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Evaluation and Assessment of Agrichemical Contaminants in the Creighton, NE Area

Mark E. Burbach

University of Nebraska at Lincoln, mburbach1@unl.edu

Roy F. Spalding

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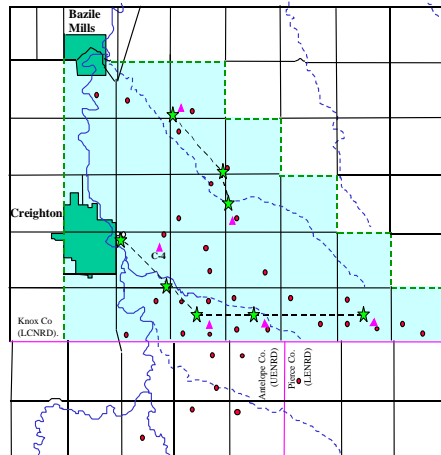


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Evaluation and Assessment of Agrichemical Contaminants in the Creighton, NE Area



Final Report For the Lewis and Clark Natural Resources District

July 20, 2000

**Mark E. Burbach
Dr. Roy F. Spalding**

**University of Nebraska Lincoln
Water Center
Water Sciences Laboratory**

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INTRODUCTION

The Lewis and Clark Natural Resources District (LCNRD) has reported elevated nitrate-nitrogen ($\text{NO}_3\text{-N}$) concentrations in ground water near Creighton, NE. The U.S. Environmental Protection Agency has set a maximum contaminant level (MCL) of 10 mg/L for $\text{NO}_3\text{-N}$ in public water supplies. $\text{NO}_3\text{-N}$ in the city of Creighton municipal drinking water wells and several rural domestic and irrigation wells have exceeded the MCL. The city of Creighton has constructed a reverse-osmosis water treatment system at a cost of \$1.1 million to reduce the $\text{NO}_3\text{-N}$ concentration below the MCL in its water supply. In response to this $\text{NO}_3\text{-N}$ contamination problem the LCNRD has begun to focus attention on the impacted area.

This Final Report represents the culmination of a two-year investigation by the University of Nebraska-Lincoln Water Sciences Laboratory (UNL WSL) to assess the persistence, source, scope and range of agrichemical contaminants in the Creighton, NE area. The results and recommendations of this report may assist the LCNRD in ground water management in the area.

Background

Irrigation dramatically increased in the Creighton area in the early 1970's. The predominant land use in the area for the past 20 years is continuous irrigated corn agriculture. The area also has many small cattle operations. Irrigated corn agriculture, confined animal feeding operations, and septic systems can result in excess nitrogen for leaching to the ground water.

Elevated ground water $\text{NO}_3\text{-N}$ levels were first observed in the Creighton area in the early to mid-1980's. A study by the UNL Conservation and Survey Division (Gosselin, 1991) identified wells with elevated $\text{NO}_3\text{-N}$ within the Bazile Triangle area in 1989. Bazile Mills roughly bounds this area on the North, Orchard on the West and Osmond on the East. The largest and most concentrated area of wells with $\text{NO}_3\text{-N}$ concentrations exceeding the MCL was located in the LCNRD immediately southeast of Creighton. Most of these wells are upgradient of the Creighton municipal drinking water supply wells. Samples collected from wells upgradient of Creighton for this study had an average $\text{NO}_3\text{-N}$ concentration of 10.6 mg/L. Samples collected by the LCNRD from the same wells in 1995 averaged 13.8 mg/L. Nitrate-N concentrations increased 3.8 mg/L in the 6-year interval. Three wells in particular increased an average of more than 13 mg/L. Factors such as variable-textured soils, variable depth to water, possible changes

in the oxidation status and multiple potential sources added to the complexity and made the source assessment of agricultural contaminants more difficult. The heterogeneous characteristics of the aquifer and vadose zone as well as the distribution of NO₃-N concentrations in the Creighton area offered unique study challenges that need to be addressed before source reduction through improved future management practices can occur. This site-specific study has been designed to address these concerns.

SITE DESCRIPTION

The Creighton study area consists of 25 mi² of land in the extreme southwestern corner of the LCNRD (figure 1).

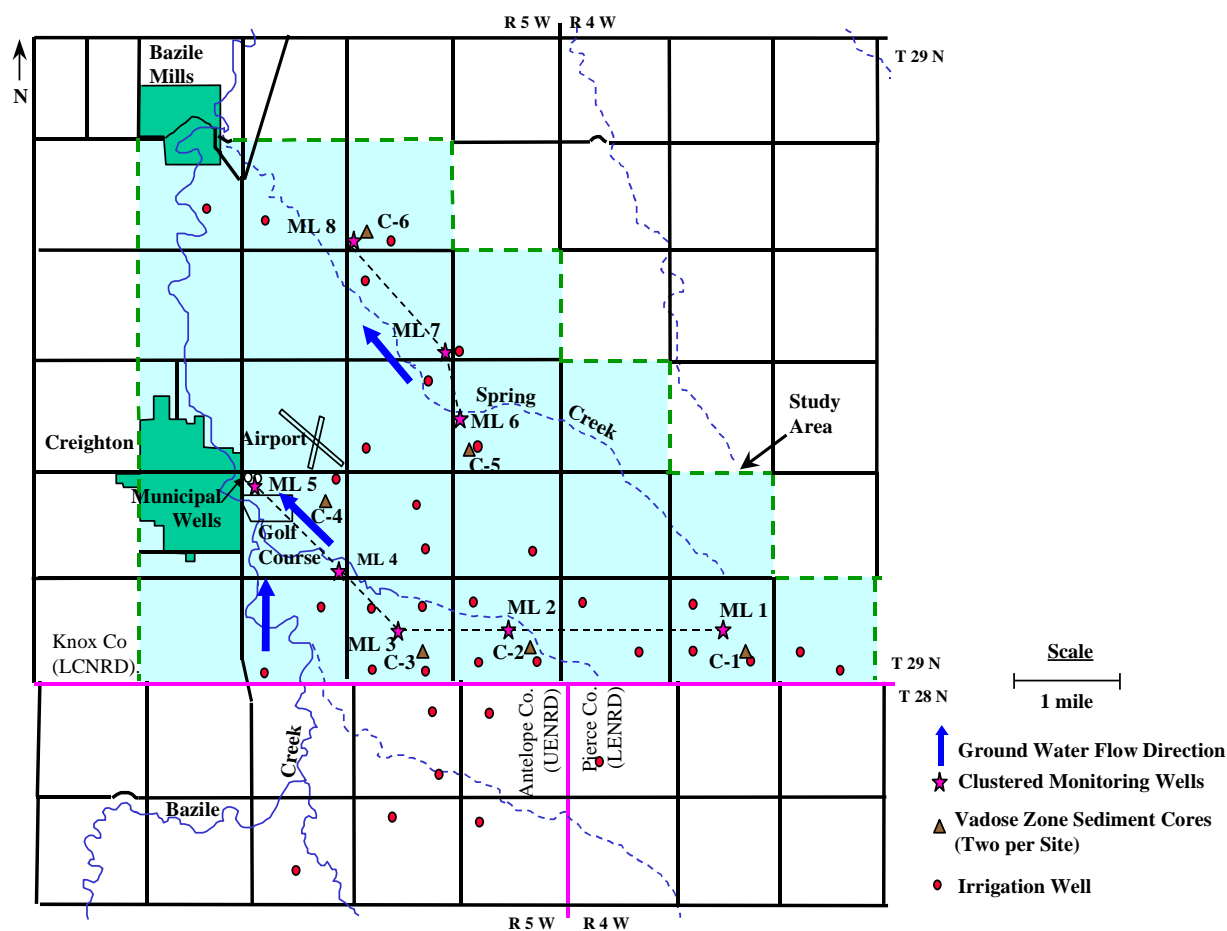


Figure 1. Diagram of study area.

Land use within the area is predominately agriculture, with irrigated corn the major cropping practice. The predominate irrigation method is the center pivot sprinkler system. Other crops grown in the area include, dryland and irrigated soybeans, milo, wheat, alfalfa, and pasture land.

Numerous farmsteads and several small cattle and hog operations are within the area. The village of Bazile Mills is in the northwest corner of the study area (figure 1).

The city of Creighton is in on the western edge of the study area (figure 1). Land use within the city is typical for a small Midwest community. The impacted Creighton municipal wells are located just east of the city. The wells' major capture area is the adjacent watershed southeast of the wells (Lackey, 1992). Other major land uses near the wells include the Creighton municipal airport that is less than ½ mile northeast of the wells. A golf course, part of which over lies a filled gravel pit, is less than ¼ mile southeast of the wells. A fertilizer facility is located within ½ mile south of the wells.

SITE HYDROGEOLOGY

The topsoil in the Creighton study area is predominately composed of moderately well drained, moderately permeable fine silts, with rapidly permeable fine sands in some upland areas (USDA, 1997). The southeastern corner of the study area is composed of highly variable glacial till soils. The soil texture within the vadose zone, the region from the ground surface to the water table, is highly variable. Significant layers of fine and course texture soils underlie the area (Appendix A). Depth to ground water ranges from less than 10 feet in the Bazile Creek floodplain near the Creighton municipal wells to more than 110 feet in the southeast corner of the study area. Wells in the southeastern region of the study area produce water from the Ogallala Aquifer that overlies Pierre Shale bedrock (Lackey, 1992). In the western two-thirds of the study area the Ogallala sediments have been removed by erosion prior to deposition of Plio-Pleistocene sediments. The wells in this portion of the study area, including the Creighton municipal wells, penetrate extensive zones of the Plio-Pleistocene sand and gravel that can be greater than 100' thick. Groundwater movement beneath the study area is generally southeast to northwest.

METHODOLOGY

Monitoring Well Installation

Clusters of three monitoring wells were installed in two southeast to northwest transects across the study area (figure 1). Each cluster consists of a well with a short screened interval near the water table, in the middle of the aquifer, and in the deeper portion of the aquifer. A clustered well design was used to generate depth profiles of water quality in order to delineate cross-sections of water quality changes beneath the study area. Short screen intervals were used to

provide discrete samples of the aquifer. Three monitoring well clusters were installed by using a Geoprobe® Systems truck mounted direct-push probe at sites ML-3, ML-4, and ML-5. At these sites, a 6" by 1/4" stainless steel tube with a stainless steel wire mesh screen was threaded to a expendable point which was hydraulically driven by 1 in probe rods to the desired depth. Attached to the stainless steel screen was 1/4" diameter polyethylene tubing. As the probe rods were retracted the expendable point released from the probe rods and anchored the monitoring well in place. A sand pack was placed around the well screen as the probe rods were extracted. The annular space created by the probe rods was sealed to the ground surface with bentonite grout as the probe rods were extracted above the screen interval.

Monitoring well clusters ML-2, ML-6, ML-7, and ML-8 were installed by hollow stem auger and consist of 2" diameter PVC casings. The shallowest well in each of these clusters has a 5' screen interval near the water table. The other two wells in each of these clusters have 2.5' screen intervals. After drilling to the appropriate depth a plate in the auger pit was knocked out and the casings and screens were placed in the annular space of the borehole. A clean sand pack was placed in the screen intervals. As the augers were removed a bentonite clay grout was placed in the annular space between screen intervals and from the top of the shallowest sand pack to the ground surface. Both installation methods were chosen to reduce mixing of aquifer water and minimize geologic disturbance.

Monitoring well cluster ML-1 also consisted of 2" diameter PVC casings with one 5' screen and two 2.5' screens but was installed by the rotary drilling technique using clean drilling water as the drilling fluid. The depth to water prohibited the other installation methods. After drilling to the appropriate depth the drill bit and drill stem were removed from the borehole and the well casing and screen were placed in the borehole which remained open due to hydrostatic pressure of the drilling fluid in the borehole. A sand pack was placed around the well screen and the annular space above the sand pack was sealed with bentonite clay.

The 1/4" monitoring wells were developed by pumping until clean with a peristaltic pump. The 2" monitoring wells were developed by pumping and surging until clean with a small diameter submersible pump.

Vadose Zone Sediment Core Sampling

A total of 348' of sediment from 12 vadose zone cores were collected from six sites within the study area (figure 1). These sites were selected because they were generally up-

gradient of clustered monitoring wells, land use at the surface was irrigated corn, and operators were kind enough to allow the coring to take place on their property. These sites also could possibly provide a rough estimate of agrichemical leachates in the study area. Historical nitrogen and pesticide inputs were unknown.

