An evaluation of the storage and movement of potential contaminants in soils at a confined feeding operation where manure is applied to highly permeable sands

Indiana Geological Survey Open-File Study 09-01

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INTRODUCTION

Several confined feeding operations (CFOs) are operating in the sandy hydrogeologic settings of southwestern Indiana. These operations are cooperating with the Indiana Department of Environmental Management (IDEM) and making every effort to conform to Best Management Practices (BMPs) by following U.S. Environmental Protection Agency (USEPA) guidelines. Notwithstanding their efforts to ensure minimal impacts on ground and surface water in the area, there is no certainty that currently recommended BMPs will be successful. Groundwater in this hydrogeologic setting (highly permeable soils and shallow water tables) is very sensitive to contamination, and because the sandy outwash parallels the White River, the river may also be affected by groundwater contamination.

The purpose of the project was to evaluate nitrate (NO_3^-) loading of groundwater underlying fields subjected to both commercial and noncommercial (animal waste) fertilizers in sandy soils with shallow water tables. Confined feeding operations are increasing in number in Indiana. Many of these CFOs are located in areas that are considered to be highly susceptible to groundwater contamination because of permeable soils and shallow water tables. Nitrate loading of water table aquifers owing to natural recharge must be evaluated in such settings so that informed management decisions about land use can be made. The results of this study indicate that natural recharge, via infiltration-driven unsaturated groundwater flow, is occurring in the project area and that the recharge water periodically contains substantial concentrations of nitrate and other nutrients.

STUDY GOALS

The goals for this project were to:

1. Install hydrochemical monitoring systems at three sites adjacent to agricultural fields near CFOs; two of the sites were located adjacent to agricultural fields that received animal waste applications and one site (a control) was located adjacent to an agricultural field that did not receive animal waste applications. The sites are located in areas with sandy soils and shallow water tables; such areas are most likely to be affected by nitrogen-rich leachate generated from animal waste and commercial fertilizer.
2. Undertake a program of monitoring that includes bi-weekly site visits to measure soil moisture profiles, download data from logging equipment, and periodically collect water samples for laboratory analyses.
3. Develop water and chemical (nitrogen) budgets for each of the study sites and calculate nitrate loading of the water table as a result of vertical recharge though the unsaturated zone.

STUDY AREA

The project area is located near the town of Washington in Daviess County, Indiana. The study area is rural and row crop farming is the primary land use. The soils are permeable alluvial sands of the Lower White River and silts deposited into low-lying dunes known as the Washington rolling loess hills.

NARRATIVE OF WORK COMPLETED

Three study sites were selected and subjected to intensive monitoring for three full water years (2004 – 2006). The locations of the three sites are shown in Figure 1. At each study site, sensors were installed to measure soil-water tension in the unsaturated zone and water-table elevation fluctuations. Access tubes were installed to allow measurements of soil moisture profiles using a neutron soil moisture gauge, and pressure-vacuum soil-water samplers were installed to allow samples of water to be extracted from the unsaturated zone for chemical analysis. Figure 2 shows a photograph of one of the equipment installations.

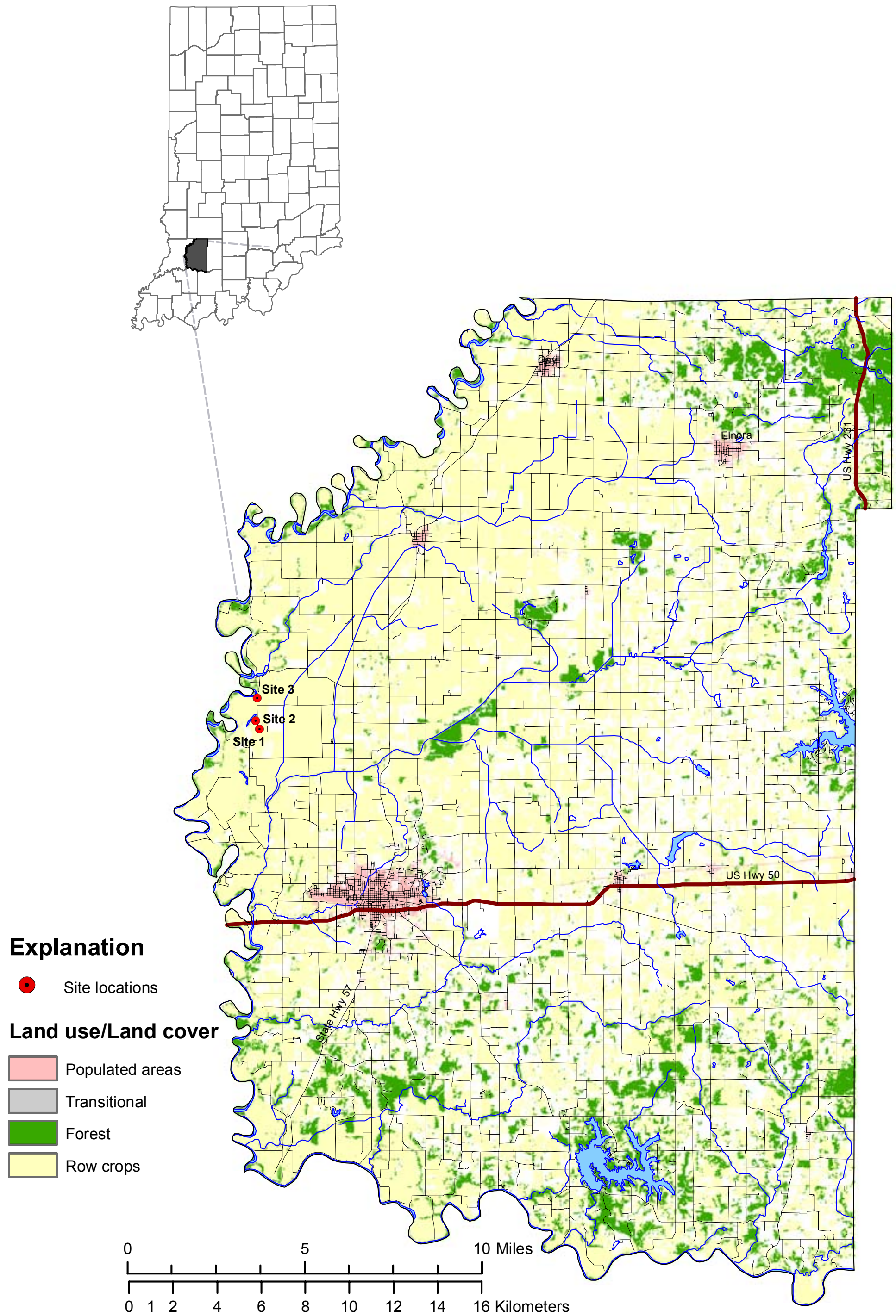

Figure 1. Land use map of Daviess County, Indiana, showing locations of the monitoring sites discussed in this report. Sites 1 and 2 are on the periphery of fields planted with row crops that received land application of noncommercial fertilizer (manure), and Site 3 (control site) is on the periphery of a field that received only commercial fertilizers during the period of study.

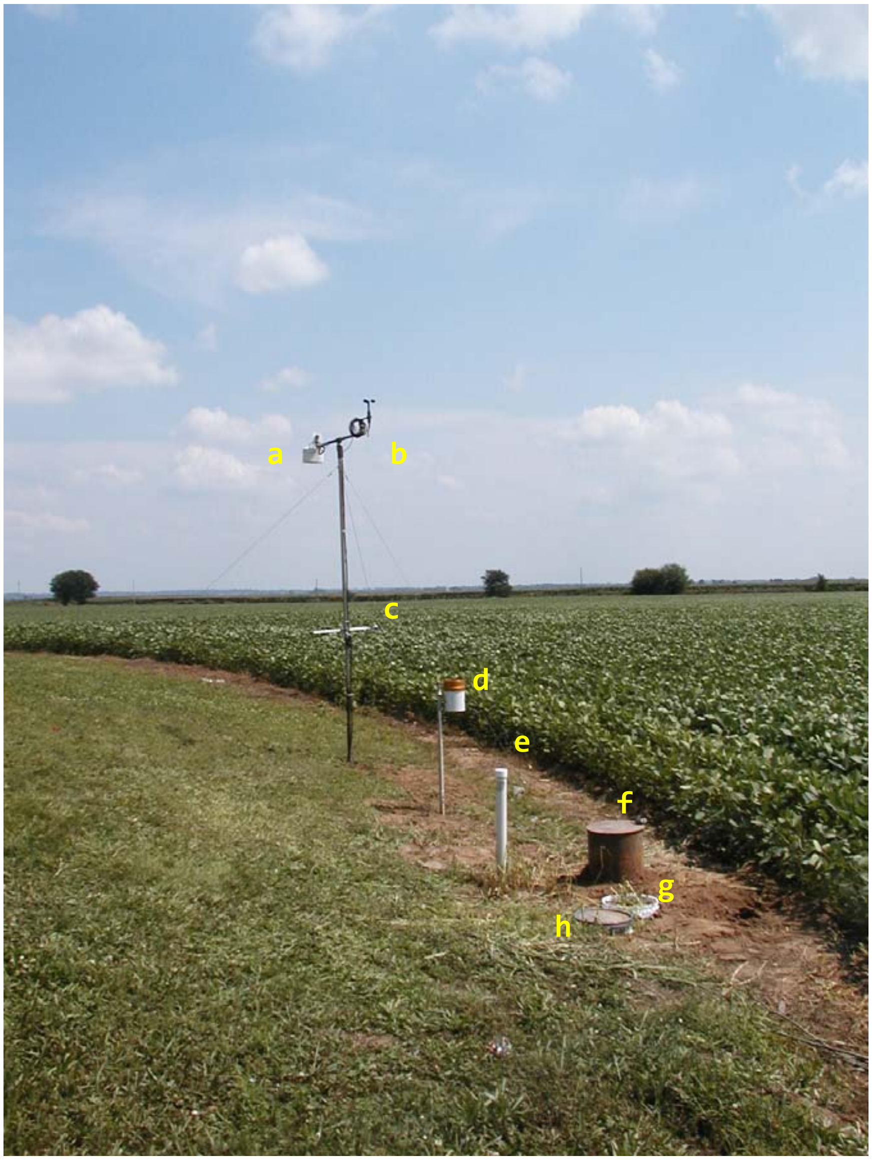

Figure 2. Photograph of monitoring instrumentation installed at Site 1 in Daviess County. The labels on the photograph denote the following instruments:

- **a.** air temperature/humidity sensor in ventilated radiation shield;
- **b.** anemometer (wind speed);
- **c.** net radiometer;
- **d.** rain gauge;
- **e.** access tube for neutron moisture gauge (soil moisture profile);
- **f.** vandal proof enclosure containing a monitoring well equipped with a pressure transducer for water table fluctuations and a specific conductivity sensor for concentration of dissolved solids, soil temperature probes, and soil-water tension sensors (gypsum blocks);
- **g.** gravity lysimeter;
- **h.** enclosure for pressure-vacuum soil-water samplers (suction lysimeters).

Over the course of the project, samples of water were collected from the saturated and unsaturated zones at each of the three study sites on 46 separate occasions. Several of the samples were collected immediately after rain storms. An attempt was made to collect water from each well and all three soil-water samplers at each study site; however, the soil-water samplers would frequently not produce because of high soil-water tension. Results of the chemical analyses of the water samples are contained in the spreadsheets named *Daviess Chemistry.xlsx*, which can be found on the CD included with this publication. Additional samples of water were collected for stable isotope analysis on May 5, 2004, and September 28, 2006. The results are presented as a separate spreadsheet in *Daviess Chemistry.xlsx*. Results of the chemical analyses are also presented in the Appendix.

Soil moisture profiles were measured at each of the study sites on 66 occasions, and the measured soil moisture contents are presented in the spreadsheet named *Daviess Neutron.xlsx* (refer to the attached CD).

Measurements of soil-water tension at three depths in the soil, water table elevation, and specific conductance of the water in the saturated zone were taken continuously at each of the three study sites. Hourly averages are tabulated in the spreadsheets named *Daviess Soil Water.xlsx,* with separate worksheets for each monitoring site. The sites are numbered "1," "2," and "3" and their locations are shown in Figure 1.

Measurements of precipitation, net radiation, wind, air temperature, and humidity were made continuously at one study site to facilitate calculations of potential evapotranspiration and net surface flux (rainfall – evapotranspiration). Hourly averages of the raw measurements and calculated daily totals of rainfall, potential evapotranspiration, and net surface flux are presented in the spreadsheet named *Daviess Weather.xlsx*.

Calculations of vertical flow through the unsaturated zone were made by combining changes in moisture content (from time-series of the neutron moisture gauge measurements) with calculated values of net surface flux. Those calculations as well as calculations of nitrate loading of the water table are included in the spreadsheet named *Daviess Flow.xlsx* on the CD included with this report.

An analysis of soils and water table depths using a geographic information system (GIS) was conducted to identify those areas of Indiana that are most suitable and least suitable for manure application; the results of the analysis are included in the summary of project results, discussed below.

FIELD MANAGEMENT DURING THE PERIOD OF MONITORING

When the project commenced in the late summer of 2003, the fields adjacent to Sites 1 and 2 were planted with soybeans and the field adjacent to Site 3 was planted with corn. All three fields were planted with corn in 2004. In 2005, the fields adjacent to Sites 1 and 2 were again planted with corn and the field adjacent to Site 3 was rotated back to soybeans. In 2006 the fields adjacent to Sites 1 and 2 were rotated back to soybeans and the field adjacent to Site 3 was rotated to corn again.

The fertilizer applications also varied during the period of study. Sites 1 and 2 received 2 tons of turkey manure per acre in fall 2003, 160 lb/acre of commercial nitrogen fertilizer in the spring of 2004, and 186 lb/acre of commercial nitrogen fertilizer in the spring of 2005. No fertilizer was applied at Sites 1 and 2 during the 2006 water year. Spring applications of commercial nitrogen fertilizer were made at Site 3 in 2004 (230 lb/acre) and 2006 (180 lb/acre).

MONITORING RESULTS

2004 Water Year

A total of 39 inches of precipitation fell during the first year of the study (August 1, 2003 to September 30, 2004) with larger and more frequent rain events during the growing season (fig. 3a). Over the full twelve months, there were six periods of pronounced water table rise at Sites 1 and 2 and nine at Site 3 (fig. 3b). The additional water table fluctuations at Site 3, which is closer to the White River, were likely caused by changes in river stage not necessarily associated with vertical recharge events.

Hydrographs of soil-water tension in the unsaturated zone are shown in Figure 4. Fluctuations in soil-water tension are greatest in the shallow unsaturated zone and decrease with depth. These fluctuations in soil-water tension, when evaluated in conjunction with the timing and amounts of precipitation, provide physical evidence for the occurrence of vertical groundwater recharge events resulting from gravity-induced drainage.

Nitrate concentrations of samples collected from the unsaturated zone are plotted for the water year in Figure 5. At Site 1, the concentration of nitrate in the soil water increased first in the shallow unsaturated zone (1 ft), to a maximum of 37 mg/L in February and then declined to less than 5 mg/L for the rest of the year (fig. 5a). The maximum observed nitrate concentration in the unsaturated zone (53 mg/L) occurred in the second week of March at a depth of 3 ft. The concentration at 3 ft also decreased promptly and only fluctuated slightly during the remainder of the year. The deepest part of the unsaturated zone did not reach its peak nitrate concentration of 49 mg/L until April and it too showed a rapid decline and remained stable for the rest of the year.

At Site 2, the nitrate concentrations were much higher than at the other two monitoring sites (fig. 5b). A concentration of 131 mg/L in late November 2003 represents the highest nitrate concentration found in the unsaturated zone (1 ft) at any of the sites for the entire period of monitoring. Unfortunately, we were unable to track short-term trends of concentration at this location because the suction lysimeter would only produce water when the soil moisture was high and the tension was low. Samples from 3 ft peaked at 121 mg/L in the first week of December 2003, then decreased to below detection limits over a span of nearly six months before increasing slightly (to 16 mg/L) at the end of the water year. The highest concentration in samples from 7 ft below the surface (105 mg/L) occurred in early January and remained high for the rest the water year.

Only two samples of soil water could be achieved from the shallow lysimeter at Site 3 and the concentrations of nitrate were low in both: 0.5 mg/L in September, 2003 and 7.5 mg/L in mid-January (fig. 5c). The nitrate concentration in samples collected at a depth of 3 ft reached a maximum of 32 mg/L at the end of March. Within five weeks, the concentration declined to below detection limits. Minor fluctuations in concentration occurred during the remainder of the water year. The nitrate concentration in samples from 7 ft were typically less than 5 mg/L over the course of the water year. The two exceptions were a concentration of 9.5 mg/L mid-January and a concentration of 20 mg/L in late April.

Nitrate concentrations in samples collected from the monitoring wells are presented in Figure 6. At Site 1, the concentrations were highly variable over the course of the water year (fig. 6a). The concentration started rising in late November and peaked at 134 mg/L in early January. The nitrate concentration then dropped sharply to 13 mg/L by the end of the month but then increased again to 40 mg/L in March. After March there was a slow decrease to <0.5 mg/L (mid-May) followed by a solitary spike and return to below detection limit concentrations until the end of August. By the end of the water year the nitrate concentration in the saturated zone had increased to 62 mg/L.

The concentrations of nitrate collected from the monitoring well at Site 2 varied less than those at Site 1 but were generally higher (fig. 6b). The lowest concentration (5.5 mg/L) was observed in late November, but for the majority of the year, concentrations fluctuated between ~50mg/L and ~100 mg/L and showed a general increasing trend with time.

