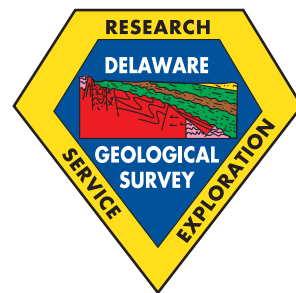


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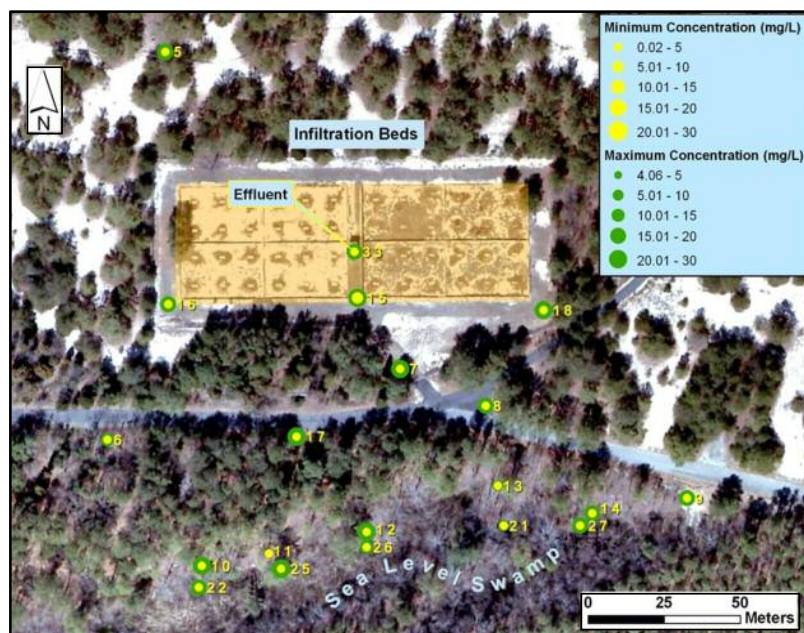


BULLETIN NO. 21C

GROUNDWATER QUALITY AND MONITORING OF RAPID INFILTRATION BASIN SYSTEMS (RIBS), THEORY AND FIELD EXPERIMENTS AT CAPE HENLOPEN STATE PARK, DELAWARE

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GROUNDWATER QUALITY AND MONITORING OF RAPID INFILTRATION BASIN SYSTEMS (RIBS), THEORY AND FIELD EXPERIMENTS AT CAPE HENLOPEN STATE PARK, DELAWARE

ABSTRACT

A rapid infiltration basin system (RIBS) consists of several simple and relatively standard technologies; collection and conveyance of wastewater, treatment, and discharge to an unlined excavated or constructed basin. By design, the effluent quickly infiltrates through the unsaturated or vadose zone to the water table. During infiltration, some contaminants may be treated by biological and/or geochemical processes and diluted by dispersion and diffusion. The combination of contaminant attenuation and dilution processes that may occur during infiltration and flow through the aquifer are termed soil-aquifer-treatment, or SAT. In the past decade, RIBS have been proposed more frequently for use in Delaware because they stop the direct discharge of treated effluent to surface water, can accommodate significant flow volumes typical of residential subdivisions, yet require much less land than options such as spray irrigation or sub-surface disposal systems.

Decades of research on the shallow Columbia aquifer of the Delmarva Peninsula have clearly identified the high susceptibility of the aquifer from land- and water-use practices, and the processes that control the fate and transport of contaminants from their origin at or near land surface to points of discharge in creeks, estuaries, and wells. The risk of aquifer contamination is great because it is highly permeable, has little organic matter in the aquifer matrix, and the depth to groundwater is very commonly less than 10 ft below land surface. USEPA guidance documents and several engineering texts that cover RIBS design clearly identify these same factors as increasing risk for groundwater contamination but do not provide much information on means to monitor and mitigate those risks. Further, design criteria are based on a small group of experiments conducted in the 1970s prior to development of current understanding of the processes that control groundwater contaminant transport.

Field and laboratory experiments to characterize the physical, chemical, and biological controls and processes associated with the rapid infiltration of treated sewage effluent through infiltration beds and the vadose zone were undertaken at a RIBS located at Cape Henlopen State Park (CHSP), Delaware. Field experiments to understand the geochemical effects of the long-term operation of a RIBS on ground and surface waters, and to evaluate monitoring systems were also conducted at the site. The CHSP RIBS has been in operation since the early 1980s.

Significant concentrations of nitrogen and phosphorus occur in groundwater from the point of effluent entry at the water table to distances greater than 150 ft from the infiltration beds. The high hydraulic, nitrogen (N), phosphorus (P), and organic loading rates associated with the operation of RIBS overwhelm natural attenuation (e.g., sorption and precipitation) processes. Data are not sufficient to indicate

whether denitrification is occurring. If there is denitrification, the rate is insufficient to remediate RIBS effluent at the site — despite a 25-ft thick vadose zone, an effluent with enough organic carbon to facilitate anaerobic conditions that permit abiotic denitrification and feed microorganism-driven denitrification processes, and hypoxic to anoxic groundwater.

Significant horizontal and vertical variability of contaminant concentrations were observed within the portion of the aquifer most impacted by effluent disposal. Despite the relatively small spatial extent of the disposal area in our study area, identification of the preferential flow zone and characterization of the vertical and temporal variability in the concentrations of contaminants required a multi-phase subsurface investigation program that included an analysis of data from samples collected at bi-monthly intervals from dozens of monitoring points and high frequency temperature monitoring in several wells. A well-designed monitoring system should be based on experimentally determined site-specific evidence collected under conditions that duplicate the flow rates that are expected during full-scale operation of the RIBS. Conservative tracers should be used to determine if the monitoring wells are in locations that intercept flow from the infiltration beds.

INTRODUCTION

A rapid infiltration basin system (RIBS) consists of several simple and relatively standard technologies employed for the land-based disposal of wastewater. In Delaware, wastewater generated by parks, homes, and businesses is collected and conveyed to a treatment plant. Following processing in the treatment plant, effluent is discharged to an unlined excavated or constructed basin. By design, the effluent quickly infiltrates through the unsaturated or vadose zone to the water table. Depending on the hydrogeological characteristics near an individual RIBS, small quantities of effluent may slowly percolate into deeper zones of the water-table aquifer or become part of a regional flow system that recharges an underlying confined aquifer.

During infiltration, some contaminants may be treated by biological and/or geochemical processes. Once in the aquifer, effluent flows away from the infiltration site toward areas of lower hydraulic pressure, such as bodies of surface water and wells. Remaining contaminants may be treated through biological and/or geochemical processes and diluted by dispersive and diffusive processes. The combination of contaminant attenuation and dilution processes that occur during infiltration and flow through the aquifer are termed soil-aquifer-treatment, or SAT (Crites et al., 2006).

If all of the individual components of a RIBS are working properly, there is potential for the water to be safely reclaimed for other human or environmental purposes. This

could be of benefit in Delaware, as the Columbia aquifer is a major supplier of water for potable, agricultural, and industrial users, for maintenance of surface water flow, and for sustaining important subaqueous and wetland habitat.

Purpose and Scope

This report covers one phase of a multi-year, multi-disciplinary project in which the components and the risks associated with the operation of the RIBS at Cape Henlopen State Park (CHSP) in Delaware were systematically analyzed (Fig. 1). We conducted field and laboratory experiments to characterize the physical, chemical, and biological controls and processes associated with the rapid infiltration of treated sewage effluent through infiltration beds and the vadose zone at the site. We also conducted a second set of field experiments to understand the geochemical effects of the long-term operation of a RIBS on ground and surface waters, and to evaluate monitoring systems. An extensive literature review was conducted to determine how USEPA and other design guidance texts compare to groundwater contaminant transport literature. Components of this project that are not documented in this report include an assessment of the treatment plants (Turkmen et al., 2015) and an assessment of the physical hydrology at an operating RIBS facility (Andres et al., 2015).

Due to site access and resource constraints we could not place monitoring wells in as many locations as would be needed to completely characterize the flow of effluent away from the infiltration beds and the distribution of contaminants in the aquifer. We also could not analyze all of the contaminants that could be in the effluent or that could be released from the aquifer matrix due to interactions with the effluent.

Previous Work

Cape Henlopen State Park Site

The hydrogeological framework of the CHSP RIBS study site is characterized in Andres et al. (2015). The site has a water-table aquifer within heterogeneous quartzose dune- and spit-complex deposits and underlain by muddy marine deposits that form a leaky confining bed. Groundwater flow directions and velocities are controlled by both wastewater discharge and head difference between the higher land-surface elevations associated with dune deposits and the adjacent low lying Sea-Level Swamp (SLS) (Fig. 2). The SLS is a small portion of the Spit Complex Swamp described by Andres et al. (2015). Groundwater temperature and water-table configuration data indicate that the flow of discharged effluent is preferentially concentrated in a zone located between the eastern and western edges of the infiltration basins and extending southward from the basins to the SLS (Fig. 3). Temporal variations in groundwater temperatures due to summertime loading of warm wastewater and particle-tracking models derived from water-table configurations indicate that maximum groundwater velocities are on the order of 2 to 3 ft per day between the infiltration basins and the SLS. These data also indicate the presence of a second, less well-defined flow direction oriented southeast from the infiltration basins toward the SLS. Though the water-table configuration indicates that flow should be

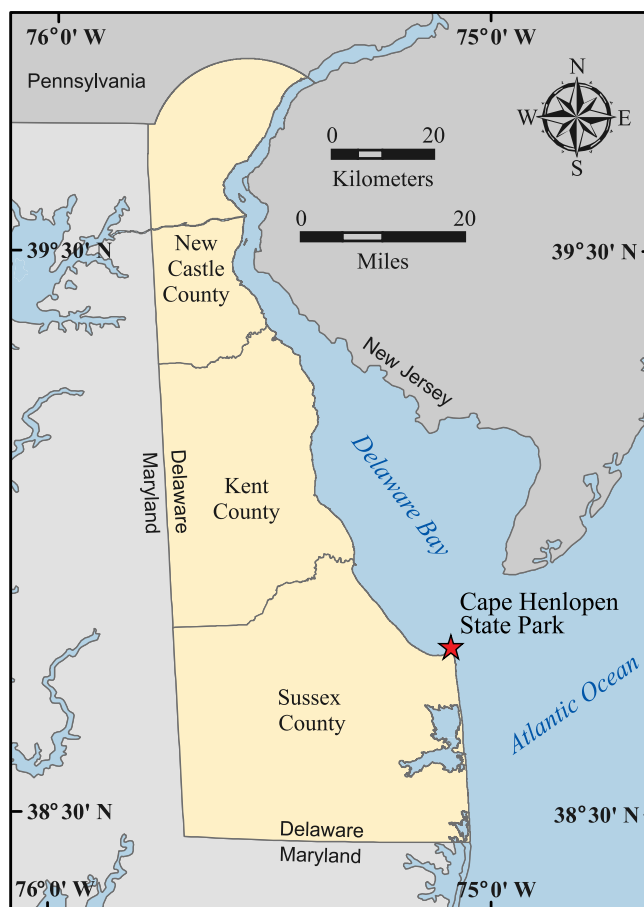


Figure 1. General location map.

directed towards the north, temperature data do not show the expected trends, and thus the flow of discharged effluent in this direction is inferred to be occurring at much smaller rates.

Military use of the area during and following World War II resulted in several potential groundwater impacts. Monitoring wells were constructed and sampled during a previous study of the area (US Army Corps of Engineers, 1997) to evaluate if there were any lasting impacts from military use and found no clear indication of groundwater contamination (US Army Corps of Engineers, 1997). Several of these wells were sampled as part of the current study (Appendix 1).

Delmarva Groundwater

Nearly 40 years of research by academic, state, and federal scientists have documented that the Columbia aquifer is highly susceptible to contamination from wastes applied onto and into the ground. Contaminants persist in the groundwater for decades, where they impact potable water supply wells. The contaminated water will eventually discharge into bodies of surface water, leading to well-documented eutrophication problems (Miller, 1972; Robertson, 1977; Ritter and Chirnside, 1982, 1984; Bachman, 1984; Denver, 1989; Denver et al., 2004; Andres, 1991, 1995; Center for the Inland Bays, 1995; Pellerito et al., 2006; Ferrari, 2001; Gutiérrez-Magness and Raffensperger, 2003; Debrewer et al., 2005). Indeed, water-quality problems in

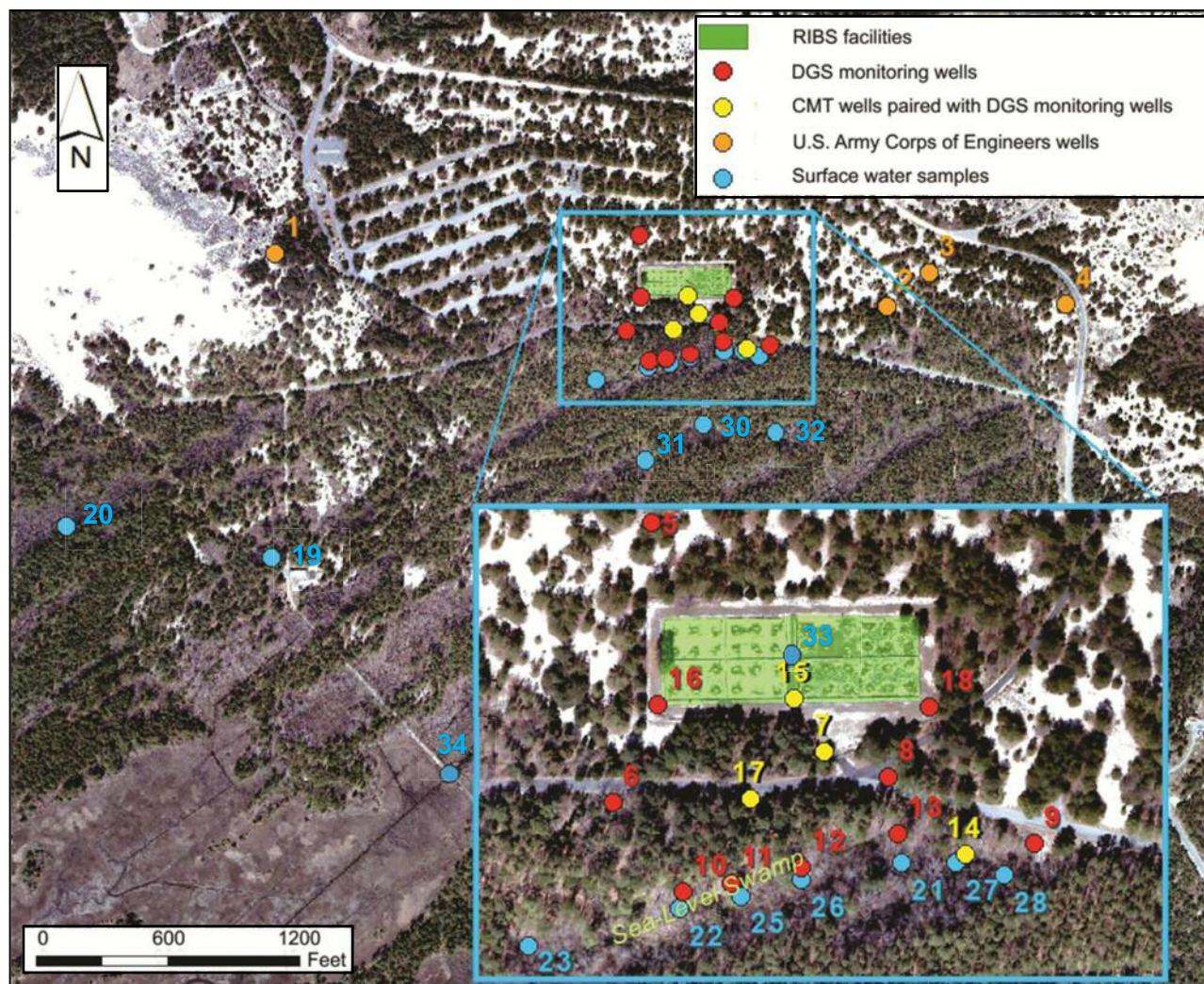


Figure 2. Locations of monitoring wells and surface-water sampling sites. CMT refers to the Solinst CMT multi-port monitoring device. Site identification numbers are indexed to wells listed in Appendix 1.

Delaware are consistent with those observed throughout the Mid-Atlantic Coastal Plain (Ator, 2008). Sensitive public (water-supply wells) and environmental (streams, wetlands) receptors are at high risk for being adversely impacted when effluent contains N or P that cannot be removed or sorbed by passage through the vadose zone or aquifer, when one or more of the pieces of a RIBS mal-functions, or if unanticipated natural hydraulic and/or geochemical factors are present.

Years of research into the impacts of land-based wastewater disposal on Delmarva groundwater have been completed. Two types of problems are pertinent to this study. First, Miller (1972), Robertson (1977), Ritter and Chirnside (1984), Bachman (1984), Denver (1989) found, for example, that the use of individual on-site wastewater systems (e.g., septic systems) can elevate nitrate concentrations to levels in excess of the drinking water standard (10 mg/L; USEPA, 2010, <http://water.epa.gov/drink/contaminants/index.cfm>).

Acknowledgments

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METHODS

The experimental methods used in this work were developed after an extensive search of literature pertaining to the discharge of treated wastewater onto and into the ground; biogeochemical processes affecting the fate and transport of nitrogen, phosphorus, carbon, and metals in subsurface environments; and the artificial recharge of aquifers. The search included peer-reviewed journal articles, technical reports

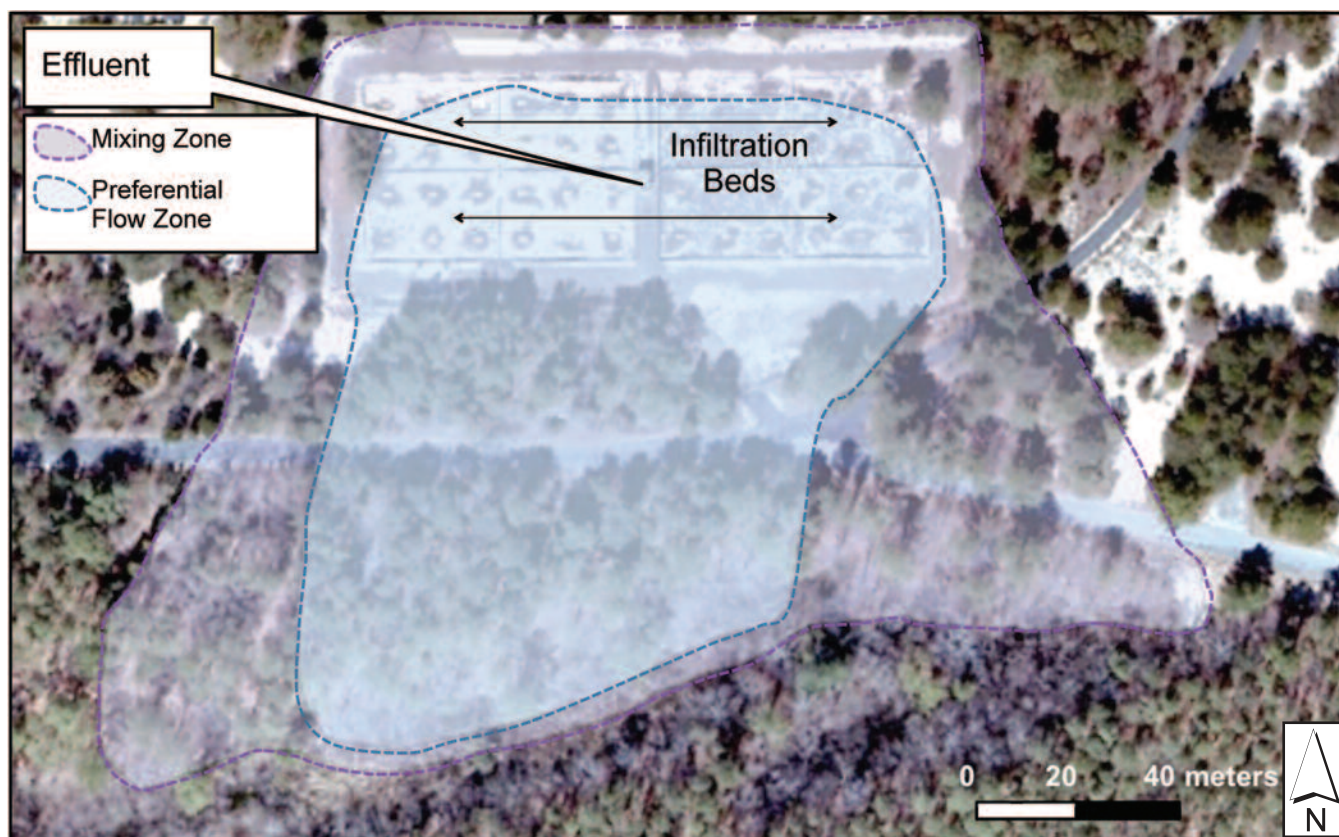


Figure 3. Preferential flow zone downgradient of the infiltration basins.

from federal and state agencies, non-technical media accounts, and technical reports from research institutes and organizations.

Automated Literature Search

We performed automated literature searches using the Compendex search engine, accessed through University of Delaware Library, and the Google and Google Scholar applications. Results were evaluated to differentiate between full text, and abstracts and conference proceedings—a distinction that separates peer-reviewed from non-reviewed and potentially less reliable sources.

We reviewed abstracts of many of the documents and downloaded full article texts of those that were found to be relevant. Texts were retrieved from UD's on-line e-journal service, library holdings or, were requested from the inter-library loan service. Not all of the references checked by this process are cited in this report

Field Methods for Characterization of Soils, Sediments, and Water

Installation of monitoring devices

Subsurface materials were characterized through test borings and direct push methods, downhole geophysical logging, and from samples that were collected and analyzed as described in Andres et al. (2015). Locations and construction information for monitoring wells that were installed during this work and locations of surface-water sampling sites are listed Appendix 1 and shown in Fig. 2.

Test borings and monitoring wells were installed at nine locations using the DGS CME 55 drill rig (Fig. 2, sites 1-9). Hand-auger methods were used at 3 locations in the SLS (sites 10, 12, 14), and at 2 locations near the toe of the dune (sites 11, 13). Standard monitoring wells consisted of 2-inch ID threaded flush joint schedule 40 PVC pipe and machine slotted schedule 40 PVC well screen. Wells installed in holes drilled by the truck-mounted equipment had 15 ft of machine slotted well screen, and those installed by hand methods had 3 ft of machine slotted well screen. Wells installed near the toe of the dune were located a few feet higher in elevation than the SLS to help with the characterization of the groundwater that originated in the area between the infiltration basins and the SLS.

All wells were gravel packed and grouted with granular sodium bentonite. In all cases, the gravel pack extended at least 1 ft above the top of the screen interval with 1 to 2 ft of bentonite pellets placed over the gravel pack. Grout was emplaced by tremie pipe in the machine-drilled holes and by hand in the hand auger holes. Protective steel casings were placed over all wells located in easily accessible areas and sealed with concrete or bentonite.

Following this work, seven-channel multi-level wells (CMT System - Solinst Canada; Einarson and Cherry, 2002) were installed next to standard wells at four locations (Appendix 1, Fig. 2, sites 7, 14, 15, 17). Three of the CMT wells were installed with the truck-mounted drill, and one well located in the SLS was installed using hand equipment. The depths of individual sample ports were chosen based on an analysis of the descriptive and geophysical logs collected

at each site. Gravel pack was emplaced to span the interval from 2 ft above the top sample port to the bottom of the CMT tube. At three locations, 1 to 2 ft of bentonite pellets were placed over the gravel pack, and bentonite grout was emplaced to within a few feet of the land surface. Protective casings were mounted over all CMT wells and sealed with concrete or bentonite. Individual CMT channels were pumped with a peristaltic pump to remove drilling fluids and formation materials. Each channel was equipped with a dedicated sampling tube consisting of a ¼ inch outside diameter polyethylene tube with a stainless steel check valve on the bottom. The check valve was used to prime the tube and allow pumping with a peristaltic pump.

Water sampling methods

Water samples were collected from wells and surface sites between April 2008 and November 2009. Sampling methods were adapted from those used in previous ground-water (Sims et al., 1996) and surface-water (Ullman et al., 2002) studies. Because this was a research study, no formal chain-of-custody procedures were employed.

During this project, field measurements of pH, temperature (T), specific conductance (SC), and dissolved oxygen (DO) were made with a YSI 556 MPS, which included a 3-meter-long cable. This instrument permits measurements within a water-tight flow-through cell, *in-situ* a 2-inch diameter or larger well or container, or in a body of water greater than 6 inches in depth. The pH and SC probes were calibrated with National Institute of Standards and Technology-traceable standards prior to each sampling event. The DO probe was also calibrated prior to each sampling event using the manufacturer's recommended procedure (YSI, Inc., 2008).

Standard monitoring wells

For each well, we measured the water level and computed the volume of standing water before taking a minimum of three samples. For wells not located in or adjacent to the swamp, we took samples with a submersible pump and tested the discharge for pH, T, SC, DO, and oxidation reduction potential (ORP) with a YSI 556 MPS meter and flow-through cell. Pumping rates were always less than 1 gallon per minute (gpm) and usually less than 0.75 gpm. Turbidity was not observed in the pump discharge. SC, T, and pH values typically stabilized before the sample volumes were removed. However, purging was stopped after DO and ORP readings stabilized; that is, when the rate of change of measured DO and ORP values decreased below 0.01 mg/L and 0.1 mV per 5 seconds, respectively. In cases in which DO and ORP readings did not stabilize after more than 10 well volumes were purged, the rate of change of DO and ORP and their final values were noted. These results were less than the last measured value and were recorded as estimated values. Samples were collected by lowering a pre-cleaned 2.5 ft PVC point-source bailer into the well until the top of the bailer was just below the water surface. The bailer was then retrieved, which kept the sample from contact with the atmosphere. The sample was pumped from the bailer with a peristaltic pump, filtered through a 0.45 micron

capsule filter (Envirotech®), and collected in bottles that had been triple rinsed with the filtered pump discharge. Personnel wore fresh PVC gloves during sample collection. Samples were placed on ice for transport to the laboratory.

Because of difficult site access, sampling procedures for wells located in and adjacent to the swamp were slightly different. A minimum of three sample volumes were removed from the well with a pre-cleaned bailer for purging; additional water was removed if the water was turbid. A sample was removed with a second pre-cleaned PVC point-source bailer, using the same process described above. The YSI 556 MPS sonde was then inserted into the well to a minimum depth of 1 ft below water level.

To avoid contamination between wells, bailers were completely disassembled; the parts and cord were cleaned with laboratory grade detergent, triple rinsed with deionized water, and rinsed with water discharged by the submersible pump.

Slightly different procedures were also needed for sampling CMT wells because of their different design. A CMT well consists of 7 individual sampling channels, each with a sample port located at a different depth. Individual sampling tubes were stored in a clean plastic bag until being inserted into a sampling channel. Each tube was attached to a peristaltic pump, and a minimum of 8 L of water was purged at flow rates of 200 to 400 mL/minute. Given that the capacity of the sample channels is 0.04 L per linear foot, 8 L represents 200 times the volume of standing water in the shallowest ports, and nearly 20 times the volume of standing water in the deepest ports.

Because of the long times needed to acquire stable measurements of DO and ORP, and early results that indicated only small differences in DO and ORP between sample channels, field measurements were made on only three sample channels per CMT. Typically the samples were from the top, middle, and bottom CMT ports. Samples were filtered and collected as described above. The peristaltic pump was used to pump deionized water through the sample tube to evacuate the remaining water. Each tube was dried in the lab by purging with compressed air. The short (<15 cm) silicone tube portion of the peristaltic pump was purged with deionized water between sample channels and replaced after each sampling event.

To compare water quality from standard and CMT wells, at each of the three standard wells located next to a CMT well, we used the point-source bailer to collect one sample from the top 2.5 ft of the water column, and a second sample from the bottom 2.5 ft of the water column. Samples were filtered and collected as described above.

Field measurements of surface-water pH, T, SC, DO, and ORP were made by submerging the YSI 556 MPS sonde into the water. Samples were collected a short distance from the probe in a pre-cleaned 250-ml polyethylene sample collection container. A telescoping extension rod attachment was used if the sample collection container could not be dipped by hand without disturbing bottom sediments. Unfiltered samples were poured into pre-cleaned bottles that had been triple rinsed with the water from the sampling site. Filtered samples were collected by pumping water from the

Table 1. Water and wastewater analysis and analytical methods.

Parameter	Method	Comments / Method Detection Limit
Biological oxygen demand	SMWW ¹ 5210B, Winkler titration	5-day BOD/1 mg/L
Total Kjeldahl nitrogen	SMWW4500C	Acid digestion/0.2 mg/L
Nitrate-Nitrogen	SMWW4500, NH ₄ ⁺ B,C	Titrimetric method/0.32 mg/L
Ammonia-Nitrogen	SMWW4500, NH ₄ ⁺ B,C	Titrimetric method/0.32 mg/L
Ortho-Phosphorus	SMWW4500E	Colorimetric-ascorbic acid;
Dissolved Total-Phosphorus	SMWW4500E	Filtration; Colorimetric-ascorbic acid; Acid digestion/0.02 mg/L
Alkalinity	SMWW	Titrimetric/1 mg/L
Metals	SMWW3120B	ICP-AES/metal dependent ²
Anions – chloride, sulfate	SMWW4100A	Ion chromatography/0.1 mg/L

¹ All SMWW are from Greenberg et al., 1998; ² Quantitation limits are tabulated in Appendix 2

sampling container with the peristaltic pump and filter system used for sampling monitoring wells. Care was taken not to disturb bottom sediments at all times during sampling or measurement of field parameters. Samples were stored and transported to the lab as described above.

Laboratory Methods and Reporting Procedures

Upon return to the University of Delaware, samples were stored in a refrigerator at 4° C. Samples collected in April 2009 were frozen until they were analyzed in October. Water-quality testing was performed at the University of Delaware College of Agriculture and Natural Resources (CANR) and analytical procedures followed standard documented methods (Table 1). Additional analytical results of wastewater samples collected at CHSP by Envirocorp, Inc. were retrieved from the files of DNREC.

In reporting the laboratory results, we used the following protocols for each method: For amounts greater than the detection limits, we provided the value reported by the laboratory with no qualification. For amounts greater than or equal to one-half the detection limit up to the detection limit, we provided the value reported by the laboratory with a qualifier that the value is estimated. For amounts less than one-half the detection limit, we reported the result as not detected at the method detection limit.

RESULTS AND DISCUSSION

Literature Search Findings

The Compendex literature search found hundreds of citations that contained the key words RIBS or SAT (Tables 2 and 3). Filtering by the secondary and tertiary search terms refined the search to those citations pertaining to the effects of RIBS/SAT on groundwater and so returned fewer citations. A review of more than 100 documents returned by the primary and secondary search terms found that most were focused on the design, testing, and performance of wastewater systems, some of which employ RIBS/SAT as a means of disposal or groundwater recharge. Of the citations identified by secondary and tertiary search terms, relatively few

were for English-language, peer-reviewed, journal articles and agency documents that provided detailed information on systematic groundwater assessments at RIBS/SAT facilities.

A more general review of the literature identified many citations of peer-reviewed journal articles and agency documents that detailed studies that, though not focused on RIBS/SAT, contained information that was related to specific aspects of RIBS/SAT. Table 3 shows thousands of citations with the key words infiltration and ground water/groundwater and hundreds of citations having the key word nitrate. The general review included the following search terms and phrases: infiltration, contaminant fate and transport, pathogens in groundwater, nitrate in groundwater, phosphate in groundwater, groundwater monitoring systems, effluent and groundwater, and denitrification. A few of these citations document groundwater contamination and remediation at wastewater disposal facilities, including RIBS/SAT facilities. Of the several hundred citations that were reviewed, over 80 are cited in this report.

Contaminant transport

Over the past 35 years, our understanding of contaminant transport in groundwater has changed from one of simple plumes or bubbles of contamination shaped by advection and dispersion (Freeze and Cherry, 1979), to highly complex spatial and temporal distributions of contamination shaped by variations in contaminant input, and heterogeneities in the physical, biological, and chemical characteristics of aquifers (Commission on Geosciences, Environment and Resources, 1994; Scheibe and Yabusaki, 1998; Hubbard et al., 2001; Tartakovsky et al., 2007).

An important component of this change has been the evaluation of data from increasingly sophisticated groundwater monitoring systems. Early systems were simple long-screen wells that were sampled monthly or quarterly. More recent systems are spatially extensive arrays of short-screened, multi-depth devices that are intensively sampled during short-term (e.g., hourly) to moderate term (e.g., monthly to bi-monthly) injection, pumping, and natural

Table 2. Results of automated search for citations containing primary key word term Rapid Infiltration.

	Full Text & Abstract	Full Text	% of Entries	% of Journal Articles
Rapid Infiltration	684	-	-	-
Journal Articles	522	-	76.3	-
Disposal	19	7	2.8	3.6
Reclamation	7	2	1.0	1.3
Proceedings	5	-	0.7	1.0
Book Chapters	2	-	0.3	0.4
Hydraulics	16	5	-	-
Journal Articles	13	5	1.9	2.5
Clogging	0	0	0	0.0
Infiltration	13	5	1.9	2.5
Modeling	1	0	0.1	0.2
Groundwater	5	3	0.7	1.0
Monitoring Well	1	1	0.1	0.2
Contamination	27	16	-	-
Journal Articles	18	12	2.6	3.4
Nitrogen	2	1	0.3	0.4
Nitrate	0	0	0.0	0.0
Ammonia	0	0	0.0	0.0
Phosphorus	1	0	0.1	0.2
Sorption	1	0	0.1	0.2
Transport	1	0	0.1	0.2
Pathogens	0	0	-	0.0
Disinfection	0	0	-	0.0
BOD	0	0	-	0.0
COD	0	0	-	0.0
Suspended Solids	1	1	-	0.2
Groundwater	12	8	-	2.3
Infiltration	15836	8	-	-
Journal Articles	11846	-	75	-
Ground water	577	-	3.6	-
Groundwater	1366	-	8.6	-
Nitrogen	381	-	2.4	-
Nitrate	196	-	1.2	-
Ammonia	81	-	0.5	-
Phosphorus	156	-	1.0	-
Rapid Infiltration	684	-	-	-
Journal Articles	522	-	76	-
Ground water	43	26	6.3	-
Groundwater	85	53	12	-
Nitrogen	17	7	2.5	-
Nitrate	9	6	1.3	-
Ammonia	2	0	0.3	-
Phosphorus	8	2	1.2	-
Rapid Infiltration Basin	39	-	-	-
Journal Articles	27	16	69	-
Ground water	5	3	13	-
Groundwater	10	6	26	-
Nitrogen	2	0	5	-
Nitrate	0	0	0	-
Ammonia	0	0	0	-
Phosphorus	2	0	5	-

Table 3. Results of automated search for citations containing primary key word term Soil Aquifer Treatment

	Full Text & Abstract	Full Text	% of Entries	% of Journal Articles
Soil Aquifer Treatment	339	-	-	-
Journal Articles	242	-	71.4	-
Disposal	21	13	6.2	8.7
Reclamation	42	32	12.4	17.4
Proceedings	3	0	0.9	1.2
Book Chapters	1	0	0.3	0.4
Hydraulics	37	17	10.9	-
Journal Articles	28	17	8.3	-
Clogging	4	3	1.2	1.7
Infiltration	6	3	1.8	2.5
Modeling	1	0	0.3	0.4
Groundwater	16	10	4.7	6.6
Monitoring Well	1	0	0.3	0.4
Contamination	75	36	22.1	-
Journal Articles	53	36	15.6	3.4
Nitrogen	4	4	1.2	1.7
Nitrate	3	3	0.9	1.2
Ammonia	1	1	0.3	0.4
Phosphorus	1	1	0.3	0.4
Sorption	0	0	0.0	0.0
Transport	0	0	0.0	0.0
Pathogens	1	1	0.3	0.4
Disinfection	1	1	0.3	0.4
BOD	0	0	0.0	0.0
COD	1	1	0.3	0.4
Suspended Solids	0	0	0.0	0.0
Groundwater	37	25	10.9	15.3
Ground water/Groundwater	-	-	-	-
Journal Articles	242	-	71.4	-
Ground water	37	20	10.9	-
Groundwater	143	90	42.2	-
Nitrogen	36	20	10.6	-
Phosphorus	5	2	1.5	-

gradient experiments (Bales et al., 1997; Day-Lewis et al., 2004). Several of these experiments have been conducted at the Dover Air Force Base in Delaware (e.g., Liu and Ball, 1999; Michalak and Kitindis, 2004). Data collected from sophisticated monitoring experiments have led to the creation of complex conceptual, physical, and mathematical models that describe aquifer heterogeneity (Scheibe and Freyberg, 1995; Hubbard et al., 2001; Day-Lewis et al., 2004) and contaminant transport (Tartakovsky et al., 2007; Scheibe and Yabusake, 1998).