Vadose zone cores at sites C-2, C-3, C-4, C-5, and C-6 were collected using a Geoprobe® Systems truck mounted direct-push probe equipped with a 2.5" diameter stainless steel core barrel. The core barrel was hydraulically pushed into the soil and retracted. A 4' core was retrieved in polyethylene liners within the core barrel, capped, immediately frozen with dry ice in the field, and stored in a freezer at -4 °F until retrieved for laboratory analysis. Care was taken to ensure that surface material did not enter the borehole after each core was retracted. Cross contamination was eliminated by cleaning the core barrel between cores, using clean liners, and only using the portion of the core that had not come in contact with the core barrel. Boreholes were sealed with bentonite clay at the completion of the sampling.

Vadose zone cores at sites C-1 were collected with a 3" diameter core barrel with an acrylic liner protruding ahead of a hollow stem auger. Continuous four-foot cores were collected from the soil surface to the water table at each site except the two cores at site C-1 which terminated at 75' and 59' because of dense, compacted sands that prohibited the collection of more sediment samples. All vadose zone sampling followed WSL standard operating procedures (Burbach, 1997). A lithologic description was conducted on each core (Appendix A). Samples in one-foot intervals (site C-2 through site C-6) or five-foot intervals (site C-1) were extracted and analyzed for NO₃-N at the WSL. Random one-foot intervals were extracted and analyzed for nitrogen isotope ratios.

Ground Water Sampling

Ground water samples were collected from all clustered monitoring wells and many irrigation wells within the study area (figure 1). Ground water samples from monitoring wells installed by direct-push were collected by attaching a peristaltic pump to the 1/4" diameter tubing and removing 3 standing volumes prior to filling each sample container. Ground water samples from the 2" monitoring wells were collected by placing a small diameter Grundfos® submersible pump in the well and removing 3 standing volumes before filling each sample container. Ground water samples from irrigation wells were collected from wells that had been in operation for

more than 15 minutes. All ground water sampling procedures followed WSL standard operating procedures (Burbach, 1997).

On one occasion, ground water samples were collected from monitoring wells and analyzed for 15 commonly used pesticides, two degradates of the pesticide atrazine and deuterium. Chlorofluorocarbons (CFCs) were collected from the 2" monitoring wells on one occasion.

Pesticides, particularly atrazine that has been extensively used on irrigated corn fields, have been found above their respective MCLs in many areas with high concentrations of NO₃-N. Pesticide samples were collected from monitoring well clusters to identify any elevated levels within the study area and potentially impacting drinking water wells.

Deuterium and Chlorofluorocarbon (CFC) samples were collected from monitoring wells to estimate ground-water ages and flow characteristics. Deuterium is an isotope of hydrogen. Practical applications of stable isotopes such as deuterium to hydrological problems rely on the characteristic isotopic compositions of waters from different origins and the conservation of the isotopic composition of the water in the ground water. Deuterium has commonly been used to indicate mixing processes within ground water flow systems and to quantify surface water recharge. All light gas stable isotope compositions are reported as positive or negative deviations from a standard, which for deuterium is Standard Mean Ocean Water (SMOW) expressed as:

$$\delta D(\text{‰}) = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} * 1000$$

where δ , reported as per mil (‰), represents the deviation from the standard, and R is the measured deuterium to hydrogen ratio of the sample and standard.

During water vapor transport from equatorial source regions to higher latitudes sequential condensations result in the progressive stable isotope depletion in precipitation. Increased δD values in precipitation at sequentially higher altitudes also reflect enrichment processes. On the global scale, the stable isotopes of hydrogen and oxygen derived from atmospheric water follow a linear relationship, where $\delta D(\text{‰}) = 8\delta^{18}\text{O} + 10$, which is referred to as the meteoric water line (MWL) (Friedman, 1953). Deviations to the left of the MWL indicate the waters have undergone further fractionation from additional evaporation. During the evaporation of water, the residual surface water is preferentially enriched in the heavier isotope that results in deviation from the MWL. Thus, in temperate and humid climates, ground waters that have been directly recharged

from surface water bodies are preferentially enriched in the heavier isotope. Ground water with an isotopic composition similar to the isotopic composition of precipitation in the region is strong evidence of direct recharge to the aquifer (Hoefs, 1980). Variations between precipitation and recharged water can be caused by several mechanisms such as recharge from partially evaporated surface bodies like streams, lakes and ponds (Hoefs, 1980). The average δD value in ground water recharged from local precipitation near Wood River, Nebraska has been determined to be -61‰ (Ma, 1996) and average δD values in precipitation across Iowa has been determined to be -75‰ (Simpkins, 1995).

Chlorofluorocarbons (CFCs) are man-made organic compounds that are produced for a range of industrial and domestic purposes. Concentrations of CFCs in the atmosphere have been increasing over the past 50 years (figure 2)(Cook and Solomon, 1997).

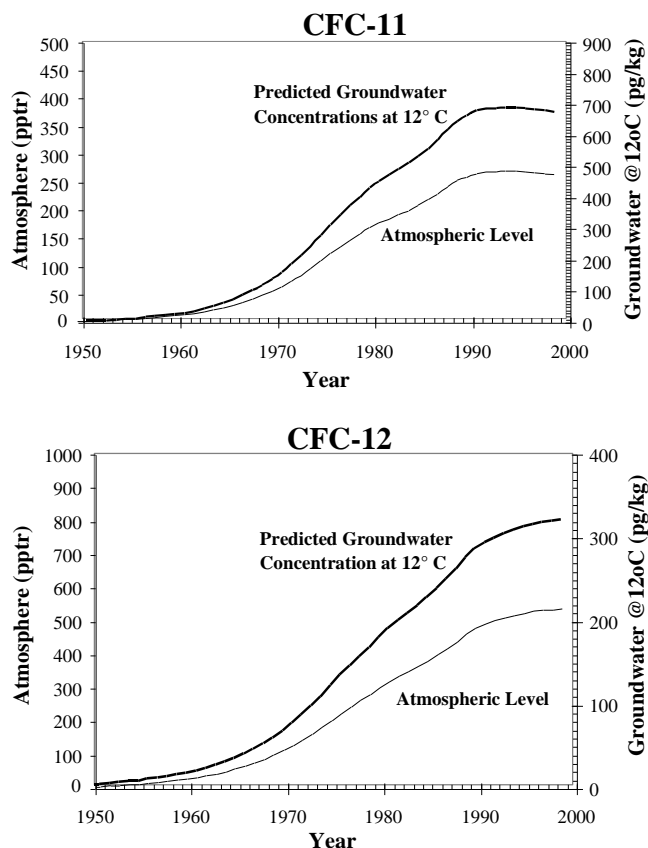


Figure 2. Ground water CFC-11 and CFC-12 concentrations in equilibrium with changes in atmospheric concentrations over the past 50 years (Walker et al., 1999).

Measurements of atmospheric concentrations have been made since 1978 at stations throughout the world and have shown little spatial variation (Cook and Solomon, 1997). Apparent CFC ages are obtained by comparing CFC concentrations in ground water samples to the annual atmospheric concentration (Cook and Solomon, 1997). In CFC age dating techniques it is assumed that concentrations in the soil gas immediately above the water table are in equilibrium with the atmosphere. Under ideal circumstances the CFC concentration in the ground water reflects the CFC concentration in the atmosphere when the water passed through the atmosphere as precipitation. Large seasonal water table fluctuations, deep water tables, and fine-grained soils affect the ground water age. Large seasonal water table fluctuations may affect soil gas diffusion. Fine-grained soils that may be near saturation all year round may also decrease downward diffusion of gases (Solomon et al, 1995; Cook and Solomon, 1997). Microbial activity may also degrade CFC concentrations in ground water in certain environments. Thus, the ground water age dating techniques are most certain in areas underlain by coarse-grained soils with shallow water tables and little microbial activity. The CFC age dating technique has been used to relate the age of the ground water to the historical application of agricultural fertilizers (Johnston et al, 1998).

Nitrogen isotope samples were collected from 20 monitoring wells and 16 irrigation wells in 1997 to determine the source(s) of NO₃ in the study area. Variations in the natural abundance of the two stable isotopes of N (¹⁵N and ¹⁴N) can be a valuable tool for semi-quantitatively resolving sources of NO₃ in ground water (Exner and Spalding, 1994). The two prevalent potential sources of NO₃ in agricultural areas are agronomic leachates from commercial fertilizer N and mineralized soil N and leachates from human and animal wastes. The two prevalent sources have different isotopic signatures. Variations in N-isotope abundance are commonly expressed as parts per thousand (‰) differences from the ¹⁵N/¹⁴N in a standard, usually atmospheric nitrogen. A positive δ (difference) ¹⁵N indicates a higher ¹⁵N/¹⁴N ratio and a negative value indicates a lower ¹⁵N/¹⁴N ratio than atmospheric nitrogen, where:

$$\delta^{15}\text{N}(\text{‰}) = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} * 1000$$

Reported δ¹⁵N values of commercial N-fertilizers range from −3 to +6‰ (Gormly and Spalding, 1979; Spalding, et al. 1982; Herbel and Spalding, 1993). Due to fractionation the δ¹⁵N value of N

derived from animal waste is normally greater than +10‰ in ground water (Gormly and Spalding, 1979).

Samples for the anions fluoride, chloride, nitrite-N, bromide, orthophosphate-P, and sulfate were collected bi-annually from monitoring wells and annually from irrigation wells beginning in the summer of 1997. The anion samples were used to determine the general geochemistry of the study area. Chloride values may be higher in areas with naturally occurring salt deposits or areas that receive waste water applications (American Public Health Association, 1998). It is also not uncommon to have elevated chloride and sulfate values in areas with intense agricultural land use (Exner and Spalding, 1991; Saffigna and Keeney, 1977).

Monitoring well sampling for the analyte of major concern, $\text{NO}_3\text{-N}$, was conducted bi-annually beginning in the fall of 1997. Irrigation wells were sampled for $\text{NO}_3\text{-N}$ during the summers of 1998 and 1999, respectively. Samples for $\text{NO}_3\text{-N}$ were collected in order to determine the concentration, extent, and trend of $\text{NO}_3\text{-N}$ in ground water upgradient of the Nebraska communities of Creighton and Bazile Mills.

RESULTS

Vadose Zone Sediment Cores Results

The $\text{NO}_3\text{-N}$ content in the vadose zone within the study area prior to modern agricultural methods is unknown; however, in previous vadose zone sampling of native grass prairies in eastern Nebraska pore water $\text{NO}_3\text{-N}$ concentrations averaged less than 0.4 mg/L (Burbach and Spalding, 1998; UNL Water Center, 1995). The vadose zone beneath six irrigated corn fields within the study area contained much higher amounts of $\text{NO}_3\text{-N}$. At all six sites $\text{NO}_3\text{-N}$ concentrations beneath the root zone, and no longer available for crop uptake, are well above the estimated pore water background concentration of 0.4 mg/L (Appendix B). The cumulative amount of $\text{NO}_3\text{-N}$ below the root zone in the soil cores, expressed as N-lbs/acre, (Appendix B) represents a significant economic loss to area farmers in terms of fertilizer inputs no longer available for crop uptake.

The average pore water $\text{NO}_3\text{-N}$ concentration below the root zone in all six sites was well above the MCL of 10 mg/L (Appendix B). The average pore water $\text{NO}_3\text{-N}$ concentration below the root zone in soil cores within the study area ranged from 14.2 mg/L at site C-6 to 35.7 mg/L at site C-4.

All the cores exhibit a great deal of NO₃-N variability with depth. Spikes with as much as 92.9 mg-N/L in the pore water below the root zone were detected. It is common to find variable nitrogen concentrations in profiles of the vadose zone beneath Nebraska corn fields (Bobier, 1990; Spalding and Kitchen, 1988; UNL Water Center, 1995). Spikes of NO₃-N in the vadose zone pore water within the study area are probably the result of the timing of fertilizer application and rain or irrigation. A heavy rain or irrigation soon after fertilizer application can result in significant amounts of nitrogen leaching through the root zone, particularly early in the growing season when root growth is small. Completely eliminating spikes of NO₃-N is probably not currently feasible; however, future management practices are key to reducing the number and concentration of future spikes.

