Impact of Animal Waste Lagoons on Ground Water Quality

Section 319, Clean Water Act
Grant Year, FY 94
Final Report

Division of Water Quality, Groundwater Section
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Executive Summary

The objective of the North Carolina Division of Water Quality's study on the "Impact of Animal Waste Lagoons on Ground Water Quality" is to determine whether federal construction standards used by North Carolina regulatory agencies for animal waste management lagoons offer adequate ground water protection.

Funded by the Environmental Protection Agency in 1994, the study reviews building requirements that the U.S. Natural Resources and Conservation Service uses for new waste lagoons. The EPA provided $94,500 in funding for the research.

DWQ's Groundwater Section evaluated 11 sites during this study, of which nine were hog farms and two were dairy operations. Results from a 12th site were not considered valid because the monitoring wells needed to be located further downstream to better reflect potential effects.

Vulnerability criteria were used to assess potential ground water contamination. Five of the farms were considered to be "less vulnerable," four were deemed "moderately vulnerable" and two were viewed as "vulnerable."

Of the five less vulnerable sites, none of the downgradient shallow monitoring wells that the Division installed revealed any seepage problems from the lagoons. Wells at three of the four moderately vulnerable farms showed an increasing trend in concentrations of one or more lagoon seepage indicators, such as nitrates and chlorides.

Wells at one of the two vulnerable sites revealed lagoon seepage contamination from ammonia, potassium and nitrates.

Only limited conclusions can be drawn from this study because a larger sampling group is needed and sufficient time must be allowed for ground water movement beneath lagoons to the monitoring wells.

The Groundwater Section has since acquired $50,000 additional funding from EPA to continue monitoring at the 11 sites. Study results are expected in 2001.

Introduction

Historical Background

Since 1992, North Carolina has experienced tremendous expansion in the animal production industry. Intensive livestock operations have been built primarily in the Coastal Plain region, with swine facilities growing at the fastest and largest pace.

North Carolina ranks second in the United States behind Iowa in the total number of swine, with 9.6 million hogs on farms as of March 1, 1998. The state had about 2.5 million hogs in 1990. Turkey production was at 53.5 million birds for 1997 -- first in the nation, and broiler production ranked fifth with 665 million chickens produced.

Rapid growth in the livestock and poultry industries basically outpaced the ability of sufficient regulatory oversight.

Technical assistance was and continues to be provided by agencies such as the NRCS and the N.C. Division of Soil and Water Conservation. However, prior to 1997 inspections of intensive livestock and poultry operations were typically in response to citizen complaints about potential problems.

That inspection practice changed with adoption of Senate Bill 1217 in 1996. This legislation has required annual inspections since Jan. 1, 1997 by both DWQ and the Division of Soil and Water Conservation. Both agencies received additional staffing and resources to carry out the legislative mandate.

Conventional technology for animal waste management statewide involves anaerobic lagoons and land application of waste for crop fertilization. Large swine operations have 250 or more head that are typically confined within buildings. Waste is collected beneath slotted floors and recycled water is used to flush it out to pipes that lead to lagoons. These liquid waste lagoons are periodically pumped down to allow land application of waste at agronomic rates.

Literature Review

The literature review for this report included a thorough search for similar studies conducted both in North Carolina and out of state.

Since the 1970s, researchers have recognized the potential for animal waste management practices to impact ground water quality. Findings have been mixed, however.

In a number of investigations conducted in the 1970s and early 1980s, researchers concluded that anaerobic lagoons seal themselves. The authors speculated that sealing occurs by the actions of biological activity and/or physical clogging of the soils and sediments over a period of time, usually within six months.

Several investigators, though, found that some soils and sediments -- coarser textured mostly -- did not completely seal and allowed lagoon seepage at a high enough rate to contaminate ground water. Because of the unpredictable and site specific nature of such contamination, it is often not possible to adequately assess potential contamination without surveying a large number of lagoons or animal confinement areas.

Staff found four papers that summarized North Carolina studies on animal waste lagoons and ground water quality. A brief summary of the findings of each of these investigations is included in the annotated bibliography section of this report.

Principal investigators on these four studies were Dr. R.L. Huffman and Dr. P.W. Westerman of N.C. State University's Department of Biological and Agricultural Engineering.

These studies relied primarily on electromagnetic ground conductivity survey technology for lagoon seepage detection. Just one of these papers included limited ground water quality data collected from monitoring wells over about a one-year period.

The results of these investigations indicated that the potential exists for lagoon seepage to contaminate ground water. Risk of seepage is greater where coarse textured sediments dominate the construction materials and a compacted liner is not present.

Currently, another study is in the final stages and is looking into the ground water impact of older lagoons constructed prior to 1993. Dr. Huffman is conducting this state-funded research using direct push or "Hydropunch" technology for a one-time sampling of ground water quality, rather than time-series data collected from monitoring wells.

According to the principal investigator, pending results from this study are similar to his earlier findings. Further details were not available at the time of writing this DWQ report and must be obtained directly from Dr. Huffman. Study results should be available by the end of 1998.

Regulatory Perspective

Amendments to the state's non-discharge rules for "Waste Not Discharged to Surface Waters" became effective in February 1993, and placed responsibility to obtain permits on animal waste operations that exceed certain thresholds for number of animals. Animal thresholds include 250 total hogs, 100 cattle, 1,000 sheep, 75 horses or 30,000 poultry with liquid waste systems.

These rules were developed as a "deemed permitted" approach with requirements that proper waste management controls, such as lagoons, meet minimum standards and specifications set by the U.S. Natural Resources and Conservation Service (NRCS).

The NRCS standards require that when rapid self-sealing is not probable, special considerations must be considered, including mechanical treatment, lining or other techniques.

A 1-foot compacted clay liner or equivalent is required in problem soils -- sandy, gravelly or silty, as classified according to the Unified Soil Classification System. Technical specialists make the determinations during on-site soil investigations as to whether a liner is needed.

If an investigation reveals that soils and sediments are sufficient, compaction is not required. Where practical, however, the side slopes and lagoon bottom should be uniform and compacted with a "sheepsfoot" roller.

No standard exists for separation distance between the bottom of a lagoon and the water table. For soils in high water tables, though, temporary storage must be above the seasonal high water table.

Technical specialists were not required to be present during construction by the 1993 standards; however, they had to sign the waste management plan verifying that the lagoon was built according to NRCS standards.

In the aftermath of several major lagoon spills and failures in 1995 and 1996, public concern prompted the Governor and the General Assembly to evaluate North Carolina's approach to regulatory oversight of the animal industry. A Blue Ribbon Study Commission on Agriculture Waste was formed to review the program and make needed recommendations to ensure an environmentally safe and economically viable industry.

Recommendations from the Commission along with that from other interests became the basis for S.B. 1217, a more comprehensive animal waste management law.

A primary component of this legislation was establishment of a program whereby farm operators would be issued permits containing explicit conditions and operational requirements necessary to protect water quality. In addition, NRCS standards for lagoon construction were amended in 1996 and included additional requirements for a lagoon to receive certification..

Readers of this study should consult the NRCS directly for the most recent details on lagoon construction standards. Ground water monitoring generally is not required as a permit condition.

Project Scope

In response to concerns about the impact of animal waste lagoons on ground water, DWQ proposed to use Federal Section 319 funding from the Clean Water Act in the fall of 1993 to support a Groundwater Section research effort.

The research was proposed to determine if standards for construction of new animal waste lagoons are adequate to prevent ground water contamination.

At the time of 1993 State animal waste rules adoption, there was no data available to DWQ as to whether the NRCS standards were sufficient to prevent adverse impact to ground water. The EPA granted $94,000 in funding in October 1994 to perform the proposed study.

Project Objective

The study's objective was to determine if the NRCS animal waste lagoon construction standards for 1993 are adequate to protect ground water quality.

Design criteria of waste storage facilities include consideration of waste seepage rates through lagoon bottoms into receiving ground waters.

The bottom of the lagoon or the constructed liner, if necessary, are built to limit the seepage rate. This is intended to allow the subsurface area downgradient from the lagoon to properly treat the waste and not permit the contamination to move farther from the lagoon.

Methods and Materials

Site Selection

Study sites were targeted in hydrogeologically vulnerable areas of nutrient sensitive river basins in the Coastal Plain of North Carolina. Hydrogeologic conditions that contribute to higher ground water vulnerability to contamination from animal waste lagoon seepage theoretically occur where:

1. The separation distance between the lagoon bottom and the seasonal high water table is not sufficient to treat the wastewater, assuming some rate of lagoon seepage;
2. Coarse grained soils and sediments exist above the first significant clay layer in the subsurface; and
3. Clay layers in the surficial aquifer are discontinuous and inter-bedded with coarse grained material.

Potential cooperators were solicited to participate in the project. Wells were installed at two dairy farms and at 10 swine operations. Selection criteria used for these sites was first to determine if it was possible to install monitoring wells down-gradient from the lagoon without potential impact from spray irrigation activities or other sources of nutrients in ground water. And, second, to determine if drilling equipment could access the site to install the wells.

The 12 sites included two dairy farms in the Piedmont, two swine operations in the Sandhills and eight swine operations in the Coastal Plain. The two dairy farms have been in operation for more than 20 years. Both of the dairy lagoons monitored for this study, however, were constructed so that they met the 1993 construction criteria defined in the NRCS guidelines. The 10 swine farms had lagoons that were constructed after January 1994 and were certified to meet the NCRS criteria. Six of the lagoons were constructed on previously undisturbed land.

All lagoons in the study were constructed with natural liner material. On one site, the fine textured material used for the liner had to be transported to the farm because there was no suitable liner material available on the property.

Well Construction

Monitoring wells were installed down-gradient from the lagoon at each of the 12 cooperator sites. In the State's ground water quality rules, 15A NCAC, Subchapter 2L, Classifications and Water Quality Standards Applicable To the Groundwaters of North Carolina, ground water protection boundaries are established for all permitted non-discharge waste disposal systems. A review boundary is defined in the rules as the distance from the waste source to where monitoring for early warning of potential ground water quality impairment is required. A compliance boundary is defined in the rules as the distance from the waste source to where ground water quality standards must be met.

For this project, four wells were installed at each site in the shallow aquifer most likely to be affected by lagoon seepage, two at approximately 125 feet (review boundary) and two at 250 feet (compliance boundary). A deeper well was also installed at each site to assess the quality of older, deeper ground water. Typically the deeper wells were screened below the first significant clay layer.

One well was constructed up-gradient in the shallow aquifer at each site to determine background ground water quality.

Because time and resources available for this study were limited, there was no opportunity for subsurface site investigation activities prior to siting and construction of the monitoring wells. The placement of the wells was based on surface topography. All wells were installed by July 1996.

Monitoring wells were installed according to the State's well construction regulations and the well construction QA/QC (quality assurance/quality control) procedures in the EPA Region IV approved Standard Operating Procedures Manual. Each of the wells was constructed using a drill rig with hollow stem augers. A continuous sampler was used to collect subsurface samples as the borehole was drilled to accurately log stratigraphic information. The wells were constructed with 2 inch PVC well screen and casing.

After each well was completed, a steel cover with locking cap was placed over the casing. Concrete grout was then used to seal around the well at the ground surface down to a depth of two feet.

Electromagnetic Ground Conductivity Surveying

In an attempt to detect underground lagoon seepage, Groundwater Section staff conducted electromagnetic ground conductivity surveys at each of the sites with a Geonics model EM 31 meter. An EM meter is a device that emits electromagnetic waves from an emitter coil. Electrically conductive material within 7 meters of the coil will conduct the EM waves and emit a secondary magnetic field. A receiver coil placed 3.66 meters from the emitter coil picks up secondary currents and deflects a needle on the instrument in proportion to the magnitude of current received.

The more conductive the material, the more the needle is deflected. The EM meter is similar to a metal detector, but it is considerably more sensitive. The readings from an EM 31 are a result of the conductance of material from the surface to a depth of 7 meters.

Due to differing electrical conductance of naturally occurring materials, the EM can also assist in mapping geologic of formations, soil types and faults. The meter can be used to search for any type of electrically conductive liquid underground, such as salt water or polluted ground water. Waste lagoon liquid is more conductive than typical ground water by a factor as much as 80.

The meter cannot be used to search for lagoon seepage effectively at every site. Several conditions can affect the reliability of an EM survey including large natural variations in conductivity based on subsurface deposits of clay (which can be highly conductive), buried trash pits, buried pipes and cables, overhead powerlines and either variations in surface topography or variations in elevation of highly conductive subsurface materials. Some sites have rolling surface topography or abrupt and patchy soil changes that cause wide fluctuations of the EM reading.

Separation of ground water conductance from soil conductance can be difficult because the EM meter reading is a combination of ground water conductivity, soil conductivity and distance of the conductive materials below the surface. The conductance of sandy soil is extremely low, but clay soils can be more electrically conductive than waste lagoon liquid.

Successful detection of waste lagoon seepage is determined by site conditions, and by the experience of the EM operators and their familiarity with the subsurface conditions of the site. Repeated surveys over a period of months or years can be used to detect waste lagoon seepage by mapping changes in terrain conductivity.

Typically, the exact reading of the meter is not as important as sudden changes in its readings. Sudden changes indicate distinct variations in subsurface conductivity. An experienced operator can use the EM to determine the shape, size, depth and strength of an area which exhibits different readings than surrounding material.

Studies have shown that careful mapping of depths and occurrences of soil layers and various soil physical and chemical parameters can be employed to filter out the parts of the signal contributed by the soil (Zheng, 1994). The remaining part of the signal is an accurate estimate of ground water conductance. The collection and evaluation of detailed soils and subsurface sediment information may have increased the sensitivity of the survey and made seepage detection more precise, but were beyond the scope of the project.

Ground Water Sampling

Staff hydrogeologists and/or technicians conducted the sampling for this study. They were trained in EPA and DWQ Groundwater Section QA/QC techniques for ground water measurements and sample collection before the project began. An electric tape or a conductivity meter was used to measure the water level in the well. To ensure a sample was collected from the formation, a standard three volume purge to remove standing water in the well was performed prior to sampling. The purge volume was determined using the following equation:

$$V3 = 3 \times (0.041 \times D^2 \times h)$$

where V3 = amount of water in three well volumes in gallons,
D = well diameter in inches, and
h = height of the water column in the well in feet.

The ground water was removed from the well using a disposable bailer or a small plastic submersible impeller pump. If the pump was used for purging and sampling it was thoroughly cleaned between each well with soap and water and diluted chlorine bleach.

After purging, six 473-milliliter sample bottles were filled for analysis of nutrients, chloride, metals, physical parameters, and sulfate. Two bottles for total and fecal coliform analysis were also collected. All bottles were placed in sealable plastic bags and then placed in a cooler filled with ice. Samples were delivered to the DWQ Laboratory in Raleigh within specified holding times for analysis with appropriate sample identification labels and Field/Lab forms.

Laboratory Methods

The EPA certified DWQ Laboratory followed accepted EPA QA/QC laboratory methods for sample storage, handling and analysis. The standard EPA methods used for the constituents analyzed in this study are listed below:

Ammonia (NH_3-N)	- Colorimetric, Automated Phenate Method (EPA Method 350.1)
Arsenic (As)	- Atomic Absorption, furnace technique (EPA Method 206.2)
Calcium (Ca)	- Inductively Coupled Plasma (ICP) method (EPA Method 200.7)
Copper (Cu)	- Atomic Absorption furnace technique (EPA Method 220.2)

Coliform, Fecal	- Direct Membrane Filter Method (EPA ? 600)
Coliform, Total	- Single-Step Membrane Filter Method (EPA ? 600)
Chloride	- Mercuric Nitrate Method (EPA Method 325.3)
Solids, Dissolved	- Gravimetric Method (EPA Method 160.1)
Iron (Fe)	- Inductively Coupled Plasma (ICP) (EPA Method 200.7)
Magnesium (Mg)	- Inductively Coupled Plasma (ICP)(EPA Method 200.7)
Manganese (Mn)	- Inductively Coupled Plasma (ICP) (EPA Method 200.7)
Nitrogen,	
Total Kjeldahl (TKN)	- Colorimetric, Automated Phenate Method (EPA Method 351.1)
Nitrate/Nitrite (NO_3-N/NO_2-N)	- Colorimetric, Automated, Cadmium Reduction Method (EPA Method 353.2)
Potassium (K)	- Inductively Coupled Plasma (ICP) (EPA Method 200.7)
Phosphorous Total (P)	- Colorimetric, Automated, Ascorbic Acid Method (EPA Method 365.1)
pH	- Electrometric Method (EPA Method 150.1)
Phosphate Ortho- (PO_4)	- Colorimetric, Automated, Ascorbic Acid Method (EPA Method 365.1)
Sodium (Na)	- Inductively Coupled Plasma (ICP)(EPA Method 200.7)
Specific Conductance	- EPA Method 120.1
Sulfate (SO_4)	- Turbidimetric Method (EPA Method 375.4)
Zinc (Zn)	- Inductively Coupled Plasma (ICP) method (EPA Method 200.7).

Demonstration Project Site

The original project proposal included the selection of a Demonstration Project Site that was to be chosen based on theoretical ground water vulnerability. The purpose of the demonstration site was to assess whether criteria for ground water vulnerability could be developed to predict where lagoon seepage would be likely to cause ground water contamination.

The original grant proposal assumed that the project would proceed with cooperation from other investigators, principally N.C. State University, through the use of several animal waste lagoon sites that had been previously studied. The proposal also assumed that sites would be chosen based on vulnerability assessments.

These early project assumptions were not realized due to limitations on the availability appropriate sites. Nevertheless, a site in this study was identified that fitted the original proposal objectives for a demonstration project site and is discussed fully in the results section of this report.

Ground Water Vulnerability Methodology

Study sites were targeted in hydrogeologically vulnerable areas of nutrient sensitive river basins in the Coastal Plain of North Carolina. Hydrogeologic conditions that contribute to higher ground water vulnerability to contamination from animal waste lagoon seepage theoretically occur where:

1. The separation distance between the lagoon bottom and the seasonal high water table is not sufficient to treat the wastewater, assuming some rate of lagoon seepage;
2. Coarse grained soils and sediments exist above the first significant clay layer in the subsurface; and
3. Clay layers in the surficial aquifer are discontinuous and inter-bedded with coarse-grained material.

Predicting what site characteristics will contribute to lagoon seepage cannot be based on soil series primarily because most lagoons are excavated to depths greater than 60 inches below the ground surface. The soil series mapped by the NRCS describe the material found only in the first 60 inches.

One of the most important aspects of ground water vulnerability at waste lagoons is the composition of the material that is found below the base of the lagoon (greater than 60 inches). For instance, if lagoon waste were to seep into a coarse grained sand beneath a lagoon it would travel at a much faster rate than it would if the material was finer grained or had a higher clay content.

Another important aspect of ground water vulnerability is the separation distance between the lagoon bottom and the water table because this separation allows for a subsurface treatment zone if lagoon seepage occurs. Conversely, if the base of a lagoon is below the top of the ground water table, relatively no treatment will occur in the event of lagoon seepage.

Because relatively few sites were included in this study, only limited conclusions concerning vulnerability methodology assessment are practical.

Results and Discussion

Lagoon Sampling and Seepage Indicators

Five swine lagoons were sampled to characterize the waste source for a typical animal operation. The lagoons were randomly chosen and no attempt to exclude dairy farms was intended. Analysis of the samples collected from these lagoons is in Table 1, which can be found on page 13.

Based on the sampling results, as well as results from a few other animal waste lagoons at similar facilities, the best indicators of lagoon seepage were determined. In general, the best indicators of lagoon seepage are the constituents in the waste that occur at the highest concentrations and are mobile in ground water. The nitrogen species, ammonia-nitrogen and organic nitrogen are excellent seepage indicators since they are at high concentrations in the waste. Also, based on monitoring well analysis from this and other studies, the nitrogen species are mobile in ground water.

These nitrogen species however, are subject to biological transformation based on the endemic microbial population and the degree to which oxygen is available. If subsurface conditions are favorable, then the organic nitrogen can be mineralized to ammonia-nitrogen or nitrate-nitrogen. When conditions favor nitrification, then the ammonia-nitrogen would be converted to nitrate-nitrogen.

Chloride, because it is negatively charged, is highly mobile in ground water and is an excellent seepage indicator. Because chloride moves so readily, it can be an early indicator of animal waste lagoon seepage.

Potassium is usually found in high concentrations in animal waste. Animals are apparently not efficient at assimilating potassium and most of it remains in the waste stream. Although potassium is positively charged and thus subject to adsorption on negatively charged clays, it is weakly held and can be displaced readily. Potassium can be quite mobile in relatively coarse textured or sandy subsurface environments.

Table 1. Concentrations of Constituents in the Animal Waste Effluent Stored in Lagoons Sampled During this Study.