N transport and denitrification during SAT

There is a significant body of literature related to the occurrence of denitrification in groundwater including many reports of successful removal of N through denitrification during SAT. Nitrogen removal processes described for SAT include: 1) biologically mediated aerobic oxidation of ammonium to nitrate followed by heterotrophic denitrification under anaerobic conditions under which organic carbon and nitrate serve as the electron donor and receptor, respectively (Rivett et al., 2008); 2) partial oxidation of ammonium

to nitrite followed by autotrophic oxidation of ammonium, with nitrite serving as the electron acceptor under anoxic conditions (Asano et al., 2007). The first process is commonly used in conventional wastewater treatment plants (Asano et al., 2007). The second process, known as ANNAMOX, or nitrate reduction by ammonium, has been demonstrated in laboratory studies (e.g., Fox and Gable, 2003; Shah and Fox, 2005); however, there are no follow-up papers on field studies in the peer-reviewed literature and few citations of independent field studies (Rivett et al., 2008). The final product of both processes is nitrogen gas, although nitrous oxide may result when the first process does not proceed to completion (Asano et al., 2007). The presence of these gases in groundwater at concentrations in excess of atmospheric is an indication that denitrification, rather than simple dispersion, is reducing nitrate concentration (Rivett et al., 2008). Tracers such as stable isotopes, bromide, and chloride are also used in mixing models to separate the effects of dispersion from denitrification (e.g., Smith et al., 1996).

We evaluated claims made in the literature for N removal by denitrification during SAT. We were especially

interested in those with a potential application to the hydro-geologic and geochemical characteristics of Delaware soils and groundwater. We eliminated from consideration study reports that were limited to literature surveys, laboratory or simulation experiments, and reports lacking well-described study methods or data to corroborate conclusions. Citations found in conference proceedings that were not available or could not be located were also not used. Nonetheless, we found many (>50) abstracts and full-text articles from conference proceedings. However, many of the citations refer to SAT facilities in arid areas of the western United States and in Israel, where the SAT facilities are paired with pumping wells that withdraw the water for agricultural purposes. We also evaluated EPA guidance documents (USEPA, 1985, 2006) and some books (Crites et al., 2006; Crites and Tchobanoglous, 1998; Asano et al., 2007; Johnson and Pyne, 1994) that are widely cited as examples of successful SAT facilities.

Most of the materials we reviewed reuse information from a small number of SAT facilities. The information is presented in data table with appropriate citations. A review of the citations, however, led to older reports containing the same data with table captions citing even older reports as the sources of the information. We determined that the primary sources of the data were conference proceedings and a series of USEPA-sponsored reports of field studies completed in the 1970s at SATs located in Landis, New Jersey, (Koerner and Haws, 1979), Lake George, New York, (Aulenbach, 1979), Milton, Wisconsin, (Benham-Blair and Affiliates, 1979), and Hollister, California, (Pound et al., 1979), and summarized in Leach et al. (1980). Despite our considerable efforts searching scientific and news media sources and making phone calls to state regulatory agencies, we were unable to locate documentation for SAT facilities located in Boulder, Colorado, and Calumet, Michigan, that were also referenced. We were also concerned about the information presented in the USEPA guidance documents and text books that did not include citations of findings in USEPA (2006) Crites et al. (2006), and Crites and Tchobanoglous (1998) for the detailed and highly publicized studies of SATs at the Massachusetts Military Reservation (MMR) and in Long Island, New York.

Reports on the Landis, Lake George, and Hollister sites documented the use of field study methods that would not be considered adequate by modern standards for even routine groundwater characterization and were entirely substandard to the detailed methods used in contaminant transport research cited in this report. In these older studies, the monitoring well transects were aligned with the presumed horizontal direction of groundwater flow; multi-level well clusters generally sampled less than 10 percent of the saturated aquifer thickness. Samples were taken only quarterly and for less than two years. The report authors acknowledge that the head data indicate that well locations may not have been adequate to characterize the direction of flow of the contaminant plume and sampling frequency may not have been adequate to characterize the variability of contamination under the groundwater flow conditions. Independent, conservative indicators of effluent were not employed to separate the

effects of the improper location of monitoring devices and dispersion-induced dilution from the biological removal of nitrogen (see below). These issues raise further concerns about the validity of claims for widespread, successful N removal by SAT.

Our review did find peer-reviewed journal articles and agency reports that contain well-documented assessments of SAT and other land-based wastewater disposal systems. The assessments report a mixture of qualified successes and failures of these systems. Many papers documenting laboratory and field studies stress the importance of the hydraulic loading rates, and the composition and concentration of organic carbon in the treated effluent and/or soils for promoting denitrification. For example, Robertson et al. (2009) summarizes several articles detailing nitrate removal by a low-tech, permeable wood, mulch-based reactor to treat tile-drain-agricultural runoff. Burde et al. (2001) describe a low-cost wastewater treatment facility developed in Germany that is a permeable, reactive reactor system that is based on plant-debris. Peat has been used to facilitate N-removal in septic effluent for decades (e.g., Brooks et al., 1984; Shahid and Viraraghavan, 1987) and systems of this type are being used in Delaware (DNREC, NonHaz database). Many laboratory studies have investigated the use of alternative carbon sources or modified hydraulics on denitrification rates (e.g., Green et al., 1994). Carbon is commonly added in sewage treatment plants for biological nitrogen removal (Asano et al., 2007).

Researchers from the US Geological Survey (USGS) also conducted intensive monitoring and process research at the MMR. Leblanc (1984) describes how the use of a RIBS consisting of secondary treatment followed by rapid infiltration into a sand and gravel aquifer led to groundwater contamination extending thousands of feet from the infiltration basins. Repert et al. (2006) report that there is a gradual decrease in N concentrations in groundwater once the N source has been removed. Still they estimate that it will take decades for the nitrate concentrations to decrease to levels that meet drinking water standards, and even longer for ammonium nitrogen concentrations to decrease to levels that will not cause eutrophication in the down-flow receiving water body. It is noteworthy that the matrix and geochemistry of the aquifer at the MMR are similar to those features in the Columbia aquifer.

Intensive studies conducted by researchers at the USGS and USEPA over several years at the RIBS located at the East Bay and Cedar Creek water reclamation and recharge facilities in Long Island, New York, found that nitrate concentrations in groundwater were reduced from those in effluent and seemed adequate to meet drinking water guidelines (Oliva, 1985; Schneider et al., 1987). Although the researchers cited denitrification as the cause of nitrate reduction, they did not perform any independent testing to address that claim. Unfortunately, the use of the recharge facilities was discontinued when excess trihalomethane concentrations in the effluent and groundwater, resulting from the need to chlorinate the effluent for disinfection, could not be overcome (Brisbin et al., 1984; Oliva, 1985; Wood, 2006).

Sumner and Bradner (1996) conducted an intensive study of the Reedy Creek RIBS located near Orlando,

Florida. They report qualified success for N removal, but noted concerns regarding incomplete nitrification in the vadose zone and resulting transport of ammonium to the water table. This work was done as part of testing a 5 mgd infiltration facility (www.rcid.org) from which the water is reused for irrigating cropland, orchards, and golf courses in the Orlando area.

P sorption and transport

There are a significant number of citations related to the successful removal of P during SAT and also to P contamination of water resources due to SAT or other P use and disposal practices. We evaluated the significance and reliability of the claims made in these publications. EPA guidance documents (USEPA, 1985, 2004, 2006) and some books (Crites et al., 2006; Crites and Tchobanoglous, 1998; Asano et al., 2007; Johnson and Pyne, 1994) contain case studies in which study methods are not well described and performance data are presented without critical evaluation of the data sources. For example, Table 2-11 in USEPA (2006) lists P removal performance for several facilities and draws data from Table 3.13 in Crites et al. (2000). Crites et al. (2000) does not cite the source of the performance data.

The P attenuation model contained in the EPA guidance documents and texts, such as Crites et al., 2000; Crites et al., 2006, Crites and Tchobanoglous, 1998, originates from the work of Enfield et al. (1981a, b), which was part of the larger EPA effort summarized by Leach et al. (1980). A model prepared by Enfield et al. (1981a) predicts that orthophosphate will react with calcareous soils through a combination of reversible P sorption and hydroxyapatite and dicalcium phosphate dehydrate precipitation or dissolution. The application of this model to the land application of wastewater predicts that P will be completely attenuated by the aquifer matrix, although the time and distance for complete attenuation depends on hydraulic load, groundwater flow, and P concentration. Enfield et al. (1981b) performed calibration and validation of the model from results of detailed laboratory column experiments and from a limited field groundwater study that was reported in Pound et al. (1979) and Aulenbach and Clesceri (1980). The Enfield (1981a) model assumes an unlimited supply of calcium in the soil matrix, and sorption and mineralization on calcium-rich soil particles. However, the soils and parent geologic materials of the Delaware Coastal Plain soils are siliceous (NRCS, 2010; Ramsey, 2005, 2007; Andres and Klingbeil, 2006) and as a result, the model is inappropriate for use.

P transport and attenuation in Delaware soils and waters have been extensively studied by research teams at the Department of Plant and Soil Sciences, University of Delaware, led by Donald Sparks and J. Thomas Sims. P attenuation processes are dominated by reversible sorption on grain coatings consisting of iron and aluminum oxides and clay minerals (Sims et al., 2002). The formation of less soluble iron- and aluminum-phosphate-bearing minerals is much slower than rates of sorption or desorption (Sparks et al., 2007). Field observations corroborate these findings: less soluble iron-phosphate bearing minerals are either not detected or are present at very small concentrations in

Delaware soils having concentrations of P in excess of predicted mineral solubility limits (Sparks et al., 2007).

Maguire and Sims (2002) found that the leaching of P from Delaware soils occurs under natural precipitation intensities even when the available P sorption sites in the soils are not fully occupied. Similar research has found this to be the case for the loss of P from agricultural fields through overland runoff, leading to the general conclusion that soils have a finite capacity to sorb P, with the sorption capacity correlated with concentrations of soil-test-determined iron and aluminum (Sims et al., 2002). Recent efforts are now focused on the development of the appropriate metrics for determining soil phosphorus capacity, which relates P, iron (Fe), and aluminum (Al) concentrations in the soil and hydrologic factors to a risk factor for P loss through overland flow or leaching (J. T. Sims, oral communication).

Some caveats to results from agronomic studies of soils are that the experiments were done under conditions representative of the agronomic soil zone and with water application rates that are representative of natural precipitation or irrigation for optimizing crop production. Most soil samples were collected from the A and B horizons (Sims et al., 2002), which are representative of the shallow vadose zone, but are not directly applicable to parent geological materials in the deeper vadose or saturated zones. Because these experiments require mixing of suspended soil particles in solution for extended periods of time, they do not appear to be representative of the conditions present during rapid infiltration through a porous media, and are likely to overestimate the ability of soils to sorb P.

Consistent with national studies, work in Delmarva groundwater has found that P solubility and transport are enhanced by reducing conditions (Vadas and Sims, 1998, 1999; Sims et al., 1996, 1998; Vadas et al., 2007; Kasper and Strohmeier, 2007). In general, reducing conditions coexist with concentrations of dissolved oxygen below 2 mg/L, conditions that would be expected with sufficient concentrations of natural- or wastewater-supplied bioavailable dissolved organic carbon (Debrewer et al., 2005; Repert et al., 2006; Parkhurst et al., 2003). However, conditions must be reducing for there to be high concentrations (>0.1 mg/L) of P in Delmarva groundwater (Kasper and Strohmeier, 2007; Vadas et al., 2007). USGS researchers (Debrewer et al., 2005) did note the co-occurrence of measurable P and low DO, but did not detect P in enough samples to infer the processes that enhance P transport.

Research on the fate of P in land-applied wastewater and groundwater remediation indicates mixed success with respect to the attenuation of P through sorption to the aquifer matrix or formation of P-bearing minerals. Baker et al. (1998), Zvomuya et al. (2006), Hu et al. (2005), McCobb et al. (2009), and AFCEE (2008) report that amendments of Fe or calcium (Ca) to the aquifer matrix or in solution facilitates P sorption or mineralization. Amendments of alum or alum-based water treatment residuals are also used in agricultural and wastewater treatment to enhance P sorption (Asano et al., 2007). McCobb et al. (2002), Robertson (2003), Robertson et al. (1998), Robertson and Harman (1999), Zurawsky et al. (2004), Parkhurst et al. (2003), and

Stollenwerk (2003) not only discuss P attenuation but also the re-release of P back to groundwater when geochemical conditions change, as would be expected when native groundwater or infiltrating rain-water flushes through aquifer materials that have been impacted by wastewater.

Large production-scale experiments for SAT were performed by the USGS at the East Meadow wastewater treatment facilities (Schneider and Oaksford, 1986; Schneider et al., 1987) and at the Cedar Creek wastewater treatment facility (Brisbin et al., 1984; Oliva, 1985; Wood, 2006), both located in Long Island, New York. In more than one year of operation it appeared that the SAT facilities were successfully attenuating P in the vadose zone. Unfortunately, the SAT facilities were abandoned because chlorination, was not adequate for disinfection, and the concentrations of trihalomethanes in the effluent and in monitoring wells were in excess of drinking water standards.

A recent study completed at a large RIBS facility in Orange County, Florida, provides information on P attenuation during SAT as well as predicting the P storage capacity of soils beneath the infiltration basin. Moura (2009) found that P concentrations in groundwater under one of four RIBS are similar to those in effluent. He also found that the P storage capacity of a soil predicted using agronomic testing protocols was twice what was observed during leaching tests conducted at the operational infiltration rates used in the RIBS. Moura (2009) attributes the lower P storage capacity to the rapid velocity of infiltration.

P-contamination of groundwater by RIBS at the MMR has been long known and is documented in tens of agency reports and peer-reviewed articles (LeBlanc, 1984; Walter et al., 1995; McCobb et al., 2002; Parkhurst et al., 2003; AFCEE, 2008). At the site, groundwater contamination extends thousands of feet from the RIBS and discharges to nearby Ashumet Pond, contributing to a serious eutrophication problem. The consensus of researchers is that the P input from RIBS far exceeds the capability of the aquifer to sorb and mineralize P, a condition exacerbated in part by dissolved organic carbon from effluent that caused reducing conditions in aquifer. A reactive barrier containing zero-valent iron has been installed along the shoreline of the pond (AFCEE, 2008), and results to date indicate that this technology can be used successfully for P abatement (AFCEE, 2008; McCobb et al., 2009).

Effects of increased ionic strength and redox reactions

The release of naturally occurring or anthropogenic contaminants present in the vadose zone and aquifer, caused by interactions with effluent, also present the risk of contamination. One example is the ionic strength effect (Freeze and Cherry, 1979; Hem, 1992; Bolton, 2000; Szabo et al., 2004; Sparks et al., 2007), in which mineral solubility and the risk of contaminant desorption increases with increasing ionic strength or increased concentrations of dissolved solids (DS). The land application of wastewater would be expected to enhance the ionic strength effect as wastewater typically contains greater concentrations of DS than does Delmarva groundwater that is not affected by wastewater (Ritter and Chirnside, 1984; Denver, 1989).

The release and/or transport of contaminants can be facilitated by the class of biologically mediated geochemical processes known as redox reactions. Degradation of organic carbon has been cited as a common cause of changing redox conditions (Ator, 2008; McMahon and Chapelle, 2008; Jurgens, et al., 2009; Repert et al., 2006; Herbel and Fendorf, 2006). Organic carbon is a common constituent in treated wastewater (Crites et al., 2006; Turkmen et al., 2008) and has been linked to the redox-related release of metals including iron, manganese, mercury, and arsenic (Oren et al., 2006; Koterba et al., 2006; Repert et al., 2006; Lee and Bennett, 1998). The transport of phosphorus in groundwater has been linked to redox and organic carbon mediated reactions (Vadas et al., 2007; McCobb et al., 2002).

Results of Field Testing and Analyses

What follows is a discussion of physical and chemical analyses on groundwater samples collected from wells, grab samples collected from surface water, and grab or composite samples collected from treatment plant effluent. All results are tabulated in Appendix 2. Well and surface-water sample locations are shown on Figure 2 and listed in Appendix 1. Note that the site index numbers shown in these locations apply only to this study and do not correspond to the site numbers contained in Andres et al. (2015). Chemical data from dissolved and suspended samples are discussed as concentrations; the term value is used for physical measurements such as specific conductance (SC in microsiemens – μ S), pH (standard pH units), redox potential (Eh in millivolts – mV), and temperature (degrees Celsius – C).

Effluent quality and flow

Andres et al. (2015) report that effluent flow rate varies by more than a factor of three over the course of the study, and the sewage collection system experiences significant groundwater infiltration when the water table is high. The highest flow rates occur during periods of peak park use and when groundwater infiltration is at a maximum (Andres et al., 2015). During some periods, there is significant intra-week variability in flow with weekend flows somewhat greater than mid-week flows.

The effluent quality in monthly grab samples varies with flow and season (Fig. 3). Results from the monthly composite samples, though fewer in number, are similar to those from the grab samples. Maximum concentrations of N and P species and maximum temperature values are observed during the summer months when water use and wastewater generation, as a result of the higher number of park visitors, are at a maximum (Figs. 4a, 4b). During the summer months (30 mg/L and 5 mg/L, respectively) at CHSP, total N and P are similar to N and P in effluent from primary treatment plants, while concentrations of total N and P during periods of non-peak park use are much lower (less than about 10 mg/L and 1 mg/L respectively) and not dissimilar to those reported for effluents from tertiary treatment plants (Asano et al., 2007, Table 3-13).

The monthly variability in the proportions of nitrate (NO_3^-), ammonium (NH_4^+), and organic-nitrogen (ON) in the effluent indicate that N processing in the treatment plant

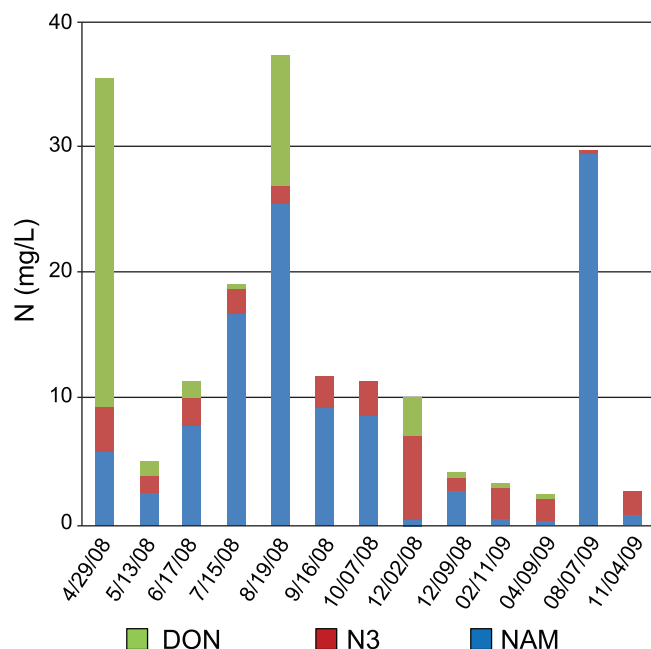


Figure 4a. Plot of effluent concentrations of nitrogen (N) species with time. The height of the bar represents total dissolved N. DON – dissolved organic N, N3 – nitrate nitrogen, NAM – ammonium nitrogen. Data from this study and from DNREC files.

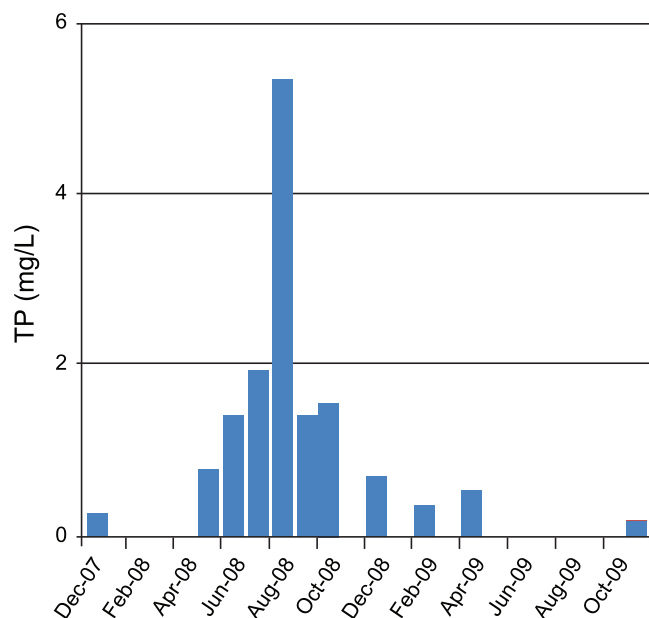


Figure 4b. Plot of effluent concentrations of total phosphorus (TP) with time. Data from this study and from DNREC files.

varies significantly from month to month. Intraweek and seasonal variations in water use, wastewater production, and time-variant rates of groundwater infiltration into the collection system, appear to have affected the forms of N entering the plant and how N is processed in the plant.

The expected covariance of SC with N and P in effluent (high values during the dryer summer months and low values when fresh native groundwater infiltrates into the sewage collection system) is not consistently observed. Elevated chloride (Cl^-) (>300 mg/L, Fig. 4c) is found in two samples, though interpretation is complicated by a lack of corresponding SC data. The use of showers at the beach bathhouse

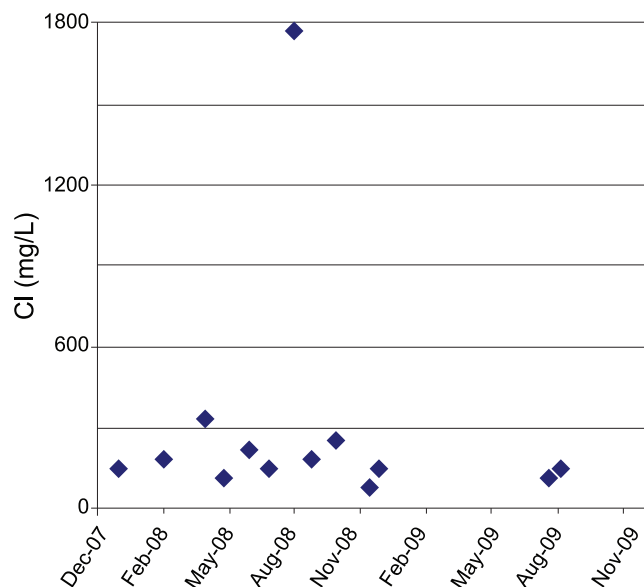


Figure 4c. Plot of effluent concentrations of chloride (Cl) with time. Data from this study and from DNREC files

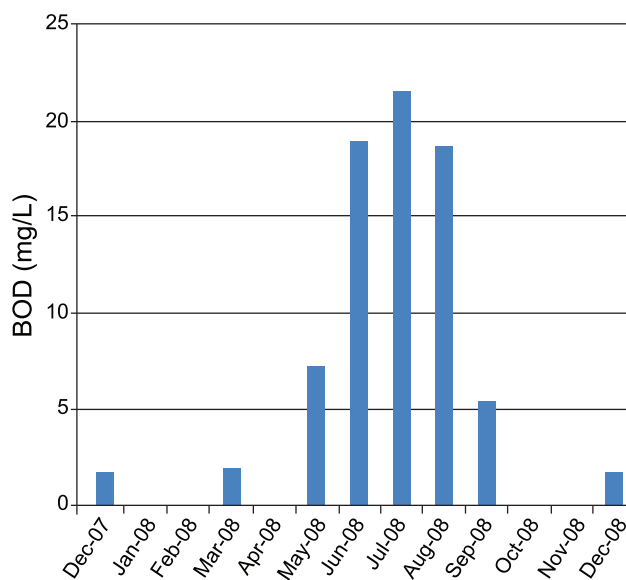


Figure 4d. Plot of effluent concentrations of biologic oxygen demand (BOD) with time. Data from this study and from DNREC files.

may add enough Cl^- to wastewater to cause elevated Cl^- and SC values; however, high SC values and low N and P concentrations in a sample collected in April 2009 during a high water-table period, and Cl^- concentrations in excess of 500 mg/L, indicate that salty water may occasionally infiltrate into the sewage collection system. We do not have enough information to determine where and if this is occurring.

Weekly and daily sampling data are sparse, and samples collected in August 2008 indicate that effluent quality may vary daily. Grab and 24-hour composite samples, collected on one day by Envirocorp, contained five- to ten-times higher than average concentrations of Cl^- and sodium (Na^+),

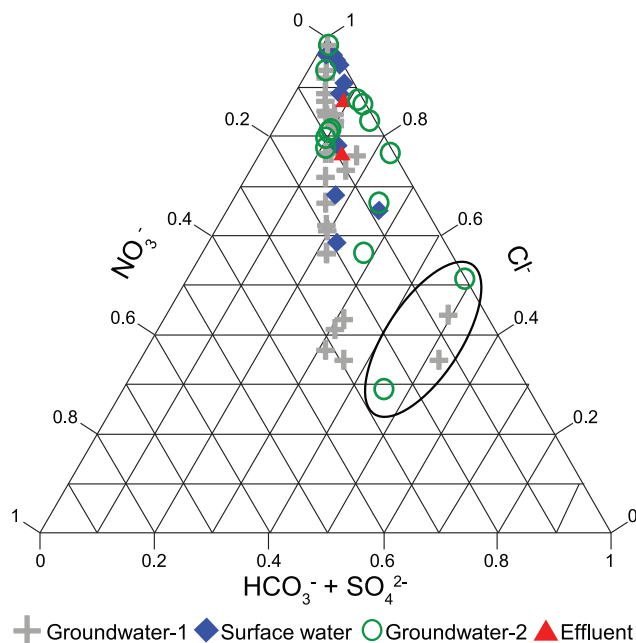


Figure 5a. Ternary plot of proportions of anions. Anion proportions in individual sample results are plotted. Groundwater-1 indicates data from wells located at land-surface elevations greater than 10 feet NAVD88. Surface water indicates data from surface-water sources in the SLS. Groundwater-2 indicates data from wells located at land-surface elevations less than 10 ft NAVD88 in, and immediately adjacent to, the SLS. Effluent indicates data from the wastewater treatment plant. The oval denotes sites 11 and 13, which are discussed in the text.

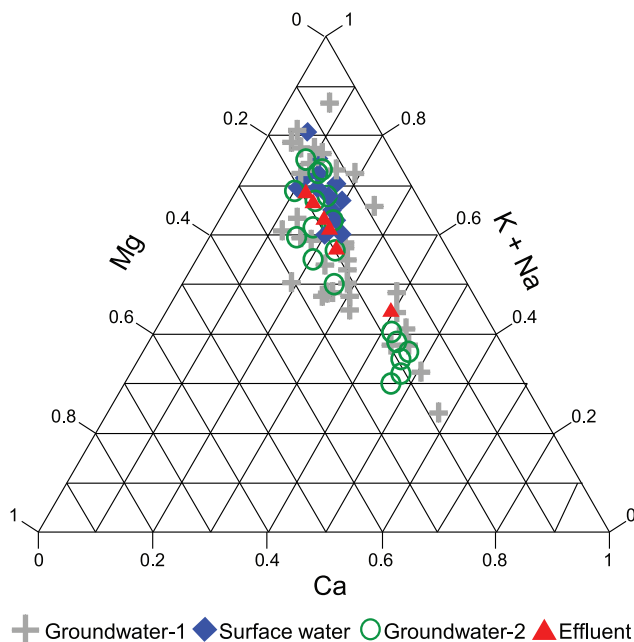


Figure 5b. Ternary plot of proportions of ions cations. Cation proportions in individual sample results are plotted. Groundwater-1 indicates data from wells located at land-surface elevations greater than 10 feet NAVD88. Surface water indicates data from surface-water sources in the SLS. Groundwater-2 indicates data from wells located at land-surface elevations less than 10 ft NAVD88 in, and immediately adjacent to, the SLS. Effluent indicates data from the wastewater treatment plant.

while an effluent grab sample collected the next day by DGS staff had a Cl^- concentration similar to average effluent. Although we could not determine the cause of the spike in Cl^- concentrations, the low water table at the time of sampling and the short duration of the excursion indicates an influx of salty water at the bathhouse or at one of the dormitories. Differences in N, P, and biologic oxygen demand (BOD, Fig. 4d) were also observed between these samples, although at a smaller magnitude. The possibility that similar short-term variability is repeated multiple times cannot be discounted.

Six samples were analyzed by ICP-AES. Arsenic was above the detection limit in three samples, below 0.01 mg/L in two samples, and had a maximum concentration of 0.023 mg/L. State and local records (Gilbert Holt, Lewes Board of Public Works) have no reports of arsenic values above the drinking water standard 0.01 mg/L in any sample from the water source serving the park.

Impact of effluent disposal on groundwater quality – contaminant tracers

Ternary plots of major anion proportions (Fig. 5a) show that a majority of samples are dominated by Cl^- and NO_3^- . Anion proportions in the effluent are dominated by Cl^- , but with slightly more NO_3^- than most groundwater and surface water sample.

Only a few groundwater samples from four wells plot in areas where bicarbonate and sulfate form a larger proportion of anions. Data (Fig. 5a - groundwater 2 group) from wells Ni45-39 (Site 11) and Ni45-41 (Site 13) reveal a greater proportion of bicarbonate than sulfate. Although shells would add bicarbonate when dissolved, none were encountered during well installation. Because these wells are a few feet above the SLS on the slope of the dune and not in the swampy area, groundwater at these sites is likely to be a mixture of water that has infiltrated through wooded areas south of the infiltration basins and an unknown proportion of effluent.

Results from two additional wells plot outside of the main data cluster (Fig. 5a – groundwater 1 group). The dominance of bicarbonate at site in Ni45-50 (Site 16), located closest to the infiltration beds, is likely to be from degraded organic material in the effluent. Well Ni45-47, at this site but finished a few feet shallower, also contains proportionally more bicarbonate. Ni44-16 (Site 1), located more distant from the infiltration beds and not in the preferential flow zone, contains more sulfate than bicarbonate, perhaps indicating that sulfide minerals oxidation affects groundwater quality at this location more than effluent disposal. Leaks in the sewage collection system near this well may have introduced sulfur-rich water to the aquifer, as indicated by elevated NO_3^- concentrations (> 1 mg/L) in a few samples.

A majority of sample locations have Na^+ and K^+ , but primarily Na^+ as the dominant cations (Fig. 5b). The dominance of Cl^- and Na^+ in major ion composition indicates that salt water has the greatest influence on the general geochemistry at the site within the aquifer. However, the average sulfate (SO_4^{2-}) : Cl^- ratio of 0.0278 is not diagnostic of a particular source of salt water (Hem, 1992).

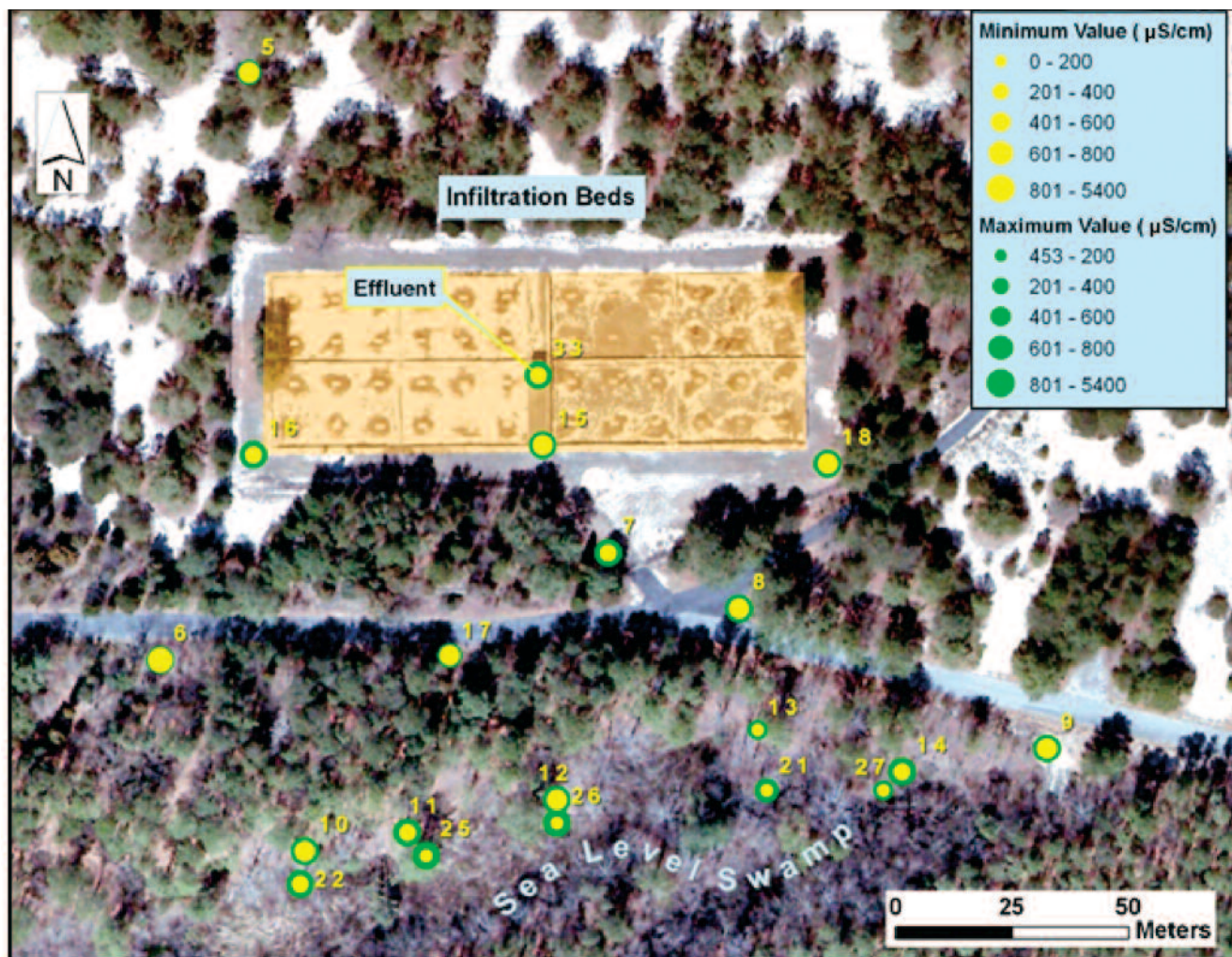


Figure 6. Spatial distribution of specific conductance. Note the widespread distribution of specific conductance values greater than 600 $\mu\text{S}/\text{cm}$, which is thought to indicate effects of effluent disposal.

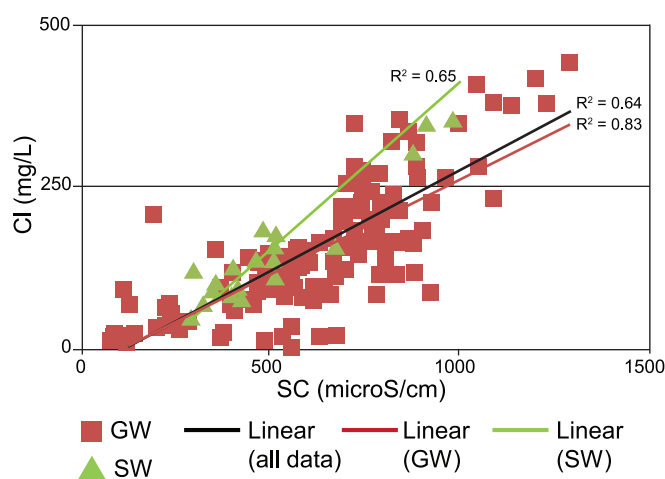


Figure 7. Comparison of chloride concentrations and specific conductance (SC) values for surface water (SW triangles) and groundwater (GW squares) and results of regression analysis. SC reported in mS/cm . R-squared coefficients indicate that SC is a good predictor of Cl^- , and the correlations are significant ($p < 1 \times 10^{-9}$ for surface water, $p < 1 \times 10^{-34}$ for groundwater).

Wells Ni44-16 (Site 1) and Ni45-41 (Site 13) show increased proportions of Ca and magnesium (Mg) that are not consistent with sulfide mineral oxidation (discussed above), and there is no direct evidence that shell bed sources of Ca and Mg are present at the sites of these wells.

Tracers as indicators of groundwater contamination

Physical properties or chemical constituents that are not naturally present in the aquifer can be used as tracers of contaminant transport. Tracers are conservative if they are not affected by interactions with the aquifer matrix (Freeze and Cherry, 1979). Andres et al. (2015) noted that that temperature can be a useful tracer of effluent disposal during the summer months when effluent temperatures are much greater than groundwater temperatures. Using spatial and temporal variations in temperature, the authors identified a preferential flow zone in which effluent from the infiltration basins flows toward the SLS located just south of the infiltration basins (Fig. 2).