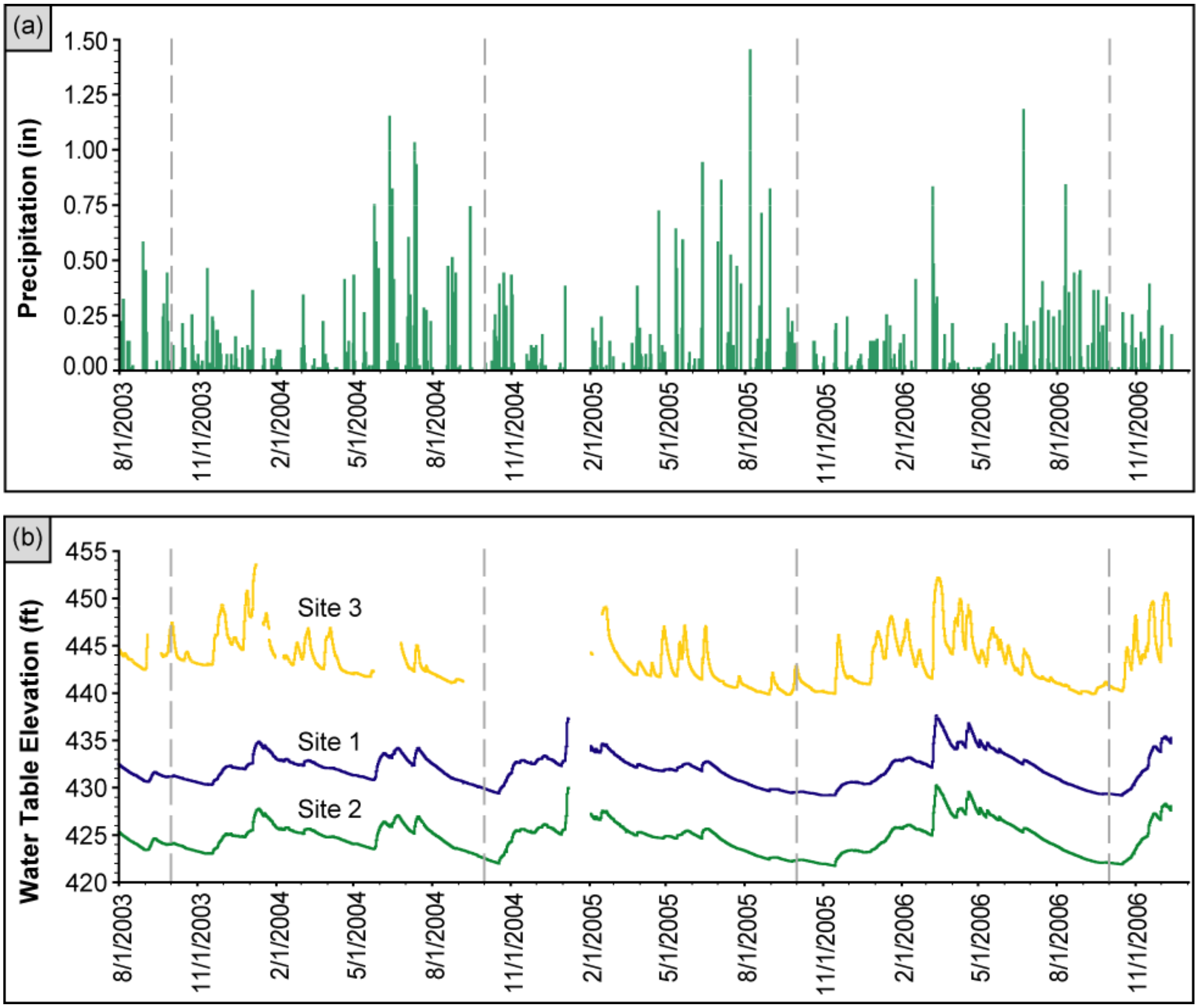

Figure 3. Daily precipitation totals measured at Site 1 (a). Water table elevations at each site (b). Dashed vertical lines separate water years. *Note: Gaps in data are due to equipment malfunction (flooding).*

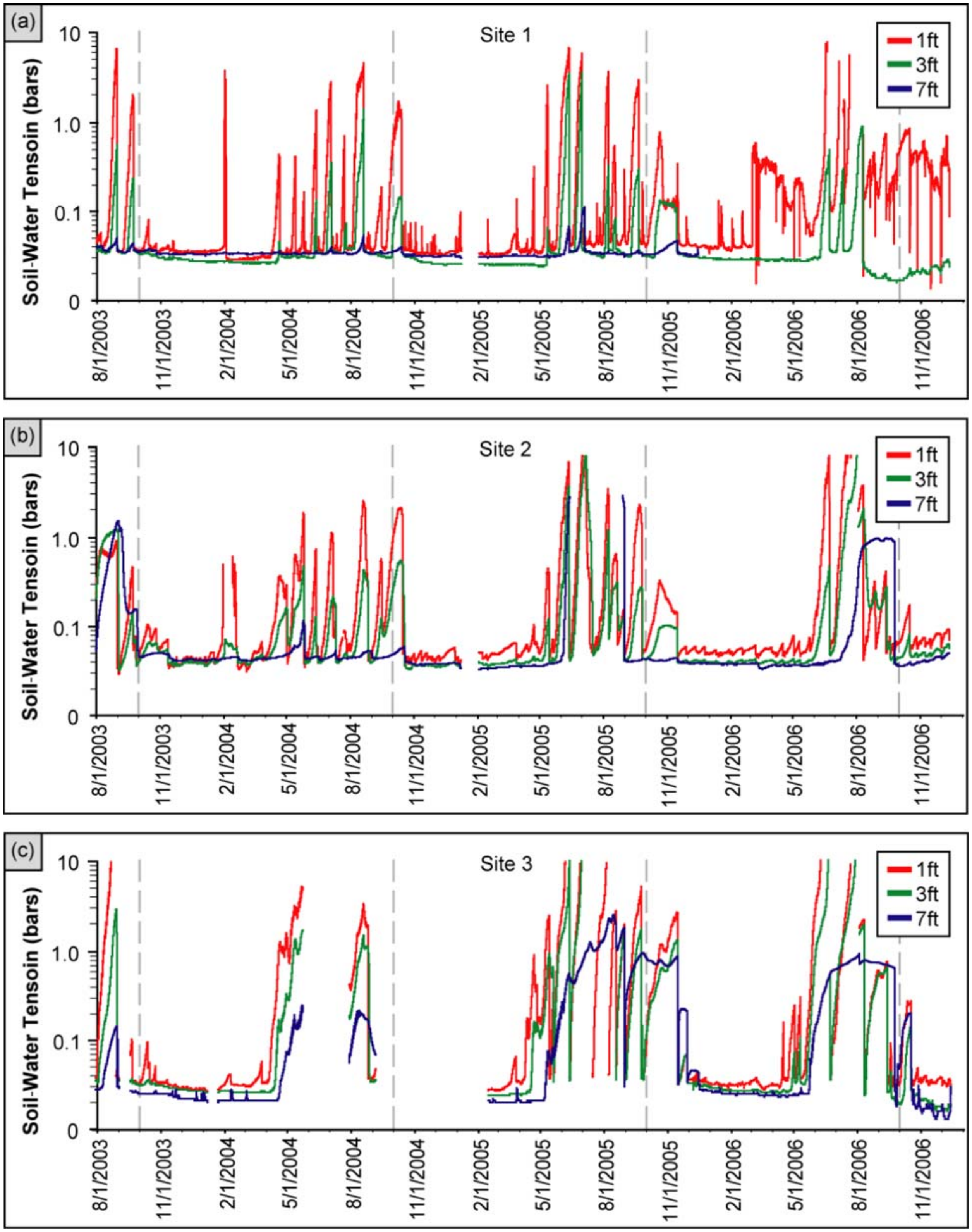

Figure 4. Soil-water tension in the unsaturated zone for Site 1 (a), Site 2 (b), and Site 3 (c). Dashed vertical lines separate water years.

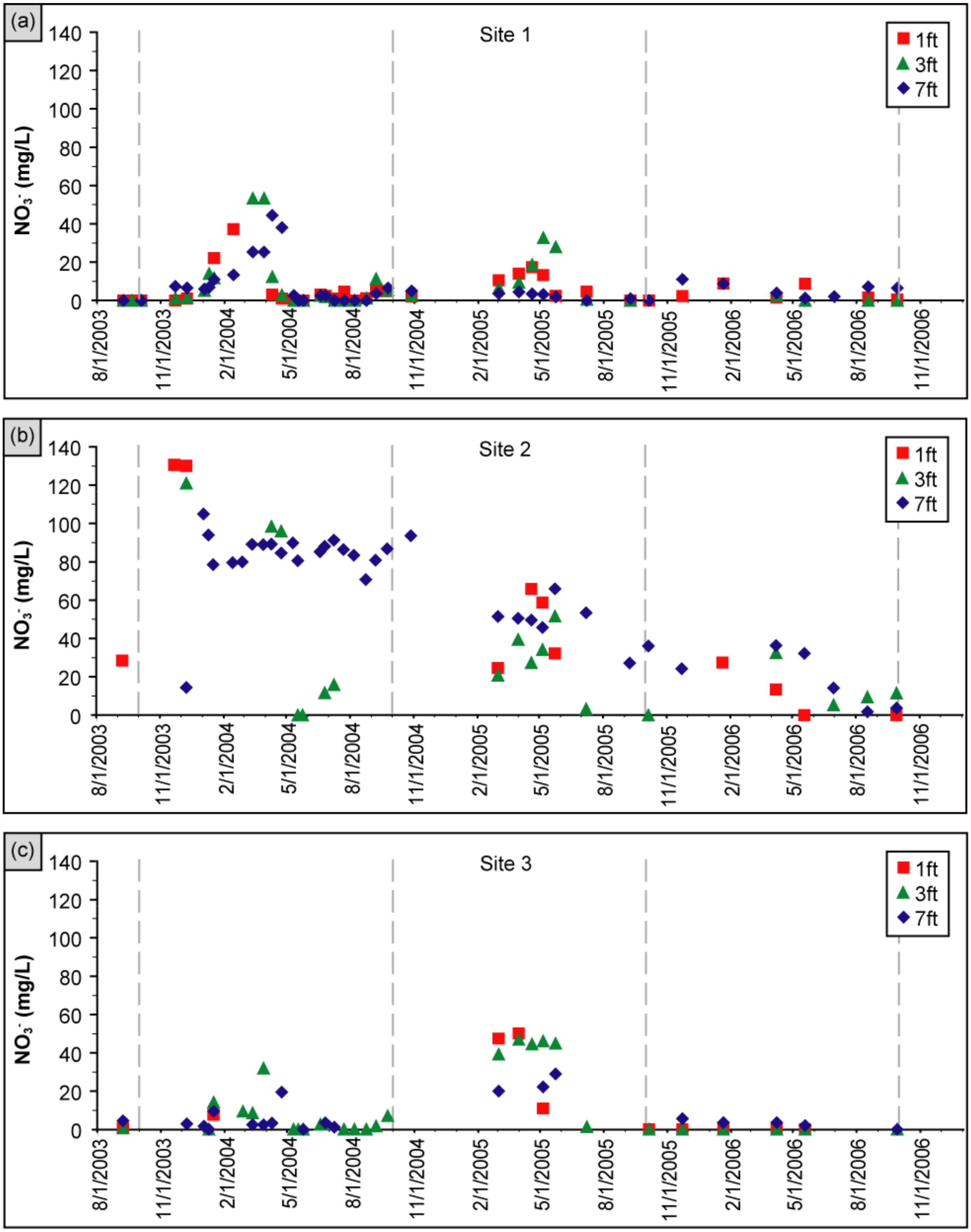

Figure 5. Values of nitrate concentration (NO_3^-) in samples of water extracted from the unsaturated zone at Site 1 (a), Site 2 (b), and Site 3 (c). Dashed vertical lines separate water years.

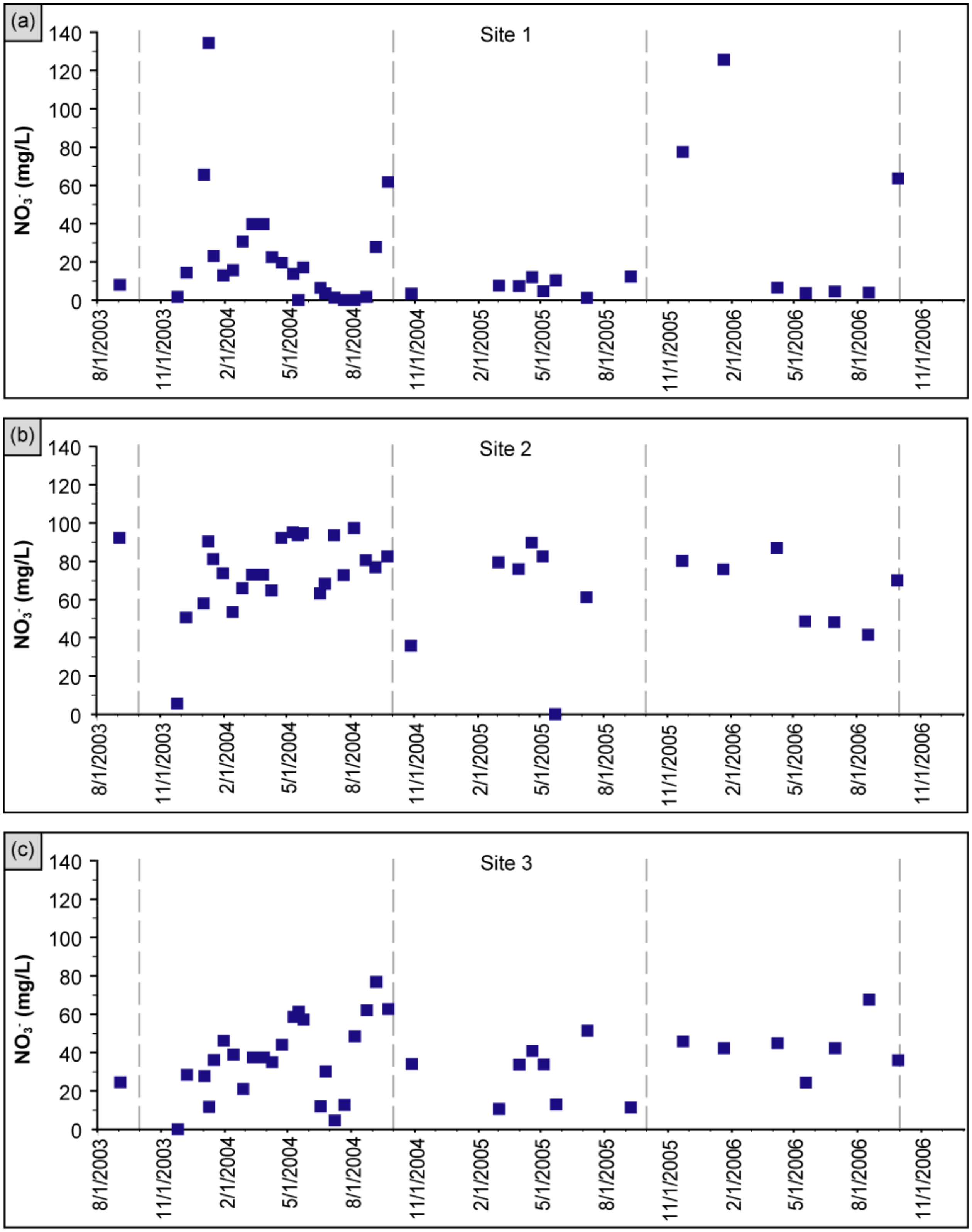

Figure 6. Values of nitrate concentration (NO_3^-) in samples collected from the saturated zone at Site 1 (a), Site 2 (b), and Site 3 (c). Dashed vertical lines separate water years.

Samples collected from the monitoring well at Site 3 produced nitrate concentrations that trended similarly to those collected at Site 2 (fluctuating, with a tendency to increase over time; fig. 6c), but the concentrations were generally lower (the highest nitrate value at Site 3 was 77 mg/L).

2005 Water Year

The study area received approximately 41 inches of precipitation, mostly in the later months of the water year 2005 (fig. 3a). This resulted in at least seven noticeable rises in the water table elevations Sites 1 and 2, and at least eight at Site 3 (fig. 3b).

The hydrographs of soil-water tension are also similar to those of 2004, but the magnitude of fluctuation was greater (fig. 4b).

At Site 1, the nitrate concentrations in the unsaturated zone were generally lower than those of the previous year (fig. 5a). The lysimeter at 3 ft depth again produced those samples having the highest concentrations of nitrate (a maximum 33 mg/L at the beginning of May). Unlike the previous year, the lysimeter in the deep unsaturated zone never produced samples that exceeded 5.0 mg/L.

At Site 2, the nitrate concentration at 1 ft increased from 25 mg/L in March to a high of 66 mg/L in mid-April, and then declined to 32 mg/L by the end of May (fig. 5b). Again, the lack of production from the shallow unsaturated zone limited the number of samples available for analysis. The suction lysimeter at 3 ft produced samples with concentrations that increased from 21 mg/L in early March to 52 mg/L at the end of May and then decreased to 3.2 mg/L by the first week of July. The highest nitrate concentration at 7 ft (94 mg/L) was observed at the very beginning of the water year, but then decreased over the rest of the water year.

Unlike Site 1 and Site 2, the nitrate concentrations in the unsaturated zone of Site 3 increased slightly from 2004 to 2005 (fig. 5c). The concentration at 1 ft was 47 mg/L at the beginning of March, increased to 50 mg/L by the end of the month and then decreased to 11 mg/L in May. At 3 ft depth the nitrate concentration was 39 mg/L in early March, then increased to 47 mg/L by the end of the month. The concentration then remained steady for two months before declining to 1.3 mg/L in early July. Nitrate concentrations in the deep unsaturated zone were relatively stable, increasing only slightly from 20 mg/L to 29 mg/L over the course of three months, March to June. It should be noted that a faulty suction lysimeter prevented the regular acquisition of deep unsaturated zone soil-water at this location.

The large fluctuations of nitrate concentration in the saturated zone at Site 1 observed in 2004 were not repeated in 2005. The initial concentration was only 3.3 mg/L and it increased to 12 mg/L by the end of the year with no major spikes in concentration (fig. 6a).

The nitrate concentration in the saturated zone at Site 2 also dropped off considerably from the end of the 2004 water year (from 82 mg/L to 36 mg/L in one month; fig. 6b). The concentrations rebounded to ~85 mg/L in March through early May, but then plummeted to below detection limits at the end of May, followed by an increase to 61 mg/L in approximately five weeks.

At Site 3, the nitrate concentration in the saturated zone declined from 63 mg/L to 34 mg/L in one month at the beginning of the 2005 water year (fig. 6c). It then fluctuated, reaching a maximum of 51 mg/L at the beginning of July before dropping to 11 mg/L a few weeks before the end of the water year.

2006 Water Year

In the final year of monitoring, the study area received approximately 35 inches of precipitation, mostly after March (fig. 3a). There were approximately six periods of pronounced water table rise at Sites 1 and 2 and approximately eleven at Site 3 (fig. 3b). Again, those additional water table fluctuations at Site 3 were likely caused by changes in river stage and not as a result of natural recharge caused by infiltration-driven unsaturated groundwater flow.

