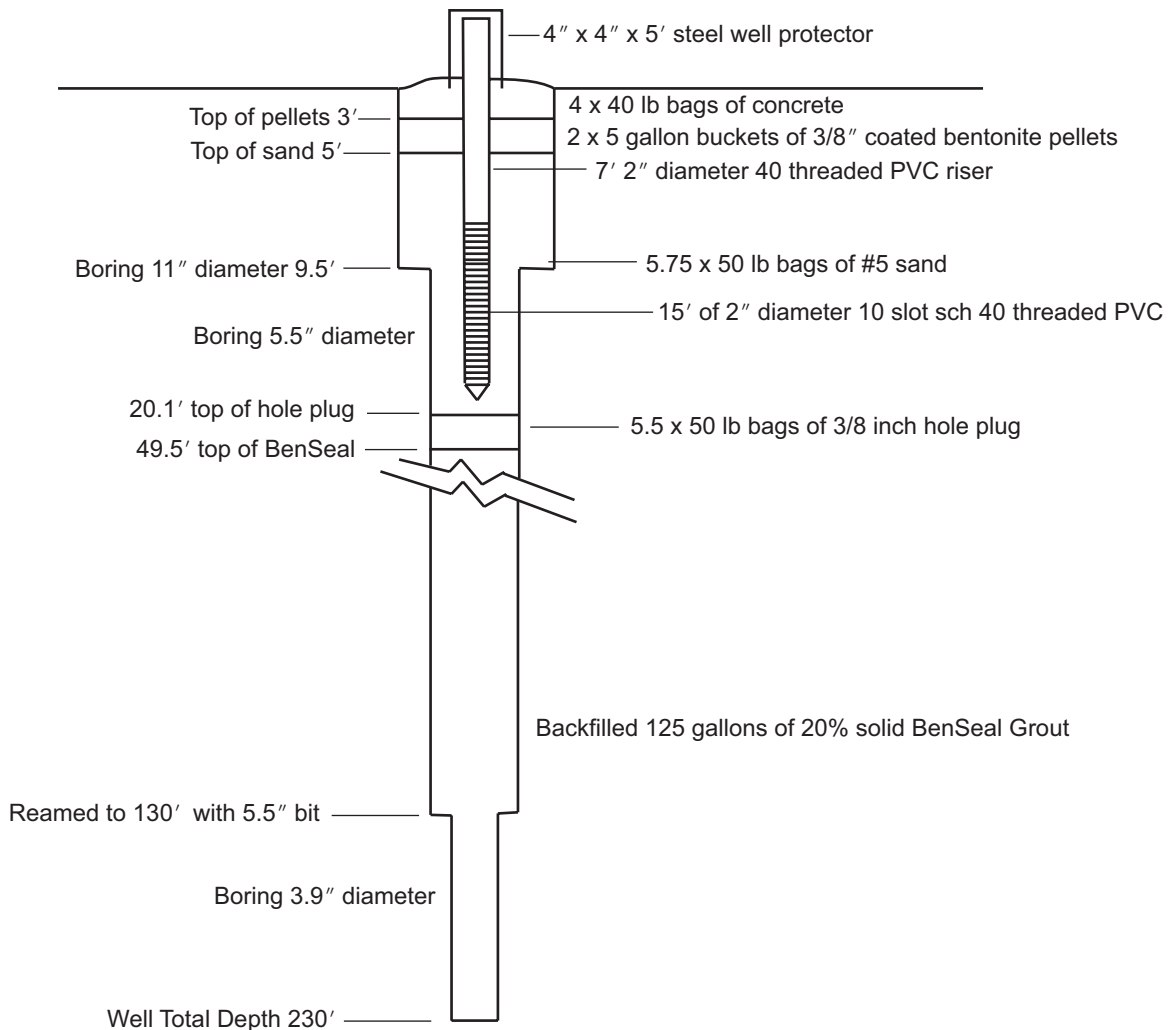


Figure 2 Well construction details for well FG-1.

reported as “never making water” and being abandoned by the land owner. The other two could not be located. A local well contractor confirmed that only shallow, large-diameter wells are being used in the area. This suggests that sand deposits in the area are either absent or too thin and discontinuous to be considered an aquifer.

In addition to wells identified in the ISGS database, the FutureGen 2 Alliance provided a list of potential well owners in the vicinity of the study site. Those contacted all agreed to have their wells sampled. Three well owners had multiple wells we could sample. The 10 wells sampled are shown in Figure 1 and listed in Table 3. Of the wells selected for sampling, three wells were in use as a domestic water supply, two were used as a livestock water supply, and five were not in active use. Eight of the wells were large-diameter (3 to 5 feet) dug or bored wells, and one well was a steel-cased, drilled well. All nine wells where depths were

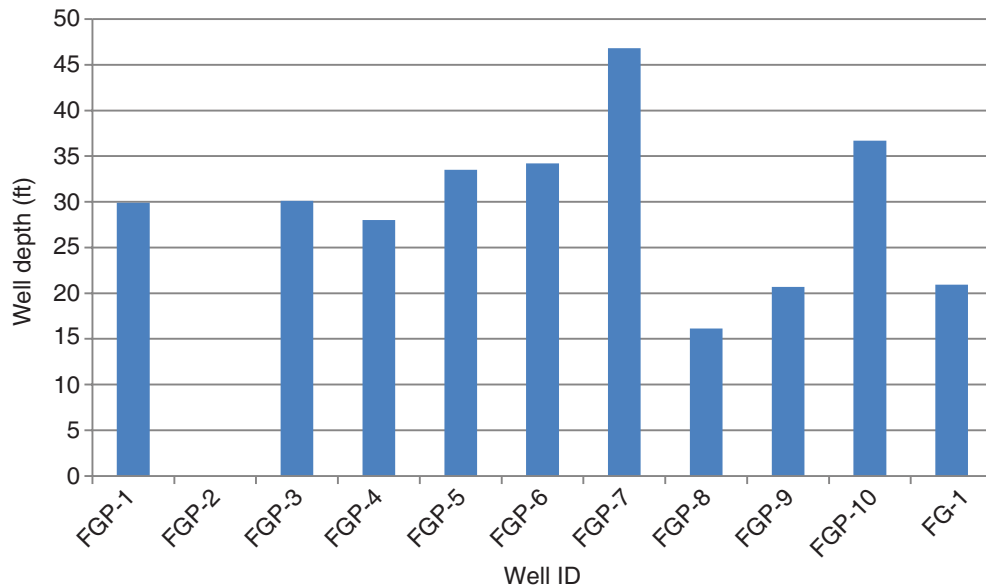


Figure 3 Well depths for water wells sampled at the FutureGen 2 site.

Table 2 Private water supply wells near FutureGen 2 site in ISGS ILWATER database.

API	Sec	Twp	Rng	Depth Drilled (feet)	Top of Screen (feet)	Well Depth (feet)	Well Yield (gpm)	Owner Matches Platbook
121370028400	23	16N	9W	405				N
121372155100	23	16N	9W	42	20	24	0	Y
121372155200	23	16N	9W	41	18	22	0	Y
121372182100	23	16N	9W	46	25	37	0	Y
121372207600	23	16N	9W	46	0	0	0	Y
121370018900	24	16N	9W	200	0	0	0	N
121372128400	24	16N	9W	40	30	31	0	Y
121372128500	24	16N	9W	37	30	32	0	?
121370018700	25	16N	9W	115	0	115	0	Y
121370028500	26	16N	9W	127	116	127	5	Y
121372128600	26	16N	9W	25	21	25	0	Y
121372173400	26	16N	9W	37	26		0	Y
121372211600	27	16N	9W	35				Y

measured, were less than 50 feet deep. Because of limited access, the depth of one well was not measured. Wells selected for sampling were within 1.5 miles of the FutureGen 2 site. None of the sampled wells had records in the ISGS ILWATER database.

An attempt was made to collect information about the age of the sampled wells. This effort met with limited success. None of the well owners knew the date his or her well was constructed. A few well owners speculated that their wells were over 100 years old. Another well owner had been told when he bought the property that the well had been installed in the 1950s, but he was not sure.

A one-time sampling was performed on the 10 selected wells between October 25 and November 17, 2011.

Table 3 Private water supply wells sampled by the ISGS.

Well ID	Status	Well Depth (ft)	Stick Up (ft)	Depth (adjusted) (ft)	Land Surface Elevation (ft) AMSL	Depth to Water (ft)	Water Depth in well (ft)	Water Elevation (ft) AMSL	Diameter (ft)	Construction	Age (years)
FGP-1	domestic	30.9	1.00	29.90	630	19.02	18.02	612	5.0	brick lined	~100
FGP-2	domestic	--	--	--	641	--	--	--	Unknown	unknown	unknown
FGP-3	domestic	40.0	0.90	30.10	630	21.37	11.47	618	5.0	unknown	~100
FGP-4	inactive	28.5	0.50	28.00	627	9.40	8.90	618	3.0	brick lined	unknown
FGP-5	livestock	35.1	1.60	33.50	607	10.12	8.52	598	3.0	unknown	~60
FGP-6	inactive	34.5	0.30	34.20	620	13.04	12.74	607	3.0	cast concrete	unknown
FGP-7	inactive	49.0	2.20	46.80	614	13.39	11.19	603	0.7	steel	unknown
FGP-8	livestock	17.45	1.30	16.15	614	6.34	5.04	609	4.0	brick lined	unknown
FGP-9	inactive	22.3	1.60	20.70	630	16.34	14.74	615	5.0	brick lined	~100
FGP-10	inactive	37.1	0.40	36.70	614	15.80	15.40	599	4.0	cast concrete	unknown
FG-1	NA	23.0	2.05	20.95	635	10.16	8.11	627	0.17	PVC	new

Field Methods

Pre-site Preparation

To maximize time efficiency in the field, ensure sample integrity, and minimize field equipment problems, field equipment was prepared in the laboratory. Field meters were calibrated in the lab and tested. Sample bottles were either purchased pre-cleaned or pre-cleaned in the laboratory as per requirements of the analytes. The bottles listed in Table 4 were prepared the day before sampling. Acids used for sample preservation were either ultrapure or reagent grade quality depending on the analyte(s) of interest. All bottles were pre-labeled and assembled into sampling kits in the lab to minimize labeling errors and ensure correct collection volumes and presentation techniques were used.

Prior to arrival, all well owners were contacted to obtain approval for sampling their wells, discuss potential sample collection locations, and to address any concerns. Additionally, efforts were made to collect samples at locations in the water distribution systems that preceded water treatment (i.e., softening, iron removal, chlorination).

Well Inventory

An on-site inventory of each well included; photographic documentation, description of the well drilling technique (i.e., bored, drilled, dug), measurement of total well depth, and measurement of depth-to-water at the time of the inventory. Table 5 shows an example of the field data that were collected. Well depth and depth-to-water were determined using either a pre-cleaned steel tape or an electronic water level meter. These data are shown in Table 3.

Field Parameters

To minimize sample contact with the atmosphere, a flow-through cell was used to measure field parameters that included electrical conductivity, pH, alkalinity, oxidation/reduction potential, dissolved oxygen, and temperature. These parameters were determined using electrodes according to standard methods (American Public Health Association, 1992). Oxidation/reduction potentials are reported relative to a standard Zobell solution (Wood, 1976).

Sample Collection

Groundwater was sampled from the shallow groundwater monitoring well (Figure 4) that was drilled by the ISGS as well from 10 private water supply wells (Table 3). Sampling of groundwater from the private wells

Table 4 Groundwater chemistry sampling requirements (parameters, sample volume and container, preservation method, holding time, and laboratory).

Parameter	Volume/Container	Preservation	Holding Time	Laboratory
Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si	3-ml plastic bottle	Filtered, HNO ₃ to pH<2	60 dys.	ISWS
Total Dissolved Solids, Alkalinity, Anions: Cl, Br F, SO ² , NO ₃ , CO ₃ ²	500-ml plastic bottle	Filtered, cool 4 °C	45 dys.	ISWS
Alkalinity- Field	60-ml plastic bottle	Filtered, cool 4 °C	24 hrs.	ISGS
Dissolved Inorganic Carbon (DIC)	60-ml plastic bottle	Filtered	24 hrs.	ISGS
Total Organic Carbon (TOC)	250-ml amber glass bottle	Unfiltered, 0.5% phosphoric acid	24 hrs.	ISWS
Dissolved Organic Carbon (DOC)	250-ml amber glass bottle	Filtered, 0.5% phosphoric acid	24 hrs.	ISWS
C ¹³ of DIC	60-ml/HDPE	Filtered	4 wks.	ISGS
C ¹⁴ of DIC	500-ml/HDPE	Filtered	4 wks.	ISGS
Tritium	500-ml/HDPE	Filtered	8 wks.	ISGS
Volatile Organic Analysis (VOA)	40-ml amber glass vials	Unfiltered, cool 4 °C	7 dys.	PNNL
Trace Metals: Sb, As, Ba, Cd, Cr, Cu, Pb, Hg, Se, Ti	30-ml plastic bottle	Filtered, HNO ₃ to PH<2	60 dys.	PNNL
Bulk water sample for compatibility studies	4-liter plastic collapsible container	Unfiltered, unpreserved		PNNL

When filtered, a 0.45-µm filter was used. Illinois State Water Survey (ISWS), Illinois State Geological Survey (ISGS), Pacific Northwest National Lab (PNNL).

Table 5 An example of field data collected for a private well sampling effort.

ISGS FutureGen 2 Project Private Well Samples

Site: Morgan County			Date:				Weather:		
Well ID:			Sampler/s:						
Sample No.	Time	Vol. Purged (L)	Alkalinity (mLs titrated)	pH	Temp (°C)	Cond. (µs/cm)	Eh (mV)	DO (mG/L)	



Figure 4 Shallow monitoring well FG-1 at the FutureGen 2 site.

involved either collecting water directly from an outside faucet at the residence, from an outside hydrant, or via a nylon tubing and peristaltic pump provided by the ISGS specifically for sampling. A vinyl garden hose with a y-splitter attachment was connected to faucets or hydrants for sample collection for wells with active pumps. For wells that were no longer in use and in which the pump had been removed or disconnected, a peristaltic pump was used to collect samples (Figure 5). For wells without an active pump, the sampling tube was positioned to the middle of the water column, and for the monitoring well the sampling tube was positioned about 2 feet above the screen to avoid turbidity.

Before sampling, wells were purged to eliminate stagnant water and ensure samples were representative of water that had been used at the residence. The purging technique involved monitoring of the field parameters. Generally the parameters were measured every 3 to 5 minutes and were recorded along with the purged volume. Sampling was initiated once parameters reached stability criteria (Table 6) as described by Puls and Barcelona (1996). Unfiltered samples (Table 4) were collected first and preserved. Each sample was filtered using a new 0.45- μm inline filter cartridge, which was flushed with a minimum of 1 liter (based



Figure 5 Private water supply well without active pump.

Table 6 Sampling stabilization criteria. To be considered stable, parameter readings were required to be stable for three readings taken 3 minutes apart.

Parameter	Stabilization Criteria
pH	± 0.1
Specific electrical conductance (EC)	± 3
Oxidation/reduction potential (ORP)	± 5 millivolts
Dissolved oxygen (DO)	± 0.3 milligrams per liter



Figure 6 Determination of alkalinity in groundwater samples using titration technique.

on manufacturer's directions) of sample prior to collection to ensure sample integrity. Titration for alkalinity was performed in the field (Figure 6). All groundwater samples were collected in accordance with the techniques described by Wood (1981) and Panno et al. (1996). Water level was measured before and after all samples were collected. Samples were then transported to multiple analytical laboratories in an ice-filled cooler. In addition to the other samples, a single unfiltered, 4-liter bulk sample was collected from one well.

Sample Handling and Analysis

All samples were kept on ice in the field and refrigerated at 4°C in the laboratory until analyzed. Anion concentrations were determined by ion chromatography (O'Dell et al., 1984) and cation concentrations by inductively coupled argon plasma (ICP) spectrophotometry (American Public Health Association, 1992). Detection limits for the anions chloride (Cl), bromide (Br), nitrate (NO₃), and sulfate (SO₄) were 0.09, 0.3, 0.7, and 0.31 mg/L, respectively. Detection limits for the cation ICP analyses were in the range of 0.00055 mg/L for constituents such as Be, Al, Si, and Na to 0.066 mg/L for most of the metals. Dissolved inorganic carbon (DIC) δ¹³C, δ¹⁸O, δD samples were processed in an off-line system where CO₂ was isolated from the groundwater by freezing and thawing and then sealed in a break tube for analysis. DIC samples were analyzed following methods by Hackley et al. (2009). Dissolved organic carbon (DOC) concentration was determined with a Dohrmann analyzer at the Illinois State Water Survey (ISWS) using the method ASTM D-4839-88 (1994). Alkalinity was measured by a titration method (Greenberg et al., 1992) and can be seen in Figure 6.

Quality Assurance

Duplicate samples were collected during each sampling trip, with 50% of the wells having duplicate samples. Blank samples were collected using deionized water under the same conditions as the well samples using a peristaltic pump. One blank sample was collected during each sample trip. Before collecting the blank, 15 liters of deionized water was purged through the sampling equipment to flush any possible contaminants present from previous sampling efforts. The same sampling procedures were followed to collect blank and duplicate samples. To avoid measurement bias by lab personnel, sample identification (i.e., a blank field sample) was not known during analysis.

Analytical Results

Chemical Analysis

Groundwater samples collected from private wells near the study site were sent to the ISWS for chemical analysis of anion and cation concentrations, as well as total dissolved solids (TDS), pH, alkalinity, total organic carbon, and dissolved organic carbon. Dissolved inorganic carbon and isotopic analyses of δ¹³C and ³H were performed at the ISGS. δ¹⁴C analysis was performed at the Accelerator Mass Spectrometry Laboratory at the University of California, Irvine. Samples were sent to Isotech Laboratories Incorporated in Champaign, Illinois, for isotopic analyses of δD and δ¹⁸O. Volatile organic analysis and trace metal concentrations were performed at PNNL in Richland, Washington (Appendix G).

Data Quality Assessment

The water quality data were evaluated to determine correctness of analyses based on anion-cation charge balances and a comparison of measured and TDS values [American Public Health Association (APHA), 2004]. A description of the method used for data quality assurance follows.

Because all potable waters are electrically neutral, the chemical analyses should yield equally negative and positive ionic activity. The anion-cation charge balance was calculated by the following method:

$$\% \text{ difference} = \frac{\sum \text{ cations} - \sum \text{ anions}}{\sum \text{ cations} + \sum \text{ anions}} \quad (\text{eq. 1})$$

where the sums of the ions are represented in milliequivalents (meq) per liter and the criteria for acceptance is as follows (APHA, 2004): ±0.2 meq/L is an acceptable difference if the anion sum is 0 to 3.0 meq/L, ±2 meq/L is an acceptable difference if the anion sum is 3.0 to 10.0 meq/L, and 5% is an acceptable difference if the anion sum is 10.0 to 800 meq/L.

The ratio of the measured TDS to the calculated TDS is considered to be acceptable within the following range (APHA, 2004):

$$1 < \frac{\text{measured TDS}}{\text{calculated TDS}} < 1.2 \quad (\text{eq. 2})$$

Table 7 Summary of data quality assessment for groundwater samples collected near the FutureGen 2 site.

MVA_ID	Well ID	Anion Sum	ChargeBalance	TDSRatio
FG_Morgan_1A_20111025	FGP-1	6.87	-0.43	1.0
FG_Morgan_1B_20111025	FGP-1	6.85	-0.11	1.0
FG_Morgan_2A_20111025	FGP-2	8.81	0.42	1.0
FG_Morgan_2B_20111025	FGP-2	8.75	0.25	1.0
FG_Morgan_3_20111025	FGP-3	7.97	0.97	1.0
FG_Morgan_4_20111025	BLANK	0.00	NA	
FG_Morgan_5_20111025	FGP-4	10.15	0.04	1.0
FG_Morgan_6A_20111102	FGP-5	10.22	1.77	1.0
FG_Morgan_6B_20111102	FGP-5	10.26	3.63	1.0
FG_Morgan_7A_20111102	FGP-6	10.63	2.28	1.0
FG_Morgan_7B_20111102	FGP-6	10.61	2.67	1.0
FG_Morgan_8A_20111102	FGP-7	11.67	-3.63	0.9
FG_Morgan_8B_20111102	FGP-7	11.99	-2.53	0.9
FG_Morgan_9_20111102	FGP-8	13.05	2.86	1.0
FG_Morgan_10_20111102	BLANK	0.00	NA	
FG_Morgan_11_20111102	FGP-9	6.85	2.51	1.0
FG_Morgan_12A_20111110	FGP-10	7.67	-0.32	1.0
FG_Morgan_12B_20111110	FGP-10	7.64	-0.52	1.0
FG_Morgan_13_20111110	BLANK	0.00	NA	
FG_Morgan_14_20111110	FG-1	8.45	-1.32	1.0

All sample analyses met the APHA charge balance criteria except for the groundwater sample collected from well FGP-9, which slightly exceeded the APHA charge difference criteria by +0.51%, suggesting that either cation concentration is overestimated, anion concentration is underestimated, or both (Table 7). The typical analytical accuracy and precision for the inorganic analytes reported by the ISWS laboratory for internal laboratory duplicate samples (Table 8; personal communication with Dan Webb, ISWS Public Service Laboratory Manager) were considered when evaluating the goals of the quality control (QC) assessment. Based on past experience evaluating groundwater quality data and typical accuracy and precision of the ISWS laboratory, the authors use a data quality criterion of $\pm 10\%$ for charge balance calculations. This is less stringent than the APHA criteria, but is suggested as more consistent with reported analytical variability. The authors have observed in past groundwater quality projects that data interpretation has not been significantly affected when using the $\pm 10\%$ acceptance criterion.