A common effluent tracer is the chloride ion (Cl^-). Cl^- is a common constituent in wastewater and does not react with the aquifer matrix. SC can be commonly used as a proxy (Freeze and Cherry, 1979). Although treated waste-

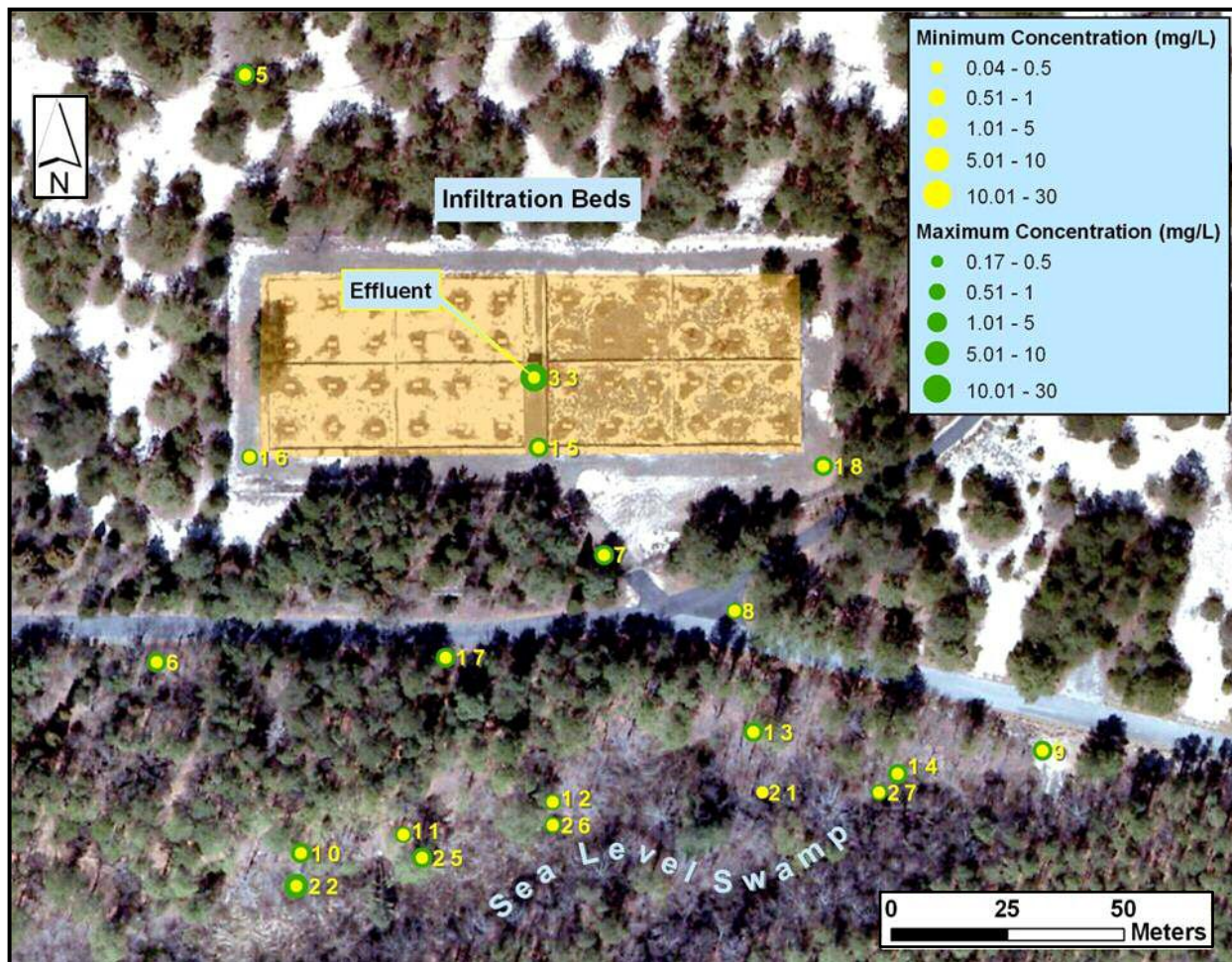


Figure 8. Spatial distribution of ammonium-nitrogen. Ammonium-nitrogen concentrations are highest in effluent, followed by wells located closest to the infiltration basins and then surface-water in the Sea-Level Swamp. The difference in ammonium-nitrogen between effluent and groundwater may reflect nitrification during infiltration.

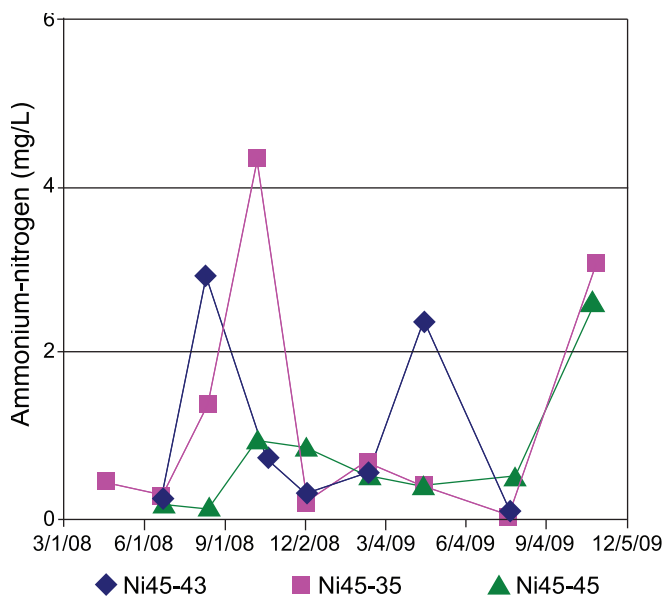


Figure 9. Time-series plot of ammonium-nitrogen for wells Ni45-43, Ni45-35, and Ni45-45.

water typically has concentrations of Cl^- , dissolved solids (DS), and SC values that are several times greater than groundwater that is not impacted by wastewater (Asano et al., 2007). The proximity of the infiltration basins in the study area to the ocean and salt marsh, and the temporal variability of wastewater quality could compromise the use of Cl^- as a tracer. Indeed, results from a geophysical log in one core hole indicated that there may be brackish groundwater at the base of the Columbia aquifer in the CHSP (Woodruff, 1970),

However, Cl^- concentrations in surface water and shallow (< 100 ft) wells in the CHSP are less than 100 mg/L. This is consistent with the lack of significant Cl^- concentrations in mineral grains; groundwater from portions of the Columbia aquifer not impacted by human activity is very dilute, containing less than 100 mg/L dissolved solids (Denver, 1989). SC values are less than 125 μS at many surface-water and groundwater sampling sites in the vicinity of the infiltration basins (Leis, 1974) (Fig. 6) These values indicate minimal or no intrusion of saline water from the ocean or other tidal water bodies. Further evidence that groundwater in the study area is not connected to the ocean or salt marsh is that groundwater levels do not exhibit a

diurnal tidal signal (Andres et al., 2015). There also is a significant correlation between SC and Cl^- in groundwater and surface water (Fig. 7). All of this is evidence that Cl^- or SC may be used as a tracer at this site.

Variability of tracers and N and P species with map location and time

In the following discussion, magnitude and variability in the horizontal and temporal dimensions of SC, N, and P concentrations in surface-water, groundwater, and effluent are illustrated by proportionally sized and color-coded symbols (Figs. 6, 8, 10, 12). At a given sampling point a small size difference between the symbols representing minimum and maximum concentrations indicates lower temporal variability. Differences in symbol size between sampling points indicates horizontal variability. Effluent quality is indicated by a single dot at Site 33 (Fig. 2). Vertical variations of water quality are discussed in a later section.

SC values in effluent are greater than 600 μS . Values greater than 600 μS are also found in groundwater closest to the infiltration basins, and in groundwater and surface water within the preferential flow zone, indicating that these sites are heavily influenced by effluent. Some of these sites show higher variability between minimum and maximum values of SC, which may be the result of temporal variability in groundwater flow directions (e.g., Andres et al., 2015) or in effluent quality. SC at surface water sites in the preferential flow zone may be reduced by dilution from storm runoff. Potential impacts from contaminant sources related to the former Fort Miles (U.S. Army Corps of Engineers, 1997) cannot be dismissed.

SC values between 200 and 600 μS are found intermittently in groundwater (< 1 ft below water table) at sites within the SLS (sites 10-14) and at many surface-water sites (sites 21, 25-27) (Fig. 2), indicating that these locations are intermittently influenced by effluent. SC between 200 and 600 μS occurs were sampled in groundwater over multiple periods at Ni45-33 (site 5), located to the north of the infiltration basins. Temperature variations of less than 1.5°C in groundwater from this site (Andres et al., 2015) indicate that flow from the basins into this site is much slower than in the preferential flow zone.

The maximum NH_4^+ concentrations in groundwater are nearly a factor of 10 smaller than those in effluent, indicating that NH_4^+ in effluent, or NH_4^+ produced by mineralization of ON, is nitrified in the vadose zone. NH_4^+ concentrations in groundwater are highly variable both spatially and temporally (Fig. 8). The greatest concentrations and temporal variability of NH_4^+ are observed in the preferential flow zone. Because the expected decrease in the magnitude of peak concentrations with distance is not consistently observed, it is likely either that the wells in Figure 9 are not on the same flow path or that the sampling frequency was not adequate to catch the peak concentration at the well nearest to the infiltration basins. Concentrations of NH_4^+ in surface water and groundwater in the SLS are slightly greater and more temporally variable towards the west, (Fig. 8), the direction of groundwater flow in this area, indicating a greater influence of effluent.

NO_3^- concentrations, which range from non-detectable to more than 20 mg/L, in groundwater are highly variable both spatially and temporally (Fig. 10). The dominant processes causing variability are seasonal differences in N concentrations, the differing forms of N in effluent, and the dilution and dispersion of effluent with distance from the infiltration basins. Denitrification, which may also play a role, is discussed in a later section. The highest NO_3^- concentrations are observed in the preferential flow zone, with NO_3^- -N concentrations in excess of 20 mg/L in wells located more than 150 ft from the infiltration basins. Time series plots of NO_3^- and temperature in three wells (Fig. 11) located at increasing distances from the infiltration beds show that warmer water with elevated NO_3^- concentrations arrive at later in time with increased distance, indicating that wastewater and groundwater are transported at roughly similar velocities. Similarly to NH_4^+ , the expected decrease in the magnitude of peak NO_3^- concentrations with distance is not consistently observed and it is likely that the wells in Figure 11 are not on the same flow path or that sampling frequency was not adequate to catch the peak concentration at the well nearest to the infiltration basins.

Concentrations of NO_3^- -N less than 0.4 mg/L represent natural groundwater; concentrations greater than 3 mg/L reflect human impact (Ator, 2008). Wells Ni45-16 (Site 2) and Ni45-17 (Site 3), located in an area where groundwater flow paths would not transport effluent from the infiltration basins, have values less than 0.4 mg/L. Well Ni44-16 (Site 1), also thought to be located in an area where groundwater would not flow from the infiltration basins, ranged from about 0.5 mg/L to nearly 21 mg/L. This suggests the presence of another potential source of NO_3^- near this well such as a historic solid waste disposal, or a leaking pipe in the campground's sewage collection system. Effluent disposal has an impact on surface water as NO_3^- -N concentrations in excess of 5 mg/L were observed in spring 2008, prior to summer drawdown of the water table.

Although there is spatial correlation of sites having SC values greater than 600 μS and NO_3^- -N greater than 10 mg/L, there is a poor linear correlation of SC with NO_3^- (Fig. 12), indicating that SC is not a good predictor of NO_3^- .

In this study, total P (TP) is the sum of orthophosphate (OP), dissolved organic phosphorus (DOP), and particulate phosphorus (PP); total dissolved P (TDP) is the sum of OP and DOP. Since surface-water and effluent samples were not filtered before analysis, P values are reported as TP. Groundwater samples were filtered and so concentrations are reported as OP or TDP.

OP concentrations in groundwater are highly variable both spatially and temporally (Fig. 13). This primarily reflects the seasonal variability of TP concentrations and the forms of P in effluent, and secondly the possible effects of P sorption/desorption from the aquifer matrix. The highest OP concentrations are observed in the preferential flow zone nearest the infiltration basins; concentrations decrease with increasing distance from the infiltration basins. The highest OP concentrations in groundwater are slightly lower than the highest TP concentrations in effluent, indicating the possible

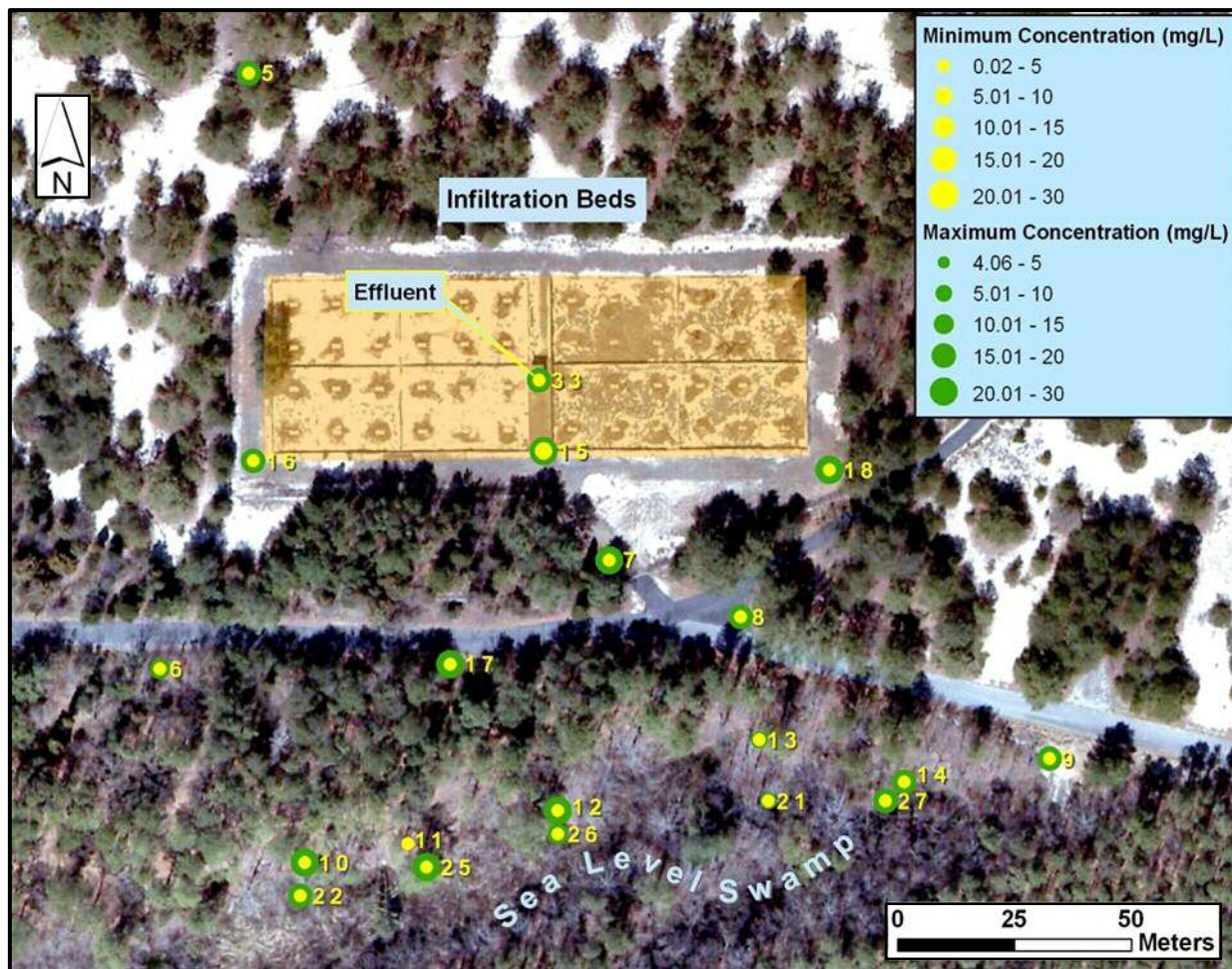


Figure 10. Spatial distribution of nitrate-nitrogen. Concentrations of nitrate-nitrogen in groundwater samples from many wells are similar to total nitrogen in effluent samples. This is thought to reflect conversion of organic and ammonium-nitrogen to nitrate-nitrogen during infiltration.

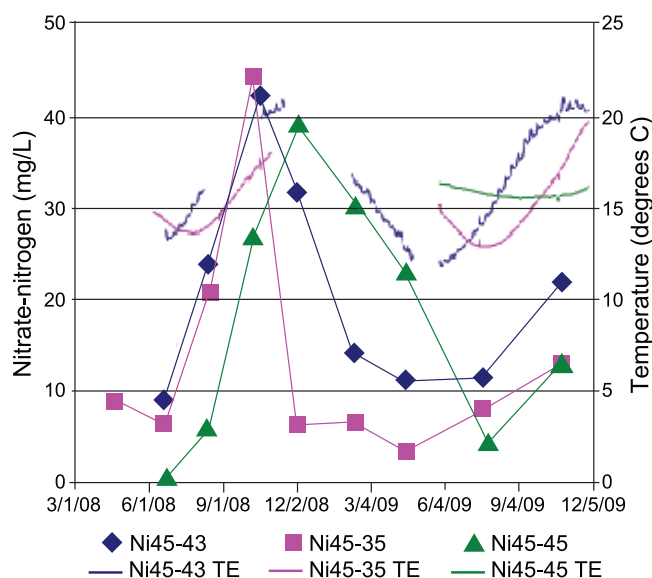


Figure 11. Time series plots of nitrate-nitrogen and temperature for wells Ni45-43, Ni45-35, and Ni45-45.

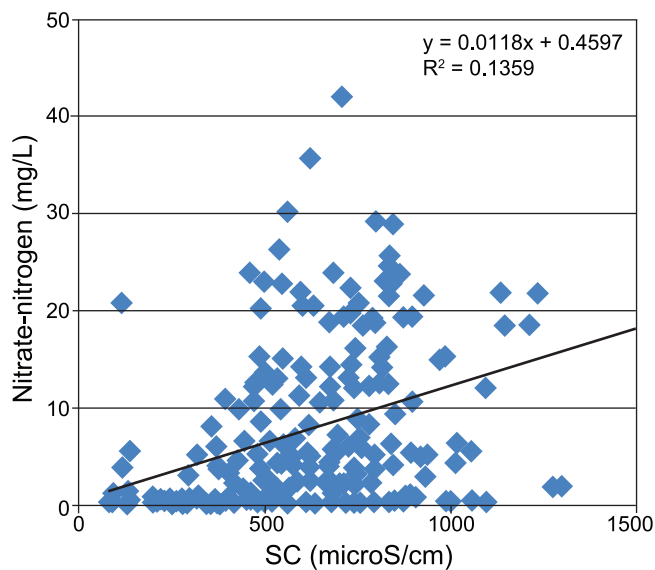


Figure 12. Comparison of specific conductance (SC) and nitrate-nitrogen concentrations for surface water and groundwater and results of regression analysis. SC reported in microsiemens per cm. The R-squared coefficient is low showing that SC is not a good predictor of nitrate. The correlation is significant at $P=1.4 \times 10^{-8}$.

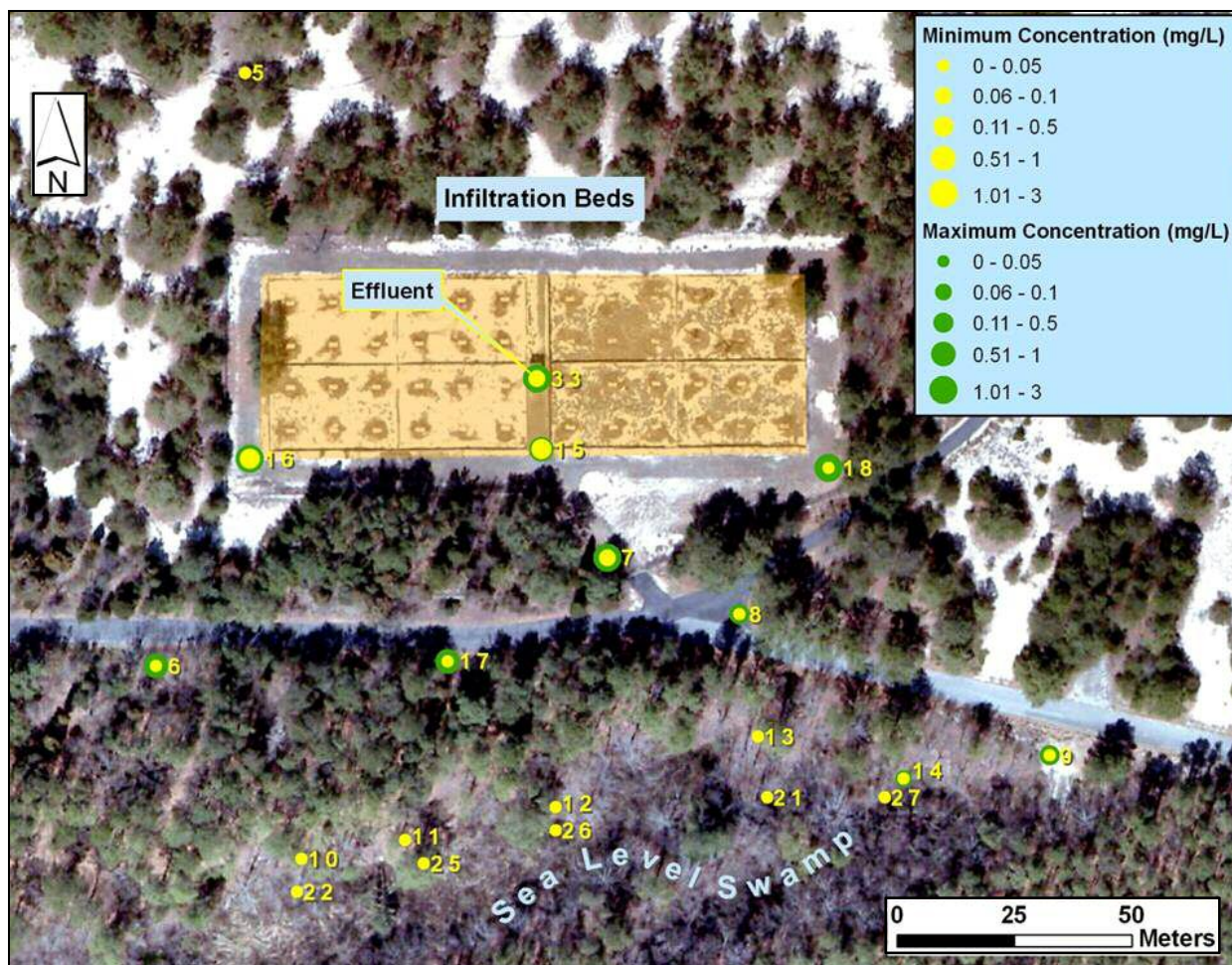


Figure 13. Spatial distribution of orthophosphate. Concentrations of orthophosphate in groundwater samples from wells located closest to the infiltration basins are similar or slightly greater than total phosphorus in effluent samples. Note that maximum orthophosphate at site 17, located nearly 50 m from the nearest infiltration basin is greater than 1 mg/L, indicating that the aquifer matrix does not have sufficient phosphorus attenuation capacity to stop transport of relatively high concentrations of phosphorus.

attenuation of P by physical filtering of particulate P in the subsurface, or from aquifer sorption effects. The difference between TP in effluent and OP in groundwater may be an artifact of the well sampling frequency; that is, we may not have sampled wells at the time P concentrations were at their maximum.

The spatial pattern of differences between minimum and maximum OP concentrations is shown (Fig. 13). The difference in concentrations in the two wells located closest to the infiltration basins is very small compared to the seasonal variability of TP concentrations in effluent. Reduced variability of OP in groundwater compared to TP in effluent is consistent with the sorption of P on the aquifer matrix during periods when P in effluent is greater than P in the aquifer, and the subsequent desorption of P from the aquifer to groundwater during periods when P concentrations in infiltrating water are lower than those in the groundwater. Samples from several other wells in the preferential flow zone exhibit temporal variability in P that is similar to that observed in effluent samples. This could indicate that groundwater is mimicking the seasonal variability of P in effluent along with lower rates of sorption and desorption

from the aquifer matrix. Concentrations of OP observed in groundwater in the preferential flow zone are much greater than the average OP concentrations of groundwater (< 0.02 mg/L) reported by Kasper and Strohmeier (2007), and greater than OP concentrations observed under fields amended with poultry litter (Sims et al., 1996, 1998).

Variability of N and P with depth and time

As was previously discussed, temporal variability in effluent quality is reflected by temporal variability in groundwater quality. In addition, data from CMTs and from shallow and deep samples within standard wells, document that concentrations also vary vertically. As a result, standard parametric tests (e.g., t-test of means, and F-tests of variance) that compare data from the group of four standard wells to the group of four CMT wells indicate that all data are drawn from the same population. The lack of discriminant power indicates that simple parametric tests are inappropriate for analyzing samples that been influenced by a complex set of flow and transport processes.

Figures 14 through 21 display variations in NO_3^- and OP concentration with depth, and between sampling periods

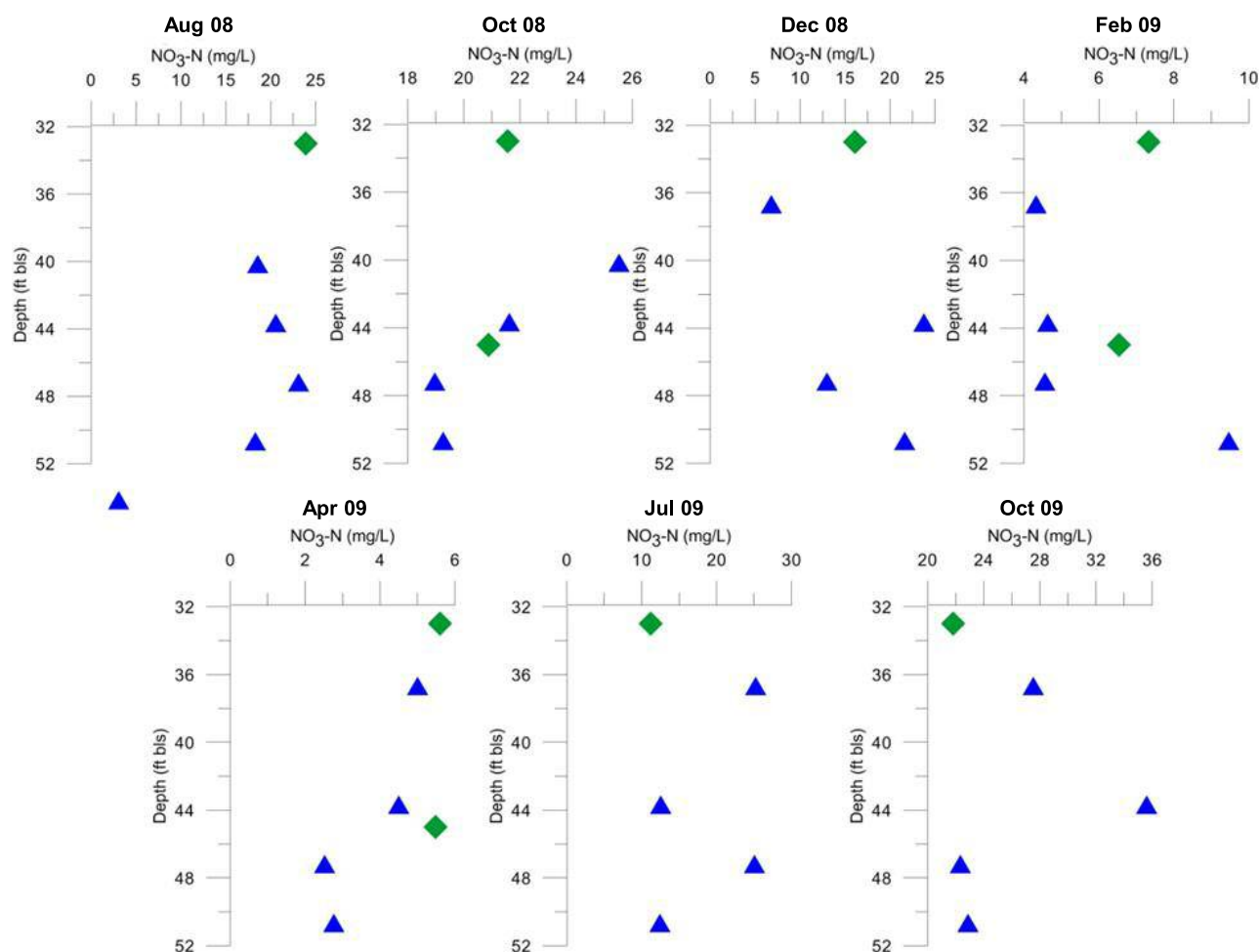


Figure 14. Nitrate-nitrogen – depth plots for standard-well Ni45-43 (diamond) and CMT1 wells Ni45-47 through 53 (triangle). Horizontal separation of wells is less than 2 m. On selected dates, the standard well was sampled at two depths with a point-source bailer.

in standard and CMT wells. Concentration scales vary by well and between sampling periods to best display vertical patterns. These plots reveal groundwater quality in terms of effluent loading and flow, and contaminant transport processes. CMT ports are labeled from one to seven in order of increasing depth.

Wells Ni45-43 and CMT1 (Ni45-47 through Ni45-53) are located between two infiltration beds (Site 15) with the nearest discharge pipes located about 7 m from the well heads. Well Ni45-43 exhibits the largest magnitude, daily effluent-related water-level and temperature fluctuations of all monitoring wells; the temporal patterns seen in the data indicate that the magnitude of water-level fluctuations is related to the location of effluent discharge.

In most samples, the highest concentrations of NO_3^- are observed in samples from shallowest to mid-depths in wells Ni45-43 and CMT1 (Fig. 14). This indicates that N enters the aquifer with infiltrating effluent and displaces native groundwater. Lower N concentrations in the bottom sampling ports of the CMT could either mean that effluent does

not displace groundwater through the entire thickness of the aquifer or that there is denitrification. Denitrification is discussed in a later section.

There is significant variability in NO_3^- concentrations between sample periods, and in the vertical distribution of NO_3^- between sample periods in wells Ni45-43 and CMT1. NO_3^- concentrations are lowest during the months when there are fewer park visitors, correlating with less water use, and less wastewater production, and highest when there are more park visitors, correlating with more water use, and more wastewater production. As such, NO_3^- data are consistent with the spatial and temporal variability of effluent loading and chemistry. Correlations of NO_3^- at similar depths from CMT ports and standard wells are inconsistent between sample periods.

OP varies substantially with depth in Ni45-43 and CMT1 (Fig. 15). In general, the highest OP concentrations are observed at the shallowest depths, indicating that the source of P is from infiltrating effluent. Groundwater OP concentrations are consistently lower than TP in the effluent; however, the variability in groundwater OP between sample

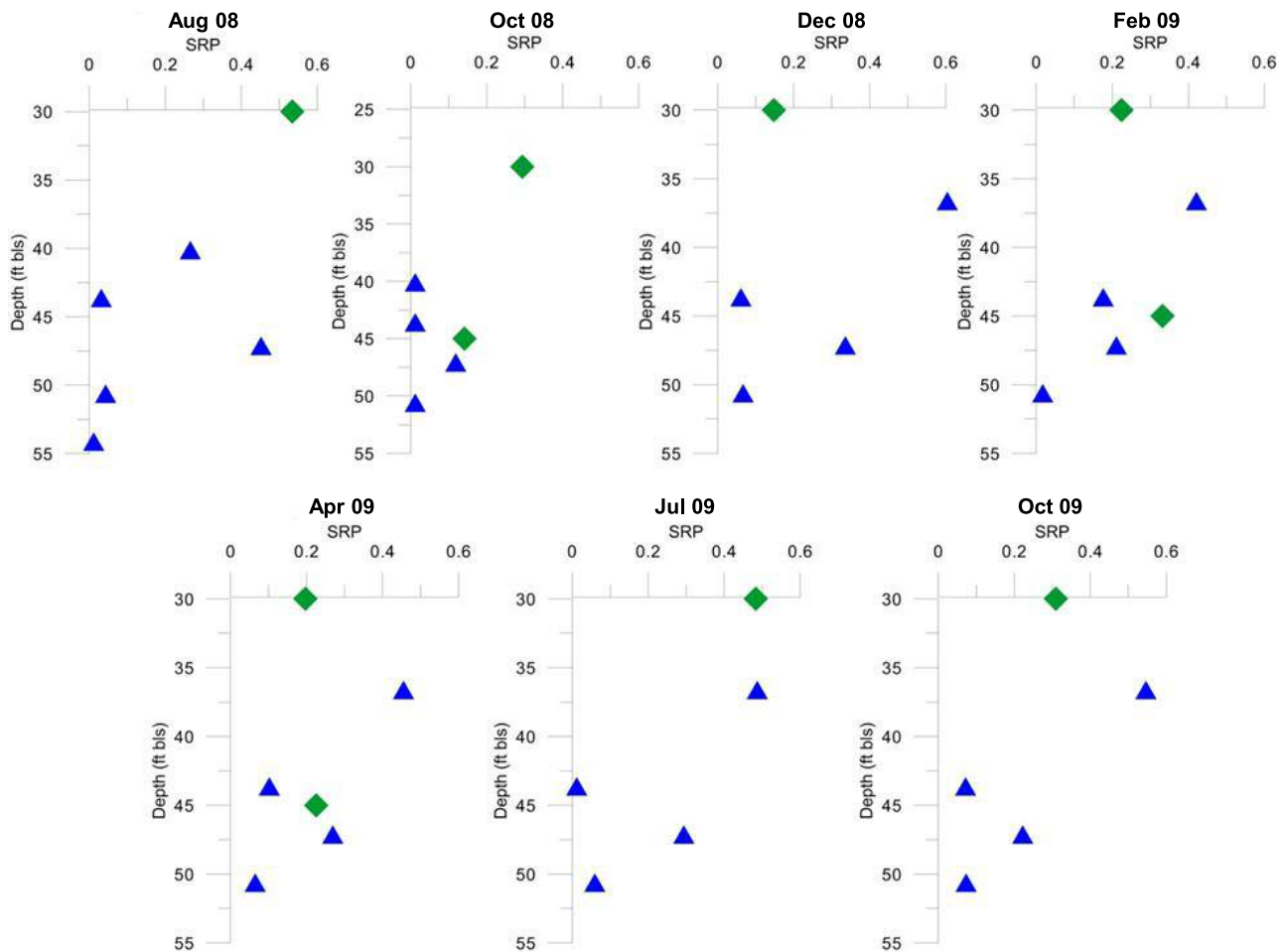


Figure 15. Orthophosphate - depth plots for standard-well Ni45-43 (diamond) and CMT1 wells Ni45-47 through 53 (triangle). Horizontal separation of wells is less than 1 m. On selected dates, the standard well was sampled at two depths with a point-source bailer.

periods is smaller than the variability in TP in effluent, indicating that there is some geochemical processing of P during effluent infiltration and transport in the aquifer. Although there are no consistent correlations of P concentrations in samples from CMT ports between all sample periods, there are some similarities between some sample periods.

Well Ni45-35 and CMT3 (Ni45-61 through Ni45-67) are located downflow of the infiltration basins (Site 7). Concentrations of NO_3^- and OP in CMT ports 3-6 are typically greater than those from ports 1, 2, and 7 (Fig. 16). Samples from standard wells typically have lower concentrations near the top of the water column than near the bottom. This indicates that contaminants have moved down in the unconfined aquifer and water at the water table originates outside of the infiltration basins.

Temporal patterns of NO_3^- in wells Ni45-35 and CMT3 are similar to each other and to changes in effluent. As discussed previously, the time offset between groundwater at this site and effluent is likely related to the travel time between basins and wells.

There is no consistent correlation in NO_3^- between Ni45-35 and CMT3 ports at the same depths. Shallow sam-

ples from the standard well tend to have lower concentrations than those from deeper CMT ports during a sampling period. In December 2008 and July 2009, samples from the top of the water column in Ni45-35 contained less than 10 mg/L N, whereas NO_3^- concentrations in samples from deeper CMT ports are two or more times higher. This indicates that data from shallow depths in Ni45-35 could lead to an erroneous interpretation of significant reductions of NO_3^- through dispersion or denitrification.

The timing of P variation in Ni45-35 and CMT3 (Fig. 17) is different than for NO_3^- and maximum concentrations are lower than those observed in effluent and in wells located closer to the infiltration basins (e.g., Ni45-43/CMT1). These observations are consistent with the effects of sorption or desorption of P to/from the aquifer matrix. The pattern of P with depth in samples from CMT ports is consistent across sample periods.