Ground water within the study area will continue to be recharged with water that contains NO₃-N concentrations well above the MCL for quite some time. The sites selected represent only a small fraction of the cultivated area within the study area. Significant nitrogen leaching is most likely occurring under other fields in the study area.

Ground Water Sampling Results

Pesticides

Atrazine was not detected in ground water samples from any monitoring well (Table 1).

Table 1. Select results of ground water sampling within the study area.

Sample ID	NO ₃ -N (mg/L)					Atrazine (µg/L)	δ ¹⁵ N (‰)	δD (‰)	Ground Water Age From CFC-11 (yrs)
	Sum/ Fall 97	Spr/ Sum 98	Fall 98	Spr/ Sum 99	Spr 00				
ML-1-S	11.9	13.1	13.5	13.6	15.4	<0.05	+2.7		34
ML-1-M	15.7	14.8	20.2	12.5	15.5	<0.05	+2.4	-61.9	36
ML-1-D	6.6	6.1	5.0	4.3	4.9	<0.05	+3.3	-66.7	36
ML-2-S	29.4	31.3	28.2	31.3	30.4	<0.05	+4.9	-63.4	5
ML-2-M	23.8	31.4	33.9	37.2	35.3	<0.05	+5.1	-69.0	23
ML-2-D	33.8	31.2	19.5	30.8	33.9	<0.05	+4.5	-64.3	27
ML-3-S	33.3	49.0	38.7	38.9		<0.05	+3.2	-66.5	
ML-3-M	40.4	39.9	38.6	38.7		<0.05	+6.4	-65.9	
ML-3-D	10.0	10.9	10.3	11.3		<0.05	+3.5	-68.0	
ML-4-S			1.6	2.2		<0.05			
ML-4-M	19.5	18.0	23.4	23.3		<0.05	+4.0	-67.4	
ML-4-D	17.0	18.5	19.7	18.8		<0.05	+4.5	-69.1	
ML-5-S	16.7	17.5	18.1	16.3		<0.05	+7.3	-57.4	
ML-5-M	16.7	13.3	16.2	13.9		<0.05	+6.7	-67.0	
ML-5-D	13.7	12.4	14.5	12.8		<0.05	+4.7	-62.3	
ML-6-S	22.4	22.4	25.8	21.5	24.3	<0.05	+4.5	-64.9	22

ML-6-M	11.0	11.1	14.4	14.7	18.0	<0.05	+3.4	-65.0	25
ML-6-D	6.8	5.9	10.9	9.5	12.7	<0.05	+3.9	-66.8	28
ML-7-S	19.2	16.3		18.1	20.6	<0.05	+3.0	-70.5	12
ML-7-M	17.4	17.4	14.5	20.5	32.7	<0.05	+4.0	-69.4	13
ML-7-D	22.8	14.4	23.9	20.8	12.8	<0.05	+5.8	-72.3	16
ML-8-S	4.6	3.4	3.4	3.3	3.3	<0.05			25
ML-8-M	7.2	2.2	7.5	8.5	7.0	<0.05			25
ML-8-D	11.2	14.1	16.9	8.4	6.3	<0.05			22
NW 31-29N-4W	9.9	10.5		10.9			+4.0		
SE 31-29N-4W				9.4					
SE 33-29N-4W	15.8	24.2		20.2			+8.0		
SW 33-29N-4W				16.5					
SW 32-29N-4W				7.1					
NW 32-29N-4W				6.0					
SE 32-29N-4W	16.0	15.1		19.4			+3.7		
SE 9-29N-5W				8.8					
SW 10-29N-5W	14.6	13.6		10.3			+3.3		
NW 12-28N-5W		6.8							
SW 13-29N-5W	19.0	19.0					+5.3		
NW 14-29N-5W	17.6			16.4			+3.7		
NE 23-29N-5W	11.2	13.3		14.8			+4.2		
SW 23-29N-5W				8.2					
SW 24-29N-5W	15.2	15.3		16.7			+5.1		
SE 25-29N-5W	10.5	12.6		12.7			+6.4		
NE 26-29N-5W	9.7	11.6							
SE 26-29N-5W		16.7		18.7			+3.3		
NE NE 27-29N-5W	10.1	9.2		10.5			+4.4		
SW 34-29N-5W	5.2	5.5		11.7					
NE 34-29N-5W		31.1		22.9			+6.7		
NE 35-29N-5W		18.7		19.6					
NW 35-29N-5W				26.3					
SE 35-29N-5W	36.0			35.0			+4.3		
SW 35-29N-5W				31.9					
NW 36-29N-5W				18.8					
SW 36-29N-5W		17.5		14.9			+3.3		
SE 36-29N-5W	16.0	16.9		20.6					
Muni. Well East	9.8				12.4		+4.4		
Muni. Well West	13.4						+5.9		
Creek Sample (Bazile Creek Trib.)	23.5		22.7		21.5				
(Outside Study Area)									
SW 6-28N-4W		8.7							
NW 1-28N-5W				13.8					
SE 2-28N-5W				16.4					
NE 2-28N-5W				22.8					
SW 10-28N-5W		28.5							
NE NW 11-28N-5W				13.8					
NW 12-28N-5W				8.2					
SE 12-28N-5W		6.9							

Except for extremely low concentrations of deethylatrazine (DEA), an atrazine metabolite, at sites ML-3, ML-4, and ML-7 no pesticides were detected (Appendix C). Although at low concentrations, DEA is a good indicator of nonpoint contamination that has leached through soils (Adams and Thurman, 1991).

Deuterium

The deuterium values are relatively uniform (table 1) and consistent with values for ground water derived from local meteoric water in Nebraska and not impacted by surface water (Ma, 1996; Simpkins, 1995). Since the ground water has not been preferentially enriched with the deuterium isotope, evaporative ponds and lakes are not contributing recharge to the local ground water. There is no evidence that surface water bodies significantly contribute to ground water recharge. Bazile Creek, Spring Creek, and their tributaries (figure 1) are “gaining” streams and thereby form active sources of ground water discharge. Deuterium results confirm that the ground water in the study area is recharge from local precipitation.

Nitrogen Isotopes

Nitrogen isotope results ranged from +2.4 to +8.0‰ (Table 1) and indicate the major source of nitrogen in the ground water within the study area is derived from commercial fertilizer. An extremely small number of wells may have contributions from animal waste. These sites may have slightly enriched $\delta^{15}\text{N}$ values as a result of manure deposited by the cattle grazing on corn stubble during fall and winter or from small amounts of denitrification. The most enriched $\delta^{15}\text{N}$ value is from an irrigation well in the extreme southeast corner of the study area.

Anions

Profiles of anion values from monitoring well clusters were averaged for consistency in comparing irrigation well concentrations which draw water from a large portion of the saturated zone. Values for fluoride, nitrite-N, bromide, and orthophosphate-P were not anomalous within the study area (Appendix D). Chloride values were elevated in areas southeast of Creighton and in a large area southeast of Bazile Mills (figure 3).

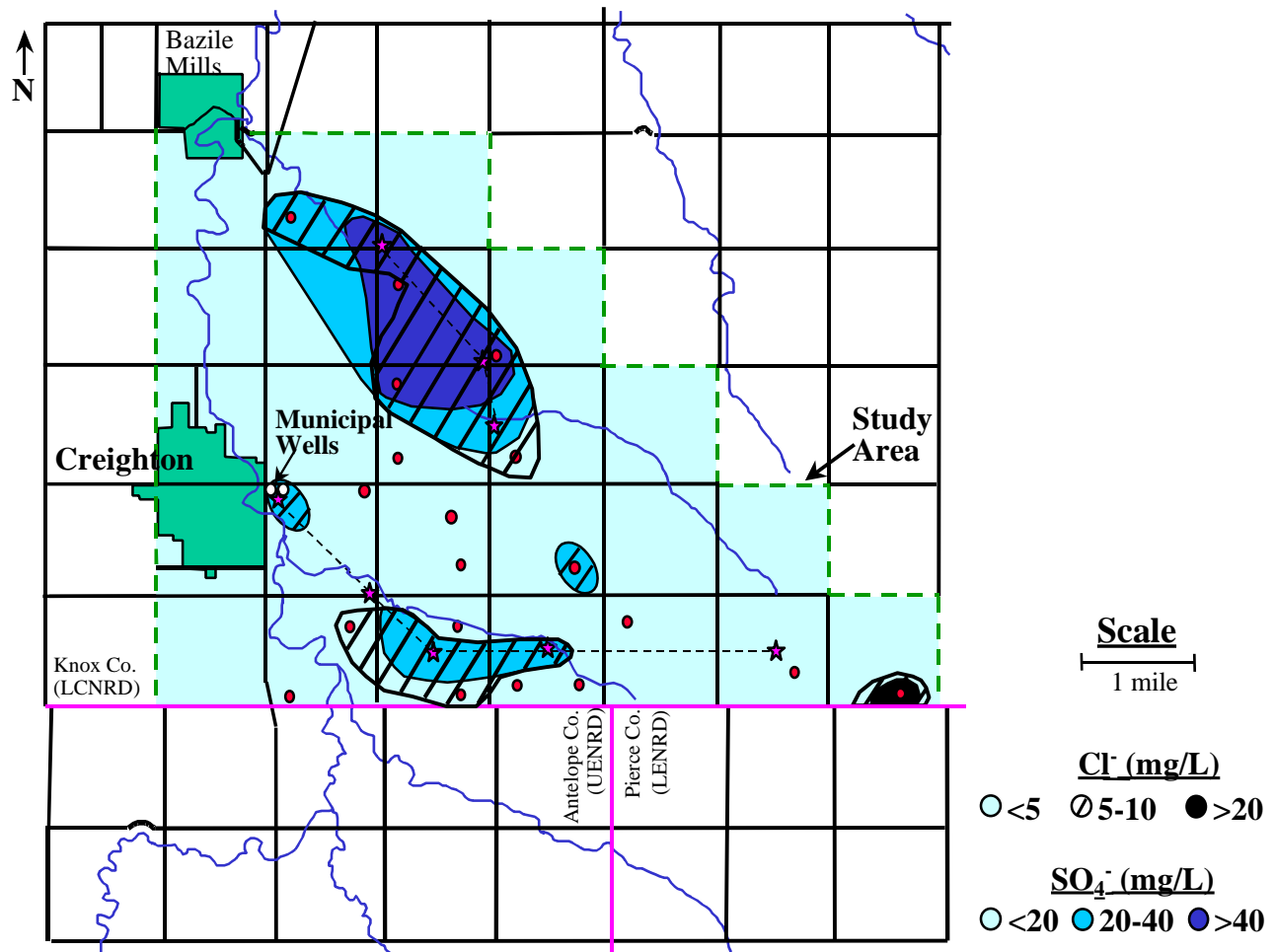


Figure 3. Distribution of chloride and sulfate within the study area.

The highest chloride concentration was in an irrigation well in the extreme southeast corner of the study area (figure 3). The cause of this anomolous value is not known. This site also had a $\delta^{15}\text{N}$ of +8. The combination suggests that this site may be impacted by animal waste inputs.

With the exception of a few wells, sulfate values correspond with chloride values (overall $r = 0.60$) (figure 3). The areas of elevated chloride and sulfate also correspond to areas of elevated $\text{NO}_3\text{-N}$ discussed below providing additional confirmation that the ground water contamination in the study area is a result of agricultural practices.

$\text{NO}_3\text{-N}$

A large majority of the ground water within the study area exceeds the MCL for $\text{NO}_3\text{-N}$. Figure 4 shows the distribution of $\text{NO}_3\text{-N}$ near the water table in the study area.