Site Name	Date Sampled	Fecal Coliform colonies / 100 ml	Total Coliform Colonies / 100 ml	Cl ppm	SO_4 ppm	NH_3 ppm	TKN ppm	NO_3 Ppm	Total P Ppm	PO_4 ppm	As ug/L	Ca ppm	Cu ug/L	Fe ug/L	K ppm	Mg ppm	Mn ug/L	Na ppm	Zn ug/L
06	6/5/97	12,000	15,000	7	22	450	460	<.01	61	46	<10	11	12	170	48	4.5	28	13	300
07	6/5/97	13,000	19,000	10	26	340	490	<.01	73	45	<10	11	8.4	180	54	5.5	27	11	41
ALB	7/31/97	<100	2,000	230	4	390	390	2.5	22	20	ns	28	2.1	140	410	37	50	130	25
ROB	12/8/97	ns*	Ns	170	7	350	380	0.21	85	48	<10	77	7.2	1,200	400	41	320	110	230
GRA	12/8/97	ns	Ns	300	< 5	650	910	0.02	93	90	<10	61	490	1,400	650	11	ns	130	ns

*ns – not sampled

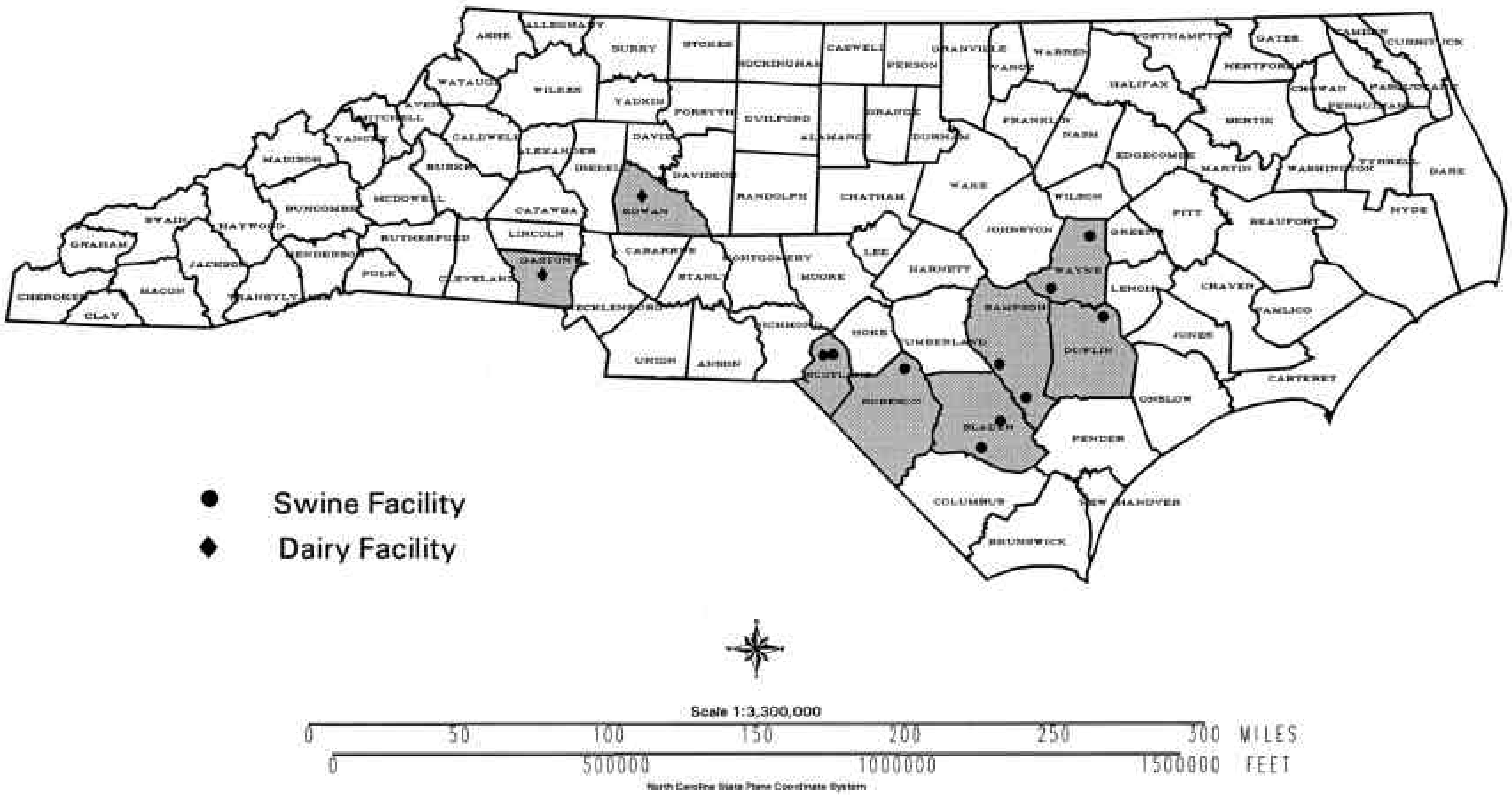
Summary of Results by Site

The results of the sampling analysis for all of the ground water monitoring wells can be found in Table 3 on page 101 and in Table 4 on page 117. A brief discussion of each site begins on page 17 and includes a summary of the results of the monitoring well sampling analysis in time-series graphs and a summary of the EM survey for each of the 12 sites in the study. Additionally, a summary of the evaluation of the site data and an assessment of the vulnerability of ground water to lagoon seepage contamination is included for each site.

All of the time-series monitoring data are presented using the same format. The monitoring wells nearest the lagoon at approximately 125 feet downgradient are shown in red dashed lines using different symbols for each well. The monitoring wells downgradient at approximately 250 feet from the lagoon berm are shown in yellow dashed lines. The deeper well is shown in a green solid line with a symbol and the upgradient well is shown in a blue solid line with a symbol (The lines and symbols are unique for each well if color is not available to the reader). Also for each site in the study a site map and a ‘fence diagram’ showing the stratigraphic data collected is included.

On the following page a state map is shown indicating the locations of all 12 sites included in this study.

Locations of Animal Waste Lagoon Ground Water Monitoring Sites.



Albertson Site (Duplin County)

The Albertson site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped in the area where the lagoon was constructed are fine to medium textured.

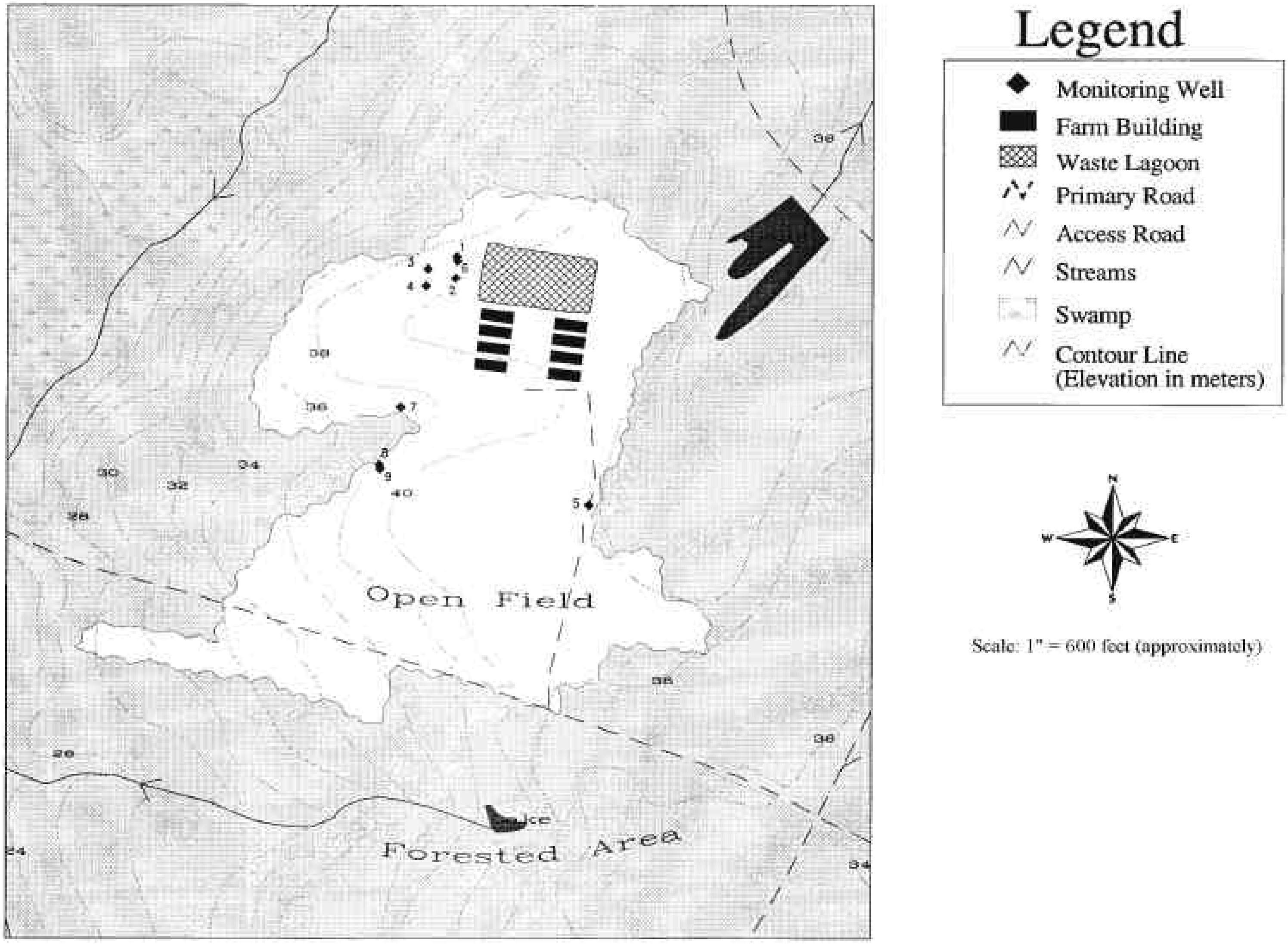
The lagoon was constructed on a nearly flat hilltop. The method of construction was excavation into the subsurface several feet and then building up the berm around the hole using the excavated material. A site map is included on the following page for reference.

This site was previously used for row crop agriculture and no clearing of vegetation was required prior to the conversion to an animal operation. Monitoring well construction was completed in January 1996. Wells were sited on the downgradient side of the lagoon based on topography; however, space for well location was somewhat limited due to the layout of the spray irrigation system.

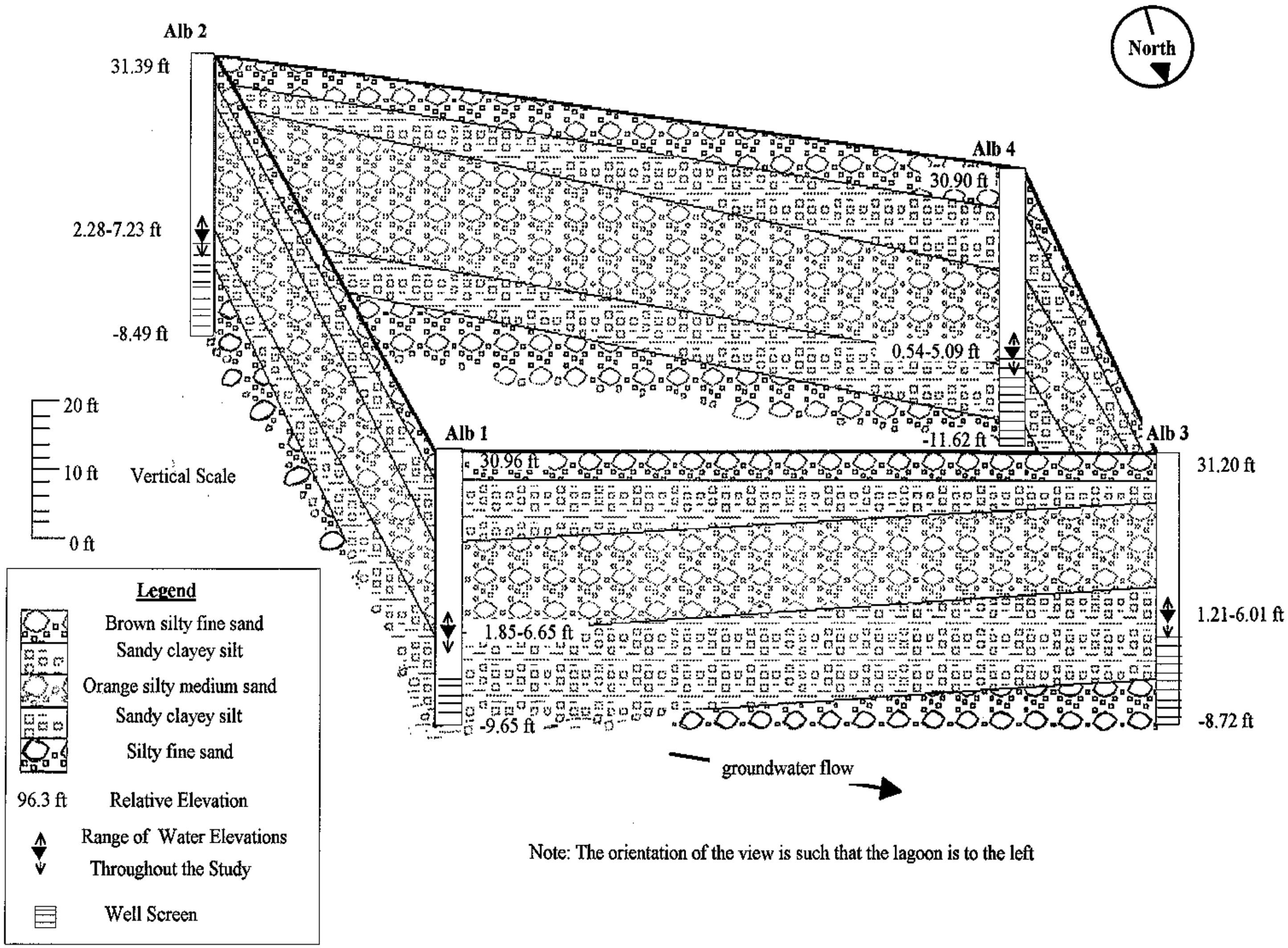
Depths of the top of the well screens ranged from about 13 feet below surface in the upgradient well to 28 to 33 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 26 to 31 feet below the ground surface.

Soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the 'fence diagram' on page 18.

Albertson Site



Borehole Stratigraphy of the Albertson Site in Duplin County



Vertical exaggeration = 1.8:1

Note: The orientation of the view is such that the lagoon is to the left

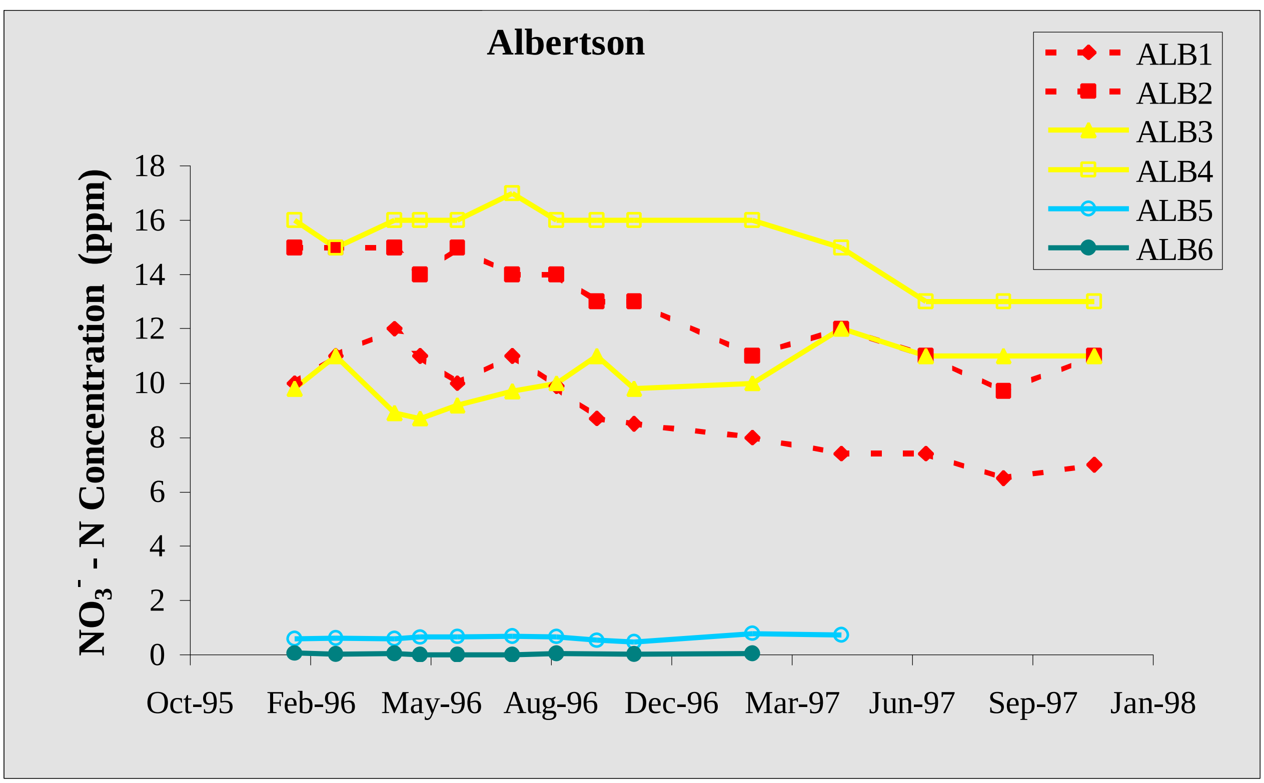
Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 350 feet.

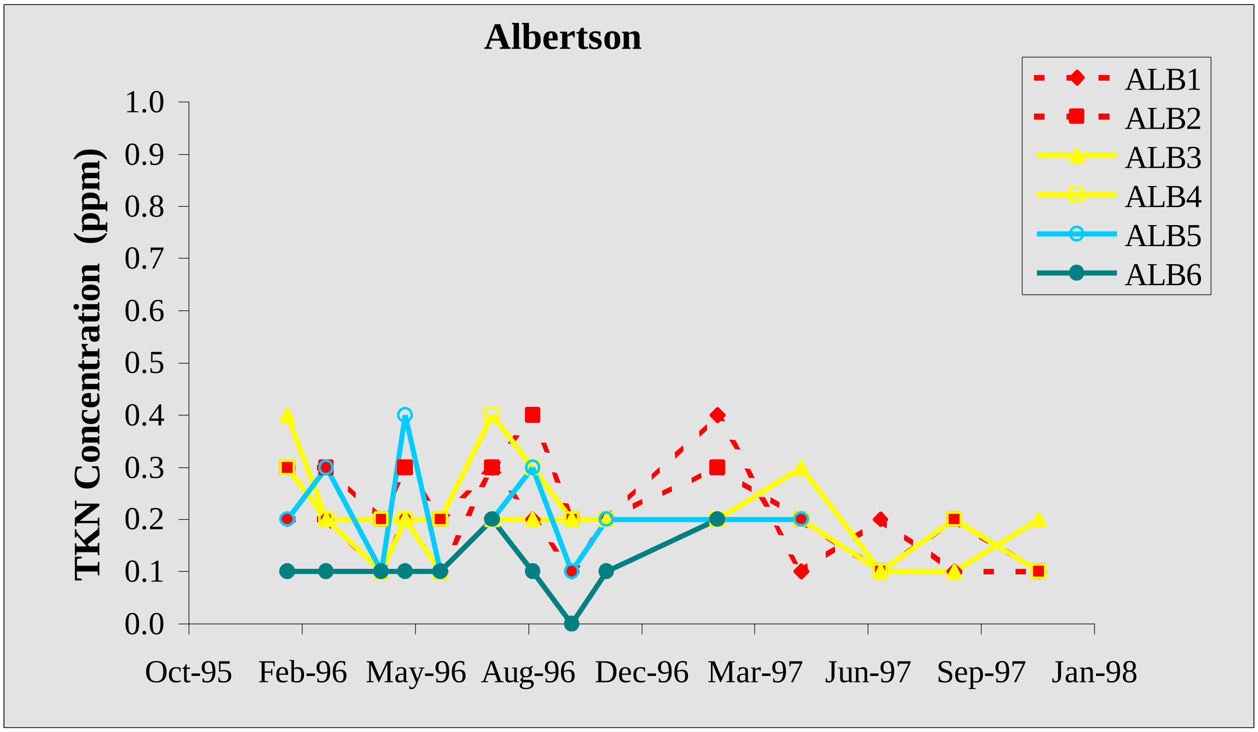
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is likely that the variability of the clay in the subsurface was such that the EM meter was unable to distinguish between higher conductive ground water and more conductive clay sediments.

The separation distance between the lagoon bottom and the water table was estimated to be more than 8 feet. Based on this limited information, the Albertson site would generally be considered to have less potential for lagoon seepage to contaminate ground water.

