Report of Investigation 121

Effects of Various Soil Amendments on Subsurface Water Quality at the ISU Farm

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Introduction

Starting in 2003, a series of field studies were conducted in conjunction with researchers from Illinois State University (ISU) at the ISU Farm north of Lexington, IL. Three sites for monitoring subsurface water quality beneath row crops receiving various soil amendments were established at or near the ISU Farm. The first site was a series of small experimental plots located on the northern edge of farm property just west of road 2550E, which were amended with various fertilizers, including compost (at two application rates), swine manure slurry, separated swine manure effluent, and synthetic fertilizer (urea). A zero-rate control plot was also initiated. The swine that produced the manure used in these studies were dosed with chlortetracycline prior to the 2004 applications and for every year afterward. A common practice in the livestock industry is to provide sub-therapeutic doses of antibiotics to prevent disease outbreaks and increase growth rates (Mason et al., 2009). Tetracyclines are one of the most commonly used families of antibiotics for these purposes.

The second site covered a larger area of privately owned fields to the north of the ISU Farm, which were amended with materials from the farm. Amendments included compost, manure slurry, and separated swine manure effluent.

The third site was located on the northern section of ISU Farm property to the east of road 2550E. Narrowly spaced tile drains were installed at this site for the application of separated effluent via subsurface irrigation.

The goal of all studies was to determine if the various soil amendments were affecting subsurface water quality. Monitoring wells were installed in up-gradient and down-gradient locations to monitor changes in shallow groundwater quality. Lysimeters were installed at the first and third sites beneath fields where various soil amendments were applied, as well as at a control location at site one. A summary of soil amendment and monitoring activities for all three sites is shown in Table 1.

In addition to the field studies, a series of flow-through soil column experiments were conducted to help understand nitrogen dynamics, especially changes in nitrate isotopes.

Table 1. Summary of Activities at the Three Experimental Sites at the ISU Experimental Farms near Lexington, IL

Site	Soil Amendments	Monitoring Wells and Lysimeters
Small Experimental Plots	1. Compost 2. Swine manure slurry 3. Separated swine manure effluent 4. Urea (CH_4N_2O) 5. Zero-rate control plot	Monitoring Wells: Up-gradient: U-1, U-2, U-3 Down-gradient: C-1, Comp-1, M-1, E-1, F-1 Lysimeters: Up-gradient: US-1 Down-gradient: CS-2, MS-2, FS-2
Large Fields	1. Compost 2. Manure slurry 3. Separated swine manure effluent	Monitoring Wells: LEX-1: separated swine manure effluent LEX-2 and -4: compost LEX-3: High topographic position LEX-5 and -6: swine manure
Subsurface Irrigation	Separated swine manure effluent delivered via subsurface tile drains	Monitoring wells: LEX-7, -8, -9 Lysimeters: LEX-S7, -S8, -S9

Field Methods

Well and Lysimeter Installation

Small experimental plots

In summer 2003, eight water table wells were installed on the small experimental plots (Figure 1). These included three up-gradient wells, U-1, U-2, and U-3 (just to the east of the synthetic fertilizer and control plots, and next to the road, respectively), and wells just down-gradient (west of the plots) for the control (C-1), compost-30 (Comp-1), manure (M-1), effluent (E-1), and synthetic fertilizer (F-1) plots. Each well was finished to a depth of 10 feet (3.05 m). The locations of the wells were selected based on the surface topography, which suggested shallow groundwater would primarily flow towards the west away from the road. All wells were flush mounted so that they would not interfere with farm equipment.

Soil lysimeters were installed to a depth of 3 feet (0.91 m) after harvest in November 2003 on the control (CS-1), manure (MS-1), and synthetic fertilizer (FS-1) plots. Unfortunately, these lysimeters failed to hold vacuums. Replacement lysimeters (CS-2, MS-2, and FS-2) were installed at these plots in August 2004. A lysimeter was also installed up-gradient of the fertilizer plot (US-1) in June 2005.

A water level transducer with a data logger was installed in up-gradient well U-3 at a depth of approximately 3.58 m below the top of the casing.

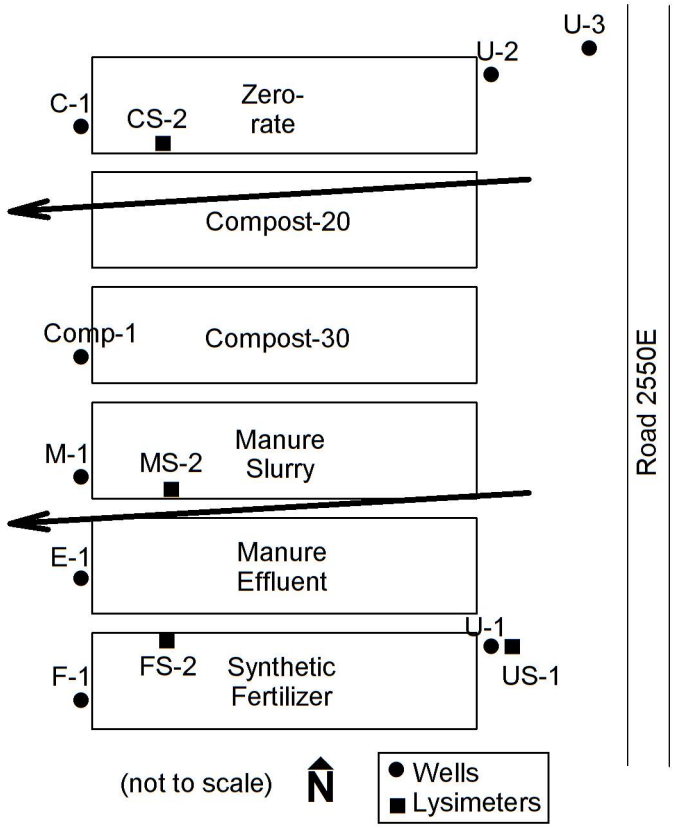

Figure 1. Map of small experimental plots showing location of monitoring wells and lysimeters. Large arrows show approximate direction of shallow groundwater flow suggested by surface topography.

Large fields

Six water table monitoring wells were installed in March 2006 and numbered Lex-1 through Lex-6 (Figure 2). Each well was finished at a depth of 12.5 feet (3.81 m) and screened on the bottom 5 feet (1.52 m). Lex-3 was located at a relatively high topographic position near the barn on the Schuler Farm. Lex-1 was located down-gradient of a field designed to receive separated swine manure effluent through a center-pivot, Lex-2 and Lex-4 down-gradient of a field amended with compost, and Lex-5 and Lex-6 down-gradient of a field receiving typical swine manure management. Well Lex-1 was destroyed shortly after installation, and was replaced in April 2008.

Subsurface irrigation

Three water table monitoring wells, one up-gradient (Lex-7) and two down-gradient of the experimental field (Lex-8 and Lex-9), were installed in April 2008 (Figure 2). Each well was 12.5 feet (3.81 m) deep and screened on the bottom 5 feet (1.52 m). Lysimeters (Lex-S7, Lex-S8, and Lex-S9) were installed adjacent to each well in August–September 2009. The lysimeters were installed vertically to a depth of 3 feet (0.91 m). All wells and lysimeters were flush mounted.

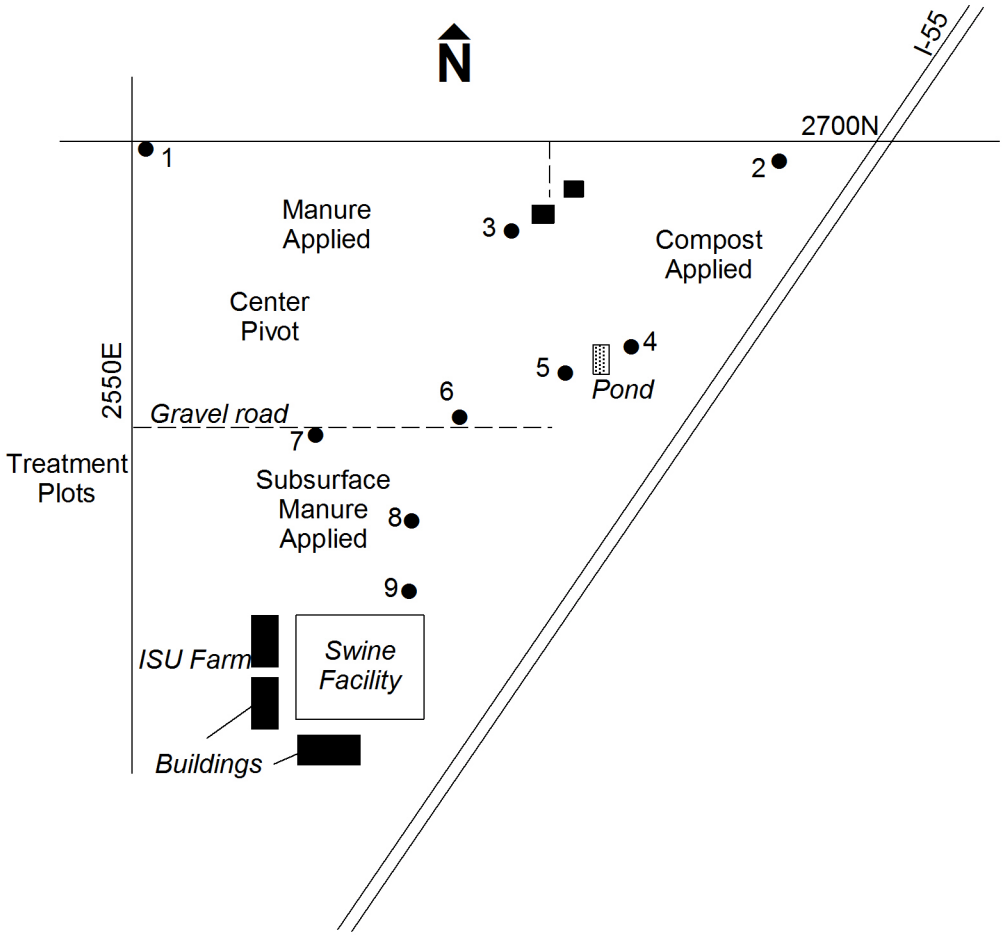

Figure 2. Map showing location of monitoring wells in fields north of the ISU Farm. Lysimeters are located at locations 7, 8, and 9.

Water and Soil Sampling

Small experimental plots

Water samples were collected from the wells and lysimeters approximately quarterly between August 2003 and September 2005, a total of nine times. Samples were also collected in April 2007 and April 2010. During dry periods such as in the summer and early fall, we often were not able to collect enough water in lysimeters for complete chemical analysis.

Soil samples were collected from the manure and effluent plots for tetracycline analysis on three occasions, June 2005, June 2009, and April 2010. Two composite samples were collected from three locations on each plot, from the surface and 1 foot deep.

Large fields

Water samples were collected from the wells approximately quarterly between June 2006 and May 2010, a total of 17 times.

Subsurface irrigation

Samples were collected quarterly from wells Lex-7–Lex-9 between June 2008 and May 2010. Additional samples were collected two additional times following subsurface effluent application, in September 2009 and July 2010. Samples were collected a total of 11 times from these wells. Water samples from the three lysimeters were collected five times between September 2009 and July 2010.

Sampling Procedures

Prior to sampling of wells, water level measurements were taken. Wells were completely purged and allowed to recover prior to sampling. A multisonde (Hydrolab®) with temperature, pH, specific conductance (SpC), dissolved oxygen (DO), and oxidation-reduction potential (ORP) probes was lowered down the well. Once the readings stabilized, the values were recorded. A dedicated piece of polyethylene tubing was put into the well and attached to a peristaltic pump. Water was passed through an in-line filter capsule (0.45 μm) into sample bottles. Samples for metals and ammonia-nitrogen (NH_3-N) were preserved in the field with nitric and sulfuric acid, respectively. Samples for dissolved organic carbon (DOC) were preserved with phosphoric acid when delivered to the analytical laboratory. Samples were stored in ice-filled coolers for transport back to the laboratory, and stored at 4°C until analyzed. Appropriate QA/QC procedures were followed during sampling and analysis.

A 60 psi vacuum was placed on the lysimeters at least 48 hours prior to sampling. Samples were collected and treated in the same manner as described for wells, except that field parameter values were not collected.

Manure samples

Manure slurry and separated effluent samples were supplied by the ISU farm for analysis on three occasions, May 2004, May 2005, and May 2009. Samples were filtered (0.45 μm) and preserved for inorganic analysis the same as water samples. Unfiltered samples were submitted for tetracycline analysis.

Chemical analysis

Mineral (inorganic), DOC, dissolved kjehldahl nitrogen (DKN), and dissolved reactive phosphorous (DRP) analyses were conducted at the Public Service Laboratory (PSL) of the Illinois State Water Survey in Champaign, IL, following standard procedures (Table 2).

Stable isotopes of nitrate were analyzed at two laboratories, the Illinois State Geological Survey (ISGS) isotope laboratory in Champaign between 2003 and 2007, and at Isotech Laboratory in Champaign between 2007 and 2010.

Tetracycline analyses were conducted at the University of Nebraska's Water Science Laboratory in Lincoln, NE. Analytes included chlortetracycline, the antibiotic with which the pigs were dosed, and between 9 and 11 other antibiotics or potential breakdown products.

Table 2. Analytical Methods for Water Samples Analyzed at the ISWS Public Service Laboratory. Standard Methods Found in Standard Methods (1995).

Constituent	Analytical Method	Method Reference
Alkalinity	Titration	Standard Methods 2320B
Metals	Inductively Coupled Plasma-Atomic Emission Spectrometry	USEPA Method 200.7, Revision 4.4
Anions	Ion Chromatography	USEPA Method 300.0, Revision 2.1
DOC	Combustion	Standard Methods 5310B
NH_3-N	Semi-Automated Colorimetry	USEPA Method 350.1, Revision 2.0
DRP	Semi-Automated Colorimetry	USEPA Method 365.1
DKN	Semi-Automated Colorimetry	USEPA 351.2, Revision 2.0

Laboratory Experimental Methods

Intact soil cores were collected on June 9, 2009, from the control plot at the small experimental plots. Previously constructed PVC columns with a length of 6 inches and an inside diameter of 4 inches that had been used in unrelated experiments were obtained from the ISGS (Ivan Krapac). The soil cores were collected by digging out around a cylinder of soil, hammering the column down over the soil sample, shaving off material as necessary, and undercutting the cylinder with a shovel. Four intact soil columns were collected in this manner (Figure 3).

The bottom of the column was sealed with a 7-inch diameter circular Plexiglas piece in which a circular groove with a 4-inch diameter had been drilled, into which an O-ring was fitted. A second circular groove with a 3-inch diameter had been drilled, into which a thin metal ring was inserted (Figure 4). The purpose of this metal ring was to separate flow from the outer edges of the column from the interior. Two ⅛-inch diameter holes had been drilled in the bottom Plexiglas piece for drainage, one at the center and the other in the space between the metal ring and outer edge of the cylinder; these are identified in the results section as either M (middle) or E (edge) ports. Each hole was fitted with PTFE tubing and stainless steel swage-lock fittings. The bottom piece was securely bolted onto the column. The soil in the cylinders weighed between 1675 and 1750 g. The cylinders were leveled prior to experiments.

The experimental design was to allow rain water to drain through the soil columns and be collected at the bottom outlet. Several liters of rain water were collected from a domestic rain barrel and filtered through a 0.45 μm filter capsule.

In initial tests, 300 mL of filtered rainwater (FRW) was added to the top of each column. All the columns leaked and there was some soil loss. The cylinder bottoms were removed, cleaned, and reattached. Additional soil was added to the top of each column and tamped down to re-establish the initial column depth. 200 mL of FRW was added to the top of each column, and no leakage was detected. The experiment was allowed to run for 25 days, at which point no more water was draining from the columns.

After the initial tests, a series of three flow-through experiments were run, lasting 21, 55, and 25 days. In Experiment 1, 100 mL of FRW was allowed to drain through all four columns. In Experiment 2, FRW and swine manure slurry were amended with sodium bromide (NaBr) as a

tracer (Br^- ~200 mg/L). FRW was added to two of the columns (numbers 1 and 4), and slurry to the other two (numbers 2 and 6). Solutions were added to each column several times during the experiment, depending on how fast the solution drained (Table 3). After Experiment 2 ended and prior to Experiment 3, all four columns were flushed with 700 mL of FRW. In Experiment 3, a urea-FRW solution replaced the manure slurry. FRW was added to columns 2 and 6 (previously had received manure slurry) and the urea-FRW solution was added to columns 1 and 4 (Table 4).

Nitrate-N and Br^- concentrations were measured using electrodes, which required a minimum of 8 mL of sample. Three-point calibrations were used (NO_3^- standards 1, 10, and 100 mg/L; Br^- standards 1, 10, and 200 mg/L). Three samples from Experiment 1 were given to the ISWS PSL to determine nitrate-nitrogen (NO_3-N) by ion chromatography to compare with electrode results. A complete analysis of a filtered rainwater sample and filtered manure slurry was done by the PSL. Nitrate isotopes were analyzed at Lawrence Livermore National Laboratory.

Figure 3. Experimental column set-up

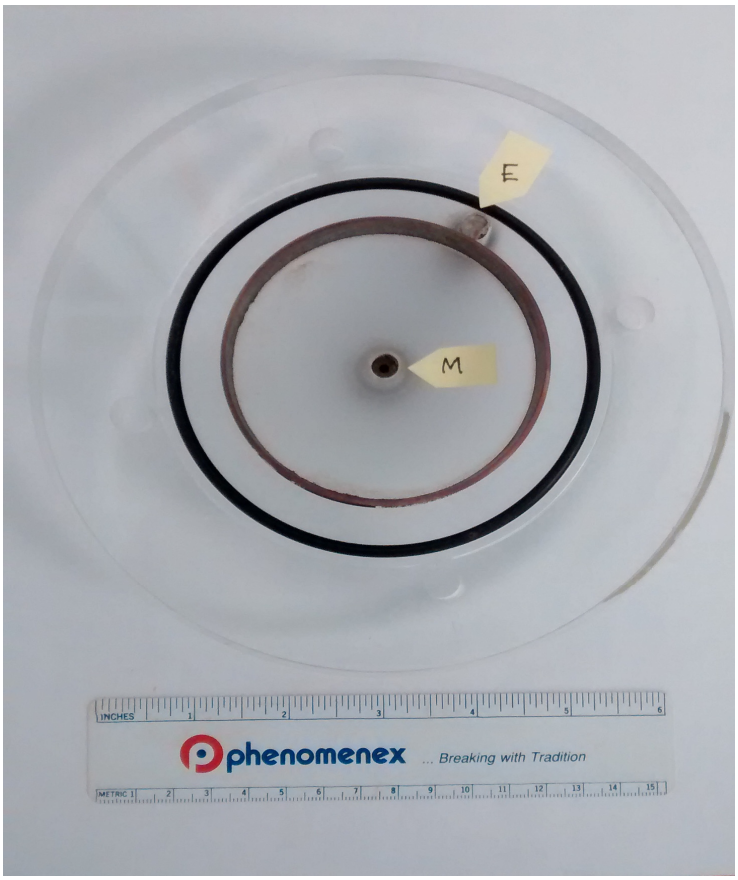

Figure 4. 7-inch diameter circular Plexiglas piece which sealed the bottom of the columns. Black O-ring (4-inch diameter) provided a water-tight seal, and the 3-inch diameter inner metal ring separated flow to the middle port (M) from flow to the exterior port (E).

Table 3. Volumes (mL) of FRW and Manure Slurry Added to Columns in Laboratory Experiment 2

Day	Volume FRW-1	Volume FRW-4	Volume slurry-2	Volume slurry-6
0	200	200	200	200
1	100	100	100	100
2	100	100	100	100
3	100	90	100	100
7*	100		100	
14*	100		100	
21*		100		
36*				100
50*				100
55	end	end	end	end
Total Volume	700	590	700	700

* No NaBr added to FRW or slurry.

Table 4. Volumes (mL) of FRW and FRW Amended with Urea Added to Columns in Laboratory Experiment 3

Day	Volume FRW-urea-1	Volume FRW-urea-4	Volume FRW-2	Volume FRW-6
0	100	100	100	100
5*	100	100	100	100
7*	100	100	100	100
19*	end	end	end	end

* NaBr added to FRW and FRW-urea solution.

Results and Discussion: Field Experiments

Manure and Separated Effluent

Manure and separated effluent had elevated levels of nutrients (potassium (K), dissolved reactive phosphorous (DRP), dissolved kjehldahl nitrogen (DKN), NH_3-N), DOC, and alkalinity (Table 5). Nitrate-N levels were low because the samples were anaerobic. Chloride (Cl^-), sodium (Na), and boron (B) levels were also elevated. Most of the sulfur that was present was in reduced forms of inorganic and organic sulfur rather than sulfate (SO_4^{2-}). Trace metals were generally below detection limits. Constituent concentrations in the separated effluent were much lower than in the manure slurry, including for nutrients, and concentrations in both the manure slurry and separated effluent decreased between 2004 and 2009 as the digestion and separation techniques were improved and optimized.

Tetracycline was found in all of the manure and effluent samples, and chlortetracycline in all but the final separated effluent sample (Table 6). Several breakdown products, including minocycline, isochlortetracycline, and several others were found in both 2009 samples. Thus these compounds were introduced to the soil in the plots amended with manure and effluent, and the potential existed for these compounds to enter the food chain with unknown effects. These and other antibiotic and endocrine-disrupting chemicals have been found in many surface waters, and fish and other aquatic populations have been negatively impacted in some cases (Jobling et al., 1998; Parks et al., 2001; Heberer, 2002; Kolpin et al., 2002; Thorpe et al., 2003; Pomati et al., 2006).

Table 5. Manure and Separated Effluent Slurry Chemistry. Results are for Filtered (0.45 µm) Samples. Concentrations Reported in mg/L except for Isotopes (‰).

Parameter	Manure slurry			Separated effluent		
	5/17/2004	5/24/2005	5/21/2009	5/17/2004	5/24/2005	5/21/2009
Al	0.407	1.005	<0.37	<0.21	0.111	0.042
As	<0.37	<1.19	<1.08	<0.37	<0.119	<0.108
B	4.52	4.48	<0.23	4.61	1.80	1.55
Ba	0.011	<0.11	0.026	0.031	0.018	0.040
Be	<0.02	<0.05	<0.0055	<0.02	<0.005	<0.00055
Ca	177	155	150	166	128	111
Cd	<0.03	<0.14	<0.12	<0.03	<0.014	<0.012
Co	<0.03	<0.16	<0.13	0.055	<0.016	<0.013
Cr	<0.03	<0.15	<0.058	<0.03	0.019	<0.0058
Cu	<0.03	<0.11	<0.0079	<0.03	<0.011	0.004
Fe	1.52	0.633	0.995	0.419	0.022	0.087
K	1834	990	1000	1551	864	665
Li	0.138	<0.70	<0.18	0.072	<0.070	<0.018
Mg	128.5	27.4	94.4	27.0	17.5	56.6
Mn	1.762	0.365	1.436	0.279	0.078	0.345
Mo	<0.06	<0.20	<0.22	<0.06	<0.020	<0.022
Na	360	246	304	323	211	231
Ni	0.205	<0.23	<0.14	0.375	<0.023	0.057
P	275.5	96.2	100.1	114.5	65.2	10.4
Pb	<0.28	0.610	<0.41	<0.28	<0.051	<0.041
S	46.9	23.7	28.6	34.7	18.3	12.9
Sb	0.280	<1.93	<0.59	<0.21	<0.193	<0.059
Se	<0.34	<1.80	<01.31	<0.34	<0.180	<0.131
Si	19.2	18.3	17.5	18.2	16.1	13.9
Sn	<0.15	<0.91	<0.86	<0.15	<0.091	<0.086
Sr	1.008	0.685	0.873	1.004	0.727	0.900
Ti	0.099	0.075	0.030	0.032	0.005	0.003
V	0.081	<0.28	<0.47	<0.02	<0.028	<0.047
Zn	<0.002	<0.08	<0.073	0.076	0.010	0.021
Alkalinity ($CaCO_3$)	9074	4812	4573	7283	4003	3563
F^-	<3.2	<2	<0.8	<3.2	<1.2	<0.08
Cl^-	859	517	606	727	472	415
NO_3-N	2.735	<0.7	<0.7	<0.7	0.146	0.175
o-PO_4-P	273	107	80	121	77	5
SO_4^{2-}	20.1	<3.1	17.9	12.1	17.4	0.426
DOC	10436	2834	1400	4872	2043	1041
DKN	3277	1401	1186	2056	1208	962
NH_3-N	2417	1314	593	1849	1023	1068
δD					-40.3	
$\delta^{15}N$-NH_3					6.2	6.14

Table 6. Concentrations of Antibiotics in Manure and Separated Effluent Samples. Results in ppb. ND = Not Determined.

	Manure slurry			Effluent		
	5/17/2004	5/24/2005	5/21/2009	5/17/2004	5/24/2005	5/21/2009
Tetracycline	32.8	15.3	463	44.8	9	32.2
Chlortetracycline	157	105.2	4018	129.2	23	< 0.20
Oxytetracycline	< 5.0	< 5.0	< 0.20	< 5.0	< 5.0	< 0.20
Minocycline	< 10.0	< 10.0	10.2	< 10.0	< 10.0	16
Sulfamethazine	ND	ND	< 0.20	ND	ND	< 0.20
Sulfadimethoxine	ND	ND	< 0.20	ND	ND	< 0.20
Penicillin	ND	ND	< 0.20	ND	ND	< 0.20
Isochlortetracycline	ND	ND	18772	ND	ND	4361
B_Apo_Oxycycline	ND	ND	54	ND	ND	2.1
Anh_TC	ND	ND	445	ND	ND	67
Anh_CTC	ND	ND	129	ND	ND	152
Virginiamycin	ND	ND	< 0.20	ND	ND	< 0.20

Small Experimental Plots

Transducer data from well U-3 show the variability in the water table (Figure 5). On several occasions following a rain event, the water table rose over 0.15 m (~0.5 ft) in 30 minutes, a maximum of 0.42 m. The total range in water table elevations during the period of sampling was about 2.5 m (~8.2 ft). During periods in December 2004 and January 2005, the water table actually reached land surface in low-lying parts of the study site.

Water level monitoring data suggested that several of the wells were not optimally sited. The potentiometric surface calculated for December 6, 2004, is shown in Figure 6; potentiometric surfaces for other dates were similar. Groundwater flow was more southwesterly than anticipated from the surface topography, and wells Comp-1, M-1, E-1, and F-1 were sited such that they may have intercepted groundwater that recharged plots north of the particular plot they were designed to monitor. For example, the direction of flow suggests that groundwater intersecting F-1 (synthetic fertilizer plot) would have passed beneath the effluent and possibly manure plots as well. This would make the water quality monitoring results somewhat ambiguous with respect to soil amendments. However, because the wells were shallow, it is possible that the screened interval was higher than the zone that would intersect water that originated as recharge to up-gradient plots. This would be especially true when the water table was low. Complete well water elevation data are presented in Table 7.

Complete chemical results for the wells at the small experimental plots are presented in Tables 8-14. Nitrate-N (NO_3-N) concentrations generally decreased in the groundwater samples from the start of the project (Figure 7). This is probably primarily due to the conversion of the plots from previous agricultural practices, i.e., from application of synthetic fertilizer across the entire site to the experimental soil amendments used in this study. It is also possible that well installation promoted oxidation of organic matter, increasing NO_3-N levels artificially at the start of the experiments. Concentrations were always lowest in U-1, statistically significant with respect to C-

1, U-2, and F-1 (Figure 8). Nitrate-N concentrations were very high in wells U-2 and C-1. These wells may be influenced by previous practices at the site, or fertilizer application off the site, as there is likely a slightly southerly component to the primarily east-west groundwater flow direction. During the period of quarterly sampling, NO_3-N concentrations were higher in well F-1 compared to M-1, E-1, and Comp-1, although the differences were not statistically significant.

Chloride concentrations also generally decreased with time (Figure 9). There were no potential sources for Cl^- during well installation, thus it is probable that previous agricultural practices left a legacy of higher concentrations. As with NO_3-N, the lowest Cl^- concentrations were found in U-1 (statistically significant with respect to C-1, U-2, and M-1), and highest concentrations were found in U-2 and C-1 (Figure 8). For the entire period of sampling, Cl^- concentrations were almost always higher in well M-1 compared to U-1, E-1, F-1, and Comp-1, but not statistically significant. Nitrate-N and Cl^- concentrations were positively correlated (Figure 10).

The concentrations and values of other parameters generally did not show any obvious spatial or temporal patterns (Figure 11). After the first sampling event, Na concentrations were low with the highest concentrations usually in U-2. The highest alkalinity concentrations were generally in U-1 and lowest in C-1. Sulfate concentrations were highest in C-1 and U-2.

Water levels appeared to affect water chemistry. For many constituents, there was a negative correlation between concentration and the height of the water table, suggesting dilution effects. For example, specific conductance (SpC) and NO_3-N concentrations are plotted as a function of water table elevation in Figures 12 and 13, respectively.

The four wells sampled for nitrate isotopes (U-1, C-1, M-1, and F-1) had results distinct from one another (Figure 14), although results suggest the sources of nitrate for all the wells were primarily synthetic fertilizer and soil organic matter. Samples from C-1 had the lightest $\delta^{15}N$ values and relatively heavy $\delta^{18}O$ values, suggesting synthetic fertilizer sources. Samples from M-1 were generally heavier in $\delta^{15}N$ than F-1, suggesting a possible manure source at the manure plot. All samples showed some denitrification, especially samples from U-1. Nitrate-N concentrations were inversely correlated with $\delta^{15}N$ values, but, except for U-1, not with $\delta^{18}O$ values (Figure 15). There were no indications of seasonal differences. However, $\delta^{15}N$ values tended to increase with time, especially for U-1, M-1, and F-1; $\delta^{18}O$ values were more variable over time (Figure 16). This trend in $\delta^{15}N$ values might suggest increasing amounts of denitrification with time, or heavier sources of nitrate.

Complete chemical results for the lysimeters at the small experimental plots are presented in Tables 15-17. Because of problems with lysimeter operation early in the study and conditions being occasionally too dry to collect soil water samples, the period of record is shorter than for the study wells. In early samples, NO_3-N concentrations were generally highest in CS-2 and lowest in MS-2, although the differences were not statistically significant (Figure 17). For the two latest sampled dates, concentrations were < 6 mg/L for all samples. Chloride concentrations were also highest in CS-2, but lowest in FS-2 (Figure 18). Both NO_3-N and Cl^- concentrations dropped dramatically in CS-2 during the sampling period. As with well data, NO_3-N and Cl^- concentrations were positively correlated (Figure 19). DOC and DKN concentrations tended to be higher in lysimeter samples than wells.

Nitrate isotopic results for the lysimeters were similar to the wells (Figure 20). Samples from CS-2 had the lightest $\delta^{15}N$ values and relatively heavy $\delta^{18}O$ values, while there was generally no difference between MS-2 and FS-2. As with the well samples, lysimeter samples indicate some denitrification, and there was no indication of seasonal differences.

Tetracycline and breakdown products were detected in the soil on both the raw manure and separated effluent plots at all sampling events. In June 2005 and 2009, soil samples were collected approximately two weeks after raw manure and separated effluent application. Chlortetracycline, the antibiotic fed to the pigs, was found in surface soil samples from both plots and 1 foot (0.3 m) down in the manure plot during both years (Tables 18 and 19). Several breakdown products were also detected in some of the samples. More compounds and higher concentrations were found in the manure plot samples.