The soil-water tension data for the 2006 water year show the usual annual fluctuation—low tension in winter and high tension in summer. However, the gypsum blocks began to deteriorate so the data are not as accurate as they were in the previous years of monitoring (fig. 4c).

Samples from the 1 ft and 3 ft deep lysimeters at Site 1 produced nitrate concentrations that were considerably lower than those of the previous two years (<11 mg/L; fig. 5a). While there is a small amount of fluctuation throughout the year, the concentration values showed no real distinction between levels.

A continued trend of nitrate concentrations distinctly lower than the previous water year is also evident at Site 2 (fig. 5b). The first sample analyzed in mid-January from 1 ft had a value of 27 mg/L. The concentration decreased to below detection limits within four months and remained low for the duration of monitoring. At 3 ft, the nitrate concentration at the start of the water year was below detection limits but increased to 33 mg/L by the first week of April. By the end of June, the concentration had decreased to 5.3 mg/L but again increased to 12 mg/L by the end of the water year. The deep lysimeter produced samples having nitrate concentrations of 36 mg/L at the beginning of the water year. The concentrations remained steady for close to six months before they decreased to 1.8 mg/L in August and 3.8 mg/L at the end of the water year.

At Site 3, the water samples collected from the shallow and mid-level unsaturated zones had nitrate concentrations that were below detection limits for the entire water year (fig. 5c). Only those samples obtained from the deep unsaturated zone had measurable concentrations of nitrate and the maximum there (at 7 ft) was only 5.6 mg/L.

Nitrate concentrations in the samples collected from the saturated zone at Site 1 exhibited a large range, similar to those observed in 2004 (fig. 6a). The concentration was 77 mg/L in late November and increased to 126 mg/L by January. Over the next two months, the concentration plummeted to 6.5 mg/L and then maintained a concentration <5 mg/L until mid-August. By the end of the water year, the concentration in the saturated zone had increased again to >50 mg/L.

The nitrate concentrations in the saturated zone at Site 2 show a weak but continued decreasing trend in 2006, falling from 80 mg/L at the beginning of the water year to 70 mg/L at the end (fig. 6b). The maximum concentration (87 mg/L) was observed in late April followed by the minimum (41 mg/L) in August.

Nitrate concentrations in the saturated zone at Site 3 remained steady at around 40 mg/L over the course of the 2006 water year (fig. 6c), but with some fluctuation. The minimum concentration of 24 mg/L occurred in mid-May and the maximum concentration of 68 mg/L occurred in mid-August.

Isotopic Samples

Samples were collected for nitrogen isotope analyses in 2004 and for nitrogen and oxygen isotope analyses in 2006 (Table 1). Most of the samples collected from the 1 ft and 3 ft deep lysimeters were either too small in volume or too dilute to allow isotopic analysis; therefore, the results pertain mainly to the deep unsaturated and saturated zones at the study sites.

Table 1. $\delta^{15}N$ and $\delta^{18}O$ of nitrate (NO_3^-).

	2004	2006	
	$\delta^{15}N$	$\delta^{15}N$	$\delta^{18}O$
Site 1 Shallow	*n/a*	*n/a*	*n/a*
Site 1 Medium	*n/a*	*n/a*	*n/a*
Site 1 Deep	7.25	1.90	-0.64
Site 1 Monitoring Well	6.91	7.03	9.64
Site 2 Shallow	*n/a*	*n/a*	*n/a*
Site 2 Medium	5.90	-13.17	-1.26
Site 2 Deep	5.47	6.03	-0.42
Site 2 Monitoring Well	2.24	0.17	3.94
Site 3 Monitoring Well	6.59	8.52	9.49

n/a = Nitrate concentration too dilute for isotopic analysis.

$\delta^{15}N$ measured in *per mil* (‰) with respect to atmospheric nitrogen (AIR).

$\delta^{18}O$ measured in *per mil* (‰) with respect to Vienna Standard Mean Ocean Water (VSMOW).

DATA INTERPRETATION

As shown in Figure 4, the soil-water tension in the unsaturated zone was below the lower limit of field capacity (0.1 bars) for much of the time during the period of monitoring, so that rainfall or snowmelt during those periods could induce gravity drainage and vertical groundwater recharge.

Values of nitrate concentration in samples collected from the unsaturated zone showed that the highest concentrations at Sites 1 and 2 (the two fields where turkey manure was applied during the first year of study) occurred in late autumn and early winter in association with stormy periods that triggered recharge events. The highest concentrations at Site 3 (which did not receive nitrogen application in autumn 2003, but received two applications of nitrogen in spring 2004) occurred in the late winter and spring of 2005. (Note that the river flooded in May 2005). In general, the highest concentrations of nitrate occurred at Site 2, but all three sites exhibited significant fluctuations over the course of monitoring, especially in the early phase when manure and commercial fertilizers were being applied.

The clearest details of the anatomy of a recharge event were captured at Site 2 in the autumn/winter of the 2004 water year (fig. 7). By the end of September, soil-water tension had decreased below field capacity so that gravity drainage could occur. Manure was applied to the field in mid-October. A series of rainstorms in November initiated the main period of recharge. Nitrate concentration peaked at 1 ft depth first, at 3 ft two weeks later, and at 7 ft a month after that (fig. 7a). Nitrate concentration in the saturated zone began rising from its seasonal low in mid-November, but did not reach its peak until January when a late-season rainstorm completed the recharge event and produced the highest water table elevation of the monitoring period (fig. 7b).

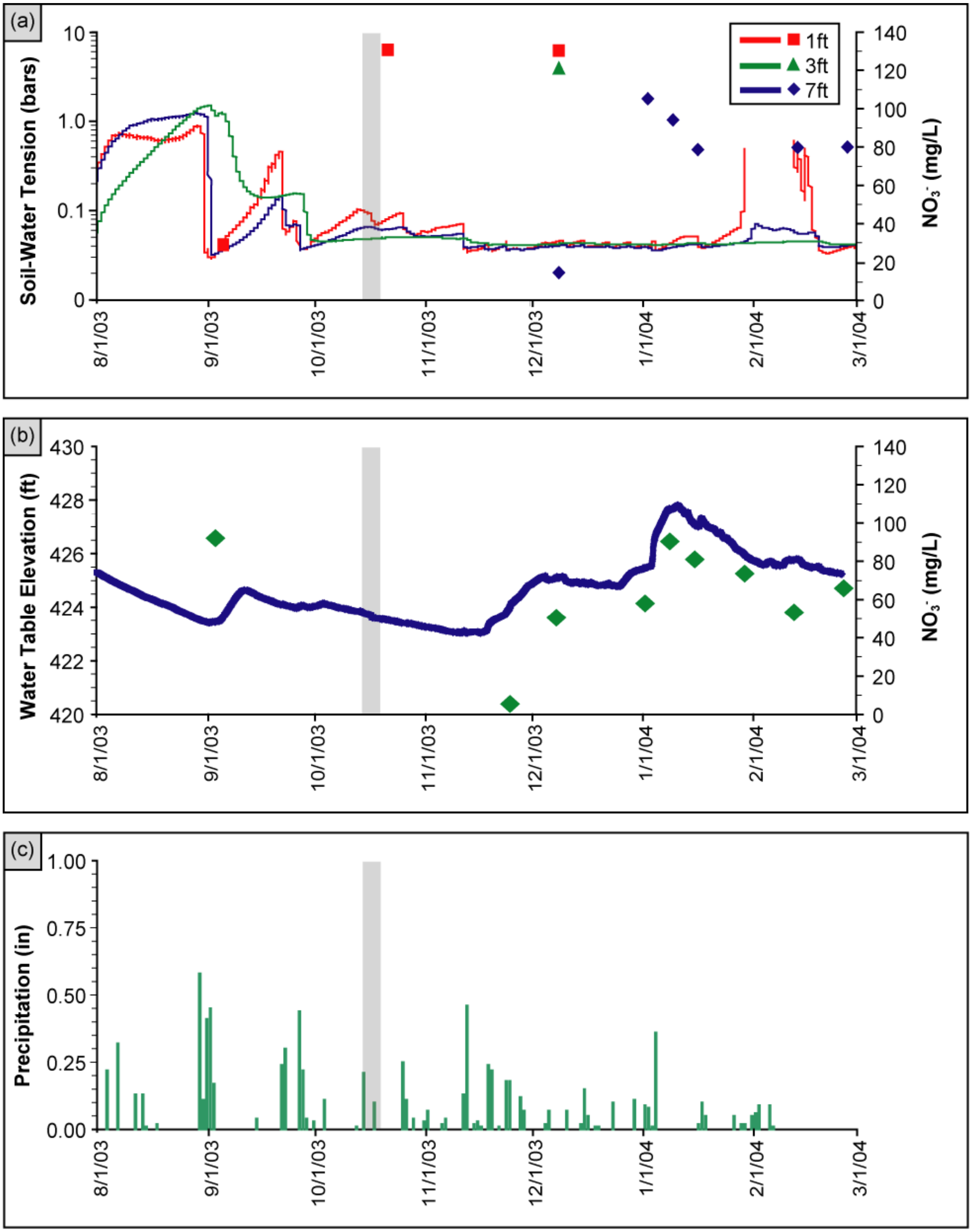

Figure 7. 2003–2004 autumn/winter recharge data from Site 2. Soil-water tension and unsaturated zone nitrate concentration (a), water-table elevation and saturated zone nitrate concentration (b), and precipitation (c). Shaded region represents the application of manure to the field in mid-October 2003.

The results of the nitrogen isotopic analysis conducted in 2004 were not conclusive in terms of determining the sources of nitrate but did offer preliminary insight into the nitrogen budget at each of the sites. For the 2004 sampling event, the highest $\delta^{15}N$ values (6.91‰ and 7.25‰) occurred in the deep unsaturated zone and shallow saturated zone at Site 1, respectively (Table 1). These values are at the upper range of those typically associated with decaying organic matter in natural soils (~2.5‰ to ~7.5‰) and at the lower range of values typically associated with animal waste (~10‰ to ~20‰). The samples from the unsaturated and saturated zones at Site 2 varied from ~2.24‰ to ~5.47‰ and are within the upper limit of $\delta^{15}N$ values for commercial fertilizers (~-5.0‰ to ~5.0‰). The nitrogen isotope composition of the sample taken from the saturated zone at Site 3 (6.59‰) is consistent with nitrate derived from soil organic matter.

In order to better clarify the source(s) of nitrate, isotopes of both nitrogen and oxygen were analyzed in the 2006 sampling event. The $\delta^{15}N$ and $\delta^{18}O$ isotope signatures of the samples collected in 2006 (Table 1) were used to determine the possible sources of nitrate based on the fields plotted in Figure 8. The samples from the monitoring wells each site indicate that the nitrate in the saturated zone likely originated from commercial fertilizer and is in various stages of denitrification by native bacteria in the soil. The samples from the deep unsaturated zones at Site 1 and Site 2 are consistent with nitrate derived from the decomposition of soil organic matter (plant materials) in the presence of water from precipitation (recall there was no fertilizer application in 2006). The water sample collected from the mid-level unsaturated zone at Site 2 has an isotopic signature that is at the low end for natural nitrate found in precipitation.

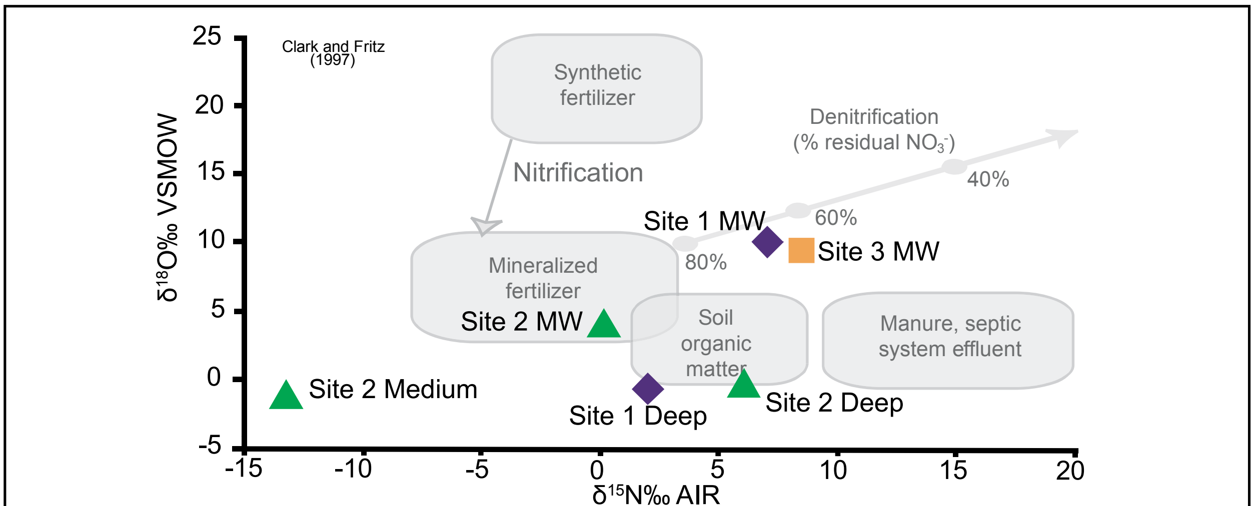

Figure 8. $\delta^{15}N$ and $\delta^{18}O$ of nitrate (NO_3^-) collected in 2006. $\delta^{15}N$ is measured with respect to atmospheric nitrogen (AIR). $\delta^{18}O$ is measured with respect to Vienna Standard Mean Ocean Water (VSMOW).

Nitrate Budget – Surface application, annual recharge, and nitrate loading of the water table

Changes in the measured soil moisture profiles were combined with data on the net surface flux between the days of measurement to calculate the flow of water through the unsaturated zone throughout the period of study. The flow calculations are based on the continuity equation for vertical unsaturated flow:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial v}{\partial z} \tag{1}$$

where θ is the moisture content at depth z and time t, and v is the Darcy flux. A finite-difference solution to the differential equation gives:

$$v_z = v_{z+\Delta z} + \frac{\Delta \theta}{\Delta t} \Delta z \tag{2}$$

where $v_{z+\Delta z}$ is the flux in the finite-difference cell above the calculation cell (Δz = 1 ft) and Δθ is the change in moisture content in cell z over the period Δt (# of days between moisture profile measurements). At the top of the moisture profile the value of $v_{z+\Delta z}$ (boundary condition) was set equal to the net surface flux over the period between moisture profile measurements.

Over the three year period of study, data were available to evaluate the flux through the unsaturated zone a total of 65 times. The results of the flux calculations are presented in Figure 9. The analysis indicated that over the entire period, 25 recharge events (net downward flux through the profile) occurred at Site 1, 24 recharge events occurred at Site 2 and 26 recharge events occurred at Site 3. Total recharge was determined to be ~30 inches at Site 1, ~25 inches at Site 2, and ~41 inches at Site 3. These calculated recharge totals were combined with average nitrate concentrations in the unsaturated zones at each study site (6.5 mg/L at Site 1.51 mg/L at Site 2, and 10 mg/L at Site 3) to determine the seasonal total nitrate loading of the water table by flushing through the unsaturated zone: 43 lb/acre at Site 1; 295 lb/acre at Site 2; 93 lb/acre at Site 3.

The precipitation totals are presented along with calculated values of groundwater recharge and nitrate loading of the water table in Table 2. The most significant finding is that the nitrate loading at Site 2 in 2004 was over 200 lb/acre; this total is almost four times greater than the 52 lb/acre N that is supposedly generated from 2 ton/acre of manure application. Also, the nitrate loading at Site 1 in 2004 was about half the total nitrogen that is supposed to be associated with the manure application. These high loading rates (of groundwater) are in part due to the fact that the manure was applied during the annual recharge season when no crops existed on the fields. Other contributing factors may have been (1) close proximity of the monitoring sites to the turkey barn (especially Site 2), and (2) the fact that nitrate buildup from previous seasons can increase the concentration of nitrate in the unsaturated zone over what would occur from just the current season's fertilizer applications.

Another significant outcome of the monitoring and modeling of nitrate fluxes was that once the manure applications were suspended, the nitrate loading of the water table declined to values that were comparable to those determined for the control site (Site 3). The lower loading rates associated with the use of commercial fertilizer has to do with the time of application; a spring application corresponds to the growing season and the nitrogen is utilized by plants.