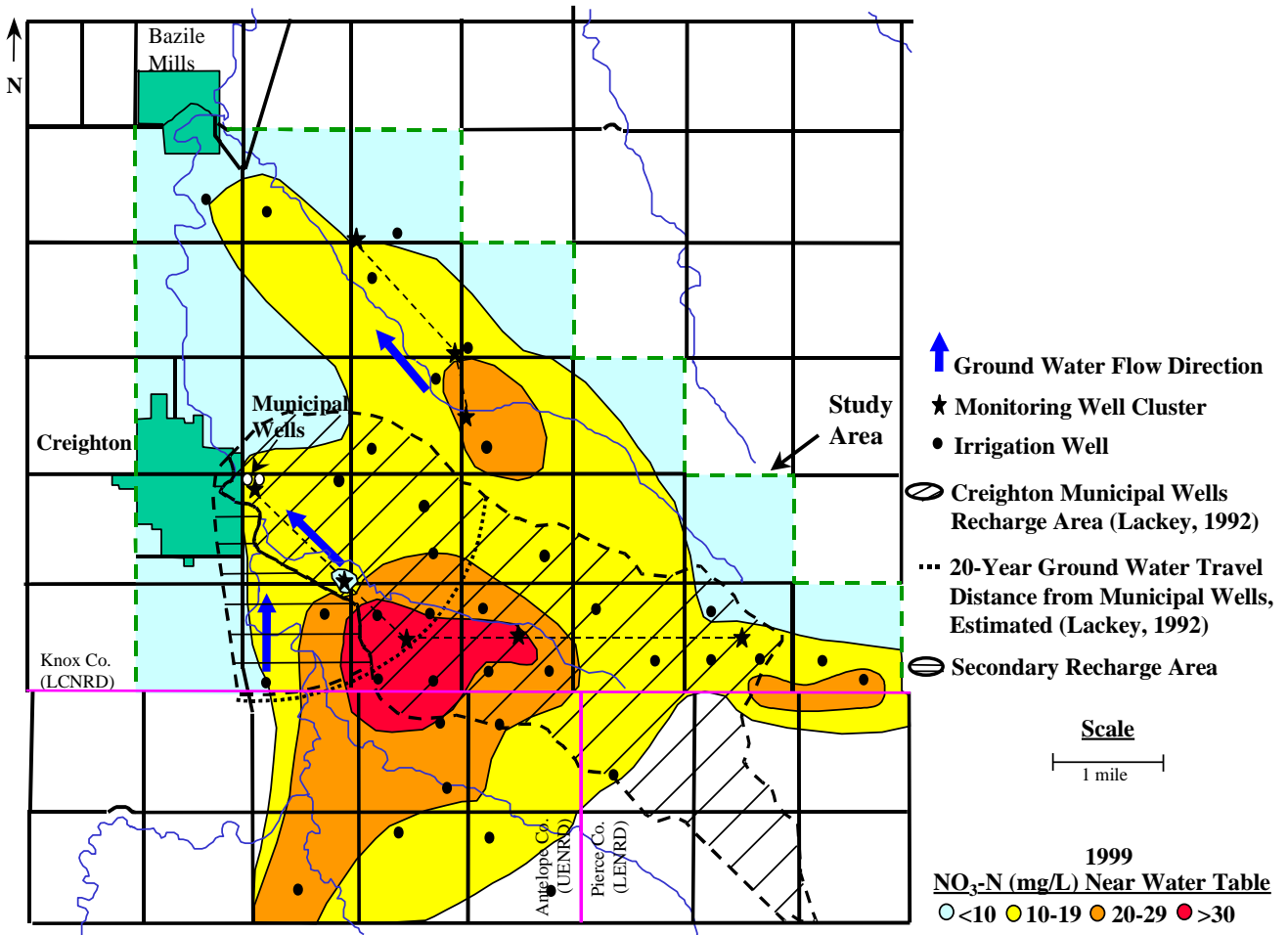


Figure 4. Distribution of NO₃-N near the water table within the study area.

The zone of NO₃-N exceeding the MCL extends beyond the LCNRD boundary to the south into the Upper Elkhorn Natural Resources District (UENRD) and the Lower Elkhorn Natural Resources District (LENRD). The leading edge of a zone of NO₃-N exceeding 30 mg/L in the ground water near the water table was found about 1.25 miles southeast (upgradient) of the Creighton municipal wells and also extends into the UENRD (figure 4). This zone comprises approximately 1.3 mi² (~830 ac). A sample from a creek that is spring fed by ground water in this area contained 23.5 mg/L NO₃-N (table 1). A zone of NO₃-N with concentrations exceeding 20 mg/L near the water table was found about 2 miles southeast (upgradient) of Bazile Mills (figure 4). Lackey (1992) identified the major watershed (capture zone) responsible for recharge to the ground water that will eventually migrate towards the Creighton municipal wells. (figure 4). She also estimated the distance ground water will migrate in 20 years based on “typical” ground water flow rates without pumping influences for similar aquifers (figure 4). Immediately

south of the Creighton municipal wells ground water flow is north, towards the wells. This region of the study area should also supply some recharge water to the municipal wells (figure 4).

The zone of $\text{NO}_3\text{-N}$ exceeding 30 mg/L penetrates deep into the aquifer, extending more than 40' (figure 5). The data confirm that the ground water within this region is well mixed and a large amount of $\text{NO}_3\text{-N}$ has been leaching through the vadose zone and entering the ground water system.

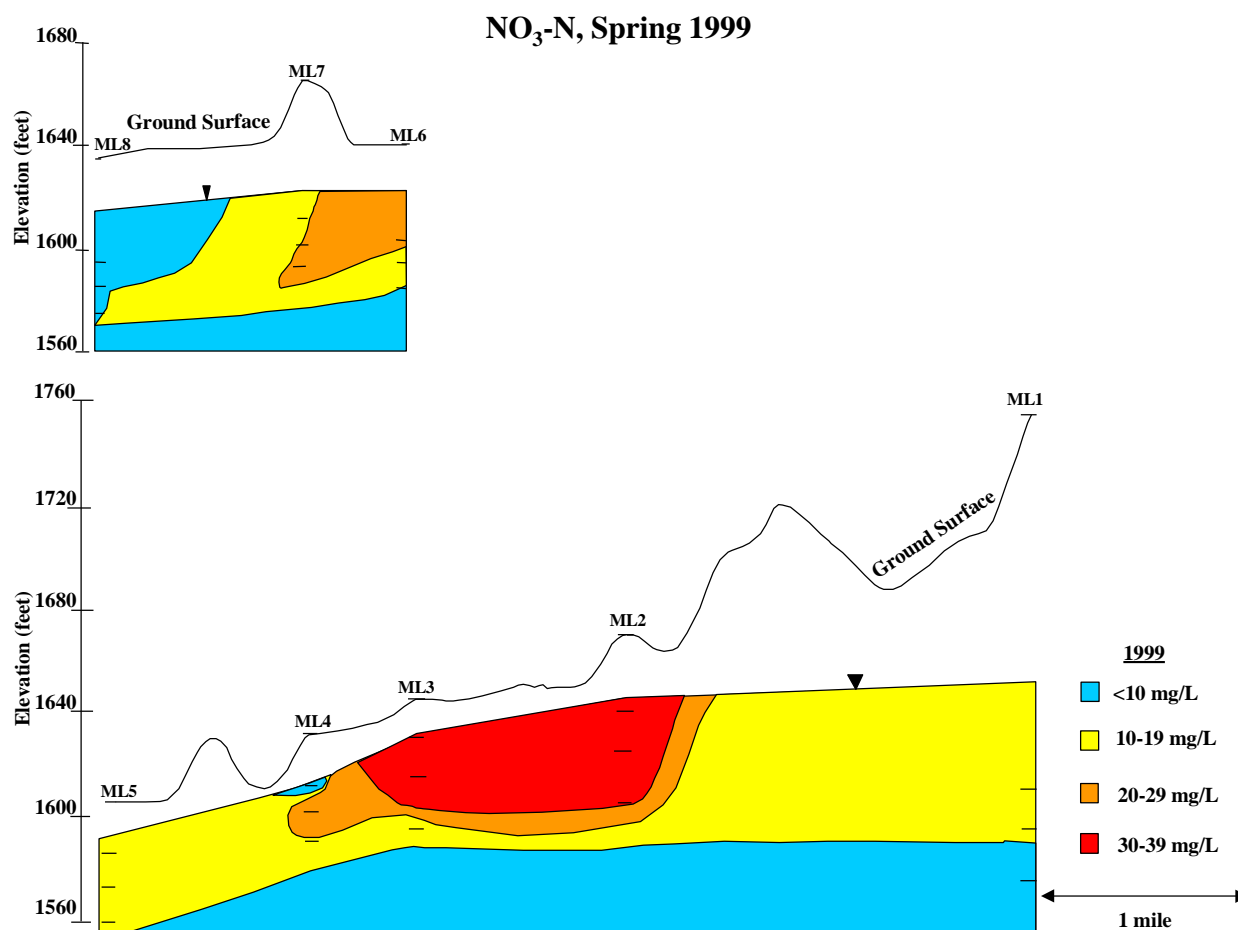


Figure 5. Cross-sections of $\text{NO}_3\text{-N}$ in monitoring well clusters.

Typically, shallow unconfined aquifers exhibit some $\text{NO}_3\text{-N}$ stratification with depth (Spalding et al, 1993; Spalding and Exner, 1980). This is the case at ML-2 and -3. The area downgradient (northwest) of ML-3 is a discharge zone where some ground water near the ground surface flows into a stream through seeps and springs. The discharge area (Bazile Creek tributary) appears to intercept the horizontal transport of the highest $\text{NO}_3\text{-N}$ in the plume. The

creek may serve as a partial divide between the main plume and the city of Creighton. Vertical ground water flow exists along this stretch of the stream. The vertical flow component may cause deeper water to move upwards to the surface and seep into the creek. Figure 6 conceptualizes this type of ground water flow pattern. In order to validate the flow more cluster wells are needed in the discharge and recharge area.

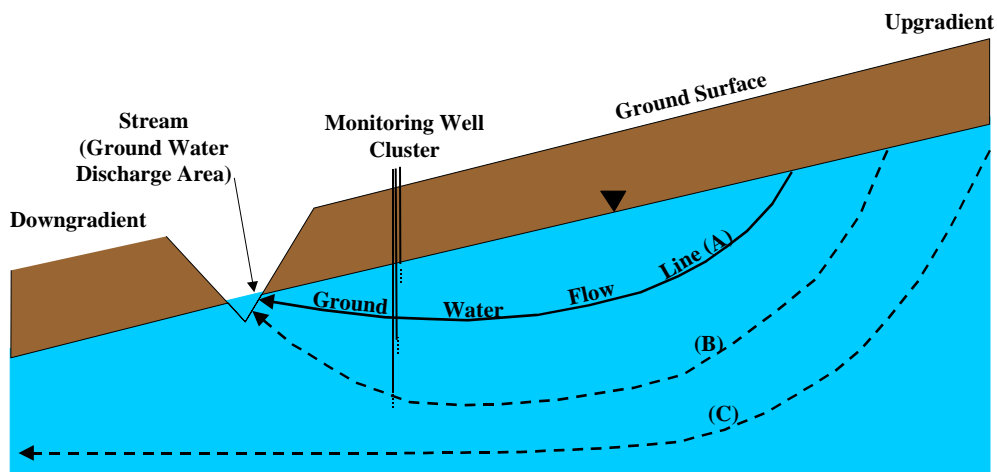


Figure 6. Hypothetical ground water flow pattern.

The aquifer in the area around ML-2 and -3 has high $\text{NO}_3\text{-N}$ values more than 40 feet below the water table. This suggests that some of the ground water contamination has probably moved downward into deeper layers from upgradient sources some distance away. The deeper water may be transported to the discharge area by upward (vertical) movement. In order to ascertain the degree of upward movement water level measurements would need to be taken in piezometers installed in the vicinity of the discharge area. Flow line A in figure 6 represents shallow ground water that is intercepted by the discharge area. Flow line B in figure 6 represents a strong upward gradient. Flow line C in figure 6 represents no upward gradient. Since the ground water in this area may be a mixture of upgradient sources, it may take a long time to observe the impact of improved management practices in shallow monitoring wells.

Another small zone with concentrations exceeding 20 mg/L NO₃-N near the water table was found on the extreme southeast region of the study area (figure 4). The depth to water in this region of the study area is more than 110'. The vadose zone in this area contains thick clay layers (Appendix A). Vadose cores from a field in this area did not reveal a significant amount of residual NO₃-N (Appendix B). An irrigation well in this area has an anomalously high chloride concentration and slightly enriched $\delta^{15}\text{N}$ values. One possible explanation for the high NO₃-N in the extreme southeast corner of the study area may be the result of nearby preferential flow through the vadose zone containing animal waste.