Soil samples collected in April 2010, about 10 months after application, still had detectable levels of chlortetracycline and several breakdown products in surface samples at both plots (Tables 18 and 19). On the manure plot, concentrations were lower in April 2010 than June 2009 for all compounds except for anhydrochlortetracycline (Anh_CTC), which had not been detected in June 2009. For the separated effluent plot, concentrations tended to be slightly higher in April 2010 than in June 2009, although concentrations were very low. For samples collected at a depth of 1 foot (0.3 m), the only compounds detected in April 2010 were chlortetracycline (raw manure plot) and isochlortetracycline (both plots), at concentrations just above the detection limits (1.0 nanogram/gram (ng/g).

Several factors limit the interpretation of the water quality data at the small experimental plots. First, wells were not optimally sited down-gradient of the plots, possibly allowing for mixing of recharge waters from different plots. Second, undocumented practices in the fields north of the plots may have influenced water quality in wells U-2 and C-1. Third, previous practices at the site prior to conversion to experimental plots appear to have affected water quality in some of the wells. Fourth, there was considerable variability in the chemistry of the manure slurry and separated effluent, making it difficult to determine a consistent source term for contaminants.

However, there are still some interesting results. The first is the legacy effects of previous fertilization practices, which can last for years in both the soil zone and shallow groundwater. Second, the large water table fluctuations mean that parts of the soil zone are saturated at times. This may result in increased denitrification rates as oxygen is limited. However, there was no obvious trend in $\delta^{15}N$ values as a function of water table elevation (Figure 21).

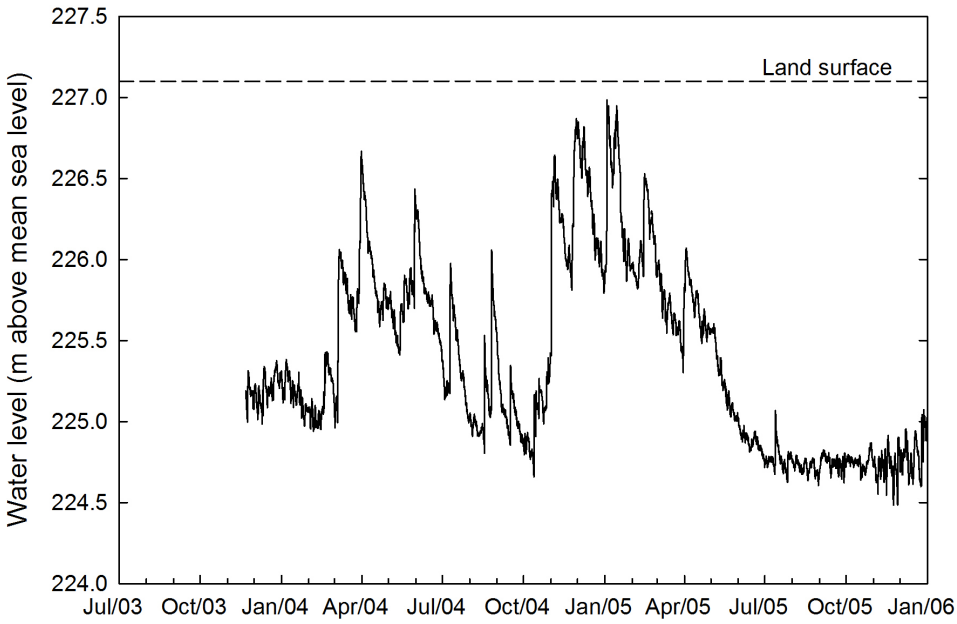

Figure 5. Water levels in well U-3 (m above mean sea level). A measurement was made every 30 minutes using a dedicated transducer. Land surface is at approximately 227.1 m.

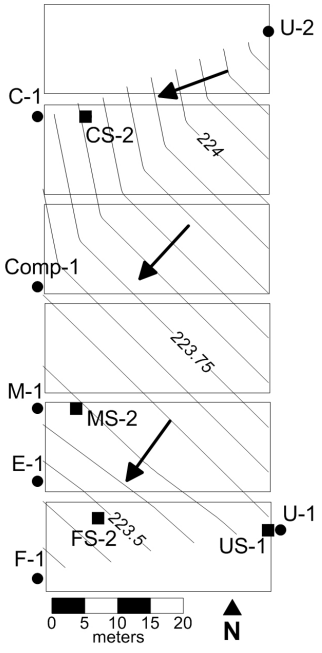

Figure 6. Potentiometric surface on December 6, 2004. Water level elevations in meters. Groundwater flow direction is perpendicular to the water level contours, as indicated by arrows.

Table 7. Water Level Elevations (m Above Mean Sea Level) for Wells at Experimental Plots

Date	U1	U2	U3	C1	Comp 1	M1	E1	F1
8/26/2003	223.19	223.86		223.52	223.29	223.01	223.13	223.23
12/9/2003	223.14	224.10	225.21	223.57	223.44	223.35	223.24	223.13
3/15/2004	224.06	224.69	225.84	224.25	224.02	223.93	223.82	223.76
6/2/2004	224.40	225.15		224.68	224.45	224.33	224.19	224.06
8/12/2004	223.31	223.98		223.46	223.37	223.22	223.10	223.05
8/24/2004	223.38	224.08	225.13	223.43	223.34	223.25	223.14	223.00
8/30/2004	223.72	224.39		223.80	223.77	223.65	223.51	223.42
10/19/2004	223.37	224.01		223.34	223.27	223.17	223.08	223.04
12/6/2004	224.65	225.92*		225.32*	225.04*	224.77*	224.40	224.23
2/22/2005	224.37	225.12	226.26		224.49	224.35	224.30	224.09
6/7/2005	223.15	224.07		223.63	223.51	223.45	223.37	223.25
9/8/2005	222.62	223.29	224.76	223.10		222.60	222.53	222.48
9/20/2005	222.46	225.92						
4/20/2007	224.33	224.95	226.06	224.63	224.36	224.25	224.14	224.07
4/26/2007	224.45	224.93		224.60	224.70	224.55	224.34	224.26
6/9/2009			225.68					
4/22/2010	224.19	224.65		224.27	224.16	224.11	224.04	223.97
7/20/2010			225.16					
7/22/2010	223.64	224.19		223.72	223.65	223.57	223.47	223.36

* Minimum elevation; water table was at or above land surface.

Table 8. Water Chemistry Results for Well C-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	16.8	10.9	7.2	12.9	17.4	11.7	9.2	15.1	24.3	10.5	9.7
SpC (µS/cm)	887	917	856	758	770	742	749	727	651	414	656
pH	6.93	6.80	7.36	7.32	6.91	7.76	7.05	7.06	7.28	7.20	7.23
ORP (mV)	405	452	529	315	353	359	397	404	382	407	371
DO	2.64	3.10	-0.40	7.11	3.62	4.5	3.8	3.6	0.5	4.2	2.8
Al	0.027	1.26	0.021	0.117	<0.059	<0.059	<0.059	0.126	<0.059	0.0272	<0.037
As	<0.037	<0.037	<0.037	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.048	0.031	0.025	0.031	0.038	<0.036	<0.036	<0.036	<0.036	0.029	0.025
Ba	0.106	0.076	0.028	0.045	0.049	0.036	0.029	0.037	0.037	0.02611	0.0239
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	90.3	117	101	111	114	95.6	101.6	104	102	90.1	91.4
Cd	<0.003	0.004	<0.003	<0.003	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.003	<0.003	<0.003	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.094	0.009	0.015	0.004	<0.015	0.022	0.016	0.036	0.038	<0.0058	<0.0058
Cu	0.004	<0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	<0.00079	<0.00079
Fe	0.330	0.675	0.067	0.080	0.039	0.088	0.068	0.179	0.142	0.0098	<0.0059
K	<3.06	3.31	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.712	0.810
Li	0.016	0.035	0.010	0.015	<0.070	<0.070	<0.070	<0.070	<0.070	0.01	<0.058
Mg	44.1	50.7	45.9	50.9	53.3	41.1	44.7	47.8	48.0	41.4	40.5
Mn	0.013	0.011	<0.002	<0.002	<0.019	<0.019	<0.019	<0.019	0.084	<0.0015	<0.0015
Mo	0.018	<0.006	<0.006	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	32.9	16.5	6.62	6.86	7.06	8.02	5.80	6.13	6.42	4.88	4.55
Ni	0.079	<0.007	<0.007	<0.007	<0.023	<0.023	<0.023	0.028	0.026	0.034	0.015
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	0.035	<0.028	<0.051	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	34.0	44.3	23.4	20.8	26.3	18.7	19.7	21.8	30.8	18.6	23.4
Sb	<0.021	0.067	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	<0.034	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	3.38	8.89	4.50	5.01	5.96	4.87	4.54	5.02	5.92	4.48	4.57
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.294	0.196	0.130	0.147	0.153	0.133	0.122	0.131	0.136	0.116	0.108
Ti	<0.002	0.035	<0.002	0.003	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.005	0.006	<0.002	0.004	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.003	0.003	0.003	0.003	<0.008	<0.008	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	237	257	234	236	243	239	250	254	260.19	254.3	259
F^-	0.261	0.21	0.17	0.17	0.20	0.18	0.177	0.19	0.22	0.192	0.17
Cl^-	24.8	25.9	29.1	27.3	26.1	20.7	19.3	20.4	19.7	14.4	10.3
NO_3-N	21.7	24.4	27.3	31.8	28.2	24.2	25.5	27.4	19.8	16.0	10.8
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.010
SO_4^{2-}	98.5	127	69.5	53.8	70.0	55.8	55.0	63.1	88.80	53.94	74.8
DOC	2.13	3.07	0.71	0.93	1.77	0.99	1.28	1.25	1.12	1.13	1.07
TKN	1.791	<0.20	0.23	<0.24	<0.24	<0.29	0.290	0.33	<0.29	<0.26	<0.26
NH_3-N	0.082	<0.03	<0.03	<0.04	<0.04	0.08	<0.06	0.25	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	5.3	5	6.9	5	4.6	4.7	6	5.4	5.4	5.70	6.3
$\delta^{18}O$-NO_3	8.60	9.95	6.8	9.7	7.6	8.9	7.9	6.7	7.8	7.64	7.2
δD	ND	ND	ND	ND	ND	ND	ND	-46.8	-53.9	ND	ND

Table 9. Water Chemistry Results for Well Comp-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	15.6	11.7	7.0	12.6	17.9	11.5	8.0	16.1		11.1	10.3
SpC (µS/cm)	730	700	691	593	629	614	628	618	555	349	560
pH	6.77	6.79	7.26	7.15	6.96	7.69	6.82	6.87	7.11	6.99	7.06
ORP (mV)	407	461	544	319	339	338	417	391	395	411	366
DO	5.05	6.40		5.49	3.96	4.07	2.5	2.1	1.1	2.9	2.7
Al	0.044	1.20	0.051	0.082	<0.059	<0.059	<0.059	0.130	<0.059	0.0293	<0.037
As	<0.037	<0.037	0.085	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.031	0.027	<0.014	0.022	<0.036	<0.036	<0.036	<0.036	<0.036	<0.023	<0.023
Ba	0.062	0.060	0.050	0.052	0.067	0.055	0.054	0.055	0.064	0.05443	0.0497
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	91.2	94.1	88.0	81.0	102	85.8	90.3	98.6	97.3	85.5	84.2
Cd	<0.003	<0.003	<0.003	<0.003	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.003	<0.003	0.003	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.034	0.021	0.007	0.010	0.019	<0.015	<0.015	0.028	0.020	<0.0058	<0.0058
Cu	<0.003	0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	<0.00079	<0.00079
Fe	0.132	0.946	0.041	0.081	0.053	0.044	0.039	0.097	0.076	0.015	0.0317
K	1.33	3.18	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.22	0.253
Li	0.007	0.028	0.019	<0.007	<0.070	<0.070	<0.070	<0.070	<0.070	0.0069	<0.058
Mg	44.2	40.8	38.9	34.9	44.7	35.9	37.76	43.0	42.6	38.15	33.3
Mn	0.002	0.012	<0.002	0.008	<0.019	<0.019	<0.019	<0.019	<0.019	<0.0015	<0.0015
Mo	<0.006	<0.006	<0.006	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	4.99	6.31	9.23	7.65	8.33	7.81	9.56	5.11	4.82	4.01	3.56
Ni	0.027	0.012	0.009	<0.007	<0.023	<0.023	<0.023	<0.023	<0.023	0.025	<0.014
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	<0.028	<0.028	<0.051	<0.051	<0.051	0.052	<0.051	<0.041	<0.041
S	9.73	10.0	10.3	7.99	9.74	7.45	8.03	7.67	8.39	7.35	6.01
Sb	<0.021	0.047	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	<0.034	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	3.31	8.31	4.30	4.64	6.37	5.30	4.74	5.52	6.18	4.74	4.94
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.133	0.124	0.115	0.107	0.139	0.110	0.115	0.130	0.128	0.12133	0.106
Ti	<0.002	0.062	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.003	0.016	<0.002	0.007	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.003	<0.002	0.002	<0.002	<0.008	0.063	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	298	282	272	273	323	310	316	349	347	289	304
F^-	0.220	0.21	0.17	0.21	0.20	0.18	0.170	0.16	0.20	0.189	0.17
Cl^-	15.1	15.9	15.6	17.3	11.1	11.3	11.46	11.7	11.2	9.09	5.04
NO_3-N	11.5	15.8	11.8	11.2	7.32	4.42	4.52	5.71	5.25	6.08	5.33
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.011
SO_4^{2-}	27.4	29.0	28.8	24.4	25.7	22.6	23.0	22.9	26.2	21.7	16.7
DOC	2.54	4.46	0.93	1.95	2.80	1.27	2.08	2.45	1.67	1.85	1.25
TKN	8.69	0.30	0.34	<0.24	<0.24	<0.29	0.409	0.42	<0.29	0.265	<0.26
NH_3-N	0.080	0.07	<0.03	<0.04	<0.04	<0.06	<0.06	0.08	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	6.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	7.98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 10. Water Chemistry Results for Well E-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	15.76	12.74	6.7	13.3	17.45	11.26	8.08	ND	23.4	10.84	10.2
SpC (µS/cm)	752	701	687	620	666	609	596	ND	577	353	534
pH	6.78	6.83	7.22	7.06	6.84	7.20	6.76	ND	7.1	6.91	7
ORP (mV)	413	451	533	322	347	365	434	ND	402	411	361
DO	5.51	5.90		2.87	6.04	4.88	2.6	ND	2.8	2.3	0.4
Al	12.4	0.083	0.046	<0.021	<0.059	<0.059	<0.059	0.114	<0.059	0.0274	<0.037
As	<0.037	<0.037	<0.037	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.050	0.026	0.018	0.027	0.045	<0.036	<0.036	<0.036	<0.036	0.032	0.029
Ba	0.136	0.066	0.067	0.080	0.089	0.060	0.064	0.075	0.079	0.06949	0.0667
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	112	90.9	87.5	88.6	101	85.6	86.8	92.9	94.8	83.4	79.2
Cd	<0.003	<0.003	0.003	<0.003	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	0.009	<0.003	0.004	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.023	0.010	<0.003	<0.004	0.026	<0.015	<0.015	<0.015	<0.015	0.0164	<0.0058
Cu	0.010	0.004	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	0.00092	<0.00079
Fe	13.8	0.098	<0.009	0.023	0.061	<0.015	<0.015	<0.015	0.031	0.0736	0.0256
K	6.89	3.31	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.2	0.333
Li	0.020	0.029	0.017	0.013	<0.070	<0.070	<0.070	<0.070	<0.070	<0.0048	<0.058
Mg	64.0	39.4	38.4	38.6	43.9	36.6	35.76	40.4	40.9	34.8	33.8
Mn	0.216	0.005	<0.002	0.013	<0.019	<0.019	<0.019	<0.019	<0.019	<0.0015	0.0065
Mo	<0.006	<0.006	<0.006	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	5.32	4.89	6.41	5.86	5.71	5.56	5.06	5.19	5.56	4.38	4.77
Ni	0.030	0.011	<0.007	<0.007	<0.023	<0.023	<0.023	<0.023	<0.023	0.029	<0.014
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	0.037	<0.028	<0.051	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	8.22	8.29	9.00	8.08	9.31	7.62	8.29	8.05	8.74	7.98	6.03
Sb	<0.021	0.047	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	0.036	<0.034	<0.034	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	16.6	5.35	4.19	4.96	6.07	5.00	4.46	5.25	6.05	4.58	4.88
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.139	0.113	0.110	0.114	0.128	0.107	0.101	0.117	0.117	0.11001	0.0950
Ti	0.482	0.003	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	0.00076
V	0.026	<0.002	<0.002	0.004	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.048	<0.002	<0.002	<0.002	<0.008	<0.008	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	285	274	238	241	289	288	289	318	315	271	276
F^-	0.193	0.19	0.15	0.18	0.19	0.15	0.160	0.16	0.20	0.172	0.16
Cl^-	14.4	14.2	18.4	17.1	13.0	12.9	12.23	9.83	11.2	12.6	6.08
NO_3-N	17.5	17.9	18.8	21.7	18.7	7.73	6.08	10.9	11.3	8.29	6.68
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.014
SO_4^{2-}	23.7	24.6	25.8	22.9	25.8	22.8	24.2	24.6	26.7	23.9	17.2
DOC	2.20	2.76	0.64	1.00	2.71	0.64	1.97	1.84	1.62	1.25	1.18
TKN	2.45	<0.20	0.22	<0.24	<0.24	0.45	<0.29	<0.29	0.85	0.421	<0.26
NH_3-N	0.052	<0.03	<0.03	0.067	0.06	<0.06	<0.06	<0.06	0.98	0.095	<0.06
$\delta^{15}N$-NO_3	6.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	9.42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 11. Water Chemistry Results for Well F-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	15.3		7.0	13.1	16.7	11.7	7.5	ND	19.8	10.3	9.5
SpC (µS/cm)	781	718	720	635	693	656	609	ND	634	321	529
pH	6.85	7.01	7.23	7.03	6.73	7.13	6.80	ND	7.13	6.88	7.05
ORP (mV)	404		539	329	354	367	437	ND	406	405	368
DO	4.41			6.15	5.5	4.77	4.8	ND	2.7	2.5	1.5
Al	0.731	<0.021	0.042	0.055	<0.059	<0.059	<0.059	0.118	<0.059	0.0237	<0.037
As	<0.037	<0.037	0.046	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.043	0.024	0.022	0.032	0.040	<0.036	<0.036	0.039	<0.036	0.031	0.025
Ba	0.070	0.059	0.060	0.081	0.090	0.061	0.058	0.054	0.069	0.05732	0.0548
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	92.0	90.8	89.0	90.7	100	88.8	83.8	92.7	94.4	72.4	76.9
Cd	<0.003	<0.003	<0.003	0.004	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.003	<0.003	0.006	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.025	0.029	<0.003	0.006	0.058	<0.015	<0.015	<0.015	0.047	0.0102	<0.0058
Cu	<0.003	<0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	<0.00079	<0.00079
Fe	0.658	0.102	<0.009	0.021	0.218	<0.015	<0.015	0.029	0.178	0.0544	<0.0059
K	<3.06	4.51	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.166	0.233
Li	0.009	0.031	0.019	0.016	<0.070	<0.070	<0.070	<0.070	<0.070	0.0053	<0.058
Mg	46.6	40.4	40.7	40.3	45.2	39.3	36.08	41.5	42.6	31.9	33.5
Mn	0.010	<0.002	<0.002	0.012	<0.019	<0.019	<0.019	<0.019	<0.019	<0.0015	0.0102
Mo	<0.006	<0.006	<0.006	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	7.38	5.52	5.41	6.22	6.78	7.64	5.78	5.75	6.34	4.65	4.79
Ni	0.023	0.020	<0.007	<0.007	0.041	<0.023	<0.023	<0.023	0.033	0.03	<0.014
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	<0.028	<0.028	<0.051	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	10.2	9.79	9.57	9.24	11.1	7.70	7.22	8.85	10.4	6.6	5.55
Sb	0.052	0.033	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	0.048	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	4.04	5.47	4.57	5.41	6.31	5.56	4.91	5.71	6.64	4.86	5.25
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.130	0.107	0.105	0.110	0.123	0.105	0.093	0.109	0.115	0.0896	0.0846
Ti	0.023	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.007	<0.002	0.008	0.020	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.005	0.003	<0.002	<0.002	<0.008	<0.008	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	285	277	243	230	263	285	296	289	303	260	278
F^-	0.217	0.19	0.15	0.18	0.18	0.14	0.142	0.21	0.20	0.158	0.16
Cl^-	15.3	14.3	15.5	15.3	13.9	11.9	9.97	10.5	11.4	8.30	4.09
NO_3-N	20.9	21.5	22.1	25.9	26.2	14.7	6.44	16.9	15.0	4.96	5.76
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.015
SO_4^{2-}	29.8	30.1	27.3	25.2	30.8	23.2	21.0	26.8	31.7	19.7	16.5
DOC	1.22	1.40	0.72	0.96	3.93	0.90	1.37	1.79	1.41	1.94	1.06
TKN	2.45	<0.20	<0.20	0.64	<0.24	0.31	<0.29	<0.29	<0.29	0.417	<0.26
NH_3-N	0.066	<0.03	<0.03	<0.04	<0.04	<0.06	<0.06	0.07	0.29	0.308	<0.06
$\delta^{15}N$-NO_3	6.8	6.6	6.4	6.5	7.2	9.1	9.5	8.3	9.3	8.60	9.9
$\delta^{18}O$-NO_3	9.14	6.90	6.5	6.0	6.7	8.2	7.4	7	6.9	7.41	4.2
δD	ND	ND	ND	ND	ND	ND	ND	-48.8	-53.2	ND	ND

Table 12. Water Chemistry Results for Well M-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	15.3	12.6	6.8	13.4	17.5	11.5	7.44	ND	21.3	10.5	10.1
SpC (µS/cm)	780	725	685	639	666	679	682	ND	640	391	603
pH	6.80	6.87	7.30	7.13	7.01	7.55	6.81	ND	7.12	6.96	6.98
ORP (mV)	414	452	535	319	328	343	423	ND	393	414	359
DO	6.15	5.20		4.91	6.57	4.67	2.6	ND	3.5	2.6	1
Al	0.075	0.025	0.023	0.029	<0.059	<0.059	<0.059	<0.059	<0.059	0.0251	<0.037
As	<0.037	<0.037	<0.037	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.032	0.026	<0.014	0.020	0.041	<0.036	<0.036	<0.036	<0.036	0.032	<0.023
Ba	0.070	0.062	0.057	0.059	0.081	0.060	0.062	0.073	0.063	0.0626	0.0619
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	92.7	92.0	87.4	88.8	103	97.7	98.8	104	99.4	90.1	89.3
Cd	<0.003	<0.003	<0.003	0.005	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.003	<0.003	0.006	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.014	0.024	0.005	0.007	0.030	<0.015	<0.015	<0.015	0.017	<0.0058	<0.0058
Cu	<0.003	<0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	<0.00079	0.00131
Fe	0.082	0.092	0.011	0.040	0.097	0.023	0.015	0.042	0.063	<0.0059	<0.0059
K	<3.06	3.94	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.141	0.222
Li	0.006	0.030	0.017	<0.007	<0.070	<0.070	<0.070	<0.070	<0.070	<0.0048	<0.058
Mg	44.6	39.3	38.1	38.0	44.9	41.8	40.66	45.9	43.3	39.3	36.3
Mn	0.005	<0.002	<0.002	<0.002	<0.019	<0.019	<0.019	<0.019	<0.019	<0.0015	0.0030
Mo	<0.006	<0.006	<0.006	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	5.67	5.32	7.35	6.08	6.65	6.43	5.39	5.68	5.84	4.71	4.69
Ni	0.021	0.014	<0.007	0.020	<0.023	<0.023	<0.023	<0.023	<0.023	0.03	<0.014
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	<0.028	<0.028	<0.051	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	10.3	10.4	11.9	9.65	11.1	10.1	10.08	9.80	9.95	9.12	7.49
Sb	<0.021	<0.021	0.028	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	<0.034	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	2.86	4.81	3.69	4.39	5.76	4.92	4.37	5.12	5.84	4.39	4.70
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.132	0.120	0.115	0.117	0.140	0.128	0.121	0.139	0.130	0.12382	0.111
Ti	<0.002	0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.005	<0.002	<0.002	0.009	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.006	0.003	<0.002	<0.002	<0.008	<0.008	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	283	271	235	265	315	311	322	356	350	295	310
F^-	0.259	0.21	0.18	0.18	0.21	0.19	0.182	0.18	0.22	0.186	0.17
Cl^-	16.1	15.9	17.9	17.0	14.1	14.9	13.8	12.4	13.0	14.2	8.64
NO_3-N	18.9	18.5	17.5	18.4	10.2	8.91	6.91	7.22	7.98	9.43	6.61
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.014
SO_4^{2-}	29.9	30.9	34.0	28.9	29.9	29.7	29.3	28.9	31.5	27.5	21.7
DOC	1.64	3.23	0.74	1.01	3.45	1.17	1.39	1.78	1.59	1.94	1.07
TKN	2.70	<0.20	0.21	<0.24	<0.24	0.52	0.335	<0.29	<0.29	<0.26	<0.26
NH_3-N	0.067	<0.03	<0.03	<0.04	<0.04	<0.06	<0.06	0.10	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	6.9	6.6	5.1	7.9	8.4	10.1	9	11.7	10.2	8.40	11.7
$\delta^{18}O$-NO_3	14.3	8.63	8.1	5.6	6.7	7.9	6.8	7.8	6.4	6.70	6.0
δD	ND	ND	ND	ND	ND	ND	ND	-47.8	-53.6	ND	ND

Table 13. Water Chemistry Results for Well U-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	17.1		6.8	12.7	17.1	11.6	7.99	ND	20.2	11.3	9.8
SpC(µS/cm)	799	693	785	674	681	667	657	ND	702	348	577
pH	6.65	6.52	7.20	6.90	6.58	6.96	6.65	ND	7.21	6.8	6.97
ORP (mV)	387			336	352	370	447	ND	432	418	369
DO	2.40		4.80	1.29	3.92	1.5	1.7	ND	6	1.4	1.9
Al	0.031	<0.021	0.050	0.057	<0.059	<0.059	<0.059	0.145	0.085	0.026	<0.037
As	<0.037	<0.037	<0.037	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.040	0.030	0.015	0.037	0.052	<0.036	<0.036	0.037	<0.036	0.03	0.034
Ba	0.070	0.068	0.067	0.084	0.096	0.074	0.067	0.076	0.069	0.06302	0.0570
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	98.5	101	99.9	108	113	99.4	100.5	108	102	86.1	89.7
Cd	0.005	<0.003	<0.003	<0.003	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.003	<0.003	0.003	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.161	0.006	0.072	0.038	0.015	<0.015	<0.015	<0.015	<0.015	<0.0058	<0.0058
Cu	0.007	<0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	<0.00079	<0.00079
Fe	0.575	<0.009	0.274	0.140	<0.015	<0.015	<0.015	0.024	0.050	0.0207	<0.0059
K	<3.06	<3.06	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.19	0.260
Li	0.007	0.028	0.009	<0.007	<0.070	<0.070	<0.070	<0.070	<0.070	<0.0048	<0.058
Mg	46.9	42.3	41.2	45.0	47.1	40.4	40.41	43.7	44.8	35.2	36.9
Mn	0.049	<0.002	<0.002	<0.002	<0.019	<0.019	<0.019	<0.019	0.028	<0.0015	<0.0015
Mo	0.024	<0.006	0.007	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	6.51	5.97	10.8	6.75	7.26	6.12	5.64	5.82	6.64	5.07	4.64
Ni	0.125	0.008	0.055	0.036	<0.023	<0.023	<0.023	<0.023	<0.023	0.026	<0.014
P	<0.047	<0.047	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	<0.028	<0.028	<0.051	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	11.6	11.1	11.9	8.91	10.8	7.45	8.45	10.3	13.4	7.85	5.99
Sb	<0.021	0.061	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	0.088	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	3.36	6.06	4.93	6.14	7.17	5.80	5.22	6.08	7.30	4.93	5.23
Sn	<0.015	<0.015	<0.015	0.027	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.135	0.124	0.119	0.134	0.145	0.122	0.118	0.131	0.130	0.112	0.103
Ti	<0.002	<0.002	<0.002	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.007	0.005	0.003	0.018	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.007	<0.002	<0.002	0.002	<0.008	<0.008	<0.008	<0.008	<0.008	<0.0073	<0.0073
Alkalinity	339	331	355	380	371	356	346	362	ND	312	332
F^-	0.258	0.18	0.13	0.12	0.16	0.13	0.136	0.14	0.19	0.153	0.14
Cl^-	8.9	9.22	9.89	10.6	8.22	10.0	8.81	7.56	8.75	4.98	2.25
NO_3-N	11.4	11.5	5.21	3.34	4.38	2.13	3.59	5.99	4.38	2.32	2.03
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.009
SO_4^{2-}	32.8	33.0	33.1	25.9	28.6	22.5	24.1	30.3	40.0	23.5	17.7
DOC	2.44	2.81	1.63	2.06	3.62	1.49	1.29	2.21	ND	2.13	1.26
TKN	5.54	<0.20	0.33	<0.24	0.42	0.39	<0.29	<0.29	ND	<0.26	<0.26
NH_3-N	0.074	<0.03	<0.03	<0.04	0.27	<0.06	<0.06	<0.06	ND	<0.06	<0.06
$\delta^{15}N$-NO_3	11.4	9.8	9.5	9.7	12.9	24.4	14.7	16.7	21.9	22.0	21.9
$\delta^{18}O$-NO_3	8.46	8.13	8.6	9.1	10.0	11.4	10.2	13.4	11.8	13.2	13.5
δD	ND	ND	ND	ND	ND	ND	ND	-47.6	ND	ND	ND