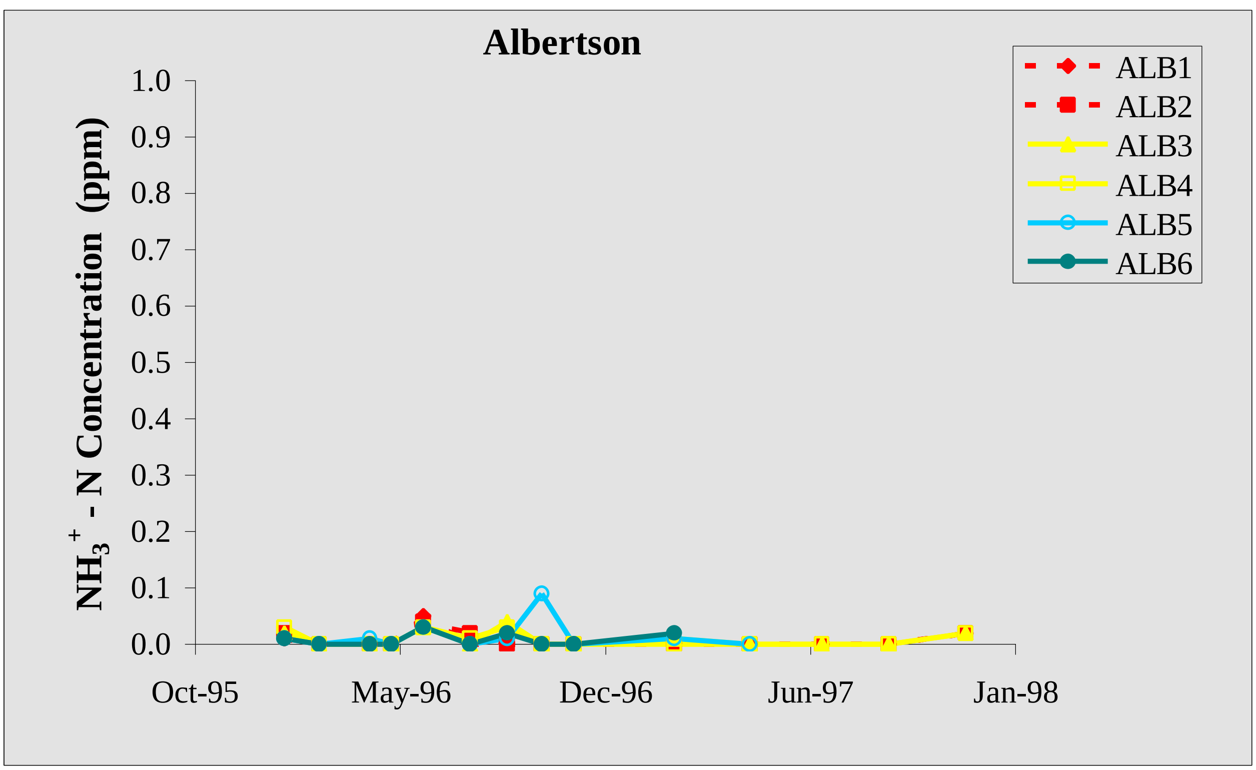
None of the seepage indicators except for nitrate-nitrogen were found in the wells at Albertson at concentrations that indicate lagoon seepage has occurred. The presence of nitrate in ground water at this site appears to be related to previous agricultural activities rather than the lagoon because the concentration levels were relatively consistent from the first sampling event through the first 18 months of the study. Also, no other seepage indicators were present in the ground water samples. In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:

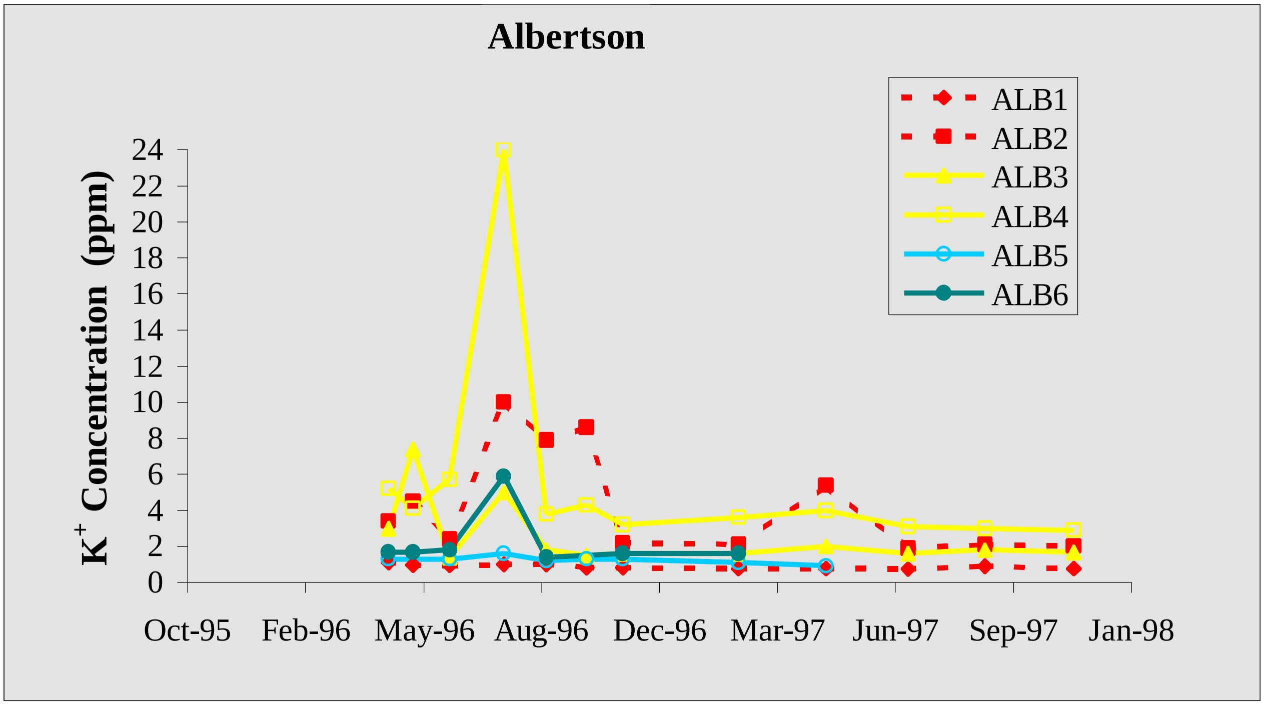


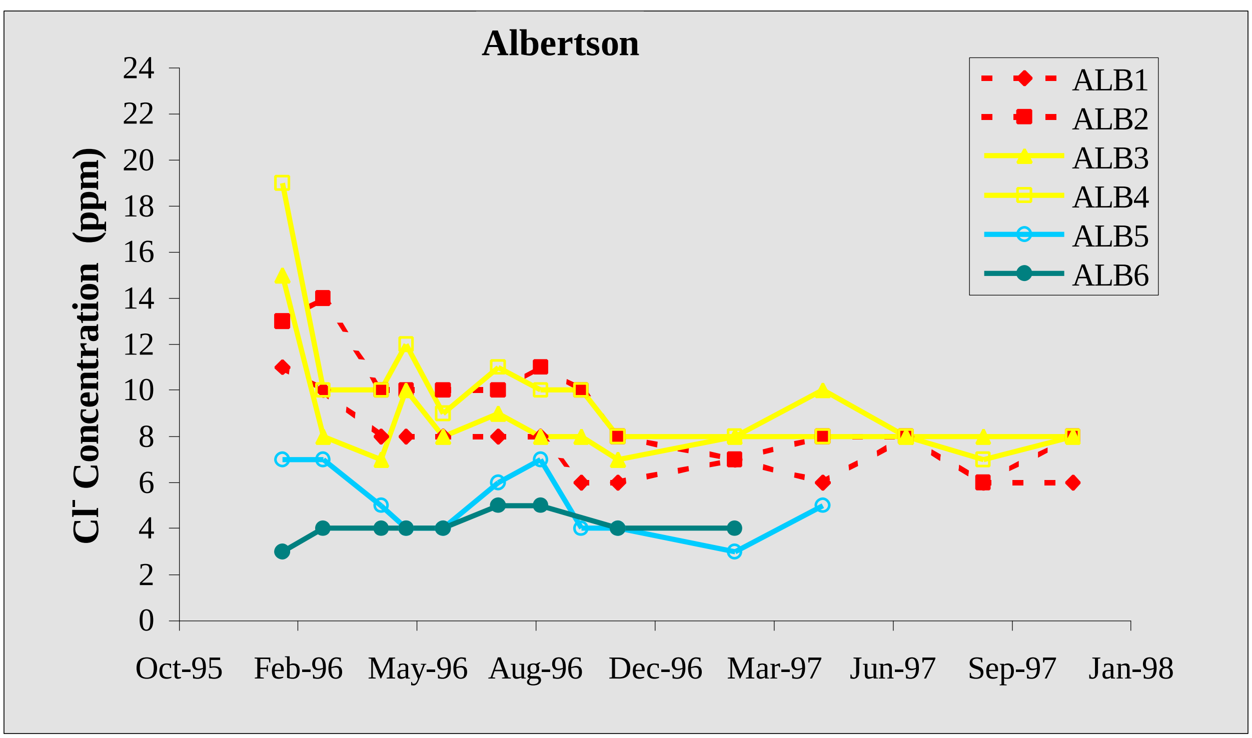


Albertson
TKN Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
ALB1
ALB2
ALB3
ALB4
ALB5
ALB6



Albertson
NH_3^+ - N Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Oct-95
May-96
Dec-96
Jun-97
Jan-98
ALB1
ALB2
ALB3
ALB4
ALB5
ALB6


Albertson
K+ Concentration (ppm)
ALB1
ALB2
ALB3
ALB4
ALB5
ALB6
0
2
4
6
8
10
12
14
16
18
20
22
24
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98


Albertson
Cl- Concentration (ppm)
ALB1
ALB2
ALB3
ALB4
ALB5
ALB6
0
2
4
6
8
10
12
14
16
18
20
22
24
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98

Clarkton Site (Bladen County)

The Clarkton site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are medium to fine textured.

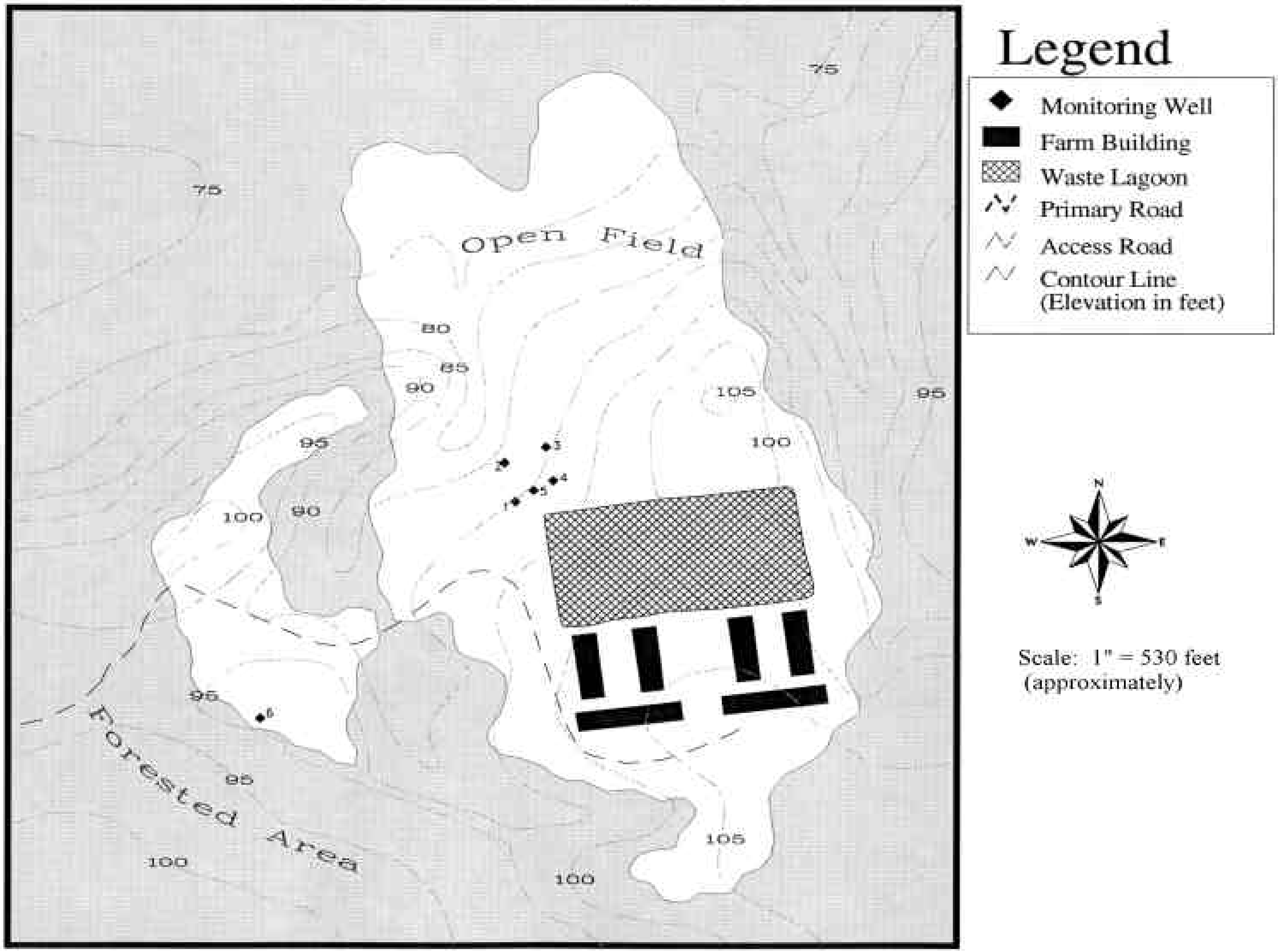
The lagoon was constructed by excavation into the side slope of the topographic high area on the site. The excavated material was used for building the berm around the hole. A map of the site is included on the following page for reference.

A majority of the site was cleared of the existing vegetation, primarily a mixed stand of pine and hardwood. Some of the land was previously used for traditional row crop agriculture. Monitoring well construction was completed in May 1996. Wells were sited on the downgradient side of the lagoon based on topography. At the time of siting of these wells, the cooperator informed us that eventually the area where the wells were located would be used for spray irrigation, but there was not an alternative location available.

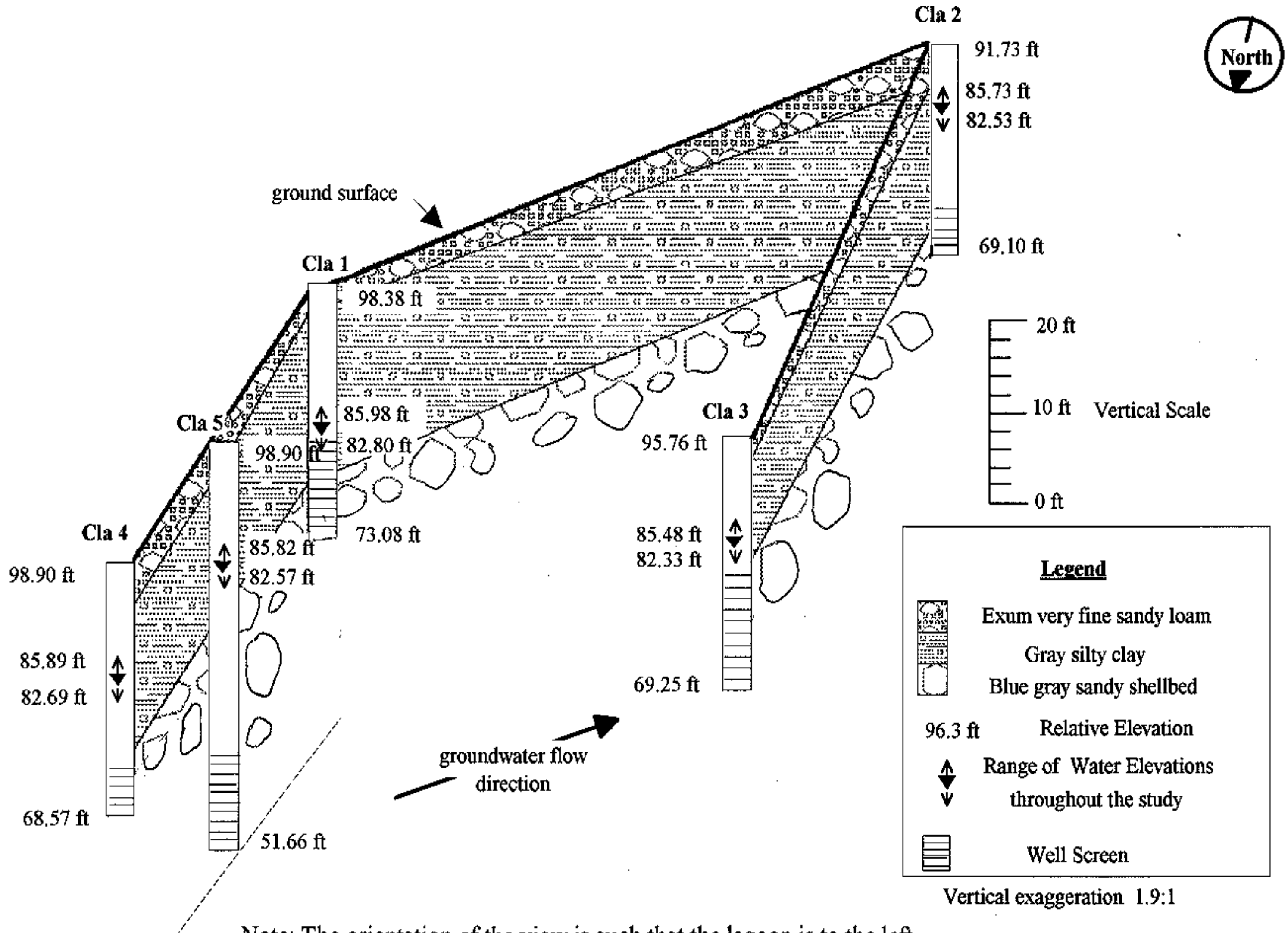
Depths to the top of the well screens ranged from 14 to 22 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 8 to 18 feet below the ground surface during the study.

Soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the 'fence diagram' on page 25.

Clarkton Site



Borehole Stratigraphy of the Clarkton Site in Bladen County



Note: The orientation of the view is such that the lagoon is to the left

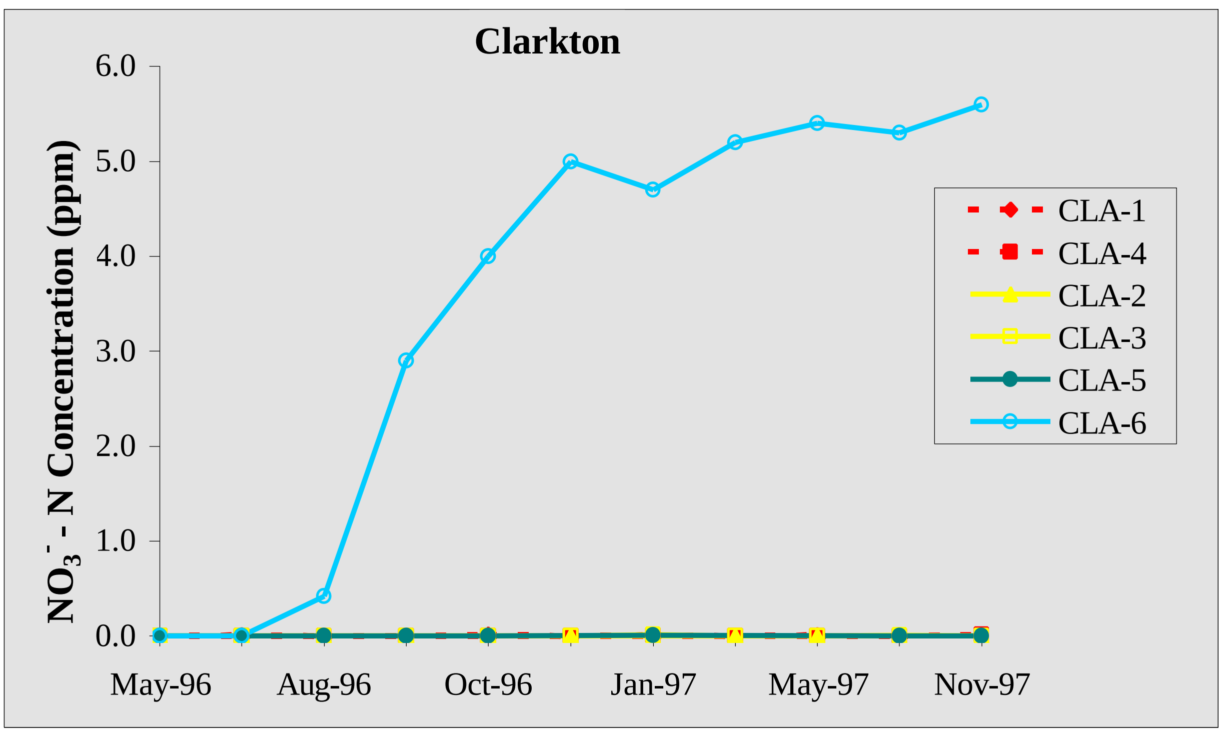
Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 1000 feet.