Correlations between P concentrations in Ni45-35 and CMT3 ports at the same depths are inconsistent temporally. Vertical patterns of OP in CMT3 are similar between sample periods while vertical variations of OP at shallow and deep depths within Ni45-35 change. The variability in OP

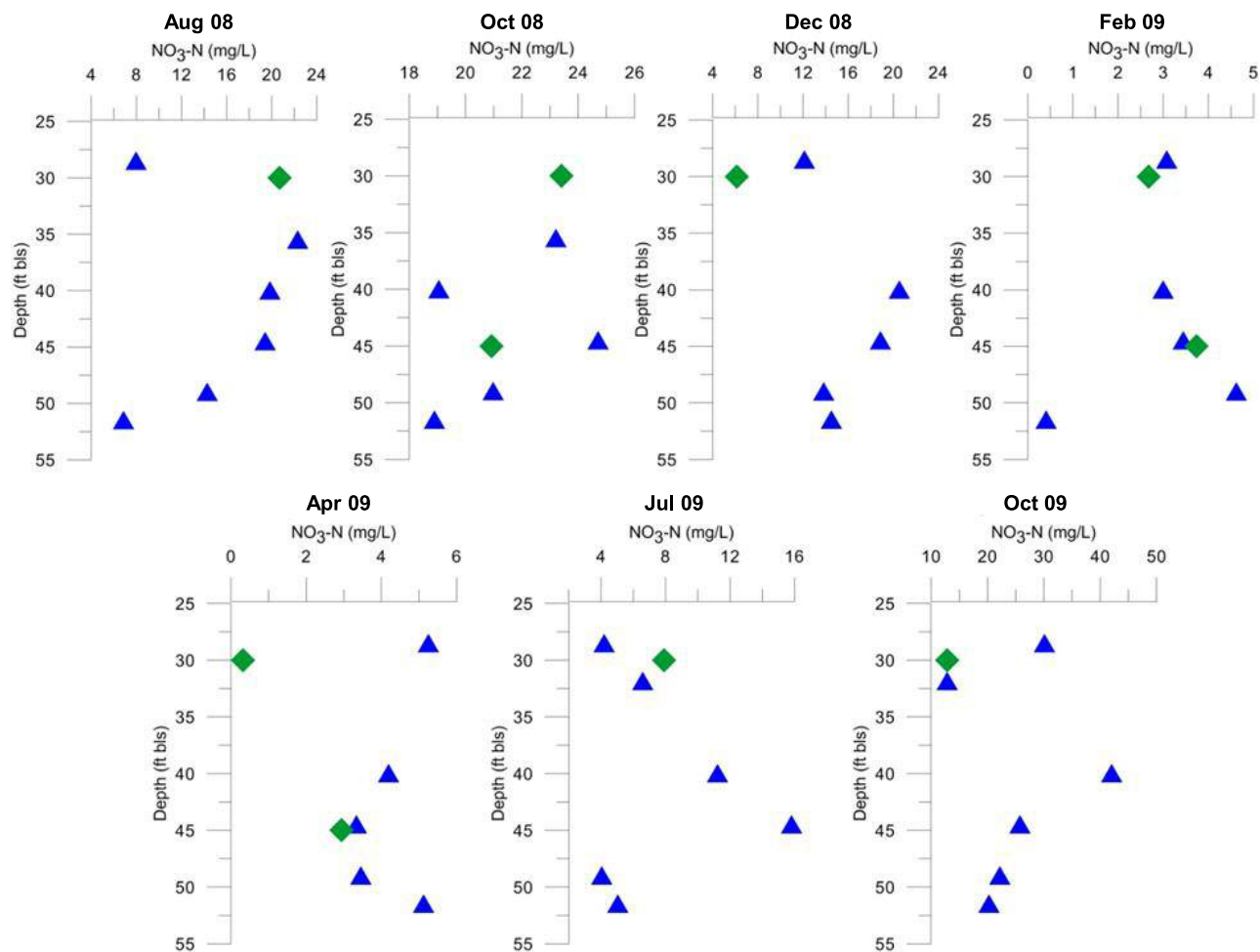


Figure 16. Nitrate-nitrogen – depth plots for standard-well Ni45-35 (diamond) and CMT3 wells Ni45-61 through 67 (triangle). Horizontal separation of wells is less than 2 m. On selected dates, the standard well was sampled at two depths with a point-source bailer.

between the standard well and the CMT indicate that well and sample protocols may affect results.

Well Ni45-45 and CMT2 (Ni45-54 through Ni45-60) are located about 160 ft downflow of the infiltration basins (Site 17). NO_3^- varies with depth in CMT2, with the bottommost samples consistently having the lowest concentrations (Fig. 18). Smaller variations in NO_3^- are observed in shallow and deep samples from Ni45-45. The temporal variation of NO_3^- in CMT2 is not consistent between sampling periods. In contrast to the other standard well-CMT pairs, NO_3^- from similar depths in CMT and standard wells appear to be well correlated.

The highest OP concentrations are observed in mid-depth ports of CMT2 (Fig. 19). In Ni45-45, the deeper sample has greater OP than the shallower sample. In CMT2, OP concentration versus depth profiles are similar between sample periods. The maximum concentrations in Ni45-45 and CMT2 vary between sample periods, with maximum concentrations in excess of 1 mg/L during four sampling

periods. The presence of OP concentrations in excess of 1 mg/L indicates that loading, flow, and transport processes exceed the ability of the aquifer to sorb and store P within the 160 ft distance to the closest infiltration bed. The variability in OP between the standard well and the CMT indicate that well and sample protocols may affect results.

Standard well Ni45-42 and CMT4 (wells Ni45-78 through Ni45-84) are located in the SLS in an area where effluent does not have as significant an impact on groundwater quality as in other well/CMT pairs (Site 14). However, both devices are finished at much shallower depths than other well/CMT pairs. The screen in Ni45-42 is 3-ft long, not long enough to allow for collection of deep samples as was done in the other standard wells.

NO_3^- in CMT4 tends to increase with depth; and with an exception in February 2009, the maximum concentration of NO_3^- is greater in CMT4 than in Ni45-42 (Fig. 20). This indicates that effluent flow has moved downward with distance from the infiltration basins and is consistent with the

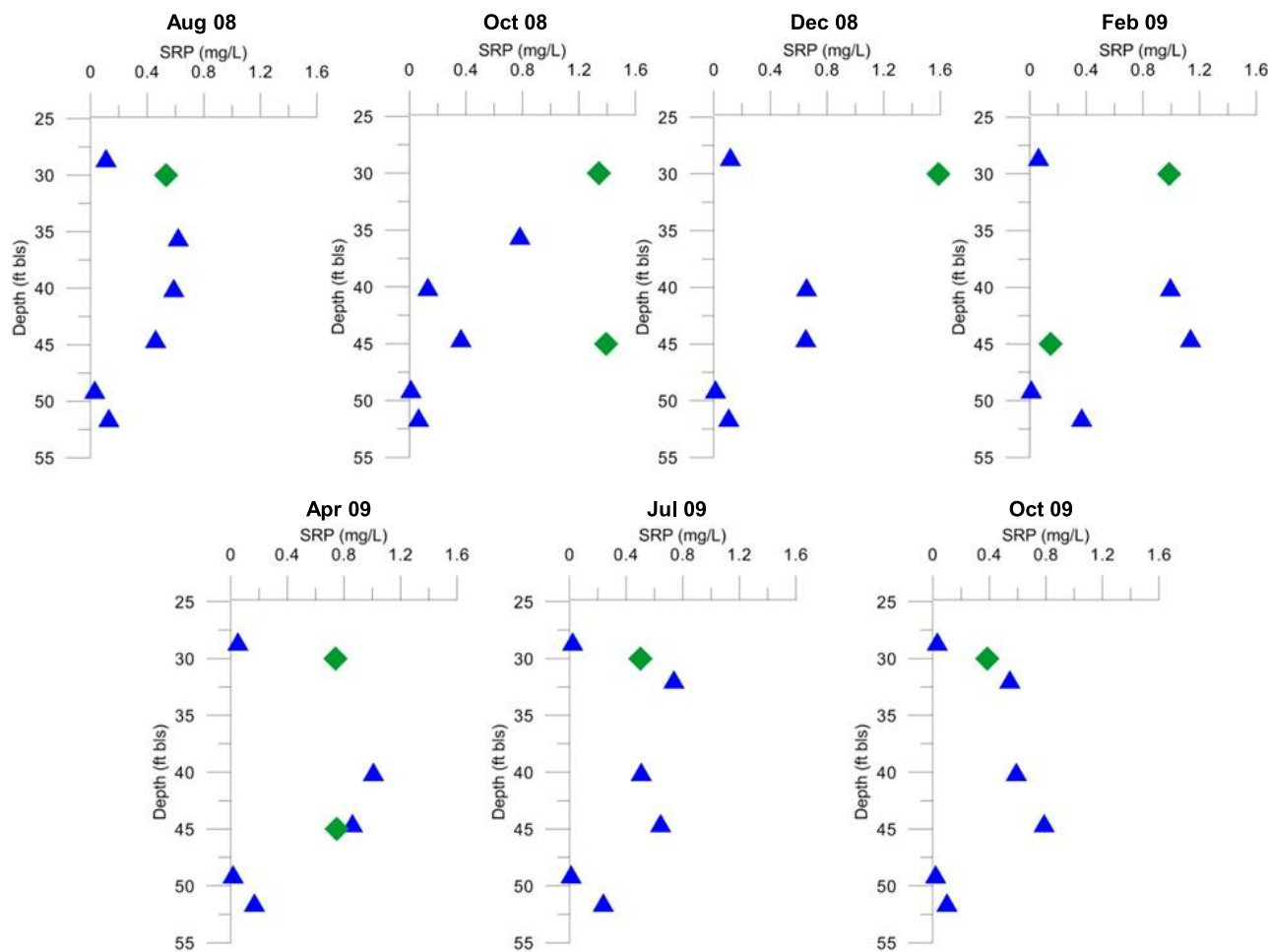


Figure 17. Orthophosphate - depth plots for standard-well Ni45-35 (diamond) and CMT3 wells Ni45-61 through 67 (triangle). Horizontal separation of wells is less than 2 m. Vertical distribution of OP changes with sampling period. On selected dates, the standard well was sampled at two depths with a point-source bailer.

interpretation that groundwater at shallow depths is likely to have recharged in areas outside of infiltration basins.

There is significant variability in NO_3^- in samples from CMT4 during the period of February to November 2009 (Fig. 20). Low NO_3^- concentrations during April and August 2009 may indicate denitrification, which is consistent with the presence of organic-rich sediments and strong hydrogen sulfide odors noted at shallow depths in the SLS. To determine the relative importance of groundwater flow and denitrification to the magnitude and variability of NO_3^- concentrations at this site, samples should be taken at greater depth and samples should be taken to look for dissolved N gas species.

Values of OP in CMT4 and Ni45-42 are much lower than those in effluent, though the observation period may not have been long enough to detect effluent related signals. Except for the November 2009 period, there is very little variability in P concentrations in CMT4 between sampling periods (Fig. 21). There are no consistent correlations in OP between CMT4 and Ni45-42.

Denitrification and other redox sensitive processes

Denitrification, facilitated by the oxidation of organic carbon and consumption of DO, is cited as a key benefit of SAT (Crites et al., 2006, Asano et al., 2007). Denitrification is a redox sensitive process that is favored by low DO (<0.5 mg/L), low redox potentials, and the presence of sulfide minerals (McMahon and Chappelle, 2008). Strong hydrogen sulfide odors, an indicator of sulfate reduction and low redox potential, were detected in several wells (sites 9, 11, 12, 14, Fig. 2) and surface water locations (sites 21, 22, 25-28) of the SLS. DO concentrations less than 1 mg/L commonly occur in groundwater and surface water; however, DO concentrations less than 0.5 mg/L, a threshold concentration strongly correlated with denitrification (McMahon and Chappelle, 2008), are less common. Redox potentials that are low enough to support denitrification (<250 mV) occur in many wells on the site (Fig. 23). Effluent BOD concentrations exceeded 20 mg/L in some samples, indicating an ample source of degradable organic carbon.

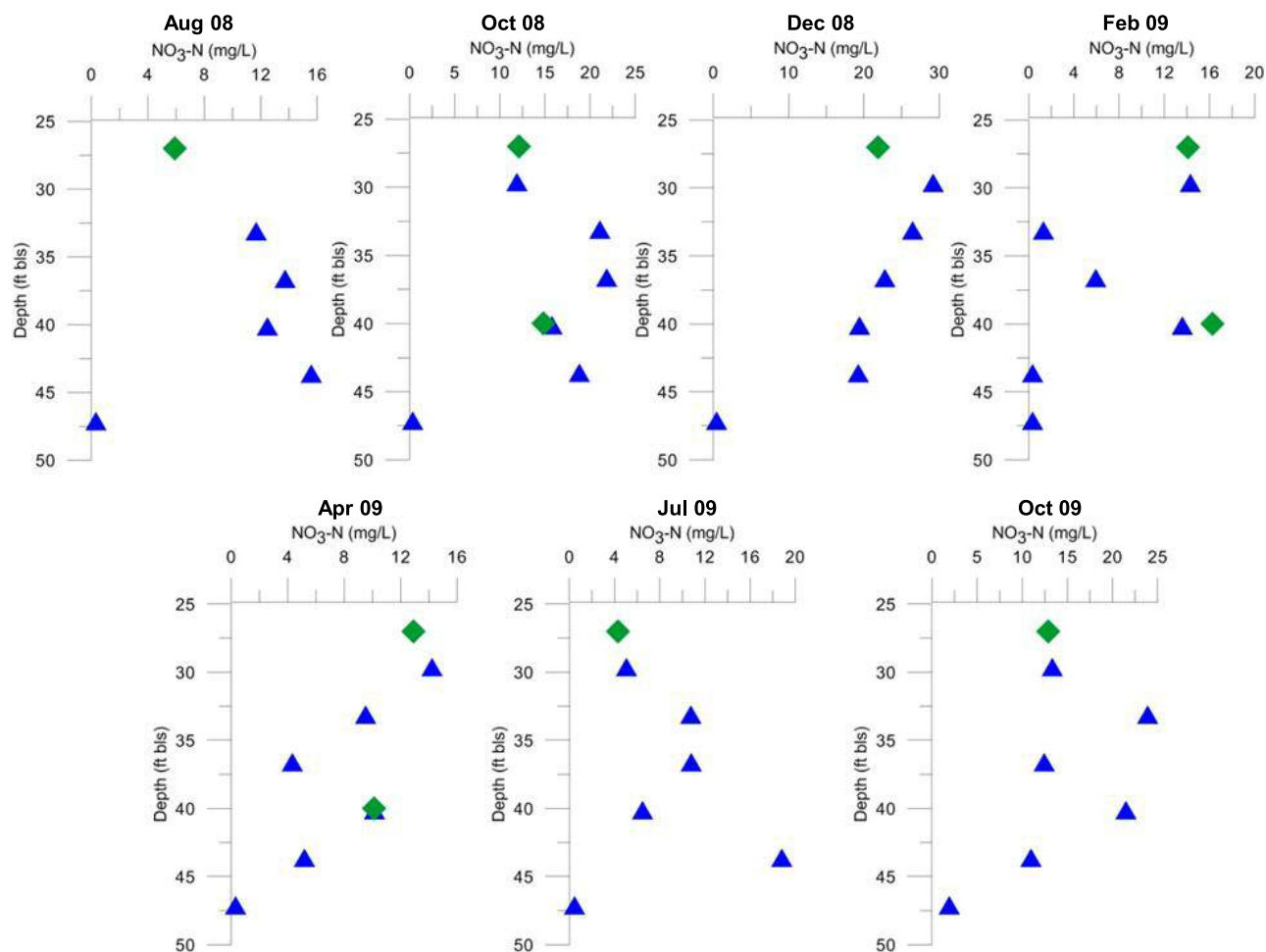


Figure 18. Nitrate-nitrogen – depth plots for standard-well Ni45-45 (diamond) and CMT2 wells Ni45-54 through 60 (triangle). Horizontal separation of wells is less than 2 m. On selected dates, the standard well was sampled at two depths with a point-source bailer.

Denitrification may be indicated by the lower concentrations of NO_3^- observed in surface water locations (sites 21 and 26, Fig. 10) in the SLS and in some wells (sites 11 and 13, Fig. 10). However, NO_3^- concentrations vary more than an order of magnitude with time, and NO_3^- -N concentrations in excess of 10 mg/L are sometimes observed at sites that also had hydrogen sulfide, low DO (Fig. 22), and low redox (Fig. 23). Thus, the co-occurrence of low DO, low Eh, and NO_3^- -N concentrations greater than 10 mg/L could indicate complex mixing of anaerobic, reduced waters with more oxidized waters, with mixing caused by small scale heterogeneities in hydraulic conductivity and aquifer matrix composition rather than denitrification (Jurgens et al., 2009).

It is also possible that both well and surface-water sampling points exhibiting lower NO_3^- concentrations are not in locations where groundwater with high NO_3^- concentrations is flowing. At sites 11, 13, and 21, at the toe of the dune (Fig. 10), NO_3^- concentrations in most samples are less than 1 mg/L, and have low DO, low Eh, and hydrogen sulfide. However, SC at site 11 is less than that observed in samples

from other wells in the preferential flow zone indicating that this well is not impacted by effluent. Given the greater NO_3^- concentrations at depth in the sampling ports in CMT4 (Fig. 20, site 14 in the SLS), it is likely that the well at site 11 is not deep enough to intersect effluent impacted groundwater.

SC at site 13 is similar to that observed in other wells in the preferential flow zone suggesting that groundwater at this site may be affected by effluent disposal. The higher SC however, may be due to the higher Cl concentrations in this well.

Data collected during this study are not adequate to determine if denitrification is occurring in the aquifer. Concentrations of NO_3^- in the aquifer and surface water indicates that if there is denitrification the rate is spatially and temporally variable. To estimate denitrification rates, additional sampling and testing for concentrations of nitrogen gas, and multi-month tracer tests using Br or other conservative tracers added to the effluent, should be performed.

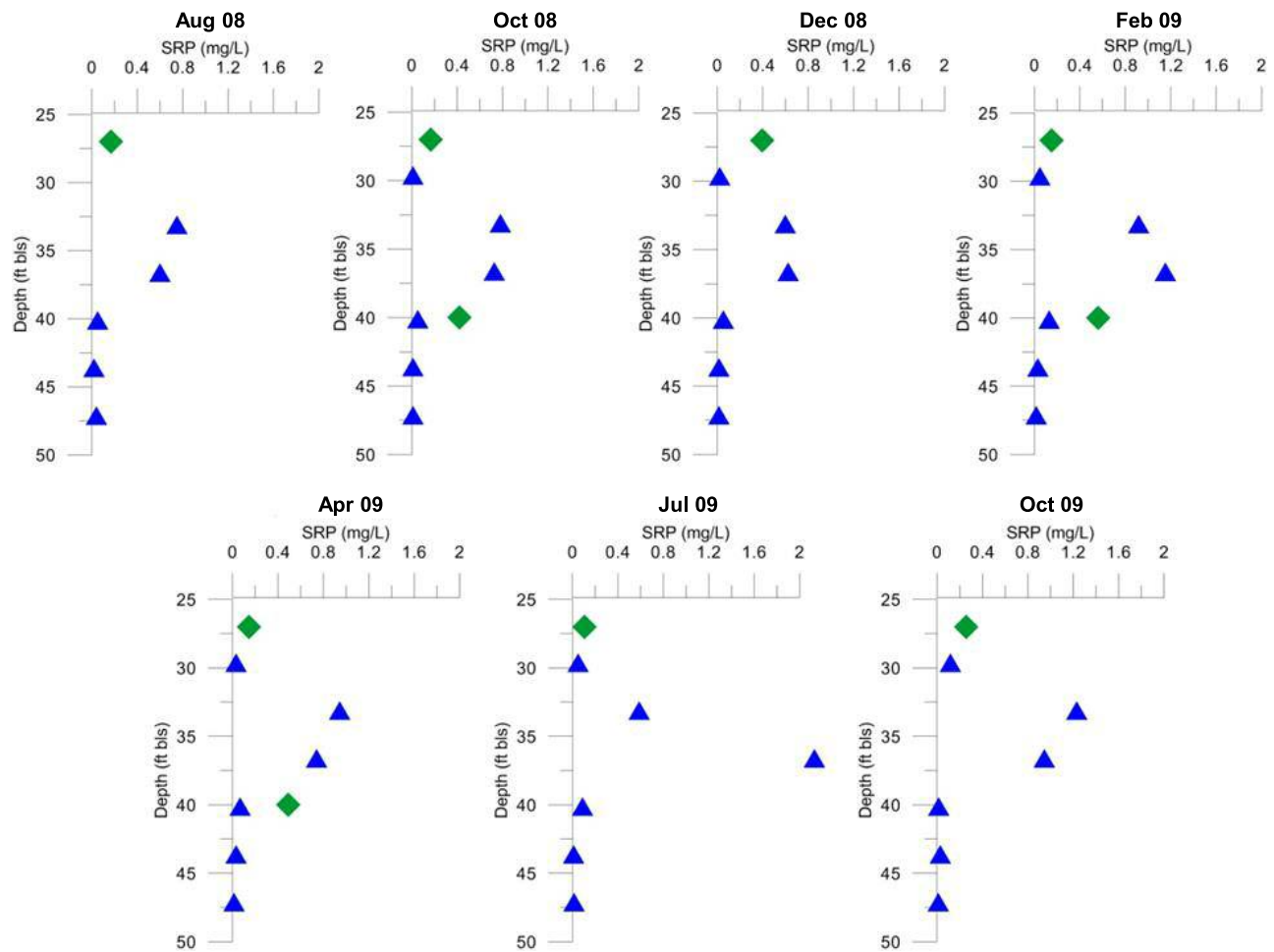


Figure 19. Orthophosphate - depth plots for standard-well Ni45-45 (diamond) and CMT2 wells Ni45-54 through 60 (triangle). Horizontal separation of wells is less than 1 m. On selected dates, the standard well was sampled at two depths with a point-source bailer.

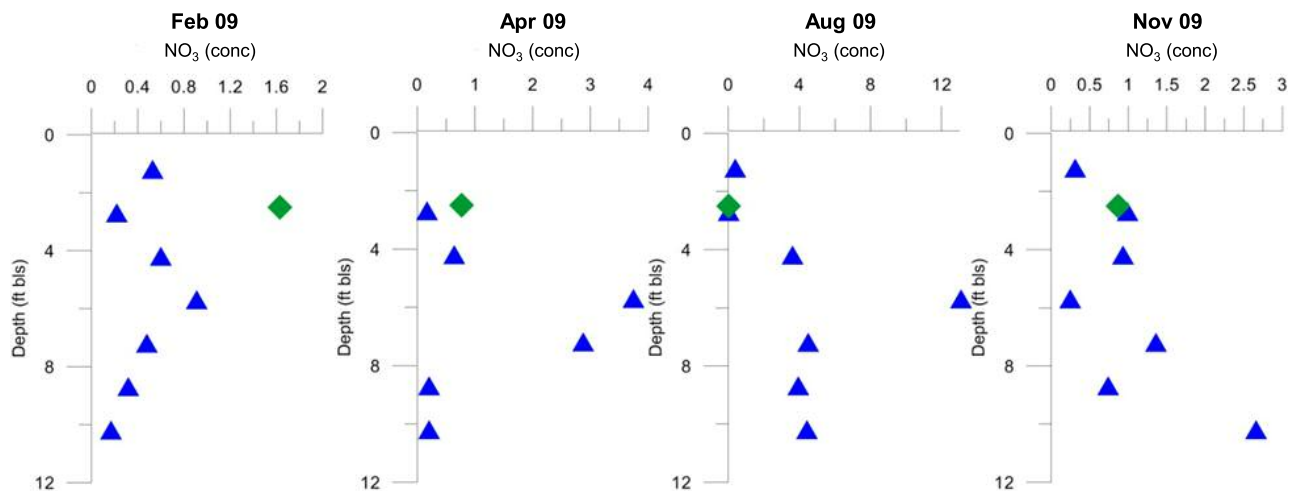


Figure 20. Nitrate-nitrogen – depth plots for standard-well Ni45-42 (diamond) and CMT4 wells Ni45-78 through 84 (triangle). Horizontal separation of wells is less than 2 m. Wells are located in the sea level swamp.

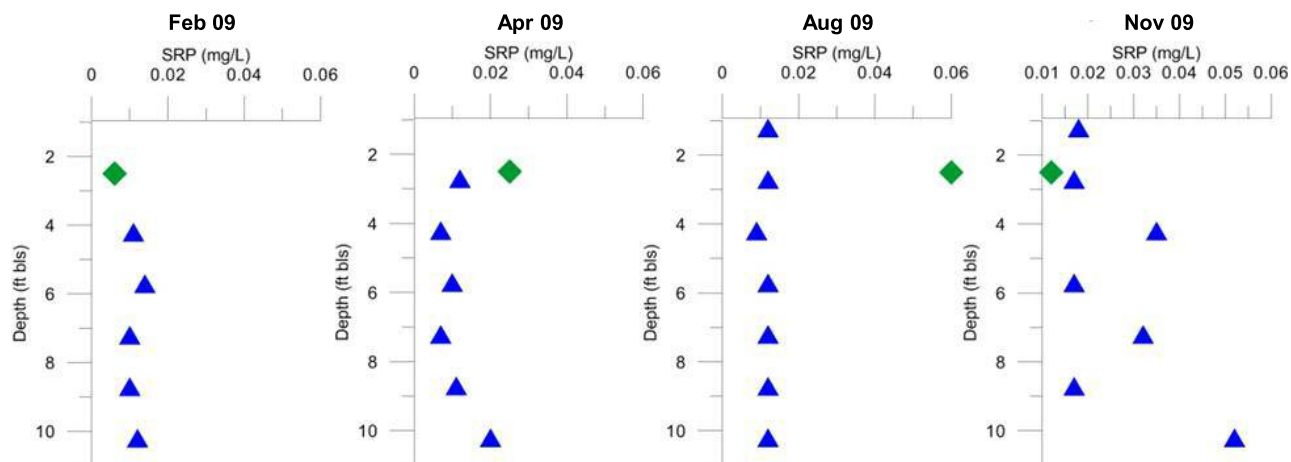


Figure 21. Orthophosphate – depth plots for standard-well Ni45-42 (diamond) and CMT4 wells Ni45-78 through 84 (triangle). Horizontal separation of wells is less than 2 m. Wells are located in the sea level swamp.

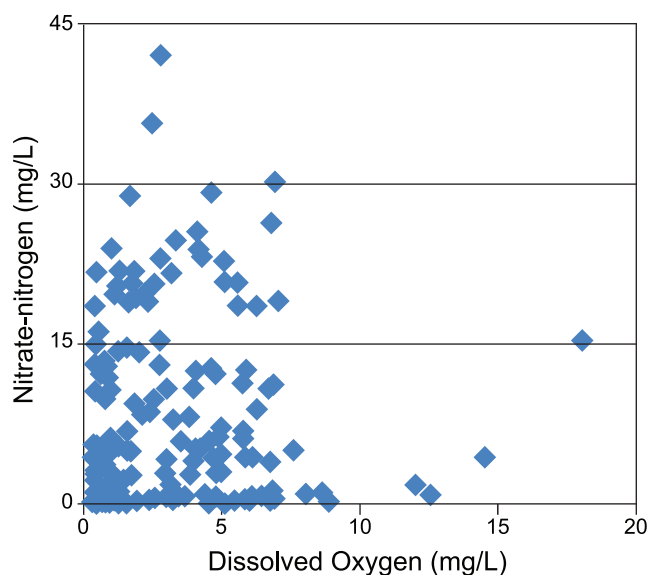


Figure 22. Comparison of dissolved oxygen and nitrate for surface water and groundwater. Note that nitrate-nitrogen concentrations in excess of 10 mg/L occur at dissolved oxygen concentrations less than 1 mg/L.

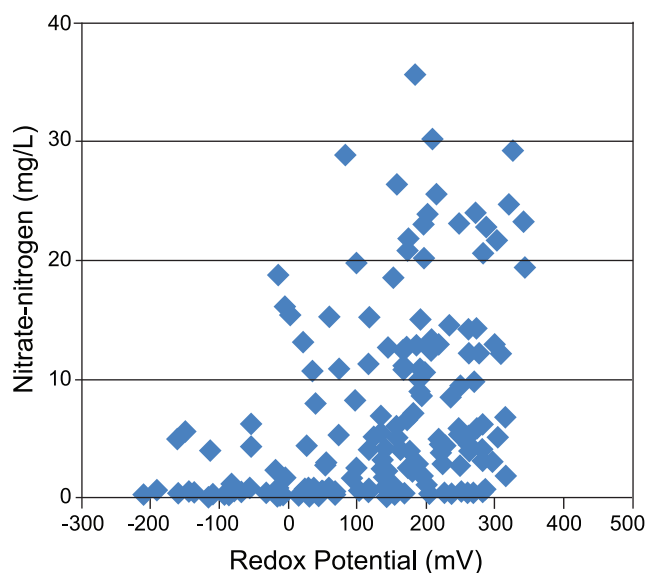


Figure 23. Comparison of redox potential and nitrate in surface water and groundwater. Redox potential (Eh) is reported in millivolts (mV). Note that nitrate-nitrogen concentrations greater than 10 mg/L occur at Eh values less than 250 mV, that being the approximate value where denitrification should occur.

Significant concentrations of dissolved iron, arsenic, and OP in groundwater are indicators of redox sensitive biogeochemical reactions (Herbel and Fendorf, 2006; McMahon and Chappelle, 2008; Vadas et al., 2007; Bell et al., 2009), as are P, iron (Vadas and Sims, 1998, 1999; Sallade and Sims, 1997) and arsenic (Sparks et al., 2007) in soils. Arsenic sorbed to iron oxide grain coatings may be released into solution when biogeochemical processes cause iron and/or manganese to reduce (Herbel and Fendorf, 2006; Haque et al., 2008). Data collected during this study clearly indicate that redox related processes affect geochemical conditions; however, the relationships are complex and indicate that redox conditions are highly spatially variable. For example, a

comparison of iron and arsenic with DO and redox potential (Figs. 24-28) shows none of the correlations that would be expected if the entire aquifer were strongly reduced. The lack of clear correlations indicates that multiple redox processes and/or the mixing of different water bodies in a heterogeneous geologic setting control the distribution of DO, OP, iron, and arsenic.

Many samples contain significant concentrations of dissolved arsenic (Fig. 29). Laboratory experiments have found that OP can outcompete arsenic for sorption sites on iron oxide coatings, leading to desorption of arsenic or selective sorption of OP (Sracek et al., 2004), although it is not clear how these results would apply to a complex ground-

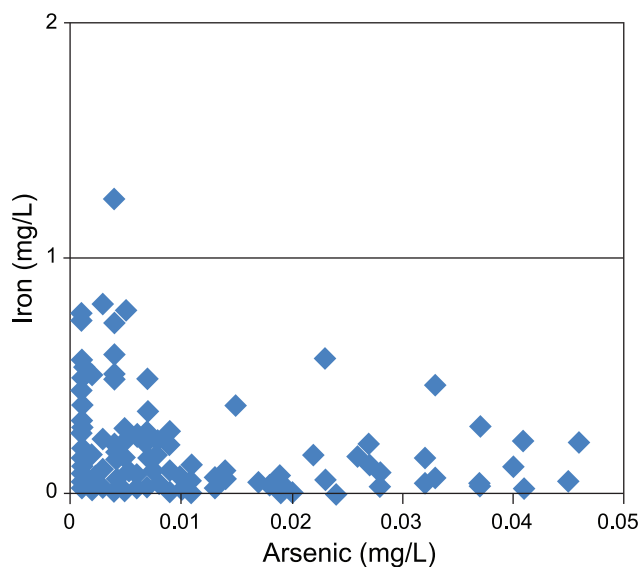


Figure 24. Comparison of dissolved iron and dissolved arsenic in groundwater and surface water.

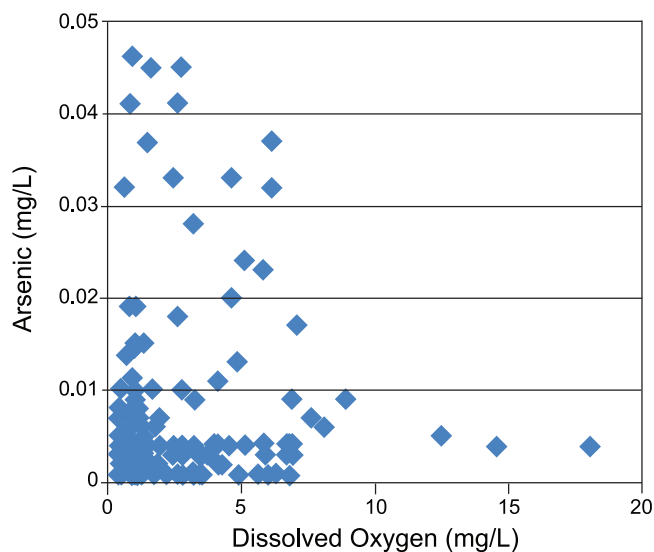


Figure 26. Comparison of dissolved oxygen and dissolved arsenic in groundwater and surface water.

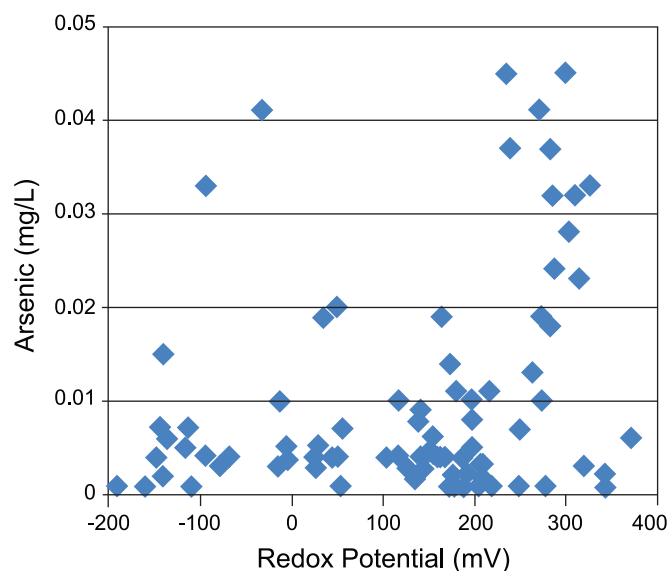


Figure 25. Comparison of redox potential and dissolved arsenic in groundwater and surface water. mV=millivolts, mg/L=milligrams per liter.

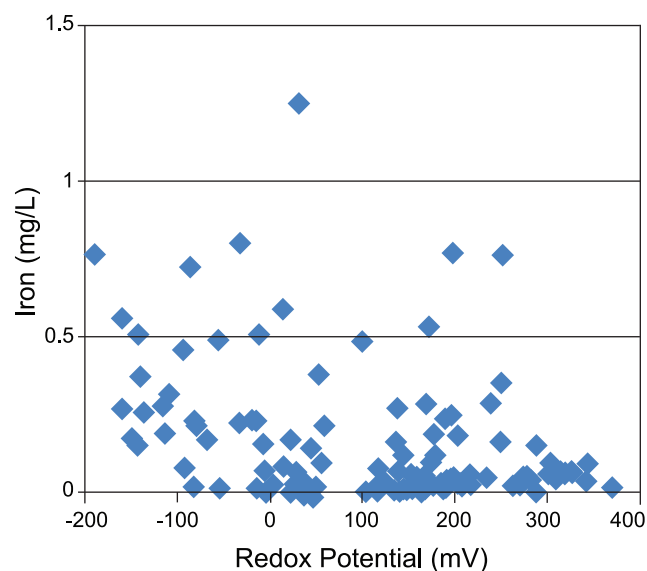


Figure 27. Comparison of redox potential and dissolved iron in ground-water and surface water.

water environment. Data from this study found no clear relationship between arsenic and OP (Fig. 30). It is also not clear if ionic strength (via SC proxy, Fig. 31) facilitates the desorption and increasing concentration of arsenic. The lack of clear correlations indicates that multiple processes and/or mixing of different water bodies within a heterogeneous geological setting control the distribution of arsenic. These findings indicate the need for further study.

Influence of monitoring methods and effluent disposal on observed groundwater quality

Because of high hydraulic loading rates and water-table mounding, groundwater flow paths near RIBS have an accentuated three-dimensional aspect compared to areas receiving natural rates of recharge. As a result, there is a

significant chance that bailer or low-flow pump sampling of long-screen wells are a biased representation of the presence and concentration of contaminants in the aquifer (i.e., false negative). Our results indicate that sampling at depths that are too shallow increases the likelihood of not detecting contaminants. This likelihood increases with increasing distance from the infiltration basins. Our study also indicates that contaminants may not be detected by low-flow sampling methods in long-screen wells when samples are collected from portions of the aquifer below those affected by effluent disposal.