Table 14. Water Chemistry Results for Well U-2. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/26/03	12/11/04	3/17/04	6/2/04	8/26/04	12/8/04	2/24/05	6/7/05	9/12/05	4/26/07	4/22/10
T (C)	17.2	11.5	7.2	11.5	17.9	12.4	9.11	16.3	19.7	9.51	10.4
SpC(µS/cm)	894	853	828	716	746	797	813	766	798	443	674
pH	6.80	6.75	7.44	7.21	6.94	8.00	6.99	6.94	7.18	7.28	7.12
ORP (mV)	380	434	ND	308	340	362	387	424	397	399	416
DO	3.67	3.90	5.10	2.48	3.7	5.24	5.3	3.9	2.5	9.3	3.8
Al	0.048	<0.021	0.023	0.038	<0.059	<0.059	0.0636	0.127	<0.059	0.0271	<0.037
As	<0.037	<0.037	0.074	<0.037	<0.119	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.038	0.032	<0.014	0.015	0.039	<0.036	<0.036	<0.036	<0.036	<0.023	<0.023
Ba	0.071	0.055	0.027	0.049	0.048	0.044	0.029	0.046	0.056	0.03676	0.0388
Be	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	102	106	95.9	101	107	108	112.3	114	108	90.1	94.5
Cd	0.005	<0.003	<0.003	<0.003	<0.014	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	0.005	<0.003	<0.003	<0.003	<0.016	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	0.403	0.008	0.039	0.012	0.019	<0.015	0.035	0.082	0.047	<0.0058	<0.0058
Cu	0.007	<0.003	<0.003	<0.003	<0.011	<0.011	<0.011	<0.011	<0.011	0.00093	0.00115
Fe	1.44	0.014	0.157	0.048	0.037	<0.015	0.128	0.303	0.203	0.0269	0.0180
K	3.43	4.48	<3.06	<3.06	<10.3	<10.3	<10.2	<10.2	<10.2	0.721	0.737
Li	0.017	0.032	0.013	0.010	<0.070	<0.070	<0.070	<0.070	<0.070	0.0085	<0.058
Mg	54.7	49.3	43.5	47.7	49.6	47.5	48.34	52.5	50.6	38.3	41.2
Mn	0.026	0.003	<0.002	0.008	<0.019	<0.019	<0.019	<0.019	<0.019	<0.0015	0.0022
Mo	0.057	<0.006	0.009	<0.006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.022	<0.022
Na	12.7	7.92	7.19	5.78	8.15	8.39	12.18	8.80	6.82	17	12.3
Ni	0.284	<0.007	0.025	<0.007	<0.023	<0.023	<0.023	0.052	0.035	0.029	<0.014
P	<0.047	0.119	<0.047	<0.047	<0.127	<0.127	<0.127	<0.127	<0.127	<0.063	<0.063
Pb	<0.028	<0.028	<0.028	<0.028	<0.051	<0.051	<0.051	0.079	<0.051	<0.041	<0.041
S	19.5	17.8	17.4	16.8	19.8	18.7	15.09	14.5	15.5	11.4	9.15
Sb	0.035	0.054	<0.021	<0.021	<0.193	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.034	<0.034	<0.034	0.072	<0.180	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	3.86	7.09	5.52	5.74	6.95	6.47	5.66	6.34	6.72	5.13	5.49
Sn	<0.015	<0.015	<0.015	<0.015	<0.091	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.169	0.153	0.136	0.141	0.148	0.139	0.136	0.149	0.149	0.123	0.124
Ti	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.00056	<0.00056
V	0.007	0.004	<0.002	0.006	<0.028	<0.028	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.009	0.011	0.003	0.002	<0.008	0.009	<0.008	<0.008	<0.008	<0.0073	0.0093
Alkalinity	301	292	278	295	305	312	330	320	310	289	329
F^-	0.327	0.31	0.21	0.20	0.23	0.21	0.182	0.21	0.22	0.201	0.20
Cl^-	17.4	19.1	21.7	17.4	19.9	18.1	21.67	19.0	16.5	18.5	9.71
NO_3-N	23.9	24.1	21.5	20.4	22.0	22.3	21.95	27.1	28.1	16.2	12.2
DRP	ND	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	<0.64	0.015
SO_4^{2-}	55.2	51.9	52.0	49.0	50.1	48.9	42.3	42.2	46.8	33.1	22.3
DOC	2.34	2.49	2.18	1.28	2.08	1.66	1.94	1.29	2.78	2.21	1.49
TKN	0.756	0.32	0.51	<0.24	<0.24	0.42	0.345	1.32	0.97	1.30	<0.26
NH_3-N	0.068	<0.03	<0.03	<0.04	<0.04	0.26	0.230	1.20	0.11	1.27	<0.06
$\delta^{15}N$-NO_3	6.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	15.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

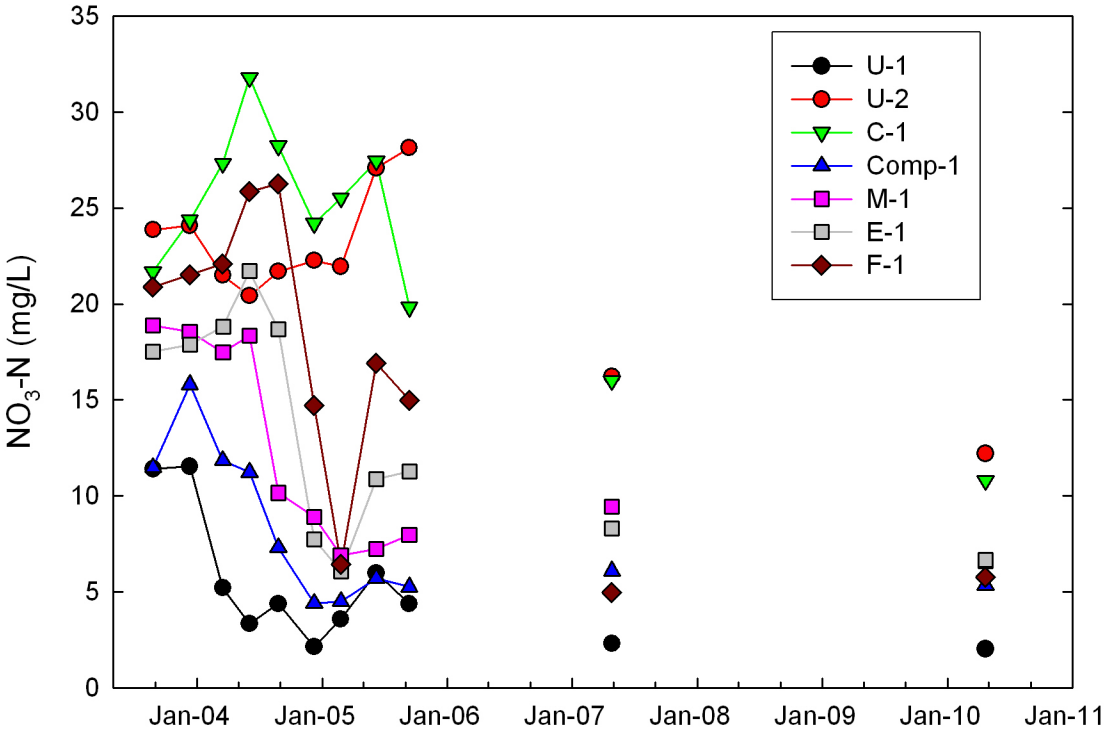

Figure 7. Nitrate-N concentrations for wells in small experimental plots

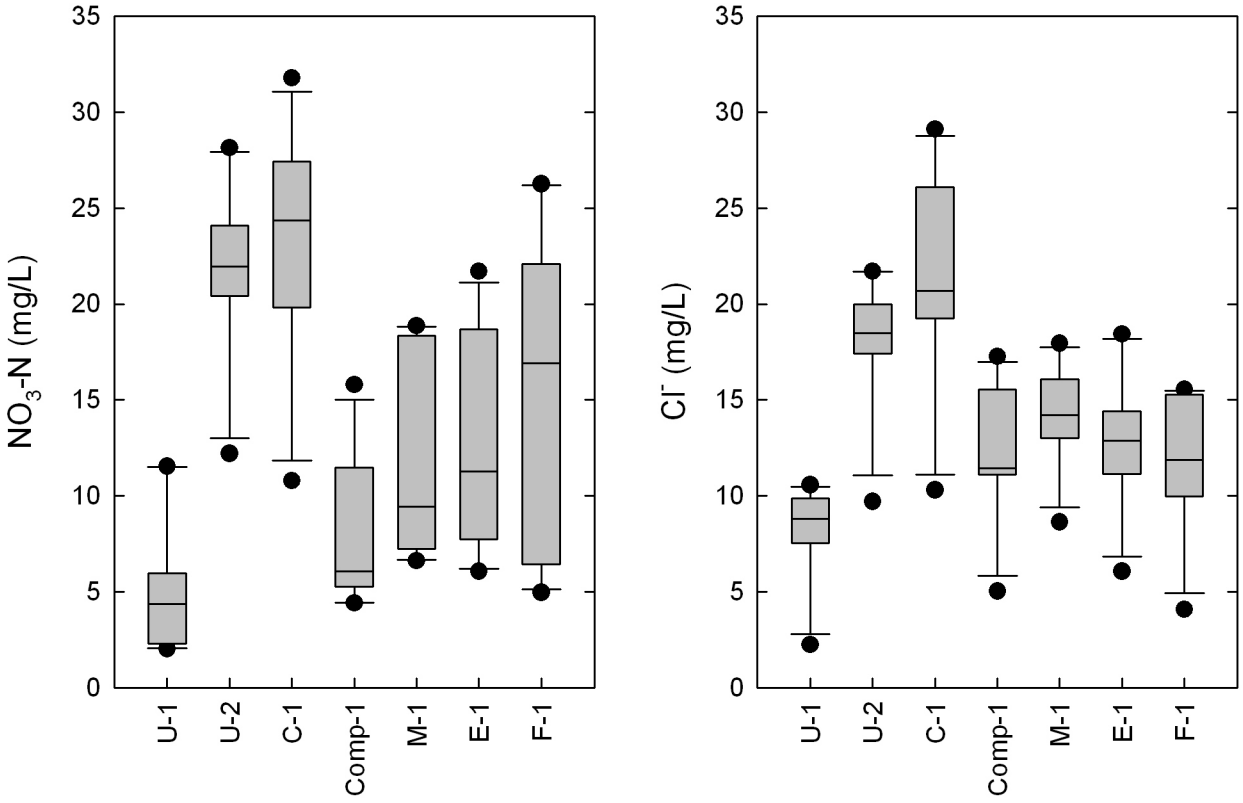

Figure 8. Box and whisker plots for nitrate-N and chloride concentrations for all samples from wells on small experimental plots. Boxes show median (middle line), 25th (bottom of box), and 75th (top of box) percentile values. Whiskers show 10th and 90th percentile values, and dots are outliers.

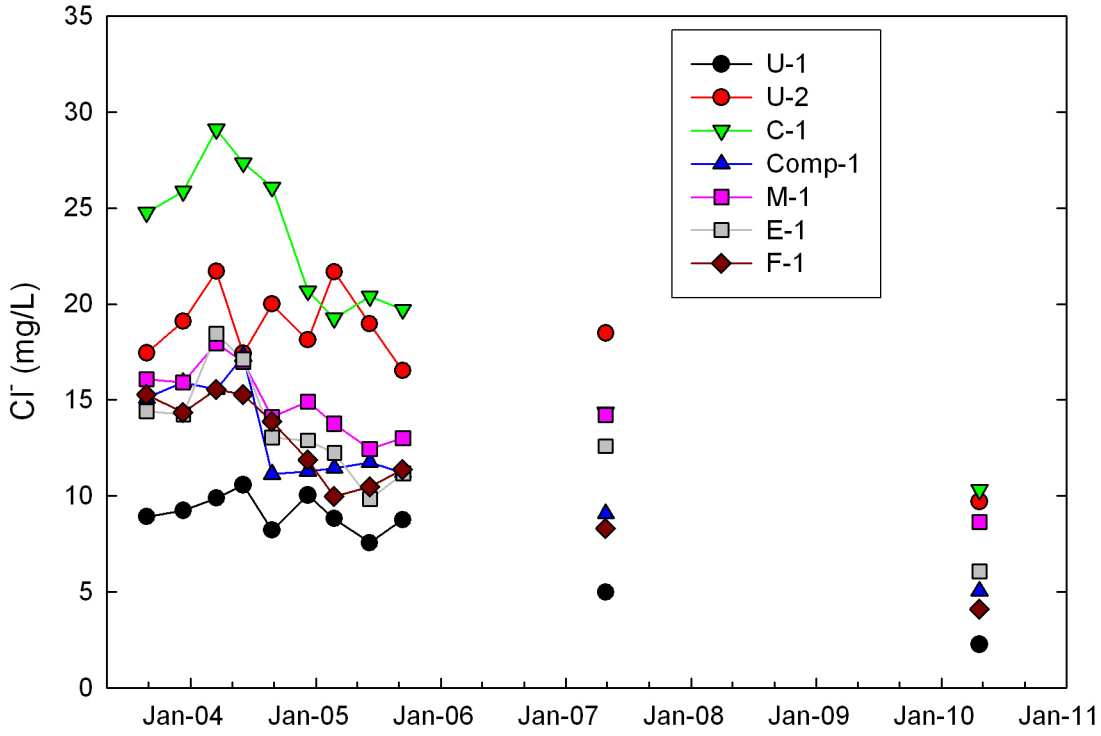

Figure 9. Chloride concentrations for wells in small experimental plots

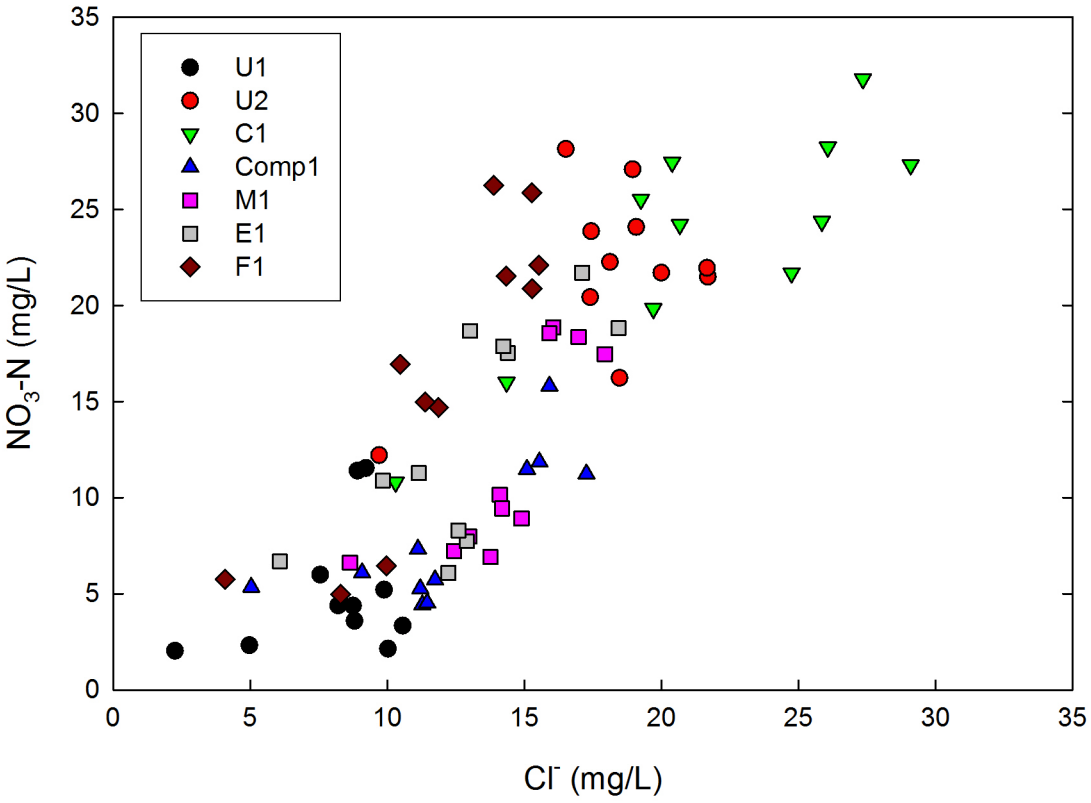

Figure 10. Chloride vs. nitrate-N concentrations for wells on small experimental plots

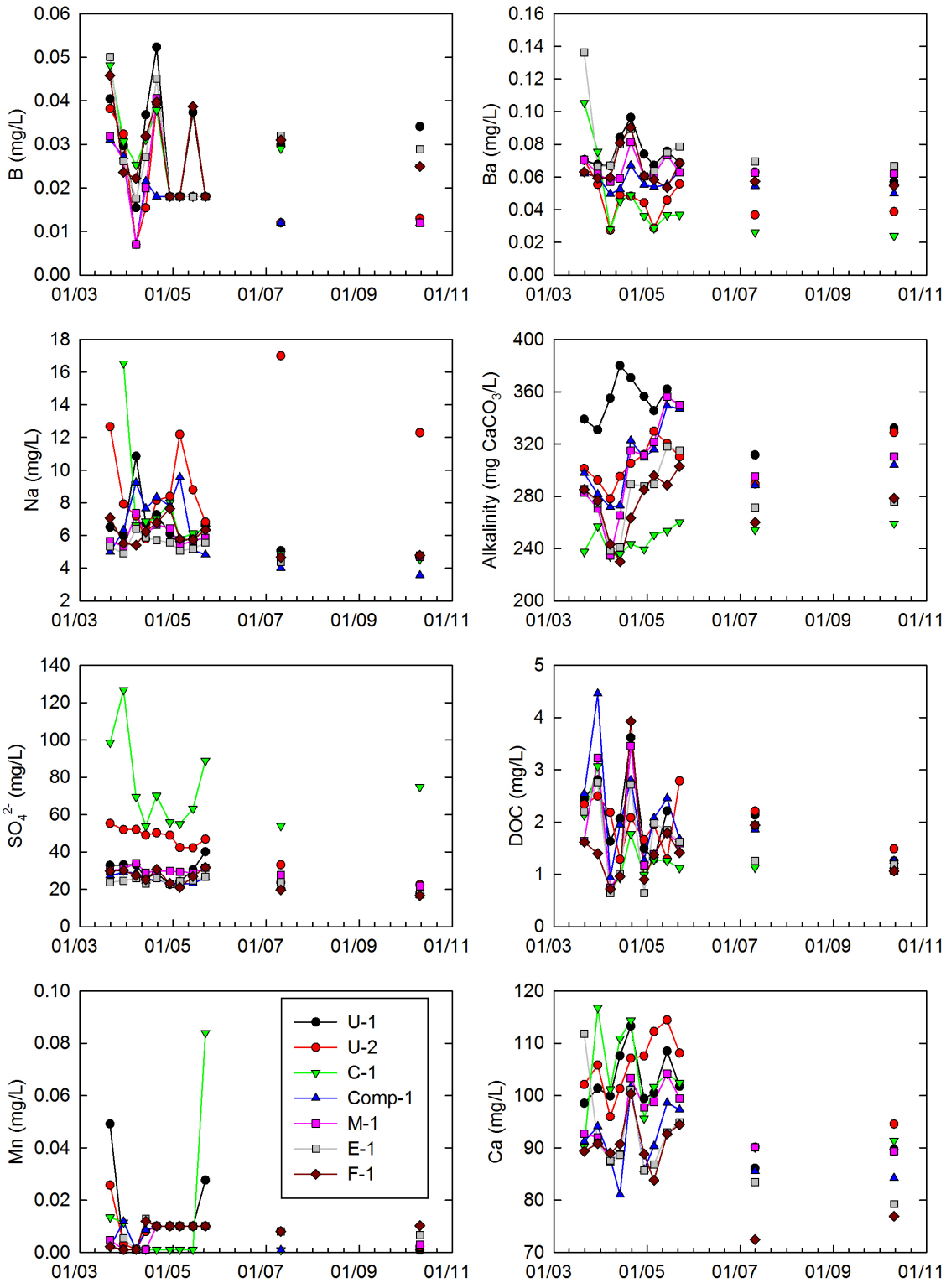

Figure 11. Concentrations of various chemical parameters for wells on small experimental plots

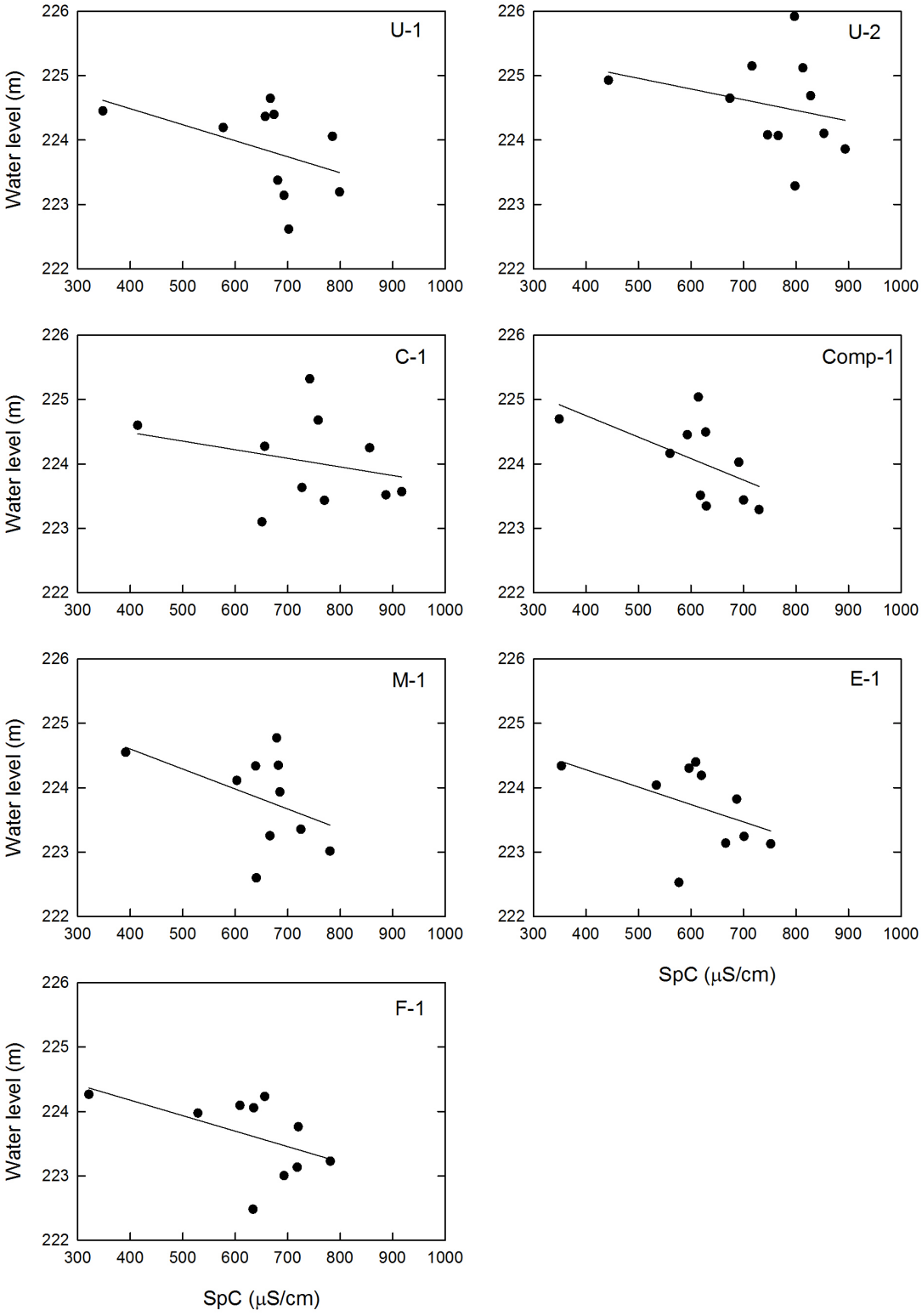

Figure 12. Specific conductance (SpC) vs. water table elevation for wells on small experimental plots. Lines are linear regressions.

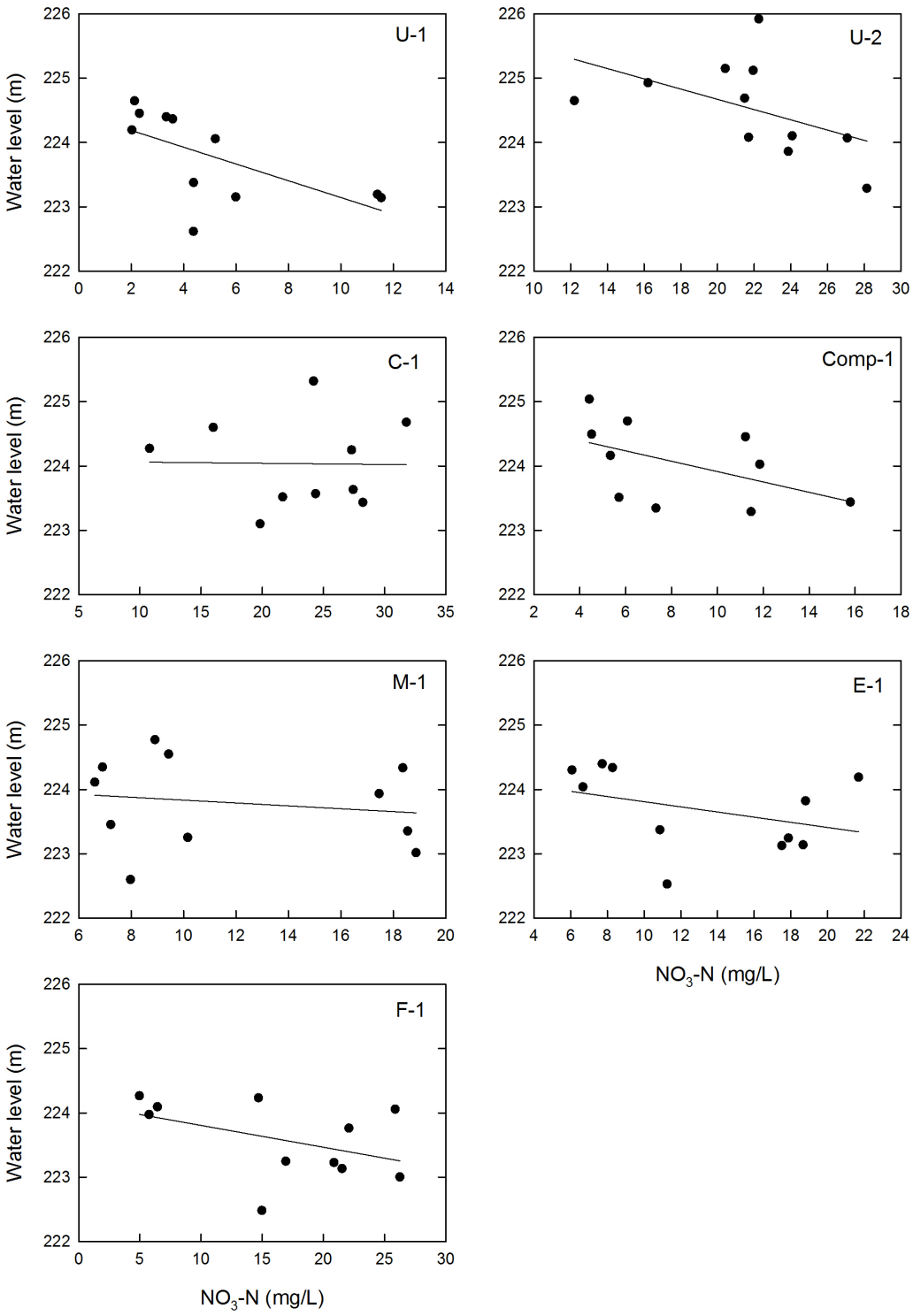

Figure 13. NO_3-N concentrations vs. water table elevation for wells on small experimental plots. Lines are linear regressions.

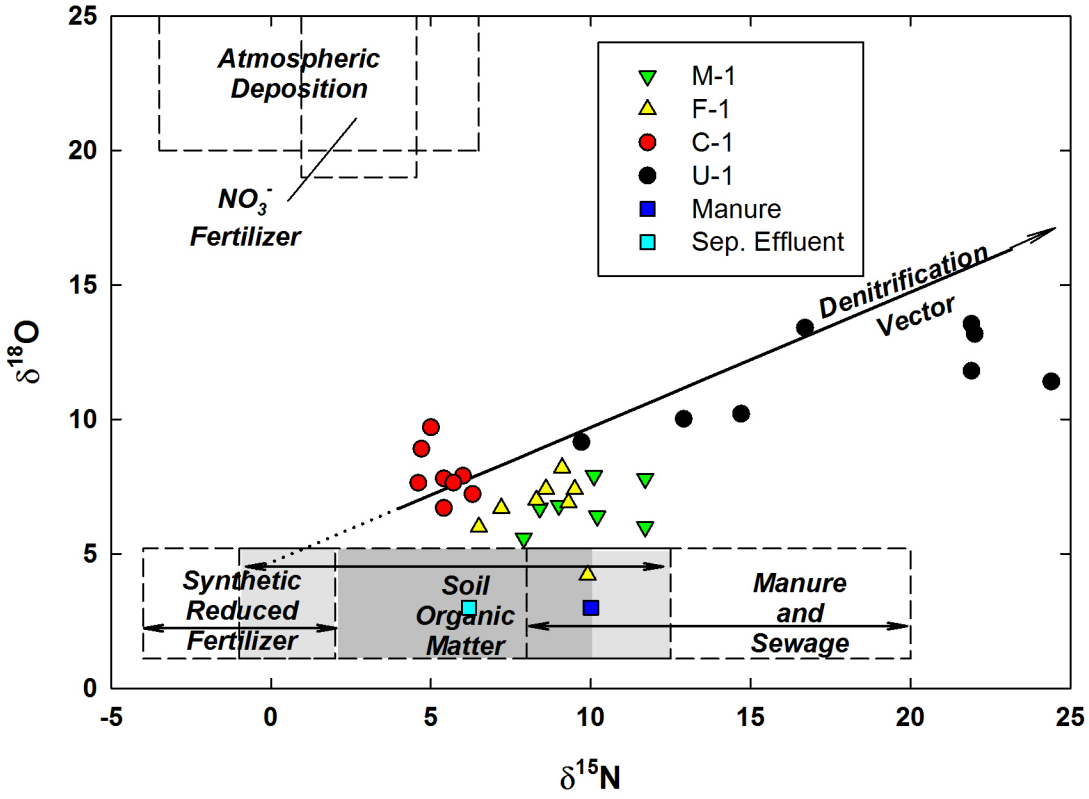

Figure 14. Nitrate isotope values for well samples on small experimental plots. Boxes outlined by dashed lines indicate isotopic ranges for potential sources of nitrate. The denitrification vector indicates the theoretical change in $\delta^{15}N$ and $\delta^{18}O$ values of residual nitrate after a fraction of the nitrate pool has been denitrified.