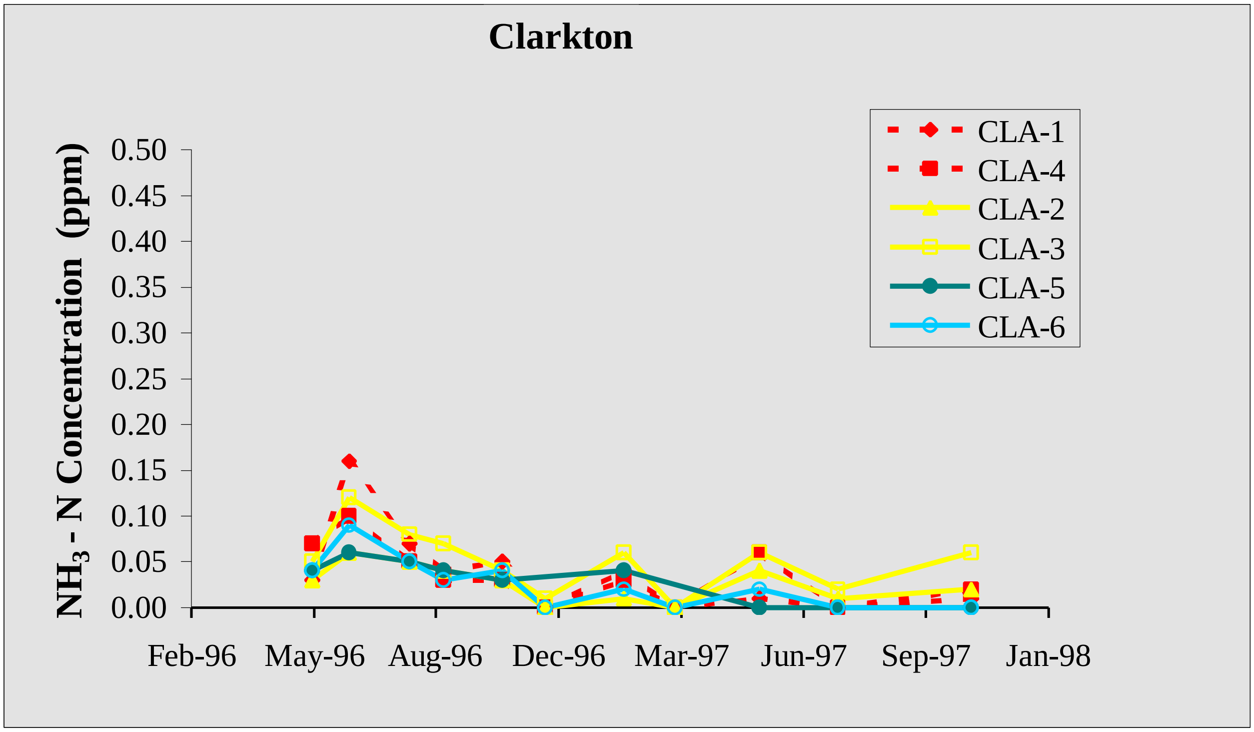
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would indicate ground water contamination. It is likely that the amount of clay in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

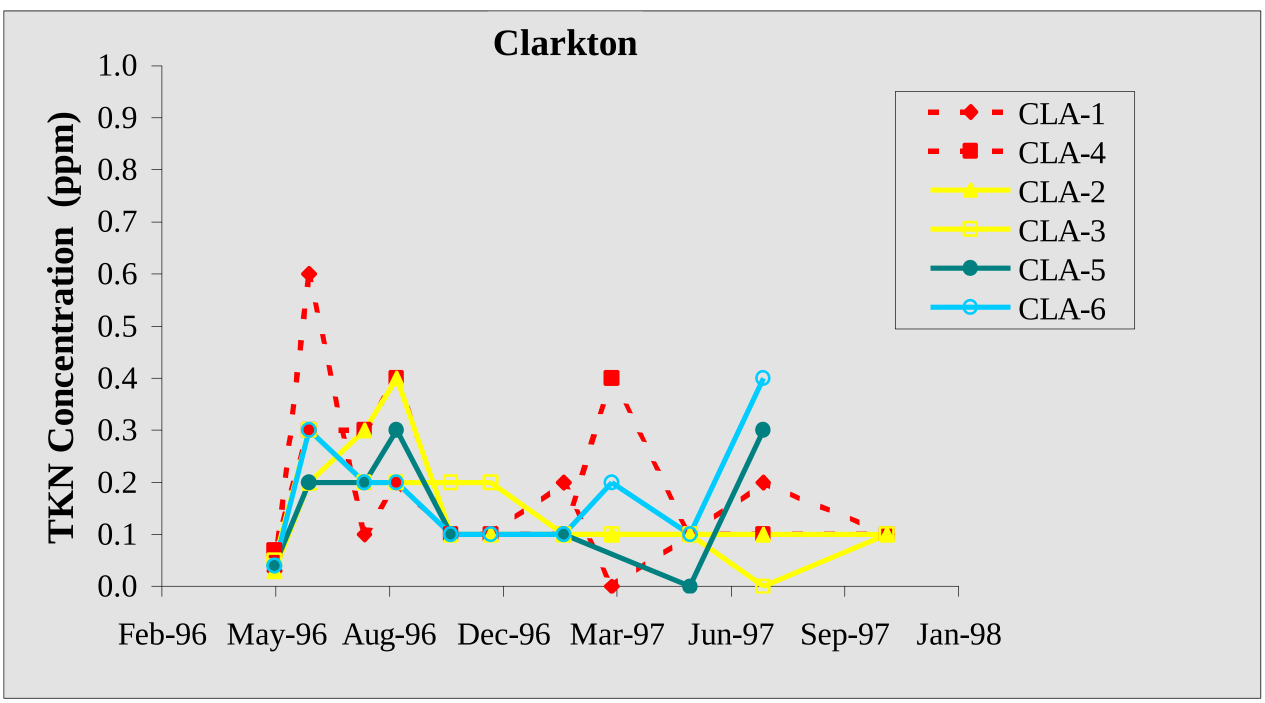
The separation distance between the lagoon bottom and the water table was estimated to be more than 15 feet. A significant clay layer that was 10 to 20 feet thick (see fence diagram) was found in each of the wells. Based on this limited information, the Clarkton site would generally be considered to have less potential for lagoon seepage to contaminate ground water.

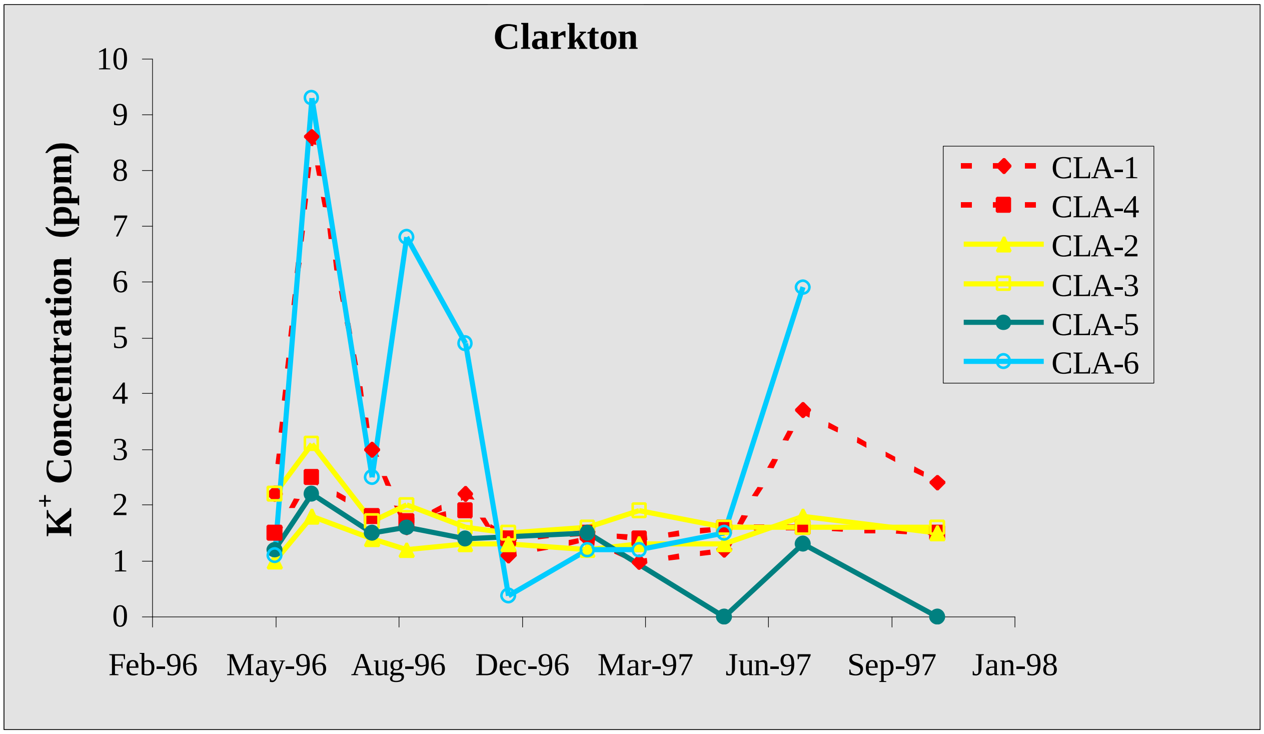
None of the indicators of lagoon seepage were consistently found in the four downgradient wells at Clarkton. The upgradient well, CLA-6, does show an increasing trend of both nitrate-nitrogen and chloride concentrations. These increasing trends may be the result of influence of the spray irrigation practices. This well was sited near spray irrigation activities because there was no other location suitable to the cooperator.

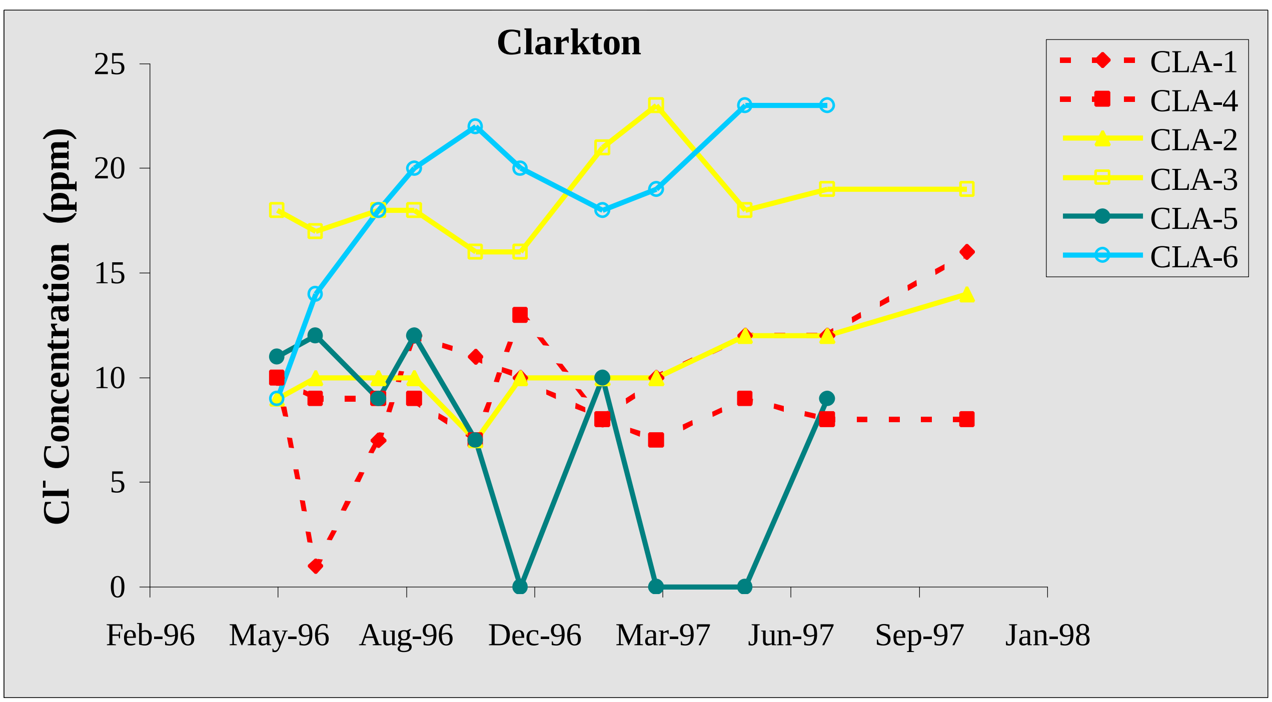
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:




Clarkton
NH3 - N Concentration (ppm)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
CLA-1
CLA-4
CLA-2
CLA-3
CLA-5
CLA-6


Clarkton
TKN Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
CLA-1
CLA-4
CLA-2
CLA-3
CLA-5
CLA-6


Clarkton
K+ Concentration (ppm)
0
1
2
3
4
5
6
7
8
9
10
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
CLA-1
CLA-4
CLA-2
CLA-3
CLA-5
CLA-6


Clarkton
Cl- Concentration (ppm)
0
5
10
15
20
25
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
CLA-1
CLA-4
CLA-2
CLA-3
CLA-5
CLA-6

Lisbon Site (Bladen County)

The Lisbon site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are medium to fine textured.

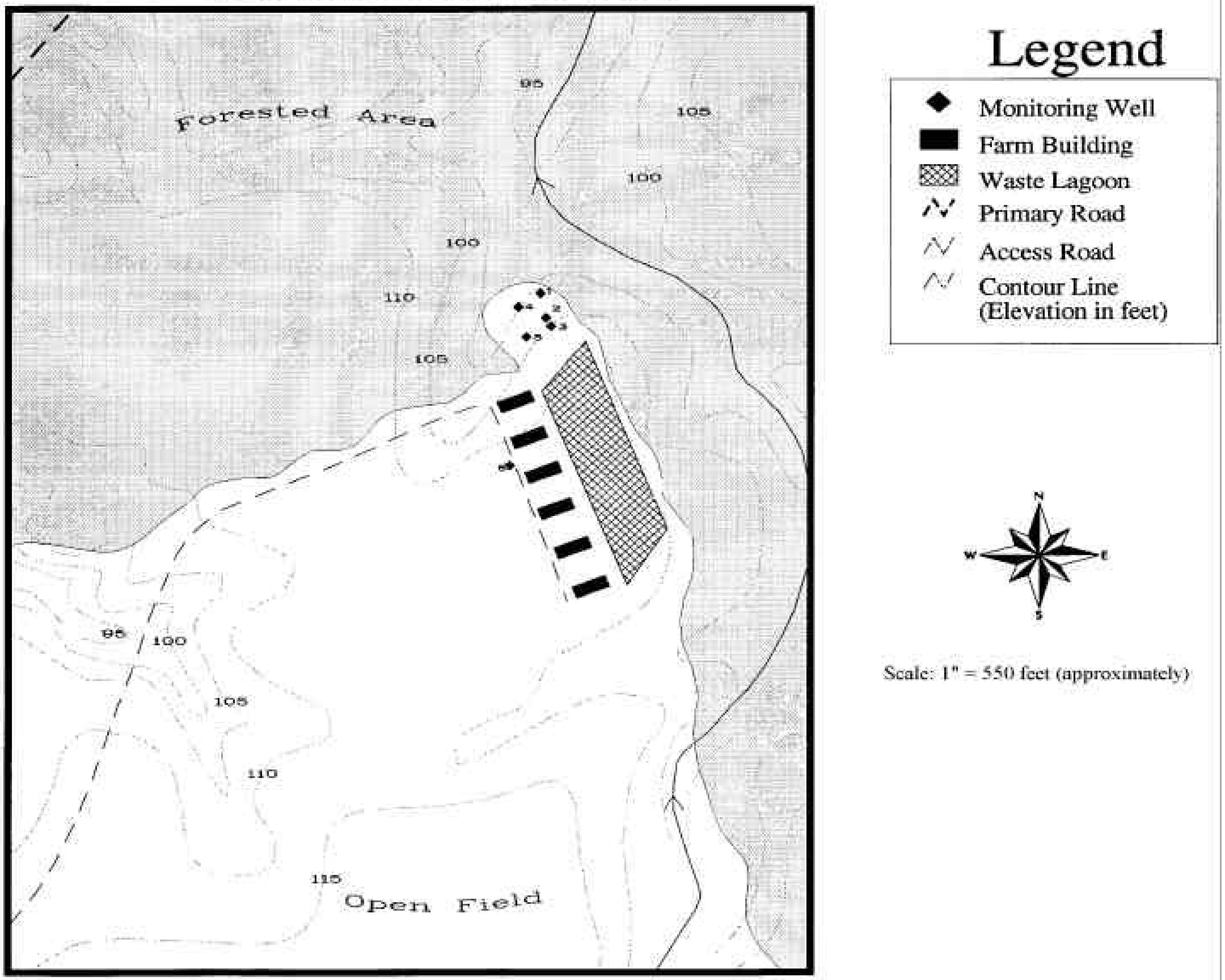
The lagoon was constructed by excavation into the topographic high area on the site. The excavated material was used for building the berm around the hole. A site map is included on the following page for reference.

This site was cleared of the existing vegetation, primarily a mixed stand of pine and hardwood trees. Monitoring well construction was completed in August 1996. Wells were sited on the downgradient side of the lagoon based on topography.

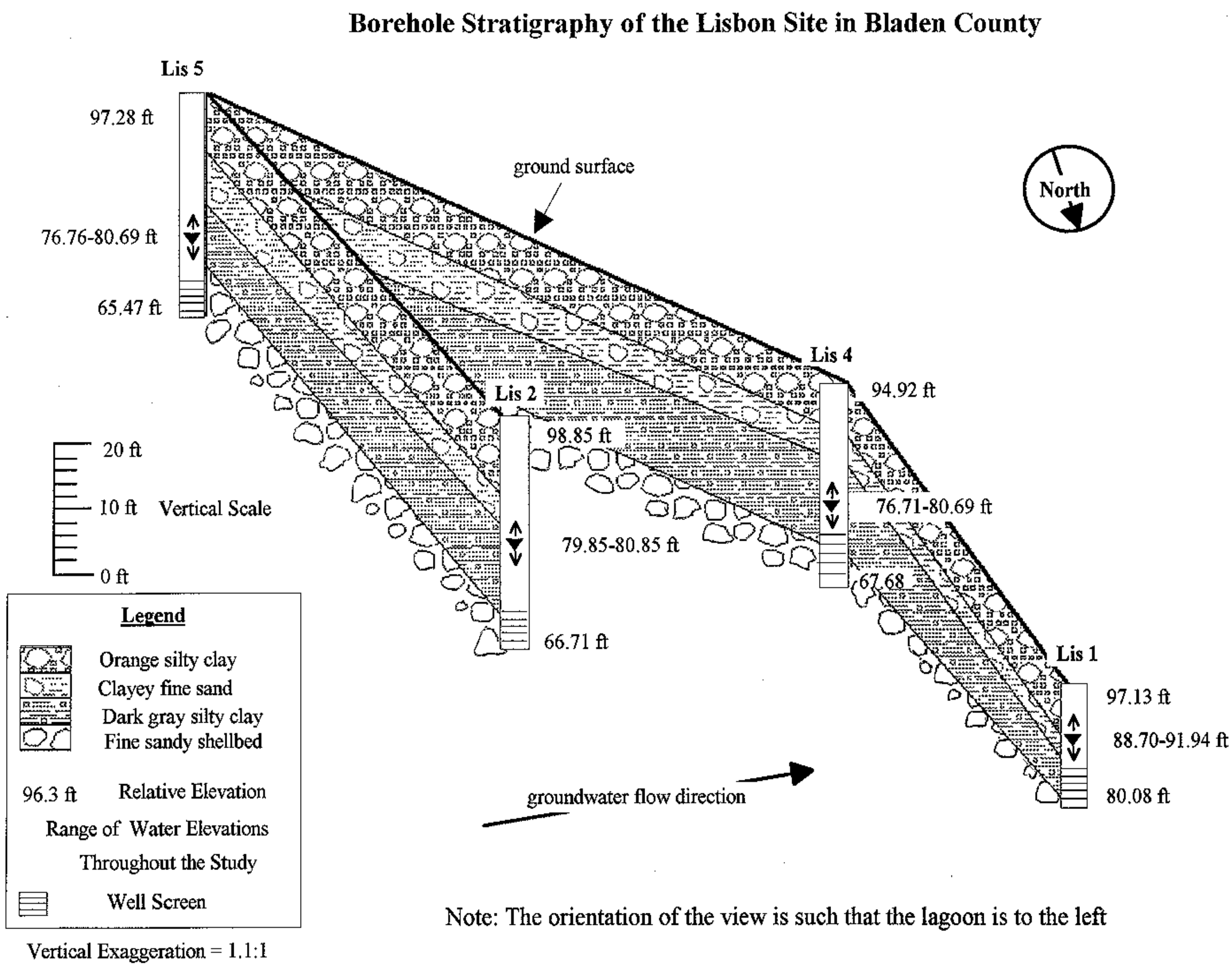
Depths to the top of the well screens ranged from 9 to 24 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 8 to 22 feet below the ground surface during the study.

Soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the fence diagram on page 31.