All samples met the APHA TDS balance criteria except for samples collected from well FGP-7. These duplicate samples both have TDS ratios that are less than 1.0, suggesting the calculated TDS, based on the sum of masses for all analytes detected in the sample, were greater than the measured TDS (Table 7). Similar to the charge balance criteria, the authors have observed that a 10% or less difference between measured and calculated TDS did not significantly affect data interpretation. The combination of both the charge and mass balance approaches indicates that water quality data for all samples met one or both of these APHA criteria.

Field Blanks

Three field blanks were collected during the groundwater sampling activities, one blank during each sampling round. Field blanks are samples of deionized water (which is brought from the laboratory to the field) that are exposed to the same field and transport conditions as the groundwater samples and sent to the laboratory for complete analyses. Field blanks were used to detect any contamination resulting from the

Table 8 Summary of laboratory analytical methods and data quality for groundwater sample analysis.

Parameter	Analysis method	Detection Limit or (Range)	Typical Precision/Accuracy	Quality Control requirements
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	ICP-AES (US EPA Method 200.7)	Listed in results table	Precision: Duplicate RPDs: average = 2%, range = 0-17%, standard deviation = 2% Accuracy: LFB recovery: average = 101%, range = 85-113%, standard deviation = 4%	Daily calibration, CCB, ICV, CCV.
Anions: Cl ⁻ , Br ⁻ , F ⁻ , SO ₄ ²⁻ , NO ₃ ⁻ , CO ₃ ²⁻	Ion Chromatography (US EPA Method 300.0)	Listed in results table	Precision: Duplicate RPDs: average = 1%, range = 0-9%, standard deviation = 1% Accuracy: LFB recovery: average = 101%, range = 92-110%, standard deviation = 2%	Daily calibration, CCB, CCV, ICV, LRB, LFB, DUP, LFM
Total Dissolved Solids (TDS)	Gravimetric Method Standard Method 2540 C	12 mg/L	0-8% / 98-108%	Balance calibration, LRB, LFB, DUP, LFM
Alkalinity	Titration, standard methods 2320B	4 mg/L	0-8% / 99-107%	Calibration, LRB, LFB, DUP, CCV
Dissolved Inorganic Carbon (DIC)	Carbon analyzer, phosphoric acid digestion of DIC	0.002%	±10%	Triplicate samples, daily calibration
Total Organic Carbon (TOC)	Combustion Method Standard Method 5310B	0.31 mg/L	0-12% / 85-114%	Calibration, ICV, CCB, CCV, LRB, LFB, DUP, LFM
pH	pH electrode	2 to 12 pH units	±0.2 pH unit for indication only	User calibrate, follow manufacturer recommendations
Specific conductance	Electrode	0 to 100 mS/cm	±1% of reading for indication only	User calibrate, follow manufacturer recommendations
Temperature	Thermocouple	5 to 50°C	±0.2°C for indication only	Factory calibration
Oxygen & Hydrogen isotopes	Cavity Ring-Down Spectroscopy	NA	d ¹⁸ O ±0.15 ‰; dD ±0.6 ‰	10% duplicates; 2 standards/batch
Tritium	Liquid scintillation	0.5 - 0.8 TU	± 0.25 TU	10% duplicates & background w/ every batch
C-14	Acceleration mass spectrometry	0.4 pMC	± 0.2 pMC	2 background & 2 intermittent standards, & 6 modern standards/ batch
C-14	Liquid scintillation	0.5 pMC	± 0.3 pMC	Background & modern standard
Carbon Isotopes of DIC	Isotope ratio mass spectrometry	NA	± 0.15 ‰	10% duplicates & 2 standards per batch
Sulfur & Oxygen Isotopes of Sulfate	Isotope ratio mass spectrometry	NA	± 0.3 ‰	10% duplicates & 2 standards per batch

ICP = Inductively coupled plasma
 MS = Mass spectrometry
 OES = Optical emission spectrometry
 (pMC = percent Modern Carbon, ‰ = per mil)

CCB = Continuing calibration blank
 CCV = Continuing calibration verification
 ICV = Initial calibration verification
 LRB = Laboratory reagent blank

LFB = Laboratory-fortified blank
 DUP = Laboratory duplicate
 LFM = Laboratory-fortified sample matrix

collection and transportation process. Trace amounts of zinc (0.0118 mg/L) and sodium (0.031 mg/L) were detected in the field blank collected on 11-10-2011 (Table 9A). Trace amounts of calcium (0.128–0.251 mg/L) were detected in all three field blanks (Table 9). All other analytes were below the method detection limits. These small concentrations confirm that contamination of the samples during the collection and transportation process was negligible.

Duplicate Samples

Six duplicate groundwater samples were collected as part of the field sampling efforts. Duplicate samples were collected from the same source immediately after the original sample in different sample containers and processed per stated protocols (Table 4). Duplicate samples were used to assess sample heterogeneity and analytical precision. For each duplicate analysis, the relative percent difference (RPD) was calculated by the following method:

$$\left| \frac{\text{concentration of original} - \text{concentration of duplicate}}{\text{average concentration of original and duplicate}} * 100 \right| \quad (\text{eq. 3})$$

Absolute values of RPDs ranged from 0 to 76% and were compared to the values of measured concentration divided by the respective MDL for each analyte (Figure 7). RPD values generally had an inverse relationship to the measured concentration (i.e., RPDs generally decreased with increasing concentration; Figure 7). In general, RPDs were less than 30%. The average RPD for all analytes measured is 6.6%, with one duplicate zinc analysis having the largest RPD of 76% (Figure 8). For the other five zinc duplicates, RPDs were less than 35%. Typical laboratory precision and accuracy of major cation analyses is 0–17% and 85–113%, respectively (Table 8). Typical laboratory precision and accuracy of anion analyses is 0–9% and 92–110%, respectively (Table 8). The largest values of RPD are related to sample heterogeneity between duplicate samples and greater analytical error near method detection limits. Variability of analytical results does not significantly affect interpretations of the data.

Water Quality Data and Interpretations

Ten private water supply wells (FGP-1 through FGP-10) and one shallow groundwater monitoring well (FG-1) were sampled near the study site. The wells were typically less than 35 feet deep, with the deepest well (FGP-7) being about 47 feet deep, and the shallowest well (FGP-8) being about 16 feet deep (Figure 3). Because well access was limited, the depth of well FGP-2 was not measured.

A total of 17 groundwater samples were collected between October 25, 2011, and November 10, 2011, including duplicate samples and blanks (Table 10). Three blanks were also collected (Table 9). In addition, a 4-liter bulk groundwater sample was collected from FGP-5 on November 16, 2011. Prior to sample collection; groundwater was purged from each well consistent with low-flow sampling procedures (Nielsen and Nielsen, 2006) to allow stabilization of field parameters such as pH, temperature, specific conductance, oxidation reduction potential (Eh), and dissolved oxygen (DO) to ensure a representative sample was collected (Table 10). Field parameters were recorded while the bulk sample was collected. The sample was shipped to PNNL. No analytical results are reported for the bulk sample. Values of pH ranged from 7.08 to 7.66, with an average of 7.37. Values for specific conductance ranged from 545 to 1164 $\mu\text{S}/\text{cm}$, with an average of 773 $\mu\text{S}/\text{cm}$. Values of Eh ranged from 105 to 532 mV, with an average of 411 mV. Values of DO ranged from below detection limit to 3.3 mg/L O_2 , with an average of 1.7 mg/L O_2 .

United States EPA drinking water standard maximum contaminant levels (MCLs) and secondary drinking water standards are also listed in Table 9 for common inorganic constituents in groundwater. Inductively coupled plasma-mass spectrometry (ICP-MS) results from PNNL (Appendix F) indicate that concentrations of arsenic (As), cadmium (Cd), lead (Pb), selenium (Se), and thallium (Tl) were less than the MCL for all samples. Chemical constituent concentrations below the method detection limit (MDL) are listed as less-value of the MDL or simply <DL (table 10; Tables 9a and 9e).

Most constituent concentrations were less than the drinking water standards. Iron (Fe), manganese (Mn), nitrate (NO_3), and total dissolved solids (TDS) were the only constituents whose concentrations exceeded USEPA primary or secondary standards in some of the groundwater samples (Tables 9b, 9d, 9e). Ground-

Table 9A Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Al (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Ca (mg/L)	Cd (mg/L)
MDL		0.037	0.11	0.023	0.00085	0.00055	0.029	0.012
MCL (Primary & Secondary Drinking water standards)		0.05-0.2	0.01		2	0.004		0.005
FG_MORGAN_1A_20111025	FGP-1	<0.037	<0.11	<0.023	0.0809	<0.00055	69.2	<0.012
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.037	<0.11	<0.023	0.0804	<0.00055	68.7	<0.012
FG_MORGAN_2A_20111025	FGP-2	<0.037	<0.11	0.036	0.148	<0.00055	101	<0.012
FG_MORGAN_2B_20111025	FGP-2 Dup.	<0.037	<0.11	0.035	0.148	<0.00055	99.3	<0.012
FG_MORGAN_3_20111025	FGP-3	<0.037	<0.11	0.034	<0.00085	<0.00055	0.119	<0.012
FG_MORGAN_4_20111025	BLANK	<0.037	<0.11	<0.023	<0.00085	<0.00055	0.232	<0.012
FG_MORGAN_5_20111025	FGP-4	<0.037	<0.11	<0.023	0.126	<0.00055	97.4	<0.012
FG_MORGAN_6A_20111102	FGP-5	<0.037	<0.11	<0.023	0.0903	<0.00055	127	<0.012
FG_MORGAN_6B_20111102	FGP-5 Dup.	<0.037	<0.11	<0.023	0.0922	<0.00055	133	<0.012
FG_MORGAN_7A_20111102	FGP-6	<0.037	<0.11	<0.023	0.253	<0.00055	121	<0.012
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.037	<0.11	<0.023	0.256	<0.00055	123	<0.012
FG_MORGAN_8A_20111102	FGP-7	<0.037	<0.11	<0.023	0.124	<0.00055	73.0	<0.012
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.037	<0.11	<0.023	0.134	<0.00055	79.4	<0.012
FG_MORGAN_9_20111102	FGP-8	<0.037	<0.11	<0.023	0.110	<0.00055	133	<0.012
FG_MORGAN_10_20111102	BLANK	<0.037	<0.11	<0.023	<0.00085	<0.00055	0.251	<0.012
FG_MORGAN_11_20111102	FGP-9	<0.037	<0.11	0.031	0.0726	<0.00055	73.0	<0.012
FG_MORGAN_12A_20111110	FGP-10	<0.037	<0.11	<0.023	0.0673	<0.00055	89.6	<0.012
FG_MORGAN_12B_20111110	FGP-10 Dup.	<0.037	<0.11	<0.023	0.0673	<0.00055	87.8	<0.012
FG_MORGAN_13_20111110	BLANK	<0.037	<0.11	<0.023	<0.00085	<0.00055	0.128	<0.012
FG_MORGAN_14_20111110	FG-1	<0.037	<0.11	<0.023	0.0743	<0.00055	61.5	<0.012
MINIMUM		<0.037	<0.11	<0.023	<0.00085	<0.00055	0.119	<0.012
MAXIMUM		<0.037	<0.11	0.036	0.256	<0.00055	133	<0.012
AVERAGE		<0.037	<0.11	0.034	0.120	<0.00055	76.9	<0.012

Table 9B Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Co (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg)	K (mg/L)	Li (mg/L)	Mg (mg/L)	Mn (mg/L)
MDL		0.013	0.0058	0.00079	0.024	0.016	0.11	0.027	0.0015
MCL (Primary & Secondary Drinking water standards)			0.1	1.3 (1.0)	0.3				0.05
FG_MORGAN_1A_20111025	FGP-1	<0.013	<0.0058	0.00122	<0.024	0.912	<0.11	36.8	<0.0015
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.013	<0.0058	0.00117	<0.024	0.906	<0.11	37.5	<0.0015
FG_MORGAN_2A_20111025	FGP-2	<0.013	<0.0058	0.00867	<0.024	0.616	<0.11	37.3	0.0272
FG_MORGAN_2B_20111025	FGP-2 Dup.	<0.013	<0.0058	0.00929	<0.024	0.612	<0.11	37.0	0.0269
FG_MORGAN_3_20111025	FGP-3	<0.013	<0.0058	0.0128	<0.024	0.055	<0.11	<0.027	<0.0015
FG_MORGAN_4_20111025	BLANK	<0.013	<0.0058	<0.00079	<0.024	<0.016	<0.11	<0.027	<0.0015
FG_MORGAN_5_20111025	FGP-4	<0.013	<0.0058	<0.00079	<0.024	7.53	<0.11	52.0	<0.0015
FG_MORGAN_6A_20111102	FGP-5	<0.013	<0.0058	0.00327	<0.024	1.43	<0.11	44.8	0.454
FG_MORGAN_6B_20111102	FGP-5 Dup.	<0.013	<0.0058	0.00291	0.083	1.46	<0.11	46.7	0.597
FG_MORGAN_7A_20111102	FGP-6	<0.013	<0.0058	<0.00079	1.60	0.969	<0.11	50.2	0.566
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.013	<0.0058	<0.00079	1.24	0.953	<0.11	50.0	0.408
FG_MORGAN_8A_20111102	FGP-7	<0.013	<0.0058	<0.00079	0.034	7.26	<0.11	63.3	0.0694
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.013	<0.0058	<0.00079	<0.024	7.04	<0.11	66.6	0.0780
FG_MORGAN_9_20111102	FGP-8	<0.013	<0.0058	0.00866	<0.024	0.439	<0.11	73.6	0.0060
FG_MORGAN_10_20111102	BLANK	<0.013	<0.0058	<0.00079	<0.024	<0.016	<0.11	<0.027	<0.0015
FG_MORGAN_11_20111102	FGP-9	<0.013	<0.0058	<0.00079	<0.024	2.05	<0.11	34.2	0.0461
FG_MORGAN_12A_20111110	FGP-10	<0.013	<0.0058	0.00115	<0.024	0.675	<0.11	34.2	<0.0015
FG_MORGAN_12B_20111110	FGP-10 Dup.	<0.013	<0.0058	0.00123	<0.024	0.669	<0.11	34.5	<0.0015
FG_MORGAN_13_20111110	BLANK	<0.013	<0.0058	<0.00079	<0.024	<0.016	<0.11	<0.027	<0.0015
FG_MORGAN_14_20111110	FG-1	<0.013	<0.0058	0.00400	<0.024	1.08	<0.11	27.3	0.464
MINIMUM		<0.013	<0.0058	<0.00079	<0.024	<0.016	<0.11	<0.027	<0.0015
MAXIMUM		<0.013	<0.0058	0.0128	1.60	7.53	<0.11	73.6	0.597
AVERAGE		<0.013	<0.0058	0.00494	0.74	2.04	<0.11	45.4	0.249

Table 9C Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Mo (mg/L)	Na (mg/L)	Ni (mg/L)	P (mg/L)	Pb (mg/L)	S (mg/L)	Sb (mg/L)	Se (mg/L)
MDL		0.022	0.026	0.043	0.073	0.041	0.22	0.059	0.13
MCL (Primary & Secondary Drinking water standards)									
FG_MORGAN_1A_20111025	FGP-1	<0.022	6.73	<0.043	<0.073	<0.041	9.64	<0.059	<0.13
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.022	6.69	<0.043	<0.073	<0.041	9.62	<0.059	<0.13
FG_MORGAN_2A_20111025	FGP-2	<0.022	17.2	<0.043	<0.073	<0.041	9.25	<0.059	<0.13
FG_MORGAN_2B_20111025	FGP-2 Dup.	<0.022	17.4	<0.043	0.118	<0.041	9.15	<0.059	<0.13
FG_MORGAN_3_20111025	FGP-3	<0.022	186	<0.043	<0.073	<0.041	8.80	<0.059	<0.13
FG_MORGAN_4_20111025	BLANK	<0.022	<0.026	<0.043	<0.073	<0.041	<0.22	<0.059	<0.13
FG_MORGAN_5_20111025	FGP-4	<0.022	19.0	<0.043	<0.073	<0.041	22.8	<0.059	<0.13
FG_MORGAN_6A_20111102	FGP-5	<0.022	11.1	<0.043	0.095	<0.041	20.2	<0.059	<0.13
FG_MORGAN_6B_20111102	FGP-5 Dup.	<0.022	11.0	<0.043	0.081	<0.041	20.0	<0.059	<0.13
FG_MORGAN_7A_20111102	FGP-6	<0.022	19.3	<0.043	0.118	<0.041	13.2	<0.059	<0.13
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.022	19.4	<0.043	0.108	<0.041	13.4	<0.059	<0.13
FG_MORGAN_8A_20111102	FGP-7	<0.022	41.3	<0.043	<0.073	<0.041	2.69	<0.059	<0.13
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.022	40.4	<0.043	<0.073	<0.041	3.88	<0.059	<0.13
FG_MORGAN_9_20111102	FGP-8	<0.022	24.9	<0.043	<0.073	<0.041	41.8	<0.059	<0.13
FG_MORGAN_10_20111102	BLANK	<0.022	<0.026	<0.043	<0.073	<0.041	<0.22	<0.059	<0.13
FG_MORGAN_11_20111102	FGP-9	<0.022	15.5	<0.043	<0.073	<0.041	12.0	<0.059	<0.13
FG_MORGAN_12A_20111110	FGP-10	<0.022	7.21	<0.043	<0.073	<0.041	18.6	<0.059	<0.13
FG_MORGAN_12B_20111110	FGP-10 Dup.	<0.022	7.22	<0.043	<0.073	<0.041	18.3	<0.059	<0.13
FG_MORGAN_13_20111110	BLANK	<0.022	0.031	<0.043	<0.073	<0.041	<0.22	<0.059	<0.13
FG_MORGAN_14_20111110	FG-1	<0.022	65.8	<0.043	<0.073	<0.041	18.5	<0.059	<0.13
MINIMUM		<0.022	<0.026	<0.043	<0.073	<0.041	<0.22	<0.059	<0.13
MAXIMUM		<0.022	186	<0.043	0.118	<0.041	41.8	<0.059	<0.13
AVERAGE		<0.022	28.69	<0.043	0.104	<0.041	14.8	<0.059	<0.13