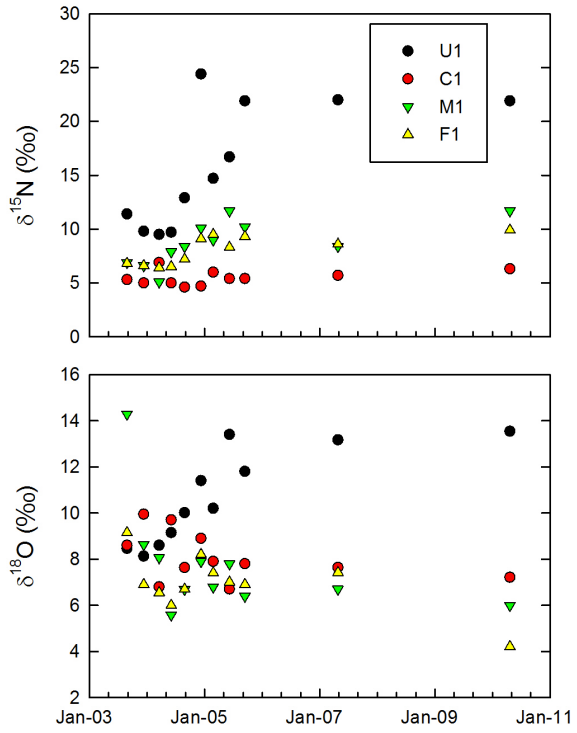

Figure 15. Nitrate isotope values for well samples on small experimental plots as a function of time

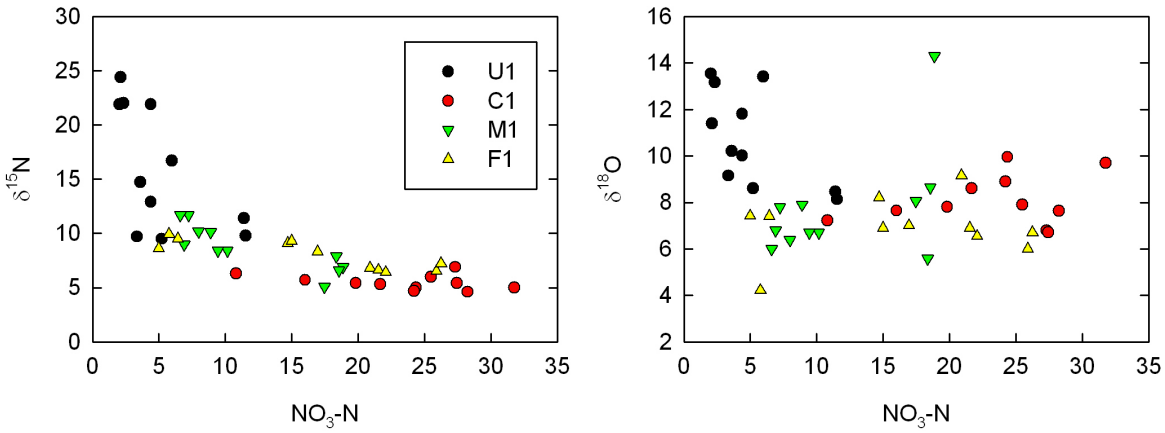

Figure 16. Nitrate isotope values vs. nitrate-N concentrations for wells on small experimental plots

Table 15. Water Chemistry Results for Lysimeters CS-2 and US-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except for Isotopes (‰). Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	CS-2						US-1
Date	8/30/2004	12/8/2004	2/24/2005	6/13/2005	4/26/2007	4/22/2010	4/26/2007
Al	0.063	<0.059	ND	ND	0.0248	0.103	0.0391
As	<0.119	<0.119	ND	ND	<0.108	<0.108	<0.108
B	0.066	<0.036	ND	ND	0.023	<0.023	0.028
Ba	0.218	0.135	ND	ND	0.07654	0.0438	0.06125
Be	<0.005	<0.005	ND	ND	<0.00055	<0.00055	<0.00055
Ca	120	111	ND	ND	67.1	24.0	67
Cd	<0.014	<0.014	ND	ND	<0.012	<0.012	<0.012
Co	<0.016	<0.016	ND	ND	<0.013	<0.013	<0.013
Cr	<0.015	0.078	ND	ND	<0.0058	<0.0058	<0.0058
Cu	<0.011	<0.011	ND	ND	0.0029	0.00566	0.00182
Fe	0.028	0.315	ND	ND	0.0234	2.35	0.0172
K	<10.3	<10.3	ND	ND	1.21	6.23	0.573
Li	<0.070	<0.070	ND	ND	<0.0048	<0.058	<0.0048
Mg	24.9	30.3	ND	ND	24.7	6.03	27.1
Mn	<0.019	<0.019	ND	ND	0.0022	0.843	0.0016
Mo	<0.020	<0.020	ND	ND	<0.022	<0.022	<0.022
Na	8.72	5.66	ND	ND	3.13	1.25	4.61
Ni	<0.023	0.050	ND	ND	0.02	<0.014	0.017
P	<0.127	<0.127	ND	ND	0.083	0.592	0.082
Pb	<0.051	<0.051	ND	ND	<0.041	<0.041	<0.041
S	25.2	12.1	ND	ND	5.40	1.93	6.95
Sb	<0.193	<0.193	ND	ND	<0.059	<0.059	<0.059
Se	<0.180	<0.180	ND	ND	<0.131	<0.131	<0.131
Si	7.33	4.05	ND	ND	3.96	3.24	4.12
Sn	<0.091	<0.091	ND	ND	<0.070	<0.086	<0.070
Sr	0.257	0.190	ND	ND	0.10813	0.0398	0.0981
Ti	<0.005	<0.005	ND	ND	<0.00056	0.00255	<0.00056
V	<0.028	<0.028	ND	ND	<0.047	<0.047	<0.047
Zn	0.031	0.016	ND	ND	0.252	0.125	0.0862
Alkalinity	179	267	ND	ND	226	87	240
F^-	0.22	0.30	0.346	0.37	0.243	0.15	0.178
Cl^-	26.6	20.8	17.47	16.2	7.48	2.86	4.72
NO_3-N	27.5	20.8	17.13	15.5	4.23	0.81	2.44
DRP	<0.64	<0.64	<0.64	<0.64	<0.64	0.368	<0.64
SO_4^{2-}	57.6	34.2	28.9	32.5	16.0	5.19	21.0
DOC	10.7	2.78	ND	ND	5.01	9.37	3.38
TKN	1.38	0.45	ND	0.66	1.05	2.27	0.280
NH_3-N	0.07	0.23	ND	0.12	0.141	1.58	<0.06
$\delta^{15}N$-NO_3	ND	7.1	7.3	6.5	6.80	ND	ND
$\delta^{18}O$-NO_3	ND	10.4	8.4	7.4	7.80	ND	ND
δD	-43.7	ND	ND	-47.8	ND	ND	ND

Table 16. Water Chemistry Results for Lysimeter FS-2. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except for Isotopes (‰). Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/30/2004	12/8/2004	2/24/2005	6/13/2005	4/26/2007	4/22/2010
Al	<0.059	<0.059	<0.059	0.106	0.4218	0.313
As	<0.119	<0.119	<0.119	<0.119	<0.108	<0.108
B	0.074	<0.036	<0.036	0.039	0.048	<0.023
Ba	0.106	0.083	0.068	0.090	0.04577	0.0358
Be	<0.005	<0.005	<0.005	<0.005	<0.00055	<0.00055
Ca	95.9	71.9	69.3	88.5	32.4	16.7
Cd	<0.014	<0.014	<0.014	<0.014	<0.012	<0.012
Co	<0.016	<0.016	<0.016	<0.016	<0.013	<0.013
Cr	<0.015	<0.015	<0.015	<0.015	<0.0058	<0.0058
Cu	<0.011	<0.011	<0.011	<0.011	0.00329	0.00247
Fe	0.021	<0.015	<0.015	0.026	0.2919	2.08
K	<10.3	<10.3	<10.2	<10.2	7.06	10.3
Li	<0.070	<0.070	<0.070	<0.070	<0.0048	<0.058
Mg	31.5	28.5	26.9	37.6	12.8	3.57
Mn	0.052	<0.019	<0.019	<0.019	0.0252	0.146
Mo	0.022	<0.020	<0.020	<0.020	<0.022	<0.022
Na	9.05	5.69	4.50	6.12	2.25	1.11
Ni	<0.023	<0.023	<0.023	<0.023	0.021	<0.014
P	0.131	<0.127	<0.127	<0.127	0.725	1.57
Pb	<0.051	<0.051	<0.051	<0.051	<0.041	<0.041
S	13.7	9.30	7.44	8.52	3.76	0.926
Sb	<0.193	<0.193	<0.193	<0.193	<0.059	<0.059
Se	<0.180	<0.180	<0.180	<0.180	<0.131	<0.131
Si	9.41	6.63	5.15	6.43	4.59	4.01
Sn	<0.091	<0.091	<0.091	<0.091	<0.070	<0.086
Sr	0.163	0.099	0.087	0.115	0.0680	0.0345
Ti	<0.005	<0.005	<0.005	<0.005	0.0129	0.0138
V	0.164	<0.028	<0.028	<0.028	<0.047	<0.047
Zn	0.019	0.016	0.0170	0.014	0.245	0.119
Alkalinity	214	232	219	269	106	76
F^-	0.26	0.22	0.193	0.18	0.233	0.14
Cl^-	15.0	9.30	9.50	10.5	4.55	4.77
NO_3-N	24.4	6.78	5.27	12.8	3.37	0.10
DRP	<0.64	<0.64	<0.64	<0.64	0.997	1.67
SO_4^{2-}	36.4	27.8	21.3	24.5	10.9	1.81
DOC	11.5	3.94	2.03	2.66	6.29	13.7
TKN	1.46	1.61	<0.29	0.47	0.637	6.81
NH_3-N	0.12	0.89	<0.06	0.10	0.087	5.51
$\delta^{15}N$-NO_3	11.1	14.9	15.6	12.5	10.9	ND
$\delta^{18}O$-NO_3	17.3	9.9	8.9	8	7.51	ND
δD	-43.6	ND	ND	-47.1	ND	ND

Table 17. Water Chemistry Results for Lysimeter MS-2. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except for Isotopes (‰). Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	8/30/2004	12/8/2004	2/24/2005	6/13/2005	4/26/2007	4/22/2010
Al	<0.059	ND	<0.059	0.126	0.0293	0.045
As	<0.119	ND	<0.119	<0.119	<0.108	<0.108
B	0.068	ND	<0.036	0.036	0.025	0.028
Ba	0.117	ND	0.074	0.091	0.0788	0.0216
Be	<0.005	ND	<0.005	<0.005	<0.00055	<0.00055
Ca	109	ND	98.9	98.6	88.0	16.7
Cd	<0.014	ND	<0.014	<0.014	<0.012	<0.012
Co	<0.016	ND	<0.016	<0.016	<0.013	<0.013
Cr	0.017	ND	<0.015	<0.015	<0.0058	<0.0058
Cu	<0.011	ND	<0.011	<0.011	0.00208	0.00330
Fe	0.030	ND	<0.015	0.030	0.0151	0.557
K	<10.3	ND	<10.2	<10.2	0.748	3.97
Li	<0.070	ND	<0.070	<0.070	0.0051	<0.058
Mg	32.0	ND	34.5	38.9	33.9	5.77
Mn	0.359	ND	0.046	0.068	0.0026	0.0805
Mo	<0.020	ND	<0.020	<0.020	<0.022	<0.022
Na	6.76	ND	4.49	5.22	4.18	1.10
Ni	<0.023	ND	<0.023	<0.023	0.024	<0.014
P	<0.127	ND	<0.127	<0.127	3.08	0.972
Pb	<0.051	ND	<0.051	<0.051	<0.041	<0.041
S	11.3	ND	9.48	8.77	8.62	1.33
Sb	<0.193	ND	<0.193	<0.193	<0.059	<0.059
Se	<0.180	ND	<0.180	<0.180	<0.131	<0.131
Si	9.82	ND	5.05	5.64	4.85	2.12
Sn	<0.091	ND	<0.091	<0.091	<0.070	<0.086
Sr	0.184	ND	0.129	0.143	0.125	0.0241
Ti	<0.005	ND	<0.005	<0.005	<0.00056	0.00207
V	<0.028	ND	<0.028	<0.028	<0.047	<0.047
Zn	0.015	ND	<0.008	0.010	0.1116	0.0511
Alkalinity	313	ND	318	338	299	62
F^-	0.26	0.24	0.230	0.23	0.220	0.11
Cl^-	11.3	10.1	12.9	10.4	13.8	2.20
NO_3-N	3.85	3.07	4.47	3.38	5.47	1.62
DRP	<0.64	<0.64	<0.64	<0.64	0.906	0.996
SO_4^{2-}	25.5	23.7	26.8	26.0	26.2	3.53
DOC	9.65	ND	ND	2.31	3.46	8.55
TKN	1.06	ND	<0.29	0.38	0.281	2.01
NH_3-N	0.16	ND	<0.06	0.11	<0.06	1.51
$\delta^{15}N$-NO_3	ND	14.8	15.1	17.1	11.0	16.4
$\delta^{18}O$-NO_3	ND	9.6	8.3	9.3	7.82	7.6
δD	-43.3	ND	ND	-47.2	ND	ND

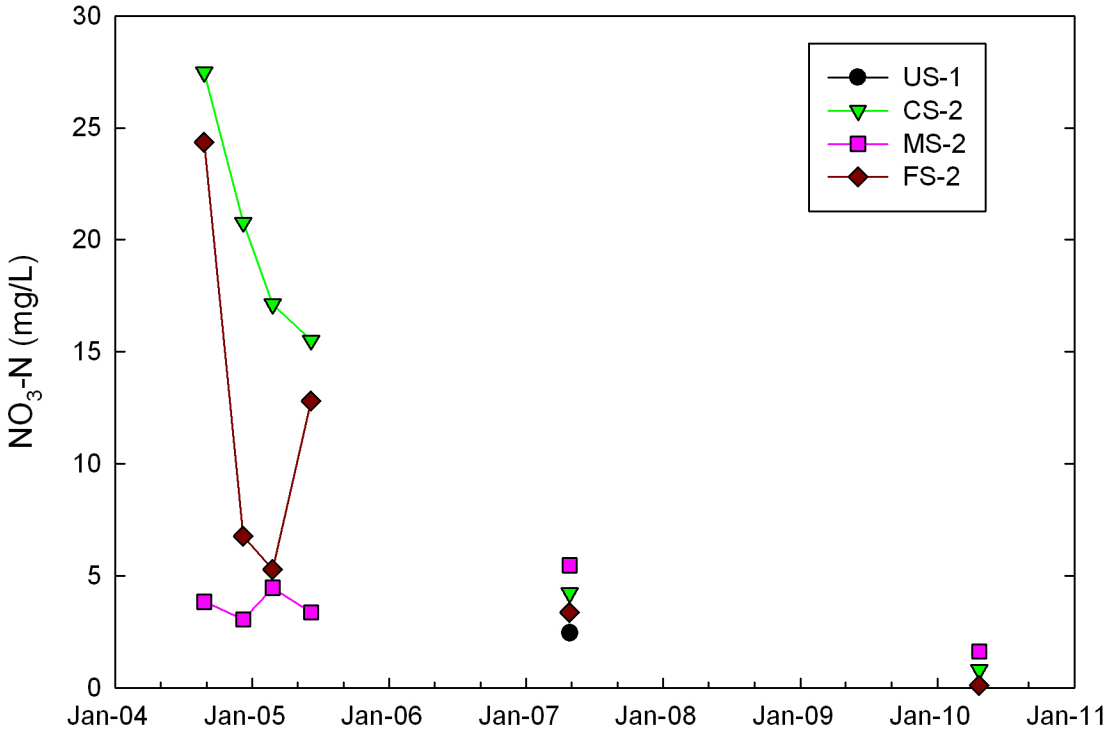

Figure 17. Nitrate-N concentrations for lysimeters in small experimental plots

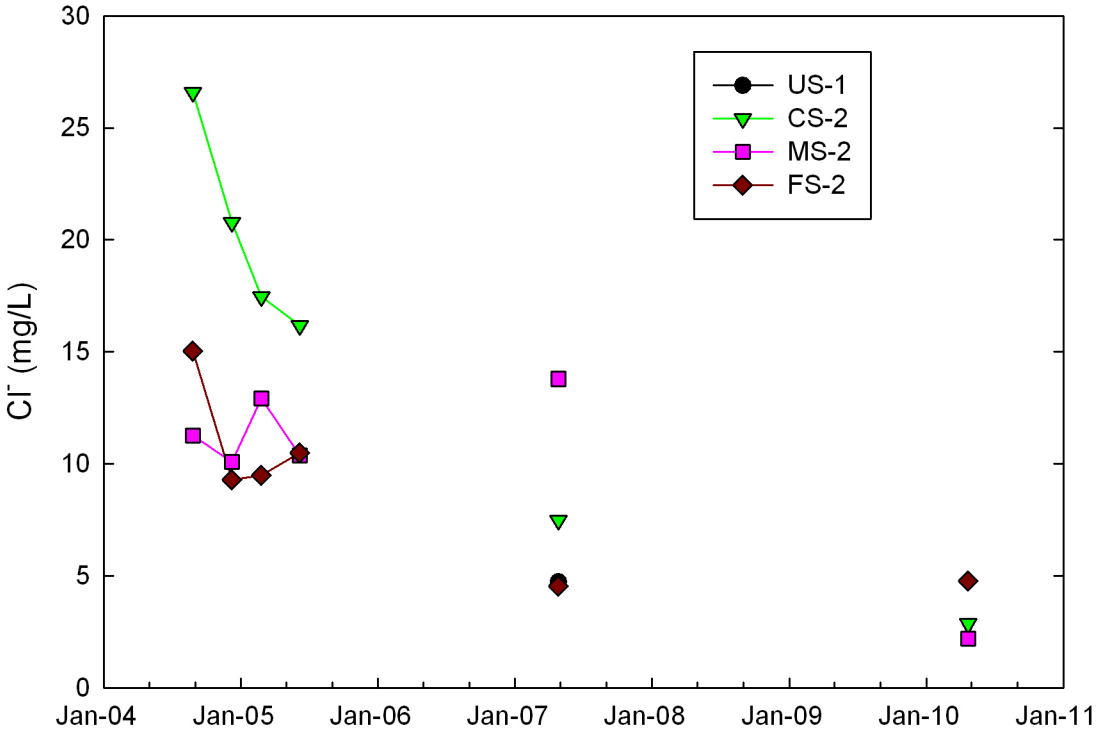

Figure 18. Chloride concentrations for lysimeters in small experimental plots

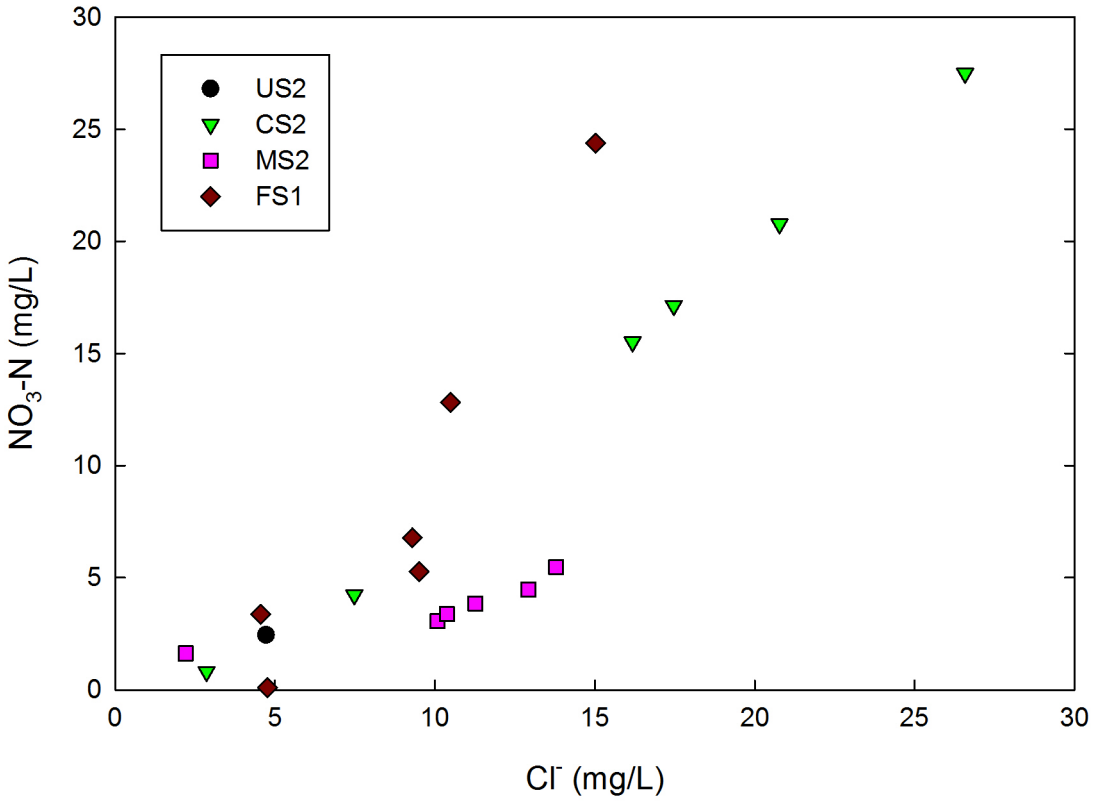

Figure 19. Chloride vs. nitrate-N concentrations for lysimeters on small experimental plots

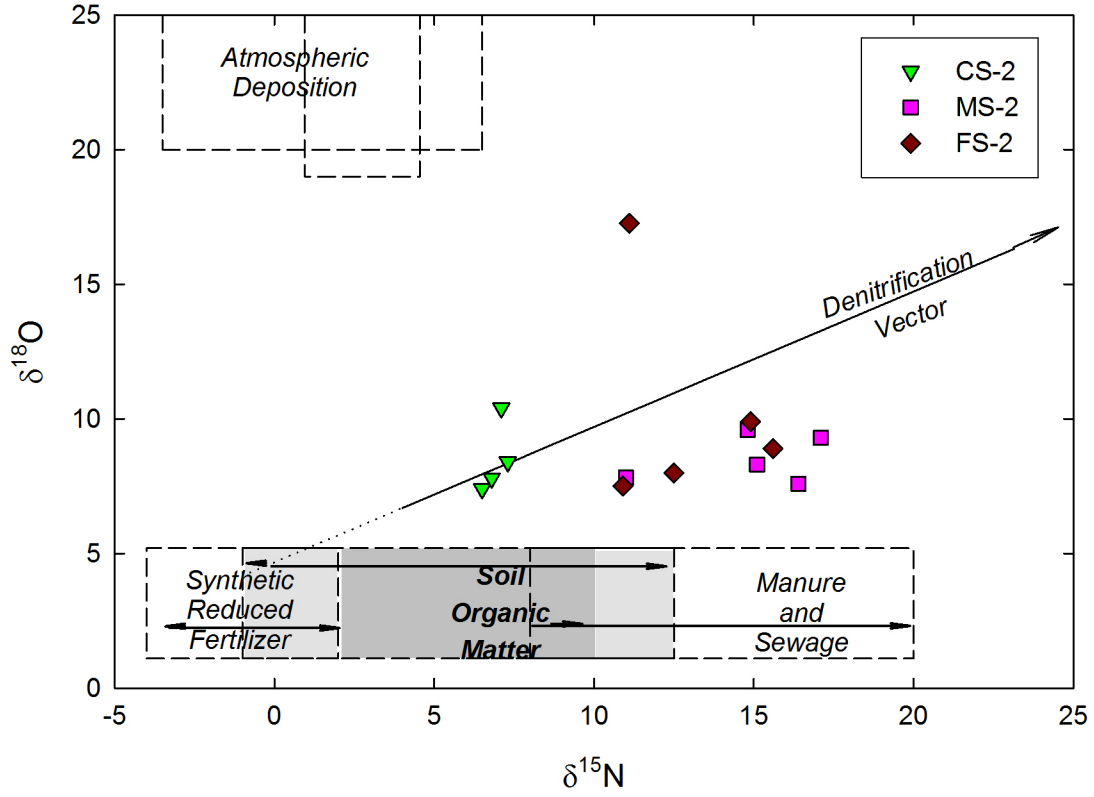

Figure 20. Nitrate isotope values for lysimeter samples on small experimental plots. Boxes outlined by dashed lines indicate isotopic ranges for potential sources of nitrate. The denitrification vector indicates the theoretical change in $\delta^{15}N$ and $\delta^{18}O$ values of residual nitrate after a fraction of the nitrate pool has been denitrified.

Table 18. Antibiotics in Soil Samples on Raw Manure Plot. Concentrations in ng/g. NA = Not Analyzed.

Sample	Surface			1 ft depth		
Date	6/13/2005	6/9/2009	4/15/2010	6/13/2005	6/9/2009	4/15/2010
Tetracycline	3.9	12	3.9	< 1.0	2.8	< 1.0
Sulfamethazine	NA	< 1.0	< 1.0	NA	< 1.0	< 1.0
Sulfadimethoxine	NA	< 1.0	< 1.0	NA	< 1.0	< 1.0
Oxytetracycline	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Minocycline	< 2.0	< 5.0	< 5.0	< 2.0	< 5.0	< 5.0
IsoChlortetracycline	NA	371	129	NA	80	2.3
Chlortetracycline	87.2	53	50	3.1	14	1.2
β_Apo_Oxycycline	< 2.0	< 5.0	< 5.0	< 2.0	< 5.0	< 5.0
Anh_TC	6.2	12	8.1	< 2.0	< 5.0	< 5.0
Anh_CTC	11.2	< 5.0	14	< 2.0	< 5.0	< 5.0

Table 19. Antibiotics in Soil Samples on Separated Effluent Plot. Concentrations in ng/g. NA = Not Analyzed.

Sample	Surface			1 ft depth	
Date	6/13/2005	6/9/2009	4/15/2010	6/9/2009	4/15/2010
Tetracycline	1.5	< 1.0	1.5	< 1.0	< 1.0
Sulfamethazine	NA	< 1.0	< 1.0	< 1.0	< 1.0
Sulfadimethoxine	NA	< 1.0	< 1.0	< 1.0	< 1.0
Oxytetracycline	6.9	< 1.0	< 1.0	< 1.0	< 1.0
Minocycline	< 2.0	< 5.0	< 5.0	< 5.0	< 5.0
IsoChlortetracycline	NA	5.5	31	22	1.3
Chlortetracycline	10.6	13	11	< 1.0	< 1.0
β_Apo_Oxycycline	< 2.0	< 5.0	< 5.0	< 5.0	< 5.0
Anh_TC	< 2.0	< 5.0	5.9	< 5.0	< 5.0
Anh_CTC	< 2.0	< 5.0	16	< 5.0	< 5.0

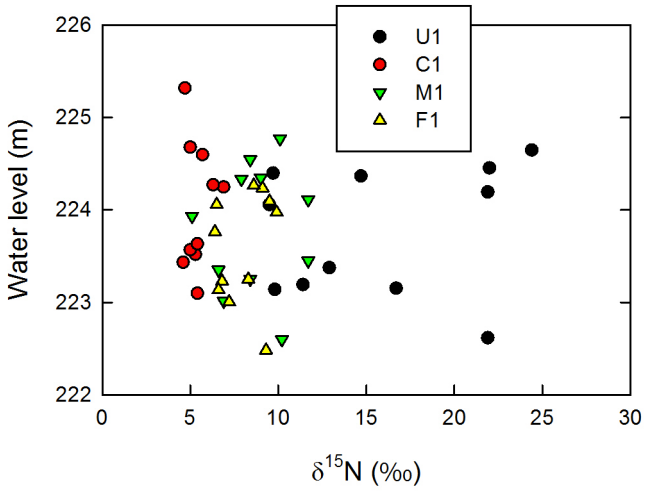

Figure 21. $\delta^{15}N$ values vs. water table elevation for samples from wells on small experimental plots

Large Fields

Complete chemical results for the wells monitoring the large fields are presented in Tables 20-25. There were wide variations in NO_3-N concentrations among the wells in the large fields north of the ISU Farm (Figure 22). The highest concentrations were in Lex-6, the well down-gradient of a field receiving manure slurry. Wells Lex-1, Lex-2, and Lex-5 had low NO_3-N concentrations; in fact, concentrations in Lex-2 were often below detection (0.07 mg/L) and never greater than 0.15 mg/L. Well Lex-3 was consistently between 3 and 5 mg/L and well Lex-4, after an initial drop from high concentrations, settled in at around 4-6 mg/L. Concentrations in wells Lex-3, Lex-4, and

Lex-6 were above what is generally considered to be background for NO_3-N in shallow groundwater (2-3 mg/L).
Chloride concentrations showed much less variability than NO_3-N, and slowly dropped throughout the sampling period (Figure 23). The highest concentrations were in Lex-3, which topographically was an up-gradient well, but was sited near farm buildings. Lex-6 had the next highest concentrations, although by the end of the sampling period its concentration was indistinguishable from the other wells (except Lex-3). Assuming a background value of 15 mg/L (Panno et al., 2006), only Lex-3 and Lex-6 between 2006 and 2008 were consistently above background.

The relationship between Cl^- and NO_3-N was less consistent than on the small plots (Figure 24). Two of the wells (Lex-1 and Lex-4) had a positive correlation between the two ions, but not the other wells. For Lex-3 and Lex-6, there even appeared to be a possible negative relationship.

There were large differences among the wells for some other chemical parameters (Figure 25). Well Lex-3 had relatively high concentrations of several parameters, including Na, alkalinity, and DOC. Wells Lex-2 and Lex-5 had relatively high concentrations of B. Sulfate concentrations were measured over a large range, with wells Lex-1 and Lex-6 having relatively low concentrations. Calcium concentrations decreased over the study period in all wells except Lex-5.

As with the small plots, nitrate isotope values for each well tended to not overlap (Figure 26). Lex-4 generally had the lightest values for both $\delta^{15}N$ and $\delta^{18}O$, suggesting minimal denitrification. Lex-1 had the widest variability; when NO_3-N concentrations were low, the isotope values suggested a large amount of denitrification. Lex-3 and Lex-6 had a similar range of $\delta^{15}N$ values, but Lex-3 tended to have slightly lighter $\delta^{18}O$ values. Values for both suggested significant denitrification; in fact, their isotope values are what would be expected if some of the nitrate in Lex-4 had been denitrified. In general, NO_3-N concentrations were inversely correlated with both $\delta^{15}N$ and $\delta^{18}O$ values (Figure 27). Values for samples from Lex-6 after subsurface irrigation (see next section) plotted in the manure source domain. This corresponded with a large increase in NO_3-N, although there was no change in Cl^-. There was also an increase in DOC during this period.

Subsurface Irrigation
Complete chemical results for the wells at the subsurface irrigation site are presented in Tables 26-28. Nitrate-N concentrations in wells Lex-7, 8, and 9 were high relative to the other wells prior to subsurface irrigation (Figure 28). Chloride concentrations were low, usually < 10 mg/L (Figure 29). After the first round of subsurface irrigation with separated manure effluent (September 2009), NO_3-N concentrations plunged in wells 7 and 8, in conjunction with large increases in reduced N (DKN and NH_3-N) and a number of other parameters, including Cl^-, alkalinity, DOC, manganese (Mn), calcium (Ca), K, and DRP (Figure 30). Eight months after the application, most of the parameters had not returned to pre-application concentrations. In 2010, subsurface application took place the first week of July. Samples were collected two weeks later, and NO_3-N concentrations had decreased and Cl^-concentrations increased dramatically in Lex-8, but not in Lex-9 (Figures 28 and 29). Spikes were again observed for many of the other parameters as well (Figure 30).

Prior to application, NO_3-N and Cl^- concentrations were positively correlated, but after application they were negatively correlated (Figure 31).

Prior to application, nitrate isotope values in Lex-7, 8, and 9 were similar to those of other wells, with two of the Lex-9 samples showing significant denitrification (Figure 32). Post-application, samples from Lex-8 and Lex-9 had very heavy values, perhaps slightly heavier in $\delta^{15}N$ relative to $\delta^{18}O$, but they were not readily distinguishable from highly denitrified samples from wells Lex-1 and Lex-6, for example. Both Lex-1 and Lex-6 were down-gradient of manure amended fields. The post-application isotopic values thus suggest that introduction of the anoxic separated effluent promoted denitrification of the *in situ* nitrate, rather than nitrification of reduced nitrogen in the effluent.

Complete chemical results for the lysimeters at the subsurface irrigation site are presented in Tables 29-31. Lysimeters Lex-7S, 8S, and 9S were not successfully sampled until after effluent application. Lex-8S and 9S had lower NO_3-N and higher DKN and NH_3-N concentrations immediately after application (Figure 33). Chloride concentrations were higher in the down-gradient lysimeters, especially 8S. 8S also had much higher levels of alkalinity, DOC, Na, K, Fe, and Mn, among others.

It is clear that groundwater chemistry was substantially altered when effluent was applied via the subsurface tiles, changes that were not observed when effluent was applied at the surface. The groundwater became much more reducing with elevated levels of parameters found in high concentrations in the effluent (Cl^-, DOC, DKN, NH_3-N). Nitrate-N concentrations were temporarily suppressed as the reducing effluent promoted denitrification of the *in situ* NO_3-N. Recovery of pre-application geochemical conditions was slow, with conditions only slightly ameliorated between the first application in September 2009 and sampling in May 2010.