Lisbon Site



Forested Area
95
105
100
100
110
105
95
100
105
110
115
Open Field
Legend
Monitoring Well
Farm Building
Waste Lagoon
Primary Road
Access Road
Contour Line
(Elevation in feet)
N
W
E
S
Scale: 1" = 550 feet (approximately)


Borehole Stratigraphy of the Lisbon Site in Bladen County
Lis 5
97.28 ft
76.76-80.69 ft
65.47 ft
ground surface
North
Lis 4
94.92 ft
Lis 2
98.85 ft
76.71-80.69 ft
79.85-80.85 ft
67.68
66.71 ft
20 ft
10 ft
Vertical Scale
0 ft
Legend
Orange silty clay
Clayey fine sand
Dark gray silty clay
Fine sandy shellbed
96.3 ft
Relative Elevation
Range of Water Elevations
Throughout the Study
Well Screen
Vertical Exaggeration = 1.1:1
Lis 1
97.13 ft
88.70-91.94 ft
80.08 ft
groundwater flow direction
Note: The orientation of the view is such that the lagoon is to the left

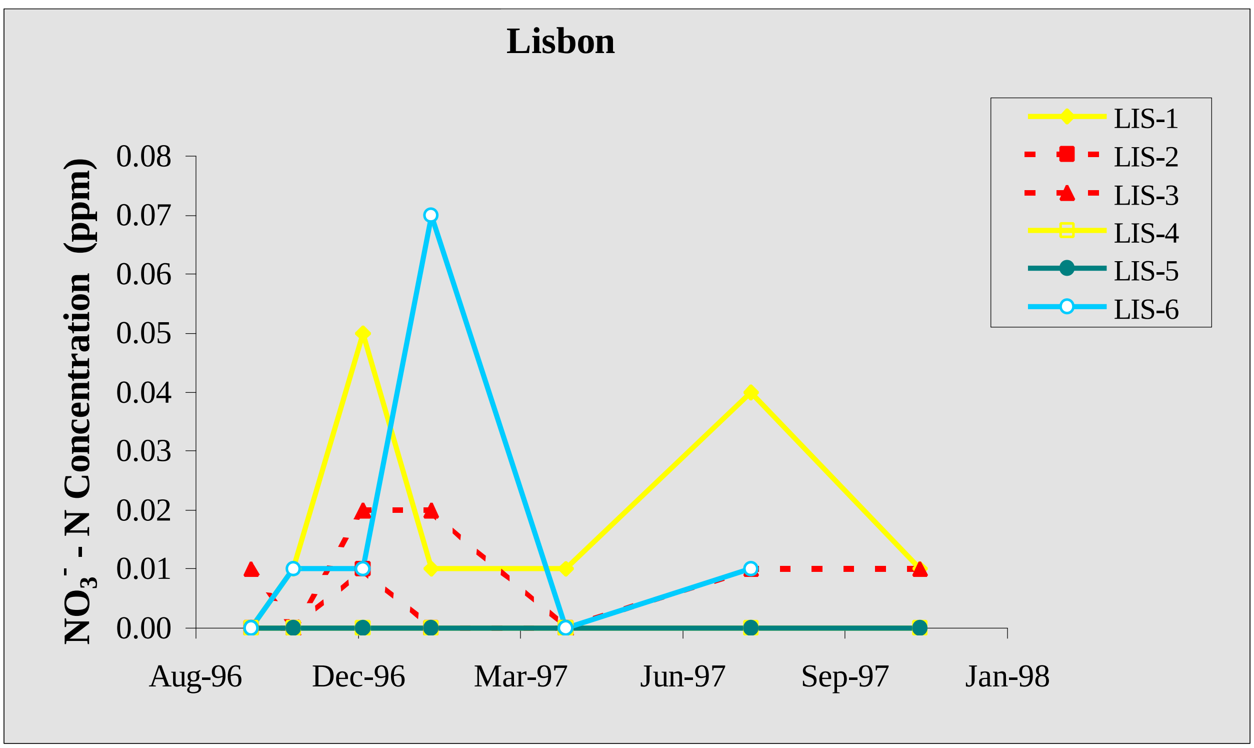
Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (as shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 500 feet.

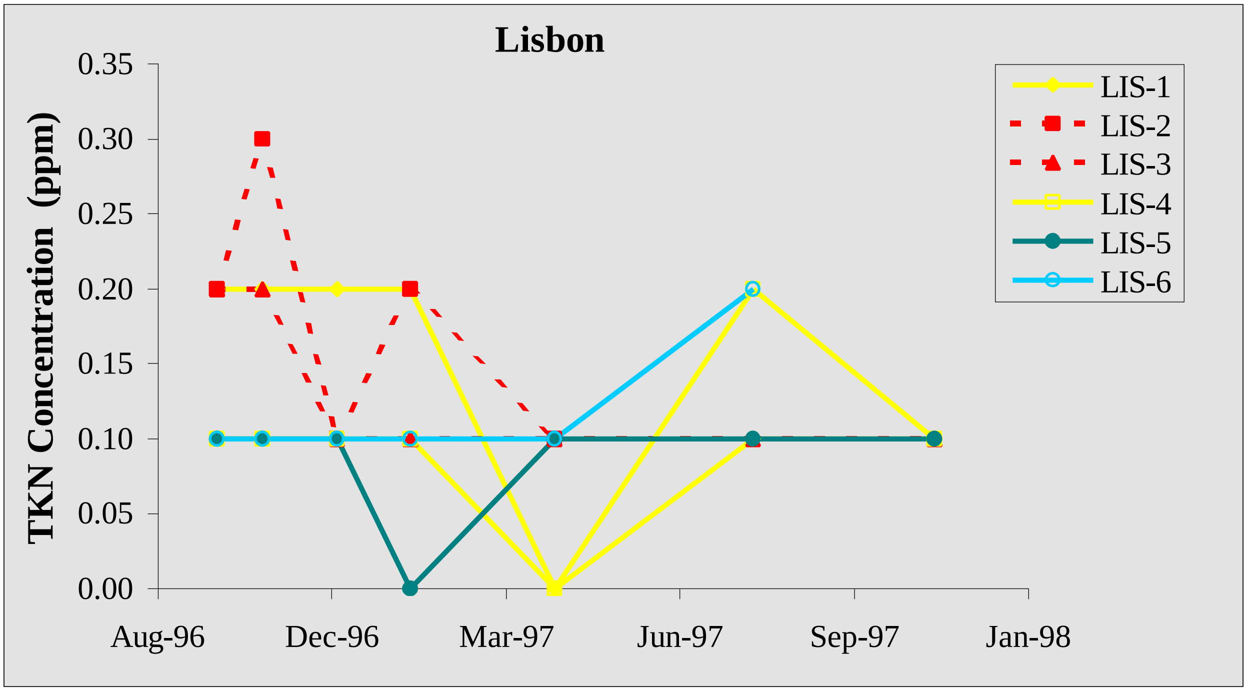
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is likely that the amount of clay in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

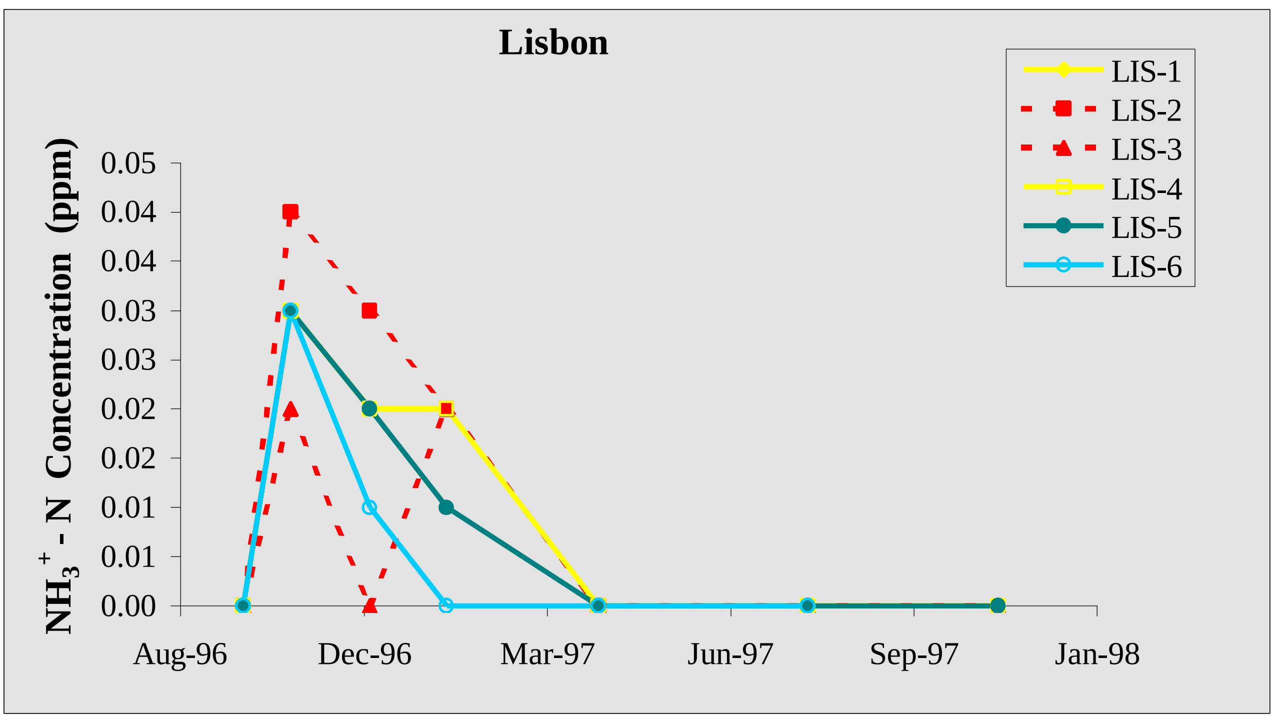
The separation distance between the lagoon bottom and the water table was estimated to be more than 8 feet. A significant clay layer that was about 10 feet thick (see fence diagram) was found in each of the wells. Based on this limited information, the Lisbon site would generally be considered to have less potential for lagoon seepage to contaminate ground water.

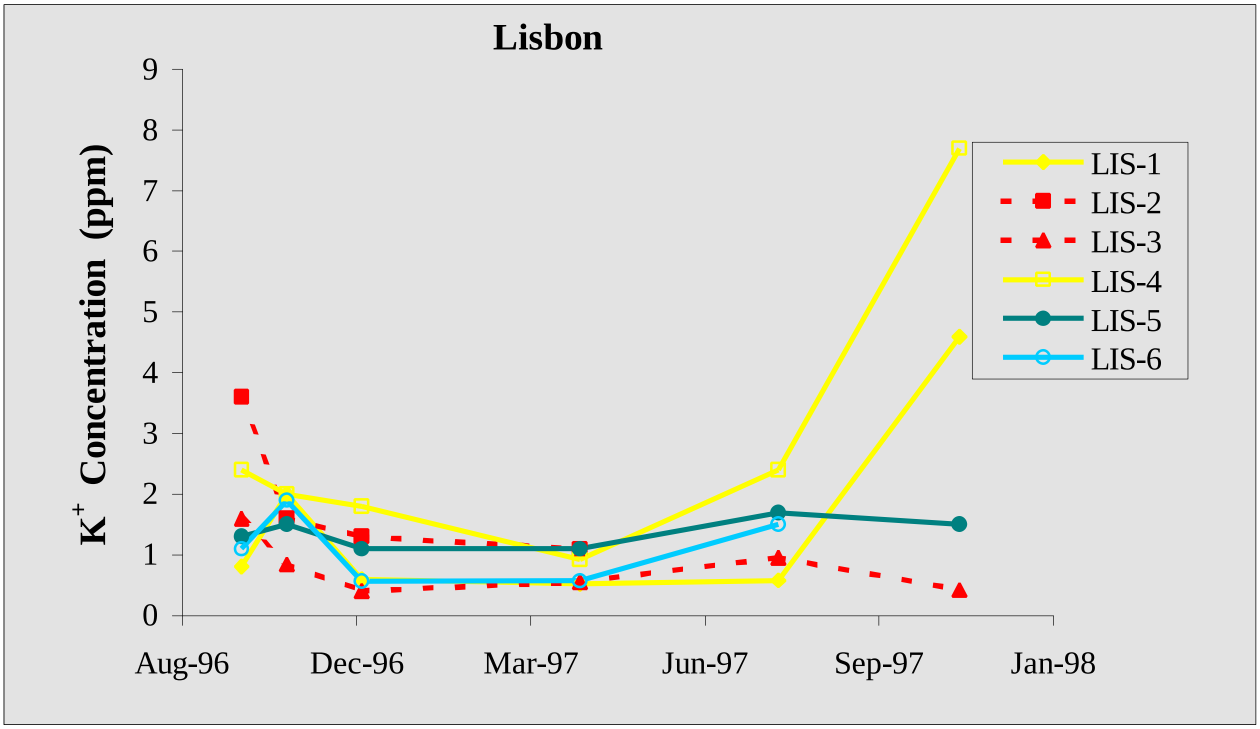
None of the seepage indicators were consistently found in the wells at Lisbon at concentrations that indicate any lagoon seepage. In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

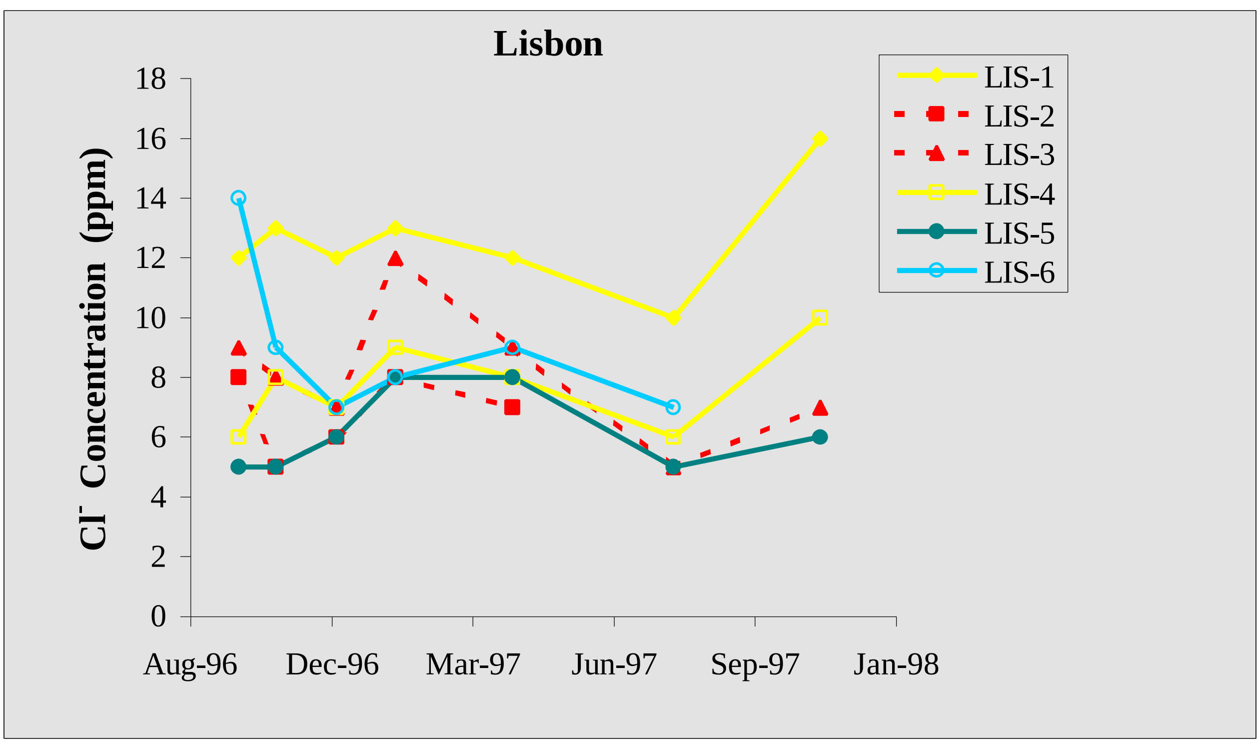
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:




Lisbon
TKN Concentration (ppm)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
LIS-1
LIS-2
LIS-3
LIS-4
LIS-5
LIS-6


Lisbon
NH_3^+ - N Concentration (ppm)
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
LIS-1
LIS-2
LIS-3
LIS-4
LIS-5
LIS-6


Lisbon
K+ Concentration (ppm)
9
8
7
6
5
4
3
2
1
0
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
LIS-1
LIS-2
LIS-3
LIS-4
LIS-5
LIS-6


Lisbon
Cl- Concentration (ppm)
18
16
14
12
10
8
6
4
2
0
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
LIS-1
LIS-2
LIS-3
LIS-4
LIS-5
LIS-6

07 Site (Scotland County)

The 07 site is located in a topographically upland setting in the Sandhills area of the Coastal Plain physiographic province. The soils mapped are coarse to medium textured.

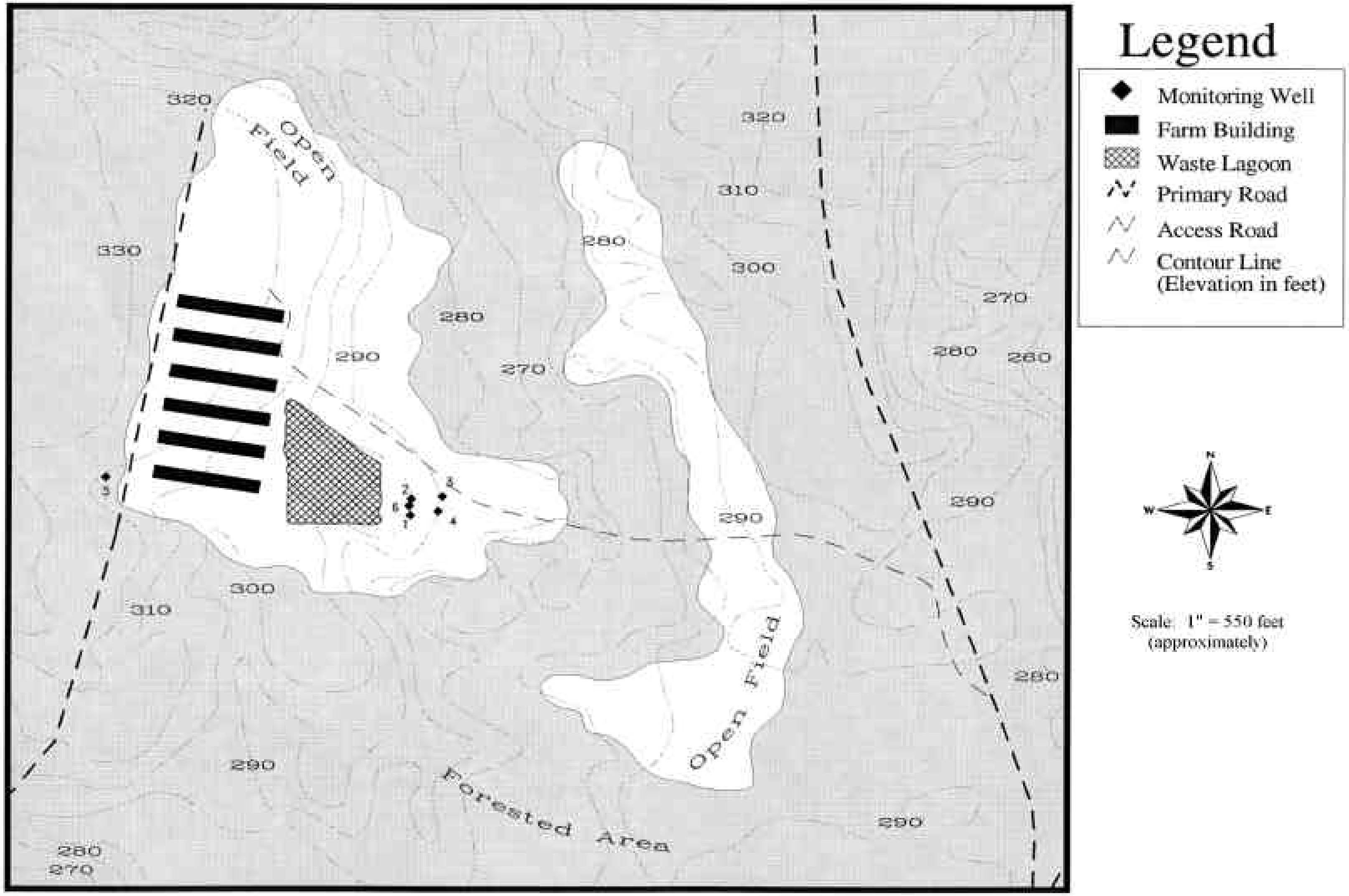
The lagoon was constructed by excavation into a portion of the side slope of the topographic high area on the site. The excavated material was used for building the berm around the hole. A site map is included on the following page for reference.

The area of this site where the lagoon was constructed and where the shallow downgradient monitoring wells were located was cleared of the existing vegetation, primarily a mixed stand of pine and hardwood trees. Monitoring well construction was completed in February 1996. Wells were sited on the downgradient side of the lagoon based on topography.

Depths to the top of the well screens ranged from 13 to 23 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 12 to 18 feet below the ground surface during the study.