Our study also found significant horizontal and vertical variability of contaminant concentrations within the portion of the aquifer most impacted by effluent disposal, e.g., the preferential flow zone (Fig. 32). Variability in contaminant

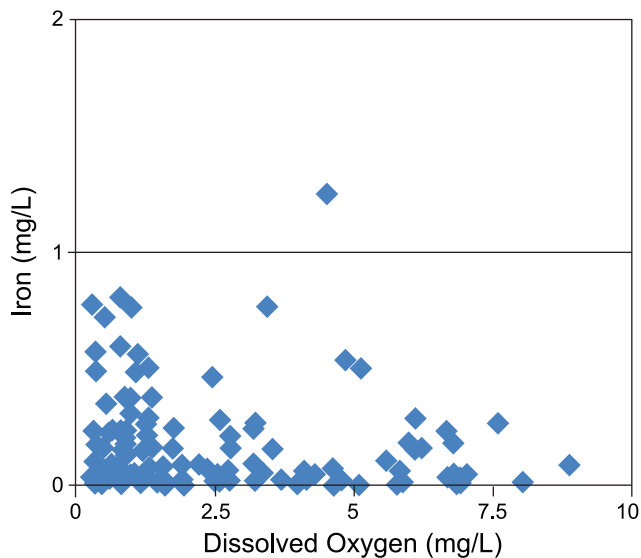


Figure 28. Comparison of dissolved oxygen and dissolved iron in groundwater and surface water.

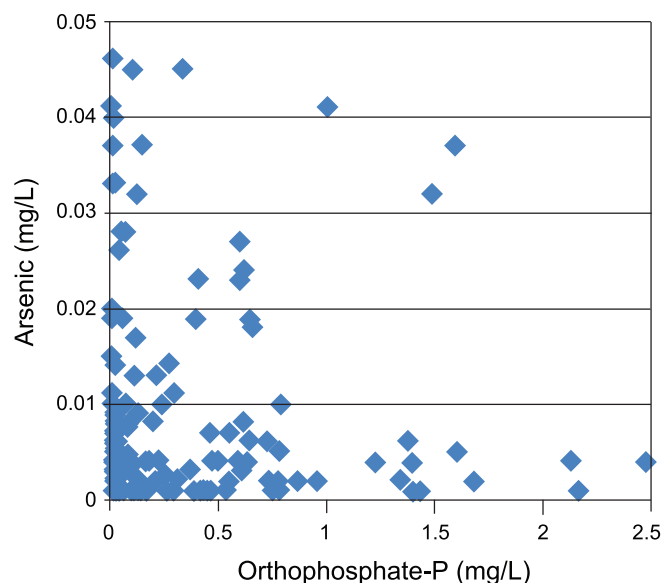


Figure 30. Comparison of orthophosphate and dissolved arsenic in groundwater and surface water.

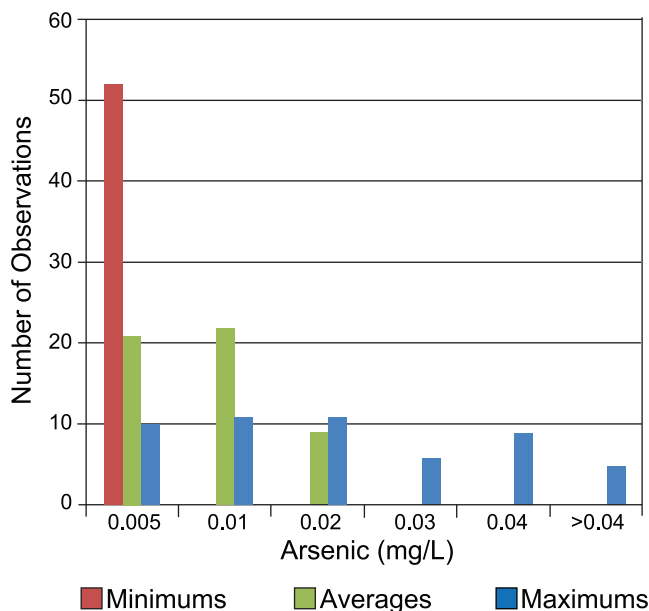


Figure 29. Frequency distribution of arsenic concentrations aggregated by sample location. Average concentrations were computed assuming that concentrations in samples reported less than detect are equal to the detection limit. The total number of sample sites is 52.

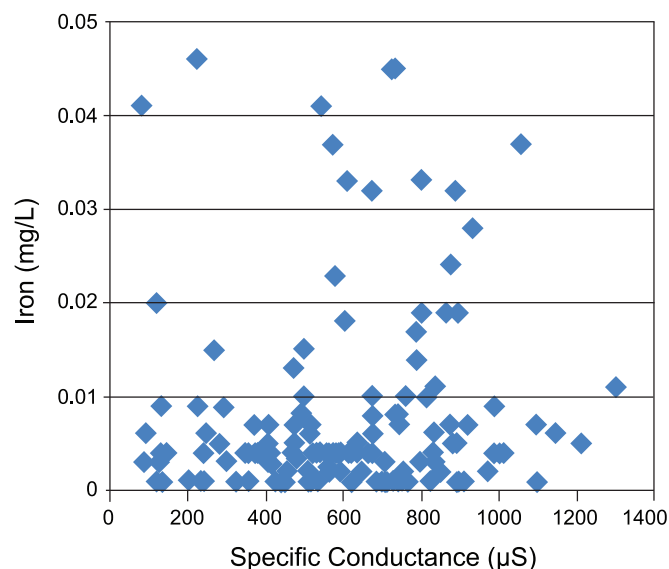


Figure 31. Comparison of specific conductance and dissolved arsenic in groundwater and surface water.

concentrations is also observed in a zone adjacent to the preferential flow zone. Because contaminant concentrations are smaller in this zone, it is likely a mixing zone between effluent and native groundwaters. Despite the relatively small spatial extent of the disposal area in our study area, identification of the preferential flow zone and characterization of the vertical and temporal variability in the concentrations of contaminants required a multi-phase subsurface investigation program that included an analysis of data from samples collected at bi-monthly intervals from dozens of

monitoring points and high frequency temperature monitoring in several wells.

Following practices used in many studies of contaminated groundwater, we used a chemically inert tracer (e.g. temperature) to independently confirm the preferential flow zone where the bulk of effluent is flowing in the aquifer. Further analysis of the temperature signal is not possible because physical interactions between effluent and the aquifer matrix dissipate heat, and we do not have independent measures of the thermal conductivity of the aquifer



Figure 32. Conceptual model of preferential flow zone. Concentrations of N and P and temperatures are generally greater in groundwater in this zone than outside of this zone.

matrix. Temperature cannot be used as a tracer of contamination at all sites because not all effluents have a temperature signature. Bromide is commonly used as the chemically inert tracer (citations in “Contaminant transport” in Results of Literature Search).

Dissolved N or P species are biogeochemically reactive and as such, should not be used as tracers. By extension, the lack of N and P species in groundwater samples is not confirmation of contaminant attenuation by SAT. Rather, the lack of N and P species in groundwater samples may indicate improper spatial location of the monitoring sites, inadequate temporal frequency of sampling, or the unintended effects of well design and sampling protocols. For the latter, the choice of well type and the sampling method used for standard wells may introduce more variability to observed P concentrations than the method used for CMT ports. The slightly higher flow rate during purging of the standard well and the greater agitation of the water column caused by insertion and removal of the bailer from the standard well could have mobilized P sorbed on the aquifer matrix. If this is the case, it is important to know if the P is naturally occurring or due to effluent disposal. Alternatively P mobility could be reduced by temporally variable geochemical conditions in the aquifer due to oxygenation of the water column in the well between sampling periods or during insertion and

removal of pumps and bailers. It cannot be determined if purging greater volumes of water from wells prior to sample collection would reduce this effect.

This study confirms that contaminant transport from RIBS/SAT is subject to the same physical and chemical processes that have been observed in field studies of groundwater contamination by hazardous and toxic materials; that is, heterogeneous hydraulic and geochemical aquifer properties, and time-varying contaminant releases cause complex spatial and temporal patterns of contaminants in the aquifer. Detailed field studies are needed to 1) determine where effluent is moving in the aquifer and how water quality changes with time and distance from the disposal site, 2) determine if serious contamination is occurring, and 3) determine how quickly contaminants are flowing away from a RIBS site. Simple monitoring systems consisting of a few long-screen wells that are sampled four times per year at low-flow rates, and with well locations and screen settings determined prior to collection and analysis of site-specific hydraulic, geochemical, and tracer test data appear to be inadequate for detecting contamination problems before they impact downflow wells and streams.

At this site, drill-rig access and resource limitations did not allow for the installation of monitoring wells around the west-south- western, northwestern, and northeastern sections

of the infiltration basins. As a result, we cannot be certain that contaminants are not flowing in those directions. Particle trackline modeling in Andres et al. (2015), however, indicates that flow paths oriented in those directions are relatively minor and should not transport significant quantities of contaminants in those directions. This topic will be addressed in an upcoming report on the results of detailed three-dimensional groundwater flow simulations of this facility.

CONCLUSIONS

Significant research is being published in peer-reviewed technical literature on topics that directly apply to RIBS, including new and novel wastewater treatment systems, infiltration, transport of contaminants in groundwater, groundwater monitoring, natural attenuation and remediation, and the affects of land-based wastewater disposal on groundwater. Many citations of RIBS-specific research also appear in non-reviewed literature such as conference proceedings, newsletters, and trade journals.

Most of the background peer-reviewed research pertaining to RIBS and cited by USEPA guidance documents and several textbooks was conducted in the 1970s. The methods and monitoring systems used for characterizing the physical and chemical conditions in the groundwater beneath a RIBS facility would be considered inadequate today. A review of these documents indicates that nitrogen and phosphorus removal statistics, for example, are unreliable.

The effects of RIBS on groundwater are highly complex. Spatially heterogeneous aquifer properties, temporal variability of the quality and quantity of effluent, and changes in disposal location associated with operation of RIBS, cause complex spatial and temporal variability of physical and chemical groundwater conditions.

A water monitoring system includes wells, surface water sampling stations, automated instrumentation, sample collection, and analyses of sediments and water. Data from simpler monitoring systems, consisting of a few wells sampled at prescribed quarterly intervals and tested for a limited suite of physical and chemical parameters, are highly likely to underestimate the impact of effluent disposal on groundwater quality. A detailed comparison of standard and multi-port groundwater monitoring systems indicates that bailer or low-flow pump sampling of standard monitoring wells is also highly likely to underestimate the impact of effluent disposal on groundwater quality.

A well designed monitoring system should be based on experimentally determined site-specific evidence collected under conditions that duplicate the flow rates that are expected during full-scale operation of the RIBS. Conservative tracers should be used to determine if the monitoring wells are in locations that intercept flow from the infiltration beds. The monitoring system should take into account site-specific biogeochemical interactions of effluent with geological materials, the direction and rate of groundwater flow, sources and behaviors of complex mixtures of contaminants, the expected variability in effluent flow and quality, and impacts to sensitive receptors. Monitoring systems that assume average effluent flow and quality characteristics, average

operation of the infiltration basins, average rate of flow for a single conservative contaminant, and no potential geo-chemical interactions with the aquifer matrix, will almost certainly not be adequate to determine the impact of the operational RIBS.

At Cape Henlopen State Park significant concentrations of nitrate, ammonium, and organic N were detected in groundwater from the point of effluent entry at the water table and in surface water in the adjacent discharge area. Data are not sufficient to indicate whether denitrification is occurring. If there is denitrification, the rate of is insufficient to remediate RIBS effluent at the site — despite a 25-ft thick vadose zone, an effluent with enough organic carbon to facilitate anaerobic conditions that permit abiotic denitrification and feed microorganism-driven denitrification processes, and hypoxic to anoxic groundwater. Given recent efforts to increase the beneficial reuse of wastewater and the infiltration of stormwater, in addition to new plans for large on-site wastewater disposal facilities, additional field research on denitrification at Delaware on-site wastewater disposal facilities is warranted.

Significant concentrations of P occur in groundwater from the point of effluent entry at the water table to distances greater than 150 ft from the infiltration beds. The high hydraulic, P, and organic loading rates associated with the operation of RIBS overwhelm natural P attenuation (e.g., sorption and precipitation) processes. The knowledge and experience gained from decades of study of P loss from agricultural systems in Delaware should have direct application to this issue, and it is important to consider that the Delaware Nutrient Management Commission continues to spend significant financial resources to mitigate P loss from agricultural systems. Additional field research on how to adapt agronomic testing and planning practices for planned large on-site wastewater disposal facilities is warranted.

Because of problems with trihalomethane (THM) generation and aquifer contamination at other RIBS facilities, we should strongly consider not permitting chlorine disinfection. If chlorine-based disinfection is necessary, additional research must be done to document the fate of THMs and other disinfection byproducts associated with the discharge of chlorinated effluent to RIBS. Understanding the bacteria and viruses, plus pharmaceutical, personal care, and household products that enter wastewater treatment and disposal systems also will require additional research.

Interactions of effluent with the aquifer and native groundwater result in geochemical changes that cause the release of naturally occurring arsenic, and other redox-sensitive compounds and elements from the aquifer matrix into the groundwater.

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Appendix 1. Construction and location information for monitoring wells and location information for surface water sampling sites. USACE= US Army Corps of Engineers well. Note: ft bls = feet below land surface, CMT=Solinst CMT multi-port well.

DGS Well Identifier	DNREC permit	Top of casing elevation (ft NAVD88)	Land surface elevation (ft NAVD88)	Depth to top of screen (ft bls)	Depth to bottom of screen (ft bls)	Map index number	NOTE
Ni44-16	109284	44.97	42.97	34.6	44.6	1	USACE
Ni45-15	109275	21.87	19.87	13	23	2	USACE
Ni45-16	109276	30.14	27.64	19	29	3	USACE
Ni45-17	109277	23.87	21.87	14.5	24.5	4	USACE
Ni45-33	223154	46.52	44.32	45	60	5	
Ni45-34	223155	30.52	28.92	30	45	6	
Ni45-35	223156	32.13	29.43	30	45	7	
Ni45-36	223157	28.07	25.77	25	40	8	
Ni45-37	223158	17.1	14.9	19.5	34.5	9	
Ni45-38	223159	3.96	1.36	1.4	3.9	10	
Ni45-39	223160	6.78	5.46	2.1	4.6	11	
Ni45-40	223161	3.83	3.05	2.5	5	12	
Ni45-41	223162	7.37	5.67	3.1	5.6	13	
Ni45-42	223163	3.97	1.47	0.5	2.5	14	
Ni45-43	224318	37.18	37.18	30	45	15	
Ni45-44	224319	37.82	35.82	30	45	16	
Ni45-45	224320	30.49	28.49	25	40	17	
Ni45-46	224324	34.5	32.5	30	45	18	
Ni45-47	225308	37.18	37.18	33.4	33.7	15	CMT1
Ni45-48	225309	37.18	37.18	36.9	37.2	15	CMT1
Ni45-49	225310	37.18	37.18	40.4	40.7	15	CMT1
Ni45-50	225311	37.18	37.18	43.9	44.2	15	CMT1
Ni45-51	225312	37.18	37.18	47.4	47.7	15	CMT1
Ni45-52	225313	37.18	37.18	50.9	51.2	15	CMT1
Ni45-53	225314	37.18	37.18	54.4	54.7	15	CMT1
Ni45-54	225335	30.49	30.49	26.4	26.7	17	CMT2
Ni45-55	225336	30.49	30.49	29.9	30.2	17	CMT2
Ni45-56	225337	30.49	30.49	33.4	33.7	17	CMT2
Ni45-57	225338	30.49	30.49	36.9	37.2	17	CMT2
Ni45-58	225339	30.49	30.49	40.4	40.7	17	CMT2
Ni45-59	225340	30.49	30.49	43.9	44.2	17	CMT2
Ni45-60	225341	30.49	30.49	47.4	47.7	17	CMT2
Ni45-61	225315	32.13	29.43	28.8	29.1	7	CMT3
Ni45-62	225316	32.13	29.43	31.8	32.1	7	CMT3

Appendix 1 (continued). Construction and location information for monitoring wells and location information for surface water sampling sites. Background indicates surface water sampling site located in area not influenced by RIBS. USACE= US Army Corps of Engineers well. Note: ft bls = feet below land surface, CMT=Solinst CMT multi-port well.

DGS Well Identifier	DNREC permit	Top of casing elevation (ft NAVD88)	Land surface elevation (ft NAVD88)	Depth to top of screen (ft bls)	Depth to bottom of screen (ft bls)	Map index number	NOTE
Ni45-63	225317	32.13	29.43	35.8	36.1	7	CMT3
Ni45-64	225318	32.13	29.43	40.3	40.6	7	CMT3
Ni45-65	225319	32.13	29.43	44.8	45.1	7	CMT3
Ni45-66	225320	32.13	29.43	49.3	49.6	7	CMT3
Ni45-67	225321	32.13	29.43	51.8	52.1	7	CMT3
Ni45-78	224321	3.51	-0.1	1	1.3	14	CMT4
Ni45-79	Ni4579	3.51	-0.1	2.5	2.8	14	CMT4
Ni45-80	Ni4580	3.51	-0.1	4	4.3	14	CMT4
Ni45-81	Ni4581	3.51	-0.1	5.5	5.8	14	CMT4
Ni45-82	Ni4582	3.51	-0.1	7	7.3	14	CMT4
Ni45-83	Ni4583	3.51	-0.1	8.5	8.8	14	CMT4
Ni45-84	Ni4584	3.51	-0.1	10	10.3	14	CMT4

Surface-water sampling sites.

DGS Site Identifier	Map index number	NOTE
Ni44-b	19	background
Ni44-c	20	background
Ni45-r	21	
Ni45-s	22	
Ni45-t	23	
Ni45-v	25	
Ni45-w	26	
Ni45-x	27	
Ni45-y	28	
Ni45-aa	34	background
Ni45-ab	30	
Ni45-ac	31	
Ni45-ae	32	
Ni45-EFF	33	effluent

APPENDIX 2. Results of water sample analyses. Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Al (mg/L)	As (mg/L)	As Flag	B (mg/L)	B Flag	Ca (mg/L)	Ca Flag	Cr (mg/L)	Cr Flag	Cu (mg/L)	Cu Flag	Fe (mg/L)	Fe Flag	K (mg/L)	K Flag	Mg (mg/L)	Mg Flag	Mn (mg/L)	Mn Flag	Na (mg/L)	Na Flag	Pb (mg/L)	Pb Flag	Si (mg/L)	Si Flag	Zn (mg/L)	Zn Flag	
N44-16	06/17/2008	06/17/2008N44-16	0.091	M	0.001	LM		11	M	0.001	M			0.184	M	0.7	M	2.2	M	0.006	M	7.4	M	0.004	LM	8.6	M	0.002	M	
	8/13/2008	08/13/2008N44-16	0.046	M	0.003	M		14.4	M	0.001	LM			0.026	M	0.3	M	2.7	M	0.001	LM	6.2	M	0.004	LM	8	M	0.001	LM	
	10/17/2008	10/17/2008N44-16	0.037	M	0.02	M		8.1	M	0.001	LM			0.001	LM	4.3	M	1.8	M	0.001	LM	7.5	M	0.003	JM	13.5	M	0.001	LM	
	12/18/2008	12/18/2008N44-16	0.046	M	0.02	M		9.66	M	0.005	LM	0.005	LM	0.001	LM	0.969	M	2.04	M	0	M	9.83	M	0.004	LM	8.01	M	0.011	M	
N44-33	2/11/2009	02/11/2009N44-16	0.09	M	0.004	LM	0.023	M	0.005	LM	0.001	LM	0.002	LM	0.001	LM	4.424	M	1.91	M	0	M	10.21	M	0.004	LM	9.07	M	0.006	M
	11/4/2009	11/04/2009N44-16	0.053	M	0.009	M	0.017	M	0.001	LM	0.001	LM	0.002	LM	0.001	LM														
	6/19/2008	06/18/2008N45-15	0.635	M	0.003	M		0.5	M	0.002	M			0.218	M	0.5	M	0.9	M	0.012	M	9.5	M	0.004	LM	9.8	M	0.012	M	
	8/13/2008	08/13/2008N45-15	0.399	M	0.003	M		0.5	M	0.001	LM			0.229	M	0.7	M	1	M	0.014	M	8.7	M	0.005	M	9.2	M	0.011	M	
N44-35	10/8/2008	10/06/2008N45-15	0.231	M	0.041	M		0.7	M	0.001	LM			0.223	M	0.6	M	0.9	M	0.008	M	8.4	M	0.004	LM	8.6	M	0.006	M	
	12/22/2008	12/02/2008N45-15																												
	2/12/2009	02/12/2009N45-15																												
	7/28/2009	07/28/2009N45-17	0.27	M	0.004	LM	0.019	M	2.14	M	0.001	M	0.008	M	0.005	M	1.249	M	1.98	M	0.039	M	14.53	M	0.004	LM	6.9	M	0.012	M
N45-17	7/28/2009	07/28/2009N45-17	0.33	M	0.004	LM	0.019	M	2.14	M	0.001	M	0.008	M	0.005	M	1.249	M	1.98	M	0.039	M	14.53	M	0.004	LM	6.9	M	0.012	M
	11/4/2009	11/04/2009N45-17	0.295	M	0.006	M	0.016	M	2.08	M	0.001	LM	0.002	LM	0.01	M	1.538	M	1.81	M	0.023	M	11.59	M	0.004	LM	6.91	M	0.009	M
	4/17/2008	04/17/2008N45-33a	0.404	M	0.002	JM		13.1	M	0.001	LM			0.069	M	5.93	M	8.95	M	0.205	M	71.99	M	0.015	M	10.97	M	0.055	M	
	4/17/2008	04/17/2008N45-33b	1.267	M	0.004	LM		21.2	M	0.001	LM			0.001	LM	10.09	M	15.13	M	0.191	M	123.2	M	0.004	LM	11.8	M	0.048	M	
N45-33	6/20/2008	06/20/2008N45-33	0.389	M	0.001	LM		9.57	M	0.003	M			0.533	M	5.8	M	7.4	M	0.032	M	53.8	M	0.004	LM	12.9	M	0.016	M	
	8/13/2008	08/13/2008N45-33	0.149	M	0.001	LM		6.3	M	0.001	LM			0.271	M	3.1	M	4.5	M	0.039	M	33.3	M	0.008	M	12.9	M	0.018	M	
	10/7/2008	10/07/2008N45-33	0.389	M	0.001	LM		3.1	M	0.001	LM			0.276	M	3.4	M	5.2	M	0.034	M	42.4	M	0.006	M	18.8	M	0.025	M	
	12/18/2008	12/18/2008N45-33	0.126	M	0.001	LM		7.1	M	0.001	LM			0.276	M	3.4	M	5.2	M	0.034	M	42.4	M	0.006	M	18.8	M	0.025	M	
N45-34	2/11/2009	02/11/2009N45-33	0.543	M	0.007	M	0.045	M	0.001	LM	0.001	LM	0.039	M	0.095	M	3.878	M	4.48	M	0.027	M	29.39	M	0.007	M	11.3	M	0.061	M
	8/7/2009	08/07/2009N45-33	0.277	M	0.004	M	0.049	M	11.24	M	0.001	LM	0.002	M	0.024	M	5.21	M	7.31	M	0.046	M	61.6	M	0.004	LM	11.67	M	0.026	M
	4/16/2008	04/16/2008N45-34a	0.18	M	0.005	M		14.8	M	0.002	M	0.001	LM	0.012	M	9.41	M	11.98	M	0.192	M	82.8	M	0.004	LM	12.36	M	0.037	M	
	4/16/2008	04/16/2008N45-34b	0.576	M	0.007	M		20.1	M	0.001	M	0.001	M	0.202	M	12.04	M	19.3	M	0.336	M	125.5	M	0.002	JM	13.43	M	0.052	M	
N45-35	6/18/2008	06/18/2008N45-34	0.19	M	0.008	M		10	M	0.001	LM			0.222	M	6.3	M	7.1	M	0.038	M	70.8	M	0.008	M	8.4	M	0.017	M	
	8/11/2008	08/11/2008N45-34	0.184	M	0.007	M		11.1	M	0.001	LM			0.348	M	6.6	M	7.8	M	0.061	M	71.4	M	0.006	M	12.3	M	0.03	M	
	10/7/2008	10/07/2008N45-34	0.597	M	0.032	M		18	M	0.001	LM			0.152	M	8.7	M	13.4	M	0.032	M	94.7	M	0.009	M	13.5	M	0.033	M	
	12/2/2008	12/02/2008N45-34	0.584	M	0.032	M		11.1	M	0.001	LM			0.152	M	8.7	M	13.4	M	0.032	M	94.7	M	0.009	M	13.5	M	0.033	M	
N45-35	2/12/2009	02/12/2009N45-34	0.579	M	0.008	M	0.046	M	0.021	M	0.001	LM	0.021	M	0.066	M	5.834	M	7.56	M	0.026	M	53.2	M	0.004	LM	8.73	M	0.049	M
	7/28/2009	07/28/2009N45-34	0.473	M	0.002	LM	0.044	M	12.86	M	0.001	LM	0.012	M	0.046	M	6.668	M	7.85	M	0.027	M	48.29	M	0.004	LM	13.84	M	0.032	M
	10/29/2009	10/29/2009N45-34	0.469	M	0.004	JM		11.7	M	0.002	M	0.002	M	0.001	LM	4.63	M	9.1	M	0.245	M	61.37	M	0.006	M	10.09	M	0.035	M	
	4/16/2008	04/16/2008N45-35a	0.239	M	0.013	M		10.2	M	0.001	JM	0.001	JM	0.001	JM	0.067	M	8.91	M	0.249	M	62.11	M	0.006	M	8.809	M	0.026	M	
N45-35	6/17/2008	06/17/2008N45-35	0.475	M	0.001	LM		19.8	M	0.001	LM			0.161	M	8.2	M	13.8	M	0.014	M	81.4	M	0.008	M	11.5	M	0.024	M	
	8/12/2008	08/12/2008N45-35	1.665	M	0.002	M		23.5	M	0.001	LM			0.046	M	11.5	M	14.7	M	0.047	M	79.7	M	0.005	M	17.5	M	0.058	M	
	10/7/2008	10/07/2008N45-35a	0.94	M	0.004	M		23.6	M	0.001	LM			0.06	M	12.6	M	14.6	M	0.041	M	86.3	M	0.011	M	16.7	M	0.04	M	
	12/1/2008	12/01/2008N45-35	2.035	M	0.037	M		15.2	M	0.001	LM			0.025	M	7.2	M	10.1	M	0.03	M	56.4	M	0.003	JM	17.9	M	0.052	M	
N45-35	2/11/2009	02/11/2009N45-35a	0.579	M	0.008	M	0.046	M	0.021	M	0.001	LM	0.021	M	0.066	M	5.834	M	7.56	M	0.026	M	53.2	M	0.004	LM	8.73	M	0.049	M
	7/28/2009	07/28/2009N45-35a	0.473	M	0.002	LM	0.044	M	12.86	M	0.001	LM	0.012	M	0.046	M	6.668	M	7.85	M	0.027	M	48.29	M	0.004	LM	13.84	M	0.032	M
	10/29/2009	10/29/2009N45-35a	0.469	M	0.004	JM		11.7	M	0.002	M	0.002	M	0.001	LM	4.63	M	9.1	M	0.245	M	61.37	M	0.006	M	10.09	M	0.035	M	
	4/16/2008	04/16/2008N45-35b	0.239	M	0.013	M		10.2	M	0.001	JM	0.001	JM	0.001	JM	0.067	M	8.91	M	0.249	M	62.11	M	0.006	M	8.809	M	0.026	M	
N45-36	6/17/2008	06/17/2008N45-36	0.203	M	0.001	LM		14.8	M	0.001	LM			0.123	M	5.2	M	10.1	M	0.02	M	84.8	M	0.015	M	8.4	M	0.024	M	
	8/11/2008	08/11/2008N45-36	0.256	M	0.001	LM		17.3	M	0.001	LM			0.049	M	6.9	M	13.8	M	0.022	M	81.3	M	0.003	JM	12.6	M	0.045	M	
	10/7/2008	10/07/2008N45-36	0.125	M	0.01	M		21.3	M	0.001	LM			0.071	M	8.2	M	15	M	0.016	M	81.3	M	0.004	LM	14	M	0.036	M	
	12/2/2008	12/02/2008N45-36	0.289	M	0.004	LM	0.032	M	0.001	LM	0.001	LM	0.014	M	0.008	M	3.555	M	4.83	M	0.008	M	40.85	M	0.004	LM	7.22	M	0.031	M
N45-37	2/12/2009	02/12/2009N45-36	0.528	M	0.004	LM		7.9	M	0.001	LM	0.014	M	0.008	M</															

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M-mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Al (mg/L)	Al Flag	As (mg/L)	As Flag	B (mg/L)	B Flag	Ca (mg/L)	Ca Flag	Cr (mg/L)	Cr Flag	Cu (mg/L)	Cu Flag	Fe (mg/L)	Fe Flag	K (mg/L)	K Flag	Mg (mg/L)	Mg Flag	Mn (mg/L)	Mn Flag	Na (mg/L)	Na Flag	Pb (mg/L)	Pb Flag	Si (mg/L)	Si Flag	Zn (mg/L)	Zn Flag
NH45-39	4/17/2008	06/17/2008NH45-39	0.238	M	0.007	M			10.5	M	0.002	M			0.187	M	1.51	M	7.41	M	0.216	M	36.35	M	0.004	LM	15.55	M	0.011	M
	6/18/2008	08/12/2008NH45-39	0.343	M	0.015	M			15.8	M	0.001	LM			0.365	M	2.9	M	8.7	M	0.021	M	62.2	M	0.002	JM	22.6	M	0.001	M
	8/12/2008	10/08/2008NH45-39	0.196	M	0.002	M			26.7	M	0.001	LM			0.506	M	4	M	15.8	M	0.057	M	94.6	M	0.01	M	29.1	M	0.003	M
	10/8/2008	12/02/2008NH45-39	0.336	M	0.033	M			17.2	M	0.001	LM			0.461	M	4.8	M	9.7	M	0.051	M	76.9	M	0.004	LM	22.4	M	0.009	M
	12/2/2008	02/13/2009NH45-39																												
	2/13/2009	02/13/2009NH45-39																												
	8/7/2009	08/07/2009NH45-39	0.17	M	0.004	LM	0.017	M	4.84	M	0.001	LM	0.003	M	0.08	M	1.233	M	2.46	M	0.012	M	12.75	M	0.009	M	12.4	M	0.007	M
	8/7/2009	11/04/2009	0.302	M	0.007	M	0.039	M	13.07	M	0.001	LM	0.002	M	0.153	M	2.899	M	8.11	M	0.058	M	49.98	M	0.004	LM	19.13	M	0.014	M
	11/4/2009	06/20/2008NH45-40	0.269	M	0.004	LM			25.3	M	0.002	M			0.064	M	12.37	M	18.89	M	0.02	M	123.8	M	0.004	M	15.59	M	0.044	M
	6/20/2008	08/12/2008NH45-40																												
NH45-40	8/12/2008	10/08/2008NH45-40	0.229	M	0.019	M			20	M	0.001	LM			0.037	M	7.7	M	12.9	M	0.021	M	123.1	M	0.012	M	10.4	M	0.02	M
	10/8/2008	12/02/2008NH45-40	0.118	M	0.001	LM			22.3	M	0.001	LM			0.034	M	7.9	M	15.7	M	0.06	M	105.1	M	0.012	M	15.6	M	0.022	M
	12/2/2008	02/13/2009NH45-40	0.127	M	0.019	M			19.2	M	0.001	LM			0	M	8.8	M	13.6	M	0.046	M	107.2	M	0.004	LM	14.6	M	0.015	M
	2/13/2009	02/13/2009NH45-40																												
	8/7/2009	08/07/2009NH45-40	0.47	M	0.004	LM	0.014	M	4.53	M	0.001	LM	0.009	M	0.016	M	1.789	M	3.28	M	0.008	M	16.96	M	0.006	M	2.84	M	0.028	M
	8/7/2009	11/04/2009NH45-40	0.374	M	0.01	M	0.052	M	17.54	M	0.001	LM	0.002	M	0.011	M	7.297	M	17.18	M	0.025	M	72.35	M	0.004	LM	13	M	0.017	M
	11/4/2009	06/20/2008NH45-41	0.043	M	0.004	M			12.4	M	0.001	M			0.175	M	0.32	M	3.27	M	0.001	LM	9.3	M	0.008	M	7.179	M	0.013	M
	6/20/2008	08/12/2008NH45-41																												
	8/12/2008	10/08/2008NH45-41	0.08	M	0.001	LM			17	M	0.001	LM			0.763	M	0.6	M	3.8	M	0.009	M	14.9	M	0.004	M	8.7	M	0.001	LM
	10/8/2008	12/2/2008NH45-41	0.076	M	0.001	LM			17.6	M	0.001	LM			0.559	M	1.1	M	4.4	M	0.029	M	17.1	M	0.01	M	11.8	M	0.001	M
NH45-41	12/2/2008	02/13/2009NH45-41	0.031	M	0.015	M			22.8	M	0.001	LM			0.373	M	1	M	5.7	M	0.006	M	18.8	M	0.002	JM	12.4	M	0.013	M
	2/13/2009	02/13/2009NH45-41																												
	8/7/2009	08/07/2009NH45-41	0.24	M	0.005	M	0.019	M	21.15	M	0.001	LM	0.003	M	0.282	M	1.203	M	5.47	M	0.017	M	22.51	M	0.003	JM	11.77	M	0.011	M
	8/7/2009	11/04/2009	0.383	M	0.006	M	0.017	M	20.82	M	0.001	LM	0.002	LM	0.254	M	1.008	M	6.25	M	0.03	M	14.42	M	0.004	LM	9.9	M	0.005	M
	11/4/2009	06/20/2008NH45-42	0.025	M	0.004	LM			22.3	M	0.002	M			0.069	M	7.55	M	15.53	M	0.104	M	102.1	M	0.008	M	9.715	M	0.03	M
	6/20/2008	08/12/2008NH45-42																												
	8/12/2008	10/08/2008NH45-42	0.141	M	0.001	LM			9.2	M	0.002	M			0.209	M	2	M	4.6	M	0.011	M	25.7	M	0.004	LM	11.6	M	0.006	M
	10/8/2008	12/02/2008NH45-42	0.108	M	0.009	M			9.5	M	0.001	LM			0.308	M	1.5	M	4.9	M	0.013	M	18.4	M	0.006	M	11.5	M	0.005	M
	12/2/2008	02/13/2009NH45-42	0.232	M	0.046	M			7.4	M	0.001	LM			0.218	M	1.4	M	3.9	M	0.016	M	26.1	M	0.006	M	13.1	M	0.004	M
	2/13/2009	02/13/2009NH45-42																												
NH45-42	4/16/2009	04/16/2009NH45-42	0.443	M	0.004	LM	0.01	M	2.09	M	0.001	LM	0.004	M	0.14	M	0.923	M	1.47	M	0.006	M	5.82	M	0.007	M	9.08	M	0.035	M
	8/7/2009	08/07/2009NH45-42	0.203	M	0.005	M	0.035	M	11.62	M	0.001	LM	0.001	JM	0.065	M	5.142	M	8.13	M	0.022	M	44.44	M	0.004	LM	13.93	M	0.016	M
	11/4/2009	11/04/2009NH45-42																												
	6/17/2008	06/17/2008NH45-43	0.393	M	0.001	LM			22	M	0.001	LM			0.161	M	10.4	M	13.3	M	0.004	M	66.9	M	0.004	LM	12.6	M	0.017	M
	8/11/2008	10/08/2008NH45-43																												
	10/8/2008	12/02/2008NH45-43	0.653	M	0.001	LM			20.3	M	0.001	LM			0.028	M	10.7	M	14.1	M	0.025	M	69.7	M	0.004	LM	18.1	M	0.039	M
	10/17/2008	10/17/2008NH45-43a	0.282	M	0.001	LM			27.1	M	0.001	LM			0.044	M	11.7	M	17.6	M	0.014	M	77.9	M	0.004	LM	17.2	M	0.03	M
	10/17/2008	12/01/2008NH45-43a	0.647	M	0.014	M			21.1	M	0.001	LM			0.059	M	8.6	M	12.9	M	0.052	M	77.7	M	0.004	LM	15.9	M	0.043	M
	12/1/2008	12/01/2008NH45-43b	0.263	M	0.037	M			26.2	M	0.001	LM			0.023	M	10.4	M	15.3	M	0.025	M	80.7	M	0.004	LM	16.4	M	0.031	M
	2/11/2009	02/11/2009NH45-43a																												
NH45-43	2/11/2009	02/11/2009NH45-43b																												
	4/16/2009	04/16/2009NH45-43a																												
	7/22/2009	07/22/2009NH45-43	0.559	M	0.004	LM	0.052	M	14.19	M	0.001	LM	0.013	M	0.018	M	5.971	M	11.35	M	0.017	M	65.37	M	0.003	JM	10.45	M	0.038	M
	10/29/2009	10/29/2009NH45-43	0.632	M	0.002	LM	0.048	M	22.89	M	0.001	LM	0.005	M	0.019	M	9.829	M	12.4	M	0.04	M	40.39	M	0.003	JM	18.09	M	0.041	M
	6/17/2008	06/17/2008NH45-44	0.438	M	0.001	LM			20.3	M	0.001	LM			0.157	M	7.2	M	14.6	M	0.021	M	84.6	M	0.003	JM	10.8	M	0.028	M
	8/12/2008	10/07/2008NH45-44	1.385	M	0.006	M			25.6	M	0.001	LM			0.012	M	15.1	M	24.1	M	0.06	M	127.3	M	0.012	M	19.6	M	0.035	M
	10/7/2008	12/01/2008NH45-44	1.705	M	0.032	M			17.5	M	0.001	LM			0.041	M	9	M	12	M	0.045	M	77.1	M	0.004	LM	17.1	M	0.048	M
	12/1/2008	02/12/2009NH45-44																												
	2/12/2009	02/12/2009NH45-44	0.258	M	0.004	LM	0.009	M	2.41	M	0.001	LM	0.013	M	0.01	M	1.049	M	1.47	M	0	M	4.48	M	0.005	M	2.44	M	0.019	M
	7/22/2009																													