Ground Water Age Dating with CFC-11

The “ages” for ground water in the study area are based on CFC-11 concentrations. At ML-1 the approximate age of the water in the shallowest monitoring well that is screened 40 ft below the water table is 34 years (figure 7).

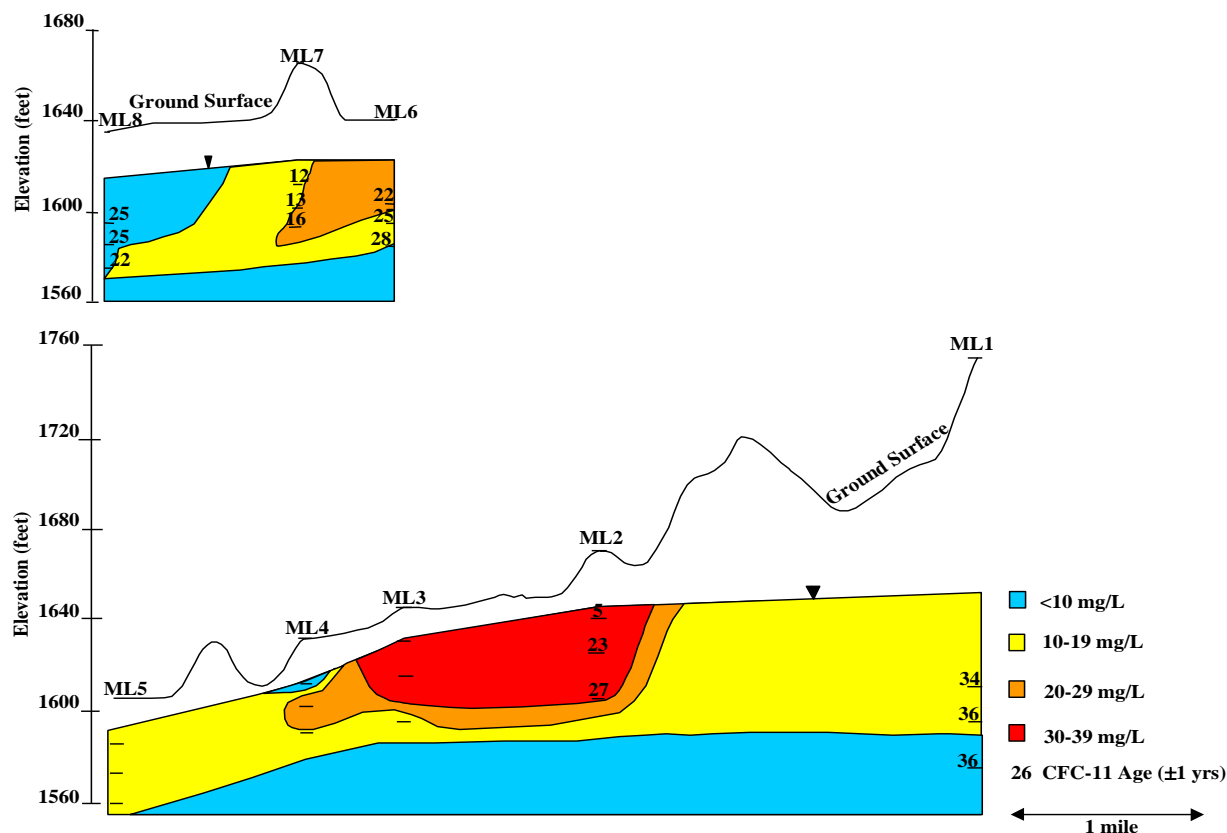


Figure 7. Ground water age (Spring, 2000) and NO₃-N (Spring, 1999).

The approximate age of the water from the deepest monitoring well that is screened about 80 ft below the water table is similar at 36 years (figure 7). The CFC-11 curve is nearly flat from 1950

to about 1965 so there is more uncertainty in the ages at ML-1. There probably is more difference in age with depth in this area than can be discerned from the CFC methodology.

It appears that the ground water near ML-2, which has some of the highest $\text{NO}_3\text{-N}$ concentrations in the study area, is stratified with an approximate age of 5 years in the shallow portion of the aquifer (figure 7). The age of the ground water is approximately 27 years in the deepest monitoring well, screened 40 ft below the water table. This indicates that the aquifer near ML-2 began receiving $\text{NO}_3\text{-N}$ enriched recharge water prior to 1973 and continues to receive $\text{NO}_3\text{-N}$ enriched recharge water.

Because the monitoring well clusters ML-3, -4, and -5 are very small diameter and must be sampled with a vacuum pump they could not be utilized for CFC sampling. Thus, ground water flow patterns in these areas must be interpreted from other information.

Ground water ages in ML-6 and ML-7 increase slightly with depth. The aquifer age at ML-7, however, is slightly younger than the aquifer age at ML-6 (figure 7). This ground water age data suggest that high $\text{NO}_3\text{-N}$ recharge water, some that has reached more than 40 feet below the water table in this area, began entering the aquifer in the early 1970s upgradient of ML-6. The ground water age in the deepest well at ML-7 that is screened 30' below the water table entered the aquifer upgradient in the mid-1980s. The ground water at ML-8 is slightly younger in the deepest well that is screened about 40' below the water table (figure 7). The flow pattern dictates that the deeper portion of the aquifer in this area is impacted by up-gradient sources.

CONCLUSIONS

A large plume of non-point source nitrogen from agronomic sources (commercial-N and fertilizer-N) lies immediately east-southeast of Creighton, NE. A golf course, abandoned gravel pit, and fertilizer plant do not appear to be significant contributors to the $\text{NO}_3\text{-N}$ in the ground water upgradient of the Creighton municipal wells. The $\text{NO}_3\text{-N}$ in this plume exceeds the MCL for drinking water and is impacting the city of Creighton municipal wells as well as numerous private drinking water wells. A portion of the plume is also migrating to the northwest towards the village of Bazile Mills. A zone underlying approximately 830 ac has a $\text{NO}_3\text{-N}$ concentration exceeding 30 mg/L. The leading edge of this area is approximately 1.25 miles downgradient of the city of Creighton municipal wells and is well within the estimated 20-year travel period to the municipal wells. However, a discharge area between the leading edge and the municipal wells may in part intercept this part of the plume.

Nitrate analyses of vadose zone cores indicate a significant amount of NO₃-N continues to leach through the sediments beneath irrigated corn fields in the study area. This will cause NO₃-N concentrations in the ground water to remain the same or continue to increase in the near future.

The city of Creighton reverse-osmosis treatment system can currently reduce 13 mg/L NO₃-N in well water by 80%. To meet demand, treated water is blended with untreated water for a final NO₃-N concentration in the municipal water supply system of 5-7 mg/L. If the NO₃-N concentration in the municipal wells increases in the future more water will need to be treated before entering the final water supply. This may cause the city to fail to meet demand.

With the exception of extremely low concentrations of deethylatrazine, no other pesticides were detected in ground water from monitoring well clusters. Nitrogen isotope values confirm that the source of nitrogen in the majority of wells in the study area is derived predominately from commercial fertilizer sources. Deuterium values confirm that the source of recharge to the ground water in the study area is derived from precipitation and not impacted by surface water bodies. Chloride and sulfate values are slightly elevated in some portions of the study area.

RECOMMENDATIONS

Practical and feasible methods to treat large non-point source nitrate contaminated ground water do not exist. The only currently available methods involve reducing future nitrogen inputs. Current best management practices for irrigated corn have been demonstrated to reduce nitrogen leaching below the root zone. These best management practices have demonstrated that they can lead to a reduction in ground water NO₃-N. Results at the Nebraska MSEA have demonstrated that reducing ground water NO₃-N from greater than 30 mg/L to about 10 mg/L may be possible without significantly sacrificing yield. Assuming economics and landowner cropping practices continue to favor irrigated corn, reducing NO₃-N below the MCL, however; will be a long-term proposition. The following recommendations are proposed:

- Fertilizer inputs for all crops should be based on realistic yield goals and should account for all sources including residual soil nitrogen in the root zone and the nitrogen available in irrigation water. Fertilizer should be applied when the crop needs it through sound fertilizer and chemigation techniques. Fertilizer rates may vary across fields and variable rate application methods are becoming available. Chlorophyll meters have been successfully used

to predict when nitrogen fertilizer should be applied (Schepers, 1993). New real-time satellite monitoring technologies may be available soon.

- Current UNL recommended irrigation scheduling practices should be employed.
- Education and demonstration programs should be developed with the assistance of the UNL Cooperative Extension division and local crop consultants. Education and demonstration programs should be coordinated with the Upper Elkhorn NRD (UENRD) and Lower Elkhorn NRD (LENRD). The UNL Cooperative Extension division may be able to assist the LCNRD with identifying potential sources of funds for education and demonstration programs.
- Crop rotation programs utilizing crops with low nitrogen requirements should be encouraged when economically feasible.
- The LCNRD should consider expanding its current soil sampling cost share program to include irrigation scheduling and other best management practices.
- The LCNRD should explore cooperative management and educational options with the UENRD, LENRD, and the Nebraska Department of Environmental Quality (NDEQ). The NDEQ could provide some assistance if the area were to be declared a Special Protection Area.
- A Geographic Information System (GIS) is being installed at the LCNRD and should be utilized as an important management tool for the LCNRD, particularly with respect to recording annual water quality data and monitoring NO₃-N trends within the study area. Irrigation and fertilizer records could also be included in the GIS.

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APPENDICES

APPENDIX A

Lithologic Descriptions of Vadose Zone Cores and Soil Logs of Monitoring Well Clusters within the Study Area

Core C-1-1

(SE1/4. Sec 32, T29N, R4W)

Interval (ft)	Description
0-2.5	Black silt w/trace sand
2.5-5	Dk. brown silt loam
5-8	Tan sand w/ trace silt
8-10	Sandy loam
10-15	Dk brown-lt. brown silt
15-18	Sand w/iron
18-20	Gray clay w/iron
20-25	Gray clay w/iron
25-26	Gray clay
26-30	Tan-lt. brown med. clay, manganese
30-36	Med. brown silty clay, calcium and iron
36-40	Clay, manganese and iron
40-47	Med. brown-tan silty clay w/iron
47-57.5	Gray-tan clay and fine sand, w/iron and manganese
57.5-58	Sand
58-60	Fine sand w/clay, iron mottling w/manganese
60-61	Clay
61-65	Med sand and clay
65-70	Brown fine sand
70-75	Fine sand, iron streaks

Core C-1-2

(SE1/4. Sec 32, T29N, R4W)

Interval (ft)	Description
0-1	Silt w/trace of sand and clay
1-7.5	Silty fine sand
7.5-20	Gray clay, w/ iron streaks
20-25	Lt. Gray clay, w/ iron and manganese stains
25-30	Grayish brown clay, high iron, high plasticity
30-36	Lt. Grayish brown clay, low plasticity
36-39	Orange clayey silt, w/ iron
39-40	Silty fine sand, w/ iron and manganese. nodules
40-41	Brown silt w/ v.f.sand
41-42.5	Lt brown silty clay, wet (perched) w/ iron
42.5-50	Grayish brown clayey silt, w/ iron and manganese stains
50-52.5	Silt w/ iron streaks
52.5-52.6	Red iron layer
52.6-52.8	Lt. Brown fine clean sand, w/ manganese
52.8-53.6	Gray fine sand
53.6-55	Sandy silt,
55-56	Sandy Silt w/ clay,
56-57	Fine Sand, dense,
57-57.5	Clay w/ sand,
57.5-59	Fine sand, dense

Core C-2-1

(SE1/4, Sec 36, T29N, R5W)

Interval (ft)	Description
0-3	Dk. brown sandy loam w/roots
3-8	Lt. brown fine sand
8-9	Lt. and dk. brown fine sand
9-11	Lt. brown fine sand
11-12	Lt. brown coarse sand
12-13	Lt. and dk. brown clay w/rusty fine sand
13-16	Brown sandy clay

Core C-2-2

(SE1/4, Sec 36, T29N, R5W)