Table 9D Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)	TDS (mg/L)
MDL		0.066	0.086	0.00037	0.00056	0.017	0.047	0.0097	12
MCL (Primary & Secondary Drinking water standards)									
FG_MORGAN_1A_20111025	FGP-1	8.28	<0.086	0.140	<0.00056	<0.017	<0.047	0.0125	343
FG_MORGAN_1B_20111025	FGP-1 Dup.	8.27	<0.086	0.140	<0.00056	<0.017	<0.047	0.0098	349
FG_MORGAN_2A_20111025	FGP-2	7.45	<0.086	0.280	<0.00056	<0.017	<0.047	0.0158	451
FG_MORGAN_2B_20111025	FGP-2 Dup.	7.40	<0.086	0.281	<0.00056	<0.017	<0.047	0.0220	442
FG_MORGAN_3_20111025	FGP-3	6.72	<0.086	<0.00037	<0.00056	<0.017	<0.047	0.0140	458
FG_MORGAN_4_20111025	BLANK	<0.066	<0.086	<0.00037	<0.00056	<0.017	<0.047	<0.0097	<12
FG_MORGAN_5_20111025	FGP-4	9.79	<0.086	0.164	<0.00056	<0.017	<0.047	0.0207	562
FG_MORGAN_6A_20111102	FGP-5	6.99	<0.086	0.226	<0.00056	<0.017	<0.047	0.113	533
FG_MORGAN_6B_20111102	FGP-5 Dup.	7.16	<0.086	0.229	<0.00056	<0.017	<0.047	0.125	533
FG_MORGAN_7A_20111102	FGP-6	9.81	<0.086	0.336	<0.00056	<0.017	<0.047	0.0487	514
FG_MORGAN_7B_20111102	FGP-6 Dup.	9.86	<0.086	0.341	<0.00056	<0.017	<0.047	0.0217	518
FG_MORGAN_8A_20111102	FGP-7	4.47	<0.086	0.244	<0.00056	<0.017	<0.047	<0.0097	521
FG_MORGAN_8B_20111102	FGP-7 Dup.	4.69	<0.086	0.251	<0.00056	<0.017	<0.047	<0.0097	552
FG_MORGAN_9_20111102	FGP-8	10.7	<0.086	0.224	<0.00056	<0.017	<0.047	0.192	703
FG_MORGAN_10_20111102	BLANK	<0.066	<0.086	<0.00037	<0.00056	<0.017	<0.047	<0.0097	<12
FG_MORGAN_11_20111102	FGP-9	9.07	<0.086	0.135	<0.00056	<0.017	<0.047	0.0187	350
FG_MORGAN_12A_20111110	FGP-10	6.53	<0.086	0.114	<0.00056	<0.017	<0.047	0.0222	404
FG_MORGAN_12B_20111110	FGP-10 Dup.	6.46	<0.086	0.114	<0.00056	<0.017	<0.047	0.0159	398
FG_MORGAN_13_20111110	BLANK	<0.066	<0.086	<0.00037	<0.00056	<0.017	<0.047	0.0118	<12
FG_MORGAN_14_20111110	FG-1	6.86	<0.086	0.207	<0.00056	<0.017	<0.047	0.0295	440
MINIMUM		<0.066	<0.086	<0.00037	<0.00056	<0.017	<0.047	<0.0097	<12
MAXIMUM		10.7	<0.086	0.341	<0.00056	<0.017	<0.047	0.192	703
AVERAGE		7.68	<0.086	0.214	<0.00056	<0.017	<0.047	0.043	475

Table 9E Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	F (mg/L)	Cl (mg/L)	NO ₃ N (mg/L)	SO ₄ (mg/L)	Br (mg/L)	Alkalinity (lab) (mg/L)	NVOC (mg/L)	DOC (mg/L)
MDL		0.08	0.09	0.07	0.31	0.08	4	0.31	0.31
MCL (Primary & Secondary Drinking water standards)		4 (2.0)	250.00	10.00	250.00				
FG_MORGAN_1A_20111025	FGP-1	0.40	8.24	7.34	27.3	<0.08	276	1.83	2.48
FG_MORGAN_1B_20111025	FGP-1 Dup.	0.41	8.25	7.38	27.4	<0.08	275	1.82	2.28
FG_MORGAN_2A_20111025	FGP-2	0.48	25.4	3.94	26.2	<0.08	362	1.61	1.84
FG_MORGAN_2B_20111025	FGP-2 Dup.	0.48	25.4	3.93	26.2	<0.08	359	1.60	1.85
FG_MORGAN_3_20111025	FGP-3	0.47	14.3	6.93	25.0	0.09	326	1.33	1.62
FG_MORGAN_4_20111025	BLANK	<0.08	<0.09	<0.07	<0.31	<0.08	<4	<0.31	<0.31
FG_MORGAN_5_20111025	FGP-4	0.40	25.3	21.5	65.4	0.09	326	1.47	1.90
FG_MORGAN_6A_20111102	FGP-5	0.21	36.6	4.53	56.1	0.15	384	1.44	1.43
FG_MORGAN_6B_20111102	FGP-5 Dup.	0.22	36.5	4.92	55.0	0.14	386	2.04	1.64
FG_MORGAN_7A_20111102	FGP-6	0.28	26.4	<0.07	35.8	0.11	456	0.85	0.84
FG_MORGAN_7B_20111102	FGP-6 Dup.	0.30	26.1	<0.07	36.3	0.13	455	0.83	0.76
FG_MORGAN_8A_20111102	FGP-7	0.18	102	4.95	6.40	0.30	414	6.99	5.52
FG_MORGAN_8B_20111102	FGP-7 Dup.	0.18	105	7.38	9.22	0.30	414	8.89	5.26
FG_MORGAN_9_20111102	FGP-8	0.25	63.2	22.8	120	0.18	356	1.76	1.86
FG_MORGAN_10_20111102	BLANK	<0.08	<0.09	<0.07	<0.31	<0.08	<4	<0.31	<0.31
FG_MORGAN_11_20111102	FGP-9	0.31	5.14	4.23	32.9	<0.08	285	2.78	2.46
FG_MORGAN_12A_20111110	FGP-10	0.23	16.0	5.97	57.7	<0.08	279	0.82	0.81
FG_MORGAN_12B_20111110	FGP-10 Dup.	0.24	16.0	5.99	57.8	<0.08	277	0.58	0.63
FG_MORGAN_13_20111110	BLANK	<0.08	<0.09	<0.07	<0.31	<0.08	<4	<0.31	<0.31
FG_MORGAN_14_20111110	FG-1	0.49	25.1	1.81	58.9	<0.08	318	1.44	1.73
MINIMUM		<0.08	<0.09	<0.07	<0.31	<0.08	275	<0.31	<0.31
MAXIMUM		0.49	105.4	22.8	120	0.30	456	8.89	5.52
AVERAGE		0.33	33.3	7.57	42.6	0.17	350	2.24	2.05

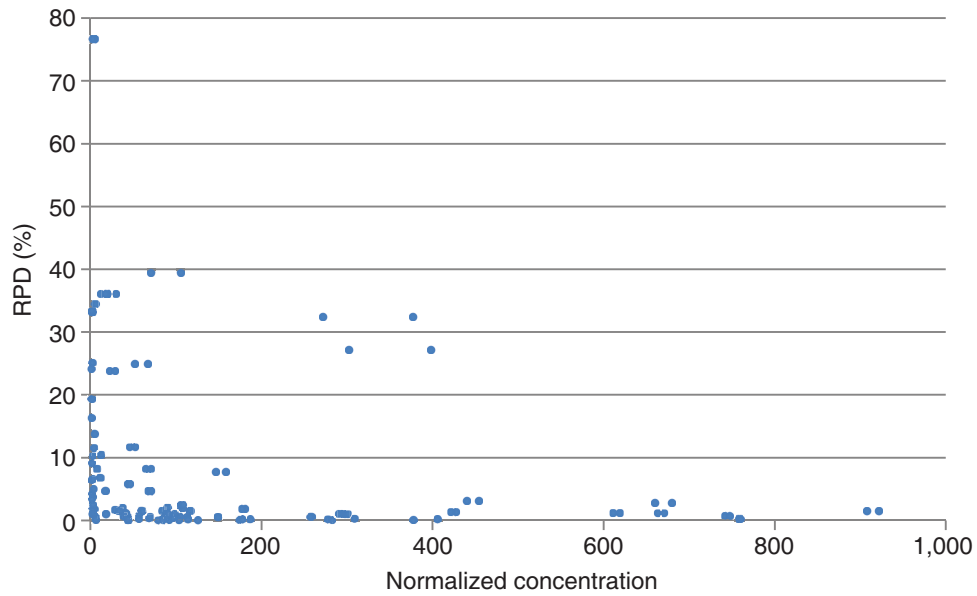


Figure 7 Relative percent differences of concentrations in duplicate groundwater samples.

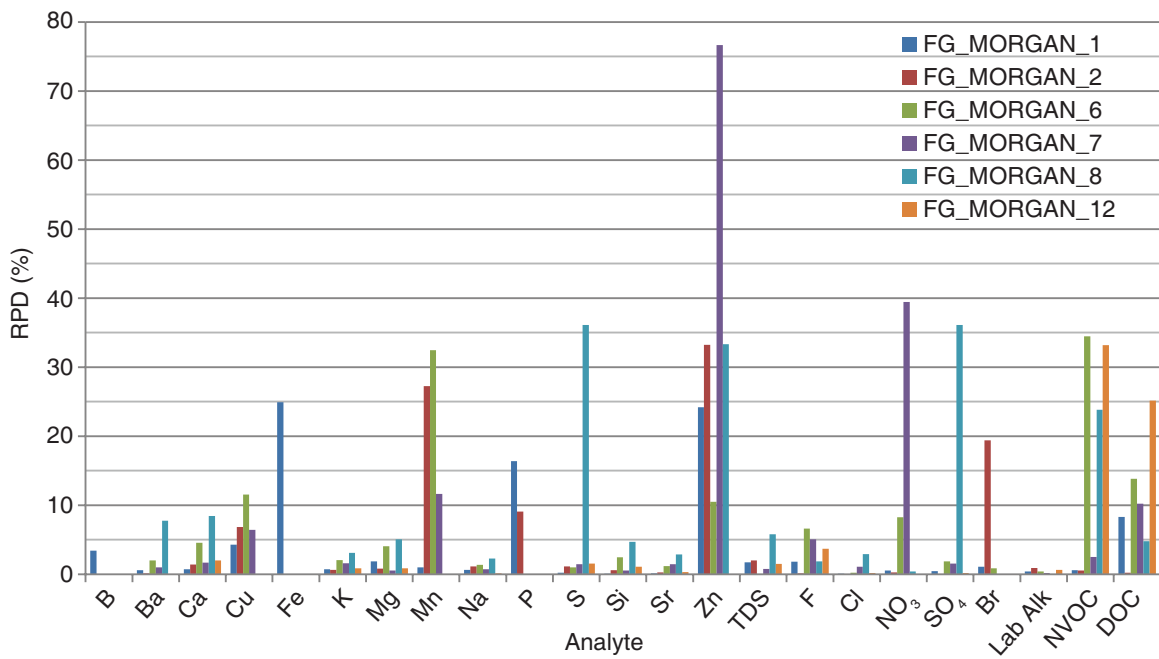


Figure 8 Relative percent differences grouped by analyte.

Table 10 Summary of field parameters

Well ID	Well Depth (feet)	Depth to Water (feet bgs)	Sample Collection Date	Field pH	Field Alkalinity (mg/L CaCO3)	Temp (°C)	EC (uS/cm)	DO (mg/L)	Uncorrected Eh (mv)	Purge Volume (L)
FGP-1	29.9	18.02	10/25/2011	7.35	284	15.2	547	3.5	258	20
FGP-1 Dup.			10/25/2011		284					
FGP-2	NM	NM	10/25/2011	7.17	372	15.4	680	0.3	204	66
FGP-2 Dup.			10/25/2011		368					
FGP-3	30.1	11.47	10/25/2011	7.12	332	16.9	782	<DL	240	49
FGP-4	28	8.9	10/25/2011	7.28	332	18.8	990	3.5	139	16
FGP-5	33.5	8.52	11/2/2011	7.20	384	14.5	782	<DL	256	102
FGP-5 Dup.			11/2/2011		388					
FGP-6	34.2	12.74	11/2/2011	7.29	460	14.1	796	<DL	-150	98
FGP-6 Dup.			11/2/2011		460					
FGP-7	46.8	11.19	11/2/2011	7.61	416	18.3	921	0.9	4	27
FGP-7 Dup.			11/2/2011		412					
FGP-8	16.15	5.04	11/2/2011	7.08	364	14.8	1164	2.6	235	45
FGP-9	20.7	14.74	11/2/2011	7.29	284	16	605	1.4	158	9
FGP-10	36.7	15.4	11/10/2011	7.66	276	12.5	617	0.9	220	48
FGP-10 Dup.			11/10/2011		276					
FG Monitoring well	20.95	8.11	11/10/2011	7.27	316	10.9	694	2.4	90	20.3
FGP-5 Bulk	33.5	NM	11/16/2011	7.25	NM	12.7	835	<DL	280	190
MINIMUM	46.8	5.04		7.08	276	10.9	547	<DL	-150	9
MAXIMUM	16.15	14.74		7.66	460	18.8	1164	3.50	258	102
AVERAGE	29.7	11.4		7.30	353	15.2	780	1.94	150	45

<DL = less than the detection limit NM=Not measured

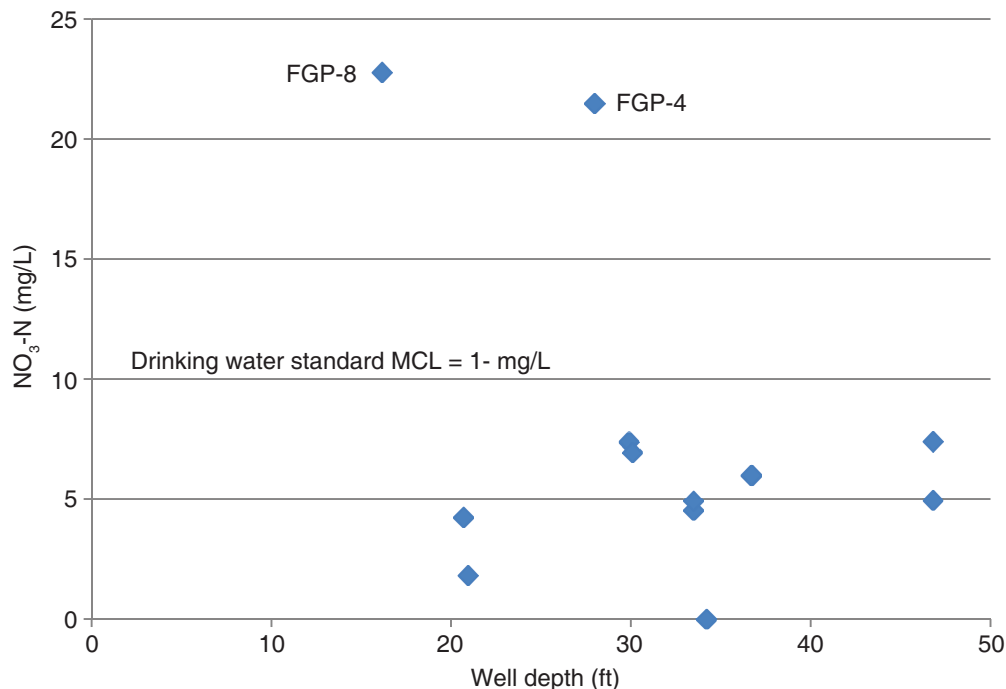


Figure 9 Dissolved nitrate (as mg N/L) concentrations in groundwater samples at the Future-Gen 2 site.

water from wells FGP-4 and FGP-8 contained nitrate concentrations above the EPA MCL of 10 mg NO₃⁻ N/L (Figure 9). The concentrations of nitrate in the groundwater from these wells were also significantly greater than those detected in other samples. Site notes indicated that these shallow wells (28 and 16 feet deep, respectively) are located near animal feedlots or barns, suggesting they are more susceptible to nitrate contamination from fertilizer or animal waste. The groundwater sample collected from FGP-8 also contained concentrations of sulfate and calcium that were greater than those in other samples (Figure 10). Although no mineralogical data are available, sulfate and calcium concentrations in the groundwater sample suggest that gypsum dissolution could be a factor in these constituent concentrations. The owners of these wells were notified of the water quality results and given information about drinking water quality concerns and treatment options.

Some chemical concentrations in groundwater from well FGP-3 were significantly different from those detected in samples from other wells near the study site. Calcium and magnesium concentrations were significantly less and the sodium concentration was significantly greater than in other well samples (Figure 11). Typical residential water softening involves an ion exchange process that removes dissolved calcium and magnesium from the water and replaces it with sodium. The results for well FGP-3 would suggest that this sample likely underwent water softening prior to collection. At each sampling location, ISGS staff consulted with well owners to identify sample collection points that would not be affected by water pre-treatment processes. In some instances, the owners were unsure about the details of their water system to verify whether the chosen sampling location was suitable.

The groundwater collected from well FGP-6 contained greater iron concentrations than did other samples (Figure 12). When this sample was collected, a distinct hydrogen sulfide odor was noted. The Eh value (-150 mV), was the most reduced of all groundwater samples collected near the study site.

Well FGP-7 was the deepest well sampled and was located in a cattle pasture. The well casing did not have a cap, was open to the atmosphere, and was corroded near the ground surface. The groundwater sample collected from this well had the largest chloride concentration of all wells sampled. This elevated concentration could possibly be related to animal waste and surface water runoff or near-surface groundwater that may be entering the well (Figure 13). Results from isotope analysis of water well samples are presented in Appendix E. Results from volatile organic compounds (VOC) and metal analysis of well water samples by PNNL labs are presented in Appendix F.

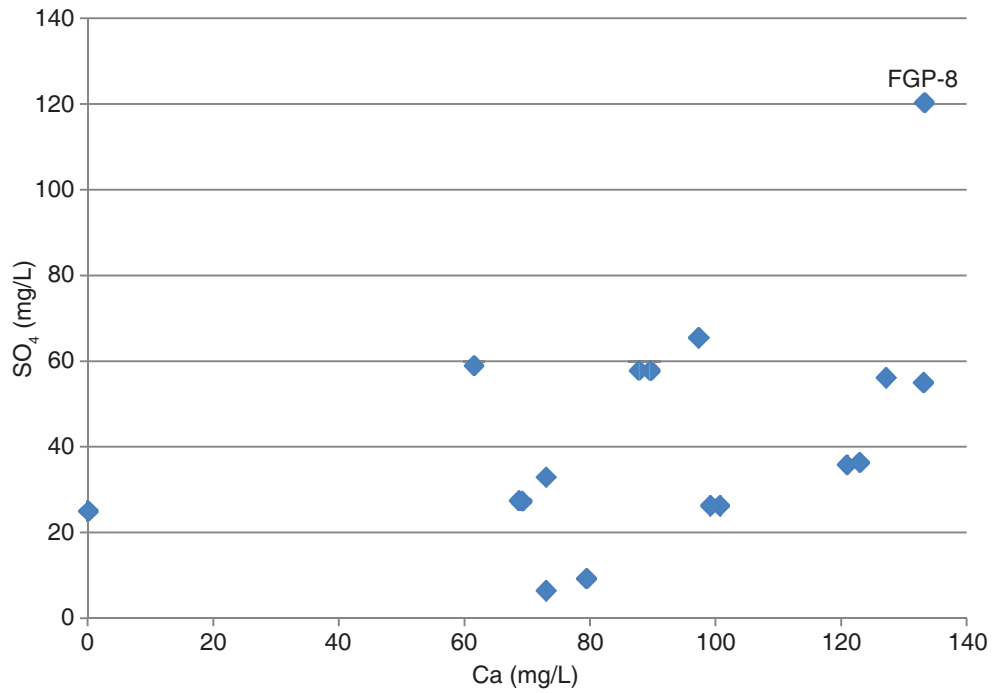


Figure 10 Sulfate and calcium concentrations in groundwater samples at the FutureGen 2 site.

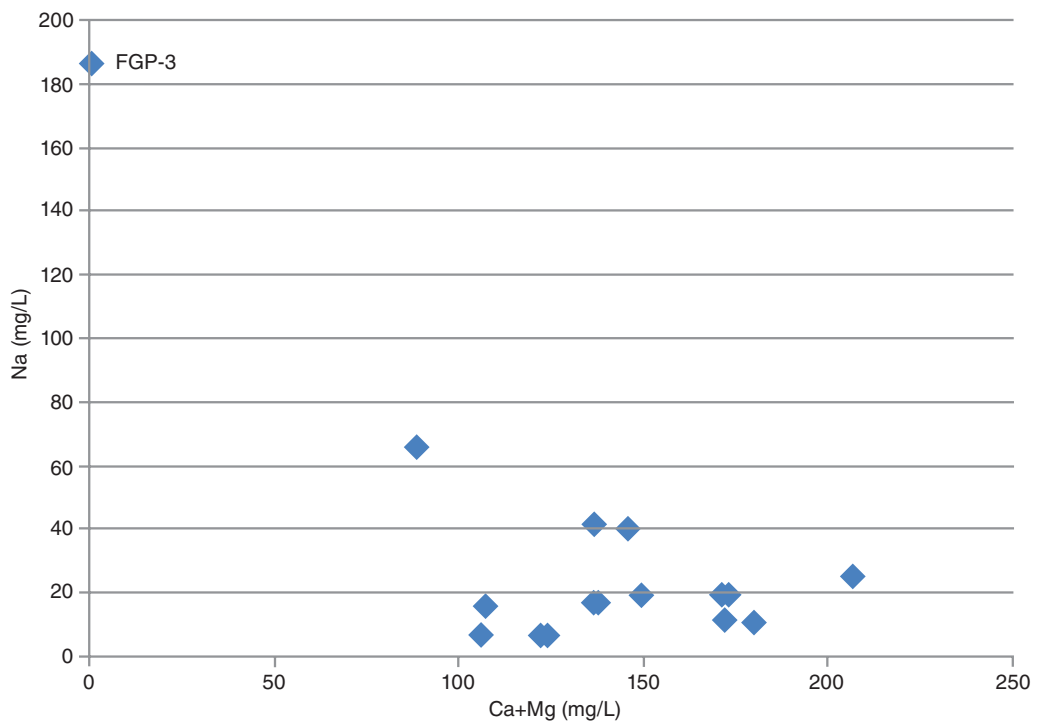


Figure 11 Sodium, calcium, and magnesium concentrations in groundwater samples at the FutureGen 2 site.