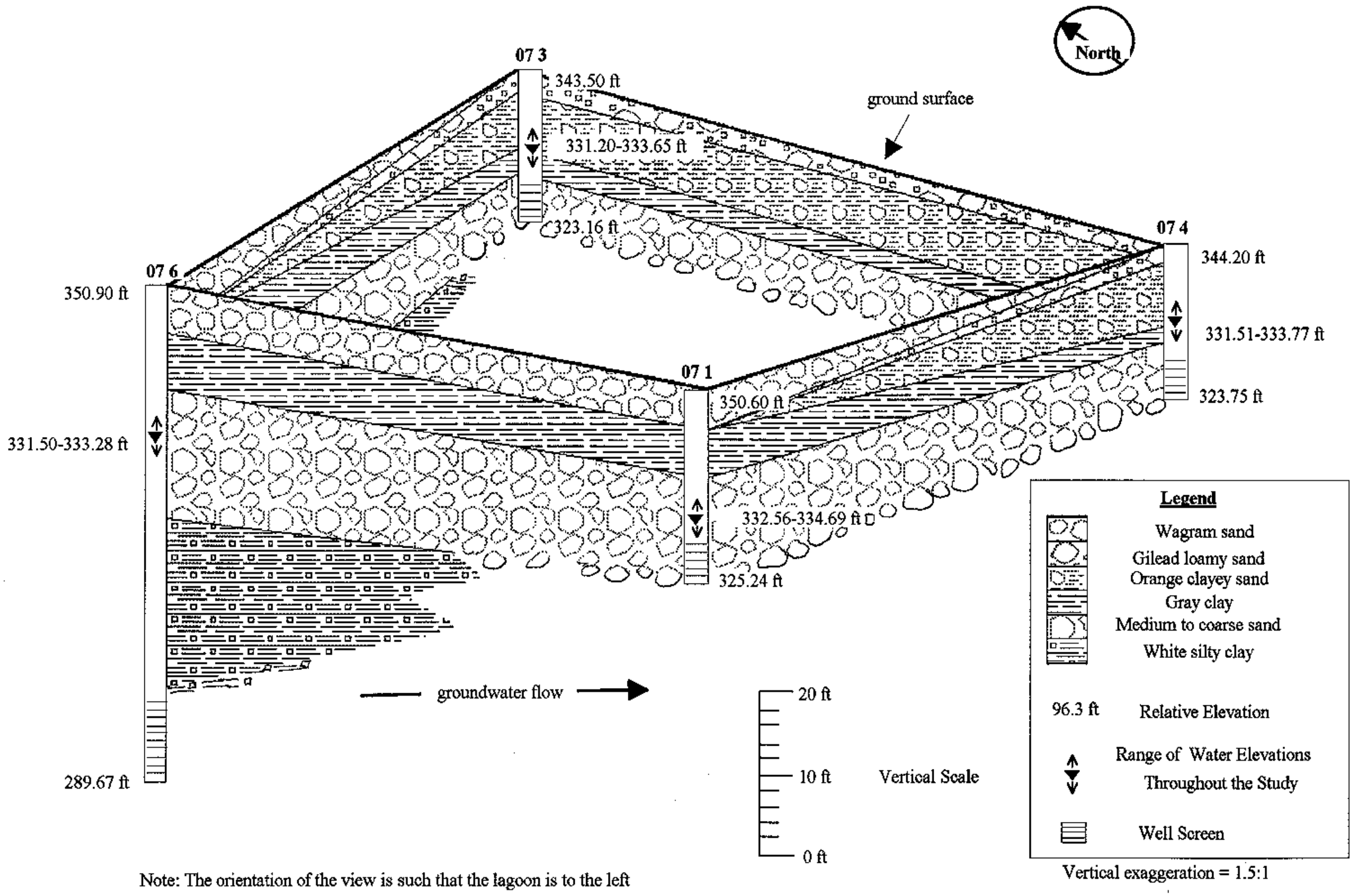
Soil and sediment textures encountered during drilling of the four wells on this site were generally medium to coarse textured. The site's stratigraphy is presented in the 'fence diagram' on page 37.

07 Site



Legend
Monitoring Well
Farm Building
Waste Lagoon
Primary Road
Access Road
Contour Line
(Elevation in feet)
Open Field
Open Field
Forested Area
320
320
330
310
300
280
280
290
270
270
280
260
290
290
300
310
290
290
280
280
270
Scale: 1" = 550 feet
(approximately)

Borehole Stratigraphy of the 07 Site in Scotland County



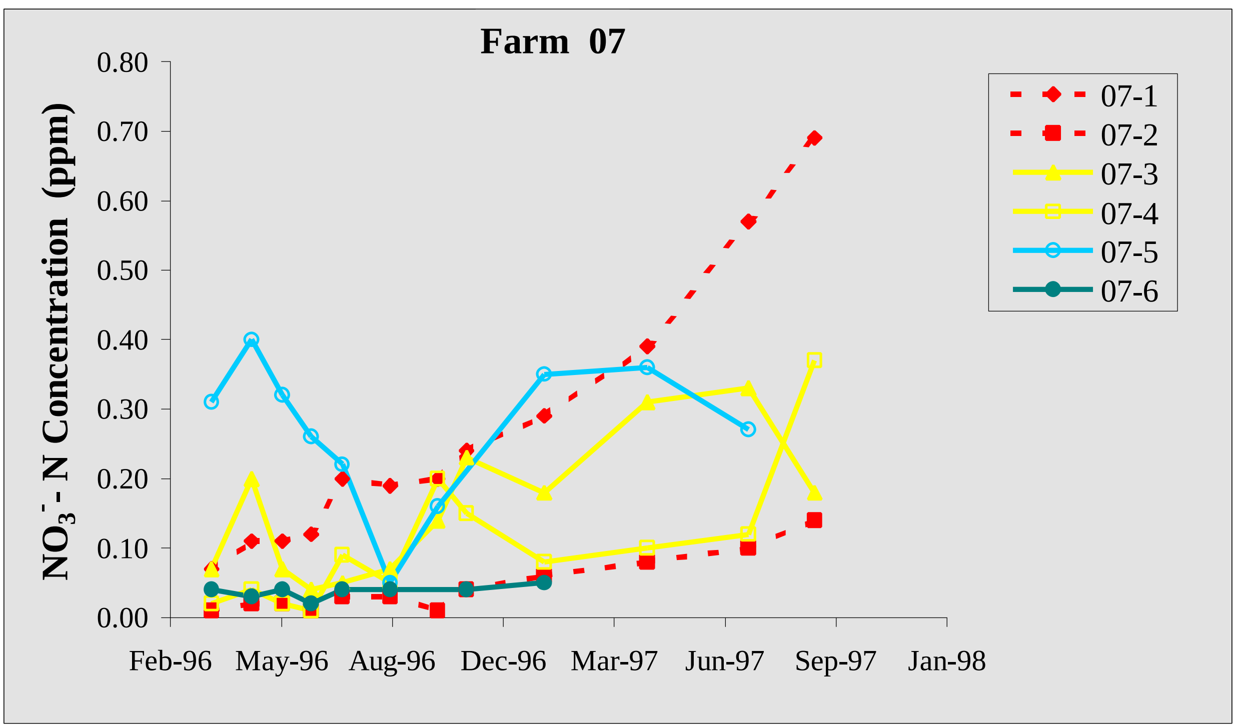
Note: The orientation of the view is such that the lagoon is to the left

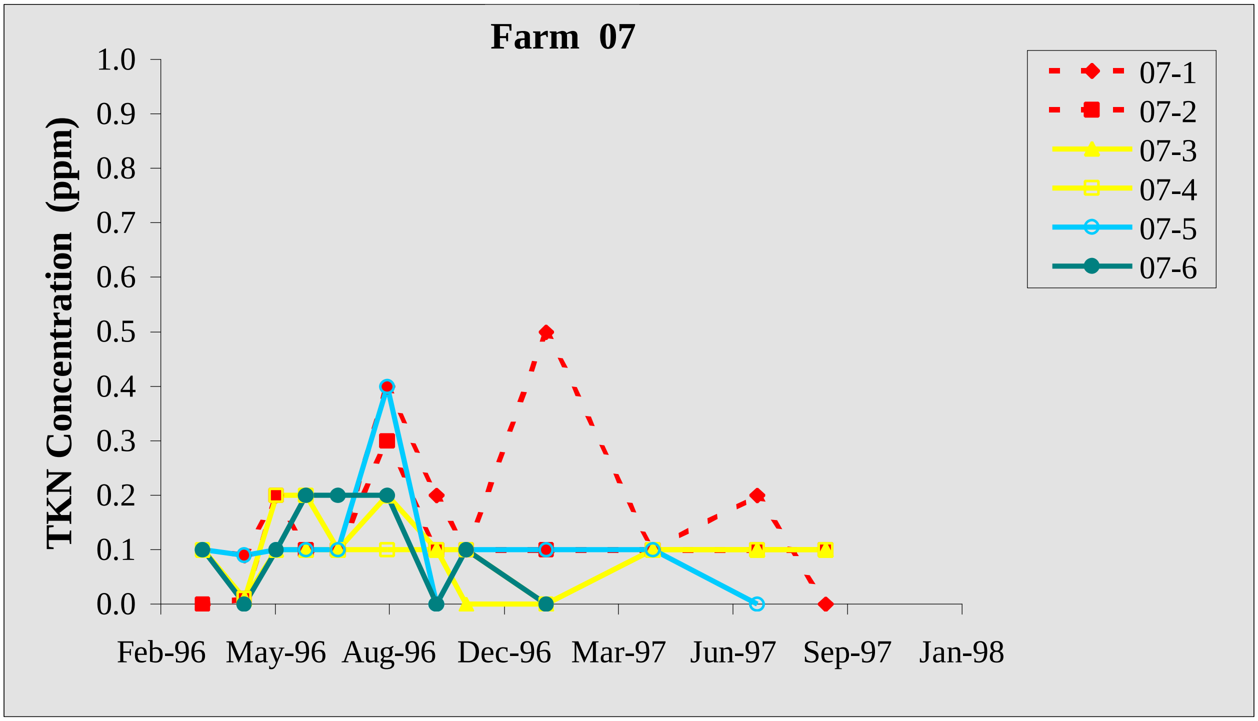
Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (as shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 250 feet.

Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. The separation distance between the lagoon bottom and the water table was estimated to be more than 13 feet. A significant clay layer was found in each of the shallow downgradient wells that was about 5 to 10 feet thick (see fence diagram). Based on this limited information, the 07 site would generally be considered to have less potential for lagoon seepage to contaminate ground water.

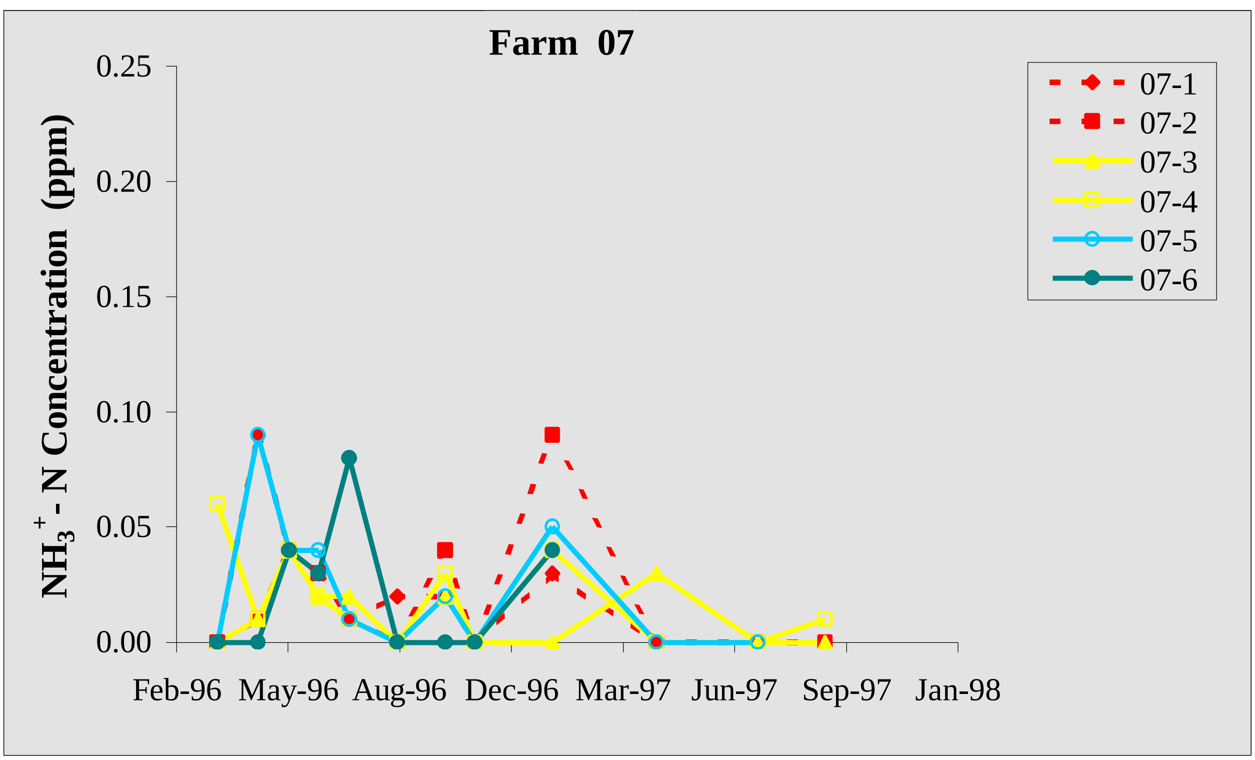
None of the seepage indicators were consistently found in the wells at the 07 site at concentrations that indicate any lagoon seepage. In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:

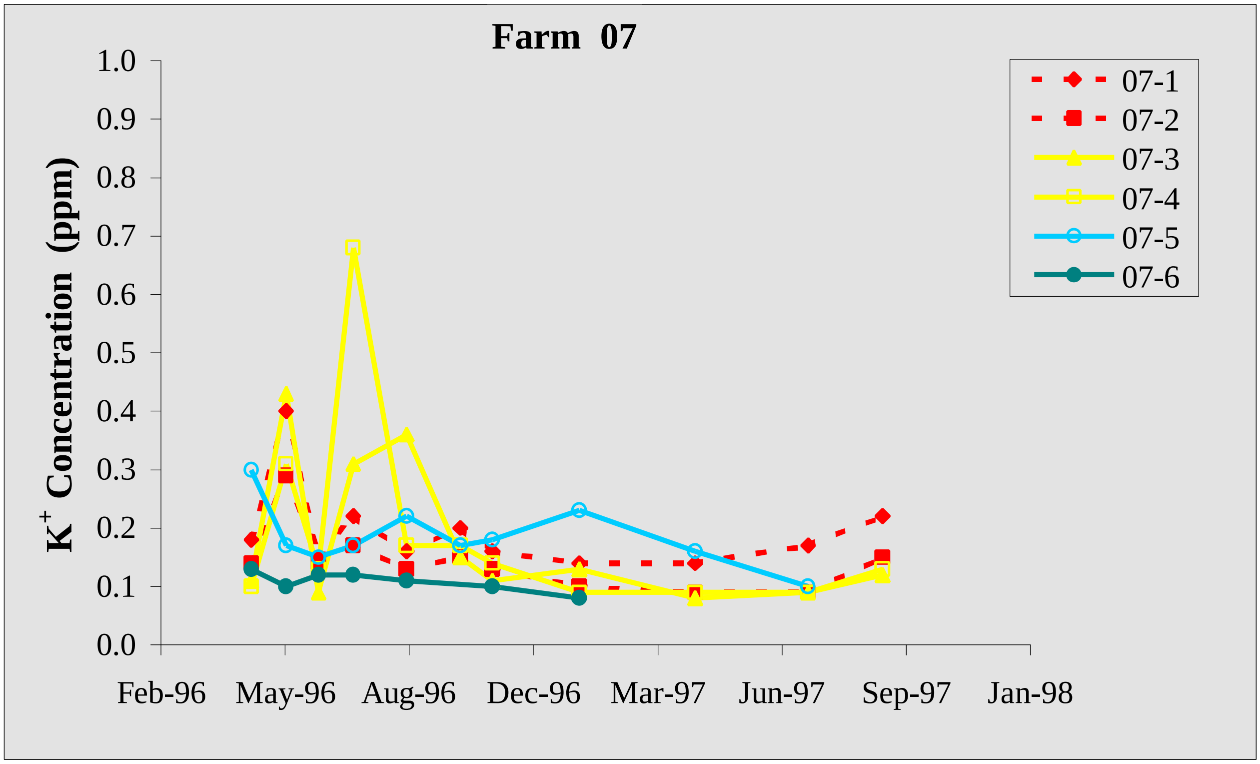


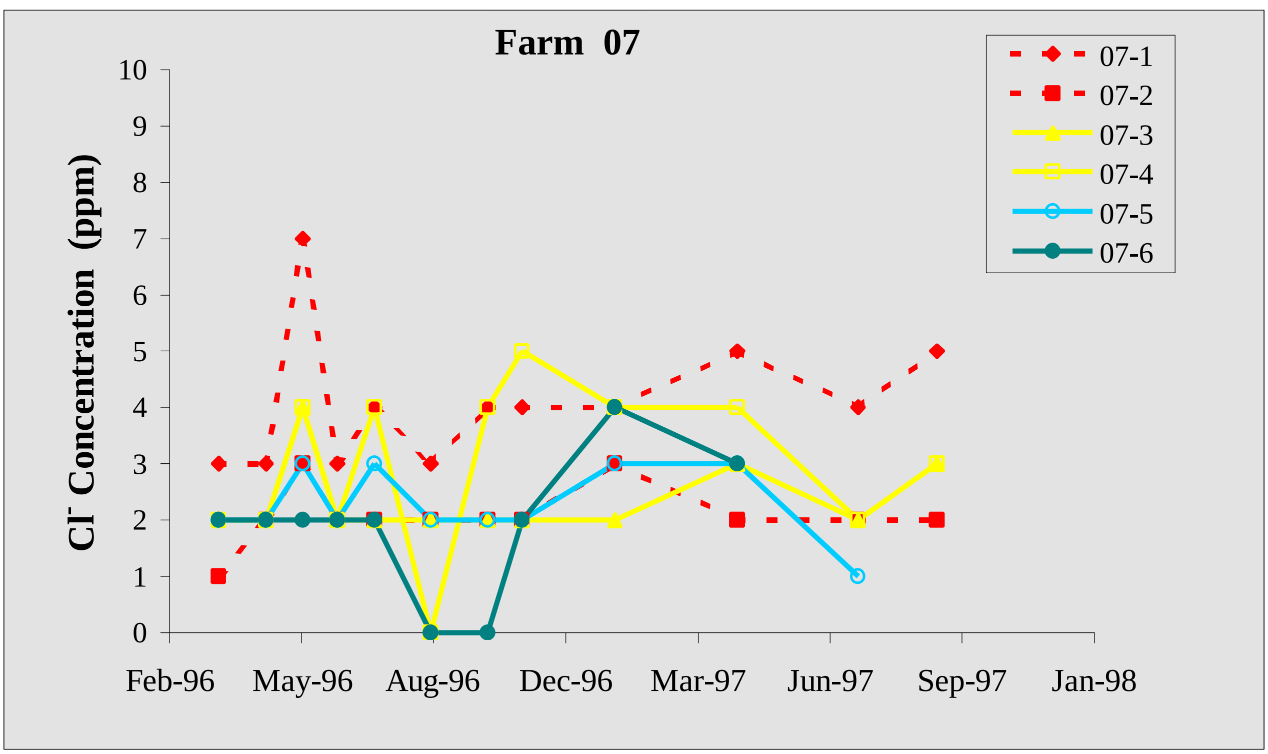


Farm 07
TKN Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
07-1
07-2
07-3
07-4
07-5
07-6



Farm 07
NH_3^+ - N Concentration (ppm)
0.25
0.20
0.15
0.10
0.05
0.00
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
07-1
07-2
07-3
07-4
07-5
07-6


Farm 07
K$^+$ Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
07-1
07-2
07-3
07-4
07-5
07-6


Farm 07
Cl$^-$ Concentration (ppm)
10
9
8
7
6
5
4
3
2
1
0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
07-1
07-2
07-3
07-4
07-5
07-6

06 Site (Scotland County)

The 06 site is located in a topographically upland setting in the Sand Hills area of the Coastal Plain physiographic province. The soils mapped are coarse to medium textured.

The lagoon was constructed by excavation into a portion of the side slope of the topographic high area on the site. The excavated material was used for building the berm around the hole. A site map is included for reference.

The area of this site where the lagoon was constructed and where the shallow downgradient monitoring wells were located was in pasture before to the study began. Monitoring well construction was completed in February 1996. Wells were sited on the downgradient side of the lagoon based on topography.

Depths to the top of the well screens ranged from 13 to 23 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 14 to 22 feet below the ground surface during the study.

The soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the 'fence diagram' on page 43.

After several months measuring the water level elevation, the ground water flow direction was determined to be generally from the shallow downgradient monitoring wells toward the lagoon as (shown on the fence diagram). The water table elevations measured over time did not show significant variation in ground water flow direction.