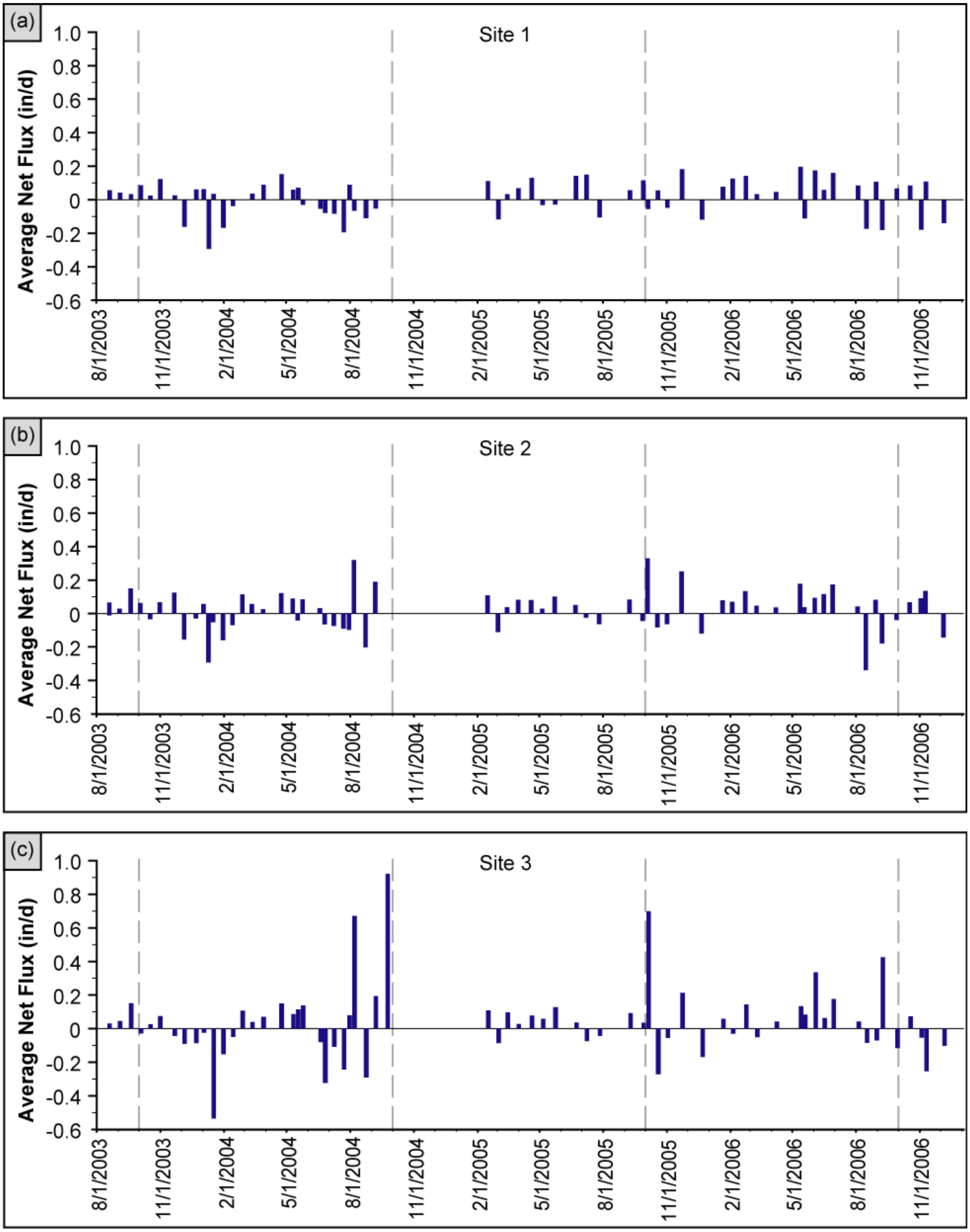

Figure 9. Vertical flow through the lower unsaturated zone (based on equation 2), Site 1 (a), Site 2 (b), and Site 3 (c). Dashed vertical lines separate water years. The annual totals were used along with nitrate concentrations in the lower unsaturated zone to calculate nitrate loading of the water table.

Table 2. Calculated nitrate loading

Water Year	NO_3^- (mg/L)	Precipitation (in)	Recharge (in)	Loading (lb/acre)
Site 1				
2004	8.3	39	13	25
2005	3.1	41	3.3	2.3
2006	5.0	35	9.7	11
Total	6.5*	115	24	**35**
Site 2				
2004	71	39	13	212
2005	45	41	2.7	27
2006	19	35	6.3	27
Total	51*	115	25	**295**
Site 3				
2004	6.4	39	22	32
2005	29	41	2.2	15
2006	2.0	35	0.70	5.8
Total	10*	115	2.7	**83**

* Average unsaturated zone nitrate concentration.

GIS ANALYSIS OF HYDROGEOLOGIC SETTINGS

Geographic information systems (GIS) software was used to conduct an analysis of similar hydrogeologic settings throughout Indiana that might be susceptible to groundwater contamination from nutrient applications to row crops. In this analysis, the spatial distribution of the following parameters was considered:

- Shallow static water levels in unconfined aquifers;
- Permeability of surficial geologic materials (based on geologic depositional settings);
- Land use (agricultural, row crops).

Depth to the water table, or static water level, was extracted from the iLITH database (Brown and others, 2000) for wells completed in unconfined aquifers. The iLITH database contains data derived from the Indiana Department of Natural Resources, Division of Water groundwater well-log database for Indiana. Data in the iLITH database include location and lithologic information. For this analysis, the iLITH database was queried to extract all well logs that met the following criteria: (1) static water level within 25 feet of the ground surface, (2) top of unconfined aquifer (determined by comparing the static water level elevation with the elevation of the aquifer) within 25 feet of the ground surface, (3) aquifer composed of permeable materials (for example, sand, gravel, sand and gravel). The data points meeting the stated criteria were converted to a point layer representing the distribution of the wells throughout the state.

The static water-level layer was used to select (using the procedure known as “select by theme”) geologic units from a statewide surficial geology data layer (Gray, 1989). Figure 10 shows the surficial geologic units selected with the static water-level data layer. The data layers selected were from depositional setting and geologic materials known to be permeable or highly permeable. These materials include:

- Outwash;
- Outwash fans;
- Alluvium;
- Beach and dune sand;
- Blanket sand;
- Ice-contact stratified glacial drift;

- Lake sand;
- Loess;
- Upland silt;
- Mixed glacial drift;
- Loam.

The last input data theme used in the analysis was the National Land Cover Dataset (NLCD) (U.S. Environmental Protection Agency and U. S. Geological Survey, 2001). The NLCD is a thematic raster data layer of the land cover of the United States that is quite detailed (30-meter resolution). This analysis made use of a subset of the data that represents the land cover and land use for Indiana. The agricultural “row crop” land use was extracted from the data layer, and subsequently intersected with a raster version of the surficial geologic materials described above. The resultant data layer, shown in Figure 11, represents the areas of Indiana having shallow static water levels in permeable surficial materials that are susceptible to groundwater contamination by nutrient applications to row crops. Because there are groundwater/surface-water interactions near the water table in permeable materials, areas where the water table is contaminated are also likely to impact streams, creating an even greater threat to groundwater quality. There are many areas of the state that are hydrogeologically sensitive to groundwater contamination by nutrient applications. Figure 12 shows these areas along with active or pending confined feeding operation locations. Many CFO locations lie over hydrogeologically sensitive areas, which emphasize the importance of protecting aquifers through an understanding of the appropriate amount of nutrients that can be applied to the land surface without migrating downward through the unsaturated zone into the water table and shallow aquifers.

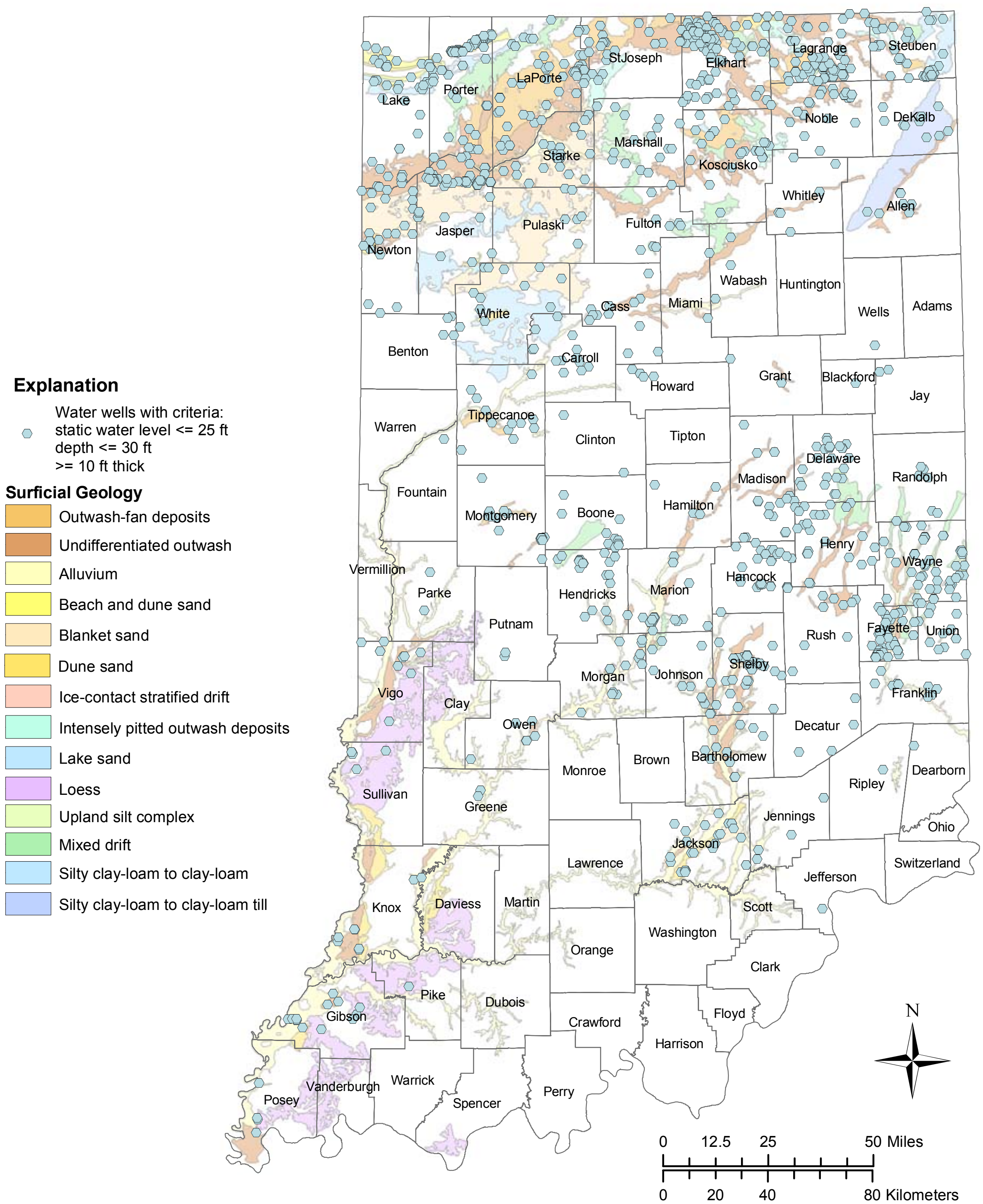

Figure 10. Map showing the surficial geologic units (Gray, 1989) from which water wells having shallow static water levels (less than or equal to 25 ft below ground surface) are withdrawing groundwater.

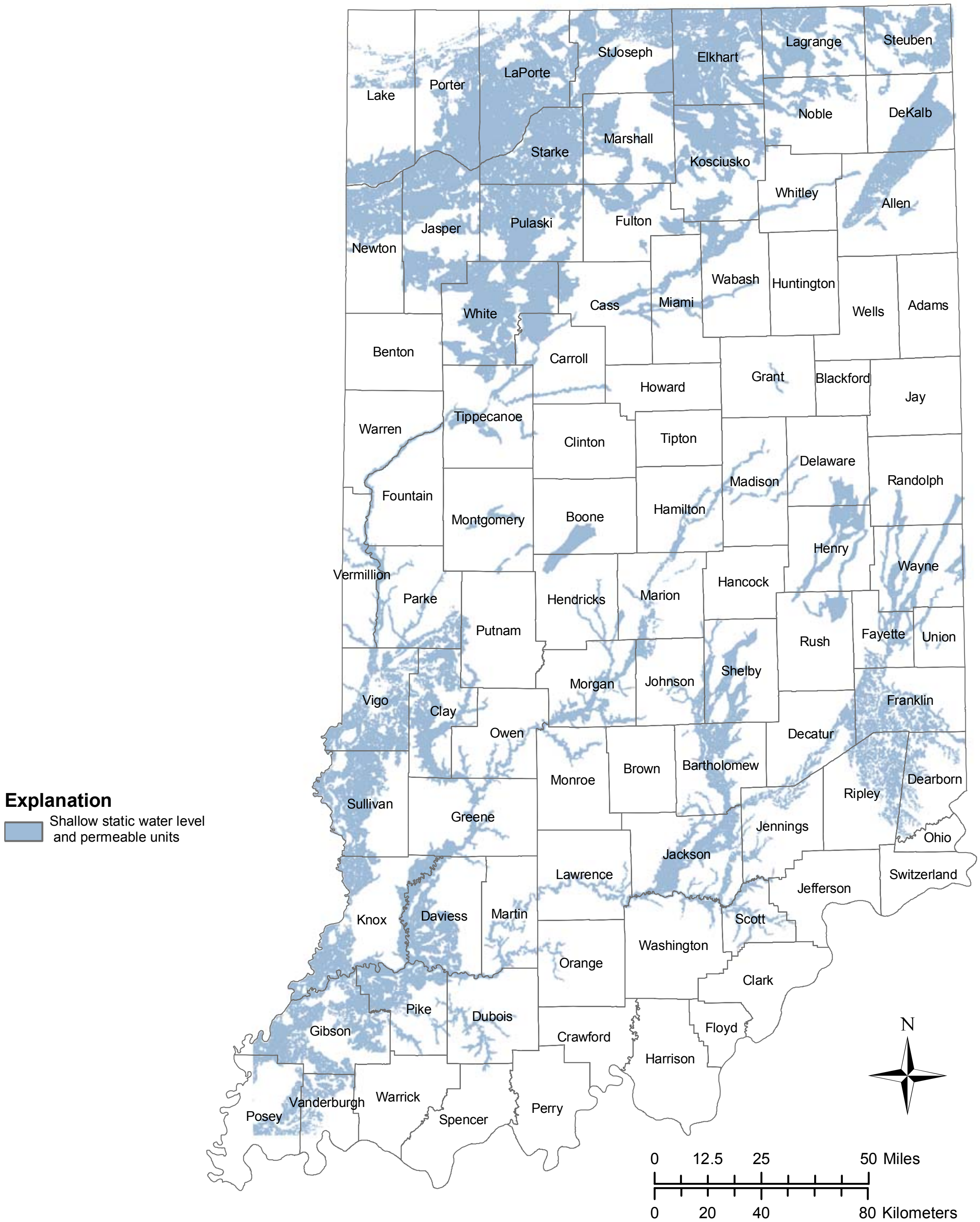

Figure 11. Map showing conditions throughout Indiana having shallow water tables (less than or equal to 25 ft below ground surface) in permeable near-surface aquifers that could potentially be impacted by contamination from nutrient application to row crops.

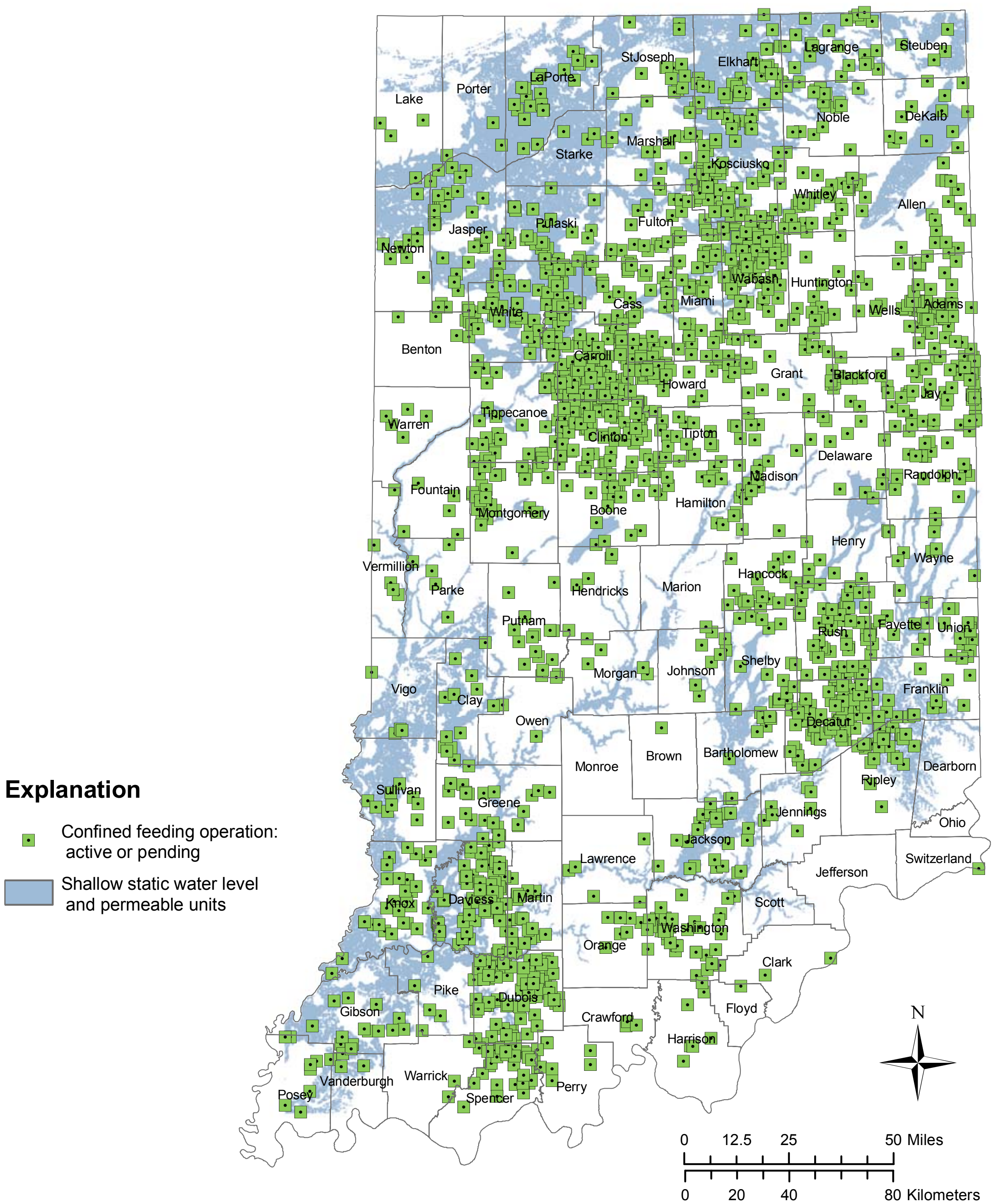

Figure 12. Map showing active or pending confined feeding operations in Indiana plotted over shallow surficial aquifers. Over 2000 confined feeding operation locations were active or pending in 2006.

RECOMMENDATIONS

The recommendations provided in this report result from our current understanding of the Indiana Department of Environmental Management confined feeding operation regulations, hydrochemical processes within the unsaturated zone, and the relationships between surface topography, unconsolidated geology/soils, and depth to shallow potable water. The data from both our monitoring studies and GIS analysis indicate that many areas of Indiana are susceptible to shallow groundwater loading of nitrate. We therefore strongly recommend that fertilizer applications (organic or commercial) should be avoided or minimized in the early spring and late fall, when storms can push contaminants through the unsaturated zone without significant attenuation through uptake or filtration by plants.

Proper rates, placement, and timing of animal waste and fertilizer applications can greatly reduce nitrogen migration into the deep unsaturated zone and water table. Nutrient management is a very effective practice for preventing groundwater contamination by nitrates (and phosphorus contamination in surface water).