Table 20. Water Chemistry Results for Well Lex-1. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	9/25/2008	1/5/2009	4/9/2009	6/9/2009	9/15/2009	12/2/2009	3/24/2010	5/24/2010
T	16.2	10.1	9.1	11.2	17.2	12.5	7.2	11.2
SpC(µS/cm)	671	601	573	583	407	632	588	575
pH	7.27	7.25	7.42	7.48	6.82	6.46	6.30	ND
ORP	401	408	408	ND	ND	ND	ND	542
DO	4.2	1.2	2.4	3.13	8.72	5.1	ND	0.3
Al	0.080	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.052	0.029	0.036	0.088	0.045	0.035	0.033	<0.023
Ba	0.097	0.110	0.105	0.093	0.079	0.114	0.118	0.114
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	82.3	71.6	71.6	74.8	80.5	82.2	77.9	74.7
Cd	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.00079	<0.00079	<0.00079	<0.00079	<0.00079	0.00086	<0.00079	0.00135
Fe	0.006	<0.0059	<0.0059	<0.0059	0.008	<0.0059	0.017	0.010
K	0.75	1.02	0.96	0.59	0.84	1.01	1.28	1.07
Li	<0.018	<0.018	<0.018	<0.018	<0.058	<0.058	<0.058	<0.058
Mg	36.6	30.3	31.3	33.7	32.9	32.0	30.7	32.2
Mn	0.087	0.058	0.132	0.079	0.137	0.030	0.060	0.207
Mo	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	7.43	6.69	6.44	5.68	6.60	6.83	8.09	6.91
Ni	<0.014	0.02	0.026	<0.014	<0.014	<0.014	0.016	0.026
P	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	7.53	8.07	8.39	6.61	6.20	8.05	9.78	8.92
Sb	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	5.74	5.82	6.41	5.16	5.52	6.45	7.10	6.37
Sn	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.140	0.146	0.168	0.131	0.129	0.162	0.169	0.172
Ti	<0.00056	<0.00056	<0.00056	<0.00056	<0.00056	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	<0.0073	<0.0073	<0.0073	0.0084	0.0104	<0.0073	<0.0073
Alkalinity	304	288	284	274	300	294	288	290
F	0.253	0.223	0.218	0.240	0.246	0.227	0.218	0.231
Cl	16.56	13.42	8.78	13.08	13.81	9.51	8.32	8.08
NO_3-N	6.30	1.15	0.21	2.73	0.91	0.68	<0.07	<0.07
SO_4	21.5	23.4	28.1	19.3	20.3	23. 7	27.6	26.6
DRP	0.02	<0.01	0.01	<0.01	0.02	0.009	0.010	0.011
DOC	0.56	0.67	1.66	1.38	1.47	0.97	0.88	0.37
TKN	0.12	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
NH_3-N	<0.06	<0.06	0.071	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N\text{-}NO_3^-$	13.7	22.8	14.3	29.8	52.6	ND	ND	ND
$\delta^{18}O\text{-}NO_3^-$	13.1	13.9	8.0	12.8	18.5	ND	ND	ND
δD	ND	ND	ND	ND	ND	ND	ND	ND

Table 21. Water Chemistry Results for Well Lex-2. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	7/21/06	11/29/06	3/29/07	4/26/07	8/29/07	11/27/07	4/17/08	6/18/08	9/25/08	4/9/09
T (C)	15.0	18.0	9.6	14.8	27.1	13.5	11.8	13.7	15.6	10.0
SpC(µS/cm)	808	662	517	437	608	768	711	709	770	755
pH	6.81	7.56	7.45	7.18	7.02	7.05	6.82	6.67	7.42	7.55
ORP (mV)	ND	235	334	392	336	220	376	330	382	402
DO	0.5	1.8	2.5	3.0	3.6	2.9	6.8	3.0	2.7	5.6
Al	<0.059	0.030	0.102	0.061	0.015	1.715	9.011	1.512	0.076	0.959
As	<0.119	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.133	0.146	0.111	0.123	0.146	0.157	0.134	0.143	0.146	0.132
Ba	0.069	0.070	0.065	0.065	0.065	0.071	0.089	0.062	0.058	0.056
Be	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	72.4	72.8	68.7	71.7	71.3	67.1	74.7	65.5	58.9	61.4
Cd	<0.014	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.016	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.015	0.016	0.056	<0.0058	<0.0058	<0.0058	0.0131	<0.0058	<0.0058	<0.0058
Cu	<0.011	<0.0007	0.001	<0.0007	0.001	0.001	0.00469	0.00102	<0.0007	0.00126
Fe	0.072	0.074	0.291	0.027	0.018	1.05	7.95	0.897	<0.0059	0.730
K	3.16	2.92	2.28	2.19	2.38	2.98	6.68	2.94	2.15	2.23
Li	<0.070	0.019	0.0196	0.019	0.0179	0.0192	0.0193	<0.018	<0.018	<0.018
Mg	31.7	33.2	31.1	31.4	32.4	29.1	35.2	28.1	27.2	27.3
Mn	0.360	0.095	0.043	0.036	0.198	0.120	0.105	0.039	0.046	0.011
Mo	0.0219	0.033	0.027	0.023	<0.022	0.023	0.024	<0.022	<0.022	<0.022
Na	69.5	76.1	79.2	62.7	68.6	61.1	74.9	72.7	86.9	84.3
Ni	<0.023	0.03	0.052	0.019	<0.014	<0.014	0.019	<0.014	<0.014	0.019
P	<0.127	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.051	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	37.2	38.6	37.9	32.9	25.2	23.6	38.5	28.1	29.8	35.9
Sb	<0.193	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.180	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	8.44	7.92	7.07	6.90	8.20	11.5	27.6	10.6	7.44	8.49
Sn	<0.091	<0.070	<0.070	<0.070	<0.070	<0.070	<0.086	<0.086	<0.086	<0.086
Sr	0.327	0.304	0.316	0.332	0.364	0.353	0.344	0.344	0.281	0.293
Ti	<0.005	<0.0005	0.0006	<0.0005	<0.0005	0.06335	0.34149	0.05116	<0.0005	0.0384
Tl	ND	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.028	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.0105	<0.0073	<0.0073	<0.0073	<0.0073	0.0076	0.0222	<0.0073	<0.0073	<0.0073
Alkalinity	335	327	315	311	337	335	309	324	339	311
F^-	0.322	0.377	0.354	0.333	0.268	0.361	0.311	0.342	0.363	0.319
Cl^-	19.4	15.6	14.6	13.3	11.2	10.8	12.2	10.7	11.1	11.2
NO_3-N	<0.07	<0.07	<0.07	0.10	0.08	0.07	<0.07	<0.07	<0.07	0.08
SO_4^{2-}	111	106	117	97.3	77.0	71.6	119	89.9	81.9	107
DRP	<0.64	<0.64	<0.64	<0.64	0.03549	0.066	<0.01	0.09	0.02	0.05
DOC	3.22	2.22	1.54	1.84	1.53	0.96	1.84	0.73	0.37	1.38
TKN	16.59	0.43	0.34	0.27	0.38	<0.26	0.48	<0.26	<0.26	<0.26
NH_3-N	<0.06	0.224	0.320	0.178	0.119	0.087	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
δD	-51.5	-52.2	ND	ND	ND	ND	ND	ND	ND	ND

Table 21 (cont.). Water Chemistry Results for Well Lex-2. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/9/09	9/15/09	12/2/09	3/24/10	5/24/10
T (C)	12.0	16.9	10.0	7.6	14.1
SpC (µS/cm)	790	844	818	766	804
pH	7.66	7.67	6.85	6.43	ND
ORP (mV)	ND	ND	ND	ND	516
DO	1.3	3.2	7.3	ND	1.7
Al	1.346	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.058	0.143	0.143	0.129	0.119
Ba	0.061	0.051	0.048	0.049	0.048
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	60.4	57.2	61.0	58.1	55.0
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0011	0.0030	<0.00079	<0.00079	<0.00079
Fe	1.123	<0.0059	0.011	<0.0059	<0.0059
K	2.54	2.20	1.85	1.85	1.78
Li	<0.018	<0.058	<0.058	<0.058	<0.058
Mg	26.0	27.2	24.1	23.2	24.4
Mn	0.023	0.018	<0.0015	<0.0015	<0.0015
Mo	<0.022	<0.022	<0.022	0.024	<0.022
Na	90.98	81.10	93.07	99.54	91.86
Ni	<0.014	<0.014	<0.014	0.020	0.019
P	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	35.3	27.2	27.7	34.9	31.6
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	9.86	6.90	6.83	6.37	6.33
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.293	0.293	0.266	0.254	0.258
Ti	0.0523	<0.00056	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	0.0136	0.0079	<0.0073	<0.0073
Alkalinity	320	328	324	311	316
F^-	0.347	0.418	0.318	0.323	0.330
Cl^-	11.7	11.3	10.4	11.1	10.6
NO_3-N	<0.07	0.09	0.15	0.14	0.08
SO_4^{2-}	107	82.9	76.3	98.2	90.1
DRP	0.0131	<0.01	0.008	0.010	0.010
DOC	1.20	1.74	0.67	1.18	0.53
TKN	<0.26	<0.26	<0.26	<0.26	<0.26
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND

Table 22. Water Chemistry Results for Well Lex-3. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	7/21/06	11/29/06	3/29/07	4/26/07	8/29/07	4/17/08	6/18/08	9/25/08	4/9/09	6/9/09
T (C)	15.4	16.3	9.2	12.8	19.3	11.7	14.4	16.1	11.9	11.8
SpC(µS/cm)	1187	1174	798	624	1074	1069	1073	1090	1022	1079
pH	6.87	7.14	7.29	6.96	6.73	6.58	6.47	7.17	7.40	7.46
ORP (mV)	ND	285	335	399	403	345	334	402	381	ND
DO	3.9	2.3	3.3	3.6	2.3	4.6	4.0	4.3	5.0	2.0
Al	<0.059	0.025	0.032	0.032	0.060	0.048	0.146	0.403	0.048	<0.037
As	<0.119	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.075	0.101	0.049	0.053	0.056	0.056	0.063	0.046	0.053	0.029
Ba	0.061	0.049	0.039	0.036	0.203	0.030	0.032	0.036	0.030	0.029
Be	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	109	103	103	109	97.8	81.5	84.3	93.6	86.2	86.2
Cd	<0.014	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.016	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.015	0.010	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.011	0.0011	<0.0007	0.0009	0.0009	0.0014	<0.0007	<0.0007	0.0011	0.0009
Fe	<0.015	0.046	0.018	<0.0059	0.054	0.025	<0.0059	0.273	0.039	<0.0059
K	4.48	3.51	2.79	2.62	3.34	2.34	2.72	3.08	2.30	2.04
Li	<0.070	0.0319	0.033	0.0327	0.0307	0.0195	0.0235	<0.018	<0.018	<0.018
Mg	58.1	52.6	53.8	57.2	54.8	42.0	45.7	51.5	46.4	43.1
Mn	<0.019	0.027	<0.0015	<0.0015	0.009	<0.0015	<0.0015	0.003	<0.0015	<0.0015
Mo	0.025	0.035	<0.022	<0.022	<0.022	<0.022	0.037	<0.022	<0.022	<0.022
Na	122	160	115	77.1	113	145	134	99.9	116	105
Ni	0.0280	0.0300	0.0220	0.0390	0.0310	0.0180	0.0170	0.0250	0.0340	0.0144
P	<0.127	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	0.0682
Pb	<0.051	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	81.9	87.9	65.4	47.9	45.8	57.7	56.4	47.2	42.3	35.6
Sb	<0.193	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.180	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	8.71	8.96	7.33	6.99	8.26	6.72	7.03	8.34	6.35	6.38
Sn	<0.091	<0.070	<0.070	<0.070	<0.070	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.214	0.191	0.195	0.196	0.207	0.159	0.176	0.185	0.171	0.163
Ti	<0.005	<0.0005	<0.0005	<0.0005	0.0010	0.0006	<0.0005	0.0133	0.0008	<0.0005
Tl	ND	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.028	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.11	<0.0073	<0.0073	<0.0073	0.0302	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073
Alkalinity	479	511	478	452	478	457	467	472	454	449
F^-	0.209	0.254	0.213	0.189	0.685	0.187	0.209	0.248	0.209	0.210
Cl^-	36.4	36.1	33.6	27.5	34.2	27.3	28.2	24.4	28.0	23.2
NO_3-N	2.17	1.74	2.03	2.46	1.84	5.88	4.59	4.66	3.61	3.97
SO_4^{2-}	245	232	174	152	164	163	153	120	123	105
DRP	<0.64	<0.64	<0.64	<0.64	<0.02	<0.01	0.02	0.05	0.02	<0.01
DOC	5.10	5.07	3.08	4.30	ND	3.42	2.65	2.25	2.79	3.36
TKN	0.35	1.74	0.45	0.39	<0.26	0.38	<0.26	0.34	0.33	0.34
NH_3-N	<0.06	1.476	0.160	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	18.1	23.9	ND	20.4	23.7	10.7	14.0	ND	15.0	13.8
$\delta^{18}O$-NO_3	6.3	10.9	ND	9.3	9.2	6.7	7.9	ND	7.5	6.6
δD	-50.3	-51.9	ND	ND	ND	ND	ND	ND	ND	ND

Table 22 (cont.). Water Chemistry Results for Well Lex-3. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	9/15/09	12/2/09	3/24/10	5/24/10
T (C)	14.8	11.7	7.5	12.4
SpC(µS/cm)	1145	1112	1027	1013
pH	6.81	6.77	6.37	ND
ORP (mV)	ND	ND	ND	545
DO	9.1	5.2	ND	0.2
Al	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108
B	0.062	0.058	0.070	0.054
Ba	0.027	0.026	0.028	0.024
Be	<0.00055	<0.00055	<0.00055	<0.00055
Ca	72.7	76.3	77.1	67.2
Cd	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0011	0.0008	<0.00079	0.0015
Fe	<0.0059	<0.0059	<0.0059	0.009
K	1.89	1.95	2.04	1.80
Li	<0.058	<0.058	<0.058	<0.058
Mg	38.5	37.6	40.4	36.0
Mn	<0.0015	<0.0015	<0.0015	<0.0015
Mo	<0.022	<0.022	<0.022	<0.022
Na	122.00	123.53	132.59	128.07
Ni	0.0190	<0.014	0.0239	0.0249
P	<0.063	<0.063	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041
S	28.70	30.48	34.98	30.59
Sb	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131
Si	7.00	7.16	6.87	6.38
Sn	<0.086	<0.086	<0.086	<0.086
Sr	0.142	0.136	0.132	0.130
Ti	<0.00056	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	0.019	<0.017
V	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	<0.0073	<0.0073	<0.0073
Alkalinity	454	448	445	456
F^-	0.202	0.233	0.198	0.211
Cl^-	20.4	20.0	22.6	22.8
NO_3-N	3.87	3.74	3.07	2.60
DRP	89.0	85.2	94.6	91.5
SO_4^{2-}	<0.01	0.014	0.014	0.014
DOC	2.83	2.83	3.42	2.18
TKN	0.41	0.28	<0.26	<0.26
NH_3-N	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND
δD	ND	ND	ND	ND

Table 23. Water Chemistry Results for Well Lex-4. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	7/21/06	11/29/06	3/29/07	4/26/07	8/29/07	11/27/07	4/17/08	6/18/08	9/25/08	4/9/09
T (C)	14.4	17.3	9.3	13.9	16.2	12.0	11.9	17.8	15.5	11.6
SpC(µS/cm)	844	750	584	333	839	946	693	588	824	733
pH	6.98	7.32	7.51	7.36	6.84	6.81	6.77	6.73	7.31	7.46
ORP (mV)	ND	329	338	390	389	366	384	329	382	347
DO	4.5	1.5	5.2	6.5	2.7	3.1	6.3	8.4	5.2	6.2
Al	<0.059	0.031	0.031	0.025	0.260	0.089	0.086	0.114	0.080	<0.037
As	<0.119	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.048	0.067	0.038	0.043	0.033	0.050	0.035	0.039	0.029	0.038
Ba	0.075	0.056	0.049	0.036	0.038	0.042	0.030	0.027	0.027	0.028
Be	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	90.5	113	109	77.3	99.2	106	87.9	70.3	84.5	79.1
Cd	<0.014	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.016	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.015	0.068	0.010	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.011	0.0024	<0.0007	0.0009	<0.0007	<0.0007	<0.0007	0.0013	<0.0007	0.0008
Fe	<0.015	0.296	0.033	<0.0059	0.183	0.056	0.047	<0.0059	<0.0059	0.012
K	4.12	3.77	2.80	1.58	2.97	2.99	1.89	1.54	2.36	1.58
Li	<0.070	0.0262	0.0242	0.0127	0.0246	0.0278	<0.018	<0.018	<0.018	<0.018
Mg	40.7	55.9	55.7	36.4	52.7	57.7	43.7	35.5	45.1	37.8
Mn	0.112	0.076	<0.0015	<0.0015	0.012	0.003	<0.0015	<0.0015	<0.0015	<0.0015
Mo	<0.020	0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	24.7	11.1	14.9	19.4	14.8	11.3	21.5	28.5	19.3	47.9
Ni	<0.023	0.0830	0.0310	0.0300	0.0250	0.0180	0.0210	<0.014	0.0270	0.0330
P	<0.127	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.051	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	42.4	63.3	65.3	26.8	42.2	55.9	38.0	22.4	36.4	34.5
Sb	<0.193	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.180	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	7.36	7.61	6.65	5.73	7.98	7.35	5.83	5.46	6.63	5.54
Sn	<0.091	<0.070	<0.070	<0.070	<0.070	<0.070	<0.086	<0.086	<0.086	<0.086
Sr	0.193	0.223	0.220	0.132	0.222	0.245	0.173	0.129	0.176	0.152
Ti	<0.005	<0.0005	<0.0005	<0.0005	0.0078	0.0013	0.0016	<0.0005	<0.0005	<0.0005
Tl	ND	<0.017	0.011	0.019	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.028	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.14	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073
Alkalinity	238	295	297	241	292	308	266	268	300	301
F^-	0.228	0.263	0.228	0.194	0.220	0.204	0.216	0.226	0.288	0.207
Cl^-	20.5	17.0	16.9	12.9	15.7	15.5	16.9	13.3	15.6	14.0
NO_3-N	19.0	8.54	7.21	4.18	5.64	3.88	8.05	4.82	5.85	5.31
SO_4^{2-}	128	171	173	73.7	148	169	118	74.2	108	101
DRP	<0.64	<0.64	<0.64	<0.64	<0.02	<0.01	0.012	0.01	0.02	0.01
DOC	2.41	ND	0.92	2.72		1.19	1.02	1.55	0.51	1.99
TKN	<0.26	ND	<0.26	0.41	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
NH_3-N	<0.06	ND	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	6.0	6.0	ND	4.1	8.8	5.1	5.4	4.5	5.1	5.1
$\delta^{18}O$-NO_3	3.2	5.5	ND	5.4	3.5	2.4	4.0	3.9	2.3	3.5
δD	-48.7	-48.8	ND	ND	ND	ND	ND	ND	ND	ND

Table 23 (cont.). Water Chemistry Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/9/09	9/15/09	12/2/09	3/24/10	5/24/10
T (C)	12.0	13.2	11.3	7.4	13.6
SpC(µS/cm)	781	940	807	748	712
pH	7.52	6.92	6.90	6.50	ND
ORP (mV)	ND	ND	ND	ND	546
DO	2.8	2.2	6.1	ND	4.7
Al	<0.037	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.027	0.040	0.036	0.040	0.027
Ba	0.027	0.031	0.029	0.026	0.028
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	78.3	81.3	74.8	74.1	72.0
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.00079	0.0014	<0.00079	<0.00079	<0.00079
Fe	<0.0059	<0.0059	0.007	<0.0059	<0.0059
K	1.54	1.78	1.48	1.60	1.42
Li	<0.018	<0.058	<0.058	<0.058	<0.058
Mg	38.5	37.6	33.4	30.4	34.6
Mn	<0.0015	<0.0015	0.011	<0.0015	<0.0015
Mo	<0.022	<0.022	<0.022	<0.022	<0.022
Na	38.8	38.6	54.5	51.0	43.6
Ni	<0.014	0.0200	<0.014	<0.014	0.0202
P	<0.063	<0.063	0.0707	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	30.68	27.70	26.77	25.99	24.35
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	5.46	5.93	5.51	5.52	5.31
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.145	0.152	0.129	0.123	0.134
Ti	<0.00056	<0.00056	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	0.0083	0.0088	<0.0073	<0.0073
Alkalinity	294	306	309	306	307
F^-	0.262	0.178	0.194	0.223	0.220
Cl^-	13.0	12.7	11.0	11.5	12.0
NO_3-N	5.11	5.53	4.83	4.12	4.03
SO_4^{2-}	93.9	81.9	70.6	73.7	82.0
DRP	<0.01	<0.01	0.015	0.013	0.014
DOC	1.57	1.48	1.31	1.67	1.26
TKN	<0.26	0.26	0.30	<0.26	<0.26
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND

Table 24. Water Chemistry Results for Well Lex-5. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	7/21/06	11/29/06	3/29/07	4/26/07	8/29/07	11/27/07	4/17/08	6/18/08	9/25/08	1/5/09
T (C)	15.9	15.0	9.8	12.4	17.5	11.5	10.8	14.7	17.0	8.4
SpC(µS/cm)	748	675	523	471	765	872	752	771	825	871
pH	7.07	7.33	7.48	7.04	6.94	6.92	6.68	6.58	7.39	7.30
ORP (mV)	ND	334	350	396	382	320	380	319	395	394
DO	0.5	4.4	3.3	0.9	2.7	1.4	2.5	1.4	4.2	4.0
Al	<0.059	0.027	0.040	0.039	0.042	0.088	1.198	0.141	1.739	<0.037
As	<0.119	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.130	0.256	0.205	0.214	0.245	0.240	0.208	0.225	0.234	0.237
Ba	0.062	0.057	0.046	0.046	0.052	0.044	0.042	0.038	0.054	0.038
Be	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	79.3	92.5	94.7	98.1	98.2	94.6	96.0	90.1	89.5	90.5
Cd	<0.014	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.016	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.015	0.007	0.020	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.011	<0.0007	0.0009	0.0009	<0.0007	<0.0007	0.0009	<0.0007	<0.0007	<0.0007
Fe	<0.015	0.031	0.085	0.018	0.021	0.065	0.781	<0.0059	1.357	<0.0059
K	2.41	2.22	1.78	1.78	2.16	1.97	2.09	1.82	2.88	1.83
Li	<0.070	0.0211	0.0204	0.0218	0.0237	0.0203	<0.018	<0.018	<0.018	<0.018
Mg	38.4	43.8	47.0	49.2	51.4	49.9	48.4	41.0	49.1	44.9
Mn	0.288	0.190	0.021	0.007	0.194	0.108	0.021	0.002	0.152	<0.0015
Mo	<0.020	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	34.0	23.3	22.9	22.0	22.6	25.3	23.7	28.5	26.2	27.0
Ni	0.0248	0.0200	0.0310	0.0310	0.0190	<0.014	0.0170	0.0160	0.0250	0.0180
P	<0.127	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.051	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	42.30	50.00	61.40	52.60	48.50	53.90	62.10	55.70	57.60	54.70
Sb	<0.193	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.180	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	6.86	7.57	6.52	6.41	7.51	7.26	9.10	6.29	11.1	6.43
Sn	<0.091	<0.070	<0.070	<0.070	<0.070	<0.070	<0.086	<0.086	<0.086	<0.086
Sr	0.261	0.360	0.368	0.360	0.447	0.380	0.384	0.367	0.400	0.347
Ti	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	0.0016	0.0472	<0.0005	0.0721	<0.0005
Tl		<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.028	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.233	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073
Alkalinity	268	296	284	282	302	301	281	287	299	292
F^-	0.282	0.353	0.302	0.278	0.280	0.278	0.260	0.268	0.352	0.308
Cl^-	21.6	13.5	14.6	15.4	13.5	13.8	14.0	14.4	14.7	14.1
NO_3-N	4.64	0.73	0.33	1.59	0.22	0.65	0.28	1.41	0.51	0.78
SO_4^{2-}	128	145	163	164	149	157	175	165	162	163
DRP	<0.64	<0.64	<0.64	<0.64	<0.02	<0.01	0.047	<0.01	0.03	<0.01
DOC	2.40		0.69	1.60	1.01	0.82	0.52	0.63	0.64	0.43
TKN	<0.26		<0.26	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
NH_3-N	<0.06		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	12.0	6.1	ND	8.3	ND	ND	ND	7.6	ND	ND
$\delta^{18}O$-NO_3	5.8	5.8	ND	8.7	ND	ND	ND	9.2	ND	ND
δD	-44.2	-37.8	ND	ND	ND	ND	ND	ND	ND	ND

Table 24 (cont.). Water Chemistry Results for Well Lex-5. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	4/9/09	6/9/09	9/15/09	12/2/09	3/24/10	5/24/10
T (C)	10.2	11.9	14.9	11.7	7.5	13.4
SpC(µS/cm)	798	836	915	876	834	803
pH	7.37	7.48	6.97	6.61	6.49	ND
ORP (mV)	384	ND	ND	ND	ND	532
DO	4.9	1.8	3.5	3.7	ND	1.7
Al	0.721	0.039	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.217	0.037	0.222	0.230	0.212	0.195
Ba	0.040	0.038	0.038	0.036	0.036	0.036
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	91.5	92.9	90.2	102	95.6	89.5
Cd	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0011	<0.00079	<0.00079	<0.00079	<0.00079	<0.00079
Fe	0.525	0.074	<0.0059	<0.0059	<0.0059	<0.0059
K	2.00	1.80	1.62	1.75	1.78	1.66
Li	<0.018	<0.018	<0.058	<0.058	<0.058	<0.058
Mg	46.8	46.3	46.0	45.8	46.8	44.9
Mn	0.010	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Mo	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	24.5	27.2	27.1	30.3	30.1	27.8
Ni	0.0290	<0.014	0.0250	<0.014	0.0153	0.0333
P	<0.063	<0.063	<0.063	0.0649	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	53.4	53.2	39.7	49.8	58.9	53.6
Sb	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	7.67	5.99	6.01	6.34	5.89	5.52
Sn	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.383	0.380	0.375	0.356	0.334	0.345
Ti	0.0326	0.0006	<0.00056	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	<0.0073	<0.0073	0.0081	<0.0073	<0.0073
Alkalinity	289	294	305	301	289	291
F^-	0.282	0.296	0.276	0.236	0.268	0.269
Cl^-	14.1	14.8	14.0	14.7	14.6	14.2
NO_3-N	0.47	1.60	2.72	0.93	0.41	0.31
SO_4^{2-}	159	155	118	148	164	158
DRP	0.07	<0.01	<0.01	0.006	0.009	0.009
DOC	1.11	0.83	0.77	0.64	0.82	0.62
TKN	0.29	<0.26	<0.26	<0.26	<0.26	<0.26
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	9.2	6.2	ND	ND	ND
$\delta^{18}O$-NO_3	ND	8.2	6.0	ND	ND	ND
δD	ND	ND	ND	ND	ND	ND

Table 25. Water Chemistry Results for Well Lex-6. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	7/21/06	11/29/06	3/29/07	4/26/07	8/29/07	11/27/07	4/17/08	6/18/08	9/25/08	4/9/09
T (C)	15.2	17.7	9.0	15.1	21.2	11.5	12.9	ND	16.7	15.3
SpC(µS/cm)	770	658	485	416	687	850	622	ND	801	640
pH	6.88	7.34	7.34	6.97	6.81	6.74	6.46	ND	7.13	7.07
ORP (mV)	ND	290	389	418	376	383	371	ND	379	352
DO	1.5	2.7	2.9	2.6	0.8	1.5	2.5	ND	1.0	2.5
Al	<0.059	0.027	0.037	0.031	0.021	0.319	0.065	0.173	0.434	0.084
As	<0.119	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	<0.036	0.031	<0.023	0.026	<0.023	<0.023	<0.023	0.032	<0.023	<0.023
Ba	0.042	0.041	0.037	0.035	0.044	0.039	0.029	0.030	0.034	0.032
Be	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	98.1	102	96.2	95.9	106	92.4	90.3	83.0	81.3	87.8
Cd	<0.014	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.016	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.015	0.043	0.010	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.011	0.0021	<0.0007	<0.0007	<0.0007	0.0009	<0.0007	<0.0007	<0.0007	<0.0007
Fe	<0.015	0.189	0.050	<0.0059	0.008	0.260	0.049	0.029	0.345	0.055
K	1.46	1.19	0.79	0.84	1.79	1.48	0.87	1.01	1.48	0.79
Li	<0.070	<0.0048	<0.0048	0.0058	0.007	0.0068	<0.018	<0.018	<0.018	<0.018
Mg	41.8	41.8	40.6	41.6	45.5	41.3	38.4	33.8	36.3	38.7
Mn	0.094	0.048	0.016	0.023	0.252	0.064	0.013	0.007	0.012	0.005
Mo	<0.020	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	10.3	10.1	9.11	9.22	12.1	18.1	10.0	16.0	32.8	14.4
Ni	0.0237	0.0540	0.0240	0.0280	0.0180	<0.014	0.0190	<0.014	0.0190	0.0310
P	<0.127	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063
Pb	<0.051	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	12.7	11.1	9.24	9.12	18.5	13.5	9.95	7.93	12.3	6.09
Sb	<0.193	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.180	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	5.92	5.66	4.86	4.96	6.23	6.51	4.87	5.41	7.50	5.56
Sn	<0.091	<0.070	<0.070	<0.070	<0.070	<0.070	<0.086	<0.086	<0.086	<0.086
Sr	0.147	0.151	0.144	0.146	0.176	0.160	0.142	0.152	0.152	0.160
Ti	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	0.0087	0.0009	0.0012	0.0164	0.0010
Tl	ND	<0.017	<0.017	<0.017	0.02	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.028	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.0947	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073
Alkalinity	304	318	289	286	318	321	278	284	318	362
F^-	0.206	0.210	0.183	0.180	0.193	0.174	0.172	0.197	0.255	0.155
Cl^-	31.1	29.9	23.9	23.3	22.5	23.6	20.9	19.2	16.8	14.9
NO_3-N	13.5	11.9	17.3	17.8	6.16	12.9	15.0	16.4	12.9	3.79
SO_4^{2-}	38.1	32.8	27.1	26.9	69.4	42.2	31.7	27.1	29.6	18.6
DRP	<0.64	<0.64	<0.64	<0.64	<0.02	<0.01	<0.01	<0.01	0.02	0.01
DOC	1.85	2.18	1.09	2.33	0.93	0.97	0.96	1.37	0.86	1.15
TKN	<0.26	4.46	0.58	<0.26	<0.26	<0.26	<0.26	<0.26	1.94	<0.26
NH_3-N	<0.06	4.78	0.976	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	13.6	21.8	ND	15.9	22.4	21.8	13.8	11.7	15.5	22.7
$\delta^{18}O$-NO_3	7.1	12.4	ND	10.8	12.8	15.2	8.8	7.2	10.8	16.0
δD	-43.1	-44.0	ND	ND	ND	ND	ND	ND	ND	ND

Table 25 (cont.). Water Chemistry Results for Well Lex-6. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/9/09	9/15/09	12/2/09	3/24/10	5/24/10
T (C)	11.6	13.7	11.3	7.6	13.4
SpC(µS/cm)	711	863	1161	716	671
pH	7.34	6.66	6.47	6.42	ND
ORP (mV)	ND	ND	ND	ND	534
DO	2.5	0.3	3.6	ND	2.3
Al	<0.037	0.209	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.032	0.037	0.037	0.034	<0.023
Ba	0.033	0.034	0.038	0.030	0.029
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	90.9	86.1	77.4	75.7	69.2
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.00079	0.0016	0.0025	0.0012	0.0024
Fe	<0.0059	0.194	0.031	0.008	0.021
K	0.77	1.69	4.65	2.79	1.69
Li	<0.018	<0.058	<0.058	<0.058	<0.058
Mg	40.2	36.0	25.4	30.6	28.6
Mn	0.020	0.173	0.020	0.008	0.045
Mo	<0.022	<0.022	<0.022	<0.022	<0.022
Na	11.0	23.9	112	45.2	39.0
Ni	<0.014	0.0180	<0.014	0.0165	0.0252
P	<0.063	<0.063	0.3269	0.2329	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	6.20	11.20	16.84	9.09	11.07
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	5.71	7.61	10.5	7.82	6.73
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.151	0.169	0.353	0.198	0.209
Ti	<0.00056	0.0065	<0.00056	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	<0.0073	0.0093	<0.0073	<0.0073
Alkalinity	353	354	271	268	304
F^-	0.200	0.198	0.230	0.198	0.316
Cl^-	13.0	12.3	9.93	9.33	11.5
NO_3-N	2.46	1.91	33.51	19.9	6.47
SO_4^{2-}	17.9	25.5	31.8	25.8	34.4
DRP	<0.01	0.02	0.143	0.206	0.086
DOC	1.47	1.78	3.53	3.96	1.99
TKN	<0.26	<0.26	<0.26	<0.26	0.39
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	26.3	34.8	14.8	17.6	21.2
$\delta^{18}O$-NO_3	12.3	15.8	3.0	2.5	5.1
δD	ND	ND	ND	ND	ND