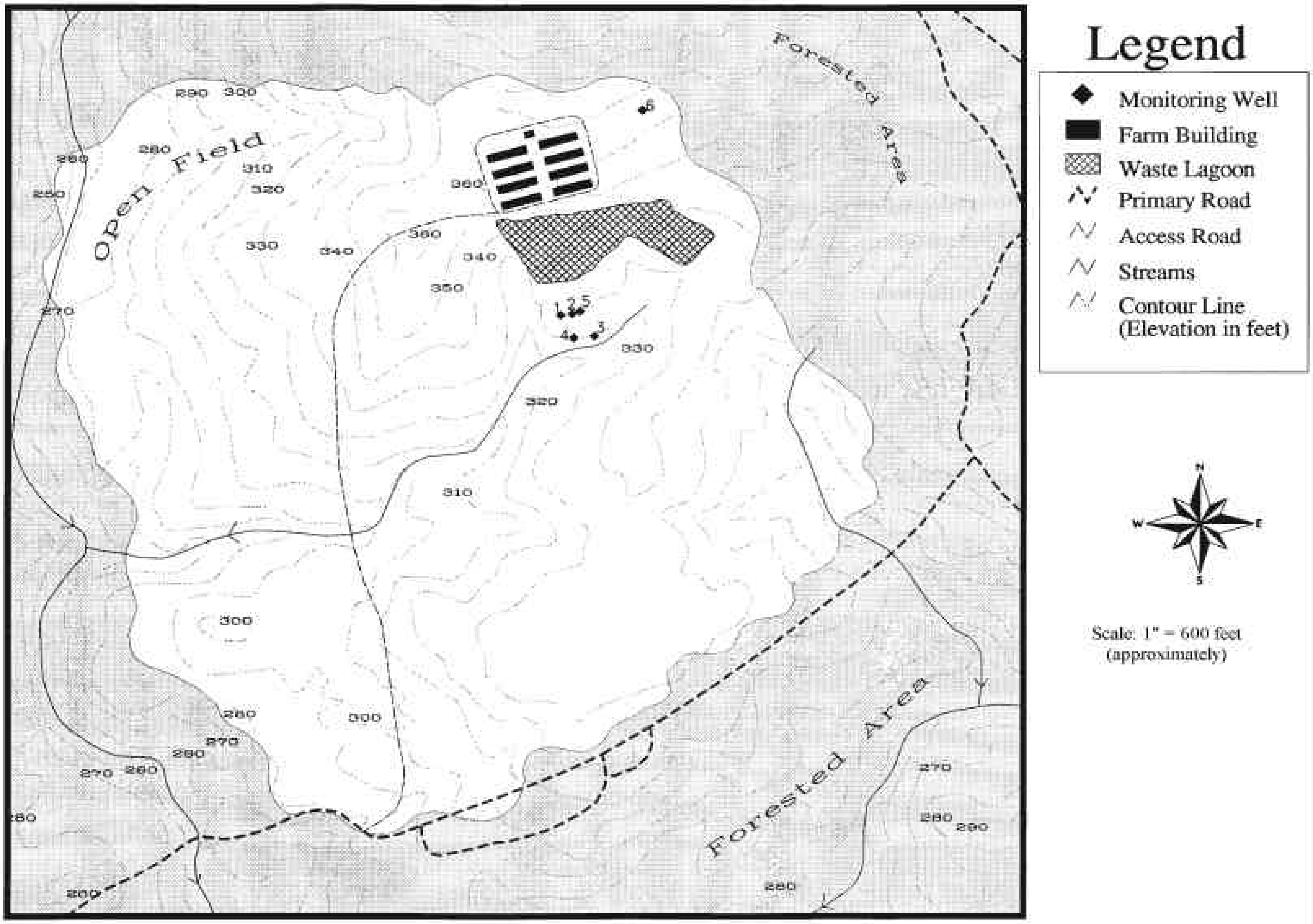
After EM surveying showed a possible area of higher conductivity in the subsurface, in May 1997, two additional shallow downgradient wells were installed by hand. The water table was measured at about 5 feet the ground surface. Ground water samples were collected twice from these wells.

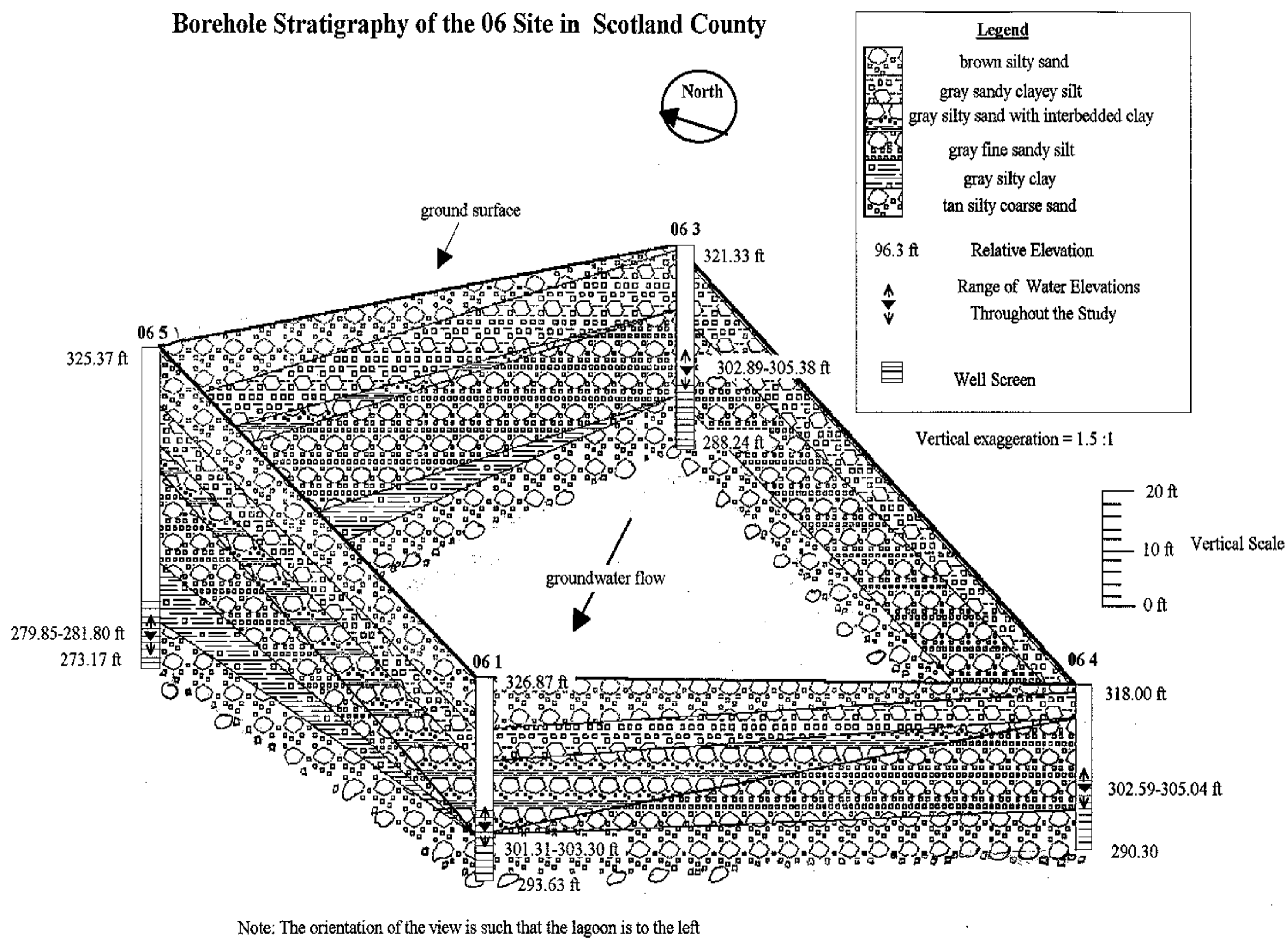
The specific conductivity and the sulfate concentrations from these samples were significantly different from the other wells. The separation distance between the lagoon bottom and the water table in the original monitoring wells was estimated to be more than 25 feet. For the wells installed by hand, the separation distance between the lagoon bottom and the water table was less than 5 feet.

It appears that the original monitoring wells were screened in a deeper aquifer. The results of the monitoring well analysis of the original monitoring wells are apparently not representative of shallow ground water downgradient from the lagoon and are therefore not shown.

Until a further site investigation can occur, no definite conclusions about lagoon seepage at this site can be made.

06 Site


Forested Area
Open Field
Forested Area
290 300
280
260
250
310
320
330
340
360
380
340
350
270
1 2 5
4
3
6
330
320
310
300
300
280
270
280
270 280
280
280 290
270
280
Legend
Monitoring Well
Farm Building
Waste Lagoon
Primary Road
Access Road
Streams
Contour Line
(Elevation in feet)
N
W
E
S
Scale: 1" = 600 feet
(approximately)



Borehole Stratigraphy of the 06 Site in Scotland County
North
Legend
brown silty sand
gray sandy clayey silt
gray silty sand with interbedded clay
gray fine sandy silt
gray silty clay
tan silty coarse sand
96.3 ft
Relative Elevation
Range of Water Elevations
Throughout the Study
Well Screen
Vertical exaggeration = 1.5 :1
20 ft
10 ft
0 ft
Vertical Scale
ground surface
06 3
321.33 ft
302.89-305.38 ft
288.24 ft
06 5
325.37 ft
279.85-281.80 ft
273.17 ft
groundwater flow
06 1
326.87 ft
301.31-303.30 ft
293.63 ft
06 4
318.00 ft
302.59-305.04 ft
290.30
Note: The orientation of the view is such that the lagoon is to the left

PRS Site (Rowan County)

The PRS site is located in a topographically upland setting in the Piedmont physiographic province. The soils mapped are medium to fine textured.

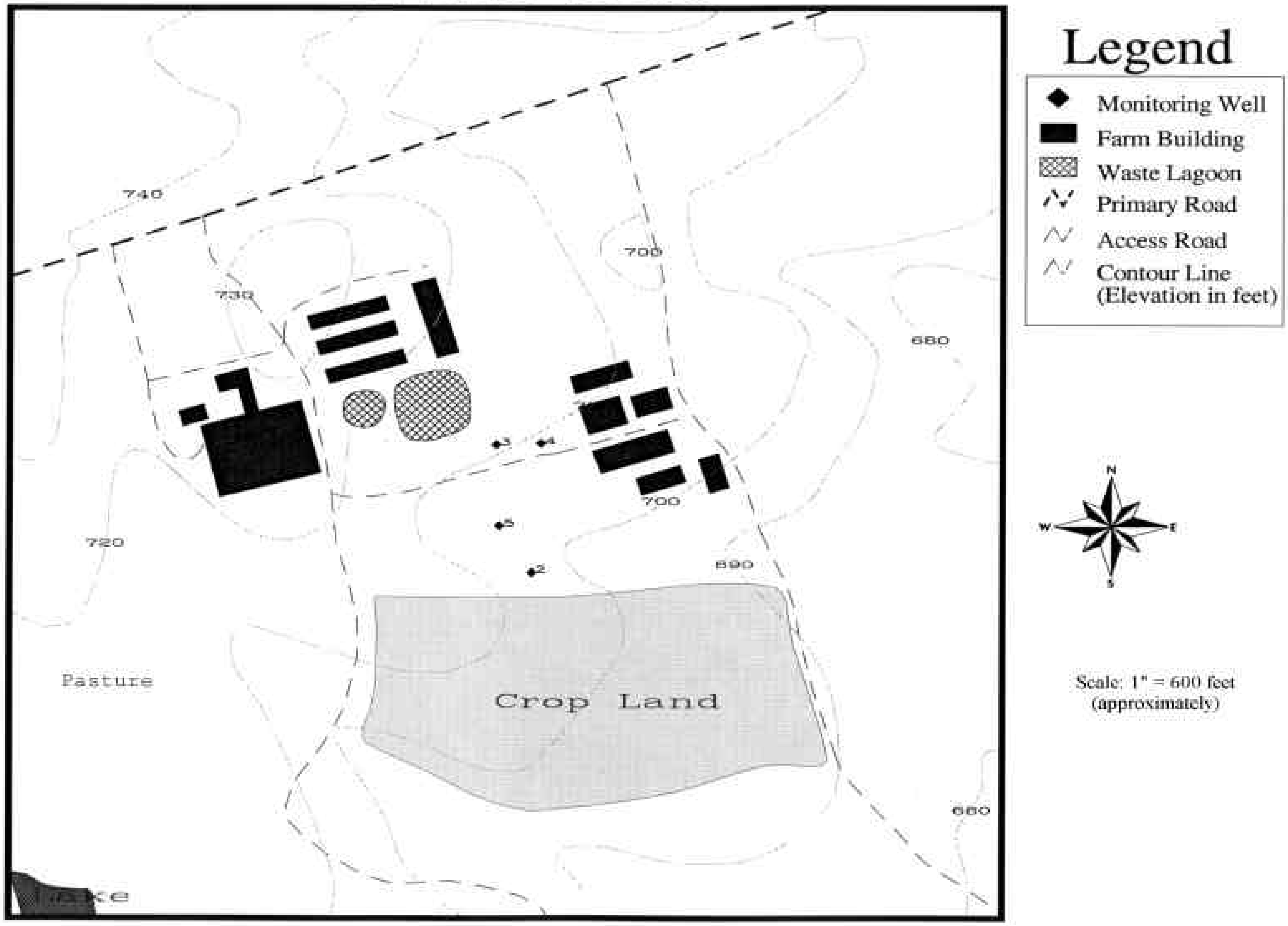
The lagoon was constructed by excavation into the gently sloping hillside area on the site. The excavated material was used for building the berm around the hole. This lagoon has been in operation for more than 20 years but was constructed so that it met the construction criteria defined in the NRCS standards. A site map is included for reference (well PRS-6 is not shown on the map because it was located a great distance from the lagoon).

This site has been an operating dairy research facility for more than 20 years. Monitoring well construction was completed in June 1996. No deep well was constructed at this facility. Wells were sited on the downgradient side of the lagoon based on topography. The layout of the farm and where fence lines were located limited the siting of the monitoring wells.

Depths to the top of the well screens ranged from 19 to 22 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 6 to 14 feet below the ground surface during the study.

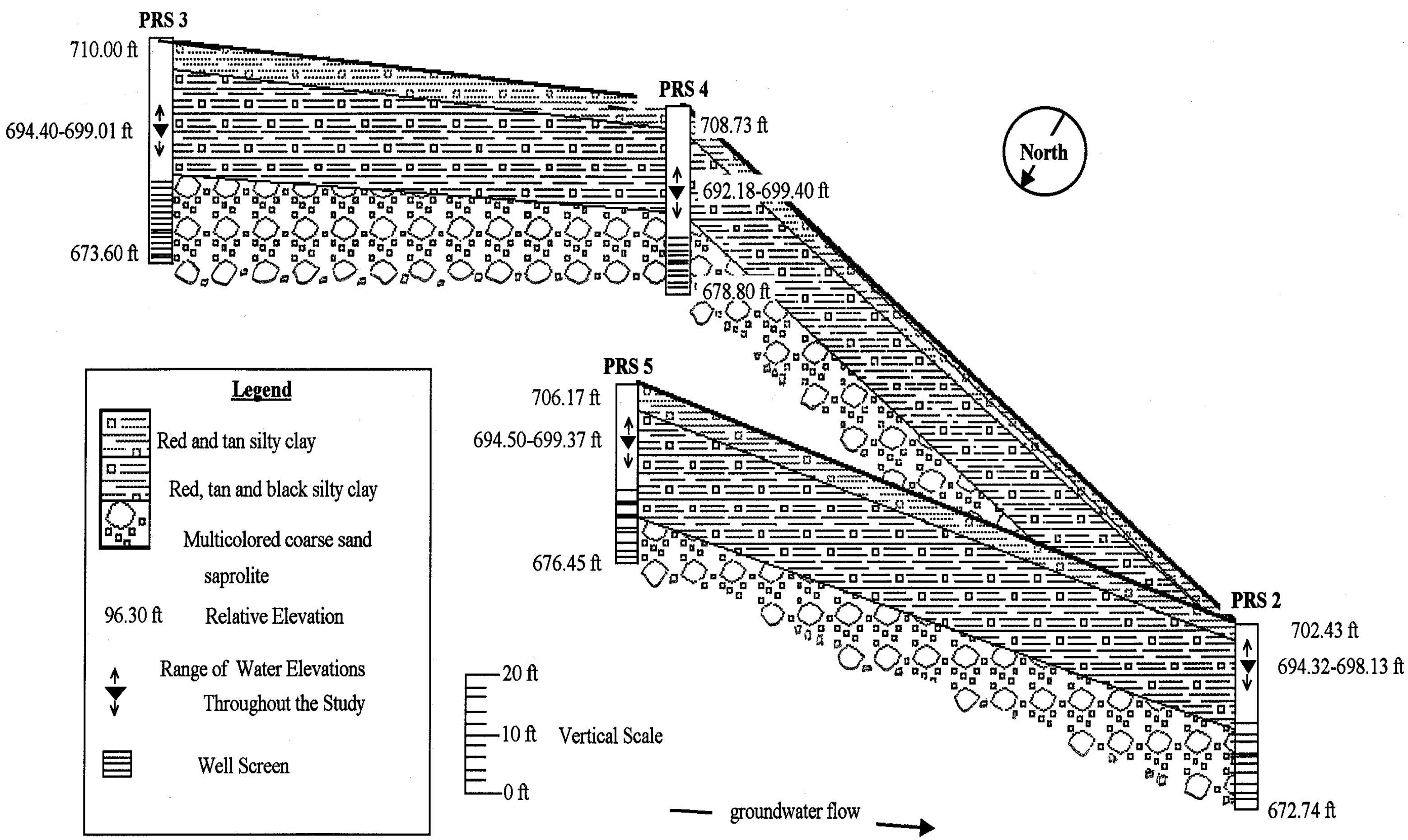
Soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the 'fence diagram' on page 46.

PRS Site



740
730
700
680
720
700
690
680
3
4
5
2
Pasture
Crop Land
Legend
Monitoring Well
Farm Building
Waste Lagoon
Primary Road
Access Road
Contour Line
(Elevation in feet)
N
W
E
S
Scale: 1" = 600 feet
(approximately)

Borehole Stratigraphy of the PRS Site in Rowan County



Vertical exaggeration = 1.25:1

Note: The orientation of the view is such that the lagoon is to the left

Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (as shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 1,500 feet.

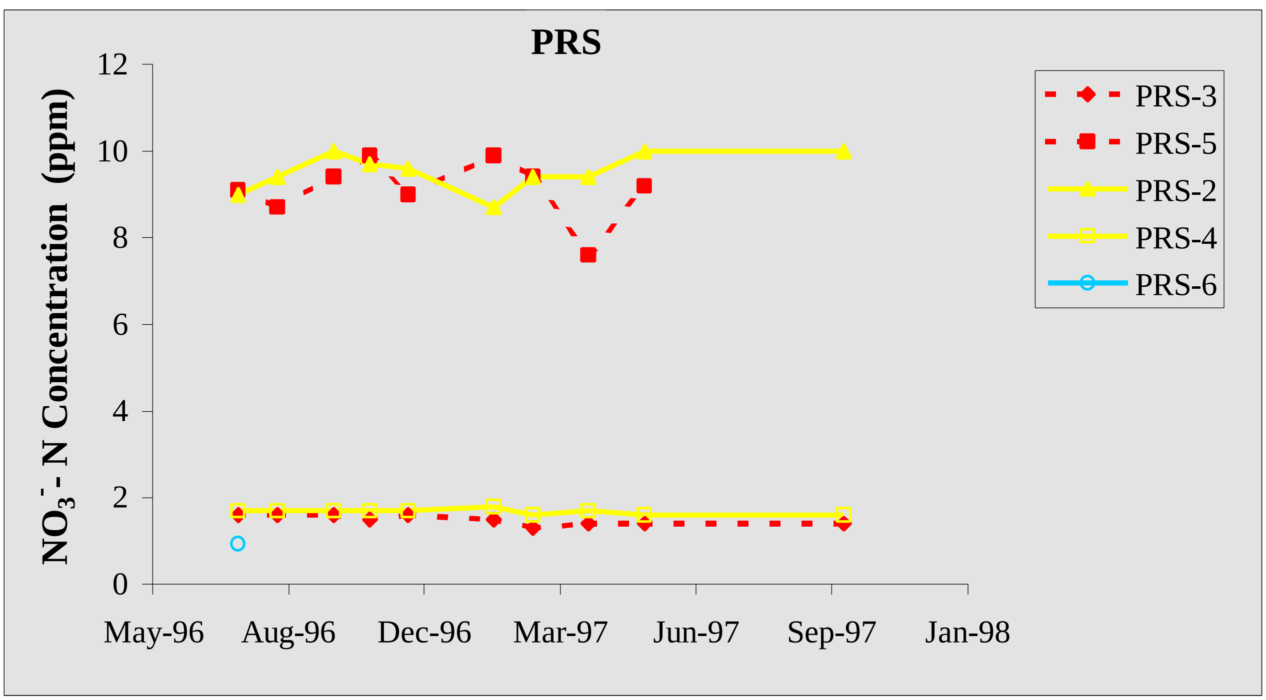
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is likely that the amount of clay in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

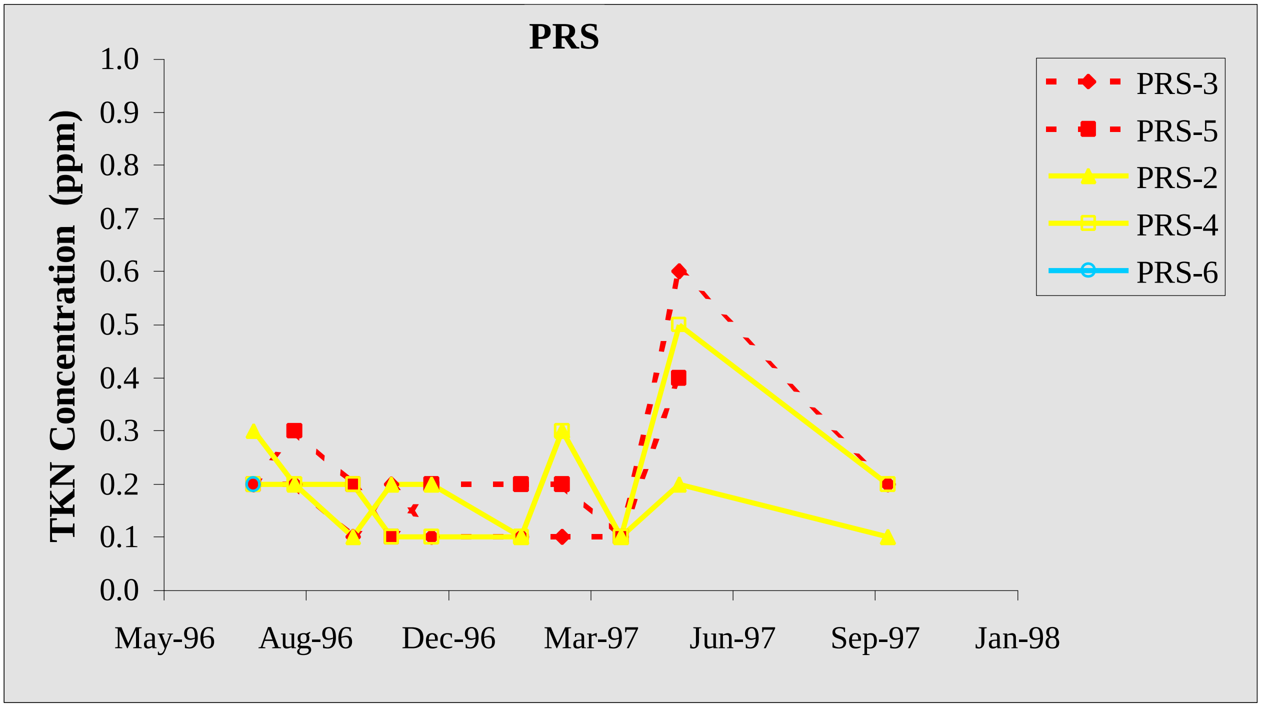
The separation distance between the lagoon bottom and the water table was estimated to be more than 6 feet. A significant clay layer more than 15 feet thick was found in each of the shallow downgradient wells (see fence diagram). Based on this limited information, the PRS site would generally be considered to have less potential for lagoon seepage to contaminate ground water.