<u>Rates – nutrient management plans</u>

- High-quality nutrient management plans should continue to be assembled and updated regularly.
- 150 lbs/acre default application rate (see 327 IAC 16-10-1; Indiana General Assembly, 2002) is too high for some hydrogeologic settings. This study suggests that an application rate one-third of the statutory limit (~50 lbs/acre based on published nitrogen yields from turkey manure) is sufficient to permit groundwater contamination by nitrates.
    - **Rule 10. Land Application of Manure, 327 IAC 16-10-1**

      (a) A minimum number of acres for manure application must be maintained and documented in the operating record at all times based on:

        (1) agronomic rates for potentially available nitrogen provided by a laboratory soil test, and a manure test; or

        (2) application rates not to exceed **one hundred fifty (150) pounds of potentially available nitrogen per acre per year,** for confined feeding operations that have not received the test results on the soil and manure.
- Cumulative effects of land application of manure in a single watershed should be considered in the nutrient management plan, especially in areas with permeable surficial geologic materials.

<u>Timing (season, storms)</u>

Land application of manure, wastewater, and even commercial fertilizers should be emplaced only when crops are on the ground and provide an opportunity for maximum uptake by the crops. Applying during the fall or early spring before crop planting (pre-application) should be avoided. The existing guidance given for land-application—originally intended to prevent surface-water contamination—should be adhered to for the protection of groundwater quality. This guidance includes the following parameters:

- Do not apply in floodplains;
- Do not apply where less than 20 inches of soil lies over bedrock;
- Do not apply to saturated ground;
- Manure or wastewater should not be ponded on the ground.

<u>Placement</u>

Avoid:

- Geologically or environmentally sensitive areas.
- Permeable geologic materials, shallow water tables, low saturated areas.
- Use the setback distance concept—or modify application rates—for avoiding areas that may be sensitive to groundwater contamination. These areas include:
    - Floodplains;
    - Areas having less than 20 inches of soil over bedrock;
    - Saturated ground;
    - Potential recharge areas;
    - Pristine or protected habitats.

Monitoring

Monitoring of saturated zones only, through monitoring wells, is insufficient to establish the degree of groundwater contamination (loading) by nitrate. In addition, quarterly sampling is arbitrary with regard to characterizing the dynamic water chemistry of shallow groundwater, and post-storm sampling can also miss the peak concentrations that can occur from a recharge event. For example, the rains that caused the recharge event in the winter season of the 2004 water year occurred only about a week prior to the maximum nitrate concentrations in the unsaturated zone resulting from that event.

Because of the long history of agriculture in Indiana, nitrate contamination is pervasive in the soil, unsaturated zone, and water table throughout the state. Even when new nitrogen sources are not being applied to farmland, the existing nitrogen in the subsurface continues to leach through the unsaturated zone into the water table. However, as documented in this study, the response of the unsaturated zone occurs quickly in comparison to that of the saturated zone when a management change is made. In contrast, the saturated zone changes slowly as a result of long-term nitrate buildup and the horizontal movement of other contaminated waters toward local streams (the White River, in this case).

Monitoring for the impact of management changes should be conducted over several seasons because loading of the saturated zone by vertical flow through the unsaturated zone depends on recharge (rate and timing) as well as solute concentration in the unsaturated zone. This study has shown that timing of precipitation and evapotranspiration combine to control the annual recharge rate which is not strictly a function of annual rainfall.

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APPENDIX. Summary of Chemical Analyses

Site	Sample ID	Date	Temp	SpCond	DO Conc	pH	Eh vs SHE	Cl	NO3	PO4	K	NH3-N	NO3-N
Number			C	uS/cm	mg/L		mV	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	Drainage Lysimeter	9/3/2003	24.5	412	7.1	7.1	229	3.4	5.7	2.5	9.4	0.14	1.3
1	Monitoring Well	9/3/2003	16.6	429	8.9	7.2	222	2.4	7.9	<0.5	5.4	<0.10	1.8
2	Drainage Lysimeter	9/3/2003	24.2	482	6.5	6.6	218	2.4	93	9.7	9.3	0.67	21
2	Monitoring Well	9/3/2003	15.3	456	9.4	7.3	231	0.5	92	1.2	9.3	0.14	21
3	Drainage Lysimeter	9/3/2003	25.6	480	7.0	7.0	236	1.4	1.6	<0.5	1.2	0.23	0.4
3	Monitoring Well	9/3/2003	14.4	579	0.7	7.1	174	28	25	<0.5	0.4	0.11	5.5
1	Shallow Lysimeter (1.75 ft)	9/7/2003	26.0	212	7.1	7.2	205	<0.5	<1.0	1.1	0.9	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)	9/7/2003	26.0	422	6.9	7.1	204	<0.5	<1.0	1.1	1.8	<0.10	<0.2
1	Deep Lysimeter (7 ft)	9/7/2003	26.8	424	6.7	7.0	208	<0.5	<1.0	<0.5	3.5	0.16	<0.2
2	Shallow Lysimeter (1.75 ft)	9/7/2003	27.8	723	7.1	7.2	208	0.7	29	12	3.4	0.22	6.4
3	Shallow Lysimeter (1.75 ft)	9/7/2003	26.5	329	6.8	6.8	221	4.3	0.5	<0.5	4.3	0.19	0.1
3	Middle Lysimeter (3.5 ft)	9/7/2003	25.2	415	6.7	6.8	210	1.4	0.8	<0.5	1.3	<0.10	0.2
3	Deep Lysimeter (7 ft)	9/7/2003	23.3	665	5.6	6.8	209	6.8	4.5	<0.5	0.6	<0.10	1.0
1	Shallow Lysimeter (1.75 ft)	9/19/2003	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<1.0	<0.5	0.5	0.16	<0.2
1	Middle Lysimeter (3.5 ft)	9/19/2003	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<1.0	<0.5	1.8	<0.10	<0.2
1	Shallow Lysimeter (1.75 ft)	10/3/2003	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<1.0	<0.5	0.4	0.12	<0.2
1	Middle Lysimeter (3.5 ft)	10/3/2003	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<1.0	<0.5	1.5	<0.10	<0.2
1	Deep Lysimeter (7 ft)	10/3/2003	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<1.0	<0.5	3.7	0.22	<0.2
1	Shallow Lysimeter (1.75 ft)	11/21/2003	13.0	350	10.1	6.6	186	10	<1.0	<0.5	4.0	0.17	<0.2
1	Middle Lysimeter (3.5 ft)	11/21/2003	16.3	406	10.0	7.1	196	8.4	1.1	2.0	2.2	0.16	0.2
1	Deep Lysimeter (7 ft)	11/21/2003	16.6	560	10.1	6.9	216	4.1	7.5	<0.5	5.2	0.16	1.7
2	Shallow Lysimeter (1.75 ft)	11/21/2003	17.4	644	10.0	7.1	210	13	131	12	14	0.59	29
1	Monitoring Well	11/25/2003	11.4	883	10.2	7.4	198	5.4	1.6	<0.5	4.9	<0.10	0.4
1	Monitoring Well	11/25/2003	na	na	na	na	na				4.9	<0.10	
2	Monitoring Well	11/25/2003	10.5	505	9.9	7.5	215	13	5.5	<0.5	6.0	<0.10	1.2
3	Monitoring Well	11/25/2003	11.1	565	3.7	7.3	196	2.7	<1	<0.5	0.5	<0.10	<0.2
1	Drainage Lysimeter	12/8/2003	6.2	337	12.1	7.0	215	16	1.5	1.9	8.30	<0.10	0.3
1	Shallow Lysimeter (1.75 ft)	12/8/2003	7.4	276	11.8	7.3	231	0.9	1.0	1.1	1.40	<0.10	0.2
1	Middle Lysimeter (3.5 ft)	12/8/2003	8.1	333	11.4	7.1	229	1.7	1.5	1.7	1.60	<0.10	0.3
1	Deep Lysimeter (7 ft)	12/8/2003	10.1	443	10.4	7.1	216	6.3	6.5	1.7	3.70	<0.10	1.5
1	Monitoring Well	12/8/2003	10.3	1089	9.7	6.6	228	6.2	14	<0.5	6.40	<0.10	3.2
2	Drainage Lysimeter	12/8/2003	6.1	329	11.8	7.4	236	4.1	18	5.1	4.40	2.38	4.0
2	Shallow Lysimeter (1.75 ft)	12/8/2003	7.3	574	11.9	7.1	219	8.5	130	10	6.30	0.11	29
2	Middle Lysimeter (3.5 ft)	12/8/2003	8.6	669	11.0	7.1	219	3.7	121	16	7.80	<0.10	27
2	Deep Lysimeter (7 ft)	12/8/2003	10.3	468	10.5	7.2	247	0.9	14	12	27.3	<0.10	3.3
2	Monitoring Well	12/8/2003	12.1	414	9.3	7.4	257	0.5	51	<0.5	6.90	<0.10	11
3	Drainage Lysimeter	12/8/2003	7.7	342	12.0	7.4	217	5.3	2.6	0.6	2.00	<0.10	0.6
3	Deep Lysimeter (7 ft)	12/8/2003	12.3	718	9.3	7.0	222	7.6	3.0	<0.5	0.50	<0.10	0.7
3	Monitoring Well	12/8/2003	11.9	588	5.9	7.2	250	18	28	<0.5	0.50	<0.10	6.4
1	Drainage Lysimeter	12/22/2003	4.3	408	13.1	7.3	297	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Shallow Lysimeter (1.75 ft)	12/22/2003	6.5	318	12.4	6.9	299	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Middle Lysimeter (3.5 ft)	12/22/2003	6.8	1266	11.4	6.6	334	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Deep Lysimeter (7 ft)	12/22/2003	8.7	443	10.4	6.9	296	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Monitoring Well	12/22/2003	10.9	447	9.5	7.2	302	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Drainage Lysimeter	12/22/2003	4.6	452	12.6	7.5	295	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Shallow Lysimeter (1.75 ft)	12/22/2003	5.5	439	12.2	7.3	303	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Middle Lysimeter (3.5 ft)	12/22/2003	7.0	634	11.3	7.3	302	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Deep Lysimeter (7 ft)	12/22/2003	9.1	624	10.5	7.3	302	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Monitoring Well	12/22/2003	12.1	409	9.2	7.5	282	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Drainage Lysimeter	12/22/2003	5.5	357	12.4	7.5	301	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Deep Lysimeter (7 ft)	12/22/2003	10.0	751	9.2	7.0	310	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Monitoring Well	12/22/2003	11.9	561	6.2	7.2	290	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Shallow Lysimeter (1.75 ft)	1/2/2004	10.1	336	11.9	7.0	214	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	Middle Lysimeter (3.5 ft)	1/2/2004	12.1	345	11.6	7.2	226	1.8	5.1	1.1	1.2	<0.10	1.2
1	Deep Lysimeter (7 ft)	1/2/2004	11.5	598	10.6	6.7	202	1.9	6.1	<0.5	3.3	<0.10	1.4
1	Monitoring Well	1/2/2004	13.9	591	7.5	7.2	219	5.5	66	<0.5	6.3	<0.10	15
2	Deep Lysimeter (7 ft)	1/2/2004	12.1	660	10.6	7.4	229	2.9	105	7.0	25	<0.10	24
2	Monitoring Well	1/2/2004	13.8	478	8.9	7.4	214	0.7	58	<0.5	6.9	<0.10	13
3	Deep Lysimeter (7 ft)	1/2/2004	12.3	697	10.2	7.1	231	6.7	1.7	<0.5	0.4	<0.10	0.4
3	Monitoring Well	1/2/2004	13.2	597	3.5	7.3	201	20	28	<0.5	0.6	<0.10	6.3
1	Drainage Lysimeter	1/9/2004	3.9	150	12.8	7.9	224	2.0	<1.0	0.7	5.4	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)	1/9/2004	4.8	353	11.5	7.2	212	2.5	14	0.5	1.2	<0.10	3.2
1	Deep Lysimeter (7 ft)	1/9/2004	7.9	431	12.1	7.3	231	2.8	6.9	0.5	3.5	<0.10	1.6
1	Monitoring Well	1/9/2004	9.2	990	4.1	6.8	197	8.3	134	<0.5	6.9	<0.10	30
1	Monitoring Well	1/9/2004	na	na	na	na	na	8.4	134	<0.5	7.0	<0.10	30
2	Drainage Lysimeter	1/9/2004	2.5	371	12.5	7.6	230	<1.0	140	0.8	4.8	8.09	32
2	Deep Lysimeter (7 ft)	1/9/2004	6.4	601	11.0	7.5	222	3.2	94	13.1	25	<0.10	21
2	Monitoring Well	1/9/2004	6.5	579	10.1	7.6	208	0.9	90	<0.5	7.8	<0.10	20
3	Middle Lysimeter (3.5 ft)	1/9/2004	10.4	644	12.3	7.2	228	3.5	<1.0	<0.5	0.9	<0.10	<0.2
3	Deep Lysimeter (7 ft)	1/9/2004	11.7	693	10.7	7.1	216	6.5	<1.0	<0.5	0.3	<0.10	<0.2
3	Monitoring Well	1/9/2004	10.7	648	3.6	7.4	193	29	12	<0.5	0.6	<0.10	2.6
1	Shallow Lysimeter (1.75 ft)	1/16/2004	4.1	285	13.5	7.3	272	2.9	22	<0.5	6.5	0.41	5.0
1	Middle Lysimeter (3.5 ft)	1/16/2004	4.2	321	12.7	7.3	275	<1.0	12	<0.5	1.2	<0.10	2.6
1	Deep Lysimeter (7 ft)	1/16/2004	5.9	383	11.7	7.1	274	2.2	11	<0.5	3.5	<0.10	2.5
1	Monitoring Well	1/16/2004	8.8	1037	10.2	6.9	274	4.0	23	<0.5	5.8	<0.10	5.2
1	Monitoring Well	1/16/2004	na	na	na	na	na	4.1	23	<0.5	6.1	<0.10	5.2
2	Deep Lysimeter (7 ft)	1/16/2004	7.9	540	11.7	7.4	265	2.1	79	8.7	24	0.10	18
2	Monitoring Well	1/16/2004	9.2	447	10.2	7.5	255	1.5	81	0.9	11	0.10	18
3	Shallow Lysimeter (1.75 ft)	1/16/2004	4.6	522	11.7	7.2	257	4.5	7.5	<0.5	0.2	<0.10	1.7
3	Middle Lysimeter (3.5 ft)	1/16/2004	6.8	568	12.2	7.1	313	7.1	14	<0.5	0.3	<0.10	3.2
3	Deep Lysimeter (7 ft)	1/16/2004	8.2	611	11.3	7.1	288	7.2	9.5	<0.5	0.2	<0.10	2.1