Interval (ft)	Description
0-3	Dk. brown, fine sandy loam w/roots and stalks
4-7	Brown sandy clay loam
7-9	Brown clay
9-10	Brown sandy clay
10-12	Brown fine sand
12-13	Lt. and dk. brown sandy clay
13-14	Lt. brown sandy clay
14-16	Lt. brown clay
16-17	Lt. brown sandy clay
17-21	Lt. brown clay
21-22	Lt. brown sandy clay
22-24	Lt. and dk. brown clay

Core C-3-1

(SE1/4, Sec 35, T29N, R5W)

Interval (ft)	Description
0-1	Dk. brown fine sandy loam w/roots and stalks
1-12	Brown fine sand

Core C-3-2

(SE1/4, Sec 35, T29N, R5W)

Interval (ft)	Description
0-1	Dk. brown, sandy clay
1-3	Loam w/roots and stalks
3-5	Brown sandy clay
5-6	Brown w/rust, sandy
6-8	Clay
8-12	Brown sandy clay

Core C-4-1

(NE1/4, Sec 27, T29N, R5W)

Interval (ft)	Description
0-1	Dk. brown silty clay loam w/roots and stalks
1-2	Dk. and med. brown sandy loam w/roots
2-8	Med. brown, v.f. sand
8-9	Lt. brown mixed w/dk. brown v.f. sand
9-15	Lt. brown v.f. sand
15-18	Brown, sandy clay loam
18-20	Brown, sandy clay

Core C-4-2

(NE1/4, Sec 27, T29N, R5W)

Interval (ft)	Description
0-2	Dk brown, silty loam w/cornstalks and roots
3-4	Med. brown silty loam
4-5	Med. brown sandy clay
5-8	Brown, v. f. sand
8-9	Med. brown mixed w/dk brown sandy clay
9-11	Lt brown, v.f. sand
11-13	Lt. brown, sandy clay
13-15	Med brown, sandy clay
15-16	Med. brown, fine sand
16-18	Lt. brown v.f. sand
18-19	Dk. brown v.f. sand
19-20	Dk. and lt. brown v.f. sand

Core C-5-1

(SW1/4, Sec 24, T29N, R5W)

Interval (ft)	Description
0-3	Dk. brown sandy loam w/roots and stalks
3-5	Dk. brown sandy clay w/roots
5-6	Brown sandy clay
6-8	Light brown fine sand
8-9	Lt. brown w/dark and rust, sandy clay
9-16	Lt. brown sandy clay

Core C-5-2

(SW1/4, Sec 24, T29N, R5W)

Interval (ft)	Description
0-2	Dk. brown sandy loam w/roots
2-4	Dk. brown sandy clay loam
4-7	Brown sandy clay w/ rust
7-8	Brown w/ rust, sandy clay
8-10	Brown, fine sand
10-12	Brown, sandy clay
12-17	Brown sandy clay w/ rust
17-20	Brown clay

Core C-6-1

(SW1/4, Sec11, T29N, R5W)

Interval (ft)	Description
0-4	Brown fine sandy loam w/roots
4-16	Brown fine sand
16-21	Brown fine sand
21-26	Brown sandy clay
26-28	Brown clay
28-33	Brown sandy clay
33-34	Brown fine sand

Core C-6-2

((SW1/4, SW1/4, Sec11, T29N, R5W)SW1/4, Sec11, T29N, R5W)

Interval (ft)	Description
0-2	Brown sandy loam w/roots
2-8	Brown fine sandy loam
8-10	Brown fine sand
10-11	Brown sand
11-12	Brown coarse sand
12-14	Brown fine sand
14-24	Brown sandy clay
25-27	Brown sandy clay
27-30	Brown fine sand
30-33	Brown sandy clay
33-36	Dk. brown coarse sand
36-40	Dk. brown very coarse sand

Monitoring Well Cluster ML 1

(NW1/4, SE1/4, Sec 32, T29N, R4W)

Interval (ft)	Description
0-5	Silty clay
5-15	Sandy silt
15-18	Sand
18-30	Clay
30-50	Silty clay
50-60	Fine sand with clay
60-63	Medium sand with clay

Monitoring Well Cluster ML 2

(NW1/4, SE1/4, Sec 36, T29N, R5W)

Interval (ft)	Description
0-2	Silt w/ trace of sand and clay
2-9	Clay
9-14	Sand
14-35	Clay
35-40	Fine sand
40-45	Clay
45-70	Fine sand

Monitoring Well Cluster ML 3

(NW1/4, SE1/4, Sec 36, T29N, R5W)

Interval (ft)	Description
0-2	Silt w/ trace of sand and clay
2-17	Sand, fine to coarse, gravel, fine to medium
17-20	Silty sand
20-21	Sand, fine to coarse, gravel, fine to medium
21-23	Silty sand
23-28	Sand. Fine to coarse, gravel fine to medium
28-30	Silt some fine sand
30-35	Sand, fine to coarse, gravel, fine
35-44	Silt. Some fine sand
44-45	Sand, fine to coarse, gravel, fine
45-48	Clay

Monitoring Well Cluster ML 4

(SE1/4, SE1/4, Sec 29, T27N, R5W)

Interval (ft)	Description
0-2	Silt w/trace fine sand
2-17	Sand, medium to coarse, gravel, fine to medium
17-18	Silty Clay
18-32	Sand, medium to coarse, gravel, fine to medium
32-33	Silty clay
33-38	Sand, medium to coarse
38-39	Sand, coarse
39-45	Sand, fine to coarse
45-47	Silty clay

Monitoring Well Cluster ML 5

(NW1/4, NW1/4, Sec 27, T29N, R5W)

Interval (ft)	Description
0-4	Silt w/ trace clay and sand
4-13	Sand, fine to coarse
13-14	Silty sand
14-18	Gravel, fine to medium
18-22	Sand, fine to coarse
22-24	Sand, fine to medium, some silt
24-26	Sand, fine to coarse, some small gravel

Monitoring Well Cluster ML 6

(NW1/4, SW1/4, Sec 24, T29N, R5W)

Interval (ft)	Description
0-3	Silt w/ fine sand
3-5	Silt
5-10	Silt
10-15	Silt, w/ some med. to coarse sand
15-20	Silty clay
20-25	Sand, medium w/silt
25-30	Sand, medium w/ silt
30-35	Sand, fine w/silt
35-53.5	Sand, fine

Monitoring Well Cluster ML 7

(SE1/4, SE1/4, Sec14, T29N, R5W)

Interval (ft)	Description
0-2	Silt w/ trace fine sand
2-21	Sandy silt
21-27	Silty clay
27-45	Sand, fine to medium w/silt
45-53	Sand, fine w/silt
53-58	Silty sand
58-70	Sand, fine to coarse

Monitoring Well Cluster ML 8

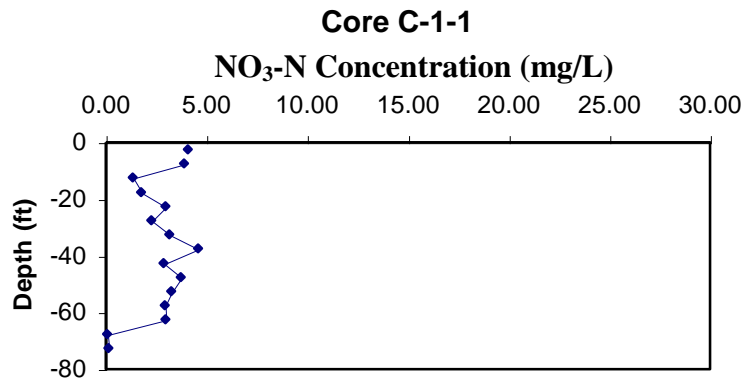
(SW1/4, SW1/4, Sec11, T29N, R5W)

Interval (ft)	Description
0-2	Silt w/ trace fine sand
2-10	Silty, some fine sand
10-15	Sand, medium and gravel
15-20	Sand, fine w/ silt
20-35	Sand, (v.c.) w/ fine gravel
35-42	Coarse silty sand w/fine gravel
42-43	Silty clay w/ sand and gravel
43-50	Clay w/ sand
50-60	Clay w/ silty sand layers

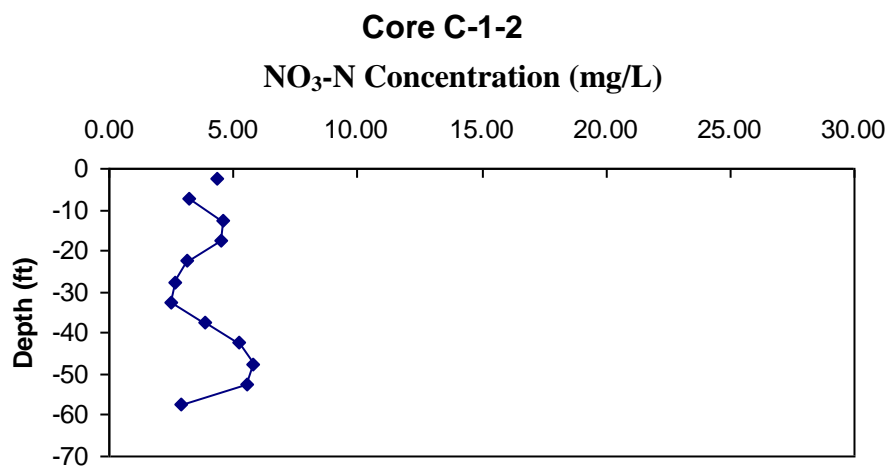
APPENDIX B

Results of Vadose Zone Sediment Analyses

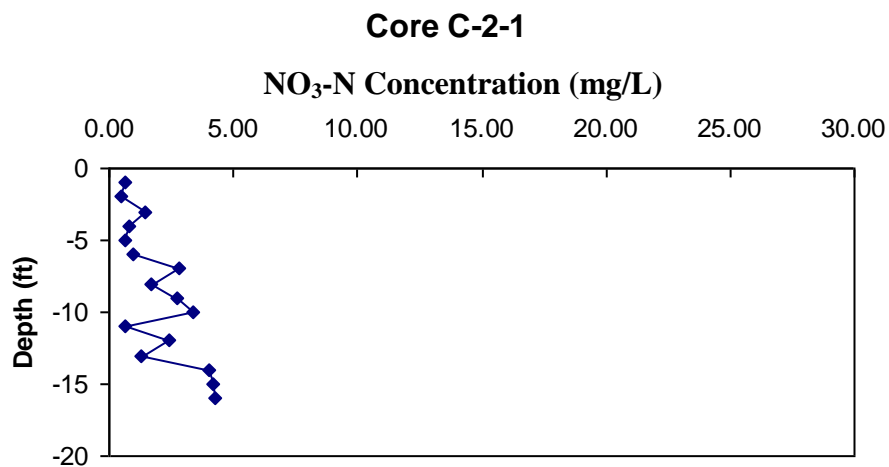
Core C-1-1				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-5	0.08	4.43	4.07	79.76
5-10	0.10	4.17	3.89	74.98
10-15	0.11	1.60	1.34	28.84
15-20	0.13	1.96	1.74	35.20
20-25	0.26	3.08	2.97	55.42
25-30	0.20	2.40	2.26	43.25
30-35	0.16	3.33	3.15	59.91
35-40	0.25	4.71	4.59	84.72
40-45	0.18	3.02	2.86	54.30
45-50	0.17	3.90	3.74	70.21
50-55	0.27	3.35	3.25	60.28
55-60	0.26	3.02	2.91	54.39
60-65	0.20	3.09	2.95	55.70
65-70	0.03	0.63	0.05	11.33
70-75	0.03	0.95	0.13	17.13
Ave. Pore Water NO₃-N below root zone (>5ft)			2.56	
Cumulative Soil NO₃-N below root zone (>5ft)				705.65



Interval (ft)	Moisture Content (g/g)	<u>Core C-1-2</u>		
		Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-5	0.24	4.49	4.37	80.78
5-10	0.26	3.35	3.25	60.38
10-15	0.26	4.67	4.56	83.97
15-20	0.26	4.65	4.54	83.69
20-25	0.19	3.32	3.18	59.81
25-30	0.22	2.80	2.68	50.45
30-35	0.22	2.64	2.51	47.46
35-40	0.20	3.98	3.84	71.70
40-45	0.24	5.32	5.20	95.67
45-50	0.29	5.86	5.76	105.41
50-55	0.19	5.66	5.52	101.94
55-59	0.22	2.99	2.86	53.83
Ave. Pore Water NO₃-N below root zone (>5ft)			3.99	
Cumulative Soil NO₃-N below root zone (>5ft)				814.32
Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-1			3.19	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-1				759.98