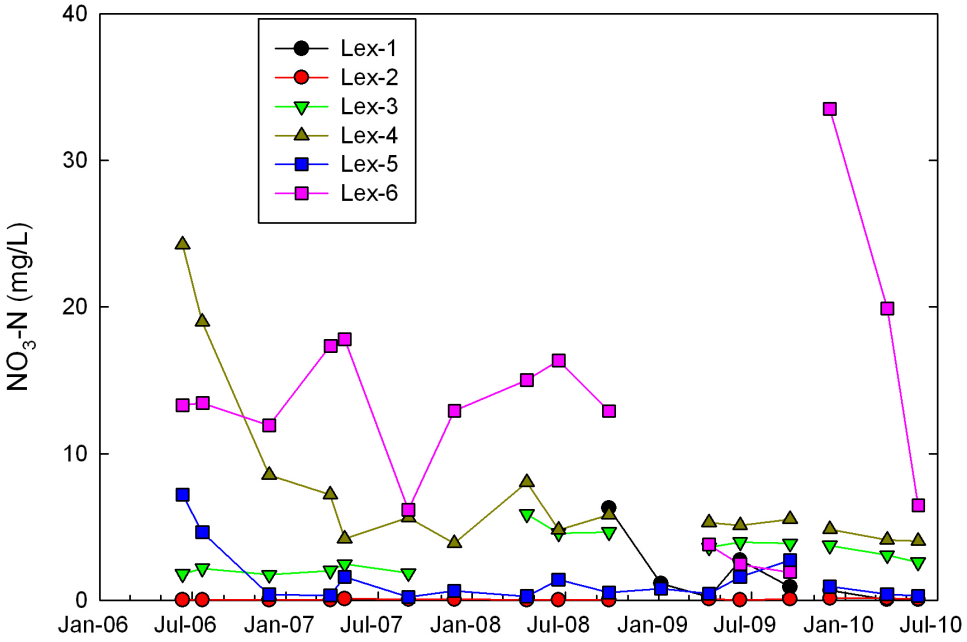

Figure 22. Nitrate-N concentrations for wells in large fields north of the ISU Farm

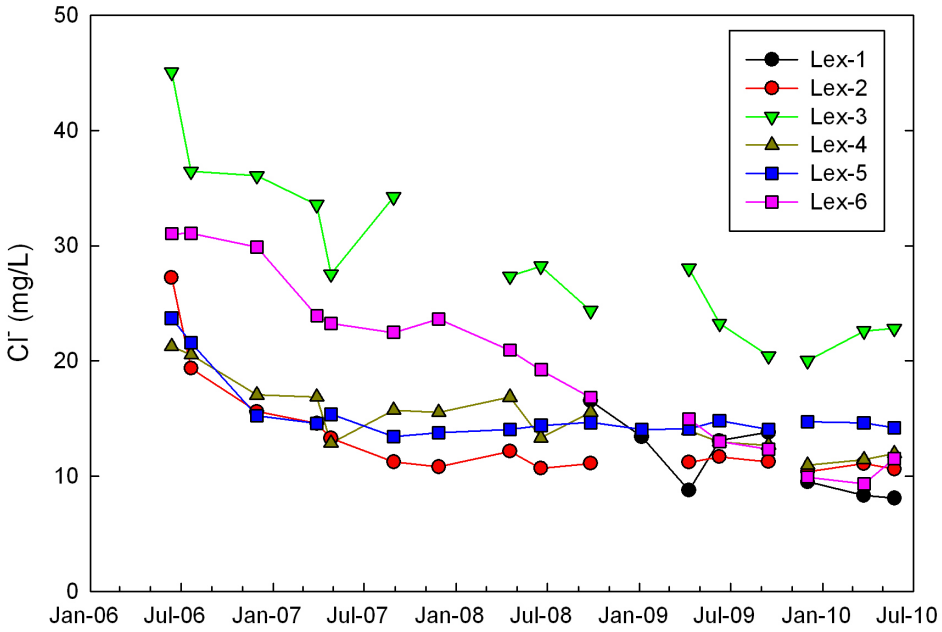

Figure 23. Chloride concentrations for wells in large fields north of the ISU Farm

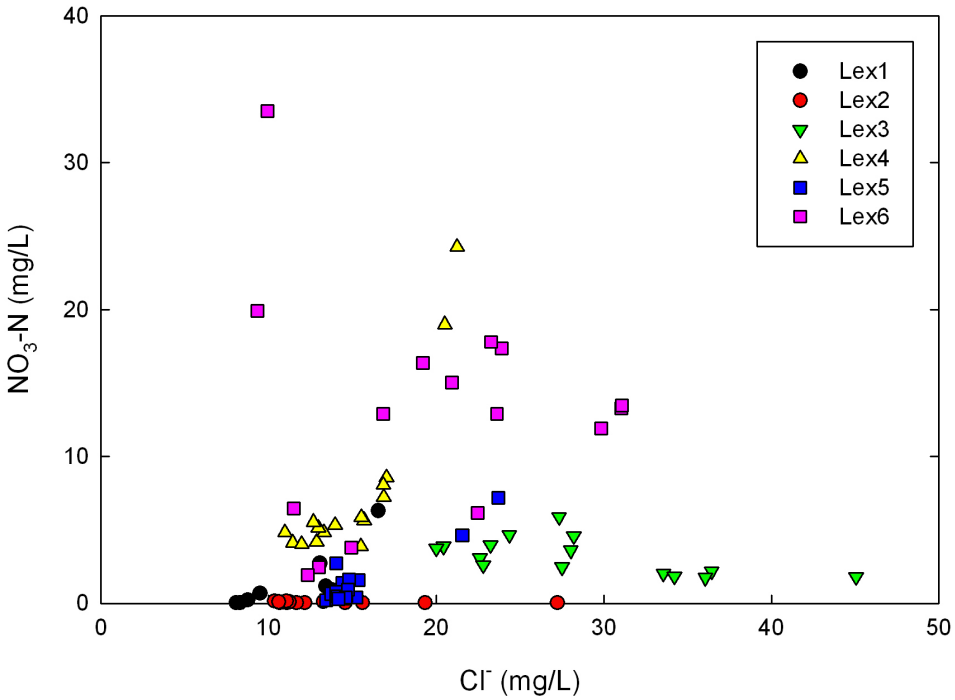

Figure 24. Chloride vs. nitrate-N concentrations for wells north of ISU Farm

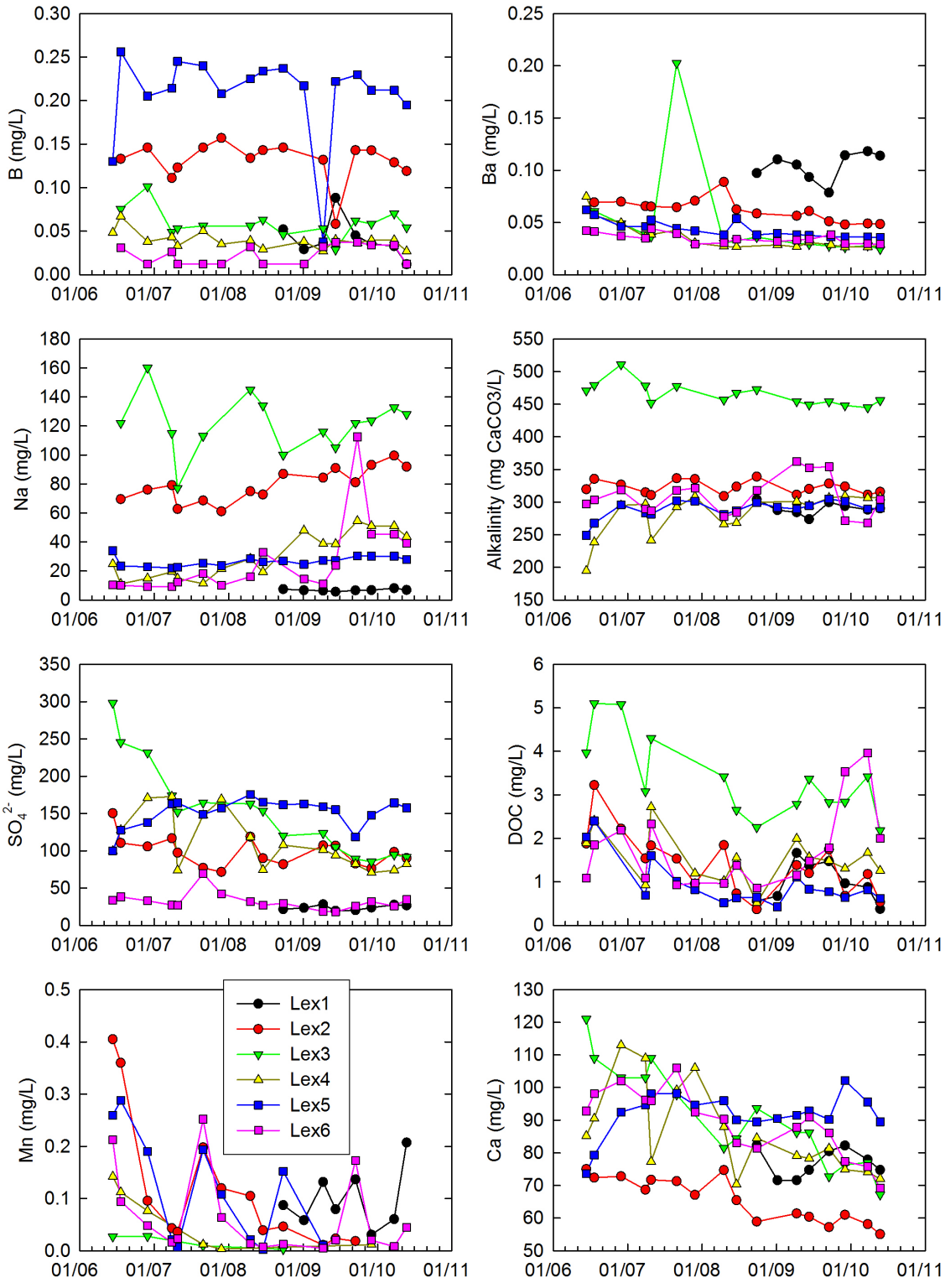

Figure 25. Concentrations of various chemical parameters for wells in large fields north of the ISU Farm

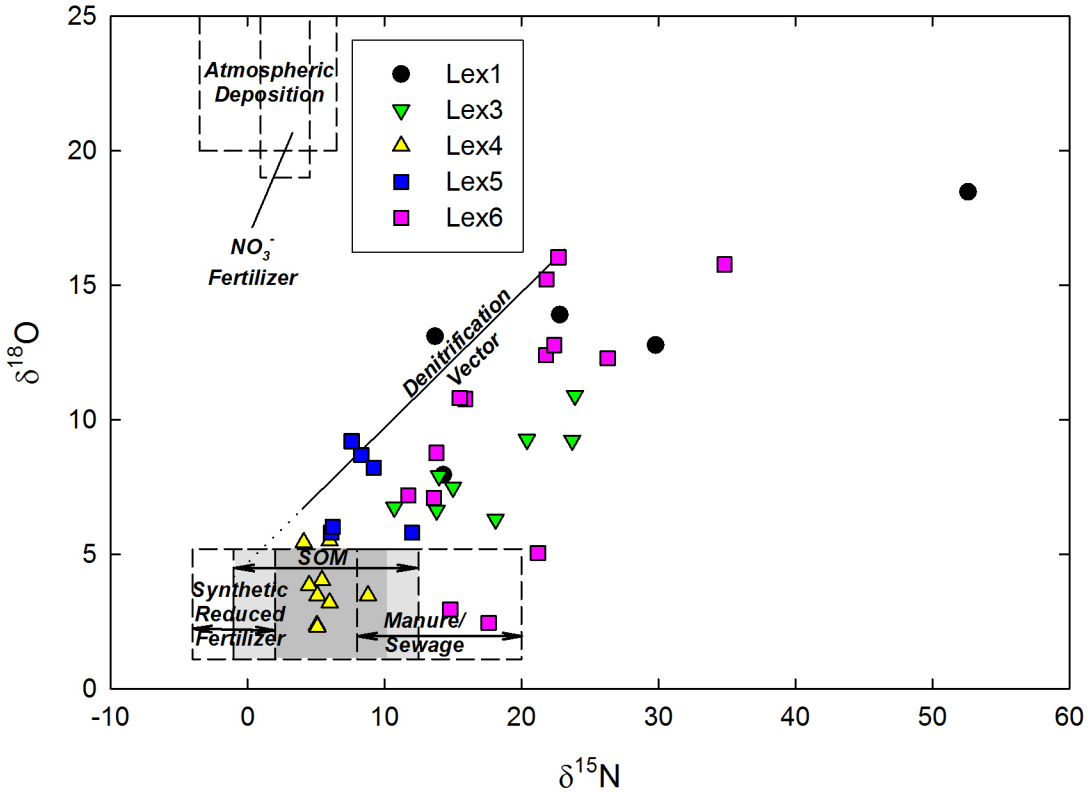

Figure 26. Nitrate isotope values for well samples on fields north of ISU Farm. Boxes outlined by dashed lines indicate isotopic ranges for potential sources of nitrate. The denitrification vector indicates the theoretical change in $\delta^{15}N$ and $\delta^{18}O$ values of residual nitrate after a fraction of the nitrate pool has been denitrified.

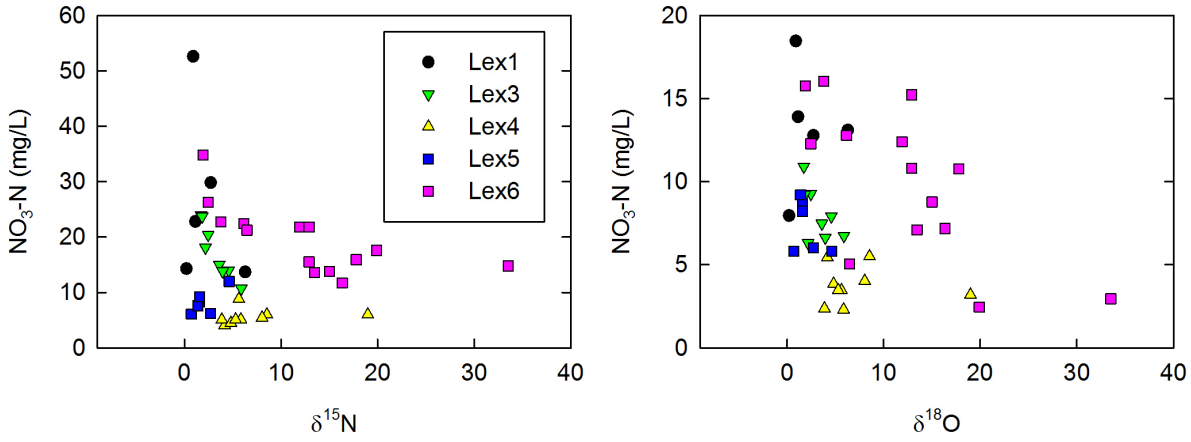

Figure 27. Nitrate isotopic values vs. NO_3-N for wells Lex-1 and Lex-3 – Lex-6

Table 26. Water Chemistry Results for Well Lex-7. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/18/08	9/25/08	1/5/09	4/9/09	6/9/09	9/15/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	16.2	16.9	8.6	14.2	12.2	13.5	11.2	7.3	13.9	15.1
SpC(µS/cm)	676	748	708	611	753	930	815	722	732	782
pH	6.50	7.17	7.26	7.28	7.58	6.94	6.46	6.47	ND	7.17
ORP (mV)	334	402	377	369	ND	ND	ND	ND	519	429
DO	2.6	6.0	8.3	4.9	1.7	0.3	2.7	ND	0.9	0.5
Al	6.847	0.240	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.053	<0.023	<0.023	<0.023	0.058	0.031	<0.023	<0.023	<0.023	0.037
Ba	0.082	0.064	0.051	0.054	0.060	0.062	0.058	0.054	0.064	0.064
Be	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ca	95.8	90.5	81.5	92.1	91.9	96.8	105	97.9	98.8	99.5
Cd	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	0.0091	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0041	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	0.0009	<0.0007	0.0011	0.0023
Fe	5.150	0.192	0.007	0.013	<0.0059	<0.0059	<0.0059	<0.0059	<0.0059	0.007
K	5.14	1.08	0.58	0.57	0.92	1.20	1.13	0.80	0.58	1.77
Li	<0.018	<0.018	<0.018	<0.018	<0.018	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	44.2	39.9	35.1	38.5	39.8	40.0	39.6	35.9	40.2	47.1
Mn	0.097	0.015	0.010	0.006	0.007	0.027	0.022	<0.0015	0.003	0.187
Mo	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	0.034	<0.022	<0.022
Na	9.72	10.8	8.29	8.02	8.83	8.54	8.91	8.38	8.12	8.88
Ni	0.0290	0.0210	0.0170	0.0280	<0.014	0.0190	0.0142	0.0141	0.0252	0.0211
P	<0.063	<0.063	<0.063	<0.063	<0.063	<0.063	3.1709	<0.063	<0.063	<0.063
Pb	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	17.8	15.9	13.0	14.9	17.3	19.3	19.8	15.8	13.1	24.1
Sb	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	20.4	6.07	3.86	4.14	4.64	5.22	5.18	4.47	4.68	5.25
Sn	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.165	0.149	0.121	0.148	0.153	0.164	0.160	0.135	0.151	0.169
Ti	0.245	0.0048	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Tl	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	0.022	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	0.0081	0.0178	<0.0073	<0.0073	0.0102
Alkalinity	275	313	276	286	294	302	325	313	327	342
F^-	0.221	0.218	0.199	0.157	0.216	0.200	0.218	0.156	0.178	0.188
Cl^-	9.20	6.27	6.18	7.24	6.88	6.48	6.45	5.70	5.71	5.78
NO_3-N	17.7	12.2	13.6	14.1	14.5	12.6	8.03	9.86	10.1	9.88
SO_4^{2-}	59.8	44.5	41.8	44.2	45.5	48.0	50.7	45.6	46.9	47.7
DRP	<0.01	0.02	<0.01	0.01	<0.01	<0.01	0.006	0.010	0.007	0.011
DOC	2.30	3.92	0.91	1.19	1.26	1.08	1.10	1.62	0.59	2.10
TKN	<0.26	<0.26	<0.26	0.35	0.54	<0.26	<0.26	<0.26	<0.26	0.35
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	9.7	10.1	10.4	10.4	10.1	11.4	11.0	11.0	11.0	14.6
$\delta^{18}O$-NO_3	6.9	7.4	6.6	6.5	7.0	6.4	7.6	7.1	7.0	10.2
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 27. Water Chemistry Results for Well Lex-8. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/18/08	9/25/08	1/5/09	4/9/09	6/9/09	9/15/09	9/24/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	ND	17.8	9.1	13.4	11.9	15.9	ND	10.8	7.7	13.6	17.1
SpC(µS/cm)	ND	763	697	598	700	1613	ND	7	1173	1144	1411
pH	ND	7.29	7.23	7.07	7.49	6.56	ND	485.00	6.35	ND	6.94
ORP (mV)	ND	373	365	359	ND	ND	ND	ND	ND	544	149
DO	ND	3.9	1.6	1.2	1.2	2.2	ND	4.4	ND	0.8	3.0
Al	8.612	0.061	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.043	<0.023	<0.023	0.035	0.050	0.112	0.092	0.086	0.055	0.058	0.125
Ba	0.079	0.059	0.045	0.045	0.051	0.167	0.145	0.150	0.099	0.102	0.156
Be	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00055
Ca	101	86.0	74.9	79.7	80.9	194	181	195	145	132	182
Cd	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	0.0091	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0055	<0.0007	<0.0007	<0.0007	0.0009	0.0010	0.0009	0.0013	0.0015	0.0017	0.0011
Fe	6.637	<0.0059	<0.0059	0.006	0.013	4.99	3.85	0.010	0.006	<0.0059	0.973
K	5.01	0.61	0.51	0.41	0.46	2.72	2.55	2.47	1.79	1.51	2.89
Li	<0.018	<0.018	<0.018	<0.018	<0.018	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	44.3	38.6	32.6	34.4	33.9	83.0	75.6	74.5	59.1	54.4	79.5
Mn	0.237	0.024	0.008	<0.0015	0.003	0.942	0.774	0.584	0.342	0.201	0.654
Mo	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	16.0	13.1	9.88	9.78	10.6	36.5	38.6	41.1	54.3	31.1	42.5
Ni	0.0300	0.0250	0.0160	0.0300	<0.014	0.0380	0.0470	0.0367	0.0339	0.0321	0.0526
P	0.0860	<0.063	<0.063	<0.063	<0.063	0.114	<0.063	0.261	<0.063	<0.063	0.138
Pb	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	21.5	16.5	13.3	12.9	14.0	82.3	15.9	20.2	21.2	12.9	12.5
Sb	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	22.7	6.09	4.44	4.40	5.03	8.52	8.14	6.75	5.98	5.69	7.82
Sn	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.175	0.147	0.116	0.133	0.136	0.335	0.322	0.323	0.239	0.221	0.307
Ti	0.2862	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	0.019	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.0258	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	<0.0073	0.220	0.101	0.100	<0.0073
Alkalinity	217	248	237	233	237	647	655	449	479	453	662
F^-	0.216	0.244	0.192	0.159	0.221	0.135	0.246	0.148	0.146	0.154	0.199
Cl^-	9.26	6.19	5.21	5.32	5.71	113	114	96.7	81.4	65.4	96.3
NO_3-N	28.4	27.5	19.5	21.5	22.2	0.15	0.08	6.74	5.04	7.75	1.17
SO_4^{2-}	79.0	44.7	39.5	38.2	40.8	38.3	49.2	39.9	67.7	42.2	32.8
DRP	<0.01	0.02	<0.01	0.01	<0.01	0.05	0.022	0.113	0.025	0.035	0.025
DOC	3.59	0.59	1.08	1.43	1.28	11.08	14.27	5.78	5.15	3.16	17.90
TKN	<0.26	<0.26	<0.26	<0.26	<0.26	3.77	2.98	1.22	0.54	0.47	3.81
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06	2.375	1.707	0.486	<0.06	0.204	2.045
$\delta^{15}N$-NO_3	8.0	8.5	11.5	11.1	11.1	ND	ND	39.6	43.1	38.4	32.1
$\delta^{18}O$-NO_3	6.3	6.5	8.6	6.7	7.2	ND	ND	19.5	19.8	15.8	18.8
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 28. Water Chemistry Results for Well Lex-9. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	6/18/08	9/25/08	1/5/09	4/9/09	6/9/09	9/15/09	9/24/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	ND	17.8	8.6	ND	11.7	16.6	ND	11.5	7.9	13.0	18.7
SpC(µS/cm)	ND	854	863	ND	806	776	ND	1120	1003	1073	1056
pH	ND	7.27	7.34	ND	7.44	6.73	ND	6.59	6.76	ND	7.17
ORP (mV)	ND	365	386	ND	ND	ND	ND	ND	ND	558	346
DO	ND	0.1	4.8	ND	0.5	0.4	ND	1.2	ND	0.2	1.6
Al	8.842	0.304	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.056	0.042	0.036	0.045	0.065	0.076	0.088	<0.023	0.063	0.056	0.092
Ba	0.108	0.084	0.071	0.070	0.067	0.097	0.148	0.030	0.108	0.105	0.113
Be	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00055
Ca	105	85.9	85.3	88.5	86.6	122	129	38.2	128	120	125
Cd	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	0.0094	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0081	<0.0007	0.0008	0.0016	<0.0007	0.0013	0.0022	0.0008	0.0014	0.0014	0.0025
Fe	8.043	0.262	0.007	0.019	<0.0059	0.018	0.019	<0.0059	0.008	<0.0059	<0.0059
K	5.35	1.16	0.83	1.60	0.69	1.70	6.52	0.64	2.01	1.79	2.22
Li	<0.018	<0.018	<0.018	<0.018	<0.018	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	44.6	38.0	36.9	38.4	38.6	53.5	54.3	13.4	56.3	52.0	56.5
Mn	0.148	0.048	0.024	0.016	0.014	0.158	0.360	0.004	0.076	0.091	0.149
Mo	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Na	19.4	48.6	36.8	27.6	30.9	25.6	35.5	6.86	51.2	47.3	40.7
Ni	0.0380	0.0220	0.0180	0.0270	<0.014	0.0250	0.0360	<0.014	0.0224	0.0207	0.0395
P	0.0790	<0.063	<0.063	<0.063	<0.063	0.0690	0.0770	0.218	<0.063	<0.063	0.0807
Pb	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041
S	18.1	24.1	21.5	23.6	16.7	33.9	13.4	20.8	20.8	19.8	19.3
Sb	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131	<0.131
Si	23.5	6.70	5.03	4.77	4.94	6.34	6.90	1.47	5.98	5.92	6.66
Sn	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.196	0.169	0.156	0.188	0.160	0.255	0.283	0.057	0.230	0.242	0.252
Ti	0.3065	0.0090	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00056
Tl	<0.017	<0.017	<0.017	0.025	<0.017	<0.017	<0.017	0.024	0.022	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.0296	<0.0073	<0.0073	0.0282	0.0102	0.0475	0.623	0.0663	0.161	0.115	0.0326
Alkalinity	232	282	275	254	258	367	530	445	456	451	474
F^-	0.248	0.277	0.225	0.224	0.253	0.225	0.126	0.215	0.188	0.226	0.228
Cl^-	10.6	11.8	8.04	10.8	7.08	40.3	71.0	55.1	58.3	51.9	53.7
NO_3-N	33.41	26.92	28.19	26.23	29.46	7.75	3.84	5.08	4.32	3.84	4.28
SO_4^{2-}	54.3	72.3	55.8	68.5	48.3	40.2	43.2	58.7	57.5	62.8	51.8
DRP	<0.01	0.04	<0.01	0.01	<0.01	0.35	0.086	0.046	0.022	0.023	0.017
DOC	20.0	0.79	1.06	2.37	1.91	6.34	6.72	4.16	3.32	2.23	4.99
TKN	0.32	<0.26	<0.26	0.64	<0.26	0.73	2.56	0.56	0.36	<0.26	0.68
NH_3-N	0.062	<0.06	<0.06	<0.06	<0.06	0.152	1.55	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	10.6	ND	ND	21.7	23.4	ND	ND	39.8	48.3
$\delta^{18}O$-NO_3	ND	ND	7.0	ND	ND	12.3	13.0	ND	ND	18.3	23.1
δD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

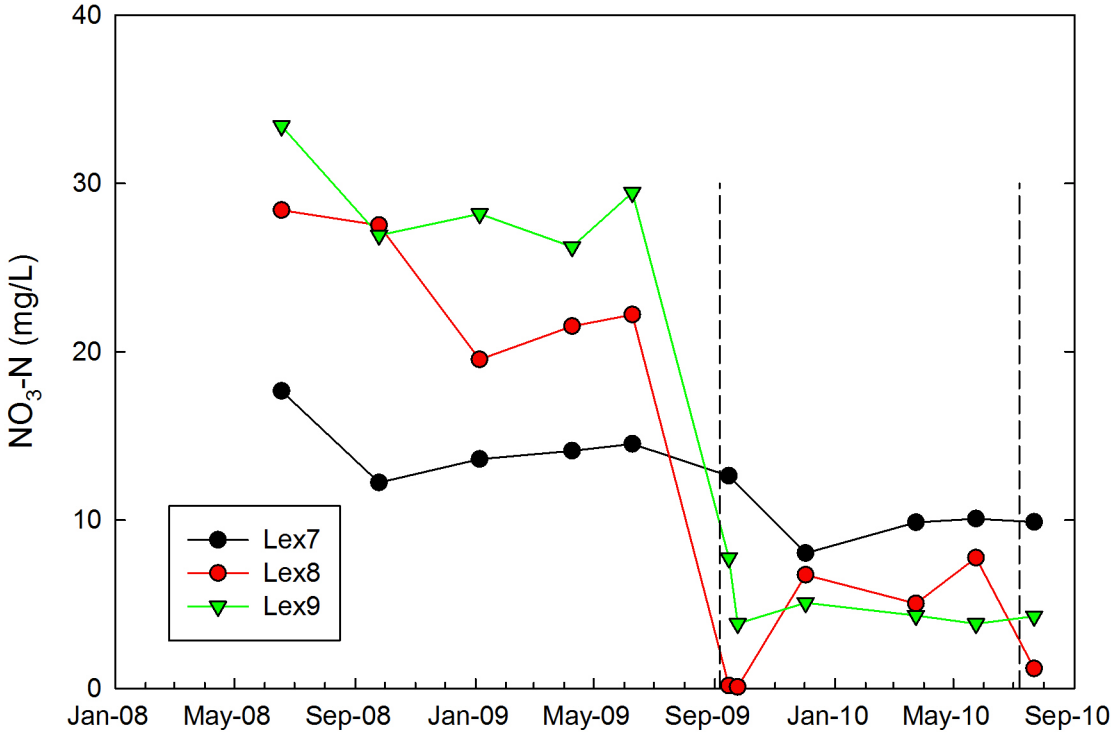

Figure 28. Nitrate-N concentrations for wells at the subsurface irrigation field at the ISU Farm. Dashed lines indicate dates of subsurface effluent application.

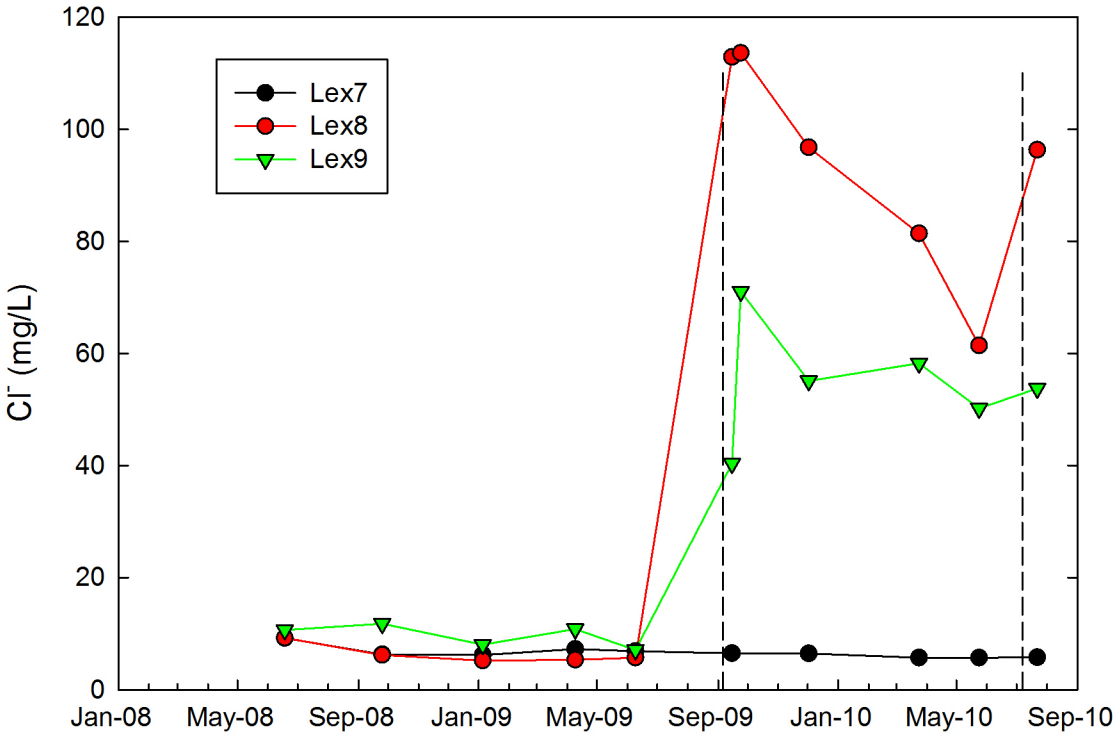

Figure 29. Chloride concentrations for wells at the subsurface irrigation field at the ISU Farm. Dashed lines indicate dates of subsurface effluent application.