APPENDIX. Summary of Chemical Analyses

Site	Sample ID		Date	Temp	SpCond	DO Conc	pH	Eh vs SHE	Cl	NO3	PO4	K	NH3-N	NO3-N
Number				C	uS/cm	mg/L		mV	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
3	Monitoring Well		1/16/2004	9.1	599	6.3	7.4	248	21	36	<0.5	0.4	<0.10	8.1
1	Monitoring Well		1/30/2004	9.4	390	11.4	7.1	225	2.6	13	<0.5	5.9	0.10	2.9
2	Monitoring Well		1/30/2004	5.8	431	11.5	7.1	245	1.0	74	0.7	14	0.23	17
3	Monitoring Well		1/30/2004	6.4	870	7.1	6.6	229	18	46	<0.5	0.2	0.14	10
1	Shallow Lysimeter (1.75 ft)		2/13/2004	1.3	328	13.4	6.9	216	1.0	37	<0.5	2.8	0.31	8.4
1	Deep Lysimeter (7 ft)		2/13/2004	4.2	712	11.8	6.6	214	<1.0	13	<0.5	2.6	<0.10	3.0
1	Monitoring Well		2/13/2004	1.0	360	11.1	7.1	221	<1.0	16	<0.5	3.9	0.15	3.5
2	Deep Lysimeter (7 ft)		2/13/2004	4.7	644	11.7	7.2	216	<1.0	80	12	21	<0.10	18
2	Monitoring Well		2/13/2004	4.6	398	10.8	7.4	210	<1.0	53	<0.5	9.0	0.12	12
3	Monitoring Well		2/13/2004	8.7	661	6.6	7.3	213	16	39	<0.5	0.3	0.11	8.8
3	Monitoring Well		2/13/2004	na	na	na	na	na	16	37	<0.5	0.3	<0.10	8.4
1	Drainage Lysimeter		2/27/2004	9.6	289	2.0	7.2	206	8.5	<1.0	1.9	7.8	1.00	<0.2
1	Middle Lysimeter (3.5 ft)		2/27/2004	10.1	431	13.1	7.4	240	#N/A	#N/A	#N/A	1.4	<0.10	#N/A
1	Monitoring Well	Pre-bail	2/27/2004	12.3	433	10.5	7.4	216	4.1	31	<0.5	3.7	<0.10	6.9
1	Monitoring Well	Post-bail	2/27/2004	12.8	429	10.0	7.4	221	4.1	29	<0.5	3.8	<0.10	6.5
2	Drainage Lysimeter		2/27/2004	5.5	289	6.2	7.1	212	1.3	45	2.9	3.2	2.43	10
2	Deep Lysimeter (7 ft)		2/27/2004	9.2	587	12.2	7.2	227	2.8	80	14	22	0.14	18
2	Monitoring Well	Pre-bail	2/27/2004	11.0	437	10.8	7.1	207	1.2	66	2.9	12	<0.10	15
2	Monitoring Well	Post-bail	2/27/2004	10.3	432	10.7	7.1	217	1.4	66	3.4	12	<0.10	15
3	Drainage Lysimeter		2/27/2004	7.0	270	12.8	7.2	214	2.4	12	1.4	0.6	<0.10	2.7
3	Middle Lysimeter (3.5 ft)		2/27/2004	11.4	679	12.5	6.9	220	7.5	9.4	<0.5	0.3	<0.10	2.1
3	Monitoring Well	Pre-bail	2/27/2004	12.3	785	3.2	6.6	189	23	21	<0.5	0.3	<0.10	4.7
3	Monitoring Well	Pre-bail	2/27/2004	na	na	na	na	na	23	21	<0.5	0.4	0.13	4.8
3	Monitoring Well	Post-bail	2/27/2004	11.8	579	3.1	6.8	208	22	21	<0.5	0.4	<0.10	4.7
1	Drainage Lysimeter		3/12/2004	7.3	299	11.0	7.3	199	5.4	<1.0	1.4	8.8	0.49	<0.2
1	Middle Lysimeter (3.5 ft)		3/12/2004	8.6	654	12.5	7.1	217	18	53	1.4	1.6	<0.10	12
1	Deep Lysimeter (7 ft)		3/12/2004	7.4	430	12.4	6.6	209	3.6	25	0.8	2.5	<0.10	5.7
1	Monitoring Well	Pre-bail	3/12/2004	8.1	718	11.4	6.2	228	4.9	40	<0.5	3.8	<0.10	9.0
1	Monitoring Well	Post-bail	3/12/2004	9.5	483	10.2	7.0	206	4.8	36	<0.5	3.9	<0.10	8.1
2	Drainage Lysimeter		3/12/2004	9.0	398	11.9	7.5	200	3.7	2.8	5.8	3.9	<0.10	0.6
2	Deep Lysimeter (7 ft)		3/12/2004	8.0	538	12.6	7.3	211	3.4	89	13	21	<0.10	20
2	Monitoring Well	Pre-bail	3/12/2004	9.1	602	11.3	7.3	198	3.0	73	2.4	11	<0.10	16
2	Monitoring Well	Post-bail	3/12/2004	9.7	448	11.2	7.4	194	3.1	76	2.2	12	<0.10	17
3	Drainage Lysimeter		3/12/2004	#N/A	#N/A	#N/A	#N/A	#N/A	3.9	19	1.1	1.0	<0.10	4.4
3	Middle Lysimeter (3.5 ft)		3/12/2004	#N/A	#N/A	#N/A	#N/A	#N/A	6.2	8.4	<0.5	0.3	<0.10	1.9
3	Deep Lysimeter (7 ft)		3/12/2004	#N/A	#N/A	#N/A	#N/A	#N/A	6.9	2.4	<0.5	0.2	#N/A	0.5
3	Monitoring Well	Pre-bail	3/12/2004	10.8	565	7.3	7.4	182	17	37	1.0	0.3	<0.10	8.4
3	Monitoring Well	Post-bail	3/12/2004	10.3	586	8.2	7.5	186	18	38	0.6	0.3	<0.10	8.5
1	Drainage Lysimeter		3/28/2004	19.0	1023	6.8	6.8	144	5.4	<1.0	1.4	1.7	0.41	<0.2
1	Middle Lysimeter (3.5 ft)		3/28/2004	15.0	440	8.9	6.9	167	18	53	1.4	2.6	<0.10	12
1	Deep Lysimeter (7 ft)		3/28/2004	17.5	649	9.1	7.0	162	3.6	25	0.8	#N/A	<0.10	5.7
1	Monitoring Well	Pre-bail	3/28/2004	#N/A	#N/A	#N/A	#N/A	#N/A	4.9	40	<0.5	3.5	#N/A	9.0
1	Monitoring Well	Post-bail	3/28/2004	17.9	384	8.2	6.8	160	4.8	40	<0.5	3.5	<0.10	9.0
2	Drainage Lysimeter		3/28/2004	#N/A	#N/A	#N/A	#N/A	#N/A	3.7	101	2.7	21	#N/A	23
2	Deep Lysimeter (7 ft)		3/28/2004	17.2	552	10.1	7.2	175	3.4	89	13	#N/A	0.10	20
2	Monitoring Well	Pre-bail	3/28/2004	#N/A	#N/A	#N/A	#N/A	#N/A	3.0	73	2.4	12	#N/A	16
2	Monitoring Well	Post-bail	3/28/2004	16.2	518	9.2	7.2	161	3.1	76	2.2	0.9	0.11	17
3	Drainage Lysimeter		3/28/2004	18.6	285	9.4	7.4	162	3.9	20	1.1	0.4	0.15	4.4
3	Middle Lysimeter (3.5 ft)		3/28/2004	15.2	682	12.1	6.9	184	5.6	32	<0.5	#N/A	0.21	7.2
3	Deep Lysimeter (7 ft)		3/28/2004	#N/A	#N/A	#N/A	#N/A	#N/A	6.9	2.4	<0.5	#N/A	#N/A	0.5
3	Monitoring Well	Pre-bail	3/28/2004	#N/A	#N/A	#N/A	#N/A	#N/A	18	37	1.0	0.5	#N/A	8.4
3	Monitoring Well	Post-bail	3/28/2004	18.0	548	3.4	7.1	153	18	38	0.6	8.1	<0.10	8.5
1	Shallow Lysimeter (1.75 ft)		4/9/2004	16.2	876	11.1	6.3	144	47	3.1	1.5	52	<0.10	0.7
1	Middle Lysimeter (3.5 ft)		4/9/2004	17.0	400	11.3	6.9	171	4.4	12	1.4	1.7	<0.10	2.8
1	Deep Lysimeter (7 ft)		4/9/2004	14.5	515	12.1	6.5	158	8.6	45	<0.5	2.9	<0.10	10
1	Monitoring Well	Post-bail	4/9/2004	13.8	416	12.4	6.8	168	4.7	22	<0.5	4.4	<0.10	5.0
1	Monitoring Well	Post-bail	4/9/2004	na	na	na	na	na	4.9	23	<0.5	4.4	<0.10	5.1
2	Middle Lysimeter (3.5 ft)		4/9/2004	14.8	777	13.8	7.1	172	1.2	98	13	4.7	0.16	22
2	Deep Lysimeter (7 ft)		4/9/2004	12.5	547	15.6	7.2	196	2.5	89	11	22	0.79	20
2	Monitoring Well	Post-bail	4/9/2004	13.5	428	13.5	7.2	168	1.3	65	1.5	7.6	<0.10	15
3	Deep Lysimeter (7 ft)		4/9/2004	13.9	365	15.5	6.9	171	7.6	3.3	<0.5	2.0	<0.10	0.7
3	Monitoring Well	Pre-bail	4/9/2004	13.5	591	9.1	7.1	163	19	35	0.7	0.4	<0.10	7.9
1	Drainage Lysimeter		4/23/2004	16.8	571	7.4	6.5	122	4.1	4.4	1.5	7.5	<0.10	1.0
1	Shallow Lysimeter (1.75 ft)		4/23/2004	16.3	194	9.7	7.1	155	3.6	1	1	2.2	0.11	0.2
1	Middle Lysimeter (3.5 ft)		4/23/2004	16.0	213	10.0	6.9	162	1.3	2.8	2	1.6	<0.10	0.6
1	Deep Lysimeter (7 ft)		4/23/2004	15.4	333	10.7	7.0	151	7.9	38	0.5	2.8	<0.10	8.6
1	Monitoring Well	Post-bail	4/23/2004	14.1	214	10.6	6.9	156	5.4	20	<0.5	4.2	<0.10	4.4
2	Middle Lysimeter (3.5 ft)		4/23/2004	14.8	256	10.6	7.3	163	1.5	96	13	4.9	0.15	22
2	Deep Lysimeter (7 ft)		4/23/2004	13.9	258	11.1	7.3	168	2.2	85	14	22	<0.10	19
2	Monitoring Well	Post-bail	4/23/2004	13.4	224	10.8	7.4	158	1.1	92	2.5	13	<0.10	21
3	Deep Lysimeter (7 ft)		4/23/2004	#N/A	#N/A	#N/A	#N/A	#N/A	5.4	20	<0.5	#N/A	#N/A	4.4
3	Monitoring Well	Post-bail	4/23/2004	14.4	412	5.5	7.2	143	16	44	<0.5	0.3	0.10	10
1	Shallow Lysimeter (1.75 ft)		5/10/2004	22.3	317	11.5	6.4	149	<1	<1	<0.5	2.0	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)		5/10/2004	19.4	231	9.9	6.7	151	<1	<1	<0.5	2.1	<0.10	<0.2
1	Deep Lysimeter (7 ft)		5/10/2004	18.0	245	10.6	6.8	151	1.5	2.7	<0.5	6.0	<0.10	0.6
1	Monitoring Well	Post-bail	5/10/2004	18.8	196	11.5	6.7	147	4.6	14	<0.5	4.1	<0.10	3.1
1	Monitoring Well	Post-bail	5/10/2004	na	na	na	na	na	4.4	14	<0.5	4.1	<0.10	3.1
2	Deep Lysimeter (7 ft)		5/10/2004	18.0	268	10.5	7.3	149	5.4	90	9.6	14	<0.10	20
2	Monitoring Well	Pre-bail	5/10/2004	16.9	228	10.6	7.3	146	1.5	95	3.4	13	<0.10	21
3	Middle Lysimeter (3.5 ft)		5/10/2004	19.2	330	9.8	6.9	154	4.1	<1	<0.5	2.5	0.10	<0.2
3	Monitoring Well	Post-bail	5/10/2004	16.3	478	6.3	7.1	130	18	59	<0.5	0.3	<0.10	13
1	Shallow Lysimeter (1.75 ft)		5/17/2004	21.0	201	9.8	6.7	139	<1	<1	<1	2.4	<0.10	<0.2

APPENDIX. Summary of Chemical Analyses

Site Number	Sample ID		Date	Temp C	SpCond uS/cm	DO Conc mg/L	pH	Eh vs SHE mV	Cl mg/L	NO3 mg/L	PO4 mg/L	K mg/L	NH3-N mg/L	NO3-N mg/L
1	Middle Lysimeter (3.5 ft)		5/17/2004	21.4	228	9.5	6.5	143	1.2	<1	<1	3.8	<0.10	<0.2
1	Deep Lysimeter (7 ft)		5/17/2004	21.8	452	9.8	6.1	138	2.5	<1	<0.5	4.2	<0.10	<0.2
1	Monitoring Well	Pre-bail	5/17/2004	17.7	177	10.4	6.4	142	2.9	<1	<0.5	4.0	<0.10	<0.2
2	Middle Lysimeter (3.5 ft)		5/17/2004	22.7	207	9.5	7.0	142	1.2	<1	13	3.6	0.17	<0.2
2	Deep Lysimeter (7 ft)		5/17/2004	21.2	239	10.5	7.0	143	1.6	81	11	8.5	0.11	18
2	Monitoring Well	Post-bail	5/17/2004	23.4	303	10.5	6.9	138	2	94	2.8	13	<0.10	21
3	Middle Lysimeter (3.5 ft)		5/17/2004	20.9	332	9.3	6.8	148	1	<1	<0.5	0.4	<0.10	<0.2
3	Monitoring Well	Pre-bail	5/17/2004	20.1	337	5.9	7.0	139	20	61	<0.5	1.2	<0.10	14
1	Shallow Lysimeter (1.75 ft)		5/24/2004	24.0	429	9.2	6.6	142	3.3	<1	<0.5	4.2	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)		5/24/2004	24.5	462	9.6	6.7	143	2.9	<1	0.9	5.3	0.13	<0.2
1	Deep Lysimeter (7 ft)		5/24/2004	21.9	438	11.0	6.8	146	<1	<1	<0.5	2.5	0.11	<0.2
1	Monitoring Well	Pre-bail	5/24/2004	18.5	581	10.2	6.2	128	2.7	17	<0.5	5.2	<0.10	3.8
2	Middle Lysimeter (3.5 ft)		5/24/2004	25.9	414	9.9	7.0	165	3	<1	9.9	6.1	#N/A	<0.2
2	Monitoring Well	Pre-bail	5/24/2004	19.7	839	13.3	6.9	206	2.5	95	1.8	11	<0.10	21
3	Middle Lysimeter (3.5 ft)		5/24/2004	22.9	670	9.6	6.8	153	6.2	<1	<0.5	7.5	<0.10	<0.2
3	Deep Lysimeter (7 ft)		5/24/2004	20.9	702	10.3	6.8	151	5.5	<1	<0.5	1.8	<0.10	<0.2
3	Monitoring Well	Pre-bail	5/24/2004	20.2	907	5.4	6.9	126	19	57	<0.5	0.4	<0.10	13
1	Drainage Lysimeter		6/18/2004	27.2	534	2.9	6.5	113	<1	2.8	1.5	14	0.10	0.6
1	Shallow Lysimeter (1.75 ft)		6/18/2004	29.1	416	7.0	6.7	148	8.9	3.1	<0.5	8.9	<0.10	0.7
1	Middle Lysimeter (3.5 ft)		6/18/2004	28.2	499	7.4	6.7	138	3.1	2.6	1.1	4.2	<0.10	0.6
1	Deep Lysimeter (7 ft)		6/18/2004	27.0	502	9.4	6.9	140	4.9	2.7	<0.5	6.8	0.13	0.6
1	Monitoring Well		6/18/2004	26.3	2720	7.7	6.3	121	2.1	6.4	<0.5	4.8	<0.10	1.4
2	Drainage Lysimeter		6/18/2004	28.7	315	12.3	6.8	134	2.8	5.7	5.2	5.0	0.43	1.3
2	Middle Lysimeter (3.5 ft)		6/18/2004	29.5	447	17.8	7.0	146	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Deep Lysimeter (7 ft)		6/18/2004	29.9	579	19.4	6.9	147	3.8	85	8.3	14	0.12	19
2	Monitoring Well	Pre-bail	6/18/2004	23.5	768	17.4	7.2	126	<1	63	1	6.7	<0.10	14
3	Drainage Lysimeter		6/18/2004	27.6	223	11.2	6.9	125	1	<1	1	1.5	0.20	<0.2
3	Middle Lysimeter (3.5 ft)		6/18/2004	27.0	630	13.4	6.5	155	2.5	2.6	<0.5	1.3	0.11	0.6
3	Deep Lysimeter (7 ft)		6/18/2004	26.6	687	12.3	6.6	154	#N/A	#N/A	#N/A	6.0	#N/A	#N/A
3	Monitoring Well	Pre-bail	6/18/2004	26.5	481	17.2	6.8	136	7	12	<0.5	0.6	0.20	2.7
1	Shallow Lysimeter (1.75 ft)		6/25/2004	25.9	438	14.5	7.0	142	1.6	2.5	<0.5	2.2	<0.10	0.6
1	Middle Lysimeter (3.5 ft)		6/25/2004	25.8	496	16.7	6.9	140	<1	1.9	0.7	2.4	<0.10	0.4
1	Deep Lysimeter (7 ft)		6/25/2004	23.8	493	14.5	6.9	137	2.3	2.6	<0.5	3.8	<0.10	0.6
1	Monitoring Well	Pre-bail	6/25/2004	22.9	405	13.2	7.2	144	3.1	3.5	<0.5	5.3	<0.10	0.8
2	Middle Lysimeter (3.5 ft)		6/25/2004	25.2	487	12.9	7.0	147	2.3	12	16	6.0	0.20	2.6
2	Deep Lysimeter (7 ft)		6/25/2004	24.8	588	11.4	7.0	136	5.3	88	12	20	<0.10	20
2	Monitoring Well	Pre-bail	6/25/2004	22.8	494	13.4	7.1	138	4.1	68	1.7	10	<0.10	15
3	Drainage Lysimeter		6/25/2004	22.9	4783	7.7	6.6	115	2.2	3.8	1.2	2.1	0.17	0.9
3	Middle Lysimeter (3.5 ft)		6/25/2004	25.8	757	5.4	6.6	200	1.6	2.7	<0.5	0.6	<0.10	0.6
3	Deep Lysimeter (7 ft)		6/25/2004	22.1	641	7.3	6.7	141	4.6	3.4	<0.5	0.2	<0.10	0.8
3	Monitoring Well	Pre-bail	6/25/2004	20.3	572	6.6	7.0	113	15	30	<0.5	0.5	<0.10	6.8
1	Drainage Lysimeter		7/8/2004	26.0	282	4.2	6.8	124	2	<1	1.1	12	#N/A	<0.2
1	Shallow Lysimeter (1.75 ft)		7/8/2004	26.6	449	8.0	6.8	136	1.5	1	<0.5	0.9	#N/A	0.2
1	Middle Lysimeter (3.5 ft)		7/8/2004	26.5	521	7.4	6.8	135	<1	<1	<0.5	2.2	#N/A	<0.2
1	Deep Lysimeter (7 ft)		7/8/2004	25.6	508	8.7	6.8	136	<1	<1	<0.5	3.6	#N/A	<0.2
1	Monitoring Well	Pre-bail	7/8/2004	24.1	529	8.8	6.7	131	1.5	1.3	<0.5	4.9	#N/A	0.3
2	Middle Lysimeter (3.5 ft)		7/8/2004	25.4	473	10.0	7.2	134	2.6	16	22	5.8	#N/A	3.6
2	Deep Lysimeter (7 ft)		7/8/2004	25.5	611	9.7	7.1	130	7.6	91	20	22	#N/A	21
2	Monitoring Well	Pre-bail	7/8/2004	21.9	485	12.5	7.3	129	6.8	94	16	19	#N/A	21
3	Drainage Lysimeter		7/8/2004	25.0	208	6.0	6.6	132	21	7	14	15	#N/A	1.6
3	Middle Lysimeter (3.5 ft)		7/8/2004	24.0	707	6.9	6.4	131	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Deep Lysimeter (7 ft)		7/8/2004	23.2	626	6.4	6.6	128	3.7	1.2	<0.5	0.2	#N/A	0.3
3	Monitoring Well	Pre-bail	7/8/2004	19.3	791	5.2	6.3	113	31	4.7	<0.5	28	#N/A	1.1
1	Drainage Lysimeter		7/22/2004	30.1	352	6.2	6.9	123	<1	<1	1.9	11	0.11	<0.2
1	Shallow Lysimeter (1.75 ft)		7/22/2004	30.2	477	12.8	6.9	135	1.1	4.6	0.7	1.3	0.14	1.0
1	Middle Lysimeter (3.5 ft)		7/22/2004	27.8	481	13.1	6.9	134	2.4	<1	1.7	3.1	0.10	<0.2
1	Deep Lysimeter (7 ft)		7/22/2004	28.3	520	16.0	6.9	139	1.8	<1	0.8	4.7	<0.10	<0.2
1	Monitoring Well		7/22/2004	25.9	458	12.1	6.8	142	1.9	<1	<0.5	5.4	0.12	<0.2
2	Drainage Lysimeter		7/22/2004	#N/A	#N/A	#N/A	#N/A	#N/A	<1	<1	5.5	5.3	0.12	<0.2
2	Deep Lysimeter (7 ft)		7/22/2004	27.1	619	19.0	6.6	144	7.9	86	12	24	0.14	20
2	Monitoring Well		7/22/2004	30.1	700	17.1	6.9	144	5.8	73	4.4	17	0.12	16
3	Drainage Lysimeter		7/22/2004	26.3	853	5.6	6.6	110	<1	1.1	0.6	1.1	<0.10	0.2
3	Middle Lysimeter (3.5 ft)		7/22/2004	26.7	750	8.7	6.5	131	<1	<1	<0.5	#N/A	0.10	<0.2
3	Monitoring Well		7/22/2004	23.2	520	7.1	6.5	122	8.7	12.7	<0.5	0.4	<0.10	2.9
1	Drainage Lysimeter		8/6/2004	23.7	526	4.4	6.4	110	<1	<1	<0.5	10	0.12	<0.2
1	Shallow Lysimeter (1.75 ft)		8/6/2004	23.8	514	9.1	7.0	133	<1	<1	<0.5	1.4	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)		8/6/2004	23.3	536	7.4	6.9	136	1.8	<1	1	4.3	<0.10	<0.2
1	Deep Lysimeter (7 ft)		8/6/2004	21.8	531	7.1	6.8	139	2.3	<1	2.5	6.1	<0.10	<0.2
1	Monitoring Well		8/6/2004	20.2	458	6.5	6.4	134	1.0	<1	<0.5	5.2	<0.10	<0.2
2	Drainage Lysimeter		8/6/2004	27.3	442	7.9	7.3	129	1.9	<1	5.2	20	0.16	<0.2
2	Deep Lysimeter (7 ft)		8/6/2004	22.5	659	9.0	7.1	129	9.0	83	10	29	0.10	19
2	Monitoring Well		8/6/2004	20.2	505	10.6	7.2	132	9.5	97	3.2	16	<0.10	22
3	Middle Lysimeter (3.5 ft)		8/6/2004	26.5	612	13.3	6.9	141	1.2	<1	<0.5	4.8	<0.10	<0.2
3	Monitoring Well		8/6/2004	22.7	748	8.5	7.2	111	18	49	<0.5	0.3	0.10	11
1	Drainage Lysimeter		8/23/2004	24.3	301	3.6	6.7	113	6.1	1.8	<0.5	30	<0.10	0.4
1	Shallow Lysimeter (1.75 ft)		8/23/2004	25.5	463	8.0	6.7	146	1.2	1.2	1.0	1.2	<0.10	0.3
1	Middle Lysimeter (3.5 ft)		8/23/2004	24.6	520	8.0	6.8	143	<1	1.2	<0.5	2.9	<0.10	0.3
1	Deep Lysimeter (7 ft)		8/23/2004	24.0	572	8.1	6.9	141	<1	<1	<0.5	3.6	<0.10	<0.2
1	Monitoring Well		8/23/2004	22.6	592	6.4	6.6	137	1.0	1.6	1.2	5.3	0.24	0.4
2	Deep Lysimeter (7 ft)		8/23/2004	23.6	684	8.8	7.0	145	5.2	71	2.6	26	0.10	16
2	Monitoring Well		8/23/2004	21.4	660	9.2	7.1	134	15	81	1.3	20	0.10	18
3	Drainage Lysimeter		8/23/2004	26.8	139	7.7	7.3	151	2.6	<1	1.0	9.3	0.23	<0.2
3	Middle Lysimeter (3.5 ft)		8/23/2004	24.9	677	7.8	6.8	144	<1	<1	<0.5	0.5	<0.10	<0.2
3	Monitoring Well	Pre-bail	8/23/2004	21.1	721	3.6	7.1	111	22	62	1.3	0.4	0.16	14