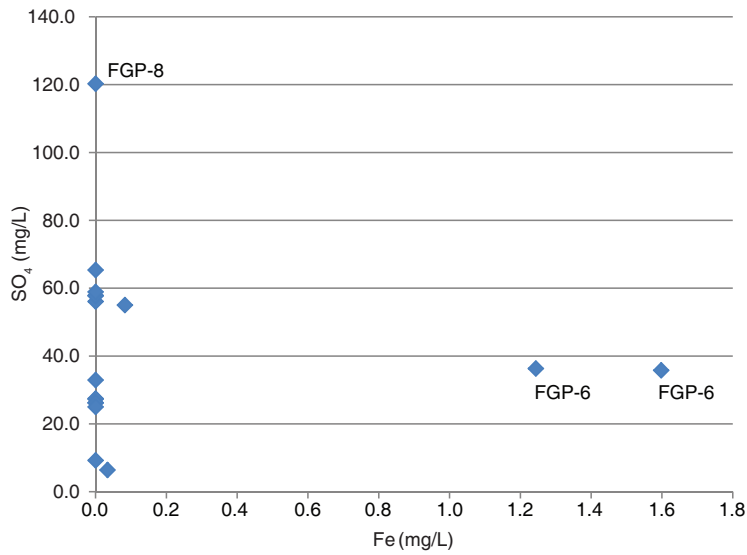


Figure 12 Sulfate and iron concentrations in groundwater samples at the FutureGen 2 site.

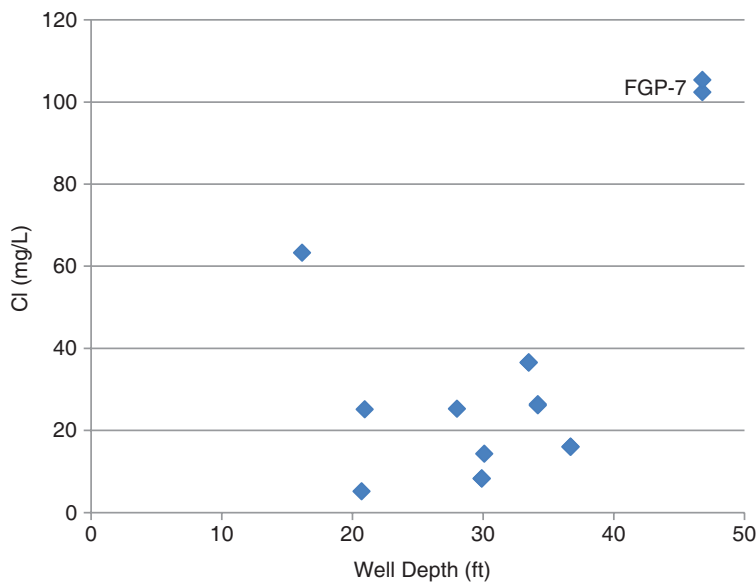


Figure 13 Chloride concentration in the groundwater samples at the FutureGen 2 site in relation to well depth.

CONCLUSIONS AND SUMMARY

A test hole was drilled to 230 feet. No aquifer material was encountered in the bore hole. A shallow monitoring well was installed. Ten private wells were sampled in the area. Water quality data from the samples have been presented. Analytical results have been shared with well owners. The owners of all private wells sampled agreed to having their wells sampled in the future. In anticipation of the FutureGen 2 carbon sequestration activities in Morgan County (Section 25, Township 16 North, Range 9 West), field work was conducted to describe shallow geologic conditions and characterize shallow groundwater quality at the site (Figure 1). The Illinois State Geological Survey (ISGS) drilled one stratigraphic boring to 230 feet. Bedrock was encountered at 123.5 feet below the land surface. No aquifer material was encountered in the Quaternary material or in the bedrock (Appendix B and C). A shallow groundwater monitoring well was installed at a depth of 20 feet (Figure 2) and developed to ensure a representative water level and water qual-

ity within the well A surficial 2-D seismic survey (Appendix A), and an electrical earth resistivity (EER) survey (Appendix D) was conducted at the site. The seismic survey was conducted before drilling primarily to assess the presence of shallow natural gas. None was detected. Results from the EER survey indicated a slight increase in resistivity to the southwest and southeast of the site. The higher resistivity may indicate a slight increase in the occurrence of shallow sand in those directions. Water from 10 domestic water supply wells and the groundwater monitoring well were sampled between October 25 and November 16, 2011. Most constituent concentrations were less than the drinking water standards. Iron (Fe), manganese (Mn), nitrate (NO³) and total dissolved solids (TDS) were the only constituents whose concentrations exceeded USEPA primary or secondary standards in some of the groundwater samples. Groundwater samples from two wells contained nitrate concentrations above the EPA MCL of 10 mg NO³-N/L. Results from isotope analysis of water well samples are reported in Appendix E. Results from water sample VOC and metal analysis by PNNL labs are reported in Appendix E.

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APPENDIX A: SURFACE REFLECTION SEISMIC SURVEY

Ahmed Ismail and Steve Sargent

Hydrogeology & Geophysics Section, Illinois State Geologic Survey

A short P-wave seismic reflection test line of 1,115 feet in length was acquired from a drilling site in Morgan County, Illinois. The goals of the seismic work were to identify the presence or absence of significant gas deposits in shallow bedrock between 50 and 500 feet and to characterize the shallow subsurface geology of the surveyed site. The seismic data were acquired using a 48-channel P-wave land streamer and a 100-lb weight drop as an energy source (Figure A1). The streamer's channels were placed at 6.7 foot intervals and both the source and the streamer were moved along the survey line at 13-foot intervals. A total of 75 seismic shots were acquired along the survey line.

The acquired seismic data were processed using Landmark's ProMAX software developed by Landmark Graphics Inc. Preprocessing steps started with converting the acquired SEG-2 data into SEG-Y format, and then converting the SEG-Y format into PROMAX internal format. The field geometry was merged into file headers followed by a routine processing sequence. This sequence included a careful first-arrival mute to remove the refracted signals followed by a bottom mute to the low-frequency surface waves. Refraction statics were applied to correct for the near surface low-velocity layer, and elevation corrections were applied to correct for elevation changes along the line. Filtering, velocity analysis, normal move-out correction (NMO), and stacking processes were then applied to generate a 2-D stacked seismic section (Figure A2). The left vertical scale of this section is the two-way travel time and the right vertical scale is the estimated depth.



Figure A1 Photo showing the acquisition process of the P-wave seismic reflection data. The long land streamer and the weight drop are towed by a car along the survey line, while data were acquired at 13 foot intervals along the line.

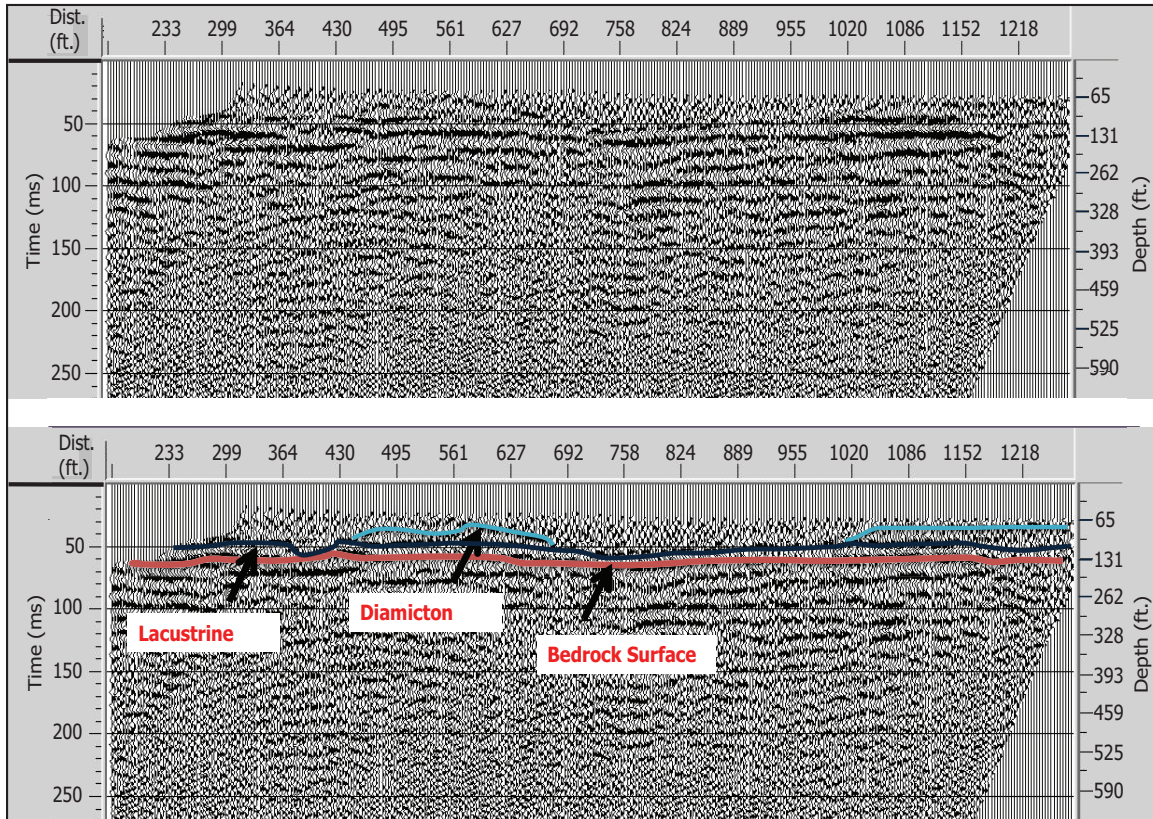


Figure A2 The stacked P-wave seismic reflection section acquired from Morgan County. The upper panel is the processed section and the lower panel is the processed and interpreted section.

Correlating the stacked seismic section to the drilling results of the nearby borehole showed a coherent strong seismic reflector at a 130-foot depth below a 625-foot elevation datum that was interpreted as the Pennsylvanian bedrock surface (Figure A2). The bedrock surface seemed to be flat and consistent along the seismic line except for the short distance between distance marks of 365 to 430 feet, where bedrock was interrupted by an overlying bowl-shaped feature. This feature could be a small attribute of a bigger valley or an erosional feature. Another somewhat interrupted seismic reflector overlies the bedrock surface and most likely corresponds to the upper surfaces of a fine-grained layer. A non-consistent shallow seismic reflector appeared at depths ranging from 56 to 85 feet and may correspond to the upper surface of the diamicton layer. Multiple coherent seismic reflectors underlie the bedrock surface and most likely correspond to different Pennsylvanian bedrock layers. No signature of gas accumulation was observed within these bedrock layers (Figure A2). A common seismic signature of gas accumulation is usually severe attenuation of the seismic amplitudes. The seismic reflections from the multiple bedrock layers did not show such an effect.

APPENDIX B: GEOLOGICAL DESCRIPTION OF CONTINUOUS CORE

William S. Dey

Hydrogeology & Geophysics Section

Scott D. Elrick and Christopher P. Korose,

Coal and Petroleum Geology Section

David A. Grimley, Andrew C. Phillips, and Elizabeth Colville

Quaternary Section, Illinois State Geological Survey

A stratigraphic bore hole was drilled at the site on August 23 and 24, 2011. Continuous core was collected during drilling (Figures B1 and B2). The contact between the unconsolidated Quaternary deposits and the Pennsylvanian bedrock was encountered at 123.5 feet. Coring continued into bedrock to a depth of



Figure B1 Section of core and sampling tube used to collect it.

230 feet. Recovery of core was 92% overall and 85 % in the unconsolidated deposits. Field descriptions and photographs were collected at the time of drilling. Core was transported to an ISGS storage facility in Champaign, Illinois Laboratory descriptions were made independently of the bedrock core and the unconsolidated core. ISGS geologists Scott Elrick and Christopher Korose, described the bedrock core and made lithostratigraphic interpretations. A key bedrock unit identified was the Colchester Coal (Smith, 1961, Korose et al., 2003). Positive identification of this unit aided in the identification of other bedrock units described by Willman et al. (1975).

David Grimley, Andrew Phillips, and Elizabeth Colville described the unconsolidated core or Quaternary materials and made lithostratigraphic interpretations. Subsamples were collected from the unconsolidated core for lab analysis, which included particle-size distribution, clay mineralogy, percentage calcite, and magnetic susceptibility (Table B1 and B2). Figure 3 graphically displays laboratory analyses with lithostratigraphic interpretations. Table B3 displays lithostratigraphic interpretations for the whole core. The interpretations were correlated to work done in southwestern (Grimley and Phillips, 2011) and central Illinois (Johnson, 1964).

Based on materials described from this test boring, no aquifers or aquifer materials were identified at this drill site, either in the Quaternary deposits or upper bedrock units.



Figure B2 Core collected from ground surface to 10 feet.

Table B1 Particle size distribution.

Depth (feet)	Clay as <2 µm			Clay as <4 µm			% gravel
	% sand	% silt	% clay	% sand	% silt	% clay	
13	1	84	15	1	62	37	0
21.5	25	38	37	25	32	43	1
25.1	4	53	43	4	48	48	0
30	34	46	20	34	42	24	4
35	32	52	17	32	46	22	4
41.4	30	54	16	30	47	23	3
45	17	67	16	17	63	20	3
50	26	48	27	26	44	30	3
55	22	49	28	22	45	32	3
60	27	48	25	27	44	29	2
63.4	27	48	24	27	42	31	3
72	25	49	26	25	43	31	2
77	27	48	25	27	43	29	3
83	19	56	26	19	51	30	2
90	23	50	28	23	46	31	3
95	15	53	32	15	50	35	1
98.2	16	45	38	16	42	42	1
99	18	44	37	18	41	41	2
101	14	56	31	14	53	33	3
107	21	41	38	21	37	43	1
112	13	57	30	13	54	33	0
117.5	26	53	20	26	50	24	0

Table B2 Clay mineralogy data.

Depth (feet)	Mineral Percentages							Munsel
	Smectite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)	Total (%)	Calcite (CPS)	Dolomite (CPS)	
13.0	48	37	9	6	100	17	28	2.5Y 6/4
21.5	55	22	13	9	100	49	66	2.5Y 6/4
25.0	59	16	14	11	100	41	42	5Y 8/1
30.0	12	63	10	14	100	719	203	2.5Y 7/2
35.0	8	65	13	13	100	525	205	2.5Y 7/2
41.4	5	68	12	15	100	558	151	2.5Y 7/2
45.0	7	66	18	9	100	798	167	2.5Y 6/2
50.0	14	54	16	15	100	359	76	2.5Y 6/2
55.0	20	49	16	15	100	279	114	2.5Y 6/2
60.0	15	52	18	16	100	336	135	5Y 5/2
63.5	14	57	14	15	100	283	98	2.5Y 7/1
72.0	23	47	16	15	100	327	166	5Y 8/1-7/1
77.0	9	59	16	16	100	539	166	5Y 6/1-7/1
83.0	32	40	10	19	100	110	103	5Y 8/1-7/1
90.0	19	46	19	16	100	236	101	2.5Y 6/2
95.0	44	26	19	11	100	45	0	5Y 5/1
98.2	36	32	21	11	100	48	30	7/5Y
99.0	36	27	24	12	100	28	53	7/5Y-6/5Y
101.0	45	25	18	13	100	79	50	6/2.5Y
107.0	40	22	26	13	100	34	62	5Y 7/1
112.0	42	24	20	14	100	26	40	5/10YR-6/10YR
117.5	37	29	24	10	100	35	54	5Y 7/1-6/1

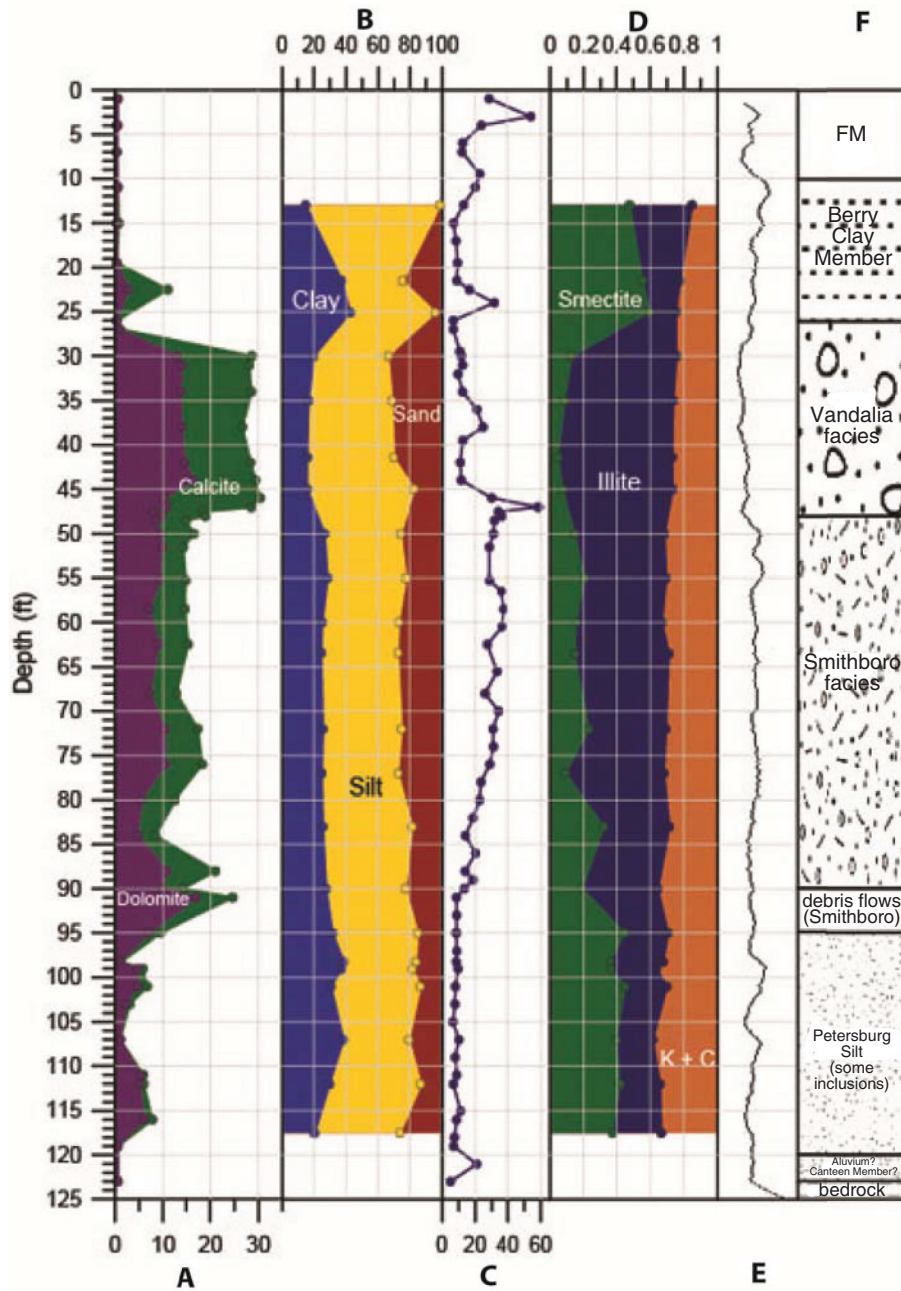


Figure B3 Quaternary sediments from the test boring. Columns A-F: A shows the ratio of calcite/dolomite; B: particle-size distribution percent sand, silt, clay; C: magnetic susceptibility (10^{-4} m³/kg); D: clay mineralogy; E: resistivity (0–200 ohm-m); F: geologic interpretation.

Table B3 Lithostratigraphic assignments to continuous core from test boring.