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M-mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Sample Date	Sample Identifier	Al (mg/L)	Al Flag	As (mg/L)	As Flag	B (mg/L)	B Flag	Ca (mg/L)	Ca Flag	Cr (mg/L)	Cr Flag	Cu (mg/L)	Cu Flag	Fe (mg/L)	Fe Flag	K (mg/L)	K Flag	Mg (mg/L)	Mg Flag	Mn (mg/L)	Mn Flag	Na (mg/L)	Na Flag	Pb (mg/L)	Pb Flag	S (mg/L)	S Flag	Zn (mg/L)	Zn Flag
N45-47	3/11/2009	02/11/2009N45-47	0.414	M	0.004	M	0.044	M	16.35	M	0.001	M	0.017	M	0.047	M	7.568	M	15.85	M	0.002	M	44.25	M	0.006	M	11.79	M	0.009	M
	4/17/2009	04/17/2009N45-47	1.004	M	0.004	M	0.035	M	14.35	M	0.001	M	0.007	M	0.035	M	6.662	M	6.53	M	0.05	M	32.47	M	0.004	M	15.73	M	0.016	M
	7/22/2009	07/22/2009N45-47	0.659	M	0.001	M	0.044	M	17	M	0.003	M	0.007	M	0.146	M	6	M	14.2	M	0.019	M	85.7	M	0.004	M	15.5	M	0.027	M
	10/29/2009	10/29/2009N45-47	0.625	M	0.023	M	0.035	M	15	M	0.001	M	0.007	M	0.062	M	6	M	9.2	M	0.028	M	67.3	M	0.003	M	13.9	M	0.028	M
	12/01/2009	12/01/2009N45-48																												
N45-48	2/17/2009	02/11/2009N45-48	0.671	M	0.004	M	0.083	M	12.97	M	0.001	M	0.029	M	0.045	M	6.157	M	11.39	M	0.012	M	76.3	M	0.004	M	10.31	M	0.025	M
	4/17/2009	04/17/2009N45-48	0.848	M	0.002	M	0.059	M	24.11	M	0.001	M	0.007	M	0.035	M	11.965	M	13.23	M	0.02	M	44.33	M	0.004	M	20.37	M	0.033	M
	7/22/2009	07/22/2009N45-48	1.011	M	0.001	M	0.044	M	23.5	M	0.002	M	0.007	M	0.104	M	11.4	M	13.8	M	0.011	M	85.9	M	0.004	M	14.2	M	0.033	M
	10/29/2009	10/29/2009N45-49	0.091	M	0.011	M	0.044	M	29.7	M	0.001	M	0.007	M	0.053	M	10	M	17.8	M	0.005	M	72.2	M	0.004	M	15.3	M	0.064	M
	12/01/2009	12/01/2009N45-49	1.169	M	0.001	M	0.044	M	19.8	M	0.002	M	0.007	M	0.194	M	8.1	M	13.8	M	0.023	M	74.4	M	0.004	M	14	M	0.083	M
N45-50	2/17/2009	02/11/2009N45-50	0.628	M	0.001	M	0.044	M	30.6	M	0.001	M	0.007	M	0.043	M	15	M	16.1	M	0.011	M	85.7	M	0.004	M	17.5	M	0.03	M
	4/17/2009	04/17/2009N45-50	0.476	M	0.019	M	0.044	M	33.7	M	0.001	M	0.007	M	0.047	M	13.7	M	16.7	M	0.032	M	89.3	M	0.004	M	17.7	M	0.018	M
	7/22/2009	07/22/2009N45-50																												
	10/29/2009	10/29/2009N45-50	0.902	M	0.003	M	0.044	M	11.78	M	0.001	M	0.013	M	0.015	M	5.082	M	9.47	M	0.008	M	48.76	M	0.002	M	7.25	M	0.03	M
	12/01/2009	12/01/2009N45-50	0.718	M	0.004	M	0.038	M	32.49	M	0.001	M	0.004	M	0.028	M	13.715	M	14.24	M	0.037	M	43.73	M	0.002	M	18.19	M	0.039	M
N45-51	3/11/2009	03/11/2009N45-51	0.149	M	0.001	M	0.044	M	26.9	M	0.002	M	0.004	M	0.161	M	8.1	M	17.4	M	0.014	M	78.6	M	0.004	M	14.4	M	0.059	M
	4/17/2009	04/17/2009N45-51	0.408	M	0.017	M	0.044	M	13.5	M	0.001	M	0.007	M	0.047	M	13.4	M	9.2	M	0.025	M	98.8	M	0.004	M	14.6	M	0.013	M
	7/22/2009	07/22/2009N45-51	0.328	M	0.045	M	0.044	M	10.5	M	0.001	M	0.007	M	0.058	M	9.7	M	8.8	M	0.017	M	91.1	M	0.004	M	12.8	M	0.009	M
	10/29/2009	10/29/2009N45-51	0.772	M	0.011	M	0.041	M	12.63	M	0.001	M	0.035	M	0.049	M	4.689	M	9.89	M	0.01	M	47.51	M	0.005	M	5.46	M	0.019	M
	12/01/2009	12/01/2009N45-51	0.415	M	0.004	M	0.035	M	18.59	M	0.001	M	0.004	M	0.029	M	10.985	M	7.78	M	0.016	M	41.45	M	0.004	M	14.41	M	0.013	M
N45-52	2/17/2009	02/11/2009N45-52	0.983	M	0.001	M	0.044	M	18.1	M	0.003	M	0.007	M	0.18	M	8.9	M	13.1	M	0.019	M	79.1	M	0.004	M	13.8	M	0.076	M
	4/17/2009	04/17/2009N45-52	0.658	M	0.007	M	0.044	M	15	M	0.001	M	0.007	M	0.083	M	13.1	M	9.3	M	0.024	M	89.8	M	0.004	M	14.6	M	0.017	M
	7/22/2009	07/22/2009N45-52	0.844	M	0.028	M	0.044	M	16.7	M	0.001	M	0.007	M	0.089	M	12.8	M	12.5	M	0.035	M	113.9	M	0.004	M	13.9	M	0.023	M
	10/29/2009	10/29/2009N45-52																												
	12/01/2009	12/01/2009N45-52																												
N45-53	2/17/2009	02/11/2009N45-53	0.531	M	0.004	M	0.049	M	11.53	M	0.001	M	0.046	M	0.056	M	4.537	M	7.94	M	0.012	M	59.22	M	0.003	M	8.08	M	0.017	M
	4/17/2009	04/17/2009N45-53	0.649	M	0.01	M	0.034	M	17.54	M	0.001	M	0.003	M	0.043	M	12.228	M	7.45	M	0.046	M	40.35	M	0.004	M	14.35	M	0.014	M
	7/22/2009	07/22/2009N45-53	0.535	M	0.001	M	0.044	M	15.9	M	0.002	M	0.004	M	0.094	M	6.4	M	13.5	M	0.039	M	80.1	M	0.004	M	10.9	M	0.059	M
	10/29/2009	10/29/2009N45-53	0.823	M	0.001	M	0.044	M	11.3	M	0.003	M	0.007	M	0.159	M	4.7	M	10	M	0.018	M	73.5	M	0.004	M	9.9	M	0.041	M
	12/01/2009	12/01/2009N45-53	1.14	M	0.001	M	0.044	M	13.7	M	0.001	M	0.007	M	0.084	M	6.3	M	13.3	M	0.01	M	86.4	M	0.004	M	12.6	M	0.044	M
N45-55	2/17/2009	02/11/2009N45-55	2.155	M	0.033	M	0.044	M	18.5	M	0.001	M	0.007	M	0.066	M	10.5	M	15.7	M	0.007	M	92.8	M	0.004	M	14.9	M	0.044	M
	4/17/2009	04/17/2009N45-55																												
	7/22/2009	07/22/2009N45-55	1.165	M	0.004	M	0.037	M	12.5	M	0.001	M	0.006	M	0.019	M	5.957	M	8.99	M	0.028	M	63.45	M	0.003	M	8.87	M	0.04	M
	10/29/2009	10/29/2009N45-55	1.067	M	0.002	M	0.037	M	8.47	M	0.001	M	0.005	M	0.029	M	10.277	M	7.88	M	0.004	M	48.56	M	0.004	M	12.72	M	0.025	M
	12/01/2009	12/01/2009N45-55	1.403	M	0.001	M	0.044	M	16.7	M	0.003	M	0.007	M	0.114	M	8.6	M	14	M	0.008	M	101.2	M	0.004	M	11.5	M	0.05	M
N45-56	2/17/2009	02/11/2009N45-56	1.23	M	0.001	M	0.044	M	18.1	M	0.001	M	0.007	M	0.07	M	9.9	M	15.3	M	0.005	M	81.3	M	0.006	M	14.1	M	0.028	M
	4/17/2009	04/17/2009N45-56	1.56	M	0.027	M	0.044	M	24.8	M	0.001	M	0.007	M	0.116	M	11.9	M	16.2	M	0.028	M	77.2	M	0.004	M	16.1	M	0.023	M
	7/22/2009	07/22/2009N45-56																												
	10/29/2009	10/29/2009N45-56	1.548	M	0.004	M	0.066	M	14.24	M	0.001	M	0.017	M	0.019	M	7.001	M	14.41	M	0.01	M	111.3	M	0.008	M	9.32	M	0.028	M
	12/01/2009	12/01/2009N45-56	1.011	M	0.004	M	0.046	M	18.43	M	0.001	M	0.002	M	0.021	M	10.653	M	10.09	M	0.009	M	48.22	M	0.004	M	15.23	M	0.017	M
N45-57	2/17/2009	02/11/2009N45-57	1.188	M	0.027	M	0.046	M	16.1	M	0.002	M	0.007	M	0.204	M	8.1	M	13.7	M	0.018	M	90.6	M	0.004	M	12.6	M	0.036	M
	4/17/2009	04/17/2009N45-57	1.304	M	0.006	M	0.046	M	18	M	0.001	M	0.007	M	0.079	M	12.4	M	13.8	M	0.021	M	85.6	M	0.004	M	14.4	M	0.028	M
	7/22/2009	07/22/2009N45-57	1.997	M	0.024	M	0.046	M	25.2	M	0.001	M	0.007	M	0.001	M	14.3	M	16.2	M	0.075	M	92	M	0.004	M	16.5	M	0.033	M
	10/29/2009	10/29/2009N45-57	0.817	M	0.004	M	0.051	M	7.41	M	0.001	M	0.006	M	0.008	M	4.021	M	8.74	M	0.001	M	52.46	M	0.007	M	8.45	M	0.011	M
	12/01/2009	12/01/2009N45-57	0.986	M	0																									

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Al Flag	As (mg/L)	As Flag	B (mg/L)	B Flag	Ca (mg/L)	Ca Flag	Cr (mg/L)	Cr Flag	Cu (mg/L)	Cu Flag	Fe (mg/L)	Fe Flag	K (mg/L)	K Flag	Mg (mg/L)	Mg Flag	Mn (mg/L)	Mn Flag	Na (mg/L)	Na Flag	Pb (mg/L)	Pb Flag	Si (mg/L)	Si Flag	Zn (mg/L)	Zn Flag	
N45-60	8/16/2008	08/16/2008N45-60	1.975	M	0.036	M	20.4	M	0.001	M	0.001	M	0.162	M	8.8	M	158.2	M	0.08	M	0.08	M	158.2	M	0.004	M	15.7	M	0.104	M
	8/19/2008	08/19/2008N45-60	1.934	M	0.037	M	20	M	0.001	M	0.001	M	0.136	M	9.2	M	133.3	M	16.4	M	0.094	M	133.3	M	0.004	M	16.2	M	0.108	M
	12/2/2008	12/02/2008N45-60	2.232	M	0.037	M	24.1	M	0.001	M	0.001	M	0.288	M	10.3	M	137.4	M	16.7	M	0.134	M	137.4	M	0.004	M	16	M	0.104	M
	2/13/2009	02/13/2009N45-60																												
	4/17/2009	04/17/2009N45-60																												
	7/22/2009	07/22/2009N45-60	2.22	M	0.005	M	20.84	M	0.008	M	0.001	M	0.008	M	5.256	M	11.728	M	38.66	M	0.141	M	114.4	M	0.004	M	14.67	M	0.093	M
	10/29/2009	10/29/2009N45-60	2.852	M	0.011	M	29.16	M	0.007	M	0.001	M	0.007	M	0.19	M	10.69	M	21.99	M	0.063	M	46.6	M	0.002	M	15.18	M	0.083	M
	8/15/2008	08/15/2008N45-61	0.106	M	0.011	M	9.5	M	0.001	M	0.001	M	0.001	M	0.14	M	4.1	M	7.3	M	0.083	M	55.5	M	0.004	M	14	M	0.083	M
	2/11/2009	02/11/2009N45-61	0.452	M	0.013	M	12.8	M	0.001	M	0.001	M	0.001	M	0.02	M	7.4	M	9.9	M	0.065	M	53.5	M	0.004	M	18.1	M	0.057	M
	02/11/2009	02/11/2009N45-61																												
N45-61	7/22/2009	07/22/2009N45-61	0.538	M	0.004	M	12.07	M	0.001	M	0.001	M	0.03	M	5.086	M	8.55	M	14.89	M	0.035	M	61.69	M	0.002	M	10.41	M	0.027	M
	10/29/2009	10/29/2009N45-61	1.496	M	0.003	M	25.35	M	0.001	M	0.001	M	0.015	M	6.325	M	10.563	M	14.79	M	0.055	M	45.34	M	0.003	M	19.61	M	0.049	M
	7/22/2009	07/22/2009N45-62	0.421	M	0.002	M	10.81	M	0.001	M	0.001	M	0.012	M	10.335	M	10.335	M	14.79	M	0.002	M	59.29	M	0.001	M	8.9	M	0.006	M
	10/29/2009	10/29/2009N45-62	0.913	M	0.007	M	13.24	M	0.008	M	0.008	M	0.008	M	7.276	M	7.276	M	6.55	M	0.042	M	34.79	M	0.002	M	14.36	M	0.044	M
	8/19/2008	08/19/2008N45-63	0.165	M	0.008	M	20.6	M	0.001	M	0.001	M	0.008	M	0.163	M	10.3	M	13.7	M	0.012	M	79.4	M	0.004	M	15.3	M	0.041	M
	8/19/2008	08/19/2008N45-63	1.318	M	0.002	M	24.8	M	0.001	M	0.001	M	0.001	M	0.042	M	13.5	M	15.5	M	0.049	M	81.9	M	0.007	M	18.6	M	0.055	M
	10/7/2008	10/07/2008N45-64	0.36	M	0.001	M	19.3	M	0.002	M	0.002	M	0.002	M	9.1	M	13.8	M	13.8	M	0.002	M	88.1	M	0.004	M	14.2	M	0.011	M
	10/8/2008	10/08/2008N45-64	0.402	M	0.001	M	24.1	M	0.001	M	0.001	M	0.001	M	0.048	M	13	M	14.5	M	0.041	M	85.5	M	0.006	M	16.8	M	0.027	M
	12/1/2008	12/01/2008N45-64	1.567	M	0.018	M	21.2	M	0.001	M	0.001	M	0.001	M	0.036	M	10.6	M	13.2	M	0.045	M	75.7	M	0.004	M	17.9	M	0.047	M
	2/11/2009	02/11/2009N45-64																												
N45-62	4/17/2009	04/17/2009N45-64	0.707	M	0.004	M	14.03	M	0.001	M	0.001	M	0.006	M	6.521	M	11.86	M	11.86	M	0.02	M	64.19	M	0.005	M	5.74	M	0.031	M
	7/22/2009	07/22/2009N45-64	0.835	M	0.003	M	35.62	M	0.001	M	0.001	M	0.03	M	18.057	M	15.04	M	15.04	M	0.085	M	52.14	M	0.004	M	21.39	M	0.027	M
	10/29/2009	10/29/2009N45-64	0.338	M	0.001	M	18.6	M	0.003	M	0.003	M	0.01	M	0.128	M	8.9	M	14.5	M	0.018	M	74.8	M	0.004	M	14.1	M	0.038	M
	8/15/2008	08/15/2008N45-65	0.655	M	0.003	M	28.7	M	0.001	M	0.001	M	0.001	M	0.058	M	13.9	M	16.1	M	0.011	M	80.9	M	0.005	M	18	M	0.032	M
	10/7/2008	10/07/2008N45-66	0.883	M	0.019	M	30.7	M	0.001	M	0.001	M	0.001	M	13.7	M	13.7	M	16	M	0.056	M	113.2	M	0.004	M	18.8	M	0.037	M
	12/1/2008	12/01/2008N45-65																												
	4/17/2009	04/17/2009N45-65	0.52	M	0.006	M	9.85	M	0.001	M	0.001	M	0.007	M	5.421	M	10.64	M	10.64	M	0.003	M	43.44	M	0.003	M	5.73	M	0.017	M
	7/22/2009	07/22/2009N45-65	0.579	M	0.01	M	22.35	M	0.001	M	0.001	M	0.005	M	10.93	M	10.67	M	6.3	M	0.004	M	40.3	M	0.004	M	15.97	M	0.014	M
	8/15/2008	08/15/2008N45-66	0.072	M	0.022	M	13.1	M	0.003	M	0.003	M	0.01	M	0.163	M	4	M	9.4	M	0.006	M	17.1	M	0.004	M	12.4	M	0.008	M
	10/29/2009	10/29/2009N45-66	0.055	M	0.008	M	22	M	0.001	M	0.001	M	0.001	M	0.042	M	7	M	9.4	M	0.045	M	112.7	M	0.006	M	15.9	M	0.005	M
12/1/2008	12/01/2008N45-66	0.027	M	0.037	M	38.2	M	0.001	M	0.001	M	0.001	M	0.045	M	12	M	9.9	M	0.081	M	158.4	M	0.005	M	16	M	0.011	M	
N45-63	4/17/2009	04/17/2009N45-66	0.072	M	0.006	M	9.85	M	0.001	M	0.001	M	0.007	M	5.421	M	10.64	M	10.64	M	0.003	M	43.44	M	0.003	M	5.73	M	0.017	M
	7/22/2009	07/22/2009N45-66	0.072	M	0.006	M	9.85	M	0.001	M	0.001	M	0.007	M	5.421	M	10.64	M	10.64	M	0.003	M	43.44	M	0.003	M	5.73	M	0.017	M
	10/29/2009	10/29/2009N45-66	0.072	M	0.006	M	9.85	M	0.001	M	0.001	M	0.007	M	5.421	M	10.64	M	10.64	M	0.003	M	43.44	M	0.003	M	5.73	M	0.017	M
	8/15/2008	08/15/2008N45-67	0.32	M	0.009	M	15.1	M	0.002	M	0.002	M	0.004	M	6.674	M	12	M	12	M	0.181	M	49.5	M	0.004	M	13.48	M	0.005	M
	10/7/2008	10/07/2008N45-67	0.381	M	0.003	M	19.2	M	0.001	M	0.001	M	0.001	M	0.087	M	8.8	M	15.6	M	0.023	M	78.3	M	0.004	M	11.1	M	0.025	M
	12/1/2008	12/01/2008N45-67	0.765	M	0.045	M	18.6	M	0.001	M	0.001	M	0.001	M	6.9	M	6.9	M	15.8	M	0.024	M	88.7	M	0.012	M	13.7	M	0.032	M
	4/17/2009	04/17/2009N45-67																												
	7/22/2009	07/22/2009N45-67																												
	10/29/2009	10/29/2009N45-67																												
	8/15/2008	08/15/2008N45-67																												
N45-67	12/1/2008	12/01/2008N45-67	0.104	M	0.003	M	16.54	M	0.001	M	0.001	M	0.009	M	5.192	M	11.55	M	7.63	M	0.026	M	54.17	M	0.004	M	7.25	M	0.026	M
	2/11/2009	02/11/2009N45-67	0.497	M	0.008	M	10.74	M	0.001	M	0.001	M	0.003	M	5.029	M	5.029	M	7.63	M	0.006	M	54.17	M	0.004	M	11.36	M	0.018	M
	4/17/2009	04/17/2009N45-67																												
	7/22/2009	07/22/2009N45-67																												
	10/29/2009	10/29/2009N45-67																												
	8/15/2008	08/15/2008N45-67																												
	12/1/2008	12/01/2008N45-67																												
	4/17/2009	04/17/2009N45-67																												
	7/22/2009	07/22/2009N45-67																												
	10/29/2009	10/29/2009N45-67																												
N45-78	4/16/2009	04/16/2009N45-78	0.248	M	0.004	M	6.75	M	0.001	M	0.001	M	0.01	M	1.172	M	2.062	M	5.51	M	0.008	M	28.26	M	0.005	M	10.47	M	0.022	M
	8/7/2009	08/07/2009N45-78	0.113	M	0.005	M	12.26	M	0.001	M	0.001	M	0.002	M	5.804	M	7.68	M	7.68	M	0.011	M	61.57	M	0.004	M	12.79	M	0.017	M
	11/4/2009	11/04/2009N45-78																												
	2/13/2009	02/13/2009N45-79																												
	4/16/2009	04/16/2009N45-79																												
	8/7/2009	08/07/2009N45-79	0.128	M	0.004	M	10.62	M	0.008	M	0.001	M	0.008	M	0.021	M	2.469	M	7.43	M	0.011	M	46.07	M	0.005	M	11.23	M	0.017	M
	11/4/2009	11/04/2009N45-79	0.09	M	0.006	M</																								

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Al (mg/L)	Al Flag	As (mg/L)	As Flag	B (mg/L)	B Flag	Ca (mg/L)	Ca Flag	Cr (mg/L)	Cr Flag	Cu (mg/L)	Cu Flag	Fe (mg/L)	Fe Flag	K (mg/L)	K Flag	Mg (mg/L)	Mg Flag	Mn (mg/L)	Mn Flag	Na (mg/L)	Na Flag	Pb (mg/L)	Pb Flag	Si (mg/L)	Si Flag	Zn (mg/L)	Zn Flag
NH45-ae	2/12/2009	02/12/2009NH45-ae	0.002	LM	0.001	LM	19	M	7.23	M	17.01	M	0.001	LM	0.082	M	8.9	M	9.4	M	0.02	M	85	M	0.004	LM	9.928	M	0.03	M
	3/4/2008	03/04/2008NH45-EFF																												
	4/29/2008	04/29/2008NH45-EFF																												
	5/13/2008	05/13/2008NH45-EFF																												
	6/17/2008	06/17/2008NH45-EFF																												
	7/15/2008	07/15/2008NH45-EFF																												
	8/19/2008	08/19/2008NH45-EFF																												
	8/20/2008	08/20/2008NH45-EFF	0.05	M	0.001	LM	15.4	M	8.9	M	9.4	M	0.002	M	0.436	M	8.9	M	9.4	M	0.02	M	56.8	M	0.004	LM	12.4	M	0.016	M
	9/16/2008	09/16/2008NH45-EFF																												
	10/17/2008	10/07/2008NH45-EFF	0.058	M	0.001	LM	16.5	M	7.1	M	12.4	M	0.001	LM	0.732	M	7.1	M	12.4	M	0.039	M	81	M	0.004	M	12	M	0.012	M
12/22/2008	12/02/2008NH45-EFF	0.186	M	0.023	M	15.3	M	3.2	M	7.5	M	0.001	LM	0.575	M	3.2	M	7.5	M	0.036	M	41	M	0.004	LM	10	M	0.044	M	
NH45-ae	12/29/2008	12/09/2008NH45-EFF																												
	2/11/2009	02/11/2009NH45-EFF																												
	4/9/2009	04/09/2009NH45-EFF	0.002	LM	0.004	M	0.036	M	15.66	M	0.001	LM	0.003	M	0.016	M	8.966	M	8.72	M	0.002	M	48.72	M	0.004	LM	12.53	M	0.003	M
	8/7/2009	08/07/2009NH45-EFF	0.047	M	0.007	M	0.03	M	18.42	M	0.001	LM	0.001	LM	0.192	M	2.485	M	4.55	M	0.039	M	22.47	M	0.004	LM	9.99	M	0.021	M
	11/4/2009	11/04/2009NH45-EFF	0.016	M	0.004	LM	16.5	M	5.78	M	8.77	M	0.001	LM	0.146	M	5.78	M	8.77	M	0.011	M	70.15	M	0.009	M	1.983	M	0.019	M
	4/29/2008	04/29/2008NH45-r	0.071	M	0.004	LM	9.7	M	3.29	M	4.77	M	0.001	M	0.48	M	3.29	M	4.77	M	0.119	M	32.56	M	0.004	LM	2.37	M	0.015	M
	12/18/2008	12/18/2008NH45-r	0.428	M	0.001	LM	11.4	M	1.2	M	5.7	M	0.001	LM	0.762	M	1.2	M	5.7	M	0.124	M	37.6	M	0.004	LM	13.5	M	0.018	M
	2/13/2009	02/13/2009NH45-r																												
	4/17/2009	04/17/2009NH45-r	0.034	M	0.004	LM	14.36	M	2.333	M	6.56	M	0.001	LM	0.588	M	2.333	M	6.56	M	0.03	M	41.73	M	0.004	LM	12.84	M	0.019	M
	8/7/2009	08/07/2009NH45-r	0.273	M	0.003	LM	10.93	M	3.953	M	7.61	M	0.001	LM	0.801	M	3.953	M	7.61	M	0.049	M	50.79	M	0.004	LM	10.98	M	0.053	M
NH45-ae	11/4/2009	11/04/2009NH45-r	0.041	M	0.004	LM	22.7	M	11.26	M	15.23	M	0.001	LM	0.029	M	11.26	M	15.23	M	0.004	M	128.6	M	0.004	LM	1.135	M	0.045	M
	4/29/2008	04/29/2008NH45-s	0.011	M	0.005	M	16.8	M	10.01	M	13.48	M	0.002	M	0.001	LM	10.01	M	13.48	M	0.001	LM	113.3	M	0.008	M	10.13	M	0.037	M
	12/18/2008	12/18/2008NH45-s	1.088	M	0.001	LM	6.9	M	2.1	M	6.8	M	0.001	LM	0.246	M	2.1	M	6.8	M	0.356	M	46	M	0.004	LM	22	M	0.022	M
	2/13/2009	02/13/2009NH45-s																												
	4/17/2009	04/17/2009NH45-s	0.032	M	0.004	LM	12.87	M	6.219	M	9.22	M	0.001	LM	0.019	M	6.219	M	9.22	M	0.011	M	59.43	M	0.004	LM	8.63	M	0.025	M
	8/7/2009	08/07/2009NH45-s	0.588	M	0.001	LM	6.85	M	4.534	M	7.37	M	0.001	LM	0.483	M	4.534	M	7.37	M	0.1	M	47.51	M	0.004	LM	12.7	M	0.034	M
	11/4/2009	11/04/2009NH45-s	0.08	M	0.004	LM	23.8	M	11.74	M	18.35	M	0.001	LM	0.014	M	11.74	M	18.35	M	0.023	M	130.7	M	0.002	LM	4.445	M	0.087	M
	4/29/2008	04/29/2008NH45-v	0.145	M	0.004	LM	13.2	M	9.51	M	10.11	M	0.001	LM	0.082	M	9.51	M	10.11	M	0.001	LM	85.62	M	0.004	LM	8.349	M	0.05	M
	12/18/2008	12/18/2008NH45-v	0.514	M	0.006	M	11.5	M	6.1	M	8.9	M	0.001	LM	0.236	M	6.1	M	8.9	M	0.154	M	79.4	M	0.004	LM	25.5	M	0.018	M
	2/13/2009	02/13/2009NH45-v																												
NH45-ae	4/17/2009	04/17/2009NH45-v	0.391	M	0.006	M	8.55	M	5.75	M	8.17	M	0.001	LM	0.234	M	5.75	M	8.17	M	0.063	M	58.75	M	0.004	LM	14.41	M	0.024	M
	11/4/2009	11/04/2009NH45-v	0.04	M	0.007	M	22.3	M	6.77	M	9.64	M	0.001	LM	0.27	M	6.77	M	9.64	M	0.078	M	84.49	M	0.003	LM	12.42	M	0.04	M
	4/29/2008	04/29/2008NH45-w	0.029	M	0.009	M	24.8	M	10.75	M	15.65	M	0.002	M	0.083	M	10.75	M	15.65	M	0.031	M	131.6	M	0.002	LM	11.16	M	0.032	M
	12/18/2008	12/18/2008NH45-w	0.494	M	0.001	LM	17.6	M	5.4	M	8	M	0.001	LM	0.28	M	5.4	M	8	M	0.101	M	81.8	M	0.004	LM	21.1	M	0.046	M
	2/13/2009	02/13/2009NH45-w																												
	4/17/2009	04/17/2009NH45-w	0.421	M	0.007	M	11.77	M	5.467	M	7.54	M	0.001	LM	0.485	M	5.467	M	7.54	M	0.007	M	58.11	M	0.004	LM	14.23	M	0.052	M
	11/4/2009	11/04/2009NH45-w	0.026	M	0.004	LM	16.1	M	5.1	M	7.67	M	0.001	LM	0.215	M	5.1	M	7.67	M	0.001	LM	73.61	M	0.004	LM	10.16	M	0.06	M
	4/29/2008	04/29/2008NH45-x	0.089	M	0.003	LM	12.1	M	3.73	M	6.15	M	0.001	LM	0.229	M	3.73	M	6.15	M	0.091	M	46.9	M	0.004	LM	8.021	M	0.018	M
	12/18/2008	12/18/2008NH45-x	0.368	M	0.009	M	8.8	M	1.6	M	5.2	M	0.001	LM	0.267	M	1.6	M	5.2	M	0.075	M	28.8	M	0.004	LM	12	M	0.018	M
	2/13/2009	02/13/2009NH45-x																												
NH45-x	4/17/2009	04/17/2009NH45-x	0.019	M	0.004	LM	11.2	M	3.873	M	6.91	M	0.001	LM	0.168	M	3.873	M	6.91	M	0.004	M	51.22	M	0.004	LM	12.53	M	0.009	M
	8/7/2009	08/07/2009NH45-x																												
	11/4/2009	11/04/2009NH45-x																												
	4/29/2008	04/29/2008NH45-x																												
	12/18/2008	12/18/2008NH45-x																												
	2/13/2009	02/13/2009NH45-x																												
	4/17/2009	04/17/2009NH45-x																												
	8/7/2009	08/07/2009NH45-x																												
	11/4/2009	11/04/2009NH45-x																												
	4/29/2008	04/29/2008NH45-x																												

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the bottom of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the top of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Ortho Phosphate P (mg/L)	Ortho Phosphate P Flag	DOP	DOP Flag	TDP	TDP Flag	Total Dissolved P (mg/L)	Total Dissolved P Flag	Ammonium N (mg/L)	Ammonium N Flag	Nitrate N (mg/L)	Nitrate-N Flag	DON (mg/L)	DON Flag	Khajidahl N (mg/L)	Khajidahl N Flag	Alkalinity as CaCO ₃ (mg/L)	Alkalinity Flag	Cl (mg/L)	Cl Flag	Sulfate (mg/L)	Sulfate Flag	
N44-16	6/17/2008	06/17/2008N44-16	0.016	M							0.199	LM	20.74	M	0.261	M	0.46	LM	17.7	M	89	M	21.03	M	
	8/13/2008	08/13/2008N44-16	0.012	LM							0.199	LM	4	M	0.261	M	0.46	LM			16	M	4.95	M	
	10/17/2008	10/17/2008N44-16	0.012	LM							0.248	M	0.68	M	1.672	M	1.92	M			7.6	M	2.6	M	
	12/18/2008	12/18/2008N44-16	0.012	LM							0.199	LM	0.53	M	0.3	M	0.5	M			9.7	M	2.7	M	
	2/11/2009	02/11/2009N44-16	0.016	M					0.036	M	0.165	JM	0.64	M	0.395	M	0.56	M							
	7/28/2009	07/28/2009N44-16	0.012	LM	0.017	M			0.011	M	0.086	LM	0.458	M	0.038	M	0.124	M			15	M	4	M	
	11/4/2009	11/04/2009N44-16	0.018	M	0.032	LM	0.034	M	0.034	M	0.167	M	1.3	M							19	M	3.6	M	
	6/18/2008	06/18/2008N45-15	0.036	M							0.199	LM	0.91	M	0.051	M	0.25	JM	21	M	15	M	4.2	M	
	8/13/2008	08/13/2008N45-15	0.006	JM							0.199	LM	0.32	LM	0.261	M	0.46	LM			18	M	3.89	M	
	10/8/2008	10/08/2008N45-15	0.024	JM							0.353	M	0.26	LM	0.107	M	0.46	LM			16	M	2.8	M	
N45-17	12/2/2009	12/02/2009N45-15	0.007	JM							0.199	LM	0.32	LM	1.66	M	1.86	LM			11	M	2	M	
	2/12/2009	02/12/2009N45-15	0.018	M	0.172	M			0.19	M	0.227	M	0.32	LM	0.513	M	0.74	M	0.5	LM					
	8/13/2008	08/13/2008N45-17	0.012	LM							0.199	LM	0.15	M	0.261	M	0.46	LM			67	M	6.15	M	
	7/28/2009	07/28/2009N45-17	0.012	LM	0.004	M	0.022	M	0.004	M	0.086	LM	0.397	M	0.534	M	0.62	M			21	M	3.4	M	
	11/4/2009	11/04/2009N45-17	0.022	M	0.016	JM			0.022	M	0.787	M	0.99	M	0.534	M	0.62	M			22	M	3.5	M	
	4/17/2008	04/17/2008N45-33a	0.012	LM							2.75	M	16.08	M	0.1	M	2.85	M	0.4	JM	187	M	9.757	M	
	6/20/2008	06/20/2008N45-33b	0.04	M							0.83	M	6.41	M	0.22	M	1.05	M	6.5	M	321	M	15.45	M	
	8/13/2008	08/13/2008N45-33	0.006	JM							2.768	M	7.21	M	6.652	M	9.42	M	2	M	205	M	10.19	M	
	10/7/2008	10/07/2008N45-33	0.012	JM							1.32	M	6.47	M	0	M	1.32	LM			142	M	10.11	M	
	12/18/2008	12/18/2008N45-33	0.029	M							0.105	JM	1.1	M	10.895	M	11	M			72	M	5.9	M	
N45-34	2/11/2009	02/11/2009N45-33	0.035	M					0.26	M	0.5	M	2.66	M	1.48	M	1.98	LM			77	M	4.7	M	
	8/7/2009	08/07/2009N45-33	0.037	M	0.017	M			0.054	M	0.973	M	3.005	M	0	M	1.528	M	0.79	M	57	M	4.8	M	
	11/4/2009	11/04/2009N45-33	0.02	M	0.016	JM	0.02	M	0.02	M	0.849	M	3.97	M	0	M	0.849	M	7.7	M	156	M	8.4	M	
	4/16/2008	04/16/2008N45-34a	0.78	M							0.199	LM	5.17	M	0.051	M	0.25	M	1.4	M	218	M	10.34	M	
	6/18/2008	06/18/2008N45-34b	0.46	M							0.199	LM	6.23	M	0.361	M	0.56	JM	0.5	LM	348	M	15.86	M	
	8/11/2008	08/11/2008N45-34	0.217	M							1.12	M	6.12	M	0	M	1.12	M	6.7	M	191	M	9.79	M	
	10/7/2008	10/07/2008N45-34	0.044	M							0.27	M	2.19	M	0	M	0.27	M			145	M	7.35	M	
	12/2/2008	12/02/2008N45-34	0.034	M							0.199	LM	2.65	M	3.051	M	3.25	M			174	M	9.4	M	
	2/12/2009	02/12/2009N45-34	0.124	M							0.199	LM	0.74	M	2.66	M	2.86	LM			160	M	8.3	M	
	7/28/2009	07/28/2009N45-34	0.064	M	0.057	M			0.121	M	0.227	M	4.05	M	1.013	M	1.24	M	1.5	M	111	M	7.9	M	
N45-35	10/29/2009	10/29/2009N45-34	0.199	M	0.01	M	0.139	M	0.209	M	0.973	M	3.687	M	0.421	M	1.394	M	7.7	M	94	M	7.4	M	
	4/16/2008	04/16/2008N45-35a	0.13	M	0.018	LM	0.139	M	0.139	M	0.353	M	10.56	M	0.143	M	0.496	M							
	6/17/2008	06/17/2008N45-35b	0.08	M							0.27	M	2.51	M	0.19	M	0.46	LM	0.5	LM	187	M	12.35	M	
	8/12/2008	08/12/2008N45-35	0.21	M							0.199	LM	6.23	M	0.051	M	0.25	JM	5.8	M	162	M	11.07	M	
	10/7/2008	10/07/2008N45-35	0.407	M							0.31	M	6.18	M	0	M	0.31	JM	1.1	M	219	M	10.66	M	
	12/2/2008	12/02/2008N45-35	0.534	M							1.39	M	20.72	M	0.34	M	1.73	M	0.8	M	174	M	9.15	M	
	2/12/2009	02/12/2009N45-35b	0.67	LM							1.097	M	23.4	M	0.673	M	1.77	M			215	M	10.6	M	
	12/1/2008	12/01/2008N45-35	0.696	LM							3.265	M	20.92	M	0	M	3.265	M			227	M	11	M	
	2/11/2009	02/11/2009N45-35a	1.588	M							0.199	LM	6.13	M	1.04	M	1.24	LM			94	M	7	M	
	4/16/2009	04/16/2009N45-35b	0.986	M	0.493	M			1.479	M	0.289	M	3.74	M	0.521	M	0.81	M	0.5	LM					
N45-36	7/22/2009	07/22/2009N45-35	0.75	M	1.201	M	1.055	LM	0.898	M	0.413	M	2.68	M	0.517	M	0.93	M	0.38	JM					
	10/29/2009	10/29/2009N45-35	0.41	M	0.157	M			0.98	M	0.199	LM	0.32	LM	0.261	M	0.46	LM	0.5	LM					
	4/16/2008	04/16/2008N45-36a	0.741	M	0.081	M	0.91	LM	0.741	M	0.199	LM	2.94	M	0.051	M	0.25	JM	0.5	LM	129	M	8.7	M	
	7/22/2009	07/22/2009N45-35	0.5	M	0.163	M			0.663	M	0.043	JM	7.9	M	0.422	M	0.465	M	0.5	LM	74	M	7.4	M	
	10/29/2009	10/29/2009N45-35	0.386	M	0.022	M	0.397	M	0.397	M	3.079	M	12.85	M	0	M	3.079	M							
	4/16/2008	04/16/2008N45-36a	0.01	JM							0.199	LM	5.73	M	0.261	M	0.46	LM	12.3	M	226	M	12.16	M	
	6/17/2008	06/17/2008N45-36b	0.012	LM							0.199	LM	7.59	M	0.231	M	0.43	JM	12.3	M	226	M	12.16	M	
	8/11/2008	08/11/2008N45-36	0.204	M							0.199	LM	2.46	M	0.231	M	0.43	JM	9.4	M	127	M	8.13	M	
	10/7/2008	10/07/2008N45-36	0.264	M							0.4	M	5.42	M	0.06	M	0.46	LM	7.1	M	220	M	11.27	M	
	12/2/2008	12/02/2008N45-36	0.464	LM							0.415	M	12.19	M	0.045	M	0.46	LM			211	M	10.5	M	
N45-37	2/12/2009	02/12/2009N45-36	0.243	M						0.2	LM	15.12	M	0.26	M	0.46	LM			2.2	M	139	M	7.9	M
	7/28/2009	07/28/2009N45-36	0.305	M	0.297	M			0.602	M	0.165	JM	5.35	M	0.885	M	1.05	M	4.9	M	81	M	5.2	M	
	10/29/2009	10/29/2009N45-36	0.182	M	0.046	M			0.228	M	0.167	M	2.261	M	0	M	0.167	M	0.2	M	291	M	12.97	M	
	4/17/2008	04/17/2008N45-37a	0.271	M	0.016	JM	0.258	M	0.271	M	0.725	M	15.02	M	0.452	M	1.177	M	0.2	M	387	M	20.37	M	
	6/18/2008	06/18/2008N45-37b	0.012	LM							1.2	M	17.44	M	0	M	1.2	M	3.5	M	291	M	12.97	M	
	8/11/2008	08/11/2008N45-37	0.01	JM							0.199	LM	0.59	M	0.301	M	0.5	M	16.9	M	84	M	5.75	M	
	10/7/2008	10/07/2008N45-37	0.058	M							0.19	M	2.89	M	0.62	M	0.81	M	15.6	M	117	M			