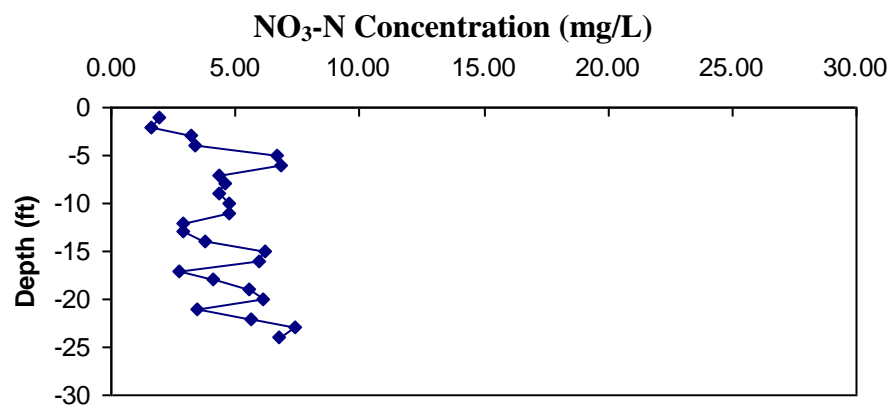


Core C-2-1				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.11	0.94	0.68	3.37
1-2	0.08	0.83	0.47	3.00
2-3	0.19	1.56	1.41	5.62
3-4	0.08	1.14	0.78	4.12
4-5	0.06	1.14	0.67	4.12
5-6	0.14	1.14	0.94	4.12
6-7	0.11	3.12	2.85	11.23
7-8	0.08	2.08	1.71	7.49
8-9	0.32	2.81	2.72	10.11
9-10	0.15	3.54	3.35	12.73
10-11	0.03	1.56	0.66	5.62
11-12	0.13	2.60	2.39	9.36
12-13	0.35	1.35	1.27	4.87
13-14	0.41	4.06	3.99	14.61
14-15	0.27	4.27	4.16	15.35
15-16	0.37	4.37	4.29	15.73
Ave. Pore Water NO₃-N below root zone (>5ft)			2.58	
Cumulative Soil NO₃-N below root zone (>5ft)				111.21

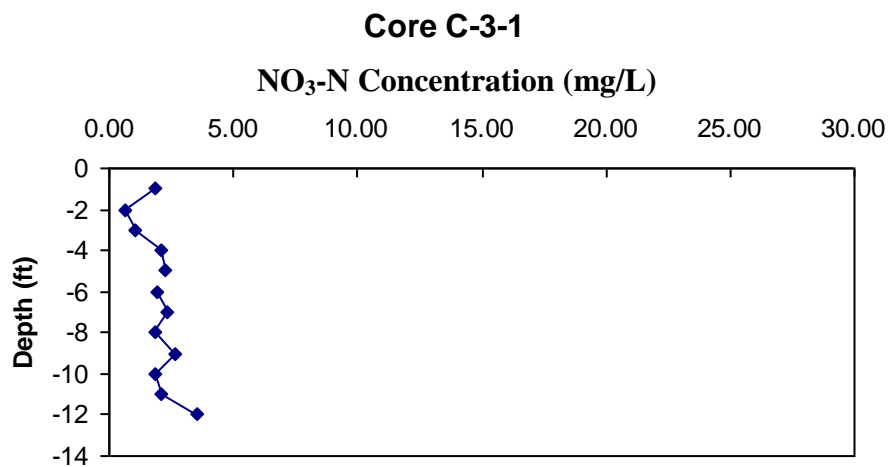


Interval (ft)	Moisture Content (g/g)	<u>Core C-2-2</u>		
		Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.17	2.08	1.91	7.49
1-2	0.19	1.77	1.62	6.37
2-3	0.16	3.43	3.25	12.35
3-4	0.13	3.64	3.42	13.10
4-5	0.19	6.86	6.71	24.70
5-6	0.19	6.97	6.82	25.09
6-7	0.21	4.47	4.34	16.09
7-8	0.24	4.68	4.57	16.85
8-9	0.22	4.47	4.34	16.09
9-10	0.19	4.89	4.75	17.60
10-11	0.11	4.99	4.73	17.96
11-12	0.11	3.12	2.87	11.23
12-13	0.13	3.12	2.90	11.23
13-14	0.26	3.85	3.74	13.86
14-15	0.35	6.24	6.16	22.46
15-16	0.31	6.03	5.94	21.71
16-17	0.30	2.81	2.72	10.11
17-18	0.29	4.16	4.06	14.98
18-19	0.43	5.62	5.55	20.22
19-20	0.31	6.24	6.15	22.47
20-21	0.31	3.54	3.45	12.73
21-22	0.33	5.72	5.64	20.60
22-23	0.38	7.49	7.41	26.96
23-24	0.39	6.87	6.79	24.71
Ave. Pore Water NO₃-N below root zone (>5ft)			4.89	
Cumulative Soil NO₃-N below root zone (>5ft)				342.96
Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-2			4.04	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-2				227.09

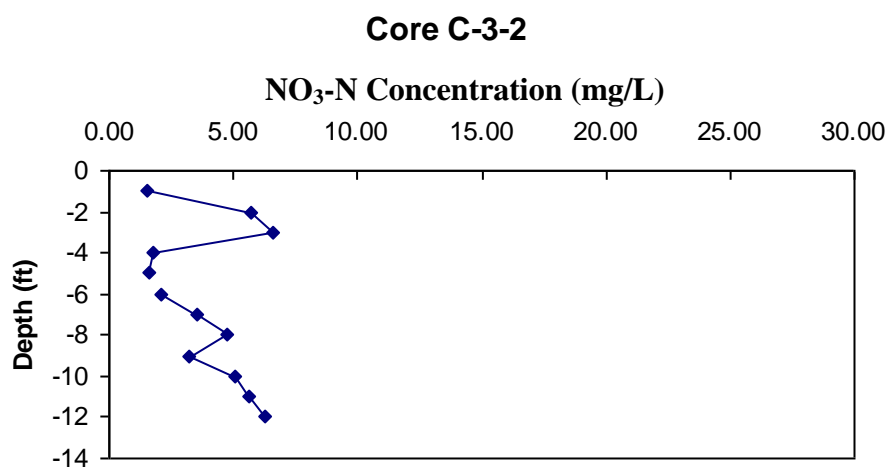
Core C-2-2



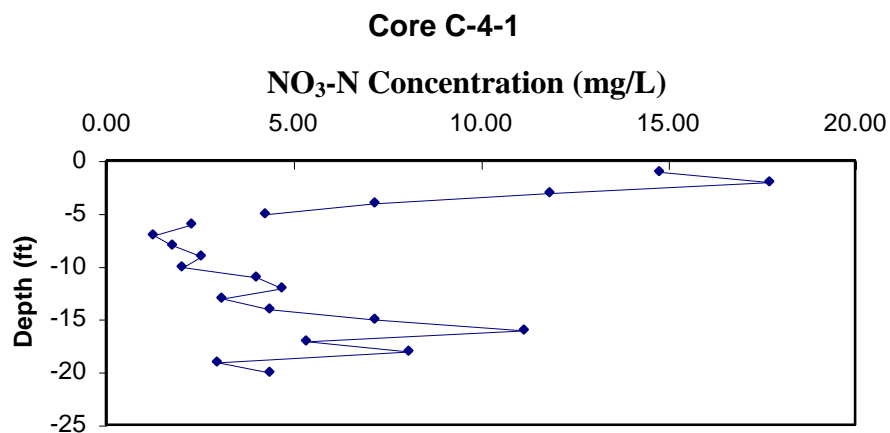
<u>Core C-3-1</u>				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.12	2.08	1.84	7.49
1-2	0.07	1.04	0.64	3.74
2-3	0.07	1.46	1.05	5.26
3-4	0.09	2.39	2.09	8.60
4-5	0.09	2.60	2.27	9.36
5-6	0.08	2.29	1.92	8.24
6-7	0.10	2.60	2.33	9.36
7-8	0.10	2.08	1.81	7.49
8-9	0.18	2.80	2.64	10.08
9-10	0.17	1.98	1.82	7.13
10-11	0.15	2.29	2.10	8.24
11-12	0.17	3.74	3.58	13.46
Ave. Pore Water NO₃-N below root zone (>5ft)			2.31	
Cumulative Soil NO₃-N below root zone (>5ft)				64.01



Core C-3-2				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.18	1.66	1.51	5.98
1-2	0.19	5.82	5.67	20.95
2-3	0.16	6.76	6.58	24.34
3-4	0.24	1.87	1.75	6.73
4-5	0.19	1.77	1.62	6.37
5-6	0.17	2.29	2.12	8.24
6-7	0.16	3.74	3.57	13.46
7-8	0.18	4.89	4.73	17.60
8-9	0.20	3.33	3.19	11.99
9-10	0.29	5.20	5.10	18.72
10-11	0.24	5.72	5.60	20.59
11-12	0.19	6.45	6.30	23.22
Ave. Pore Water NO₃-N below root zone (>5ft)			4.38	
Cumulative Soil NO₃-N below root zone (>5ft)				113.83
Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-3			3.34	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-3				88.92

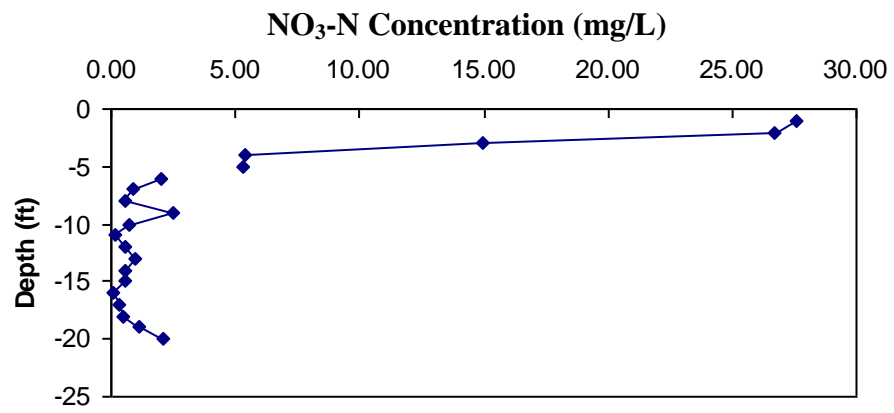


Core C-4-1				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.14	14.98	14.77	53.93
1-2	0.15	17.89	17.70	64.40
2-3	0.06	12.27	11.83	44.17
3-4	0.05	7.70	7.17	27.72
4-5	0.05	4.78	4.24	17.21
5-6	0.04	2.91	2.27	10.48
6-7	0.05	1.87	1.25	6.73
7-8	0.07	2.18	1.76	7.85
8-9	0.05	3.12	2.52	11.23
9-10	0.05	2.60	2.02	9.36
10-11	0.05	4.58	4.01	16.49
11-12	0.07	5.10	4.69	18.36
12-13	0.08	3.43	3.08	12.35
13-14	0.09	4.68	4.35	16.85
14-15	0.14	7.38	7.18	26.57
15-16	0.12	11.38	11.15	40.97
16-17	0.16	5.51	5.33	19.84
17-18	0.19	8.22	8.08	29.59
18-19	0.17	3.12	2.96	11.23
19-20	0.26	4.47	4.36	16.09
Ave. Pore Water NO ₃ -N below root zone (>5ft)			4.33	
Cumulative Soil NO ₃ -N below root zone (>5ft)				253.98