Description	Thick (feet)	Top (feet)	Bottom (feet)
<u>Fill, Gravel</u> – gravel, light gray, over black geomembrane	0.3	0.0	0.3
<u>Fill, Clayey Silt to Silty Clay</u> - Dark brown to yellowish brown, blocky to weak blocky structure, friable to firm consistency	9.7	0.3	10
<u>Berry Clay M.</u> – Dark brown to yellowish brown, mottling to gray near base, massive structure, friable consistency near top transitioning to firm at base.	16	10	26
<u>Vandalia M.</u> – Mottled 60% Brown 40% Grey trending to all gray at base, common small gravel, massive structure, firm to very firm consistency,	22	26	48
<u>Smithboro M.</u> gray to dark grey, few to common small gravel, very firm consistency, massive structure, few to common small gravel	42	48	90
<u>Clay loam, debris flow</u> – dark grayish brown to very dark grey, few small gravel, rare coarse sand grains and small wood fragments, very firm consistency, massive structure with some laminar bedding	7	90	97
<u>Petersburg Silt M.</u> – Gray to very dark grayish brown, firm consistency, massive structure, some organic rich zones	23	97	120
<u>Silt (alluvial)</u> – Very dark gray to dark gray, firm consistency, massive structure	3.5	120	123.5
<u>Clay Shale</u> - Medium light gray, weakly laminated, lightly mottled with medium gray, sideritic lenses and nodules throughout, nodules up to 2 inches, more commonly about 1 inch. Single Pecopteris frond at 157.5. A few pyrite trails towards base. Fairly uniform, little if any evidence of tidal rhythmites. Lower contact gradational	40.5	123.5	164.0
<u>Shale</u> - Dark gray, semi-fissile, pecten fragments and whole shells throughout, but mostly very small in size. Pyrite trails in upper 4 inches. Carbonaceous, debris, fine-grained throughout, lower contact sharp.	3.6	164.0	167.6
<u>Siltstone</u> - Medium light gray, laminated, interlaminations of fine, light gray sandstone, darker gray laminations are micaceous and have coarsely ground plant debris, laminations are dominantly planar, with a few angular and wavy laminated zones a few inches thick. Sandier at top, grading to siltier at the base, no fossils seen. Lower contact gradational.	18.4	167.6	186.0
<u>Mudstone</u> - Medium gray at top, grading to medium brown gray. Massive, non-fissile, pyrite trails in upper few inches. Lower contact gradational.	3.9	186.0	189.9
<u>Claystone</u> - Dark gray, massive, non-fissile, pervasive pyrite trails, scattered mica flakes, numerous siderite nodules up to 3 inches thick every few feet, finely chopped organic debris. Increasingly calcareous towards base. Lower contact gradational.	7.3	189.9	197.2
<u>Oak Grove Limestone</u> - Medium dark gray, mottled and variegated with lighter and darker patches. Wackestone. Shell fragments, crinoid columnals, rugose corals common throughout. Grades to calcareous shale at lower contact.	0.8	197.2	198.0
<u>Mecca Quarry Shale</u> - Black, fissile, hard, lower density, commonly interspersed with thin limestone bands, lower contact sharp	1.5	198.0	200.5
<u>Colchester Coal</u> - Black, bright banded, pyrite visible on cleats towards base, clacite filled veins throughout, lower contact obscured due to core breakage, likely sharp	2.2	200.5	202.7

Table B3 Continued.

Description	Thick (feet)	Top (feet)	Bottom (feet)
<u>Claystone</u> - Medium gray, rooted, massive, slickensides towards base, non-calcareous in upper 1.5 feet, lower 0.2 ft slightly reactive, hackly fracture, lower contact gradational.	1.7	202.7	204.4
<u>Shale</u> - Medium mottled gray grading to olive gray at base. Siltier at top, grading to clay at base, organic rich zone 0.2 inches thick at 210.0. Thin organic mottles present in lower half. Lower contact gradational	6.2	204.4	210.6
<u>Seahorne Limestone</u> - Medium gray to buff gray in upper 3 feet, grades to very light gray to whitish from 213 to 219, then grading back to medium gray to light buff gray at base, wackestone, massive, stylolites prominent in lower half, irregular contacts between contrasting colors, possible burrow infilling, shell fragments of brachiopods, rugose corals, possible pectins. Thin argillaceous zones at base. Lower contact sharp	9.5	210.6	220.1
<u>Claystone</u> - Dark gray to very dark gray, mottled in upper half, medium gray with darker gray mottles in lower half, significant rooting and organic material in upper half, less common rooting in lower half, pervasive slickensides, becoming less common at base. A single extremely thin coaly zone with fusain at 222.1. Lower contact gradational	5.9	220.1	226.0
<u>Shale</u> - Medium olive gray with darker mottling at top, grading to medium gray at base, scattered plant fragments, possibly lycopod leaves in lower half, fine, thin, silty interlamination in upper 1/3.	4.0	226.0	230.0
End of Core			

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APPENDIX C: GEOPHYSICAL DOWNHOLE LOGGING

Timothy C. Young

Hydrogeology & Geophysics Section, Illinois State Geological Survey

INTRODUCTION

Downhole geophysical logging was performed in the shallow stratigraphic borehole drilled by the ISGS on August 25, 2011. The goal of the logging was to assist in characterization of geological material at the site. At the time of logging, the borehole was cased within the unconsolidated drift with 3.9 inch diameter steel casing from 2.6 feet above ground surface (ags) to a depth of 130.3-feet below ground surface (bgs). The bedrock portion of the borehole was uncased 130.3 to 230.0 feet bgs. The fluid in the borehole was at the top of the casing and had been recirculated with fresh water prior to logging. It was noted that the water had remained within a foot of the top of the HW casing for the duration of the logging, approximately 8 hours.

Logging was performed in both the uncased (open) and cased portions of the borehole. The only logs recorded in the cased portion of the borehole were gamma, acoustic imaging, and full waveform sonic (FWS). The gamma was the only log that provided data relative to the formation outside of the casing. Data from the acoustic televiewer (ATV) and FWS logs recorded data relative to the inside of the steel casing, not the formation outside the casing. The purpose of recording data using the ATV probe on the inside of the casing was specifically for calibrating the logs to a known inside diameter for processing an acoustic caliper measurement. The purpose of recording FWS log data inside the casing was to help in establishing velocity picks within a known material (steel) with an expected range of velocity for both compressional and shear waves.

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Logging Methodology

Log Data Acquisition System and Software

Logging was performed using an MGXII data acquisition system manufactured by Mount Sopris Instrument (MSI) Co., Golden, Colorado. The wireline winch is a Mount Sopris, 4WNA-1000 model capable of holding 5,900 feet of 3/16-inch steel-armored, single-conductor coaxial cable. Data were recorded on a rack-mounted PC, capable of recording large amounts of data and displaying high-resolution, detailed images in real time on a rack-mounted LCD screen monitor. The entire system was mounted within a 1-ton 2000 Ford Excursion (4WD and V-10) and was powered by a 5,000 watt Auragen generator mounted on the engine. Power was delivered to an electronic control unit (ECU) housed on the floor of the Excursion, where it was regulated and distributed to the various components used for the logging operation.

The logging system software produced a proprietary log file (extension RD) in addition to a version 2.0, Log Ascii Standard (LAS) file format. However, both the ATV and FWS logs were not supported by the LAS format; therefore, logs were created in the proprietary RD format. The ISGS uses WellCAD v4.3 software, developed by Advance Logic Technology (ALT), Luxembourg, specifically for post-processing Mt. Sopris proprietary RD files. WellCAD also has a module for importing from and exporting to Schlumberger LIS and DLIS file formats.

Natural Gamma and E-Logging

Gamma and e-logging are performed using a Mt. Sopris model 2PGA/2PEA-1000 combination gamma and electric probe, which includes self-potential (SP), single-point resistance (SPR), and 8, 16, 32, and 64 inch normal-resistivity probe measurements. The combination probe is 7.2 feet long, 1.63 inches in diameter, and weighs approximately 16.5 lb.

Natural Gamma

A natural gamma log is a graph of the gross gamma radiation (high-energy electromagnetic radiation) emitted by the earth materials surrounding the sonde. The chief use of the gamma log is for stratigraphic correlation and identification of lithology. Detrital sediments with fine-grained textures, such as shale and unconsolidated clay, normally have the highest gamma intensity from naturally occurring radioisotopes, including Potassium-40, Thorium-232, and Uranium-238. In Illinois, these radioisotopes are more abundant in clay-rich deposits of both sedimentary bedrock and unconsolidated formations. Consequently, low CPS values on natural gamma logs generally indicate zones of porous and permeable sand and gravel in unconsolidated deposits, and more crystalline (less argillaceous) limestone and dolomite formations within bedrock. Gamma logs can be recorded within fluid, air-filled, plastic or steel cased boreholes. The radius of detection is generally considered to be about 6 inches.

Single-Point Resistance

A single-point resistance (SPR) probe measures electrical resistance in ohms between 2 electrodes, one within the borehole (the probe) and one at the ground surface, commonly referred to as mud-pit or surface electrode. The surface electrode remains constant while the probe is traversed through the borehole and formations. Single-point resistance uses a single electrode that measures resistance at single point or path through the formation the electrode traverses. Because it does not measure volume, it is a qualitative or relative measurement. The SPR is very useful for helping to identify basic lithology, especially when used in combination with gamma. The response from SPR is generally inverted to the response of the gamma; increased gamma radiation typically reflects a decrease in resistance and decreased gamma radiation reflects an increase in resistance. Therefore, an increase in clay/shale content usually reflects a decrease in resistance, and vice-versa. Because it is a single-point measurement, SPR provides good thin-bed resolution as compared with other methods, especially in smaller diameter boreholes. However, the resolution will diminish as the borehole diameter increases up to and beyond the range of the probe. Increased borehole fluid conductivity could further diminish sensitivity and resolution.

Self-Potential

A self-potential, or spontaneous potential (SP) log is generally recorded in conjunction with an SPR log. Spontaneous potential is a passive measurement of the change in potential voltage (millivolts) that occurs within the borehole fluid column, across different strata, and between formation and borehole fluids of different quality, in particular, saline versus fresh water and/or mud. Historically, the main use of SP logs has been in conjunction with SPR in the oil industry to help determine thin-bed resolution and formation salinity and the presence of oil and gas. Within much of the oil and gas industry, resistivity and SP were logged in recirculated drilling mud that maintained similar physical and chemical properties from top to bottom within the borehole with known properties such as mud resistivity, temperature, viscosity, density, or weight. A fluid temperature and conductivity log may be necessary in water wells where the borehole fluid chemistry is not controlled or unknown.

Normal Resistivity

Normal resistivity logging, unlike single-point resistance, is a multi-electrode, volumetric measurement of everything within and surrounding a borehole, including drilling fluid or mud, drilling fluid that has invaded the rock or formation matrix, the buildup of mud along the borehole wall or interface (mud cake), the formation itself, and the native fluid (if saturated) within any interstitial pore spaces in the rock not invaded by drilling fluid or mud. The area or volume measured is a function of the current and potential electrode spacing on the probe and generally range from 8 to 64 inches. A major function of multiple electrodes is to account for the near-borehole resistivity in order to better determine resistivity further away from the borehole, or within the non-invaded zone. This generally relates to freshly drilled boreholes using mud. Normal resistivity logging, as well as other electrical methods, requires fluid in the borehole for proper logging.

Apparent formation resistivity logs are useful for correlating near-surface methods such as 1-D or 2-D resistivity surveys. As with resistance, resistivity in general is high in pure dolomite and limestone and low in shale and other argillaceous, clay-rich formations. Changes in water quality; rock structure; grain size, shape, and distribution can affect overall resistivity.

Acoustic Imaging

The model ABI40 acoustic imaging probe is manufactured by Advanced Logic Technology (ALT) of Luxembourg. The basic operation of the acoustic televiewer probe involves the transmission and measurement of focused high-frequency (1.2-MHz) sonic pulse echoes from the probe to the borehole wall. The nearly continuous pulses are transmitted 360° around the surface of the borehole wall with a rotating transducer at a rate of up to 600 rpm. The waves are reflected back from the borehole wall to a mirrored disk, and the resulting amplitudes and travel times are processed and sent back up hole where they are displayed in real time and stored on a hard drive. The amplitude of the signal in large part is a function of rock wall hardness and texture. Travel time is the measurement of the time required for the pulse echo to travel from the transmitter/receiver, to the borehole wall, and back again. Travel time is used to identify fractures, vugs, and voids, as well as to accurately determine borehole diameter, or rugosity. By combining the amplitude and travel time together, a high-resolution 3-D representation of the borehole can be made. In addition to recording the amplitude and travel time of the signal being recorded, the probe houses three inclinometers and a triple axis magnetometer. This provides the user with accurate determination of borehole deviation in PVC cased or open boreholes, as well as bed and fracture orientation and dip.

Certain conditions are necessary in order to obtain quality data from the ATV probe. Precise centralization within the borehole is important in regard to post-processing and producing higher quality images. Borehole rugosity and overall condition are therefore important in whether significant in controlling data quality. Borehole fluid is necessary in transmitting the high-frequency sonic pulses; therefore, formation data cannot be collected in air-filled boreholes. The condition of borehole fluid can have a major impact on results as well. Gas, density, and suspended particles can affect the outcome of the log record. In general, if the contrast in density between the borehole fluid and the density of the formation (or borehole wall) is relatively small, the borehole wall may not be detected by the probe. The presence of gas bubbles in the borehole fluid will absorb most, if not all, the acoustic energy, whereas the presence of suspended particles (fine sand or coarser) may deflect or reflect the pulses, resulting in a log that is not representative of the formation.

Mud cake (filtrate) along the borehole wall can also minimize the quality of the data, particularly if the borehole wall or formation is soft and the mud cake is thick or viscous. In reference to drilling methods, heavier, denser mud is typically used when direct mud rotary is the method of choice for hole and fluid stabilization. Drill bits will vary, but commonly a tri-cone rock/roller bit is used. The resulting borehole wall may be somewhat rugose in comparison with other methods, such as with a core bit. Core drilling typically uses light mud and provides a very smooth borehole wall in comparison with mud rotary, and therefore provides an ideal setting for logging with the ATV probe. As previously stated, wireline coring was used for this borehole.

Post-processing techniques can correct data recorded in some unfavorable borehole conditions, and are dependent on the level of resolution required for any given project. Regardless, the ATV probe is very reliable for detecting voids and fractures, even in less than optimal conditions.

Full Waveform Sonic (FWS)

The ISGS uses a 2SAA-1000/F model sonic probe manufactured by Mt. Sopris, Inc. This probe incorporates a single transmitter-dual receiver configuration with a transmitter-receiver spacing of 3 and 4 feet. The receivers are stacked and connected toward the top of the probe, whereas the transmitter is fixed at the bottom. An isolator section is situated between the transmitter and receivers and is made from a heavy-duty hydraulic hose. As the name implies, the “isolator” is used to prevent propagation of the acoustic signal (along the probe) from transmitter to receivers. The 2SAA-1000/F has the flexibility to be outfitted with as many as two transmitters and eight receivers. The FWS is logged from the bottom to the top of the hole.

Acoustic velocity logs provide information on lithology and porosity of earth materials when run in uncased, fluid-filled boreholes. An increase in fluid and/or pore space (porosity) increases transit time and decreases wave velocity. Changes in transit time above or below typical or expected velocity ranges may indicate significant changes in porosity. Cycle skipping (reduction of the amplitude of the compression wave in one receiver) may be related to the presence of fractures, solution openings, gas, and large changes in earth materials that attenuate the signal in the borehole fluid.

An acoustic signal created by the transmitter travels through the borehole fluid and adjacent formation at a velocity related to the lithology and porosity of the earth materials. The frequency of the signal is much lower as compared to the ATV probe and is within the range of human hearing. The transmitter creates a “ticking” sound at frequencies ranging from 1–30 kHz. The incoming acoustic wave energy recorded by the receivers is displayed as a full waveform. Acoustic logs are recorded with velocity and the interval transit time increasing from left to right. In general, the radius of investigation of the FWS probe is about three times the wavelength, or from about 1 to 4 feet. The wavelength is equal to the velocity divided by the frequency, which ranges for this probe from 1 to 30 kHz. Velocities and transit times for various earth materials and fluids are shown in Table C1.

Table C1 The approximate range of velocities for compressional waves in soil, rock, and fluid (after Jakosky 1957).

Material or Fluid	Velocity (ft/sec)	Transit Time (µs/ft)
Weathered Surface	800–2,000	1,250–500
Gravel or Dry Sand	1,500–3,000	666.7–333.4
Saturated Sand	4,000–6,000	250–166.7
Saturated Clay	3,000–9000	333.3–111.1
Water	4,700–5,500	212.8–181.8
Sea Water	4,800–5,000	208.3–200
Sandstone	6,000–13,000	166.7–76.9
Shale	9,000–14,000	111.1–71.4
Chalk	6,000–13,000	166.7–76.9
Limestone	7,000–20,000	142.9–50
Granite	15,000–19,000	66.67–52.6
Metamorphic Rock	10,000–23,000	100–43.5

RESULTS

The results of the geophysical logging supported the decision not to construct a monitoring well within the bedrock from 130 to 230 feet bgs. Multiple intervals from the core and geophysical logs were observed and compared closely on site for possible screened intervals. The Seahorn Limestone (Table B3) from 21 to 200 feet bgs (as well as the upper and lower contact), the Colchester Coal and upper and lower contacts from 200 to 203 feet bgs, and the siltstone from 167.6 to 186 feet bgs were all considered as possible intervals for a monitoring well based on the real-time logging. Another major consideration was the borehole fluid, which had stayed within 1 foot of the top of the casing for the duration of the logging, approximately 8 hours. The driller noted that he used a thin mud and that there was no noticeable mud loss to the hole during drilling. The mud had been recirculated with clean water prior to the logging. These field observations strongly suggested that no zones of significant porosity and permeability existed that would be suitable for monitoring well construction.

The compressional and in particular, the shear wave velocities from the FWS log velocity analysis were picked both automatically and manually. Where the wave peaks from the automatic velocity analysis were not obvious, picks were drawn manually. This occurred at several intervals throughout the FWS log, specifically where lower velocities were recorded, where sharp transitions occurred, and where cyclical layering was evident. This can create a challenge in determining precise velocities within those intervals, not only for shear wave, but also for compressional waves. The FWS probe used in this study uses a single transmitter-dual receiver configuration. Shear and compressional wave velocities can be ascertained with this probe configuration in formations where velocities are higher and borehole conditions are optimum. However, where formation velocities are lower than that of the borehole fluid, the velocity of the fluid will be pronounced. Therefore, discretion should be used when referencing both p-and s-wave velocities, and in particular the s-wave velocities. Throughout most of the borehole, p-waves were relatively well pronounced as compared with the s-waves. The Poisson's ratio and tube wave reflection logs warrant the same consideration and are presented for general reference only. The software used for post-processing of the geophysical logs was WellCAD v4.3. In addition to the geophysical log profiles, lithologic and stratigraphic descriptions are provided as well.

Geophysical Log Files

The file format for the geophysical logs is PDF. The PDF format has proved to be excellent for converting large graphic files with minimal sacrifice for image quality while creating a manageable file size. The following describes the PDF files delivered to the funding agent and naming convention:

121372213100_ALL_BR_6SCALE_36W
121372213100_ALL_BR_12SCALE_36W
121372213100_ALL_BR_60SCALE_36W
121372213100_ALL_120SCALE_36W
121372213100_TRACE&FWS_60SCALE_11W
121372213100_TRACE&FWS_120SCALE_11W
121372213100_TRACE&FWS_240SCALE_11W

For file names, the beginning series of numbers are the American Petroleum Institute (API) number provided by the ISGS for this particular well. "ALL" indicates that all logs recorded are in the file. "BR" denotes that only the bedrock portion of the hole is shown. "TRACE" stands for simple line trace logs (non-image logs). "FWS" stands for "full waveform sonic" log, which is a combination of multiple image and trace logs, all recorded from a single probe, referred to as an FWS probe. "SCALE" provides information on the log depth scale. For instance, 6SCALE is a log with a 1:6 ratio, or 1 inch = 0.5 feet. The last portion of the file represents the page width in inches for which the file was created.