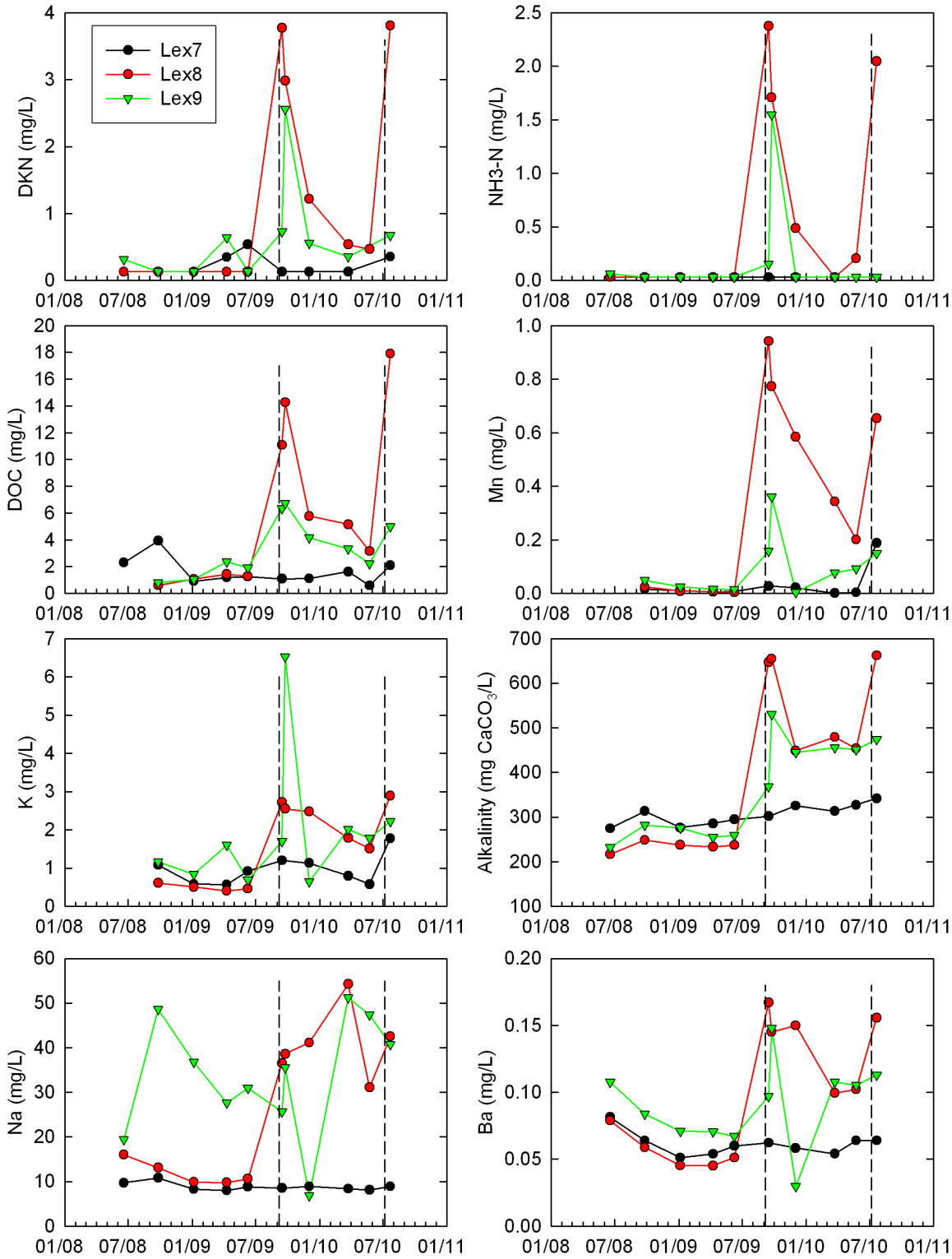

Figure 30. Concentrations of various parameters for wells at subsurface irrigation field at the ISU Farm. Dashed lines indicate dates of subsurface effluent application.

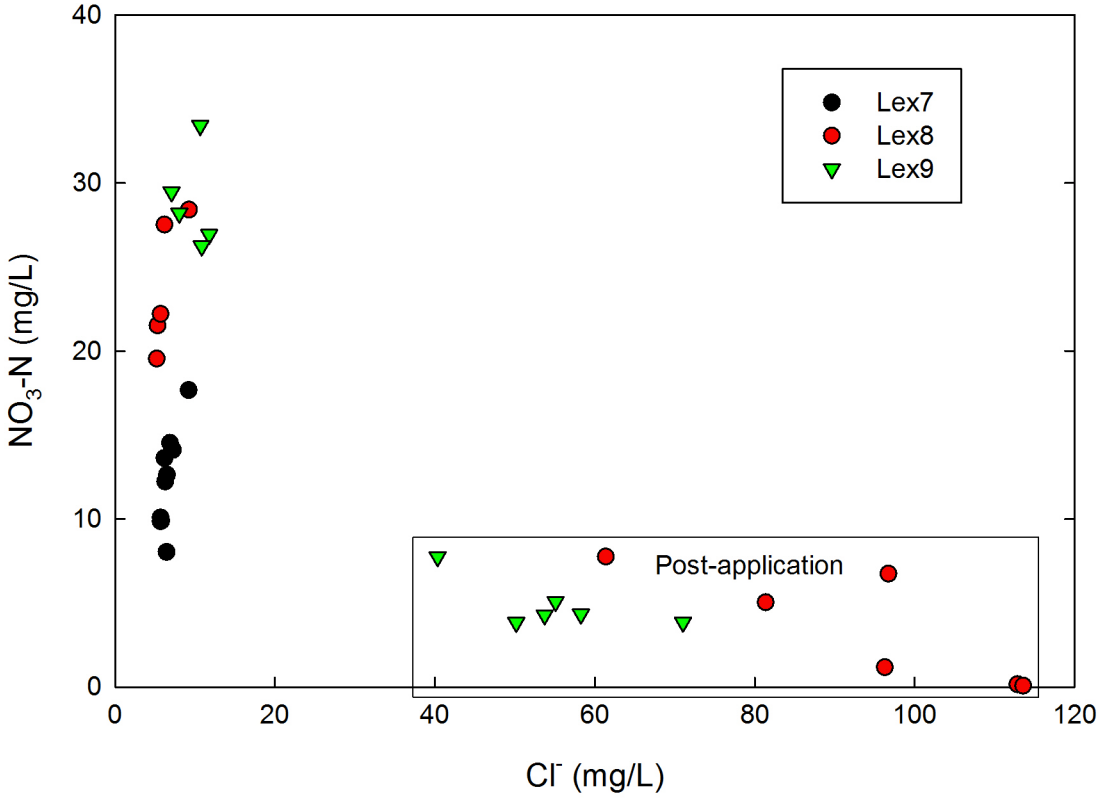

Figure 31. Chloride vs. nitrate-N concentrations for wells at subsurface irrigation field at the ISU Farm. Samples collected after subsurface effluent application in box.

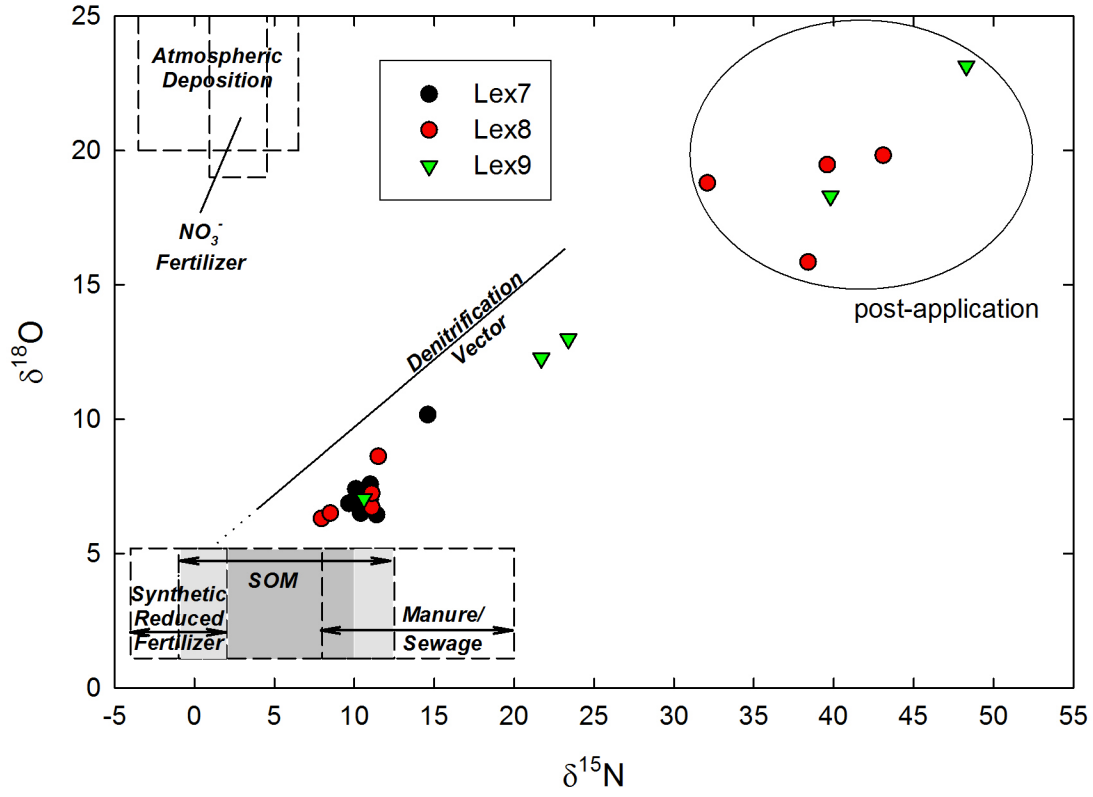

Figure 32. Nitrate isotope values for well samples at the subsurface irrigation site at the ISU Farm. Boxes outlined by dashed lines indicate isotopic ranges for potential sources of nitrate. The denitrification vector indicates the theoretical change in $\delta^{15}N$ and $\delta^{18}O$ values of residual nitrate after a fraction of the nitrate pool has been denitrified. Samples collected from Lex-8 and Lex-9 after application are circled.

Table 29. Water Chemistry Results for Lysimeter Lex-S7. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	9/24/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	ND	ND	ND	ND	ND
SpC(µS/cm)	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND
ORP (mV)	ND	ND	ND	ND	ND
DO	ND	ND	ND	ND	ND
Al	<0.037	<0.037	0.042	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.063	0.032	0.036	<0.023	0.060
Ba	0.059	0.112	0.080	0.078	0.102
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	121	154	105	98.3	106
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0026	0.0037	0.0038	0.0030	0.0035
Fe	<0.0059	<0.0059	0.061	<0.0059	0.020
K	1.87	1.89	0.79	0.72	1.02
Li	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	29.6	43.9	31.8	33.1	37.4
Mn	0.322	0.108	0.032	0.008	0.020
Mo	0.033	<0.022	<0.022	<0.022	<0.022
Na	11.1	21.3	9.49	8.40	9.63
Ni	0.0150	<0.014	0.0254	<0.014	0.0291
P	0.1190	0.3566	0.1024	<0.063	0.1416
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	10.2	26.0	14.1	13.1	11.7
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	8.74	7.04	5.37	5.00	7.12
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.230	0.242	0.154	0.163	0.178
Ti	<0.00056	<0.00056	0.0014	<0.00056	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017
V	0.165	0.088	<0.047	<0.047	<0.047
Zn	<0.0073	0.0218	0.0229	0.0083	<0.0073
Alkalinity	ND	400	330	329	361
F^-	0.245	0.267	0.217	0.220	0.282
Cl^-	9.77	50.0	5.77	4.92	4.71
NO_3-N	3.10	2.25	5.76	5.61	3.35
SO_4^{2-}	31.0	73.9	38.5	36.7	33.9
DRP	0.099	0.237	0.083	0.060	0.094
DOC	ND	6.03	2.94	2.02	4.57
TKN	1.12	0.70	<0.26	<0.26	0.63
NH_3-N	<0.06	<0.06	<0.06	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	17.0	ND
$\delta^{18}O$-NO_3	ND	ND	ND	8.0	ND
δD	ND	ND	ND	ND	ND

Table 30. Water Chemistry Results for Lysimeter Lex-S8. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

Date	9/24/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	ND	ND	ND	ND	ND
SpC(µS/cm)	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND
ORP (mV)	ND	ND	ND	ND	ND
DO	ND	ND	ND	ND	ND
Al	<0.037	<0.037	0.087	<0.037	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.097	0.090	0.097	0.081	0.166
Ba	0.267	0.210	0.169	0.151	0.188
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	283	278	176	145	173
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0017	0.0023	0.0034	0.0018	0.0030
Fe	1.70	0.015	0.139	0.047	0.072
K	6.46	3.97	4.17	3.61	5.54
Li	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	96.4	100.1	84.4	68.9	76.6
Mn	5.56	4.34	1.83	1.95	2.56
Mo	<0.022	<0.022	<0.022	<0.022	0.098
Na	55.5	61.9	52.5	39.4	41.1
Ni	0.0550	0.0525	0.0390	0.0449	0.0484
P	0.0880	0.2513	0.1046	<0.063	0.0947
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	3.26	5.24	7.02	773	6.69
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	10.9	7.78	6.57	6.01	7.57
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.548	0.424	0.312	0.278	0.306
Ti	<0.00056	<0.00056	0.0030	<0.00056	<0.00056
Tl	0.019	<0.017	0.019	<0.017	<0.017
V	<0.047	<0.047	<0.047	<0.047	<0.047
Zn	0.0105	0.0136	0.0352	0.0317	0.0106
Alkalinity	965	849	649	581	658
F^-	0.414	0.209	0.171	0.184	0.213
Cl^-	195	150	125	78.4	84.9
NO_3-N	0.18	1.49	2.36	3.91	0.55
SO_4^{2-}	8.63	26.7	19.7	25.6	18.3
DRP	0.029	0.064	0.036	0.028	0.050
DOC	26.21	ND	11.31	6.11	12.58
TKN	3.11	1.66	1.80	<0.26	2.87
NH_3-N	0.671	0.288	0.911	1.499	1.844
$\delta^{15}N$-NO_3	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND

Table 31. Water Chemistry Results for Lysimeter Lex-S9. Results are for Filtered (0.45 µm) Samples, and are in mg/L Except Where Indicated. Alkalinity Reported as mg/L $CaCO_3$. Isotopes reported in ‰. ND = Not Determined.

	9/24/09	12/2/09	3/24/10	5/24/10	7/22/10
T (C)	ND	ND	ND	ND	ND
SpC(µS/cm)	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND
ORP (mV)	ND	ND	ND	ND	ND
DO	ND	ND	ND	ND	ND
Al	<0.037	<0.037	0.164	0.137	<0.037
As	<0.108	<0.108	<0.108	<0.108	<0.108
B	0.054	0.031	0.027	0.043	0.068
Ba	0.078	0.085	0.094	0.103	0.115
Be	<0.00055	<0.00055	<0.00055	<0.00055	<0.00055
Ca	117	127	112	104	115
Cd	<0.012	<0.012	<0.012	<0.012	<0.012
Co	<0.013	<0.013	<0.013	<0.013	<0.013
Cr	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	0.0023	0.0019	0.0081	0.0018	0.0021
Fe	0.020	<0.0059	0.316	0.161	<0.0059
K	3.10	0.96	1.26	1.07	1.30
Li	<0.058	<0.058	<0.058	<0.058	<0.058
Mg	32.3	34.7	42.2	39.9	45.2
Mn	0.191	0.246	0.081	0.008	0.006
Mo	0.053	<0.022	<0.022	<0.022	0.027
Na	18.0	11.1	19.2	17.6	19.7
Ni	0.0180	<0.014	0.0242	0.0311	0.0290
P	0.3090	0.2335	0.1043	0.1299	0.1309
Pb	<0.041	<0.041	<0.041	<0.041	<0.041
S	12.4	14.6	14.4	12.9	13.2
Sb	<0.059	<0.059	<0.059	<0.059	<0.059
Se	<0.131	<0.131	<0.131	<0.131	<0.131
Si	8.67	6.12	5.46	5.97	6.77
Sn	<0.086	<0.086	<0.086	<0.086	<0.086
Sr	0.243	0.184	0.179	0.178	0.204
Ti	0.0008	<0.00056	0.0065	0.0073	<0.00056
Tl	<0.017	<0.017	<0.017	<0.017	<0.017
V	0.378	<0.047	<0.047	<0.047	<0.047
Zn	<0.0073	0.0100	0.122	0.0113	0.0227
Alkalinity	363	357	ND	ND	373
F^-	0.277	0.212	0.207	0.220	0.280
Cl^-	46.3	86.1	33.5	31.2	33.1
NO_3-N	1.27	1.53	10.4	13.9	11.5
SO_4^{2-}	40.5	30.2	41.0	38.6	39.3
DRP	0.271	0.065	0.113	0.119	0.164
DOC	11.1	3.93	4.15	ND	5.04
TKN	1.11	0.54	ND	1.19	0.59
NH_3-N	0.204	<0.06	ND	<0.06	<0.06
$\delta^{15}N$-NO_3	ND	ND	ND	ND	ND
$\delta^{18}O$-NO_3	ND	ND	ND	ND	ND
δD	ND	ND	ND	ND	ND

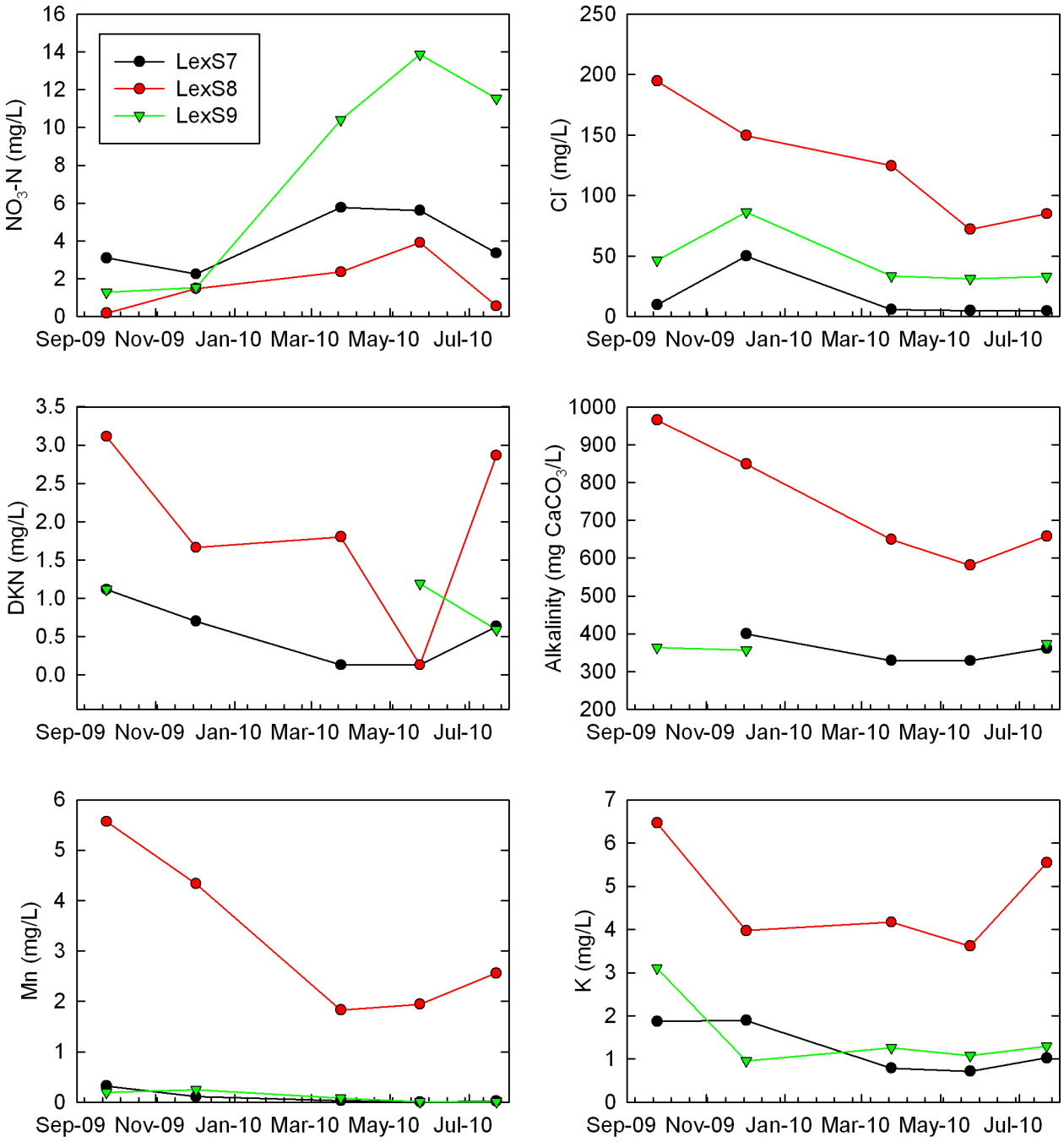

Figure 33. Concentrations of various parameters for lysimeters at the subsurface irrigation field at the ISU Farm

Results and Discussion: Laboratory Experiments

Nitrate-N concentrations determined by electrode were higher than those determined by ion chromatography (IC), by 2.0 to 8.5% (Table 32). Concentrations of major constituents of the filtered rainwater and filtered manure slurry samples are shown in Table 33. The $\delta^{15}N\text{-}NH_3$ concentration for filtered manure slurry is also shown (data from Richard Mulvaney, UIUC NRES).

Flow

Flow rates and locations varied considerably in the different columns and experiments. For example, in Experiment 1, most of the flow in Column 2 was through the middle ports, most of the flow in Columns 1 and 6 was primarily through the edge port, and there were significant fractions through both ports for Column 4. Table 34 shows the volume of flow through each port for all experiments. In Experiment 2, noticeable cracks formed in Columns 1 and 2, leading to macropore flow and relatively high flow rates. The ratio of middle to edge flow changed significantly from experiment to experiment, showing the complexity of flow in intact soil columns.

Chemistry

Experiment 1

Initial samples were collected from columns 1, 2, and 6 approximately two days after experiment initiation. Nitrate-N concentrations varied from 1.5 to 6.2 mg/L, which was much lower than in the initial test, where initial concentrations varied between 25.6 and 32.9 mg/L. This suggests that the most labile NO_3^- was removed from the soil columns in the initial test, but that the soil still was producing excess NO_3^- compared to the input water. In subsequent samples, NO_3-N concentrations decreased with time, with final concentrations being < 1 mg/L (Figure 34). Samples for NO_3^- isotope analysis were collected from 1E and 2M at two and four days after the start. The initial samples suggest denitrified soil organic matter (SOM), while later samples indicated more denitrification, especially in 2M (Figure 35). There was no evidence of a rainwater signal.

Experiment 2

Sodium bromide was added to the initial solutions (FRW for columns 1 and 4, manure slurry for columns 2 and 6), with an initial Br^- concentration of approximately 200 mg/L for the spiked FRW. 200 mL of FRW or manure slurry was added to each column at the start of the experiment, and 100 mL was added after 29, 48, and 71 hours. After 71 hours, FRW that was not spiked with NaBr was added to each column as needed (Figure 36).

Bromide concentrations tended to drop with time, with a small spike in concentration sometimes observed after the addition of solution (Figure 36). The manure slurry contained significant amounts of Br^-. There was an immediate drop in Br^- concentration in column 2 after the first input of FRW with no NaBr, showing rapid movement. At later times, Br^- concentrations increased in columns 4 and 6, which had the slowest flow rates of the columns. At this point, only FRW with no NaBr was being added to the columns. This suggests release of earlier NaBr-spiked water during this period, i.e., dual porosity flow.

There were very high initial NO_3-N concentrations in the manure slurry columns (2, 6), probably due to oxidation of reduced N in the manure source (Figure 37). Nitrate-N concentrations spiked in

Column 1 shortly after the experimental start (~20 mg/L), but not in column 4. Nitrate-N concentrations tended to decrease with time. However, in both manure columns, there was an increase in NO_3-N in the final samples, after manure slurry had stopped being added. As with the Br^- results, this suggests dual porosity flow.

For the NO_3^- isotopes, multiple samples were collected from columns 1 and 4 (FRW). Samples that passed rapidly through the columns maintained a rainwater signal, although there appeared to be a significant SOM component, especially in column 1 (Figure 38). In column 1, after three days (three solution inputs), the sample resembled either slightly denitrified SOM or a mixture of denitrified SOM and a small amount of rainwater; a relatively heavy N-15 value suggests the former. Subsequent samples appeared to have a greater input of SOM and were more denitrified. In column 4, the samples looked more like a mixture of SOM and rainwater, with the SOM fraction increasing with time.

We were able to get isotope data from only two samples from manure slurry columns. The results were surprising (Figure 39). A sample from column 2 collected after 15 days had an isotopic signal similar to that of column 1. It is possible that the sample represents a mixture of slurry and FRW (200 mL of which was added to the column after the final slurry addition at two days). The isotopic values for the sample from 6E, collected after seven days, resembled those of rainwater, which was an unexpected result. The values suggest the water is almost all FRW, which seems unlikely; no FRW had yet been added to Column 6 during Experiment 2. It appears that there was either contamination during analysis or the sample was mislabeled.

Experiment 3

There were elevated levels of Br^- in all four columns early on during Experiment 3, although the FRW added during this experiment was not amended with NaBr (Figure 40). This indicates that there was residual Br^- in the pore water from the previous experiment. The highest concentrations were in columns 2 and 6, which had received manure slurry in the previous experiment. Bromide concentrations decreased only slightly or not at all with time.

Concentrations of NO_3-N were extremely high in columns 2 and 6 at the start, and stayed high or increased during the experiment (Figure 41). This suggests residual reduced N in the manure slurry that was being oxidized. Nitrate-N concentrations increased in columns 1 and 4 after the FRW-urea solution was added after 148 hours (~6 days), which appeared to be at levels higher than anticipated by the amount of N in urea. In columns 4 and 6, NO_3-N concentrations were consistently lower in edge port samples than in middle port samples. This might suggest more rapid movement through the edges of these columns.

The isotope results for Columns 1 and 4, which received urea, suggest an initial mixing between denitrified SOM and FRW + urea, then increasing denitrification (Column 4) (Figure 42). One of the samples from Column 2, which had received manure slurry during the previous experiment, had an isotopic signature suggestive of manure. The sample collected two days later suggested a mixture between manure and FRW.

Discussion

There are large natural variations in the soil cores, which makes data interpretation challenging. Even though they came from the same plot, flow dynamics were substantially different. Nitrogen dynamics also differed among the columns, although some of this may be attributable to differences in flow.

Processes that were affecting NO_3-N concentrations in the column experiments include nitrification, denitrification, adsorption/desorption, and mixing of sources. Figure 43 shows NO_3-N concentrations for all the experiments. The highest NO_3-N concentrations were in the columns that received manure slurry (2 and 6), but not until significantly afterwards. The manure slurry trapped in the columns after Experiment 2 oxidized, converting reduced N to NO_3-N (original analysis showed NO_3-N BDL). It is likely that the NH_4^+ in the slurry adsorbed to the soil.

Table 32. Comparison of NO3-N Concentrations (mg/L) Determined by Electrode and IC

Sample	NO_3-N by electrode	NO_3-N by IC
1E-1	25.6	23.6
2M-1	30.3	29.7
2M-4	6.43	5.96

Table 33. Chemical Analysis of Filtered Rainwater and Manure Slurry. Concentrations in mg/L Except Where indicated.

	Rainwater	Manure
Ca	5.78	150
K	1.34	1000
Mg	0.44	94.4
Na	0.29	304
Si	0.57	17.5
Alkalinity ($CaCO_3$)	12.2	4573
F^-	<0.08	<0.8
Cl^-	0.39	606
NO_3-N	1.04	<0.7
SO_4^{2-}	3.77	17.9
DRP	0.02	79.6
DOC	10.2	1400
DKN	1.71	1186
NH_3-N	1.11	593
$\delta^{15}N$-NH_3 (‰)		5.53

Table 34. Volumes of Solutions (mL) Collected from the Middle and Edge Ports in Each Column for the Three Experiments. % is Percentage of Volume Added that was Collected at the Column Outlet.

Experiment	1			2			4			6		
	Middle	Edge	%	Middle	Edge	%	Middle	Edge	%	Middle	Edge	%
1	80	0	80	2	84	86	51	23	74	86	0	86
2	64	416	69	0	527	89	166	171	48	318	141	66
3	22	80	34	13	184	66	136	128	88	190	73	88

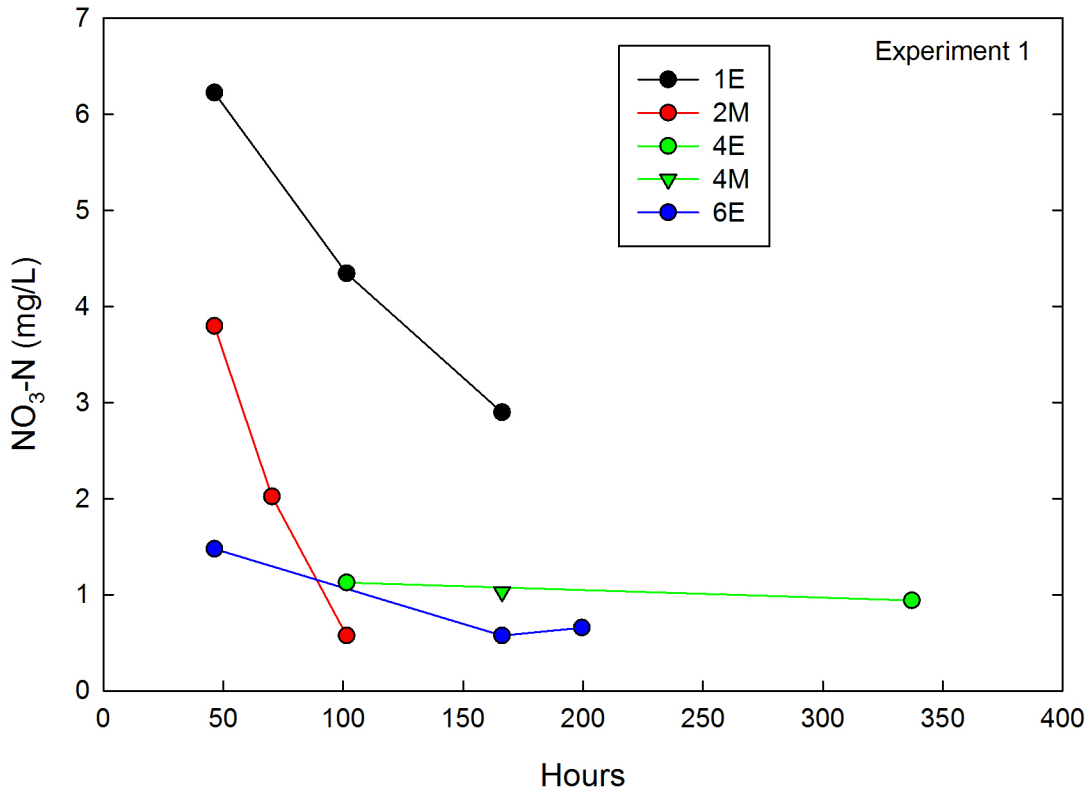

Figure 34. Experiment 1 NO_3-N results. Data points identified by column number and exit port location (M = middle; E = edge).