APPENDIX. Summary of Chemical Analyses

Site Number	Sample ID	Date	Temp C	SpCond uS/cm	DO Conc mg/L	pH	Eh vs SHE mV	Cl mg/L	NO3 mg/L	PO4 mg/L	K mg/L	NH3-N mg/L	NO3-N mg/L
1	Drainage Lysimeter	9/6/2004	28.5	266	5.8	7.2	132	4.7	2.2	0.7	19	<0.10	0.5
1	Shallow Lysimeter (1.75 ft)	9/6/2004	29.7	348	7.3	7.1	144	7.0	4.9	<0.5	1.5	<0.10	1.1
1	Middle Lysimeter (3.5 ft)	9/6/2004	29.0	373	6.2	6.9	138	2.9	11	<0.5	3.0	<0.10	2.6
1	Deep Lysimeter (7 ft)	9/6/2004	27.7	376	7.2	6.9	142	1.4	3.6	<0.5	6.6	<0.10	0.8
1	Monitoring Well	9/6/2004	24.5	694	8.1	7.2	132	53	28	<0.5	3.1	<0.10	6.3
2	Drainage Lysimeter	9/6/2004	28.8	240	6.8	7.0	133	2.5	1.6	2.1	12	<0.10	0.4
2	Deep Lysimeter (7 ft)	9/6/2004	26.1	448	7.6	7.2	131	1.3	81	6.1	15	<0.10	18
2	Monitoring Well	9/6/2004	24.2	361	8.0	7.3	131	7.0	77	0.6	12	<0.10	17
3	Drainage Lysimeter	9/6/2004	26.8	204	6.8	6.9	124	1.6	1.5	0.6	2.1	<0.10	0.3
3	Middle Lysimeter (3.5 ft)	9/6/2004	27.0	519	6.5	6.8	129	5.0	1.6	<0.5	0.4	<0.10	0.4
3	Monitoring Well	9/6/2004	21.6	429	3.9	7.0	111	7.0	77	0.6	0.4		17
1	Drainage Lysimeter	9/23/2004	27.5	314	6.4	7.1	528	4.4	2.4	0.5	19	0.10	0.5
1	Shallow Lysimeter (1.75 ft)	9/23/2004	25.8	446	8.5	7.1	523	1.2	4.9	<0.5	1.6	<0.10	1.1
1	Middle Lysimeter (3.5 ft)	9/23/2004	25.1	464	8.2	7.1	515	1.3	5.4	<0.5	2.4	<0.10	1.2
1	Deep Lysimeter (7 ft)	9/23/2004	24.1	483	8.0	7.0	526	3.0	6.5	<0.5	2.9	0.10	1.5
1	Monitoring Well	9/23/2004	22.2	626	7.8	7.2	547	10	62	<0.5	1.5	<0.10	14
2	Deep Lysimeter (7 ft)	9/23/2004	26.3	628	8.8	7.1	494	<1	87	6.0	13	0.11	20
2	Monitoring Well	9/23/2004	20.8	516	9.9	7.5	503	10	82	<0.5	10	<0.10	19
3	Drainage Lysimeter	9/23/2004	26.2	3703	8.9	7.3	493	NA	8.4	<0.5	2.6	0.14	1.9
3	Middle Lysimeter (3.5 ft)	9/23/2004	24.6	791	8.1	7.0	514	8.4	7.1	<0.5	1.2	<0.10	1.6
3	Monitoring Well	9/23/2004	21.4	2079	4.3	7.1	487	25	63	<0.5	0.6	0.10	14
1	Drainage Lysimeter	10/27/2004	17.6	222	7.0	7.5	404	1.5	1.1	0.5	9.6	<0.10	0.2
1	Shallow Lysimeter (1.75 ft)	10/27/2004	17.7	372	9.6	7.2	421	<1	2.1	<0.5	1.2	0.11	0.5
1	Middle Lysimeter (3.5 ft)	10/27/2004	#N/A	#N/A	#N/A	#N/A	#N/A	<1	2.7	<0.5	1.9	0.11	0.6
1	Deep Lysimeter (7 ft)	10/27/2004	#N/A	#N/A	#N/A	#N/A	#N/A	1.1	5.0	<0.5	2.5	<0.10	1.1
1	Monitoring Well	10/27/2004	18.6	535	9.6	7.4	391	1.1	3.3	<0.5	4.2	<0.10	0.7
2	Drainage Lysimeter	10/27/2004	17.6	393	6.6	6.9	472					<0.10	
2	Deep Lysimeter (7 ft)	10/27/2004	19.0	562	10.2	7.1	432	<1	94	10.5	13	<0.10	21
2	Monitoring Well	10/27/2004	18.7	653	9.0	7.1	457	<1	36	<0.5	5.7	<0.10	8.1
3	Drainage Lysimeter	10/27/2004	18.4	328	7.0	7.0	448	13	1.9	<0.5	0.9	0.10	0.4
3	Middle Lysimeter (3.5 ft)	10/27/2004	18.6	336	10.0	6.9	442	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Monitoring Well	10/27/2004	18.5	814	7.8	6.6	457	14	34	<0.5	0.4	0.11	7.7
1	Drainage Lysimeter	3/2/2005	4.1	604	15.1	8.1	423	1.1	0.8	0.6	12	0.25	0.2
1	Shallow Lysimeter (1.75 ft)	3/2/2005	4.3	574	13.9	7.5	425	8.4	11	1.5	2.1	<0.10	2.4
1	Middle Lysimeter (3.5 ft)	3/2/2005	5.8	672	13.2	7.5	425	37	6.4	1.2	2.9	0.12	1.4
1	Deep Lysimeter (7 ft)	3/2/2005	7.1	587	14.1	7.7	415	0.9	3.6	1.0	2.4	<0.10	0.8
1	Monitoring Well	3/2/2005	8.4	553	12.1	7.8	413	1.8	7.6	<0.5	3.0	<0.10	1.7
2	Drainage Lysimeter	3/2/2005	7.4	524	15.4	7.4	399	2.7	29	5.6	8.5	0.41	6.6
2	Shallow Lysimeter (1.75 ft)	3/2/2005	5.5	549	14.3	7.0	399	9.6	25	11	1.5	0.17	5.6
2	Middle Lysimeter (3.5 ft)	3/2/2005	6.5	584	13.6	7.3	404	23	21	15	5.0	0.17	4.7
2	Deep Lysimeter (7 ft)	3/2/2005	7.8	717	13.9	7.6	423	17	51	13	16	0.14	12
2	Monitoring Well	3/2/2005	13.0	731	12.1	7.6	402	12	79	4.5	13	0.12	18
3	Drainage Lysimeter	3/2/2005	4.4	479	15.7	7.8	390	0.9	1.1	<0.5	1.2	0.25	0.2
3	Shallow Lysimeter (1.75 ft)	3/2/2005	5.1	731	14.1	7.3	393	21	47	1.4	2.1	<0.10	11
3	Middle Lysimeter (3.5 ft)	3/2/2005	6.8	692	12.3	7.0	394	43	39	0.8	2.9	0.13	8.9
3	Deep Lysimeter (7 ft)	3/2/2005	7.2	815	12.5	7.2	428	15	20	<0.5	2.4	<0.10	4.5
3	Monitoring Well	3/2/2005	10.8	739	6.4	7.4	350	19	11	<0.5	0.4	<0.10	2.4
1	Drainage Lysimeter	3/31/2005	12.3	165	11.6	6.4	327	0.8	1.8	<0.5	4.6	<0.10	0.4
1	Shallow Lysimeter (1.75 ft)	3/31/2005	14.0	243	14.3	6.4	371	5.3	14	2.8	6.5	<0.10	3.2
1	Middle Lysimeter (3.5 ft)	3/31/2005	12.8	346	12.4	6.4	361	8.9	9.4	<0.5	3.3	0.11	2.1
1	Deep Lysimeter (7 ft)	3/31/2005	12.4	315	13.2	6.7	369	0.8	4.5	<0.5	2.7	0.13	1.0
1	Monitoring Well	3/31/2005	12.1	292	12.1	6.1	328	2.0	7.3	0.5	3.4	0.10	1.6
2	Drainage Lysimeter	3/31/2005	13.0	382	11.4	6.8	376	35	82	3	13	1.09	19
2	Shallow Lysimeter (1.75 ft)	3/31/2005	11.5	172	12.0	7.2	373	4.1	40	12	1.4	<0.10	8.9
2	Middle Lysimeter (3.5 ft)	3/31/2005	11.4	217	12.0	7.1	370	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Deep Lysimeter (7 ft)	3/31/2005	11.4	398	11.8	6.9	378	15	51	13	16	#N/A	11
2	Monitoring Well	3/31/2005	12.9	391	10.9	6.8	375	5.5	76	0.5	6.3	0.12	17
3	Drainage Lysimeter	3/31/2005	13.5	120	11.2	7.2	373	0.3	0.7	<0.5	0.7	<0.10	0.2
3	Shallow Lysimeter (1.75 ft)	3/31/2005	13.5	452	12.3	6.9	386	15	50	<0.5	0.9	<0.10	11
3	Middle Lysimeter (3.5 ft)	3/31/2005	#N/A	#N/A	#N/A	#N/A	#N/A	23	47	<0.5	0.7	<0.10	11
3	Deep Lysimeter (7 ft)												
3	Monitoring Well	3/31/2005	13.9	494	5.9	6.8	383	23	34	<0.5	0.6	<0.10	7.6
1	Drainage Lysimeter	4/19/2005	20.2	358	10.1	7.4	693	0.4	0.6	<0.5	13	<0.10	0.1
1	Shallow Lysimeter (1.75 ft)	4/19/2005	18.8	280	10.5	7.4	696	0.7	17	<0.5	2.5	<0.10	3.9
1	Middle Lysimeter (3.5 ft)	4/19/2005	18.1	365	11.1	7.4	699	2.8	19	2.4	2.5	<0.10	4.2
1	Deep Lysimeter (7 ft)	4/19/2005	17.6	379	11.5	7.4	703	0.4	3.5	<0.5	1.7	<0.10	0.8
1	Monitoring Well	4/19/2005	7.7	628	12.7	7.4	715	1.1	12	<0.5	3.0	<0.10	2.7
2	Drainage Lysimeter	4/19/2005	21.7	399	10.4	0.9	707	28	50	<0.5		<0.10	11
2	Shallow Lysimeter (1.75 ft)	4/19/2005	21.7	246	10.1	0.5	725	2.8	66	<0.5	1.8	<0.10	15
2	Middle Lysimeter (3.5 ft)	4/19/2005	21.1	259	11.4	0.6	719	4.7	27	<0.5	5.6	<0.10	6.2
2	Deep Lysimeter (7 ft)	4/19/2005	17.5	441	11.6	0.5	712	12	50	<0.5	16	<0.10	11
2	Monitoring Well	4/19/2005	16.2	534	10.7	0.5	716	16	90	0.6	12	<0.10	20
3	Shallow Lysimeter (1.75 ft)	4/19/2005	16.6	507	11.1	7.2	719	#N/A	#N/A	#N/A	0.6	<0.10	#N/A
3	Middle Lysimeter (3.5 ft)	4/19/2005	16.9	491	10.7	7.0	518	15	44	<0.5	0.5	<0.10	10
3	Monitoring Well	4/19/2005	10.5	738	5.7	7.0	435	23	41	<0.5	1.0	<0.10	9.2
1	Drainage Lysimeter	5/5/2005	15.6	289	13.0	6.9	383	1.4	3.7	1.1	11	<0.10	0.8
1	Shallow Lysimeter (1.75 ft)	5/5/2005	15.7	303	11.7	7.0	387	6.9	13	3	11	<0.10	3.0
1	Middle Lysimeter (3.5 ft)	5/5/2005	15.9	370	10.2	7.2	385	3.2	33	1.5	4.9	<0.10	7.4
1	Deep Lysimeter (7 ft)	5/5/2005	15.4	379	10.4	7.2	401	0.7	3.2	1	2.4	#N/A	0.7
1	Monitoring Well	5/5/2005	15.0	679	11.1	6.7	381	23	4.6	0.3	30	<0.10	1.0
2	Shallow Lysimeter (1.75 ft)	5/5/2005	17.7	237	9.9	7.0	671	1.1	59	9.5	1.8	<0.10	13
2	Middle Lysimeter (3.5 ft)	5/5/2005	16.2	244	9.7	6.7	680	2.9	34	24	6.5	<0.10	7.7
2	Deep Lysimeter (7 ft)	5/5/2005	16.4	368	10.2	6.9	688	2.3	46	16	12	<0.10	10
2	Monitoring Well	5/5/2005	17.1	524	9.9	6.9	600	6.1	83	1.2	5.4	<0.10	19