APPENDIX D: SURFACE 1-D EARTH ELECTRICAL RESISTIVITY SURVEY

Timothy C. Young

Hydrogeology & Geophysics Section, Illinois State Geological Survey

INTRODUCTION

An electrical earth resistivity (EER) study was undertaken on August 31, 2011. The purpose of the EER survey was to test the unconsolidated material above the bedrock in order to obtain a basis for suggesting an alternative test drilling location and possibly the construction of an additional shallow monitoring well. The project investigators needed to know if there was a more suitable location for shallow groundwater testing purposes. A shallow monitoring well was completed at the site on August 26, 2011, and was limited for testing due to low permeability of the formation in which the well was constructed. In an attempt to place the screen within an interval that might produce sufficient fluid for sampling, a well was constructed within a zone that appeared to be the most favorable for that purpose. Core samples and the gamma log indicated that conditions were marginal for the production of groundwater.

Location and Coverage

A total of 20 EER stations were flagged on average, on a grid with nodes at 100- to 150-foot intervals (Table D1, Figure D1), and their locations determined with a GPS. Thirteen stations (1–13) bordered the ~7.0-acre outer perimeter of the site, which was the edge of the surrounding cornfield at the time of the survey, as shown in Figure D1. Seven stations (14–20) bordered the gravel drilling pad perimeter. A total of six depth soundings were recorded at each station at 20-foot intervals to a maximum depth of 120 feet.

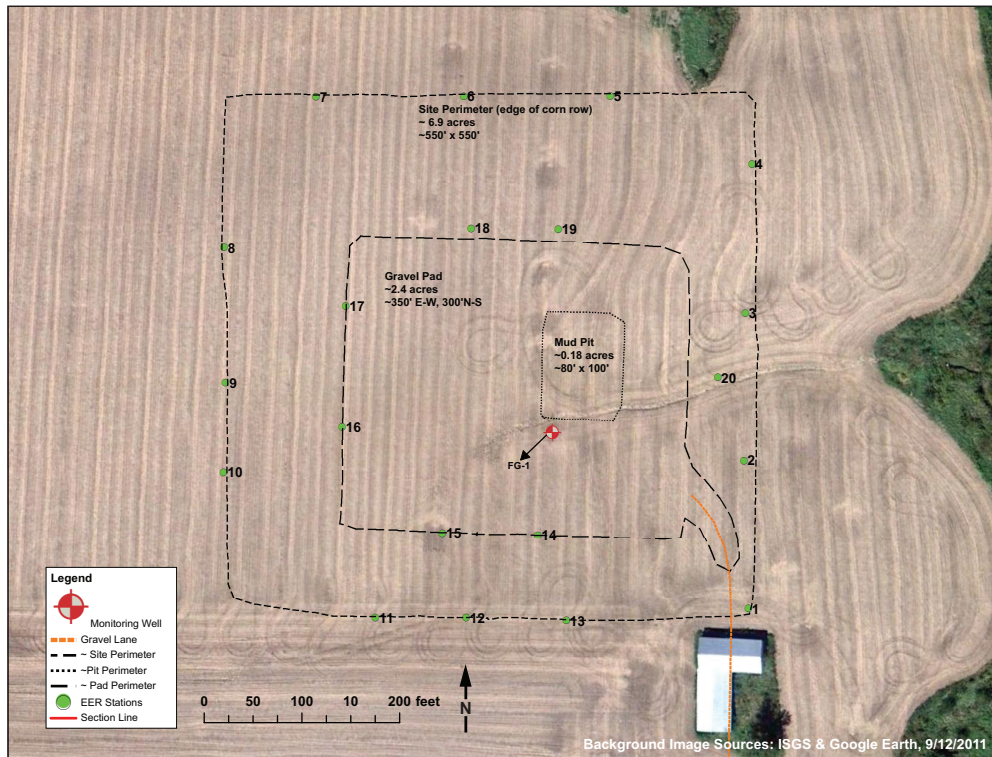


Figure D1 Site map showing the perimeters of the standing corn, gravel pad, and mud pit. The EER stations, monitoring well, gravel lane, and a preexisting structure are also shown.

Methodology

An EER is based on the principle that fine-grained, compact, non-water-yielding earth materials, such as glacial till and shale, present less resistance (i.e., higher conductivity) to the passage of electrical current than coarse grained, water-bearing deposits (such as sand and gravel). Higher resistivity typically indicates water-bearing sand and gravel deposits, whereas lower resistivity may indicate less permeable, fine-grained deposits composed of clay and silt. Overall groundwater chemistry can also have a pronounced effect on resistivity, particularly if it is highly mineralized. The resistivity method is sensitive to naturally occurring and manmade conditions and can be useful in delineating variations in groundwater quality in shallow alluvial (sand and gravel) aquifers. For this study, a Wenner electrode configuration was used where electrode spacing (a-spacing) is the same between all four electrodes. The station point is the center of the line, with current electrodes (one on each side) being the furthest outer electrodes and the potential electrodes being the inner electrodes. As the spacing between electrodes (a-spacing) increases, the depth of investigation increases. At each station a total of six soundings were recorded at 20-foot a-spacing up to 120-foot a-spacing (Figure D1). This particular 1-D method by the ISGS requires a five-person field crew: 1 person for each electrode and cable, and the equipment operator, as shown in Figure D2. An Abem, 300B Terrameter was used to record the soundings for this study.

The EER serves as a screening tool by delineating areas that are favorable to finding aquifer materials as opposed to areas that are less favorable for finding these materials. Reasons for using EER are to 1) investigate a large area where test drilling has been unsuccessful in identifying aquifer material or limited geological data exists from well logs or other sources, 2) investigate an area that is considered marginal or limited in terms of groundwater, and/or 3) determine the most favorable locations over the least favorable locations for well placement before investing in further test drilling. The base map and resistivity contour maps show the locations and corresponding apparent resistivity contours of the 20 stations. The contour plot maps were



Figure D2 Taking a reading at 20-foot a-spacing, where the interval between electrodes is 20 feet, along south edge of the gravel pad. The 2-outer reels are the current electrodes and the inner ones are potential.

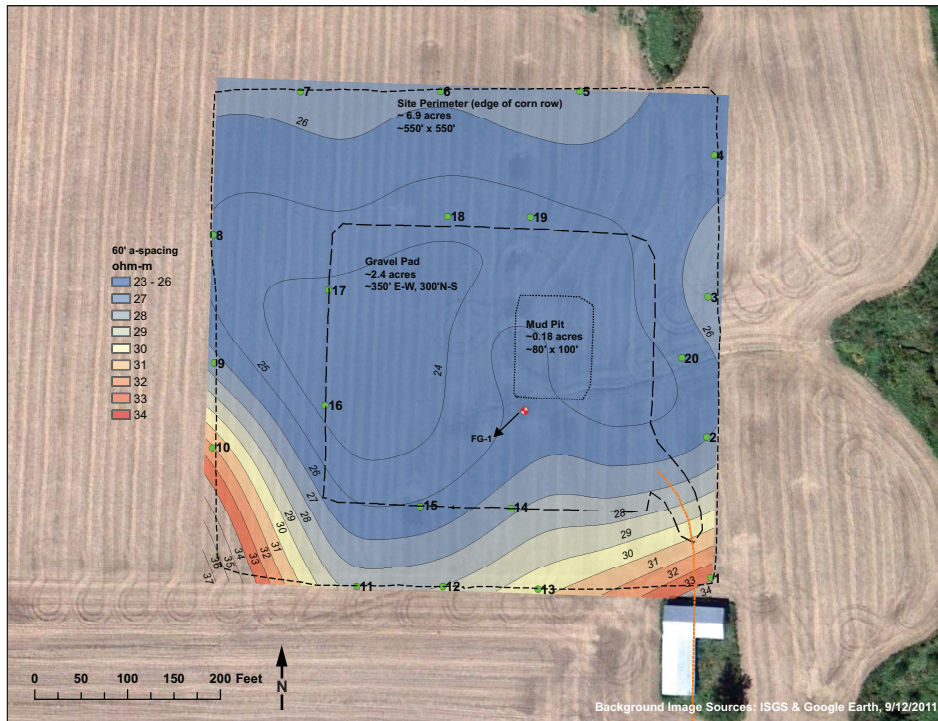


Figure D3 Resistivity contour of the 60 foot a-spacing, where the interval between electrodes is 60 feet, showing increased resistivity in the southwest and southeast portions of the FutureGen 2 site.

created using spatial analysis for interpolating and plotting the data in a graphic format, showing trends that would otherwise be difficult to detect. The color variations on the contour maps reflect the range in apparent resistivity values. Red, orange, and yellow colors indicate higher resistivity values, and blue reflects lower resistivity values.

Sandstone and limestone bedrock are more resistant to the passage of current (as opposed to clay-rich material), and locations with limestone or sandstone at the bedrock surface are not always interpreted as such. However, it is unlikely that any increased resistivity noticed within the range of the survey was due to the presence of limestone or sandstone at the bedrock surface. A slight increase in overall resistivity detected at the southwest and southeast corners of the site appeared to be from shallower formations. It is also a possibility that an unknown manmade feature, such as buried pipe or tile, is causing the increased resistivity.

A Trimble Pro XR Global Positioning System (GPS) was used to create the north-south and east-west grid orientation within the floodplain. The positional accuracy of the GPS coordinates at each location after differential correction is less than 3 feet.

RESULTS

The general trend within the range of the survey suggests that the southwest and southeast corners of the survey may have slightly better potential for an increased presence of sand or gravel. A pattern was detected in the southwest portion of the site near stations 10 and 11 as well as near station 1 (Figure D3). The slightly increased resistivity values in the area decrease with depth, suggesting that the increased resistivity is likely from within the upper one-half or two-thirds of the unconsolidated Quaternary sediments. The slightly higher resistivity at station 1 occurs shallower (higher elevation) than at station 10. A possible reason for the increased resistivity at station 1 might be that a shed existed just south of this station and where the resistivity lines would have crossed. The structure can be seen in Figure D1, and was removed before this survey was conducted. Any remaining structure buried beneath the surface such, as a foundation (gravel, concrete, etc.), would almost certainly increase resistivity. Another possible explanation is that the increase in elevation at this station could increase the thickness of material above the water table, resulting in an increased resistivity with depth.

CONCLUSIONS

The slight increase in resistivity in the southwest and southeast portions of the study area suggests there is a slightly greater potential for increases in, sand, and/or gravel content within or between the Vandalia and Smithboro till units (Table B3). This could be due to an overall increase in the percentage of coarser-grained material throughout an entire till unit, or it could be due to the presence of a thin water-bearing sand or silt layer such as might exist as a transition between the Smithboro or Vandalia till units. An increase in calcite or dolomite clasts within the till would also increase resistivity. Note the increase in calcite and dolomite as well as sand between 27 to 47 feet in Figure D4. The downhole gamma log revealed a slightly lower count rate from within this same interval (Appendix C). As already indicated, unknown man-made objects could also increase resistivity, which may be the case at station 1.

If the decision is made to construct another well, a test hole should be drilled in either the southwest or southeast corner of the site perimeter as shown on the site map. Anything encountered near station 1 is expected to be shallower than near station 10. The test hole should be drilled 5 feet into bedrock if possible and provisions should be made to allow for open-hole logging if possible. This will allow for running resistivity and full-waveform sonic logs in addition to gamma and will help to determine which formation might be best for the construction of a monitoring well. It will also provide a baseline for any further shallow test drilling in the future. Test drilling should be performed as close to the recommended locations as possible. Locating the stations should be performed with a GPS capable of at least 10-foot accuracy when navigating in real time. If there is a need to install additional monitoring wells within the unconsolidated glacial drift, consideration should also be given to expanding the resistivity grid. This will help to determine if the trends in the southwest and southeast continue and whether or not more favorable locations exist for the construction and development of a monitoring well or wells beyond the perimeter of the drill pad.

Figures D5 to D9 show the results from the different spacings at which data were collected. Figure D10 shows an overview of the surrounding area and a GPS trace of the road constructed by FutureGen 2.

Table D1 EER site survey, August 31, 2011, GPS coordinates, WGS84

Station	Latitude	Longitude
1	39.806231220	-90.052073657
2	39.806647340	-90.052108078
3	39.807060575	-90.052121523
4	39.807480370	-90.052116678
5	39.807656539	-90.052638525
6	39.807641163	-90.053170599
7	39.807626544	-90.053706539
8	39.807193665	-90.054021324
9	39.806815865	-90.053999379
10	39.806565976	-90.053996147
11	39.806170142	-90.053426675
12	39.806178790	-90.053097208
13	39.806180676	-90.052732809
14	39.806419164	-90.052846905
15	39.806415564	-90.053194034
16	39.806702210	-90.053570427
17	39.807041759	-90.053572648
18	39.807272213	-90.053126818
19	39.807278790	-90.052811168
20	39.806877477	-90.052213500

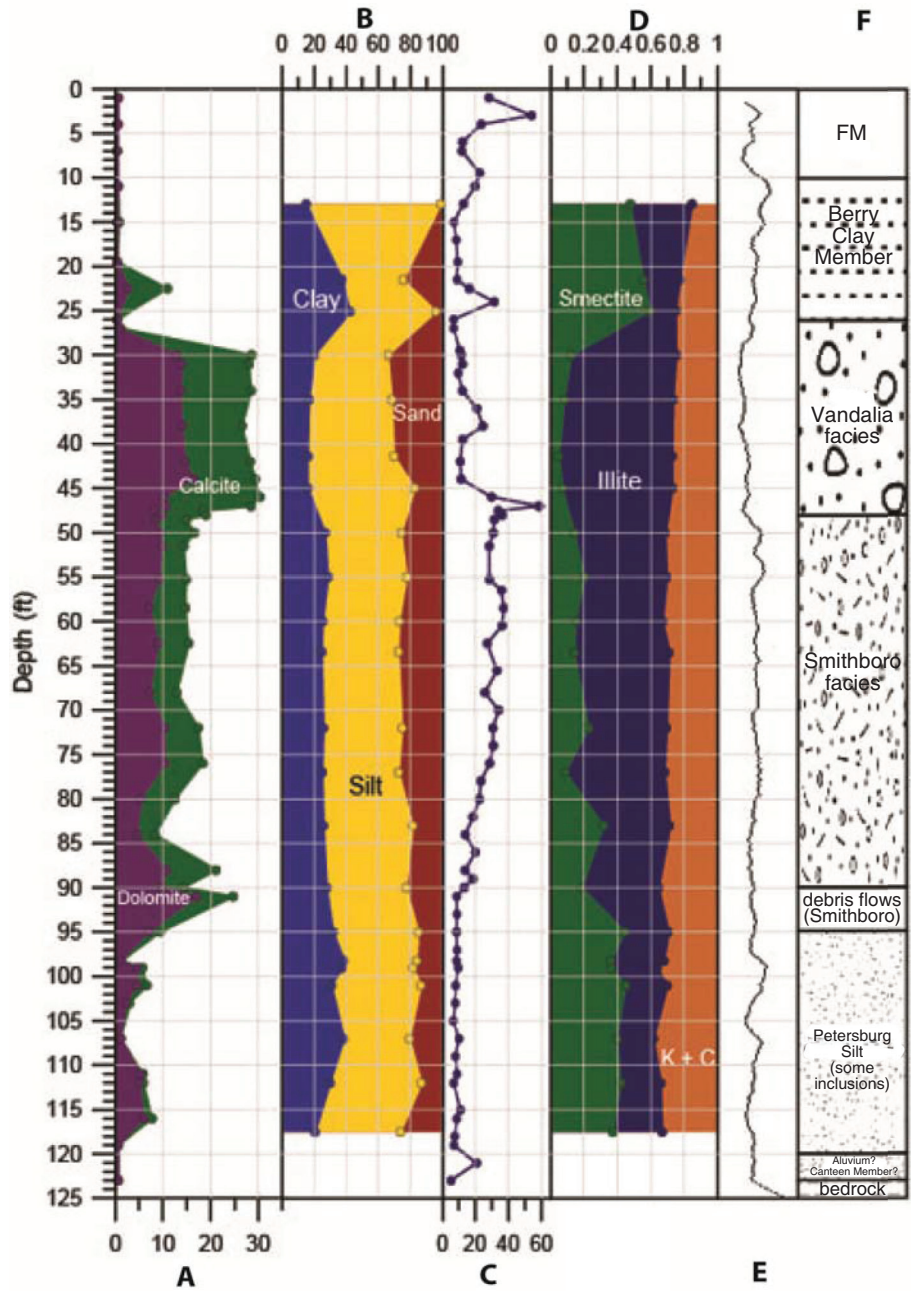


Figure D4 Quaternary sediments from the test boring. Columns A-F: A shows the ratio of calcite/dolomite; B: particle size distribution percent sand, silt, clay; C: magnetic susceptibility ($10^{-4} \text{ m}^3/\text{kg}$); D: clay mineralogy; E: resistivity (0–200 ohm-m); F: geologic interpretation.

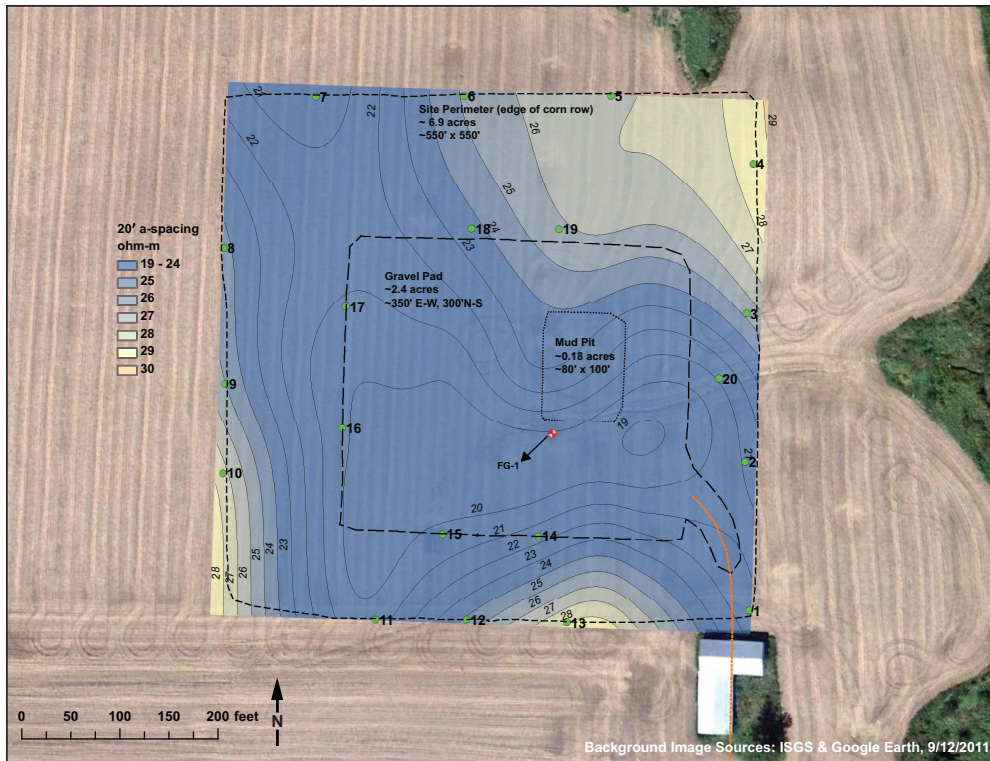


Figure D5 Resistivity contour of the 20-foot a-spacing, where the interval between electrodes is 20 feet.

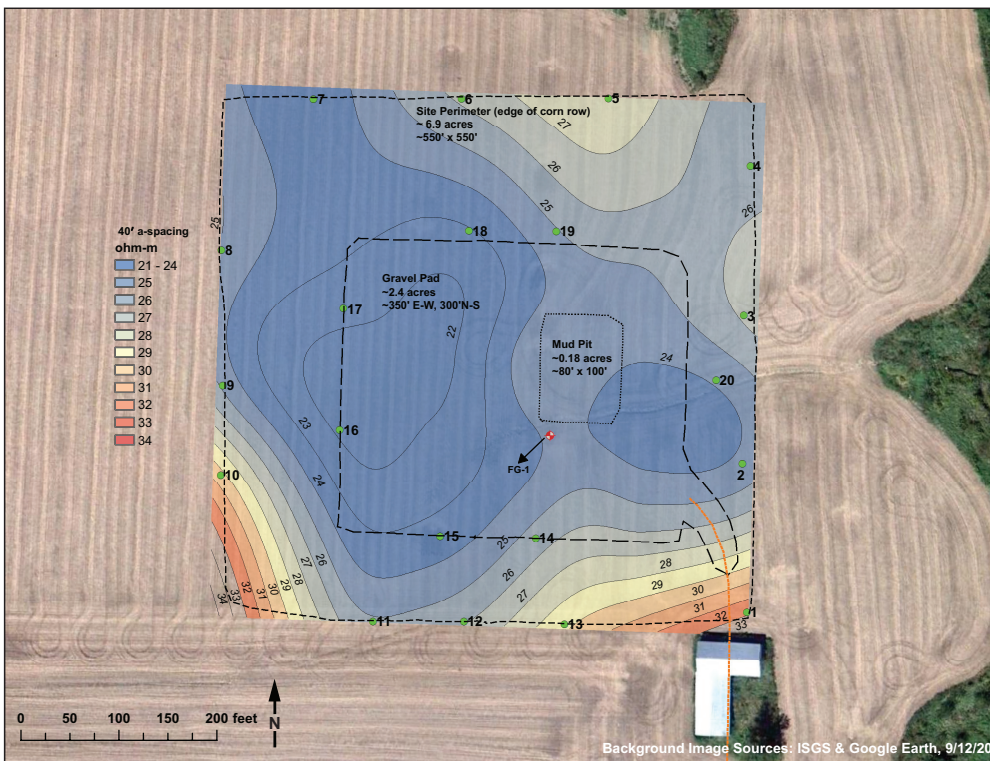


Figure D6 Resistivity contour of the 40-foot a-spacing, where the interval between electrodes is 40 feet.