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Ortho Phosphate P Flag	Ortho Phosphate P Flag	DOP	DOP Flag	TDP	TDP Flag	Total Dissolved P (mg/L)	Ammonium N (mg/L)	Ammonium N Flag	Nitrate N (mg/L)	Nitrate-N Flag	DON (mg/L)	Khajdahi N (mg/L)	Khajdahi N Flag	Alkalinity as CaCO ₃ (mg/L)	Alkalinity Flag	Cl (mg/L)	Cl Flag	Sulfate (mg/L)	Sulfate Flag	
N45-39	4/17/2008	04/17/2008N45-39	0.008	JM						0.199	LM	4.06	M	0.261	M	0.46	LM	37.2	M	93	M	12.45	M
	6/18/2008	06/18/2008N45-39	0.02	M					0.398	JM	0.29	M	0.472	M	0.87	M	21.2	M	115	M	8.21	M	
	8/12/2008	08/12/2008N45-39	0.009	JM					0.46	M	0.32	LM	0	M	0.46	LM	6	M	146	M	12.63	M	
	10/8/2008	10/08/2008N45-39	0.024	JM					0.167	JM	0.26	LM	0.113	0	0.113	M	0.28	JM	354	M	15.8	M	
	12/2/2008	12/02/2008N45-39	0.009	JM					0.199	LM	0.32	LM	0.2	M	0.4	JM	0.62	M	152	M	7.5	M	
	2/13/2009	02/13/2009N45-39	0.017	M					0.351	M	0.52	M	0.015	LM	1.661	M	1.952	M	22	M	3.1	M	
	8/7/2009	08/07/2009N45-39	0.012	LM					0.004	LM	0.291	M	0.015	LM	6.276	M	6.939	M	131	M	9.9	M	
	11/4/2009	11/04/2009N45-39	0.017	M					0.017	M	0.663	M	0.5	M	0	M	4.4	M	204	M	10.19	M	
	4/17/2008	04/17/2008N45-40	0.009	JM					0.199	LM	0.28	M	0.361	M	0.261	M	0.46	LM	346	M	14.91	M	
	6/20/2008	06/20/2008N45-40	0.021	M					0.042	M	8.38	M	10.62	M	0.698	M	0.74	M	204	M	10.19	M	
	8/12/2008	08/12/2008N45-40	0.009	JM					0.33	M	0.33	M	0.13	M	0.111	M	0.46	LM	280	M	13.23	M	
	10/8/2008	10/08/2008N45-40	0.024	JM					0.229	M	5.31	M	0.34	M	0.111	M	0.34	JM	317	M	15.3	M	
N45-40	12/2/2008	12/02/2008N45-40	0.002	LM					0.199	LM	3.84	M	0	M	0.26	M	0.46	M	200	M	18.8	M	
	2/13/2009	02/13/2009N45-40	0.017	M					0.723	M	28.83	M	0	M	0	M	0.723	M	31	M	3.7	M	
	8/7/2009	08/07/2009N45-40	0.012	LM					0.041	M	0.086	LM	0.465	M	0.75	M	0.836	M	172	M	9.8	M	
	11/4/2009	11/04/2009N45-40	0.026	M					0.016	JM	0.477	M	0	M	0	M	0.477	LM	30	M	6.7	M	
	4/17/2008	04/17/2008N45-41	0.012	LM					0.7	M	5.55	M	1.1	M	1.1	M	15.5	M	16	M	3.02	M	
	6/20/2008	06/20/2008N45-41	0.019	M					0.042	M	0.32	LM	0.698	0	M	0.74	M	56	M	206	M	10.23	M
	8/12/2008	08/12/2008N45-41	0.011	JM					4.11	M	0.77	M	0	M	0	M	4.11	M	32	M	2.63	M	
	10/8/2008	10/08/2008N45-41	0.024	JM					0.787	M	0.26	LM	0	M	0	M	0.787	JM	44	M	4.2	M	
	12/2/2008	12/02/2008N45-41	0.007	JM					0.199	LM	0.32	LM	1.1	M	1.1	M	1.3	LM	28	M	9.8	M	
	2/13/2009	02/13/2009N45-41	0.034	M					0.289	M	0.7	M	0.701	M	0.99	M	0.651	M	43	M	3.5	M	
	8/7/2009	08/07/2009N45-41	0.016	M					0.353	M	0.015	LM	0.015	LM	0.298	M	0.651	M	39	M	6.7	M	
	11/4/2009	11/04/2009N45-41	0.018	M					0.415	M	0.56	M	0	M	0	M	0.415	M	30	M	6.7	M	
N45-42	4/17/2008	04/17/2008N45-42	0.017	M					1.32	M	16.14	M	0	M	0	M	1.32	M	320	M	18.79	M	
	6/20/2008	06/20/2008N45-42	0.022	M					0.227	M	5.47	M	0.273	M	0	M	0.5	M	408	M	18.19	M	
	8/12/2008	08/12/2008N45-42	0.012	LM					0.199	LM	0.32	LM	0.111	M	0.111	M	1	M	70	M	5.5	M	
	10/8/2008	10/08/2008N45-42	0.012	LM					0.415	M	0.26	LM	0.295	M	0.295	M	0.71	M	62	M	2.6	M	
	12/2/2008	12/02/2008N45-42	0.012	LM					0.5	M	1.63	M	1.3	M	1.3	M	1.8	LM	35	M	6.1	M	
	2/13/2009	02/13/2009N45-42	0.006	JM					0.227	M	0.77	M	0.823	M	1.05	M	0.823	M	140	M	9.6	M	
	8/7/2009	08/07/2009N45-42	0.025	M					0.199	LM	0.077	M	0.261	M	0.46	LM	0.4	JM	135	M	15.4	M	
	11/4/2009	11/04/2009N45-42	0.06	M					0.415	M	0.015	LM	0.015	LM	0.236	M	0.651	M	14	M	2.6	M	
	4/17/2008	04/17/2008N45-43	0.012	LM					0.19	JM	8.9	M	0.27	M	0.27	M	0.46	LM	275	M	13.36	M	
	8/11/2008	08/11/2008N45-43	0.534	M					2.94	M	23.88	M	0	M	0	M	0.9	M	157	M	8.38	M	
	10/8/2008	10/08/2008N45-43	0.294	M					0.186	JM	21.56	M	0.184	M	1.46	M	0.37	JM	108	M	7.2	M	
	10/17/2008	10/17/2008N45-43a	0.142	M					0.558	M	20.88	M	0.002	M	0.002	M	0.56	M	120	M	33.9	M	
N45-43	12/1/2008	12/01/2008N45-43a	0.259	M					0.12	JM	15.37	M	3.12	M	3.12	M	3.24	I	135	M	15.4	M	
	2/11/2009	02/11/2009N45-43b	0.148	M					0.16	LM	16.11	M	0.72	M	0.72	M	0.92	JM	140	M	9.6	M	
	4/16/2009	04/16/2009N45-43b	0.332	M					0.475	M	6.53	M	0.455	M	0.93	M	0.5	LM	135	M	15.4	M	
	7/22/2009	07/22/2009N45-43b	0.224	M					0.248	M	7.33	M	0.827	M	0.93	M	0.93	M	140	M	9.6	M	
	10/29/2009	10/29/2009N45-43b	0.322	M					0.103	JM	5.48	M	0	M	0	M	2.193	M	135	M	15.4	M	
	4/16/2009	04/16/2009N45-43b	0.225	M					2.193	M	5.6	M	0	M	0	M	2.193	M	135	M	15.4	M	
	7/22/2009	07/22/2009N45-43b	0.197	M					0.197	LM	5.6	M	0	M	0	M	2.193	M	135	M	15.4	M	
	10/29/2009	10/29/2009N45-43b	0.483	M					0.199	LM	5.6	M	0	M	0	M	2.193	M	135	M	15.4	M	
	4/16/2009	04/16/2009N45-43b	0.483	M					0.086	LM	11.184	M	0.503	M	0.503	M	0.589	M	143	M	8.8	M	
	7/22/2009	07/22/2009N45-43	0.309	M					0.324	M	11.184	M	0.503	M	0.503	M	0.589	M	143	M	8.8	M	
	10/29/2009	10/29/2009N45-43	0.309	M					0.324	M	11.184	M	0.503	M	0.503	M	0.589	M	143	M	8.8	M	
	N45-44	6/17/2008	06/17/2008N45-44	2.64	I					0.19	JM	8.53	M	0.86	M	0.86	M	1.05	M	346	M	18.01	M
8/12/2008		08/12/2008N45-44	0.131	M					0.52	M	18.55	M	0.48	M	0.48	M	1	M	189	M	10.05	M	
10/7/2008		10/07/2008N45-44	1.372	M					0.68	LM	12.08	M	0	M	0	M	1.46	M	377	M	14.4	M	
12/1/2008		12/01/2008N45-44	1.489	M					0.199	LM	2.89	M	0.361	M	0.361	M	0.56	M	133	M	8.9	M	
2/12/2009		02/12/2009N45-44	1.184	M					0.211	M	2.169	M	0.563	M	0.563	M	0.9	M	8	M	1.7	M	
7/22/2009		07/22/2009N45-44	0.178	M					0.178	M	2.169	M	0.563	M	0.563	M	0.9	M	8	M	1.7	M	
10/29/2009		10/29/2009N45-44	1.68	M					0.747	LM	9.88	M	1.231	M	1.231	M	1.43	M	76	M	6.8	M	
6/20/2008		06/20/2008N45-45	0.02	M					0.199	LM	0.32	LM	0.32	LM	1.231	M	1.43	M	19	M	3.18	M	
8/12/2008		08/12/2008N45-45	0.17	M					0.15	M	5.91	M	0.31	M	0.31	M	0.46	LM	184	M	9.8	M	
10/7/2008		10/07/2008N45-45a	0.166	M					0.124	M	14.85	M	0	M	0	M	0.46	LM	224	M	11.9	M	
12/2/2008		12/02/2008N45-45a	0.066	M					0.867	M	17.35	M	0.26	M	0.26	M	0.46	LM	228	M	11.2	M	
2/12/2009		02/12/2009N45-45b	0.397	M					0.199	LM	14.11	M	0.541	M	0.541	M	0.68	LM	147	M	8.8	M	
N45-45	4/16/2009	04/16/2009N45-45b	0.491	M					0.32	M	16.27	M	0.55	M	0.55	M	0.87	M	125	M	8.5	M	
	7/28/2009	07/28/2009N45-45b	0.491	M					0.199	LM	12.91	M	0.051	M	0.051	M	0.25	JM	105	M	7.6	M	
	10/29/2009	10/29/2009N45-45	0.105	M					0.199	LM	10.12	M	0.261	M	0.261	M	0.46	LM	125	M	8.5	M	
	6/17/2008	06/17/2008N45-45	0.966	M					0.539	M	4.306	M	0.421	M	0.421	M	0.96	M	105	M	7.6	M	
	8/11/2008	08/11/2008N45-46	1.602	M					2.646	M	12.91	M	2.497	M	2.497	M	5.143	M	215	M	11	M	
	10/7/2008	10/07/2008N45-46	2.166	M					0.87	M	12.68	M	0	M	0	M	0.87	M	163	M	9.49	M	

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Ortho Phosphate P (mg/L)	Ortho Phosphate P Flag	DOP	DOP Flag	TDP	TDP Flag	Total Dissolved P (mg/L)	Total Dissolved P Flag	Ammonium N (mg/L)	Ammonium N Flag	Nitrate N (mg/L)	Nitrate-N Flag	DON (mg/L)	DON Flag	Kjeldahl N (mg/L)	Kjeldahl N Flag	Alkalinity as CaCO ₃ (mg/L)	Alkalinity Flag	Cl (mg/L)	Cl Flag	Sulfate (mg/L)	Sulfate Flag
N45-47	2/11/2009	02/11/2009N45-47	0.925	M	1.257	LM	1.043	M	2.065	M	0.217	M	3.94	M	0.993	M	1.21	M						
	4/17/2009	04/17/2009N45-47	0.532	M	0.04	M			0.572	M	0.199	LM	6.03	M	0.261	M	0.46	LM						
	7/12/2009	07/12/2009N45-47	0.504	M	0.119	M			0.623	M	0.601	M	26.363	M	0.359	M	0.96	M	18.6	M	78	M	5.8	M
	10/29/2009	10/29/2009N45-47	0.633	M	0.354	LM	0.81	M	0.81	M	0.105	M	10.81	M	0	M	0.105	JM			67	M	6.6	M
	8/19/2008	08/19/2008N45-48	0.426	M							0.199	LM	20.6	M	0.051	M	0.25	M			198	M	10.4	M
N45-48	12/1/2008	12/01/2008N45-48	0.604	M							0.37	M	6.82	M	1.11	M	1.48	LM			124	M	18.6	M
	2/11/2009	02/11/2009N45-48	0.421	M	0.494	M			0.915	M	0.199	LM	4.32	M	0.761	M	0.96	M						
	4/17/2009	04/17/2009N45-48	0.455	M	0.046	M			0.501	M	0.199	LM	5	M	0.261	M	0.46	LM						
	7/12/2009	07/12/2009N45-48	0.487	M	0.203	M			0.69	M	0.954	M	25.217	M	0	M	0.954	M	0.5	LM	162	M	9.2	M
	10/29/2009	10/29/2009N45-48	0.546	M	0.034	LM	0.563	M	0.563	M			27.53	M							84	M	8.3	M
N45-49	8/19/2008	08/19/2008N45-49	0.266	M							1.88	M	18.56	M	10.26	M	12.14	M			243	M	10.8	M
	10/17/2008	10/17/2008N45-49	0.012	LM							0.199	LM	25.53	M	0.481	M	0.68	M			113	M	9	M
	8/19/2008	08/19/2008N45-50	0.032	M							0.199	LM	20.54	M	0.481	M	0.68	M			149	M	8.5	M
	10/8/2008	10/08/2008N45-50	0.012	LM							3.346	M	21.62	M	0.244	M	3.59	M			142	M	8.8	M
	12/1/2008	12/01/2008N45-50	0.061	M							0.199	LM	23.79	M	0.26	M	0.46	LM			164	M	10.1	M
N45-50	2/11/2009	02/11/2009N45-50	0.176	M	0.004	M			0.18	M			4.63	M	0.881	M	1.08	M						
	4/17/2009	04/17/2009N45-50	0.102	M	0.059	M			0.161	M	0.204	M	4.5	M	0.256	M	0.46	LM						
	7/12/2009	07/12/2009N45-50	0.012	LM	0.138	M			0.136	M	0.167	M	12.547	M	0.607	M	0.774	M	141.2	M	87	M	6.7	M
	10/29/2009	10/29/2009N45-50	0.072	M	0.03	LM	0.087	M	0.087	M	1.221	M	35.59	M	0	M	1.221	LM			94	M	7.1	M
	8/19/2008	08/19/2008N45-51	0.452	M							24.74	M	23.08	M	0	M	24.74	M			167	M	10.3	M
N45-51	10/17/2008	10/17/2008N45-51	0.119	M							14.808	M	18.96	M	0	M	14.808	M			183	M	10.3	M
	12/1/2008	12/01/2008N45-51	0.336	M							5.95	M	13.01	M	0	M	5.95	M			159	M	8.7	M
	2/11/2009	02/11/2009N45-51	0.211	M	0.211	M			0.148	M	0.155	JM	4.56	M	0.745	M	0.9	M						
	4/17/2009	04/17/2009N45-51	0.269	M	0.006	M			0.275	M	1.258	M	2.52	M	0	M	1.258	LM			93	M	6.7	M
	7/12/2009	07/12/2009N45-51	0.294	M	0.041	M			0.335	M	0.167	M	25.062	M	0.546	M	0.713	M			88	M	7.3	M
N45-52	10/29/2009	10/29/2009N45-51	0.222	M	0.046	LM	0.245	M	0.245	M	5.372	M	22.33	M	0	M	5.372	JM						
	8/19/2008	08/19/2008N45-52	0.043	M							2.646	M	18.259	M	0.764	M	3.41	M			188	M	9.2	M
	10/17/2008	10/17/2008N45-52	0.012	LM							12.454	M	19.27	M	0	M	12.454	M			165	M	8.1	M
	12/1/2008	12/01/2008N45-52	0.067	M							7.13	M	21.62	M	0	M	7.13	M			225	M	10.1	M
	2/11/2009	02/11/2009N45-52	0.017	M	0.017	M			0.009	M	2.2	M	9.46	M	0.12	M	2.32	M						
N45-53	4/17/2009	04/17/2009N45-52	0.065	M	0.013	M			0.078	M	0.199	LM	2.77	M	0.051	M	0.25	JM			119	M	8.5	M
	7/12/2009	07/12/2009N45-52	0.06	M	0.027	M			0.087	M	0.105	M	12.423	M	0.453	M	0.558	M			89	M	7.4	M
	10/29/2009	10/29/2009N45-52	0.073	M	0.168	LM	0.157	M	0.157	M	4.69	M	22.89	M	0	M	4.69	M						
	8/19/2008	08/19/2008N45-53	0.012	M							0.539	M	3.079	M	0.821	M	1.36	M			222	M	13.7	M
	8/15/2008	08/15/2008N45-55	0.012	LM							1.76	M	2.63	M	0	M	1.76	LM			181	M	9.7	M
N45-55	10/8/2008	10/08/2008N45-55	0.009	JM							0.199	LM	11.88	M	0.261	M	0.46	LM			233	M	11.5	M
	12/2/2008	12/02/2008N45-55	0.021	M							0.43	M	29.18	M	1.99	M	2.42	M			165	M	12.4	M
	2/12/2009	02/12/2009N45-55	0.046	M	0.046	M			0.009	M	0.199	LM	14.29	M	0.451	M	0.65	M						
	4/17/2009	04/17/2009N45-55	0.032	M	0.004	LM			0.032	M	0.328	M	14.23	M	0.132	M	0.46	LM						
	7/18/2009	07/18/2009N45-55	0.05	M	0.034	M			0.084	M	0.086	LM	5.05	M	0.286	M	0.372	M			153	M	9.1	M
N45-56	10/29/2009	10/29/2009N45-55	0.119	M	0.096	LM	0.167	M	0.167	M	6.115	M	13.35	M	0	M	6.115	M			113	M	7.5	M
	8/15/2008	08/15/2008N45-56	0.75	M							1.69	M	11.68	M	0.73	M	2.42	M			248	M	11.6	M
	10/8/2008	10/08/2008N45-56	0.782	M							1.43	M	21.1	M	0.09	M	1.52	M			231	M	11	M
	12/2/2008	12/02/2008N45-56	0.599	M							0.56	M	26.46	M	0	M	0.56	LM			140	M	8.2	M
	2/12/2009	02/12/2009N45-56	0.918	M	0.918	M			0.654	M	0.199	LM	1.28	M	1.131	M	1.33	M						
N45-57	4/17/2009	04/17/2009N45-56	0.945	M	0.175	M			1.12	M	0.266	M	9.52	M	0.194	M	0.46	LM			276	M	13	M
	7/18/2009	07/18/2009N45-56	0.588	M	0.257	M			0.846	M	0.043	JM	10.75	M	0.391	M	0.434	M			104	M	8.2	M
	10/29/2009	10/29/2009N45-56	1.229	M	0.016	M	0.975	M	1.229	M	4.442	M	23.88	M	0	M	4.442	M			225	M	10.9	M
	8/15/2008	08/15/2008N45-57	0.6	M							2.99	M	13.72	M	0.54	M	3.53	M			239	M	10.4	M
	10/8/2008	10/08/2008N45-57	0.729	M							2.85	M	21.85	M	3.78	M	6.63	M			171	M	8.5	M
N45-58	12/2/2008	12/02/2008N45-57	0.624	M							2.42	M	22.8	M	0	M	2.42	JM						
	2/12/2009	02/12/2009N45-57	1.151	M							0.199	LM	5.93	M	1.631	M	1.83	M						
	4/17/2009	04/17/2009N45-57	0.741	M	0.141	M			0.882	M	0.143	JM	4.32	M	0.317	M	0.46	LM			101	M	7.4	M
	7/18/2009	07/18/2009N45-57	2.131	M	0.004	LM			2.131	M	0.105	M	10.812	M	0.886	M	0.991	M			103	M	8.2	M
	10/29/2009	10/29/2009N45-57	0.945	M	0.016	JM	0.93	M	0.945	M	3.823	M	12.42	M	0	M	3.823	M			257	M	13.6	M
N45-59	8/15/2008	08/15/2008N45-58	0.05	M							0.39	M	12.48	M	0.07	M	0.46	LM			205	M	10.6	M
	10/8/2008	10/08/2008N45-58	0.053	M							0.372	M	15.78	M	0.8									

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Ortho Phosphate P (mg/L)	Ortho Phosphate P Flag	DOP	DOP Flag	TDP	TDP Flag	Total Dissolved P (mg/L)	Total Dissolved P Flag	Ammonium N (mg/L)	Ammonium N Flag	Nitrate N (mg/L)	Nitrate N Flag	DON (mg/L)	DON Flag	Kjeldahl N (mg/L)	Kjeldahl N Flag	Alkalinity as CaCO ₃ (mg/L)	Alkalinity Flag	Cl (mg/L)	Cl Flag	Sulfate (mg/L)	Sulfate Flag
N45-60	8/15/2008	08/15/2008N45-60	0.04	LM							0.167	M	0.32	LM	0.263	M	0.43	M			436	M	34.9	M
	10/8/2008	10/08/2008N45-60	0.012	LM							0.805	M	0.35	M	1.095	M	1.86	M			381	M	43.9	M
	12/2/2008	12/02/2008N45-60	0.015	M							1.24	M	0.4	LM	1.12	M	2.36	LM			279	M	35.6	M
	2/12/2009	02/12/2009N45-60	0.014	M	0.004	LM			0.014	M	0.413	M	0.32	LM	1.447	M	1.86	M						
	4/17/2009	04/17/2009N45-60	0.012	LM	0.012	M			0.014	M	0.638	M	0.32	LM	0	M	0.638	LM						
	7/22/2009	07/22/2009N45-60	0.012	LM	0.004	LM			0.005	M	1.221	M	0.465	M	0	M	1.221	M			312	M	33	M
	10/29/2009	10/29/2009N45-60	0.012	LM	0.068	LM			0.04	M	0.991	M	1.92	M	0	M	0.991	LM			443	M	44	M
N45-61	8/15/2008	08/15/2008N45-61	0.11	M							0.199	LM	7.96	M	0.541	M	0.74	M			151	M	11.1	M
	12/1/2008	12/01/2008N45-61	0.116	M							0.31	M	12.11	M	1.89	I	0.46	LM			96	M	6.1	M
	2/11/2009	02/11/2009N45-61	0.061	M	0.004	LM			0.061	M	0.199	LM	3.08	M	6.091	M	6.29	LM						
	4/17/2009	04/17/2009N45-61	0.052	M	0.004	LM			0.052	M	0.266	M	5.25	M	0.194	M	0.46	LM						
	7/22/2009	07/22/2009N45-61	0.021	M	0.004	LM			0.021	M	0.086	LM	4.182	M	0.038	M	0.124	M			142	M	8.8	M
	10/29/2009	10/29/2009N45-61	0.032	M	0.016	JM	0.032	M	0.032	M	1.053	M	30.11	M	0	M	1.053	M			107	M	8.9	M
N45-62	7/22/2009	07/22/2009N45-62	0.737	M	0.183	JM			0.92	M	0.229	M	6.599	M	0	M	0.229	M			146	M	8.5	M
	10/29/2009	10/29/2009N45-62	0.546	M	0.316	LM	0.704	M	0.704	M	2.354	M	12.89	M	0	M	2.354	M			83	M	7.8	M
N45-63	8/19/2008	08/19/2008N45-63	0.62	M							1.406	M	22.29	M	0.764	M	2.17	M			283	M	13.1	M
	10/7/2008	10/07/2008N45-63	0.782	M							0.867	M	23.21	M	0.683	M	1.55	M			230	M	11.1	M
N45-64	8/15/2008	08/15/2008N45-64	0.59	M							3.594	M	19.86	M	0	M	1.2	LM			325	M	15.1	M
	10/8/2008	10/08/2008N45-64	0.13	M							0.5	M	20.54	M	0	M	0.5	LM			244	M	11.7	M
	12/1/2008	12/01/2008N45-64	0.656	M							0.211	M	3	M	2.609	M	2.82	M			138	M	11.9	M
	2/11/2009	02/11/2009N45-64	0.994	M	0.004	LM			0.994	M	0.086	LM	4.19	M	0.261	M	0.46	LM						
	4/17/2009	04/17/2009N45-64	1.008	M	0.004	LM			1.008	M	0.199	LM	11.239	M	6.544	M	6.63	M			141	M	8.8	M
	7/22/2009	07/22/2009N45-64	0.507	M	0.039	M			0.546	M	0.086	LM	42.01	M	0	M	1.487	LM			122	M	6.8	M
N45-65	10/29/2009	10/29/2009N45-64	0.592	M	0.124	LM	0.654	M	0.654	M	1.487	M	19.42	M	0.6	M	0.93	M			256	M	12.8	M
	8/15/2008	08/15/2008N45-65	0.46	M							0.33	M	24.7	M	0	M	1.735	JM			216	M	9.4	M
	10/7/2008	10/07/2008N45-65	0.366	M							1.735	M	18.9	M	0	M	2.24	LM			232	M	11.5	M
	12/1/2008	12/01/2008N45-65	0.649	M							1.61	M	18.87	M			0.84	M						
	2/11/2009	02/11/2009N45-65	1.135	M	0.004	LM			1.135	M	0.351	M	3.44	M	0.489	M	0.84	M						
	4/17/2009	04/17/2009N45-65	0.862	M	0.138	M			1	M	0.199	LM	3.33	M	0.921	M	1.12	M						
	7/22/2009	07/22/2009N45-65	0.645	M	0.068	M	0.771	M	0.713	M	0.086	LM	15.824	M	1.091	M	1.177	M			91	M	6.9	M
	10/29/2009	10/29/2009N45-65	0.789	M	0.016	JM			0.789	M	3.636	M	23.77	M	0	M	3.636	M			89	M	8.9	M
N45-66	8/15/2008	08/15/2008N45-66	0.03	M							0.199	LM	14.28	M	0.791	M	0.99	M			209	M	29.6	M
	10/8/2008	10/08/2008N45-66	0.012	LM							0.199	LM	20.98	M	0.851	M	1.05	LM			176	M	10.5	M
	12/1/2008	12/01/2008N45-66	0.01	JM							0.99	M	13.85	M	0	M	2.1	LM			231	M	10	M
	2/11/2009	02/11/2009N45-66	0.009	JM					0.009	M	0.847	M	4.62	M	1.723	M	2.57	M						
	4/17/2009	04/17/2009N45-66	0.017	M	0.023	M			0.04	M	0.199	LM	3.45	M	0.261	M	0.46	LM						
	7/22/2009	07/22/2009N45-66	0.012	M	0.004	LM			0.012	M	0.706	M	4.052	M	0	M	0.706	M			304	M	13	M
	10/29/2009	10/29/2009N45-66	0.021	M	0.016	JM	0.021	M	0.021	M	1.859	M	22.24	M	0	M	1.859	LM			97	M	7.7	M
N45-67	8/15/2008	08/15/2008N45-67	0.13	M							0.229	M	6.86	M	3.551	M	3.78	M			191	M	12.4	M
	10/7/2008	10/07/2008N45-67	0.067	M							0.991	M	18.9	M	0	M	0.991	M			269	M	14.2	M
	12/1/2008	12/01/2008N45-67	0.105	M							0.31	M	14.53	M	0.25	M	0.56	M			175	M	22.3	M
	2/11/2009	02/11/2009N45-67	0.366	M	0.107	M			0.473	M	0.289	M	0.4	M	3.091	M	3.38	M						
	4/17/2009	04/17/2009N45-67	0.169	M	0.004	LM			0.169	M	5.967	M	5.12	M	0	M	5.967	M						
	7/22/2009	07/22/2009N45-67	0.24	M	0.059	M			0.299	M	0.086	LM	5.043	M	0.286	M	0.372	M			226	M	13	M
	10/29/2009	10/29/2009N45-67	0.101	M	0.016	JM	0.051	M	0.101	M	1.053	M	20.26	M	0	M	1.053	M			112	M	7.9	M
N45-78	2/13/2009	02/13/2009N45-78	0.02	M	0.004	LM			0.02	M	0.103	JM	0.53	M	0.267	M	0.37	JM						
	4/16/2009	04/16/2009N45-78	0.011	LM	0.004	LM			0.011	M	0.199	LM	0.32	LM	0.261	M	0.46	LM			54	M	5.4	M
	8/7/2009	08/07/2009N45-78	0.012	LM	0.039	M			0.043	M	3.247	M	0.397	M	0	M	3.247	M			166	M	9.4	M
N45-79	11/4/2009	11/04/2009N45-78	0.018	M	0.016	JM	0.018	M	0.018	M	1.654	M	0.31	M	0	M	1.654	LM						
	2/13/2009	02/13/2009N45-79	0.034	M	0.004	LM			0.034	M	0.351	M	6.399	M	6.75	M	6.75	M						
	4/16/2009	04/16/2009N45-79	0.012	LM	0.026	M			0.031	M	0.199	LM	0.17	LM	0.481	M	0.68	M			64	M	12	M
	8/7/2009	08/07/2009N45-79	0.012	LM	0.004	LM			0.004	M	0.086	LM	0.015	LM	0.41	M	0.496	M			167	M	9.2	M
	11/4/2009	11/04/2009N45-79	0.017	M	0.016	JM	0.017	M	0.017	M	0.539	M	0.99	M	0	M	0.539	M						
N45-80	2/13/2009	02/13/2009N45-80	0.011	JM	0.004	LM			0.011	M	0.199	LM	0.6	M	0.111	M	0.31	JM						
	4/16/2009	04/16/2009N45-80	0.007	JM	0.008	M			0.017	M	0.199	LM	0.64	M	0.261	M	0.46	LM			90	M	11	M
	8/7/2009	08/07/2009N45-80	0.009	JM	0.016	JM	0.035	M	0.035	M	0.086	LM	3.618	M	0.658	M	0.744	M			188	M	10	M
N45-81	11/4/2009	11/04/2009N45-80	0.035	M	0.016	JM			0.035	M	0.725	M	0.93	M	0	M	0.725	M						
	2/13/2009	02/13/2009N45-81	0.014	M	0.006	M			0.02	M	0.199	LM	0.91	M	3.951	M	4.15	M						
	4/16/2009	04/16/2009N45-81	0.01	JM	0.004	LM			0.01	M	0.199	LM	3.74	M	0.261	M	0.46	LM			133	M	9.8	M
	8/7/2009	08/07/2009N45-81	0.012	LM	0.03	M			0.02	M	1.45	M	13.098	M	0	M	1.45	LM			169	M	9.3	M
	11/4/2009	11/04/2009N45-81	0.017	M	0.016	JM	0.017	M	0.017	M	1.592	M	0.25	M	0	M	1.592	LM						
N45-82	2/13/2009	02/13/2009N45-82	0.01	JM	0.016	M			0.026	M	0.413	M	0.48	M	0.047	M	0.46	LM						
	4/16/2009	04/16/2009N45-82	0.007	JM	0.027	M			0.034	M	0.199	LM	2.87	M	0.051	M	0.25	JM			98	M	7.9	M
	8/7/2009	08/07/2009N45-82	0.012	LM	0.043	M			0.026	M	0.706	M	4.486	M	1.772	M	2.478	M			216	M	11	M
	11/4/2009	11/04/2009N45-82	0.032	M	0.016	JM	0.032	M	0.032	M														