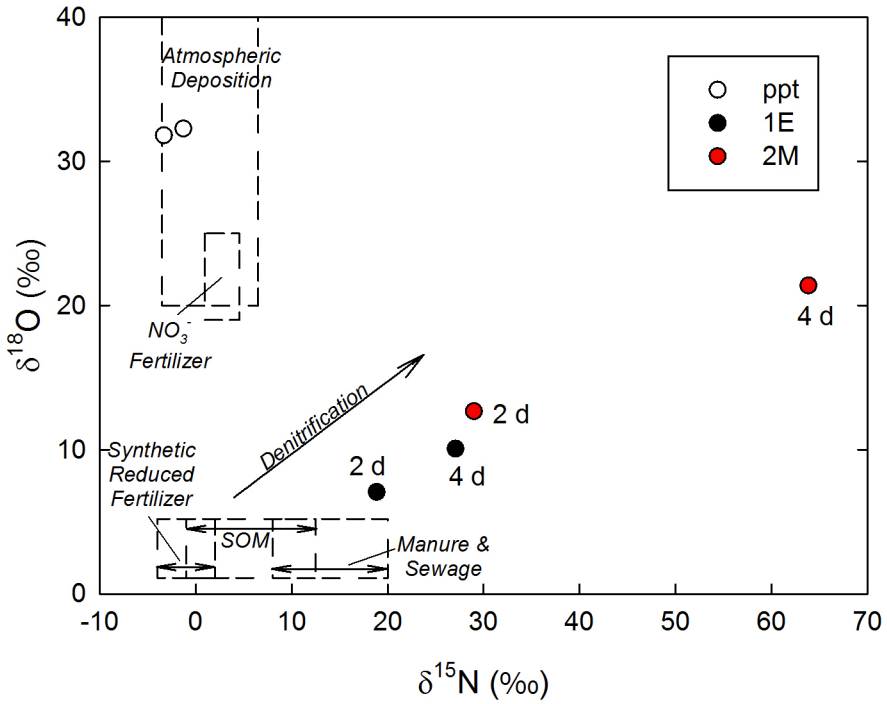

Figure 35. Nitrate isotope values for samples collected during Experiment 1. Samples from 1E and 2M collected after 2 and 4 days. Dashed lines delineate potential source terms; arrow shows denitrification trend.

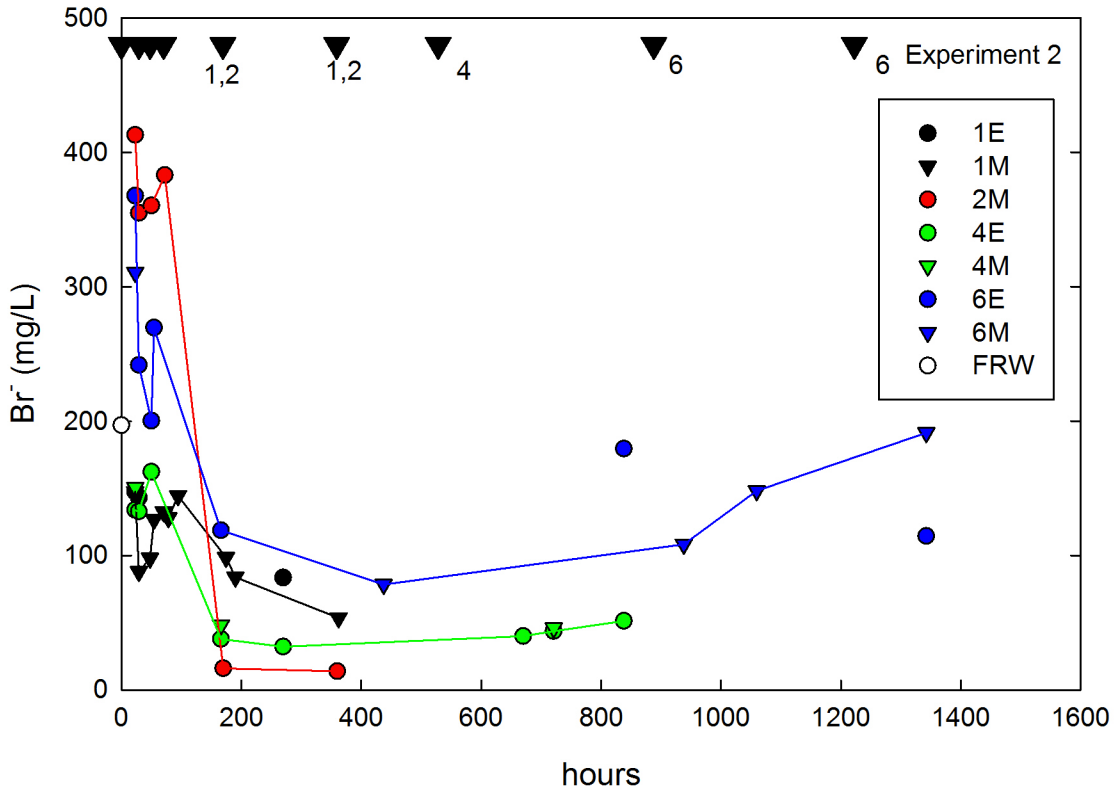

Figure 36. Bromide concentrations in Experiment 2. Large black triangles indicate when solution was added to columns identified by number. Starting with the addition at 170 hours, solutions did not include any NaBr. Data points identified by column number and exit port location (M = middle; E = edge).

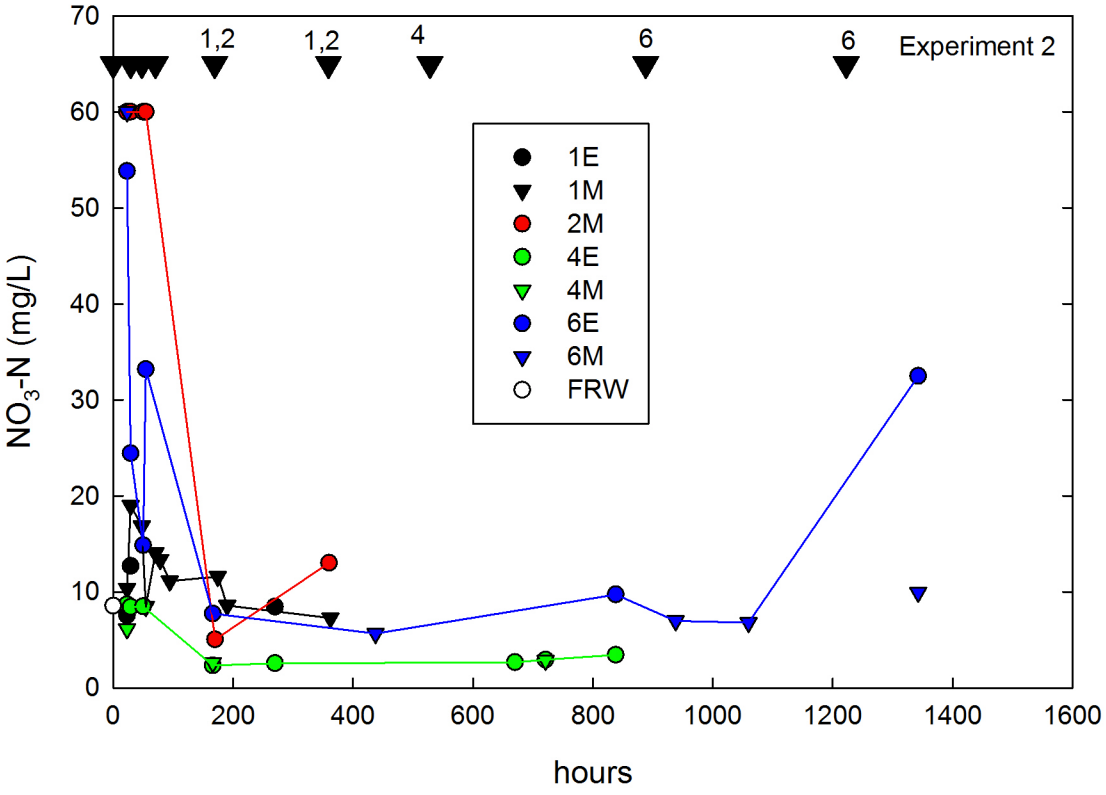

Figure 37. Nitrate-N concentrations in Experiment 2; initial NO_3-N concentration in FRW indicated by open circle. Large black triangles indicate when solution was added to columns identified by number. Starting with the addition at 170 hours, solutions did not include any NaBr. Data points identified by column number and exit port location (M = middle; E = edge).

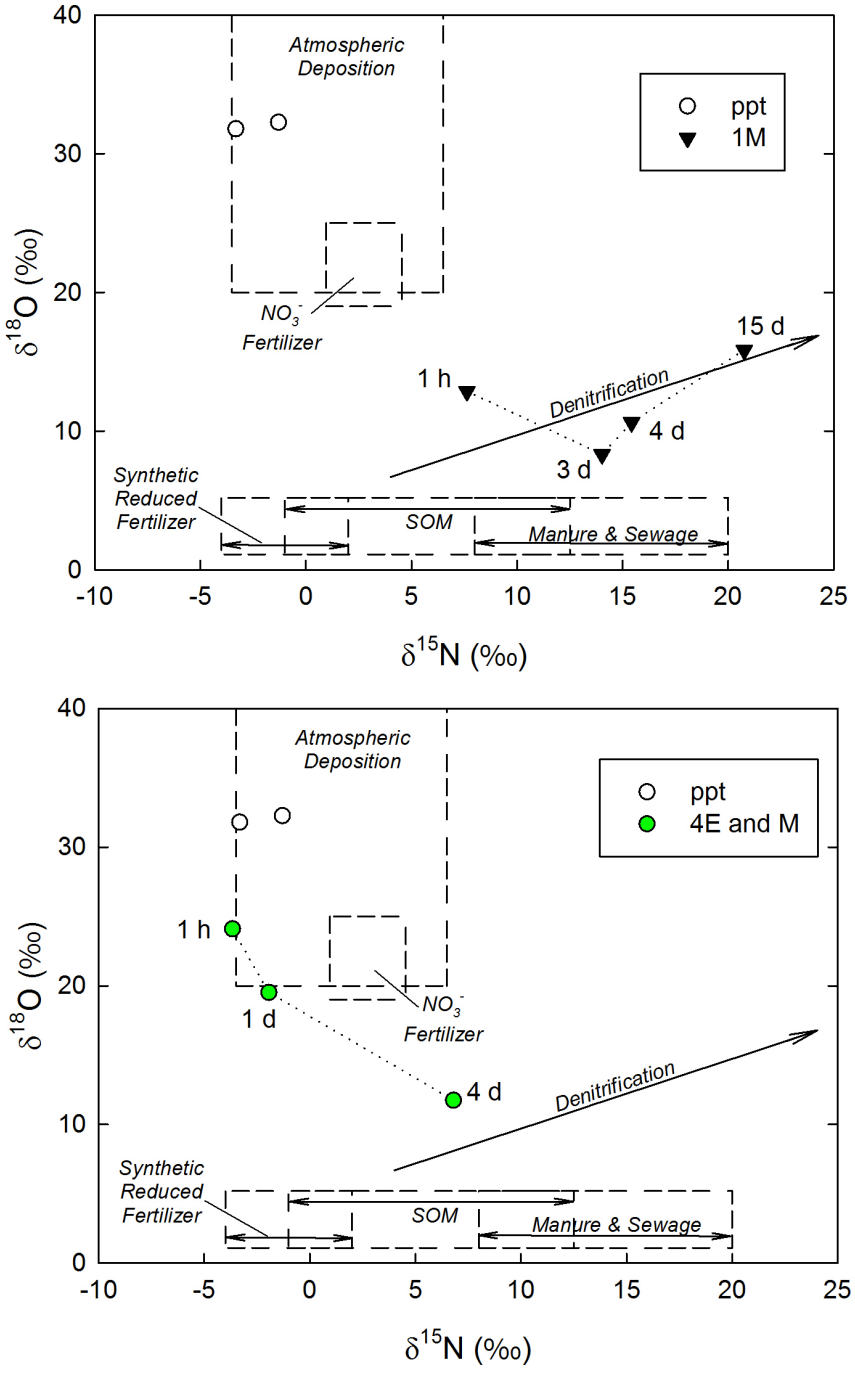

Figure 38. Nitrate isotope values for samples collected during Experiment 2 from columns receiving only FRW. Samples from 1M and 4E and 4M (combined) collected after times indicated. Dashed lines delineate potential source terms; arrow shows denitrification trend.

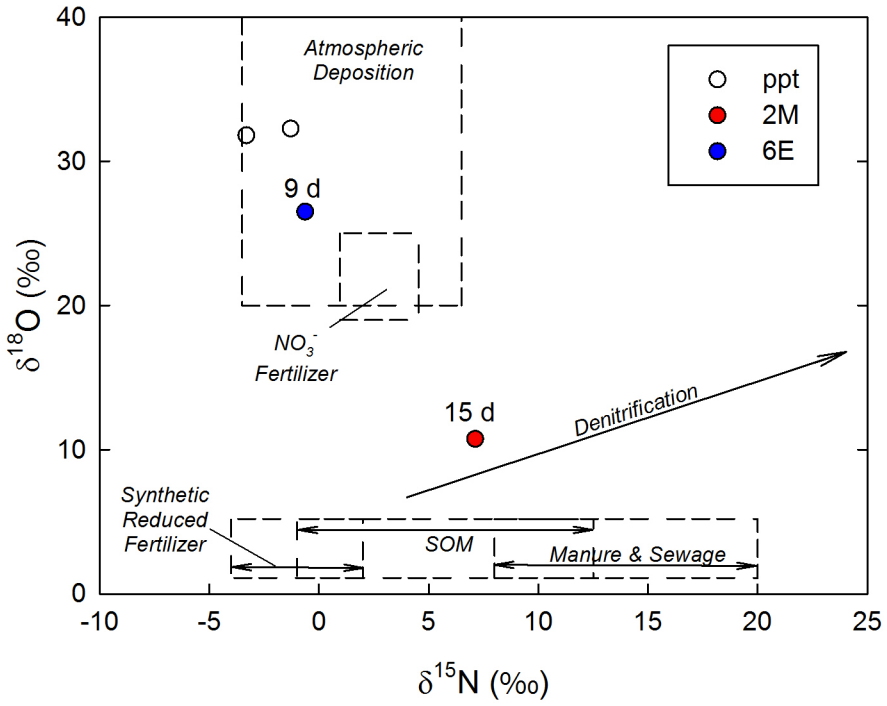

Figure 39. Nitrate isotope values for samples collected during Experiment 2 from columns receiving manure slurry. Samples collected after times indicated. Dashed lines delineate potential source terms; arrow shows denitrification trend.

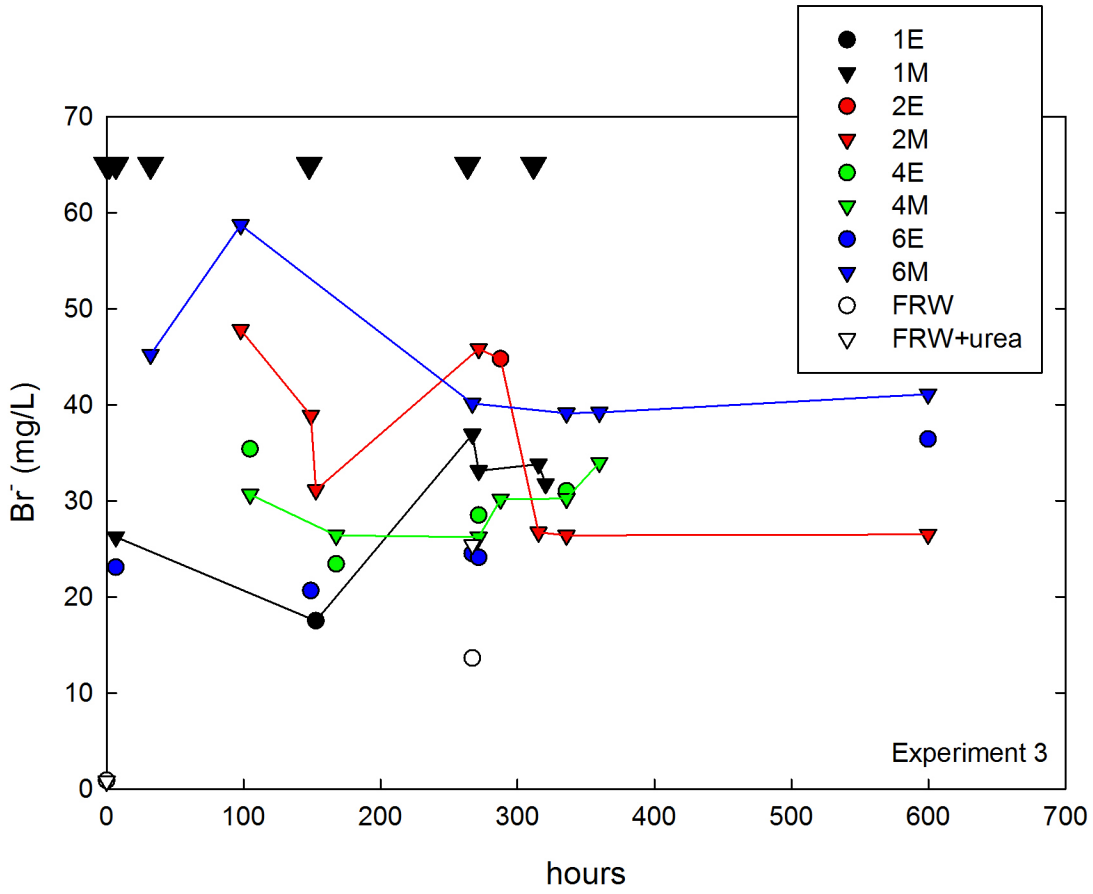

Figure 40. Bromide concentrations in Experiment 3. Large black triangles indicate when solution was added to columns. FRW used in initial addition; starting at 148 hours, FRW-urea with NaBr solution added to Columns 1 and 4 (initial Br- concentrations indicated by open symbols). Data points identified by column number and exit port location (M = middle; E = edge).

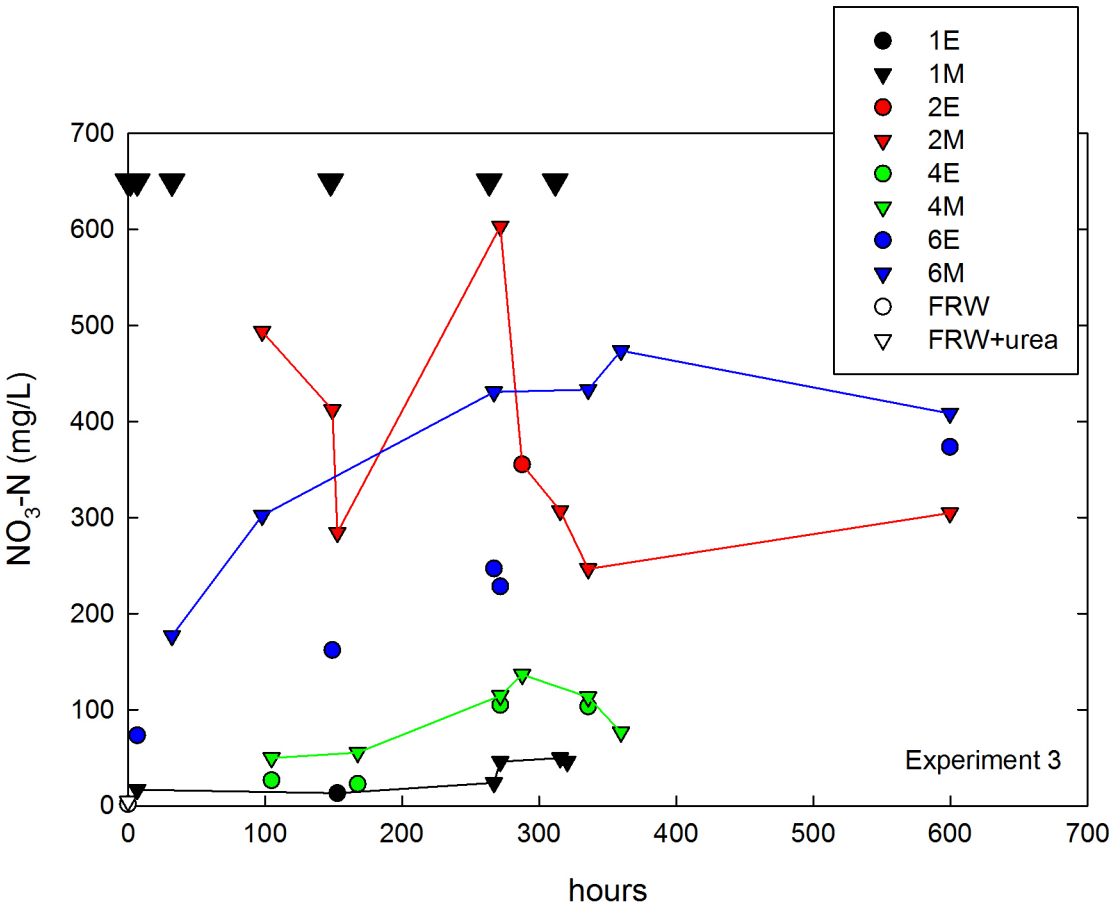

Figure 41. Nitrate-N concentrations in Experiment 3; initial NO_3-N concentration in FRW and FRW-urea solution indicated by open symbols (near 0,0). Large black triangles indicate when solution was added to columns. FRW used in initial addition; starting at 148 hours, FRW-urea with NaBr solution added to Columns 1 and 4. Data points identified by column number and exit port location (M = middle; E = edge). Columns 2 and 6 were amended with manure slurry in the previous experiment.

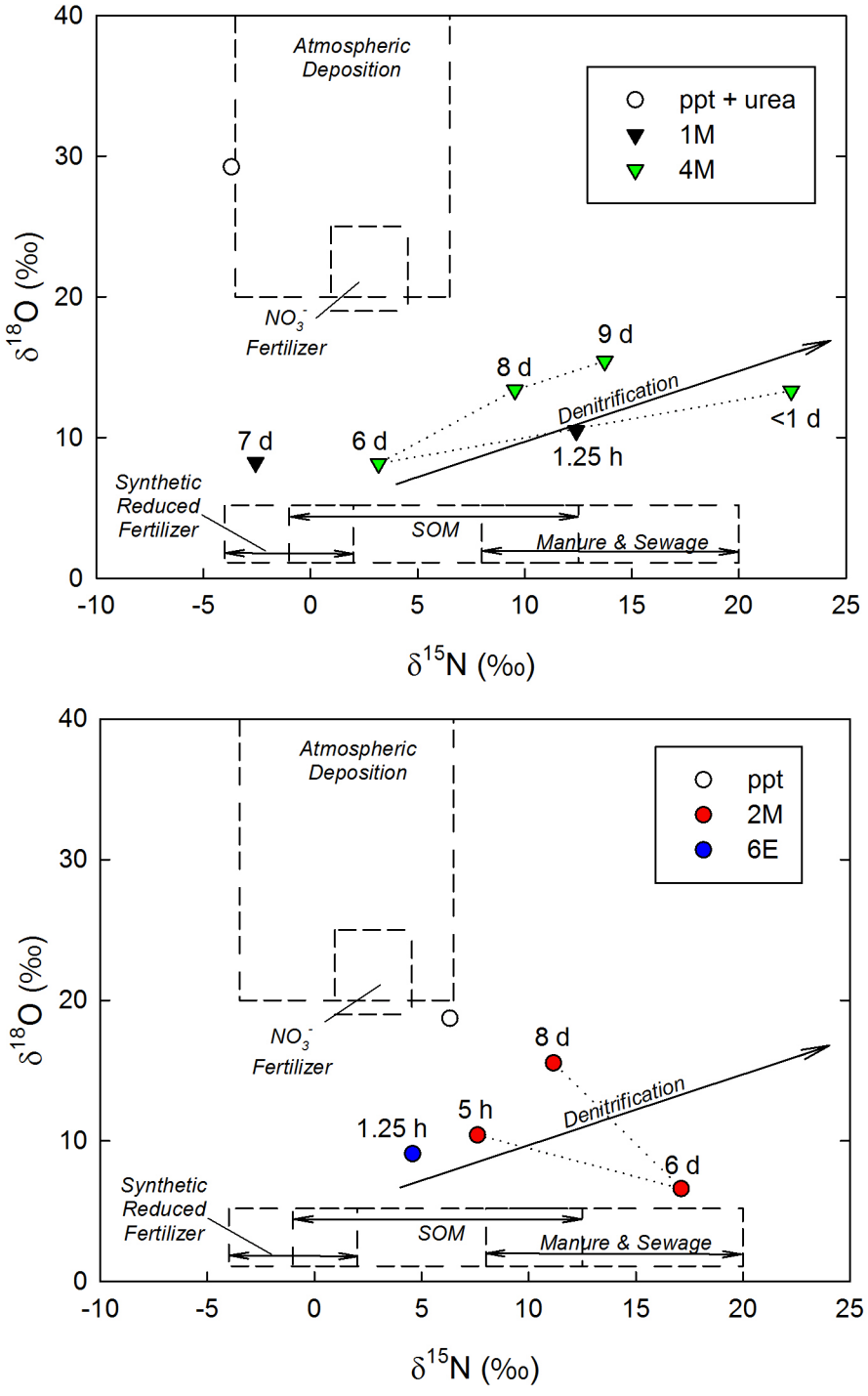

Figure 42. Nitrate isotope values for samples collected during Experiment 3.
Samples from 1M, 4M, 2M, and 6E collected after times indicated.
Dashed lines delineate potential source terms; arrow shows denitrification trend.

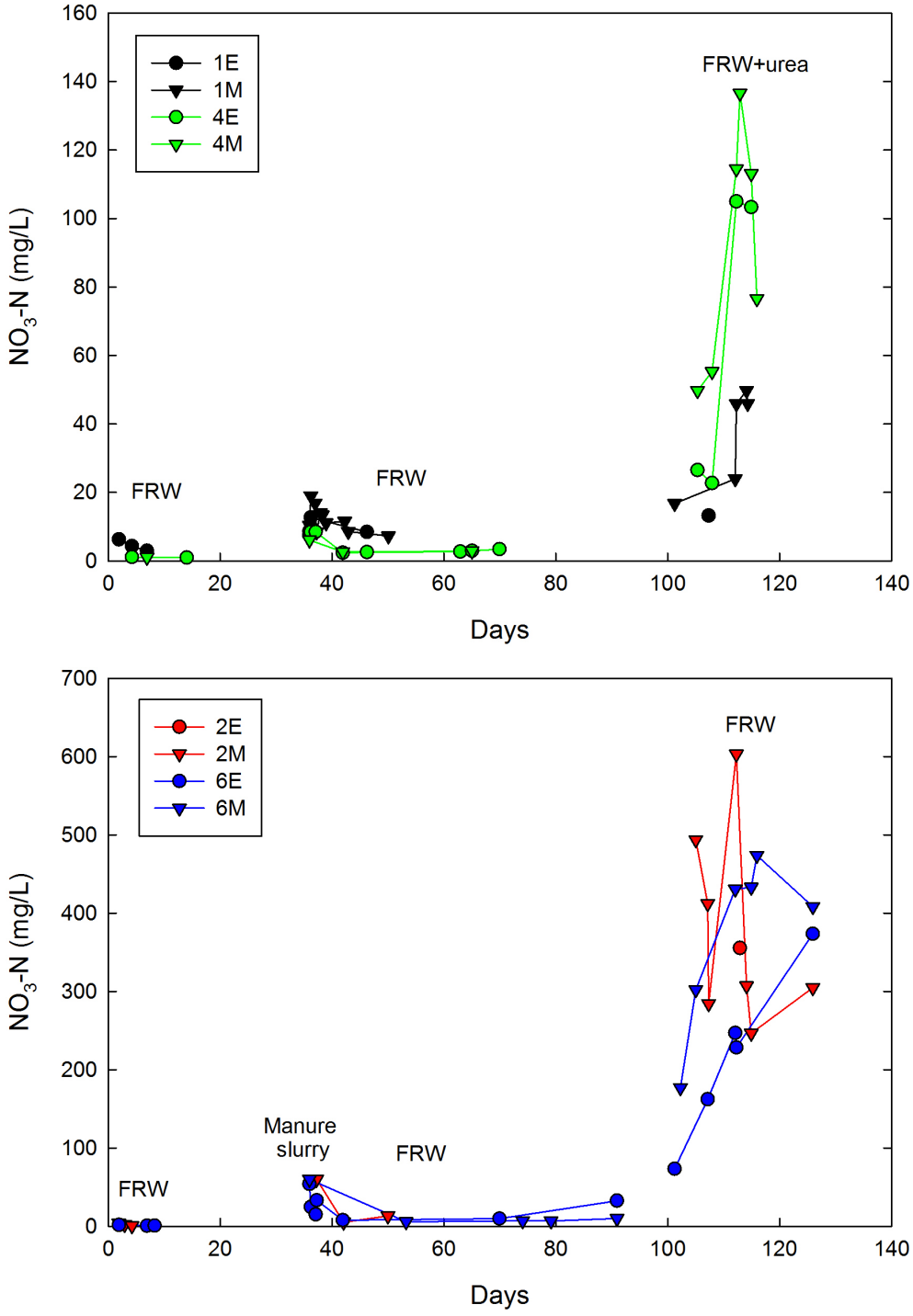

Figure 43. Nitrate-N concentrations for all experiments. Columns 1 and 4 received FRW in the first 2 experiments and FRW-urea in Experiment 3. Columns 2 and 6 received manure slurry at the start of Experiment 2 and FRW at all other times.

Summary

Starting in 2003, a series of field studies were conducted in conjunction with researchers from Illinois State University (ISU) at the ISU Farm north of Lexington, IL. The goal was to monitor subsurface water quality beneath row-crop plots and fields where soils were being treated with various amendments, including compost, swine manure slurry, separated swine manure effluent, and synthetic fertilizer (urea).

Shallow groundwater and soil water chemistry showed considerable variability, but not always in a way that could be linked to the particular soil treatment. One of the main findings was that previous practices at the sites and undocumented practices up-gradient of the sites influenced the water quality, and the legacy effects could last for years afterwards.

This is also an area with large annual water table fluctuations (2-4 m), resulting in parts of the soil zone being saturated at times. This could allow for significant fluctuations in redox conditions and redox reactions, such as an increase in denitrification rates during saturated periods.

The use of subsurface tiles to deliver manure effluent to crops significantly degrades the subsurface water quality. There was a clear signal of contamination in groundwater after the effluent was delivered, including highly reducing conditions with elevated levels of nutrients and other contaminants. Recovery of pre-application geochemical conditions was slow. It thus appears that using subsurface tiles to deliver fertilizer is a poor alternative to surface application with respect to water quality.

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