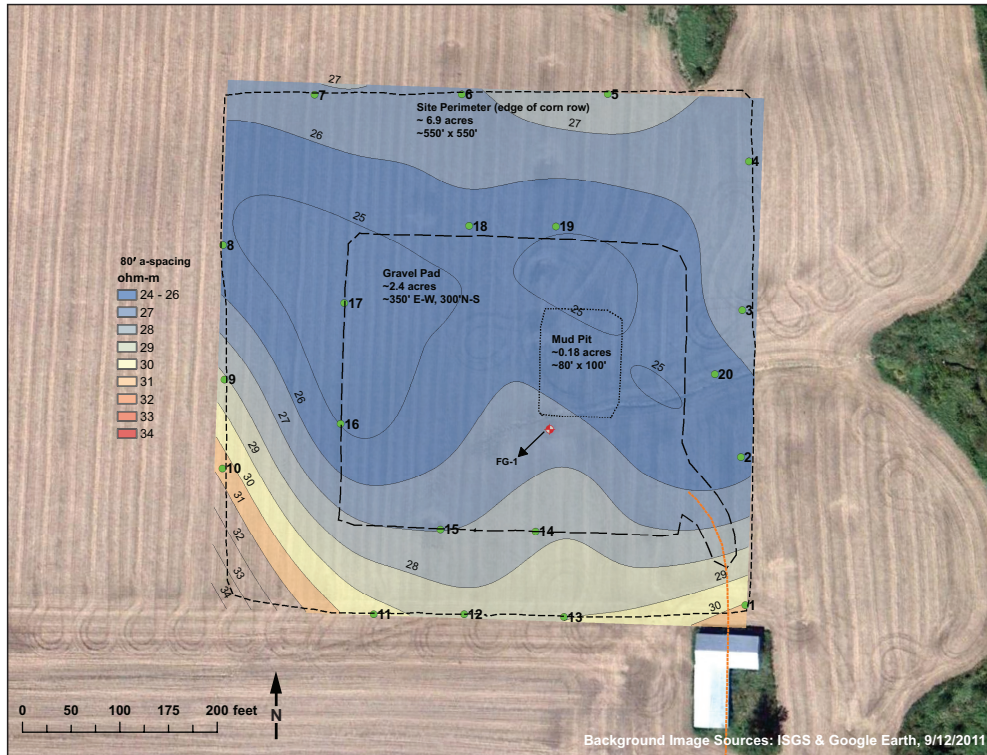


Figure D7 Resistivity contour of the 80-foot a-spacing, where the interval between electrodes is 80 feet.

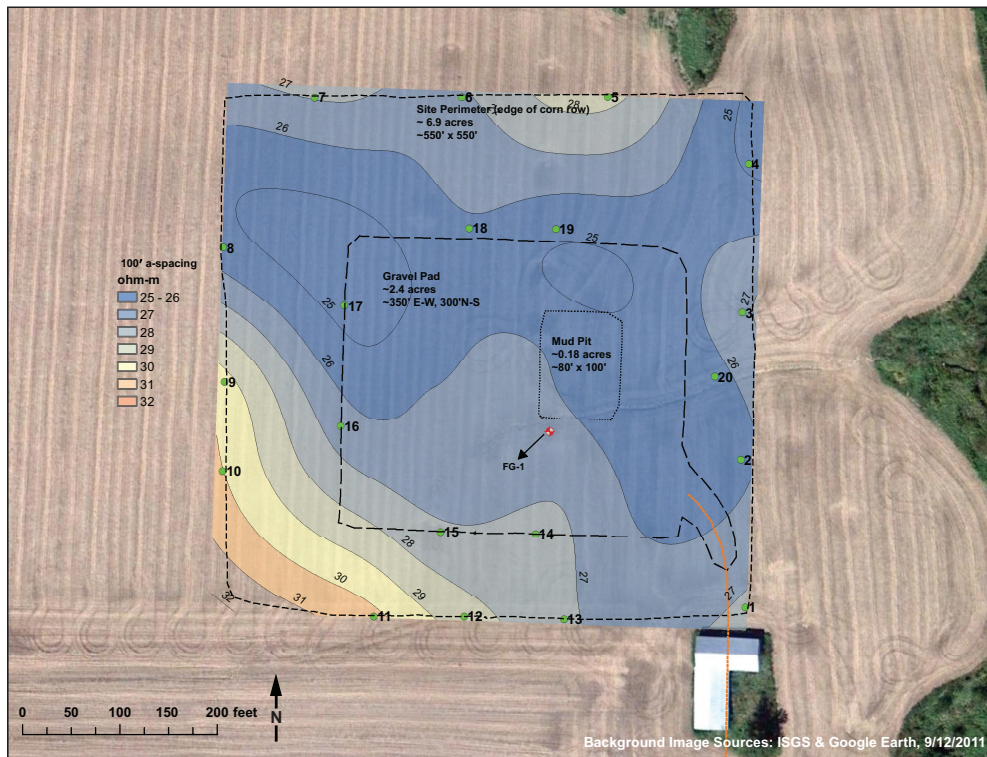


Figure D8 Resistivity contour of the 100-foot a-spacing, where the interval between electrodes is 100 feet.

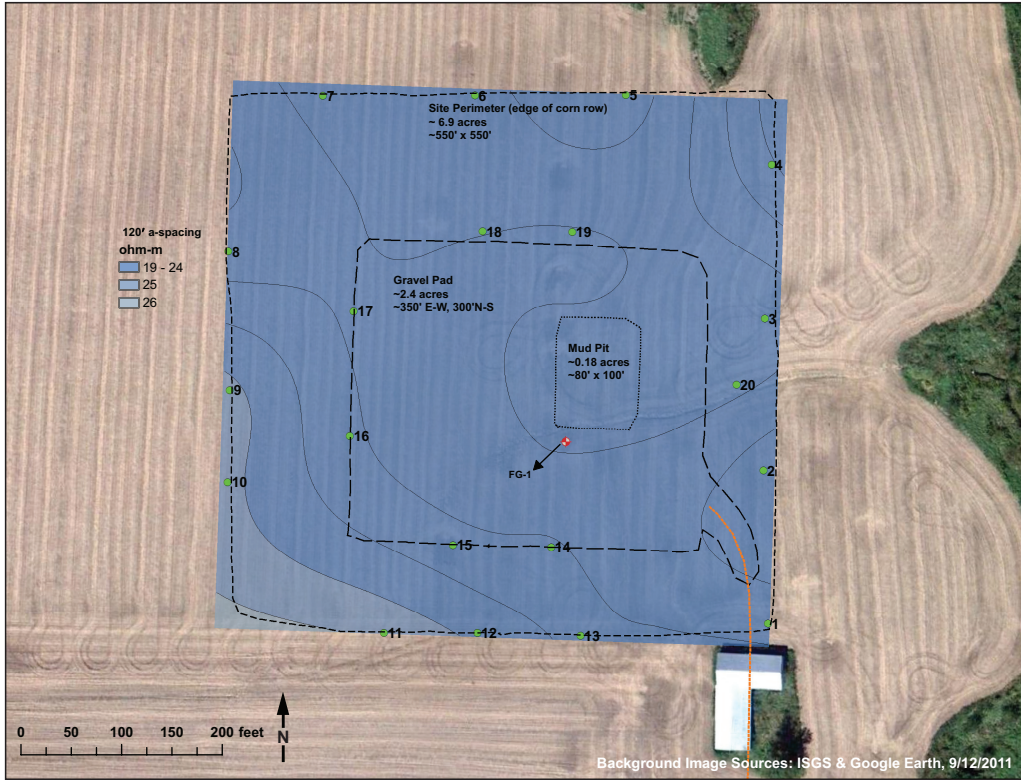


Figure D9 Resistivity contour of the 120-foot a-spacing, where the interval between electrodes is 120 feet.



Figure D10 Overview of survey area and GPS trace of road built for the FutureGen 2 site.

APPENDIX E: RESULTS FROM ISOTOPE ANALYSIS OF WELL WATER SAMPLES

Keith Hackley

Isotope Geochemistry Section, Illinois State Geological Survey

The oxygen ($\delta^{18}\text{O}$) and hydrogen (δD) isotopic compositions of the groundwater samples collected at the FutureGen 2 site were very consistent, falling within a narrow range of $-6.98 \pm 0.13\text{‰}$ and $-46.0 \pm 1.1\text{‰}$, respectively (Table E1). The range of isotopic composition fits well within the range observed for other groundwater samples collected from unconsolidated sand and gravels in Central Illinois, such as the Glasford and Mahomet aquifers (Hackley et al., 2010). The data from the FutureGen 2 site are typical of present-day precipitation (Holocene type climate) and show no evidence of input from Pleistocene water (Figure E1). These results put an upper limit on the age of the groundwater sampled to less than about 10,000 to 11,000 years, the beginning of the modern climate in Illinois as determined by palynology studies (Van Zant, 1979, King, 1981). The climate during the late Pleistocene was very cold and continental glaciers were present. Recharge to the groundwater during the colder climate of the Pleistocene and from glacial meltwaters had much lower isotopic ratios compared with modern precipitation (Clark and Fritz, 1997).

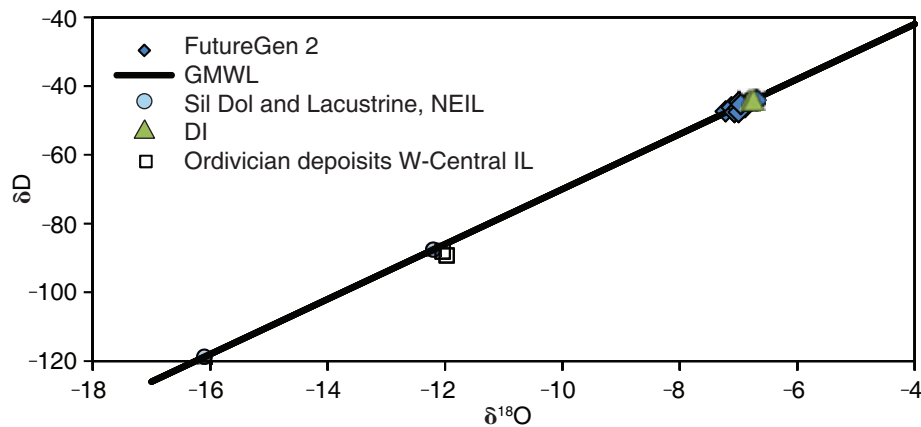


Figure E1 Isotopic composition of groundwater samples from the FutureGen 2 site. Above graphs demonstrates the relationship of the groundwater samples from the site and distilled water field blank samples (DI) with the Global Meteoric Water Line (GMWL) and two examples of groundwater in Illinois that show evidence of significant inputs of water from the cold climate during the Pleistocene glaciation periods. (The square symbols are data from Gilkenson et al, (1981) and the circles are from Hackley et al., (1999).

Table E1 Isotopic composition of aqueous samples from FutureGen 2.

Sample ID	Date	TDIC mg/L	$\delta\text{DH}_2\text{O}$ (‰)	$\delta^{18}\text{OH}_2\text{O}$ (‰)	$\delta^{13}\text{C}_{\text{DIC}}$ (‰)	Tritium (TU)	std dv. ± TU	$^{14}\text{C}_{\text{DIC}}$ pMC	std dv. ± pMC
FG-Morgan-1A-20111025	10/25/11	368.5	-46.1	-6.89	-13.3	5.59	0.23	95.9	0.17
FG-Morgan-2A-20111025	10/25/11	496.2	-45.0	-6.86	-12.4	4.54	0.24	74.8	0.17
FG-Morgan-3-20111025	10/25/11	459.1	-46.2	-7.12	-12.8	3.51	0.26	65.9	0.17
FG-Morgan-5-20111025	10/25/11	437.7	-44.1	-6.71	-12.1	4.16	0.25	87.4	0.18
FG-Morgan-6A-20111102	11/02/11	524.9	-44.7	-6.99	-13.3	5.30	0.25	96.2	0.22
FG-Morgan-7A-20111102	11/02/11	604.3	-45.7	-6.96	-9.3	4.62	0.27	60.9	0.17
FG-Morgan-8A-20111102	11/02/11	537.2	-47.6	-7.07	-17.4	3.96	0.26	57.8	0.17
FG-Morgan-8A-20111102 (Dup)	11/02/11	516.3			-17.4				
FG-Morgan-9-20111102	11/02/11	496.2	-46.4	-7.00	-13.0	5.06	0.27	89.4	0.17
FG-Morgan-11-20111102	11/02/11	372.2	-47.6	-7.00	-12.2	4.73	0.26	81.8	0.17
FG-Morgan-12A-20111110	11/10/11	352.9	-47.4	-7.22	-12.5	4.47	0.27	76.0	0.16
FG-Morgan-14-20111110	11/10/11	478.8	-45.3	-6.96	-10.6	5.50	0.30	69.3	0.17
FG-Morgan-10-20111102	11/02/11		-44.1	-6.82					
FG-Morgan-13-20111110	11/10/11		-43.9	-6.76					

The carbon isotopic composition ($\delta^{13}\text{C}$) ranged from -9.3 to -17.4‰ , with most of the results falling between -12.1 and -13.3‰ (Table 1). Carbon isotopic composition of -12 to -13‰ is typical for dissolved inorganic carbon (DIC) of groundwater for temperate areas with vegetation dominated by plants that utilize the Calvin cycle photosynthetic pathway, often referred to as “ C_3 ”-type plants. C_3 -type plants include the majority of plants, including most trees, shrubs, legumes, and cool-season grasses (Clark and Fritz, 1997). The fractionation associated with C_3 -type photosynthesis yields a $\delta^{13}\text{C}$ composition for the plant ranging from -22 to -35‰ , with majority of values falling between -24 to -28‰ (Deines, 1980; Farquhar et al., 1982; Ehleringer, 1988). Considering the effects of diffusion as soil CO_2 escapes from the soil environment to the atmosphere, which is typically about a 4‰ fractionation (Cerling et al., 1991), soil CO_2 dominated by C_3 -type vegetation typically ranges between -20 and -24‰ . Other plants that grow in more arid and water-stressed environments, as well as some common agricultural crops such as corn and sorghum, use the Hatch-Slack photosynthetic cycle and are often referred as “ C_4 ”-plants (Ehleringer, 1988). The $\delta^{13}\text{C}$ of C_4 vegetation ranges from about -7 to -16‰ and typically average about -12‰ (Deines, 1980; Ehleringer, 1988). There is a third photosynthetic pathway, Crassulacean acid metabolism (CAM), that is utilized by plants that are predominant in desert environments that we will not address in this report since this type of environment has no relevance in Illinois.

The $\delta^{13}\text{C}$ of the DIC in shallow groundwater is quite dependent on the type of vegetation growing in the area. The soil CO_2 , produced from root respiration and organic degradation, is dissolved into water that infiltrates the soil zone. Thus, the recharge water accumulates the soil CO_2 as it percolates through the ground. As the water penetrates deeper into the sediments, it will begin to dissolve any sedimentary carbonates present in the ground. Most sedimentary carbonates originate from marine environments and have $\delta^{13}\text{C}$ values close to 0‰ plus or minus a few per mil (Anderson and Arthur, 1983). The final $\delta^{13}\text{C}$ of the total DIC for shallow groundwater will be a combination of soil CO_2 (e.g., -24‰) and dissolution of carbonates (e.g., 0‰). Thus, for soils dominated by C_4 plants and dissolution of carbonates in a closed system, the $\delta^{13}\text{C}$ of the total DIC will be some average value between the $\delta^{13}\text{C}$ of the soil CO_2 and of carbonates, resulting in a value close to -12‰ . There are sometimes more complicated details, such as whether the dissolution of carbonate occurs in an open versus a closed system relative to the reservoir of soil CO_2 , that could also be considered. However, it is reasonable to assume the dissolution of most carbonates occurs in a closed system, considering the water table in Illinois is typically very close to the surface and, in the shallow groundwater environments, percolation occurs fairly rapidly to the water table. Of course, as the groundwater continues to move deeper into the sediments, additional reactions may begin which could affect the carbon isotopic composition, especially as the system becomes more reducing and redox reactions involving organic carbon become relevant. For example, if microbial sulfate reduction occurs that involves the oxidation of organic carbon, then this can significantly affect the $\delta^{13}\text{C}$ value of the DIC, causing it to shift to more negative values. On the other hand, if microbial methanogenesis occurs, then the $\delta^{13}\text{C}$ of the DIC would shift to more positive values. These types of effects have been observed by Hackley et al. (2010) in the Mahomet and Glasford aquifers in Central Illinois.

The tritium concentration of the groundwater sampled from the shallow wells at the FutureGen 2 site had a fairly narrow range from 3.5 to 5.6 TU (Table 1). This range of tritium is typical of groundwater recently recharged within the past few years to decades. The range of tritium observed in these wells is similar to that observed in the shallow karst springs of southwestern Illinois (Hackley et al., 2007). Tritium is useful for determining whether there has been recent recharge into an aquifer. Normally, if tritium is detectable in groundwater at levels greater than 0.8 to 1 TU, then the aquifer contains some component of modern water, or water that precipitated since the early 1950's. Water recharged prior to 1950, with an initial tritium concentration of 10 TU, would now have tritium levels less than 0.8 TU today. Alternatively, low tritium concentrations in groundwater may be a result of a mixture of much older groundwater with relatively young recently recharged water.

The carbon-14 (^{14}C) activity ranged from 57.8 to 96.2 pMC (percent modern carbon); (Table 1). For groundwater, this range of ^{14}C activity suggests relatively modern water recharge. In an open system, the ^{14}C activity of DIC will be the same as the soil CO_2 . Usually, soil CO_2 is presumed to have a ^{14}C activity of 100 pMC, because it is dominated by root respiration (Clark and Fritz, 1997). In a closed system, the ^{14}C activity of the DIC will represent a “50:50” mixture of carbon from the soil CO_2 and from the carbonate

minerals. This occurs because one mole of dissolved CO_2 is neutralized to HCO_3^- by one mole of calcite. The carbonates in most soils, especially those in glacial tills that cover much of the landscape in the Midwest, are from ancient limestone and dolomite deposits that are millions of years old and free of ^{14}C activity. Thus, as infiltrating groundwater dissolves carbonates under closed system conditions, the ^{14}C activity of DIC should be about 50 pMC (half from the soil CO_2 and half from the carbonates); (Clark and Fritz, 1997). In reality, the dissolution of carbonates during groundwater infiltration occurs in some combination of open and closed systems. Therefore, the initial DIC in groundwater that has passed through the soil zone should have a ^{14}C activity somewhere between 100 and 50 pMC. The use of tritium in combination with ^{14}C analyses can indicate whether a component of the groundwater has recharged within the past 50 years. If no tritium is detected and the ^{14}C activity is less than 50 pMC, the groundwater is likely to be hundreds or thousands of years old (Mook, 1980).

As long as the background conditions have been well characterized, it should be possible to monitor future changes in the chemistry and isotopic composition of the shallow groundwater system and determine whether the shallow aquifers have been affected by injected CO_2 . The sensitivity of detecting the injected CO_2 in the shallow aquifer using isotopic analyses will depend on how large the difference is between the isotopic compositions of the injected and the dissolved CO_2 in the shallow aquifers.

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APPENDIX F: RESULTS FROM VOC AND METAL ANALYSIS OF WELL WATER SAMPLES BY PNNL LABS

James E. Szecsody

Pacific Northwest National Laboratory

Twenty water samples were collected by ISGS personnel in Morgan County, IL, and were shipped to the Pacific Northwest National Laboratory (PNNL) for analysis. The samples were analyzed for volatile organic compounds (VOC) using a gas chromatography (GC)-mass spectrometry (MS) system, a GC-purge and trap (P&T) system, and a GC-flame ionization (FID) system; and for trace metals using an inductively coupled plasma-mass spectrometer (ICP-MS) system.