APPENDIX 2. Results of water sample analyses (continued). Flag values indicate concentration units (M–mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Ortho Phosphate P (mg/L)	DOP	DOP Flag	TDP	TDP Flag	Total Dissolved P (mg/L)	Total Dissolved P Flag	Ammonium N (mg/L)	Ammonium N Flag	Nitrate-N (mg/L)	Nitrate-N Flag	DON (mg/L)	DON Flag	Kjeldahl N (mg/L)	Kjeldahl N Flag	Alkalinity as CaCO ₃ (mg/L)	Alkalinity Flag	Cl (mg/L)	Cl Flag	Sulfate (mg/L)	Sulfate Flag
NH45-ae	2/12/2009	02/12/2009NH45-ae	0.007	JM						0.165	JM	0.85	M	0.335	M	0.5	M						
NH45-EFF	3/4/2009	03/04/2009NH45-EFF								0.612	M	1.65	M										
	4/29/2008	04/29/2008NH45-EFF	0.098	M						5.411	M	4.12	M	26.064	M	31.475	M	34	M			170	M
	5/13/2008	05/13/2008NH45-EFF						0.386	M	2.51	M	1.25	M									324	M
	6/17/2008	06/17/2008NH45-EFF						1.37	M	7.9	M	2.13	M									115	M
	7/15/2008	07/15/2008NH45-EFF						1.92	M	16.7	M	2.17	M									187	M
	8/19/2008	08/19/2008NH45-EFF						5.09	M	25.4	M	1.39	M									1780	M
	8/20/2008	08/20/2008NH45-EFF	1.43	M						9.26	M	16.71	M	21.641	M	27.57	M					125	M
	9/16/2008	09/16/2008NH45-EFF						1.35	M	9.26	M	2.34	M									155	M
	10/7/2008	10/07/2008NH45-EFF	1.398	M						8.55	M	2.73	M	0								228	M
	12/2/2008	12/02/2008NH45-EFF	0.41	LM						0.5	M	6.76	LM	2.79	M	6.08	LM					132	M
	12/9/2008	12/09/2008NH45-EFF						0.45	M	2.44	M												
	2/11/2009	02/11/2009NH45-EFF	0.096	M	0.058	M	0.154			0.413	M	2.58	M	0.017	M	0.43	JM	5.4	M				
	4/9/2009	04/09/2009NH45-EFF	0.2	M	0.004	LM		0.2	M	0.199	LM	1.82	M	0.051	M	0.25	JM	50.3	M				
	8/7/2009	08/07/2009NH45-EFF	2.479	M						29.455	M	0.025	M	0		29.455	M						
	11/4/2009	11/04/2009NH45-EFF	0.06	M	0.036	M	0.078	M		0.663	M	1.98	M	0		0.663	LM					108	M
NH45-r	4/17/2008	04/17/2008NH45-r	0.008	JM						0.27	M	0.28	JM	0.16	M	0.43	M	6.9	M			174	M
	4/29/2008	04/29/2008NH45-r	0.009	JM						5.41	M	4.12	M	26.07	M	31.48	M	34.4	M			85	M
	12/18/2008	12/18/2008NH45-r	0.012	LM						0.199	LM	0.62	M	1.23	M	1.43	M					69	M
	2/13/2009	02/13/2009NH45-r	0.006	JM						0.537	M	5.25	M	0.083	M	0.62	M						
	4/17/2009	04/17/2009NH45-r	0.011	JM	0.023	M	0.057	LM	0.034	0.199	LM	0.32	LM	1.531	M	1.73	M	11	M			93	M
	8/7/2009	08/07/2009NH45-r	0.011	JM						3.185	M	0.149	M	0		3.185	M						
	11/4/2009	11/04/2009NH45-r	0.021	M	0.016	JM	0.021	M	0.021	0.787	M	0.5	M	0		0.787	LM					127	M
NH45-s	4/17/2008	04/17/2008NH45-s	0.019	M						0.199	LM	15.27	M	0.611	M	0.81	M	32.6	M			359	M
	4/29/2008	04/29/2008NH45-s	0.012	M						1.03	M	0.84	M	0		1.03	LM	13.4	M			305	M
	12/18/2008	12/18/2008NH45-s	0.012	M						0.199	LM	1.8	M	2.28	M	2.48	LM					78	M
	2/13/2009	02/13/2009NH45-s	0.018	M						1.095	M	8.22	M	1.135	M	2.23	M						
	4/17/2009	04/17/2009NH45-s	0.012	LM	0.02	M	0.04	LM	0.02	0.199	LM	0.64	M	0.261	M	0.46	LM	14.8	M				
	8/7/2009	08/07/2009NH45-s	0.014	M						2.627	M	1.202	M	0		2.627	M					138	M
	11/4/2009	11/04/2009NH45-s	0.034	M	0.016	JM	0.034	M	0.034	0.849	M	2.6	M	0		0.849	LM					112	M
NH45-v	4/17/2008	04/17/2008NH45-v	0.011	JM						0.199	LM	4.31	M	0.671	M	0.87	M	0.1	LM			614	M
	4/29/2008	04/29/2008NH45-v	0.012	LM						0.58	M	27.97	M	0.6	M	1.18	M	20.3	M			269	M
	12/18/2008	12/18/2008NH45-v	0.006	JM						0.199	LM	2.79	M	1.78	M	1.98	LM					222	M
	2/13/2009	02/13/2009NH45-v	0.022	M						0.537	M	0.72	M	0		0.537	JM					160	M
	4/17/2009	04/17/2009NH45-v	0.012	LM	0.062	M	0.115	LM	0.054	0.199	LM	0.52	M	0.111	M	0.31	JM	14.1	M				
	11/4/2009	11/04/2009NH45-v	0.022	M	0.016	JM	0.022	M	0.022	0.787	M	2.29	M	0		0.787	LM					141	M
NH45-w	4/17/2008	04/17/2008NH45-w	0.012	LM						0.08	M	4.99	M	0.73	M	0.81	JM	26.8	M			349	M
	4/29/2008	04/29/2008NH45-w	0.01	JM						0.199	LM	0.32	LM	0.261	M	0.46	LM					20.42	M
	12/18/2008	12/18/2008NH45-w	0.006	JM						0.199	LM	10.76	M	1.53	M	1.73	M	25.1	M			358	M
	2/13/2009	02/13/2009NH45-w	0.038	M						0.537	M			1.013	M	1.55	M					162	M
	4/17/2009	04/17/2009NH45-w	0.025	M	0.004	M	0.031	LM	0.028	0.199	LM	1.08	M	0.421	M	0.62	M	16.6	M				
	11/4/2009	11/04/2009NH45-w	0.039	M	0.016	JM	0.014	M	0.039	0.849	M	0.81	M	0		0.849	LM					139	M
NH45-x	4/17/2008	04/17/2008NH45-x	0.012	LM						0.39	M	15.27	M	0.23	M	0.62	M	12.1	M			185	M
	4/29/2008	04/29/2008NH45-x	0.027	M						0.199	LM	0.59	M	0.361	M	0.56	M	12.6	M			121	M
	12/18/2008	12/18/2008NH45-x	0.012	LM						0.199	LM	0.32	LM	1.35	M	1.55	M					49	M
	2/13/2009	02/13/2009NH45-x	0.022	M						0.165	JM	0.54	M	0.955	M	1.12	M					6	M
	4/17/2009	04/17/2009NH45-x	0.134	M	0.204	M	0.542	LM	0.338	0.199	LM	0.32	LM	1.601	M	1.8	M	3.4	M			85	M
	8/7/2009	08/07/2009NH45-x	0.011	JM						0.086	LM	0.458	M	0.781	M	0.867	M					92	M
	11/4/2009	11/04/2009NH45-x	0.023	M	0.016	JM	0.023	M	0.023	0.663	M	0.12	M	0		0.663	LM					4.1	M

APPENDIX 2. Results of field water sample analyses. Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Specific Conductance (μSiemens)	pH	Temperature (degree C)	Redox Potential (mVolts)	Flag	Dissolved Oxygen (mg/L)	Flag
Ni44-16	5/6/2008	05/06/2008Ni44-16	110	5.9	18.46	222.7		8.22	M
	6/17/2008	06/17/2008Ni44-16	115	6.16	15.72	174.6		5.57	M
	8/13/2008	08/13/2008Ni44-16	119	6.08	15.59	176.9		6.78	M
	10/17/2008	10/17/2008Ni44-16	124	5.01	15.11			3.7	M
	12/18/2008	12/18/2008Ni44-16	119	6.02	15.3	48.3		4.64	M
	2/11/2009	02/11/2009Ni44-16	114	5.76	15.62	249.5		6.46	LM
	7/28/2009	07/28/2009Ni44-16	128	5.79	14.98	104		5.82	M
	11/4/2009	11/04/2009Ni44-16	132	5.7	15.07	140.9		6.87	M
Ni44-b	3/17/2008	03/17/2008Ni44-b	83.5		7.6				
	4/29/2008	04/29/2008Ni44-b	94	6	14	83		6.95	M
Ni44-c	3/17/2008	03/17/2008Ni44-c	54.5		7.8				
Ni45-15	5/6/2008	05/06/2008Ni45-15	106	4.5	16.24	112.8		2.57	M
	6/18/2008	06/18/2008Ni45-15	100	4.96	14.96	-13.7		4.37	M
	8/13/2008	08/13/2008Ni45-15	88	4.38	16.18	-78.9		0.59	M
	10/8/2008	10/08/2008Ni45-15	86	4.32	16.9	-14.5		0.66	M
	12/2/2008	12/02/2008Ni45-15	79	4.26	16.64	-32.5		0.81	M
	2/12/2009	02/12/2009Ni45-15	93	4.33	15	31		1.32	LM
Ni45-16	5/6/2008	05/06/2008Ni45-16	144	5.07	18.24	-27.3		6.24	M
	7/28/2009	07/28/2009Ni45-16	128	5.79	14.98	104		5.82	M
Ni45-17	5/6/2008	05/06/2008Ni45-17	129	5.06	16.43	180.7		8.44	M
	8/13/2008	08/13/2008Ni45-17	133	4.82	15.35	204.3		6	M
	7/28/2009	07/28/2009Ni45-17	143	5.01	14.72	149		6.93	M
	11/4/2009	11/04/2009Ni45-17	92	4.85	16.53	154.6		8.05	M
Ni45-33	4/17/2008	04/17/2008Ni45-33	744	4.67	15.6	150.2		0.36	M
	6/20/2008	06/20/2008Ni45-33	700	4.81	16.1	182.8		5	M
	8/13/2008	08/13/2008Ni45-33	449	5.05	16.31	172.3		4.86	M
	10/7/2008	10/07/2008Ni45-33	450	4.9	15.79			0.38	M
	12/18/2008	12/18/2008Ni45-33	621	4.84	15.76	53.7		0.88	M
	2/11/2009	02/11/2009Ni45-33	625	4.97	16.06	219		1.6	LM
	8/7/2009	08/07/2009Ni45-33	407	5.13	15.99	55.5		0.31	M
	11/4/2009	11/04/2009Ni45-33	580	5.25	15.86	117.3		0.6	M
Ni45-34	4/10/2008	04/10/2008Ni45-34	1020	4.83	16.2	-57		0.1	LM
	4/16/2008	04/16/2008Ni45-34	1018	4.9	16.1	-146.2		0.51	M
	6/18/2008	06/18/2008Ni45-34	700	4.92	16.84	156.5		0.97	M
	8/11/2008	08/11/2008Ni45-34	741	4.77	16.26			0.31	M
	10/7/2008	10/07/2008Ni45-34	743	4.72	16.52	250		0.55	M
	12/2/2008	12/02/2008Ni45-34	886	4.73	16.52	288.2		6.1	M
	2/12/2009	02/12/2009Ni45-34	846	4.79	16.48	282.4		0.75	M
	7/28/2009	07/28/2009Ni45-34	675	5.03	16.35	139		0.87	M
	10/29/2009	10/29/2009Ni45-34	648	4.55	16.32	199		0.4	M
Ni45-35	4/10/2008	04/10/2008Ni45-35	5400	5.29	18	-77			
	4/16/2008	04/16/2008Ni45-35	498	4.7	17.2	63.6		11.62	M
	6/17/2008	06/17/2008Ni45-35	841	4.95	14.36	-52.8		5.76	M
	8/12/2008	08/12/2008Ni45-35	751	4.8	13.86			1.75	M
	10/7/2008	10/07/2008Ni45-35	842	4.78	16.58	351		1.05	M
	12/1/2008	12/01/2008Ni45-35	570	4.49	18.7	282.8		1.48	M
	2/11/2009	02/11/2009Ni45-35	378	4.35	19.48	287.1		4.07	LM
	4/16/2009	04/16/2009Ni45-35	550	4.96		37		4.22	M
	7/22/2009	07/22/2009Ni45-35	576	5.52	13	40.1		3.23	M
	10/29/2009	10/29/2009Ni45-35	438	4.92	16.83	187.6		0.45	M
Ni45-36	4/16/2008	04/16/2008Ni45-36	680	5.15	17.1	9.8		6.95	M
	6/17/2008	06/17/2008Ni45-36	586	5.18	17.36	134.1		1.18	M
	8/11/2008	08/11/2008Ni45-36	700	5.05	16.38			0.51	M
	10/7/2008	10/07/2008Ni45-36	742	4.97	16.05	278.1		0.48	M
	12/2/2008	12/02/2008Ni45-36	812	4.96	15.98	118.4		0.45	M
	2/12/2009	02/12/2009Ni45-36	481	5.21	16.91	263.6		0.71	M
	7/28/2009	07/28/2009Ni45-36	664	5.53	16.2	145		1.16	M
	10/29/2009	10/29/2009Ni45-36	550	4.79	15.21	192.6		0.42	M

APPENDIX 2. Results of field water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Specific Conductance (μSiemens)	pH	Temperature (degree C)	Redox Potential (mVolts)	Flag	Dissolved Oxygen (mg/L)	Flag
Ni45-37	4/16/2008	04/16/2008Ni45-37	988	5.55	15.7	28		2.09	M
	6/18/2008	06/18/2008Ni45-37	933	5.44	15.85	136.4		0.42	M
	8/11/2008	08/11/2008Ni45-37	890	5.4	16.39	197.6		0.3	M
	10/7/2008	10/07/2008Ni45-37	909	5.43	16.93			0.38	M
	12/2/2008	12/02/2008Ni45-37	788	5.46	17.06	173.4		0.73	M
	2/12/2009	02/12/2009Ni45-37	719	5.5	16.24	260.9		0.83	LM
	7/28/2009	07/28/2009Ni45-37	634	5.98	16.2	144		0.5	M
	10/29/2009	10/29/2009Ni45-37	565	5.4	17.07	136.5		0.41	M
Ni45-38	4/17/2008	04/17/2008Ni45-38	1213	4.82	15.8	153.2		0.43	M
	5/6/2008	05/06/2008Ni45-38	1274	4.68	15.2	50		0.93	M
	5/22/2008	05/22/2008Ni45-38	1187	4.64	15.25	201		0.47	M
	6/5/2008	06/05/2008Ni45-38	1120	4.7	15.63	-186		0.22	M
	6/18/2008	06/18/2008Ni45-38	1237	4.68	16.73	174.6		0.45	M
	8/12/2008	08/12/2008Ni45-38	970	4.75	17.8			0.5	LM
	10/8/2008	10/08/2008Ni45-38	475	4.98	17.45	-6.7		0.82	LM
	12/2/2008	12/02/2008Ni45-38	761	4.79	13.82	274		1.06	M
	2/13/2009	02/13/2009Ni45-38	730	4.77	13.78	99.2		1.13	LM
	8/7/2009	08/07/2009Ni45-38	535	5.77	17.36	-3.1		0.46	M
	11/4/2009	11/04/2009Ni45-38	755	5.3	15.65	134.4		1.6	M
Ni45-39	4/17/2008	04/17/2008Ni45-39	371	5.19	14.6	-112.8		0.79	M
	5/6/2008	05/06/2008Ni45-39	391	5.17	14.96	-168.7		0.46	M
	5/22/2008	05/22/2008Ni45-39	367	5.27	15.56	-189		0.4	M
	6/5/2008	06/05/2008Ni45-39	710	5.48	15.73	-260.5		0.19	M
	6/18/2008	06/18/2008Ni45-39	794	5.52	16.84	-208.9		0.46	M
	8/12/2008	08/12/2008Ni45-39	499	5.34	18	-140		1	LM
	10/8/2008	10/08/2008Ni45-39	850	5.33	17.91	-140.9		1.3	LM
	12/2/2008	12/02/2008Ni45-39	610	5.24	13.82	-92.9		2.44	M
	2/13/2009	02/13/2009Ni45-39	367	4.82	11.96	68.6		2.4	M
	8/7/2009	08/07/2009Ni45-39	381	6.02	18.01	-92		1.57	M
	11/4/2009	11/04/2009Ni45-39	474	5.7	16.29	-142.8		1.2	M
Ni45-40	4/17/2008	04/17/2008Ni45-40	1002	5.39	15.7	139.6		0.87	M
	5/6/2008	05/06/2008Ni45-40	1240	5.16	15.03	-110		0.58	M
	5/22/2008	05/22/2008Ni45-40	979	5.15	15.28	-78.2		1.05	M
	6/5/2008	06/05/2008Ni45-40	752	5.41	16.8	-91.7		2.24	M
	6/20/2008	06/20/2008Ni45-40	779	5.16	17.34	237.1		2.12	M
	8/12/2008	08/12/2008Ni45-40	895	5.28	17.5	36		1	LM
	10/8/2008	10/08/2008Ni45-40	893	5.52	17.4			1.27	LM
	12/2/2008	12/02/2008Ni45-40	800	5.57	15.17	164.3		0.83	M
	2/13/2009	02/13/2009Ni45-40	847	5.4	13.51	84.1		1.69	LM
	8/7/2009	08/07/2009Ni45-40	560	5.24	16.81	51		0.43	M
	11/4/2009	11/04/2009Ni45-40	672	5.66	15.4	-13.7		1.63	M
Ni45-41	4/17/2008	04/17/2008Ni45-41	139	6.4	14.2	-148.5		0.37	M
	5/6/2008	05/06/2008Ni45-41	162	6.07	14.97	-245.9		0.34	M
	5/22/2008	05/22/2008Ni45-41	148	6.11	15.39	-255		0.2	M
	6/5/2008	06/05/2008Ni45-41	171	5.88	16.31	-237.3		0.26	M
	6/20/2008	06/20/2008Ni45-41	195	6	18.03	-160.1		0.87	M
	8/12/2008	08/12/2008Ni45-41	202	5.87	19.7	-190		1	LM
	10/8/2008	10/08/2008Ni45-41	240	5.85	18.57	-159.4		1.12	LM
	12/2/2008	12/02/2008Ni45-41	265	5.83	12.92	-139		1.36	M
	2/13/2009	02/13/2009Ni45-41	453	5.93	10.7	-17.7		1.4	M
	8/7/2009	08/07/2009Ni45-41	281	6.35	19.35	-115.8		1.28	M
	11/4/2009	11/04/2009Ni45-41	247	6.25	15.89	-136		1.23	M

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Site Identifier	Date Sampled	Sample Identifier	Specific Conductance		Temperature (degree C)	Redox Potential		Dissolved Oxygen	
			(μSiemens)	pH		(mVolts)	Flag	(mg/L)	Flag
Ni45-42	4/17/2008	04/17/2008Ni45-42	828	5.2	15	-5.2		0.56	M
	5/6/2008	05/06/2008Ni45-42	678	5.17	14.9	-143.7		0.53	M
	5/22/2008	05/22/2008Ni45-42	892	5.17	15	-111		0.6	M
	6/5/2008	06/05/2008Ni45-42	1072	5.23	16.25	17		0.98	M
	6/20/2008	06/20/2008Ni45-42	1055	5.04	16.72	135.6		0.74	M
	8/12/2008	08/12/2008Ni45-42	233	5.41	18.7	-109		1	LM
	10/8/2008	10/08/2008Ni45-42	227	5.32	18			0.96	LM
	12/2/2008	12/02/2008Ni45-42	220	5.32	27.4			0.88	M
	2/13/2009	02/13/2009Ni45-42	442	5.38	11.8	92		0.99	LM
	4/16/2009	04/16/2009Ni45-42	323	5.32	13.14	118.3		0.73	M
	8/7/2009	08/07/2009Ni45-42	372	5.33	18.6	45		0.96	M
	11/4/2009	11/04/2009Ni45-42	406	5.5	15.37	29.1		0.69	M
Ni45-43	6/17/2008	06/17/2008Ni45-43	750	4.65	13.5	190		6.29	M
	8/11/2008	08/11/2008Ni45-43	684	4.72	4.72			1.02	M
	10/17/2008	10/17/2008Ni45-43	834	4.93	20.25	221		2.25	M
	12/1/2008	12/01/2008Ni45-43	755	4.86	20.73	304.7		2.52	M
	2/11/2009	02/11/2009Ni45-43	512	4.69	16.56	238.3		3.83	LM
	4/16/2009	04/16/2009Ni45-43	688	4.55	13.46	218.2		3.78	M
	7/22/2009	07/22/2009Ni45-43	593	4.68	14.38	169		6.9	M
	10/29/2009	10/29/2009Ni45-43	595	5.12	20.5	177		1.9	M
Ni45-44	6/17/2008	06/17/2008Ni45-44	726	4.55	13.5	194		2.42	M
	8/12/2008	08/12/2008Ni45-44	705	4.58	4.58			6.25	M
	10/7/2008	10/07/2008Ni45-44	1147	4.48	20.32	370.7		0.85	M
	12/1/2008	12/01/2008Ni45-44	672	4.15	20.75	309.8		0.63	M
	2/12/2009	02/12/2009Ni45-44	294	4.26	17.65	296.6		2.97	LM
	7/22/2009	07/22/2009Ni45-44	490	5.02	15.14	145		1.46	M
	10/29/2009	10/29/2009Ni45-44	430	4.33	21.15	190		0.8	M
Ni45-45	6/20/2008	06/20/2008Ni45-45	679	4.3	16.7	270		5.48	M
	8/12/2008	08/12/2008Ni45-45	727	4.33	16.52			3.55	M
	10/7/2008	10/07/2008Ni45-45	781	4.28	16.18	312.8		2.41	M
	12/2/2008	12/02/2008Ni45-45	782	4.23	16.15	320.2		0.87	M
	2/12/2009	02/12/2009Ni45-45	600	4.32	16.25	271.7		2.32	LM
	4/16/2009	04/16/2009Ni45-45	610	4.13	28.51	212.8		2.7	M
	7/28/2009	07/28/2009Ni45-45	676	4.54	15.98	162		3.98	M
	10/29/2009	10/29/2009Ni45-45	536	4.27	15.36	218		0.89	M
Ni45-46	6/17/2008	06/17/2008Ni45-46	808	5.36	14.25	173		4.64	M
	8/11/2008	08/11/2008Ni45-46	634	5.05	18.57			1.28	M
	10/7/2008	10/07/2008Ni45-46	897	4.17	20.6	343.5		2.21	M
	12/1/2008	12/01/2008Ni45-46	542	4.62	20.37	270.2		2.58	M
	2/12/2009	02/12/2009Ni45-46	490	4.78	15.58	263.3		4.75	LM
	7/22/2009	07/22/2009Ni45-46	562	5.67	15.82	117		1.94	M
	10/29/2009	10/29/2009Ni45-46	459	3.87	20.41	203		4.17	M
Ni45-47	7/22/2009	07/22/2009Ni45-47	541	4.28	18.9	159		6.8	M
	10/29/2009	10/29/2009Ni45-47	396	4.13	20.48	191		6.69	M
Ni45-48	12/1/2008	12/01/2008Ni45-48	579	4.11	19.05	314.4		5.81	M
	2/11/2009	02/11/2009Ni45-48	623	4.14	15.83	265.5		6.15	LM
Ni45-49	8/19/2008	08/19/2008Ni45-49	765	5.26	17.95			5.6	M
	10/17/2008	10/17/2008Ni45-49	837	5.17	21	216.4		4.11	M
Ni45-50	12/1/2008	12/01/2008Ni45-50	865	4.6	19.07	273.9			
	2/11/2009	02/11/2009Ni45-50	426	4.72	16.3	264.6		5.02	M
	4/17/2009	04/17/2009Ni45-50	553	4.63	13.65	218.2		5.83	M
	7/22/2009	07/22/2009Ni45-50	473	4.92	17.7	145		5.9	M
	10/29/2009	10/29/2009Ni45-50	621	4.48	20.07	185.1		2.48	M
Ni45-51	8/19/2008	08/19/2008Ni45-51	822	4.39	18.18	249		2.8	M
	10/17/2008	10/17/2008Ni45-51	786	5.2	21.33			7.05	M
	12/1/2008	12/01/2008Ni45-51	726	4.42	19.38	300.1		2.75	M

APPENDIX 2. Results of field water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Specific Conductance (μSiemens)	pH	Temperature (degree C)	Redox Potential (mVolts)	Dissolved Oxygen (mg/L)	Flag
Ni45-52	10/17/2008	10/17/2008Ni45-52	873	4.47	20.2		1.91	M
	12/1/2008	12/01/2008Ni45-52	930	4.39	19.06	303.6	3.19	M
	2/11/2009	02/11/2009Ni45-52	853	4.57	16.8	249.6	1.87	LM
	4/17/2009	04/17/2009Ni45-52	728	4.58	14.32	225	3.86	M
	7/22/2009	07/22/2009Ni45-52	522	4.4	18.2	168	4.1	M
	10/29/2009	10/29/2009Ni45-52	499	4.47	19.32	196.2	2.77	M
Ni45-53	8/19/2008	08/19/2008Ni45-53	741	4.77	21.97		0.31	M
Ni45-55	8/27/2008	08/27/2008Ni45-55	2180	4.41	17.19	281.6	2.93	M
	10/8/2008	10/08/2008Ni45-55	1096	4.56	16.51		0.87	M
	12/2/2008	12/02/2008Ni45-55	800	4.35	15.18	326.3	4.62	M
	2/12/2009	02/12/2009Ni45-55	816	4.39	15.45	272.8	1.24	LM
	4/17/2009	04/17/2009Ni45-55	676	4.35	15.62	261.2	2.02	M
	7/28/2009	07/28/2009Ni45-55	573	4.5	17.3	158	4.07	M
	10/29/2009	10/29/2009Ni45-55	507	4.45	15.72	208.8	0.76	M
Ni45-56	8/27/2008	08/27/2008Ni45-56	1206	4.34	17.15	279.9	1.55	M
Ni45-57	8/27/2008	08/27/2008Ni45-57	1133	4.19	17.11	274.4	2.34	M
	10/8/2008	10/08/2008Ni45-57	833	4.35	16.41		1.32	M
	12/2/2008	12/02/2008Ni45-57	875	4.16	15.2	288.1	5.1	M
	2/12/2009	02/12/2009Ni45-57	368	4.34	15.46	248.1	4.55	LM
	4/17/2009	04/17/2009Ni45-57	567	4.13	15.93	229.9	4.67	M
	7/28/2009	07/28/2009Ni45-57	470	4.4	17.55	168	4	M
	10/29/2009	10/29/2009Ni45-57	547	4.24	15.41	207.8	0.78	M
Ni45-58	8/27/2008	08/27/2008Ni45-58	1317	4.11	16.9	272.6	1.59	M
Ni45-59	8/27/2008	08/27/2008Ni45-59	1078	4.49	17.28	272.4	6.12	M
Ni45-60	8/27/2008	08/27/2008Ni45-60	1906	4.5	17.36		1.65	M
	10/8/2008	10/08/2008Ni45-60	1096	4.56	16.54		0.87	M
	12/2/2008	12/02/2008Ni45-60	1057	4.49	14.68	238.5	6.11	M
	2/12/2009	02/12/2009Ni45-60	875	4.46	15.18	228.2	1.54	LM
	4/17/2009	04/17/2009Ni45-60	837	4.31	15.66	202	1.59	M
	7/28/2009	07/28/2009Ni45-60	1035	4.35	18.4	157	1.09	M
	10/29/2009	10/29/2009Ni45-60	1301	4.4	15.6	180	0.87	M
Ni45-61	8/15/2008	08/15/2008Ni45-61	357	5.11	17.53			
	12/1/2008	12/01/2008Ni45-61	473	4.63	16.96	263.4	4.8	M
	2/11/2009	02/11/2009Ni45-61	297	4.43	17.43	298.1	4.78	M
	4/17/2009	04/17/2009Ni45-61	320	4.64	16.53	247.8	4.23	M
	7/22/2009	07/22/2009Ni45-61	533	4.57	16.25	140	5.85	M
	10/29/2009	10/29/2009Ni45-61	561	4.37	16.47	208.9	6.93	M
Ni45-63	8/19/2008	08/19/2008Ni45-63	734	5.02	15.18			
	10/7/2008	10/07/2008Ni45-63	836	4.72	17.41	343	4.3	M
Ni45-64	12/1/2008	12/01/2008Ni45-64	603	4.31	16.15	283.7	2.56	M
	2/11/2009	02/11/2009Ni45-64	406	4.68	17.73	282.2	4.99	LM
	4/17/2009	04/17/2009Ni45-64	422	4.27	17.02	267.9	3.03	M
	7/22/2009	07/22/2009Ni45-64	591	4.93	19.2	117	5.78	M
	10/29/2009	10/29/2009Ni45-64	706	4.25	16.43	206.2	2.78	M
Ni45-65	8/15/2008	08/15/2008Ni45-65	711	5.1	16.1			
	10/7/2008	10/07/2008Ni45-65	833	4.67	16.86	319.7	3.37	M
Ni45-67	10/7/2008	10/07/2008Ni45-67	795	5.22	18.24		2.37	M
	12/1/2008	12/01/2008Ni45-67	734	4.72	15.8	234.4	1.6	M
	2/11/2009	02/11/2009Ni45-67	736	4.45	16.68	283.8	2.55	LM
	4/17/2009	04/17/2009Ni45-67	938	4.38	17.68	305.1	1.73	M
	7/22/2009	07/22/2009Ni45-67	798	4.72	18.87	125	1.11	M
	10/29/2009	10/29/2009Ni45-67	490	4.62	16.06	197.8	1.17	M
Ni45-73	7/9/2009	07/09/2009Ni45-73	539	7.25	21.41	-100	2.4	M
Ni45-78	2/13/2009	02/13/2009Ni45-78	278	5.49	11.9	-16.9	1	M
	4/16/2009	04/16/2009Ni45-78	211	5.55	12.57	-10	0.44	M
	8/7/2009	08/07/2009Ni45-78	241	5.76	19.7	-68	0.44	M

APPENDIX 2. Results of field water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Specific Conductance		Temperature (degree C)	Redox Potential		Dissolved Oxygen	
			(μSiemens)	pH		(mVolts)	Flag	(mg/L)	Flag
Ni45-79	2/13/2009	02/13/2009Ni45-79	339	5.41	12.48	36.4		0.83	M
Ni45-81	2/13/2009	02/13/2009Ni45-81	685	5.43	13.77	59.8		0.4	M
	4/16/2009	04/16/2009Ni45-81	740	5.34	14	221.3		0.48	M
	8/7/2009	08/07/2009Ni45-81	614	5.49	17.11	22.3		0.34	M
Ni45-84	2/13/2009	02/13/2009Ni45-84	759	5.66	15.2	68.7		0.34	M
	4/16/2009	04/16/2009Ni45-84	755	5.78	14.81	156		0.5	M
	8/7/2009	08/07/2009Ni45-84	544	5.62	16.19	26.2		0.27	M
Ni45-aa	4/29/2008	(blank)	200	5.57	14.2	-22		3.22	LM
Ni45-ab	4/9/2009	04/09/2009Ni45-ab	252	4.28	9.86	228		5.26	M
	8/7/2009	08/07/2009Ni45-ab	357		22.77	32		4.53	M
Ni45-ac	4/9/2009	04/09/2009Ni45-ac	464	5.74	8.22	-70		3.67	M
	8/7/2009	08/07/2009Ni45-ac	520		45.44	-11		5.13	M
Ni45-EFF	6/6/2008	06/06/2008Ni45-EFF	675	6.88	19.49	273.1		5.31	M
	4/9/2009	04/09/2009Ni45-EFF	1277	6.96	11.62	317		12.05	M
	5/28/2009	05/28/2009Ni45-EFF	360	6.8	17.2	315		8.76	M
	6/23/2009	06/23/2009Ni45-EFF	480	7	19.2	75		3.3	M
	7/22/2009	07/22/2009Ni45-EFF	651	6.99	22.32	225		1.52	M
Ni45-r	3/14/2008	03/14/2008Ni45-r	168	6.23	10.8				
	5/22/2008	05/22/2008Ni45-r	648	5.97	15.21	-126.3		2.88	M
	6/5/2008	06/05/2008Ni45-r	345	6.01	19.13	-136		0.8	M
	12/18/2008	12/18/2008Ni45-r	324	4.02	6.98	252.6		3.45	M
	2/13/2009	02/13/2009Ni45-r	615	5.96	8.35	74.1		4.04	LM
	4/9/2009	04/09/2009Ni45-r	290	6.54	10.5	157		5.23	M
	4/17/2009	04/17/2009Ni45-r	223	5.94	12.17	148.8		5.48	M
	8/7/2009	08/07/2009Ni45-r	418	6.01	21.21	15.1		0.8	M
	11/4/2009	11/04/2009Ni45-r	405	5.84	12.16	-31.5		0.81	M
Ni45-s	3/14/2008	03/14/2008Ni45-s	251	4.76	18.9				
	4/17/2008	04/17/2008Ni45-s	988	6.07	21.2	3.6		18.05	M
	4/29/2008	04/29/2008Ni45-s	880	6	14.1	37.5		12.5	M
	5/22/2008	05/22/2008Ni45-s	1000	5.51	15	108.9		4.26	M
	6/5/2008	06/05/2008Ni45-s	863	5.34	17.61	-52.6		3.07	M
	12/18/2008	12/18/2008Ni45-s	425	4.96	7.5	195.6		3.19	M
	2/13/2009	02/13/2009Ni45-s	617	5.45	11.13	96.5		3.84	LM
	4/17/2009	04/17/2009Ni45-s	317	5.5	12.76	205		4.8	M
	8/7/2009	08/07/2009Ni45-s	463	6.09	19.73	-82		3.23	M
Ni45-t	11/4/2009	11/04/2009Ni45-s	513	5.45	12.32	100.1		1.07	M
	3/14/2008	03/14/2008Ni45-t	136	5.78	13.9				
Ni45-t	4/17/2008	04/17/2008Ni45-t	744	6.41	13.8	164.1		12.98	M
Ni45-v	3/17/2008	03/17/2008Ni45-v	191		17.4				
	4/17/2008	04/17/2008Ni45-v	1011	6.06	12.4	-54.3		14.53	M
	5/22/2008	05/22/2008Ni45-v	878	5.58	14.34	-212.1		0.45	M
	6/5/2008	06/05/2008Ni45-v	418	5.55	18.25	-211.9		1.69	M
	12/18/2008	12/18/2008Ni45-v	676	5.04	9.11	188.4		1.77	M
	2/13/2009	02/13/2009Ni45-v	546	5.71	8.61	25		4.37	LM
	4/17/2009	04/17/2009Ni45-v	463	5.56	12.76	158.1		1.28	M
	8/7/2009	08/07/2009Ni45-v	495	6.12	19.08	-106		2.95	M
	11/4/2009	11/04/2009Ni45-v	511	5.9	12.62	-18		0.94	M
Ni45-w	3/17/2008	03/17/2008Ni45-w	193		16.4				
	4/17/2008	04/17/2008Ni45-w	919	6.16	17.5	-159.5		7.6	M
	4/29/2008	04/29/2008Ni45-w	990	6.2	14.3	15.3		8.88	M
	5/22/2008	05/22/2008Ni45-w	992	5.86	14.07	-54		3.46	M
	6/5/2008	06/05/2008Ni45-w	790	5.83	17.18	-179		1.18	M
	12/18/2008	12/18/2008Ni45-w	517	4.78	9.45	168.9		2.6	M
	2/13/2009	02/13/2009Ni45-w	685	5.78	9.75	75.4		3.02	LM
	4/17/2009	04/17/2009Ni45-w	412	5.78	14.56	141.2		8.65	M
	8/7/2009	08/07/2009Ni45-w	736	5.99	18.83	33.5		0.25	M
Ni45-w	11/4/2009	11/04/2009Ni45-w	517	6.1	12.4	-55.3		1.08	M

APPENDIX 2. Results of field water sample analyses (continued). Flag values indicate concentration units (M- mg/L) and if the reported value is estimated (J) or less than (L) the number reported. Sample identifiers ending with “a” represent results from samples collected from the top of the screened interval of that well. Sample identifiers ending with “b” represent results from samples collected from the bottom of the screened interval. Additional discussion of estimated values and detection limits is contained in the methods section of the report. Additional discussion of issues related to dissolved oxygen and redox potential in mixed redox environments is contained in the results and discussion section of the report.

Site Identifier	Date Sampled	Sample Identifier	Specific Conductance (μSiemens)	pH	Temperature (degree C)	Redox Potential (mVolts)	Flag	Dissolved Oxygen (mg/L)	Flag
Ni45-x	3/17/2008	03/17/2008Ni45-x	157						
	4/17/2008	04/17/2008Ni45-x	487	5.77	19.6	58.8		2.78	M
	4/29/2008	04/29/2008Ni45-x	300	6.47	14.4	-80		6.67	M
	5/22/2008	05/22/2008Ni45-x	462	5.56	15.21	-70.2		1.64	M
	6/5/2008	06/05/2008Ni45-x	372	5.87	18.46	-195.9		3.74	M
	12/18/2008	12/18/2008Ni45-x	292	4.9	7.55	138.2		3.24	M
	2/13/2009	02/13/2009Ni45-x	452	5.62	6.46	-83.5		3.02	LM
	4/9/2009	04/09/2009Ni45-x	270	6.56	9.63	163		4.78	M
	4/17/2009	04/17/2009Ni45-x	204	5.84	11.63	153.5		6.76	M
	8/7/2009	08/07/2009Ni45-x	397	5.99	21.3	23.6		1.38	M
	11/4/2009	11/04/2009Ni45-x	347	5.88	11.35	-85.9		0.5	M
Ni45-y	3/17/2008	03/17/2008Ni45-y	120						
	4/29/2008	04/29/2008Ni45-y	378	5.76	14.4	-116		3.56	M



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