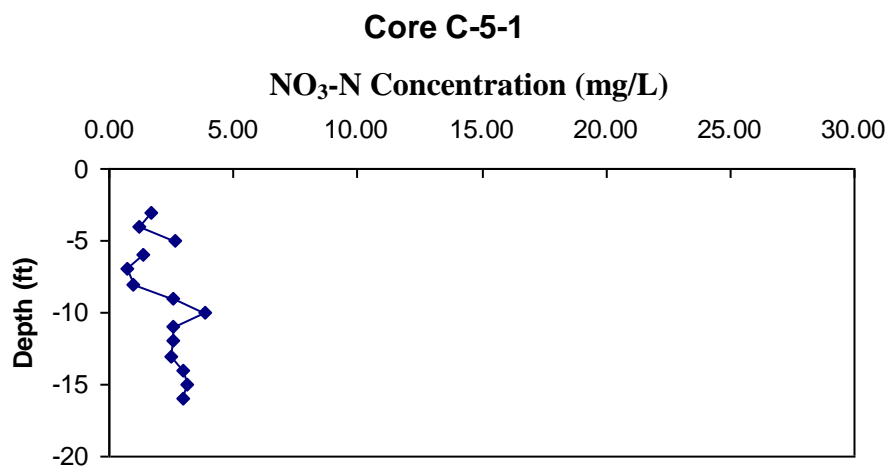


<u>Core C-4-2</u>				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.19	27.77	27.62	99.97
1-2	0.21	26.84	26.71	96.62
2-3	0.21	15.08	14.95	54.29
3-4	0.19	5.51	5.36	19.84
4-5	0.21	5.41	5.28	19.48
5-6	0.12	2.29	2.05	8.24
6-7	0.05	1.46	0.86	5.26
7-8	0.05	1.14	0.60	4.10
8-9	0.05	3.12	2.52	11.23
9-10	0.09	1.04	0.74	3.74
10-11	0.04	0.83	0.13	3.00
11-12	0.10	0.83	0.54	3.00
12-13	0.05	1.56	0.94	5.62
13-14	0.10	0.83	0.55	3.00
14-15	0.16	0.73	0.55	2.62
15-16	0.06	0.52	0.05	1.87
16-17	0.05	0.94	0.35	3.37
17-18	0.06	0.94	0.45	3.37
18-19	0.13	1.35	1.13	4.86
19-20	0.14	2.29	2.09	8.24
Ave. Pore Water NO₃-N below root zone (>5ft)			0.90	
Cumulative Soil NO₃-N below root zone (>5ft)				71.52
Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-4			2.62	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-4				162.75

Core C-4-2

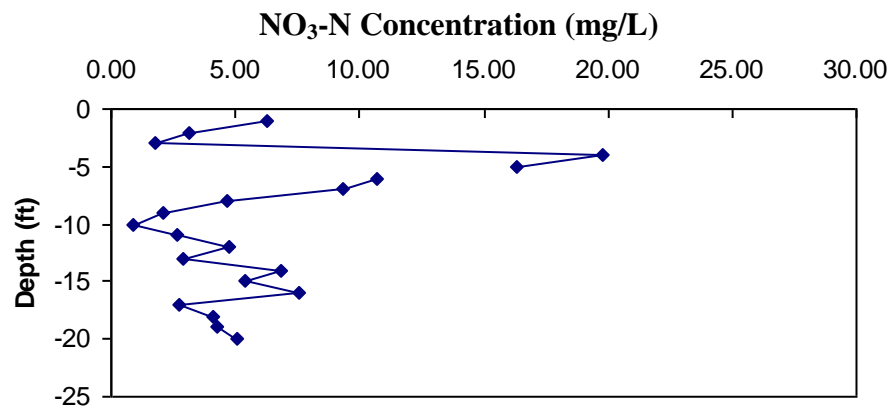


Core C-5-1				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
2-3	0.17	1.87	1.71	6.74
3-4	0.18	1.35	1.20	4.87
4-5	0.19	2.81	2.66	10.11
5-6	0.14	1.56	1.36	5.62
6-7	0.07	1.14	0.73	4.12
7-8	0.10	1.25	0.96	4.49
8-9	0.17	2.70	2.54	9.73
9-10	0.18	4.06	3.90	14.61
10-11	0.22	2.70	2.57	9.73
11-12	0.24	2.70	2.59	9.73
12-13	0.21	2.60	2.47	9.36
13-14	0.21	3.12	2.99	11.23
14-15	0.18	3.33	3.18	11.98
15-16	0.25	3.12	3.01	11.23
Ave. Pore Water NO₃-N below root zone (>5ft)			2.49	
Cumulative Soil NO₃-N below root zone (>5ft)				96.22



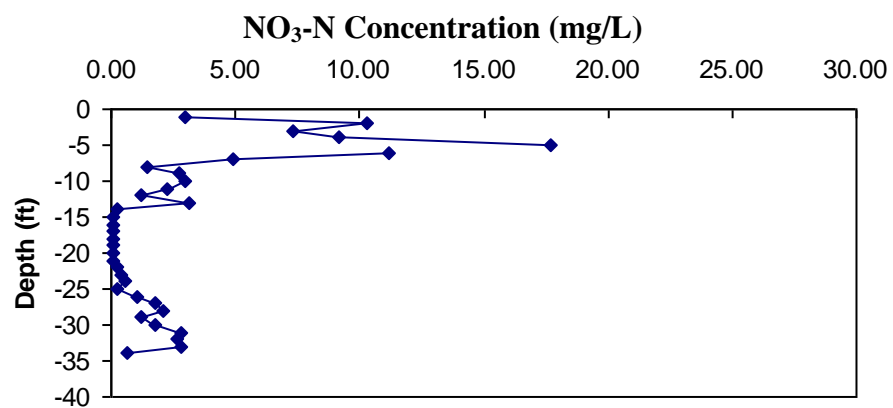
<u>Core C-5-2</u>				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.20	6.45	6.31	23.22
1-2	0.22	3.22	3.10	11.61
2-3	0.34	1.87	1.79	6.74
3-4	0.33	19.87	19.78	71.52
4-5	0.27	16.43	16.33	59.16
5-6	0.25	10.82	10.70	38.94
6-7	0.27	9.47	9.36	34.07
7-8	0.21	4.79	4.65	17.23
8-9	0.07	2.50	2.10	8.99
9-10	0.08	1.25	0.91	4.49
10-11	0.19	2.81	2.66	10.11
11-12	0.18	4.89	4.73	17.60
12-13	0.19	3.02	2.87	10.86
13-14	0.18	6.97	6.81	25.09
14-15	0.27	5.51	5.41	19.85
15-16	0.27	7.70	7.59	27.71
16-17	0.20	2.91	2.77	10.48
17-18	0.43	4.16	4.10	14.98
18-19	0.38	4.37	4.30	15.73
19-20	0.41	5.10	5.03	18.35
Ave. Pore Water NO₃-N below root zone (>5ft)			4.93	
Cumulative Soil NO₃-N below root zone (>5ft)				274.47
Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-5			3.96	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-5				185.35

Core C-5-2



<u>Core C-6-1</u>				
Interval (ft)	Moisture Content (g/g)	Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.10	3.22	2.95	11.61
1-2	0.09	10.61	10.30	38.19
2-3	0.07	7.70	7.31	27.71
3-4	0.07	9.57	9.17	34.45
4-5	0.07	18.15	17.73	65.34
5-6	0.06	11.60	11.15	41.75
6-7	0.09	5.25	4.94	18.91
7-8	0.09	1.77	1.46	6.36
8-9	0.14	2.96	2.77	10.67
9-10	0.14	3.17	2.97	11.42
10-11	0.25	2.34	2.23	8.42
11-12	0.25	1.30	1.19	4.68
12-13	0.26	3.22	3.12	11.61
13-14	0.15	0.42	0.23	1.50
14-15	0.01	0.42	0.05	1.50
15-16	0.04	0.31	0.05	1.12
16-17	0.06	0.10	0.05	0.37
17-18	0.07	0.26	0.05	0.94
18-19	0.09	0.26	0.05	0.94
19-20	0.05	0.26	0.05	0.94
20-21	0.08	0.47	0.11	1.68
21-22	0.13	0.42	0.20	1.50
22-23	0.16	0.59	0.42	2.12
23-24	0.14	0.77	0.57	2.77
24-25	0.18	0.38	0.22	1.37
25-26	0.21	1.21	1.08	4.36
26-27	0.26	1.91	1.81	6.89
27-28	0.26	2.21	2.10	7.94
28-29	0.25	1.28	1.17	4.62
29-30	0.28	1.85	1.74	6.65
30-31	0.26	2.89	2.78	10.41
31-32	0.27	2.72	2.62	9.79
32-33	0.27	2.93	2.82	10.54
33-34	0.08	1.02	0.67	3.69
Ave. Pore Water NO₃-N below root zone (>5ft)			1.68	
Cumulative Soil NO₃-N below root zone (>5ft)				195.46

Core C-6-1

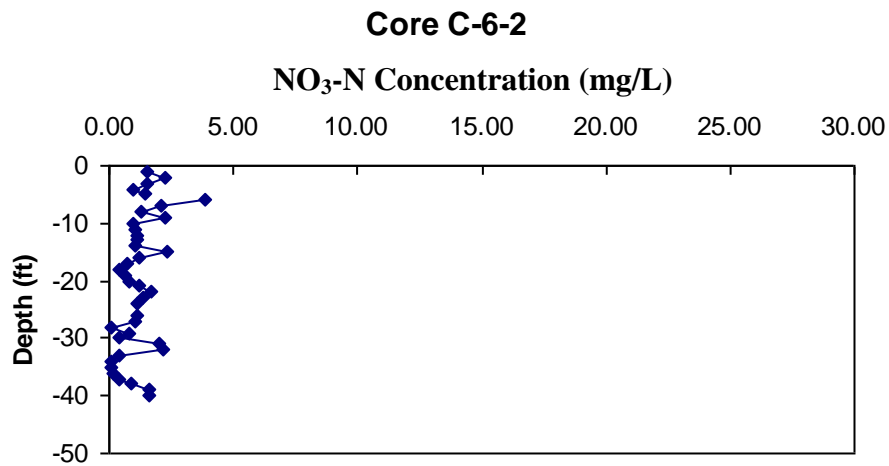


Interval (ft)	Moisture Content (g/g)	<u>Core C-6-2</u>		
		Nitrate-N (ug/g)	Calculated Pore Water NO ₃ -N (mg/L)	Calculated Soil NO ₃ -N (lbs/acre)
0-1	0.07	1.92	1.52	6.91
1-2	0.08	2.56	2.22	9.23
2-3	0.11	1.79	1.54	6.44
3-4	0.10	1.24	0.96	4.46
4-5	0.09	1.74	1.43	6.27
5-6	0.06	4.33	3.89	15.60
6-7	0.07	2.46	2.08	8.86
7-8	0.09	1.62	1.31	5.84
8-9	0.07	2.62	2.23	9.42
9-10	0.10	1.23	0.94	4.42
10-11	0.12	1.27	1.03	4.59
11-12	0.13	1.37	1.15	4.94
12-13	0.10	1.39	1.11	5.02
13-14	0.11	1.27	1.02	4.57
14-15	0.11	2.58	2.32	9.30
15-16	0.11	1.49	1.22	5.36
16-17	0.22	0.85	0.73	3.07
17-18	0.23	0.55	0.43	1.99
18-19	0.22	0.76	0.63	2.73
19-20	0.26	0.92	0.81	3.31
20-21	0.24	1.36	1.24	4.89
21-22	0.26	1.77	1.66	6.36
22-23	0.21	1.52	1.39	5.47
23-24	0.15	1.27	1.09	4.59
25-26	0.20	1.25	1.11	4.51
26-27	0.22	1.19	1.07	4.29
27-28	0.04	0.56	0.05	2.00
28-29	0.20	0.96	0.82	3.45
29-30	0.22	0.57	0.44	2.05
30-31	0.18	2.14	1.98	7.71
31-32	0.30	2.24	2.15	8.07
32-33	0.12	0.67	0.44	2.42
33-34	0.05	0.43	0.05	1.55
34-35	0.04	0.37	0.05	1.35
35-36	0.09	0.50	0.20	1.80
36-37	0.20	0.53	0.38	1.89
37-38	0.15	1.03	0.85	3.71

38-39	0.09	1.92	1.62	6.91
39-40	0.11	1.90	1.64	6.85

Ave. Pore Water NO₃-N below root zone (>5ft)	1.15	
Cumulative Soil NO₃-N below root zone (>5ft)		168.87

Ave. Pore Water NO₃-N below root zone (>5ft) at Site C-6	1.39	
Ave. Cumulative Soil NO₃-N below root zone (>5ft) at Site C-6		182.16



APPENDIX C

Results of Pesticide Analyses

APPENDIX D

Results of Anion Analyses