GC-MS for VOC

A Hewlett Packard 5890 gas chromatograph equipped with a MS was used for sample analysis. Procedure PNNL-VOA-4, entitled “Volatile Organic Compounds in Water by Gas Chromatography/Mass Spectrometry Capillary Column Technique with Head Space Sample Introduction”, was followed. Organic compounds were separated on a 30 mL and 0.32 mm I.D. GS Gas Pro column. Four-level calibration was applied. Calibration standards were prepared from commercial preparations containing a set of volatile organic compounds. Quality Control (QC) procedures included the use of QC standards and daily calibration. Satisfactory instrument operation was verified by using QC standards for sensitivity and stability. Internal standards were also included with all of the calibration standards and samples. The results are presented in Table F1.

GC-P&T for VOC

The water samples were analyzed using a Hewlett Packard 5890 gas chromatograph fitted with a Purge and Trap system (Model Eclipse 4460, O. I. Analytical) with Photoionization (Model 4430, O.I. Analytical) and Electrolytic Conductivity. (Model 5300, O.I. Analytical) detectors. Solute compounds were separated on a 105 meter by 0.53 millimeter megabore capillary column (RTX 502.2, Restek Corporation) and quantified using a four-point calibration. Calibration standards were prepared from two commercial standards consisting of 20 volatile hydrocarbons in methanol (Restek DW-VOC Mix #1A and Restek DW-VOC Mix #2). Only chloroform was detected in three samples, FG_MORGAN_6A_20111102, FG_MORGAN_6B_20111102, and FG_MORGAN_14_20111110. Results are presented in Table G2.

GC-FID for VOC

Water samples were analyzed for methane, ethane, ethylene, and acetylene by headspace analysis using a Hewlett Packard 5890 gas chromatograph with a flame ionization detector (FID). A gas sampling loop was used to introduce samples into a 30 m x 0.32 mm I.D. GS Gas Pro column. Calibration standards were prepared from a 1% Scotty standard (01-04-216-48) containing the four components of interest. A four-point calibration curve ranging from 1 to 1000 ppm was used.

VOC Analysis Results

VOC concentrations were generally near or less than analytical detection limits, and were much less than applicable U.S. EPA drinking water standards. Methane was the only VOC measured at elevated concentrations in a few of the groundwater samples. However, because of inconsistencies in comparative analyses for duplicate samples, multiple replicates of individual samples, and sample blanks, the validity of these results is suspect and thus, the GC-FID results have not been reported. Although the exact cause of the measurement irregularities is unknown, they are thought to result from sample contamination and/or microbial reactions that occurred in the sample vials during the holding time (the samples were not acid-preserved). It is also possible that the absence of other VOCs in the samples may have been the result of degradation. During future sampling events, VOA samples may be collected and analyzed so that the concentration of methane and other volatile compounds in site groundwater can be effectively assessed. All future sampling will be conducted using pre-acidified vials.

Table F1a Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Methylene Chloride (ppb)	Dibromo Methane (ppb)	1,1-ichloro ethene (ppb)	Trans-1,2 dichloro-ethane (ppb)
MDL		0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
MCL (Primary & Secondary Drinking water standards)				7	100
FG_MORGAN_1A_20111025	FGP-1	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.01	<0.01	<0.01	0.01
FG_MORGAN_2A_20111025	FGP-2	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_2B_20111025	FGP-2 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_3_20111025	FGP-3	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_4_20111025	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_5_20111025	FGP-4	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_6A_20111102	FGP-5	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_6B_20111102	FGP-5 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_7A_20111102	FGP-6	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8A_20111102	FGP-7	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_9_20111102	FGP-8	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_10_20111102	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_11_20111102	FGP-9	<0.01	<0.01	<0.01	0.04
FG_MORGAN_12A_20111110	FGP-10	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_12B_20111110	FGP-10 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_13_20111110	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_14_20111110	FG-1	<0.01	<0.01	<0.01	0.06
MINIMUM		<0.01	<0.01	<0.01	<0.01
MAXIMUM		<0.01	<0.01	<0.01	0.06
AVERAGE		<0.01	<0.01	<0.01	0.037

Table F1b Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Chloro- form (ppb)	1-propene-1, 1-dichloro (ppb)	Bromo- dichloro methane (ppb)	1, 2 dichloro- ethane (ppb)
MDL		0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
MCL (Primary & Secondary Drinking water standards)		70			7
FG_MORGAN_1A_20111025	FGP-1	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_2A_20111025	FGP-2	0.05	<0.01	<0.01	<0.01
FG_MORGAN_2B_20111025	FGP-2 Dup.	0.05	<0.01	<0.01	<0.01
FG_MORGAN_3_20111025	FGP-3	<0.01	0.03	0.02	<0.01
FG_MORGAN_4_20111025	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_5_20111025	FGP-4	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_6A_20111102	FGP-5	0.56	<0.01	<0.01	<0.01
FG_MORGAN_6B_20111102	FGP-5 Dup.	0.56	<0.01	<0.01	<0.01
FG_MORGAN_7A_20111102	FGP-6	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8A_20111102	FGP-7	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_9_20111102	FGP-8	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_10_20111102	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_11_20111102	FGP-9	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_12A_20111110	FGP-10	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_12B_20111110	FGP-10 Dup.	0.01	<0.01	0.06	<0.01
FG_MORGAN_13_20111110	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_14_20111110	FG-1	0.74	<0.01	<0.01	0.06
MINIMUM		<0.01	<0.01	<0.01	<0.01
MAXIMUM		0.74	0.03	0.06	<0.01
AVERAGE		0.33	0.03	0.04	<0.01

Table F1c Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	1, 2 dibromo methane (ppb)	2, 2-dichloro propane (ppb)	Trichloro-ethene (ppb)	1, 1, 2-trichloro ethane (ppb)
MDL		0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
MCL (Primary & Secondary Drinking water standards)				5	5
FG_MORGAN_1A_20111025	FGP-1	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_1B_20111025	FGP-1 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_2A_20111025	FGP-2	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_2B_20111025	FGP-2 Dup.	<0.01	<0.01	<0.01	0.09
FG_MORGAN_3_20111025	FGP-3	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_4_20111025	BLANK	<0.01	<0.01	0.01	<0.01
FG_MORGAN_5_20111025	FGP-4	0.04	<0.01	<0.01	<0.01
FG_MORGAN_6A_20111102	FGP-5	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_6B_20111102	FGP-5 Dup.	<0.01	0.03	<0.01	<0.01
FG_MORGAN_7A_20111102	FGP-6	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_7B_20111102	FGP-6 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8A_20111102	FGP-7	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_8B_20111102	FGP-7 Dup.	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_9_20111102	FGP-8	<0.01	0.19	<0.01	<0.01
FG_MORGAN_10_20111102	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_11_20111102	FGP-9	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_12A_20111110	FGP-10	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_12B_20111110	FGP-10 Dup.	<0.01	0.09	<0.01	<0.01
FG_MORGAN_13_20111110	BLANK	<0.01	<0.01	<0.01	<0.01
FG_MORGAN_14_20111110	FG-1	<0.01	<0.01	<0.01	0.19
MINIMUM		<0.01	<0.01	<0.01	<0.01
MAXIMUM		0.04	0.19	0.01	0.19
AVERAGE		0.04	0.1033	0.01	0.14

Table F1d Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Chloro-benzene (ppb)	Tetra-chloro-ethylene (ppb)	1, 3-dichloro benzene (ppb)	1, 4-dichloro benzene (ppb)
MDL		0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
MCL (Primary & Secondary Drinking water standards)		100	5	75	75
FG_MORGAN_1A_20111025	FGP-1	0.10	0.01	<0.01	<0.01
FG_MORGAN_1B_20111025	FGP-1 Dup.	0.11	0.02	<0.01	<0.01
FG_MORGAN_2A_20111025	FGP-2	0.10	0.01	<0.01	<0.01
FG_MORGAN_2B_20111025	FGP-2 Dup.	0.11	0.01	<0.01	<0.01
FG_MORGAN_3_20111025	FGP-3	0.09	0.01	<0.01	<0.01
FG_MORGAN_4_20111025	BLANK	0.11	0.01	<0.01	<0.01
FG_MORGAN_5_20111025	FGP-4	0.13	0.02	<0.01	<0.01
FG_MORGAN_6A_20111102	FGP-5	0.15	0.01	<0.01	<0.01
FG_MORGAN_6B_20111102	FGP-5 Dup.	0.16	0.01	<0.01	<0.01
FG_MORGAN_7A_20111102	FGP-6	0.19	0.03	0.11	0.12
FG_MORGAN_7B_20111102	FGP-6 Dup.	0.16	0.01	0.09	0.08
FG_MORGAN_8A_20111102	FGP-7	0.17	0.01	0.06	0.06
FG_MORGAN_8B_20111102	FGP-7 Dup.	0.14	0.02	0.05	0.07
FG_MORGAN_9_20111102	FGP-8	0.19	0.01	0.04	0.04
FG_MORGAN_10_20111102	BLANK	0.12	0.01	0.07	0.06
FG_MORGAN_11_20111102	FGP-9	0.21	0.03	0.06	0.06
FG_MORGAN_12A_20111110	FGP-10	0.23	0.01	0.06	0.06
FG_MORGAN_12B_20111110	FGP-10 Dup.	0.22	0.01	0.04	0.07
FG_MORGAN_13_20111110	BLANK	0.15	0.01	<0.01	<0.01
FG_MORGAN_14_20111110	FG-1	0.20	0.01	0.07	0.05
MINIMUM		0.09	0.01	<0.01	<0.01
MAXIMUM		0.23	0.03	0.11	0.12
AVERAGE		0.152	0.0135	0.065	0.067

Table F1e Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	P/M xylene (ppb)	O-xylene (ppb)	Styrene (ppb)	1-chloro-2-methyl benzene (ppb)
MDL		0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
MCL (Primary & Secondary Drinking water standards)		10,000	10,000	100	
FG_MORGAN_1A_20111025	FGP-1	0.24	0.10	0.14	<0.01
FG_MORGAN_1B_20111025	FGP-1 Dup.	0.21	0.12	0.14	<0.01
FG_MORGAN_2A_20111025	FGP-2	0.20	0.11	0.13	<0.01
FG_MORGAN_2B_20111025	FGP-2 Dup.	0.19	0.11	0.15	<0.01
FG_MORGAN_3_20111025	FGP-3	0.14	0.10	0.11	<0.01
FG_MORGAN_4_20111025	BLANK	0.16	0.12	0.10	<0.01
FG_MORGAN_5_20111025	FGP-4	0.21	0.12	0.13	<0.01
FG_MORGAN_6A_20111102	FGP-5	0.14	0.28	0.14	<0.01
FG_MORGAN_6B_20111102	FGP-5 Dup.	0.13	0.25	0.12	<0.01
FG_MORGAN_7A_20111102	FGP-6	0.12	0.27	0.18	<0.01
FG_MORGAN_7B_20111102	FGP-6 Dup.	0.16	0.23	0.15	<0.01
FG_MORGAN_8A_20111102	FGP-7	0.14	0.25	0.20	<0.01
FG_MORGAN_8B_20111102	FGP-7 Dup.	0.13	0.20	0.20	<0.01
FG_MORGAN_9_20111102	FGP-8	0.12	0.20	0.25	<0.01
FG_MORGAN_10_20111102	BLANK	0.11	0.18	0.20	<0.01
FG_MORGAN_11_20111102	FGP-9	0.14	0.23	0.13	<0.01
FG_MORGAN_12A_20111110	FGP-10	0.13	0.18	0.15	<0.01
FG_MORGAN_12B_20111110	FGP-10 Dup.	0.11	0.17	0.19	<0.01
FG_MORGAN_13_20111110	BLANK	0.12	0.17	0.11	<0.01
FG_MORGAN_14_20111110	FG-1	0.12	0.20	0.22	<0.01
MINIMUM		0.11	0.10	0.10	<0.01
MAXIMUM		0.24	0.28	0.25	<0.01
AVERAGE		0.151	0.1795	0.1615	<0.01

Results from GC-MS analysis are present in Table F1(a–e). All compounds were less than or very close to detection limits.

Results from GC-P&T analysis showed all compounds were less than detection limits, except for chloroform. Chloroform was detected in three samples representing 2 wells (Table F2).

ICP-MS for Metals

An inductively coupled plasma-mass spectrometer (ICP-MS) was used to analyze for the metals shown in Table F3. The PNNL procedures that were followed are based on U.S. EPA Method 6020 (EPA 2000a). The QC requirements, calibration requirements, and acceptance criteria are defined in the on-line Quality Assurance (QA) plan “Conducting Analytical Work in Support of Regulatory Programs” (CAWSRP). Quality Control (QC) includes a daily checking for sensitivity and stability, mass calibration (performed daily), calibration standards and blanks (analyzed at the beginning of an analytical run), and independent check standards (analyzed at the beginning, end, and every 10 samples). Calibration and check standards are National Institute of Standards and Technology (NIST) traceable. Additional QC includes an interference check, a serial dilution, and a post-spike, which are included in each sample batch (a batch is 20 samples).

Trace Metals Analysis Results

Results from the ICP-MS analyses are presented in Table F3. As indicated, the concentration of each analyte was less than applicable drinking water standards. The concentration of arsenic was the only analyte that occurred at levels that were a significant fraction ($\leq 40\%$) of the drinking water standard at five sampling locations.

Table F2 Analytical results for the groundwater samples taken near the FutureGen 2 site using GC-P&T.

Sample ID	Well ID	Chloroform (ppb)
		0.01-0.1
MCL (Primary & Secondary Drinking water standards)		70.0
FG_MORGAN_6A_20111102	FGP-1	0.57
FG_MORGAN_6B_20111102	FGP-1 Dup.	0.47
FG_MORGAN_14_20111110	FG-1	0.67
MINIMUM		0.47
MAXIMUM		0.67
AVERAGE		0.57

Table F3a Analytical results for the groundwater samples taken near the FutureGen 2 site.

Sample ID	Well ID	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)
MDL		6.26E-01	9.36E-01	3.66E-01	1.35E-01	1.01E-01	3.83E-01
MCL (Primary & Secondary Drinking water standards)		6.00E+00	1.00E+01	2.00E+03	4.00E+00	1.00E+02	1.00E+02
FG_MORGAN_1A_20111025	FGP-1	<6.26E-01	4.00E+00	8.25E+01	<1.35E-01	<1.01E-01	3.88E-01
FG_MORGAN_1B_20111025	FGP-1 Dup.	<6.26E-01	3.82E+00	8.06E+01	<1.35E-01	<1.01E-01	4.07E-01
FG_MORGAN_2A_20111025	FGP-2	<6.26E-01	<9.36E-01	1.52E+02	<1.35E-01	<1.01E-01	<3.83E-01
FG_MORGAN_2B_20111025	FGP-2 Dup.	<6.26E-01	<9.36E-01	1.50E+02	<1.35E-01	<1.01E-01	<3.83E-01
FG_MORGAN_3_20111025	FGP-3	<6.26E-01	3.63E+00	3.87E+01	<1.35E-01	<1.01E-01	<3.83E-01
FG_MORGAN_4_20111025	BLANK	<6.26E-01	<9.36E-01	<3.66E-01	<1.35E-01	<1.01E-01	<3.83E-01
FG_MORGAN_5_20111025	FGP-4	<6.26E-01	<9.36E-01	1.32E+02	<1.35E-01	<1.01E-01	<3.83E-01
FG_MORGAN_6A_20111102	FGP-5	<6.26E-01	<9.36E-01	9.29E+01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_6B_20111102	FGP-5 Dup.	<6.26E-01	1.03E+00	9.78E+01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_7A_20111102	FGP-6	<6.26E-01	<9.36E-01	2.56E+02	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_7B_20111102	FGP-6 Dup.	<6.26E-01	<9.36E-01	2.61E+02	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_8A_20111102	FGP-7	<6.26E-01	1.59E+00	1.41E+02	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_8B_20111102	FGP-7 Dup.	<6.26E-01	1.25E+00	1.12E+02	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_9_20111102	FGP-8	<6.26E-01	<9.36E-01	1.12E+02	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_10_20111102	BLANK	<6.26E-01	<9.36E-01	<3.66E-01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_11_20111102	FGP-9	<6.26E-01	<9.36E-01	7.53E+01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_12A_20111110	FGP-10	<6.26E-01	<9.36E-01	7.35E+01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_12B_20111110	FGP-10 Dup.	<6.26E-01	<9.36E-01	7.19E+01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_13_20111110	BLANK	<6.26E-01	<9.36E-01	<3.66E-01	<6.73E-02	<1.01E-01	<3.83E-01
FG_MORGAN_14_20111110	FG-1	<6.26E-01	1.46E+00	7.99E+01	<6.73E-02	<1.01E-01	<3.83E-01
MINIMUM		<6.26E-01	<9.36E-01	<3.66E-01	<6.73E-02	<1.01E-01	<3.83E-01
MAXIMUM		<6.26E-01	4.00E+00	2.61E+02	<1.35E-01	<1.01E-01	<3.83E-01
AVERAGE		<6.26E-01	2.40E+00	1.26+E02	<1.35E-01	<1.01E-01	<3.83E-01

Table F3b Analytical results for the groundwater samples taken near the FutureGen 2 site

Sample ID	Well ID	Lead (µg/L)	Mercury (µg/L)	Selenium (µg/L)	Thallium (µg/L)	Silver (µg/L)
MDL		9.32E-01	1.50E+00	2.71E-00	6.00E-02	6.00E-01
MCL (Primary & Secondary Drinking water standards)		1.50E+02	2.00E+00	5.00E+01	2.00E+00	1.00E+02
FG_MORGAN_1A_20111025	FGP-1	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_1B_20111025	FGP-1 Dup.	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_2A_20111025	FGP-2	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_2B_20111025	FGP-2 Dup.	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_3_20111025	FGP-3	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_4_20111025	BLANK	<9.32E-01	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_5_20111025	FGP-4	2.89E+00	<1.50E+00	<2.71E-00	<6.00E-02	<6.00E-01
FG_MORGAN_6A_20111102	FGP-5	<9.32E-01	<1.50E+00	<2.71E-00	1.10E-01	<6.00E-01
FG_MORGAN_6B_20111102	FGP-5 Dup.	<9.32E-01	<1.50E+00	<2.71E-00	1.00E-01	<6.00E-01
FG_MORGAN_7A_20111102	FGP-6	<9.32E-01	<1.50E+00	<2.71E-00	7.06E-02	<6.00E-01
FG_MORGAN_7B_20111102	FGP-6 Dup.	<9.32E-01	<1.50E+00	<2.71E-00	7.29E-02	<6.00E-01
FG_MORGAN_8A_20111102	FGP-7	<9.32E-01	<1.50E+00	<2.71E-00	1.26E-01	<6.00E-01
FG_MORGAN_8B_20111102	FGP-7 Dup.	<9.32E-01	<1.50E+00	<2.71E-00	1.08E-01	<6.00E-01
FG_MORGAN_9_20111102	FGP-8	<9.32E-01	<1.50E+00	<2.71E-00	8.65E-02	<6.00E-01
FG_MORGAN_10_20111102	BLANK	<9.32E-01	<1.50E+00	<2.71E-00	<3.00E-02	<6.00E-01
FG_MORGAN_11_20111102	FGP-9	4.50E-00	<1.50E+00	<2.71E-00	<3.00E-02	<6.00E-01
FG_MORGAN_12A_20111110	FGP-10	<9.32E-01	<1.50E+00	3.35E-00	3.17E-02	<6.00E-01
FG_MORGAN_12B_20111110	FGP-10 Dup.	<9.32E-01	<1.50E+00	4.28E-00	3.33E-02	<6.00E-01
FG_MORGAN_13_20111110	BLANK	<9.32E-01	<1.50E+00	<2.71E-00	<3.00E-02	<6.00E-01
FG_MORGAN_14_20111110	FG-1	<9.32E-01	<1.50E+00	<2.71E-00	4.97E-02	<6.00E-01
MINIMUM		<9.32E-01	<1.50E+00	<2.71E-00	<3.00E-02	<6.00E-01
MAXIMUM		4.50E-00	<1.50E+00	4.28E-00	1.26E-01	<6.00E-01
AVERAGE		3.70E+00	<1.50E+00	3.82E+00	7.88E-01	<6.00E-01

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