APPENDIX. Summary of Chemical Analyses

Site Number	Sample ID	Date	Temp C	SpCond uS/cm	DO Conc mg/L	pH	Eh vs SHE mV	Cl mg/L	NO3 mg/L	PO4 mg/L	K mg/L	NH3-N mg/L	NO3-N mg/L
3	Drainage Lysimeter	5/5/2005	17.4	265	9.9	6.0	742	1.9	1.3	1	9.2	<0.10	0.3
3	Shallow Lysimeter (1.75 ft)	5/5/2005	18.3	307	8.7	-0.6	738	4.0	11	<0.5	0.6	<0.10	2.5
3	Middle Lysimeter (3.5 ft)	5/5/2005	17.8	442	9.3	-0.6	746	15	46	<0.5	0.9	<0.10	10
3	Deep Lysimeter (7 ft)	5/5/2005	16.7	694	9.3	-0.7	748	15	22	0.7	0.8	<0.10	5.0
3	Monitoring Well	5/5/2005	20.0	351	5.6	5.9	737	26	34	<0.5	1.7	<0.10	7.6
1	Drainage Lysimeter	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	1.0	<0.5	7.1	<0.10	0.2
1	Shallow Lysimeter (1.75 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	2.5	0.8	3.1	<0.10	0.6
1	Middle Lysimeter (3.5 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	2.1	28	<0.5	3.2	<0.10	6.3
1	Deep Lysimeter (7 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	1.9	<0.5	1.9	<0.10	0.4
1	Monitoring Well	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	14	10	<0.5	18	<0.10	2.3
2	Drainage Lysimeter	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	0.9	21	11	8.5	0.57	4.8
2	Shallow Lysimeter (1.75 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.9	32	22	1.3	<0.10	7.3
2	Middle Lysimeter (3.5 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.4	52	13	6.9	<0.10	12
2	Deep Lysimeter (7 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	2.6	66	0.5	11	<0.10	15
2	Monitoring Well	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	22	<0..5	4.9	4.8	0.15	<0.1
3	Drainage Lysimeter	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.0	0.8	<0.5	5.3	<0.10	0.2
3	Shallow Lysimeter (1.75 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	<0.10	#N/A
3	Middle Lysimeter (3.5 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	15	45	<0.5	0.5	<0.10	10
3	Deep Lysimeter (7 ft)	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	16	29	<0.5	0.3	<0.10	6.5
3	Monitoring Well	5/23/2005	#N/A	#N/A	#N/A	#N/A	#N/A	26	13	<0.5	0.5	<0.10	2.9
1	Drainage Lysimeter	7/7/2005	27.3	1285	5.6	6.9	453	38	1.4	1.1	46	<0.10	0.3
1	Shallow Lysimeter (1.75 ft)	7/7/2005	27.3	283	9.6	6.9	492	0.8	4.6	3.0	2.8	0.10	1.0
1	Middle Lysimeter (3.5 ft)	7/7/2005	26.5	365	9.7	6.9	472	<0.5	0.5	1.3	2.9	0.12	0.1
1	Deep Lysimeter (7 ft)	7/7/2005	26.1	480	10.8	6.8	486	<0.5	<1	0.8	3.0	<0.10	<0.2
1	Monitoring Well	7/7/2005	27.0	371	9.6	6.6	488	2.6	1.1	<0.5	5.6	<0.10	0.3
2	Middle Lysimeter (3.5 ft)	7/7/2005	27.5	249	7.6	7.1	461	0.7	3.2	26	7.0	0.16	0.7
2	Deep Lysimeter (7 ft)	7/7/2005	27.2	540	10.5	7.0	469	1.6	53	13	23	0.12	12
2	Monitoring Well	7/7/2005	22.2	447	10.5	7.0	472	17	61	6.6	21	<0.10	14
3	Drainage Lysimeter	7/7/2005	26.1	139	7.1	7.2	474	1.7	0.5	0.6	3.6	<0.10	0.1
3	Middle Lysimeter (3.5 ft)	7/7/2005	23.6	496	10.4	6.7	486	6.7	1.3	<0.5	0.5	0.30	0.3
3	Monitoring Well	7/7/2005	21.5	559	5.0	6.9	406	19	51	<0.5	0.8	<0.10	12
1	Drainage Lysimeter	9/8/2005	25.7	401	4.0	7.0	433	1.6	<1	<0.5	11	<0.10	<0.2
1	Shallow Lysimeter (1.75 ft)	9/8/2005	27.2	305	8.7	7.0	437	1.8	<1	<0.5	3.1	<0.10	<0.2
1	Middle Lysimeter (3.5 ft)	9/8/2005	27.5	434	8.3	6.9	437	7.0	<1	<0.5	23	0.10	<0.2
1	Deep Lysimeter (7 ft)	9/8/2005	26.2	454	8.7	6.9	441	2.4	1	<0.5	9.4	<0.10	0.2
1	Monitoring Well	9/8/2005	24.3	2566	10.0	7.2	468	4.6	12	<0.5	4.7	<0.10	2.8
2	Drainage Lysimeter	9/8/2005	25.6	153	6.7	7.0	429	<1	<1	2.7	11	0.28	<0.2
2	Shallow Lysimeter (1.75 ft)	9/8/2005	27.5	244	9.1	6.9	436	#N/A	#N/A	#N/A	1.4	#N/A	#N/A
2	Deep Lysimeter (7 ft)	9/8/2005	27.7	571	9.1	7.0	434	1.8	27	4.5	13	<0.10	6.1
2	Monitoring Well	9/8/2005	22.5	475	10.2	7.2	433	#N/A	#N/A	#N/A	8.1	0.11	#N/A
3	Drainage Lysimeter	9/8/2005	27.4	180	9.0	7.0	441	1.0	<1	<0.5	1.6	<0.10	<0.2
3	Middle Lysimeter (3.5 ft)	9/8/2005	26.6	453	8.9	6.7	426	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Deep Lysimeter (7 ft)	9/8/2005	26.2	418	9.4	6.9	427	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Monitoring Well	9/8/2005	23.6	550	4.0	7.0	440	18	11	<0.5	0.4	<0.10	2.6
1	Shallow Lysimeter (1.75 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.3	<1	<0.5	3.4	<0.10	<0.2
1	Deep Lysimeter (7 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	18	<1	<0.5	3.8	<0.10	<0.2
2	Drainage Lysimeter	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	14	20	0.9	19	0.55	4.4
2	Shallow Lysimeter (1.75 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	0.6	<1	1.5	8.3	0.14	<0.2
2	Middle Lysimeter (3.5 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.8	4.2	9.5		<0.10	0.9
2	Deep Lysimeter (7 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.2	36	1.9	14	0.23	8.1
3	Shallow Lysimeter (1.75 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	28	<1	<0.5	1.1	0.10	<0.2
3	Middle Lysimeter (3.5 ft)	10/5/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.1	<1	<0.5	1.0	<0.10	<0.2
1	Drainage Lysimeter	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.2	4.5	<0.5	7.9	#N/A	1.0
1	Shallow Lysimeter (1.75 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	2.0	2.3	2.4	2.4	#N/A	0.5
1	Deep Lysimeter (7 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	7.6	11	<0.5	8.7	#N/A	2.5
1	Monitoring Well	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	5.9	77	<0.5	5.7	#N/A	17
2	Drainage Lysimeter	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	2.4	27	7.1	6.9	#N/A	6.0
2	Deep Lysimeter (7 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	1.0	24	12	11.2	#N/A	5.5
2	Monitoring Well	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	12	80	<0.5	4.5	#N/A	18
3	Drainage Lysimeter	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	2.7	1	<0.5	1.6	#N/A	0.2
3	Shallow Lysimeter (1.75 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	22	<1	<0.5	0.2	#N/A	<0.2
3	Middle Lysimeter (3.5 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	3.1	<1	<0.5	0.1	#N/A	<0.2
3	Deep Lysimeter (7 ft)	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	5.8	5.6	<0.5	0.2	#N/A	1.3
3	Monitoring Well	11/22/2005	#N/A	#N/A	#N/A	#N/A	#N/A	21	46	0.5	0.6	#N/A	10
1	Drainage Lysimeter	1/20/2006	11.8	117	9.1	7.3	361	1.9	1.7	<0.5	6.9	<0.10	0.4
1	Shallow Lysimeter (1.75 ft)	1/20/2006	11.1	78	10.3	7.4	351	1.7	8.9	<0.5	1.5	<0.10	2.0
1	Deep Lysimeter (7 ft)	1/20/2006	12.8	126	9.7	7.3	358	1.0	8.7	<0.5	1.7	<0.10	2.0
1	Monitoring Well	1/20/2006	15.4	270	6.3	7.0	372	10	126	<0.5	7.5	0.17	28
2	Drainage Lysimeter	1/20/2006	12.6	324	4.0	7.6	340	96	<1	<0.5	21.0	0.29	<0.2
2	Shallow Lysimeter (1.75 ft)	1/20/2006	12.2	76	10.1	7.2	336	4.8	27	1.4	2.2	#N/A	6.2
2	Monitoring Well	1/20/2006	16.1	154	8.9	7.3	354	27	76	35	5.0	0.12	<0.2
3	Drainage Lysimeter	1/20/2006	10.4	121	10.6	6.7	378	<1	<1	<0.5	1.4	0.14	<0.2
3	Shallow Lysimeter (1.75 ft)	1/20/2006	10.3	182	10.3	6.9	377	12	<1	<0.5	2.4	0.33	<0.2
3	Middle Lysimeter (3.5 ft)	1/20/2006	11.0	159	9.8	6.8	379	5.2	<1	<0.5	1.3	0.18	<0.2
3	Deep Lysimeter (7 ft)	1/20/2006	11.6	240	9.6	6.8	380	5.3	3.6	<0.5	0.1	0.23	0.8
3	Monitoring Well	1/20/2006	13.0	711	6.9	6.4	379	32	42	<0.5	7.0	0.20	9.5
1	Drainage Lysimeter	4/7/2006	16.7	715	2.2	7.1	192	<0.5	<0.5	<0.5	6.4	0.11	<0.1
1	Shallow Lysimeter (1.75 ft)	4/7/2006	19.2	619	8.1	7.3	191	<0.5	1.5	<0.5	1.6	0.10	0.3
1	Middle Lysimeter (3.5 ft)	4/7/2006	18.8	654	8.2	7.3	199	<1.0	2.7	<0.5	1.4	0.48	0.6
1	Deep Lysimeter (7 ft)	4/7/2006	18.2	685	8.1	7.1	208	<0.5	4	<0.5	1.5	0.13	0.9
1	Monitoring Well	4/7/2006	18.1	3279	8.5	7.2	241	<1.0	6.5	<0.5	2.5	<0.10	1.5
2	Drainage Lysimeter	4/7/2006	18.4	1095	3.9	6.8	194	14	233	1.6	25	22	53
2	Shallow Lysimeter (1.75 ft)	4/7/2006	18.8	662	8.1	7.3	193	<1.0	13	1.3	0.6	0.17	3.0
2	Middle Lysimeter (3.5 ft)	4/7/2006	18.9	734	8.0	7.3	189	2.9	33	27	5.8	0.23	7.3

APPENDIX. Summary of Chemical Analyses

Site Number	Sample ID	Date	Temp C	SpCond uS/cm	DO Conc mg/L	pH	Eh vs SHE mV	Cl mg/L	NO3 mg/L	PO4 mg/L	K mg/L	NH3-N mg/L	NO3-N mg/L
2	Deep Lysimeter (7 ft)	4/7/2006	19.7	798	8.1	7.3	191	2.1	36	2.1	9.7	0.18	8.2
2	Monitoring Well	4/7/2006	18.4	944	7.0	7.1	189	17	87	<0.5	11	0.15	20
3	Drainage Lysimeter	4/7/2006	17.4	823	4.1	7.1	202	<1.0	<0.5	<0.5	0.2	<0.10	<0.1
3	Shallow Lysimeter (1.75 ft)	4/7/2006	18.0	860	8.7	7.1	189	9.8	<0.5	<0.5	0.1	0.12	<0.1
3	Middle Lysimeter (3.5 ft)	4/7/2006	17.8	825	8.3	7.0	190	7.5	<1.0	<0.5	0.1	<0.10	<0.2
3	Deep Lysimeter (7 ft)	4/7/2006	18.4	1015	7.4	7.1	196	4.6	3.6	<0.5	0.1	0.11	0.8
3	Monitoring Well	4/7/2006	17.5	969	2.6	7.1	186	23	45	<0.5	0.5	0.19	10
1	Drainage Lysimeter	5/18/2006	19.5	489	8.1	7.4	63	<0.5	<0.5	<0.5	#N/A	<0.10	<0.1
1	Shallow Lysimeter (1.75 ft)	5/18/2006	20.4	248	8.6	7.2	74	<0.5	8.8	<0.5	2.6	<0.10	2.0
1	Middle Lysimeter (3.5 ft)	5/18/2006	19.3	261	8.9	7.2	69	<0.5	<0.5	<0.5	2.0	<0.10	<0.1
1	Deep Lysimeter (7 ft)	5/18/2006	19.2	342	7.5	7.2	65	<0.5	1.3	<0.5	1.8	<0.10	0.3
1	Monitoring Well	5/18/2006	20.4	258	9.7	7.4	63	<1	3.6	<0.5	2.2	<0.10	0.8
2	Drainage Lysimeter	5/18/2006	#N/A	#N/A	#N/A	#N/A	#N/A	<1	<1	<0.5	9.8	#N/A	<0.2
2	Shallow Lysimeter (1.75 ft)	5/18/2006	21.7	185	8.6	7.1	84	<0.5	<1	1.2	0.7	0.10	<0.2
2	Deep Lysimeter (7 ft)	5/18/2006	22.6	374	8.8	7.3	81	2.3	32	15	12	<0.10	7.3
2	Monitoring Well	5/18/2006	19.8	336	9.2	7.5	81	4.7	49	17	20	<0.10	11
3	Drainage Lysimeter	5/18/2006	17.4	1942	9.9	7.2	90	<0.5	<0.5	<0.5	1.0	<0.10	<0.1
3	Shallow Lysimeter (1.75 ft)	5/18/2006	22.3	481	6.2	7.2	79	<0.5	<0.5	<0.5	#N/A	<0.10	<0.1
3	Middle Lysimeter (3.5 ft)	5/18/2006	20.9	412	7.7	6.9	84	1.0	<0.5	<0.5	0.1	<0.10	<0.1
3	Deep Lysimeter (7 ft)	5/18/2006	18.1	593	5.8	7.0	85	9.1	2.1	<0.5	0.0	<0.10	0.5
3	Monitoring Well	5/18/2006	16.9	559	4.6	7.3	86	24	24	<0.5	1.2	0.14	5.5
1	Drainage Lysimeter	6/29/2006	26.8	345	8.8	6.9	21	3.2	9.3	1.6	9.5	0.19	2.1
1	Shallow Lysimeter (1.75 ft)	6/29/2006	27.5	295	8.2	7.2	40	<0.5		2.9	1.8	0.19	
1	Middle Lysimeter (3.5 ft)	6/29/2006	25.6	334	8.7	7.2	41	0.6		<0.5	2.4	0.12	
1	Deep Lysimeter (7 ft)	6/29/2006	25.7	497	9.3	7.2	42	<0.5	2.0	<0.5	2.1	0.11	0.5
1	Monitoring Well	6/29/2006	24.3	346	9.8	7.5	23	1.0	4.5	<0.5	2.6	<0.10	1.0
2	Drainage Lysimeter	6/29/2006	28.2	493	8.9	6.2	55	23	154	10	16	0.33	35
2	Middle Lysimeter (3.5 ft)	6/29/2006	25.9	256	8.6	7.0	53	1.3	5.3	29	6.3	0.14	1.2
2	Deep Lysimeter (7 ft)	6/29/2006	26.1	427	8.6	7.3	50	1.8	14	17	9.3	<0.10	3.2
2	Monitoring Well	6/29/2006	22.0	453	9.6	7.3	45	8.8	48	12	13	0.14	11
3	Drainage Lysimeter	6/29/2006	24.9	811	8.0	6.6	6	3.2	2.8	2.5	8.7	0.27	0.6
3	Middle Lysimeter (3.5 ft)	6/29/2006	24.5	485	8.6	6.8	8	2.3		<0.5	1.7	0.10	
3	Deep Lysimeter (7 ft)	6/29/2006	22.6	718	8.8	7.0	4	#N/A	#N/A	#N/A	4.7	0.15	#N/A
3	Monitoring Well	6/29/2006	20.5	638	5.3	7.2	-17	20	42	<0.5	0.3	0.14	9.5
1	Drainage Lysimeter	8/17/2006	29.4	199	2.7	7.0	**138**	0.7	<0.5	<0.5	4.5	0.25	<0.1
1	Shallow Lysimeter (1.75 ft)	8/17/2006	28.5	208	8.8	7.0	**386**	0.9	1.6	<0.5	1.7	<0.10	0.4
1	Middle Lysimeter (3.5 ft)	8/17/2006	28.1	155	8.8	7.1	**380**	<0.5	<0.5	<0.5	1.4	<0.10	<0.1
1	Deep Lysimeter (7 ft)	8/17/2006	29.0	443	9.3	7.1	**460**	<0.5	7.2	<0.5	2.1	<0.10	1.6
1	Monitoring Well	8/17/2006	25.2	352	10.4	7.4	**369**	1.0	4.0	<0.5	3.9	<0.10	0.9
2	Drainage Lysimeter	8/17/2006	30.8	613	8.6	6.3	**414**	43	205	9.8	13	0.42	46
2	Middle Lysimeter (3.5 ft)	8/17/2006	28.3	208	8.0	7.0	**432**	0.5	9.4	23	5.9	#N/A	2.1
2	Deep Lysimeter (7 ft)	8/15/2006	28.3	353	9.8	7.3	**442**	<0.5	1.8	11	11	<0.10	
2	Monitoring Well	8/17/2006	25.5	360	11.1	7.4	**495**	1.6	41	4.7	17	<0.10	9.3
3	Drainage Lysimeter	8/17/2006	26.3	256	8.8	6.7	**404**	12	2.4	<0.5	10	0.13	0.5
3	Monitoring Well	8/17/2006	23.7	549	4.6	7.1	**496**	27	68	<0.5	0.4	<0.10	15
1	Drainage Lysimeter	9/28/2006	19.0	346	-45	7.0	221	<0.5	<0.5	<0.5	3.8	0.11	<0.1
1	Shallow Lysimeter (1.75 ft)	9/28/2006	20.6	286	-29	7.2	234	<0.5	0.5	3.2	1.8	<0.10	0.1
1	Middle Lysimeter (3.5 ft)	9/28/2006	20.8	262	-27	7.2	238	<0.5	<0.5	2.7	1.3	<0.10	<0.1
1	Deep Lysimeter (7 ft)	9/28/2006	20.8	435	-36	7.2	228	<0.5	6.6	<0.5	2.3	<0.10	1.5
1	Monitoring Well	9/28/2006	19.5	524	-34	7.3	237	4.6	63	<0.5	3.7	<0.10	14
2	Drainage Lysimeter	9/28/2006	19.4	872	-29	6.4	240	23	410	5.2	11	0.22	93
2	Shallow Lysimeter (1.75 ft)	9/28/2006	19.3	191	7	7.1	225	<0.5	<0.5	<0.5	0.6	<0.10	<0.1
2	Middle Lysimeter (3.5 ft)	9/28/2006	20.3	247	-24	7.2	225	3	12	28	8.9	#N/A	2.6
2	Deep Lysimeter (7 ft)	9/28/2006	19.7	387	-25	7.2	232	<0.5	3.8	14	10	<0.10	0.9
2	Monitoring Well	9/28/2006	19.2	418	-23	7.3	235	9.5	70	1.9	6.1	<0.10	16
3	Drainage Lysimeter	9/28/2006	19.0	676	4	7.0	236	6	1.1	4.4	9.0	<0.10	0.2
3	Shallow Lysimeter (1.75 ft)	9/28/2006	18.5	557	-43	7.2	236	5.6	<0.5	3.3	1.2	<0.10	<0.1
3	Middle Lysimeter (3.5 ft)	9/28/2006	#N/A	#N/A	#N/A	#N/A	#N/A	<0.5	<0.5	<0.5	<0.5	<0.10	<0.1
3	Monitoring Well	9/28/2006	17.9	728	-52	7.1	224	20	36	3.3	1.4	<0.10	8.1

Color Code

Black	QC approved data
Blue	looks like numbers are invalid because water was mixed with atmospheric oxygen (because of bailing and lysimeter samples)
Red	not distilled (value can be 40% to 50% higher; indicates that there can be interference in the samples)
#N/A = no data available	
<	Detection limit - determined from sample dilution in combination with the method detection limit
Orange	Conductivity data suspected to be inaccurate based on check standard values or inconsistent patterns in field data
na	not applicable (duplicate sample for lab analyses taken from same collected field sample)
Violet	Eh data inconsistent with historical data pattern. Cause unknown.