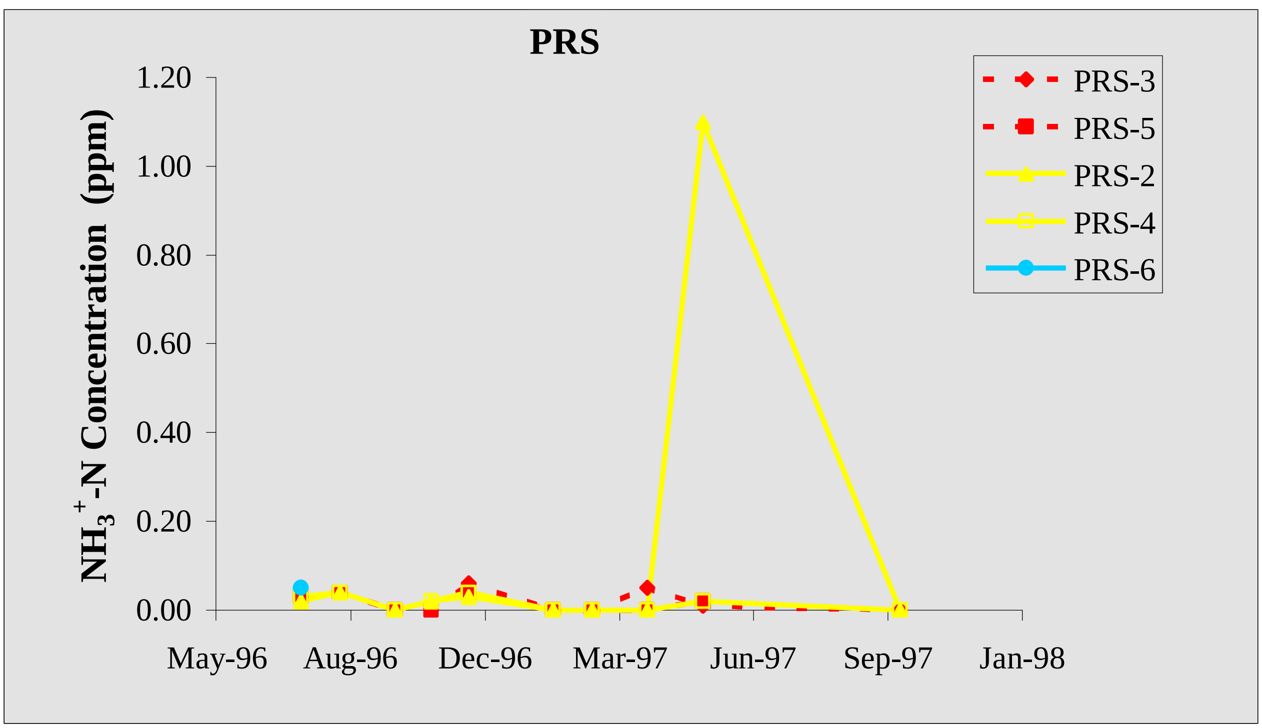
None of the seepage indicators were consistently found in the wells at the PRS site at concentrations that indicate any lagoon seepage. There are slightly elevated concentrations of nitrate-nitrogen in two of the shallow monitoring wells downgradient from the lagoon; however, they are also located in a pasture which is used periodically for confining dairy cows. The nitrate may be present in ground water due to the pasture management activities.

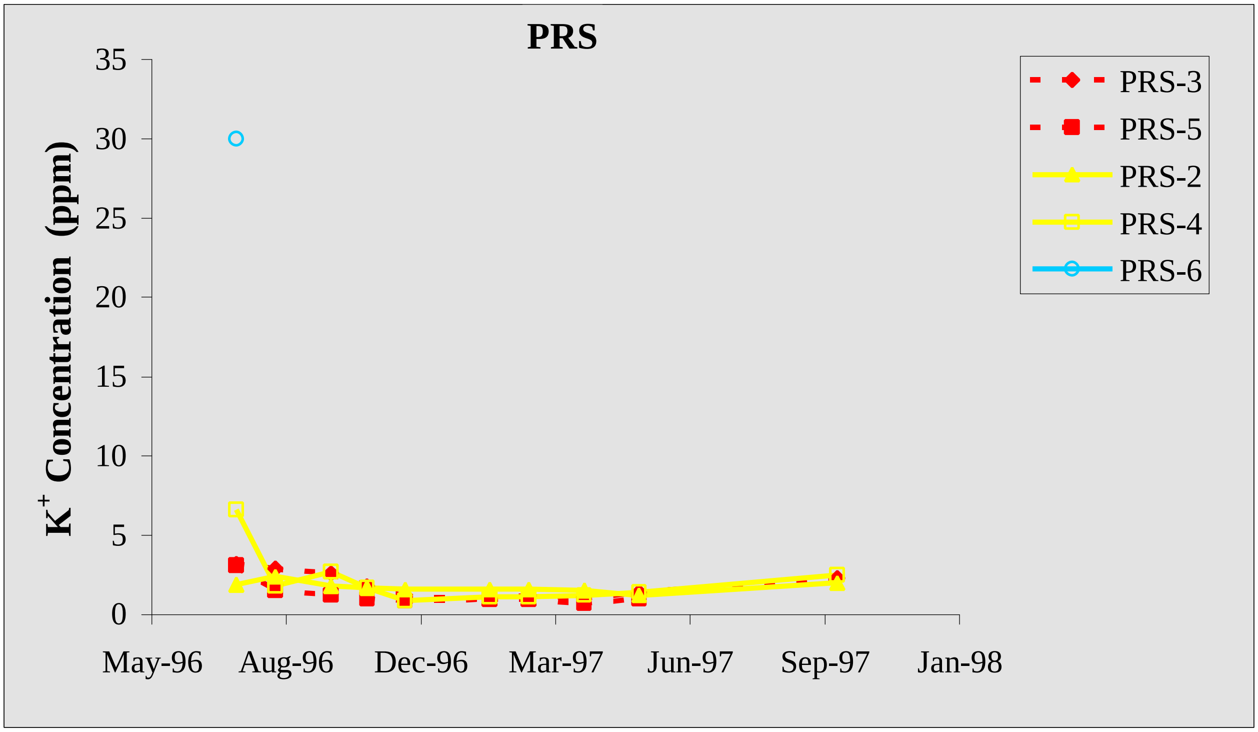
The wells were sited here because there was no alternative place on the farm downgradient from the lagoon. Since no other lagoon seepage indicators were detected in the wells, it is unlikely that lagoon seepage contributed to the nitrate concentrations in ground water.

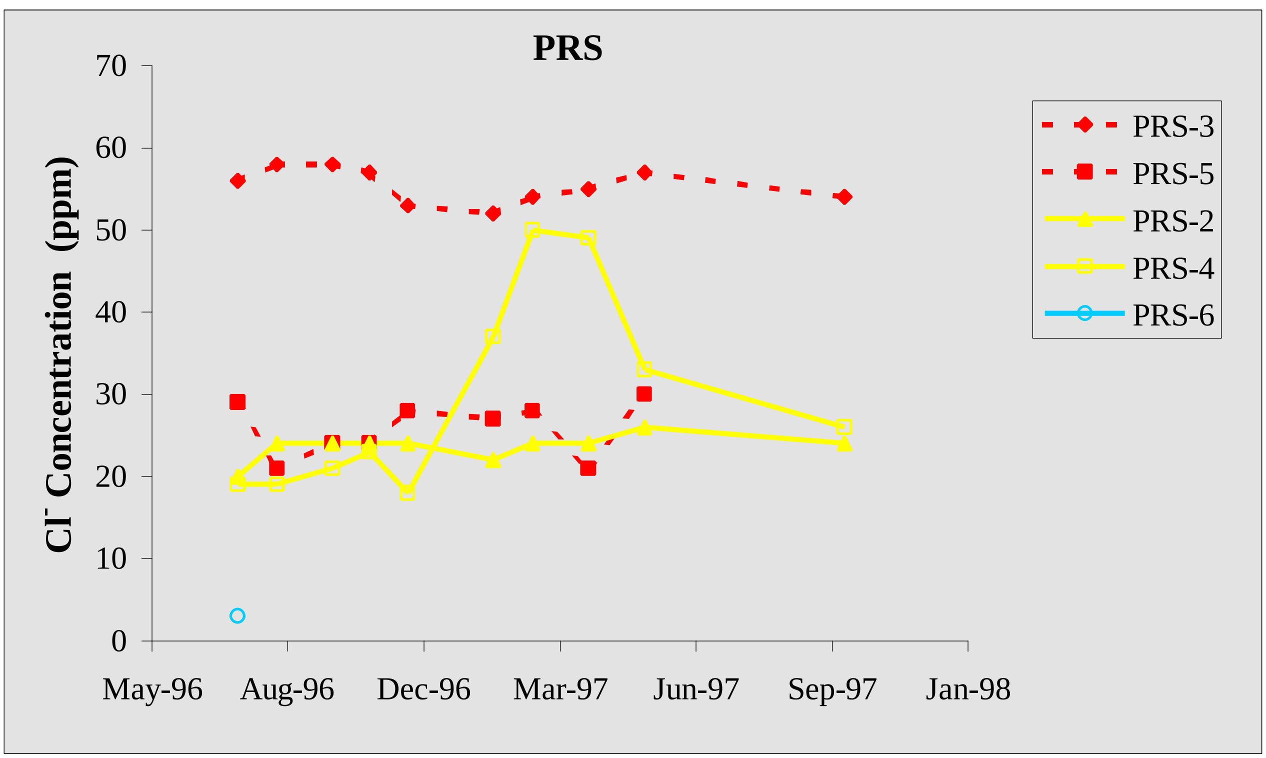
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs: (The upgradient well, PRS-6, was sampled only once during the study.)




PRS
TKN Concentration (ppm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
PRS-3
PRS-5
PRS-2
PRS-4
PRS-6


PRS
NH_3^+-N Concentration (ppm)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
PRS-3
PRS-5
PRS-2
PRS-4
PRS-6


PRS
K+ Concentration (ppm)
35
30
25
20
15
10
5
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
PRS-3
PRS-5
PRS-2
PRS-4
PRS-6


PRS
Cl- Concentration (ppm)
70
60
50
40
30
20
10
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
PRS-3
PRS-5
PRS-2
PRS-4
PRS-6

Gaston Site (Gaston County)

The site known as the Gaston site is located in the Piedmont physiographic province and encompasses a small stream valley. The soils mapped are medium to fine textured.

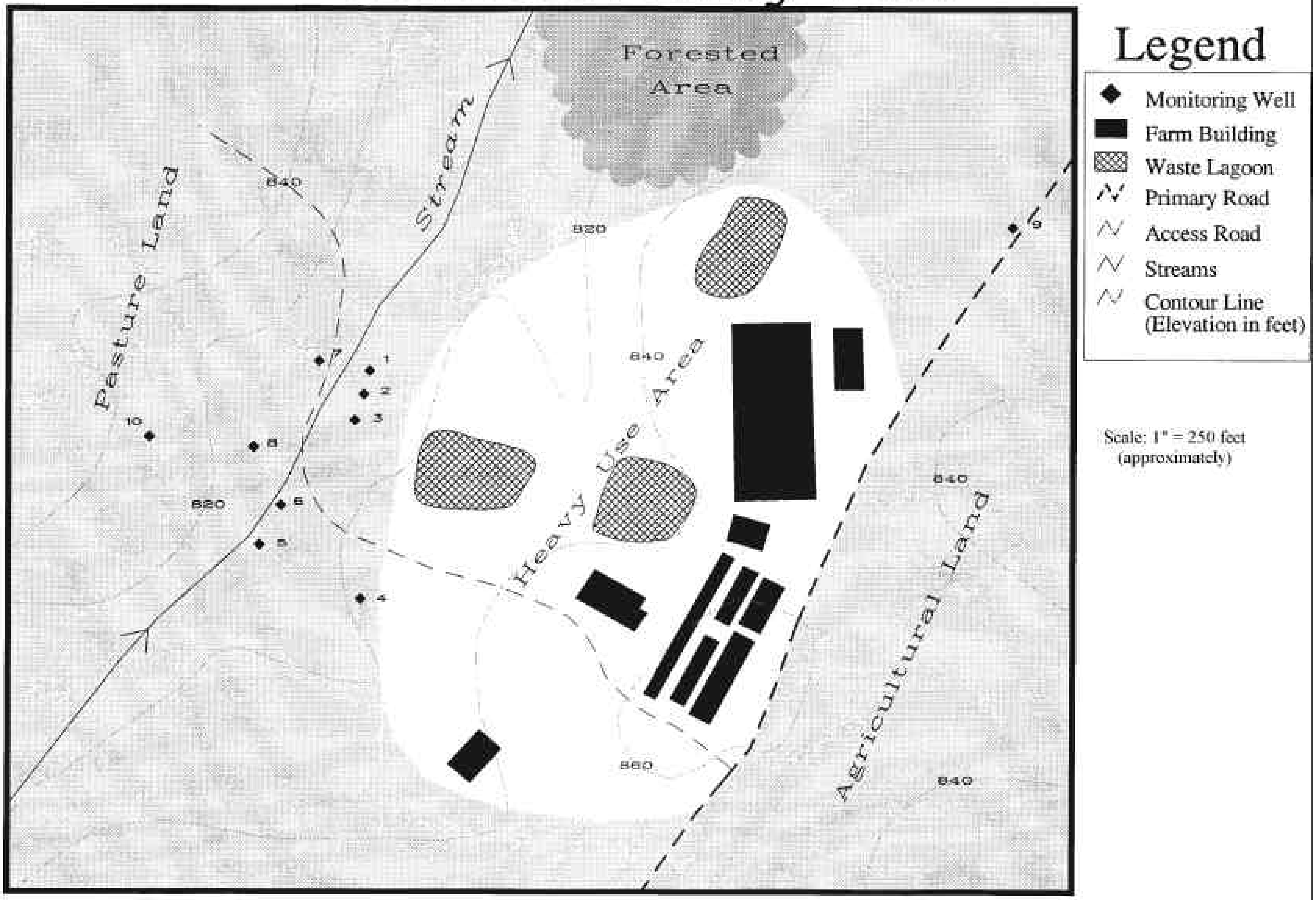
The lagoon was constructed by excavating into the side slope. The excavated material was used for building the berm around the hole. This lagoon has been in operation for several years but was constructed so that it met the construction criteria defined in the NRCS standards. A site map is included on the following page for reference.

This site has been an operating dairy facility for more than 20 years. Monitoring well construction was completed in July 1996. Wells were sited on the downgradient side of the lagoon based on topography. There were only three downgradient shallow wells constructed to monitor lagoon seepage due to the small size of the lagoon and limited space. The additional wells shown on the map were installed at the same time to monitor other site conditions not related to lagoon seepage.

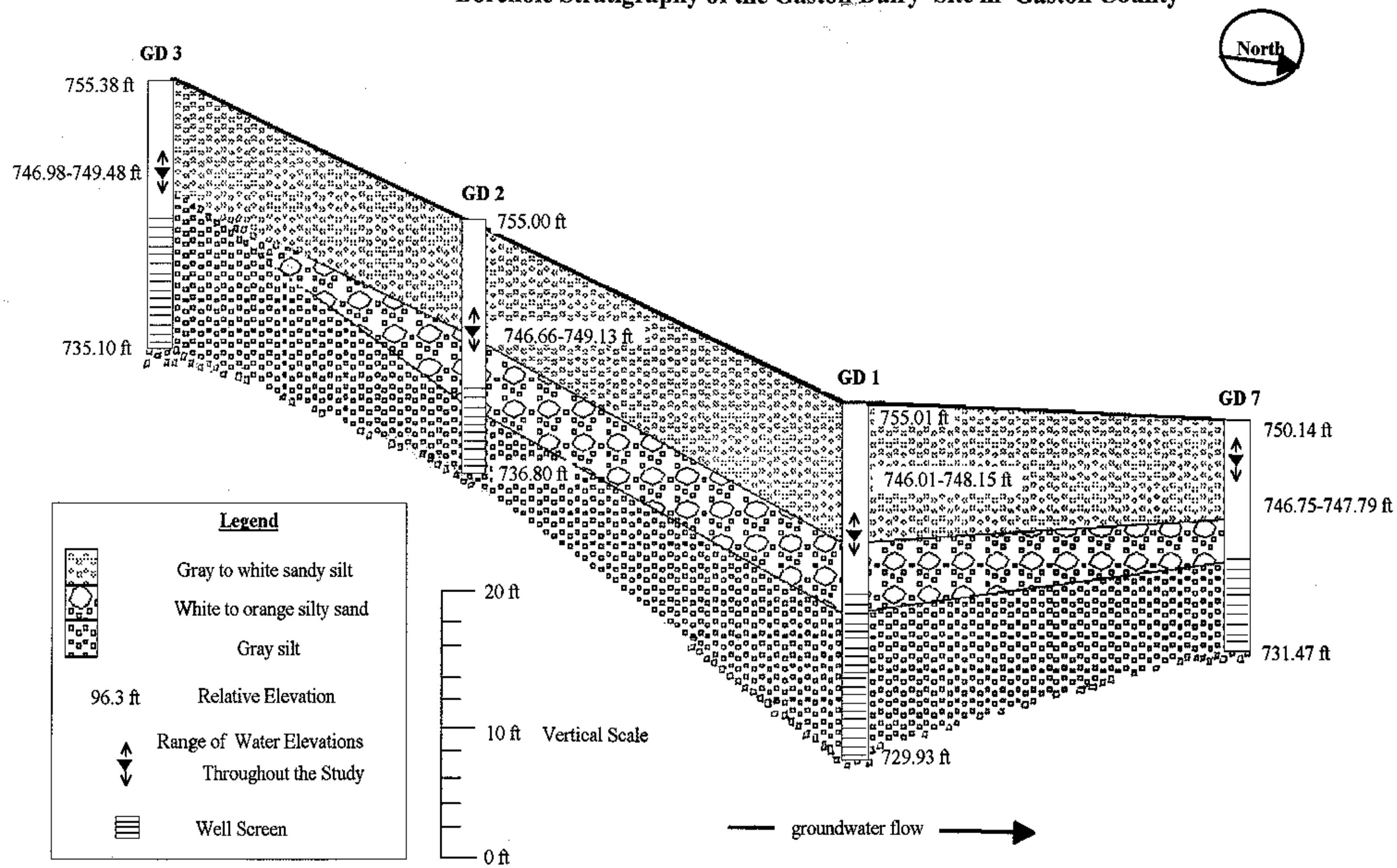
Depths to the top of the well screens ranged from 3 to 5 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 7 to 9 feet below the ground surface during the study.

Soil and sediment textures encountered during drilling of the four wells were generally medium textured. The site's stratigraphy is presented in the 'fence diagram' on page 52.

Gaston Dairy Site



Borehole Stratigraphy of the Gaston Dairy Site in Gaston County



Vertical exaggeration = 1.3:1

Note: The orientation of the view is such that the lagoon is to the left

Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (as shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 75 feet.

Results of the EM survey did not show any significant changes in conductivity in the subsurface that would indicate ground water contamination. It is likely that the amount of clay in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

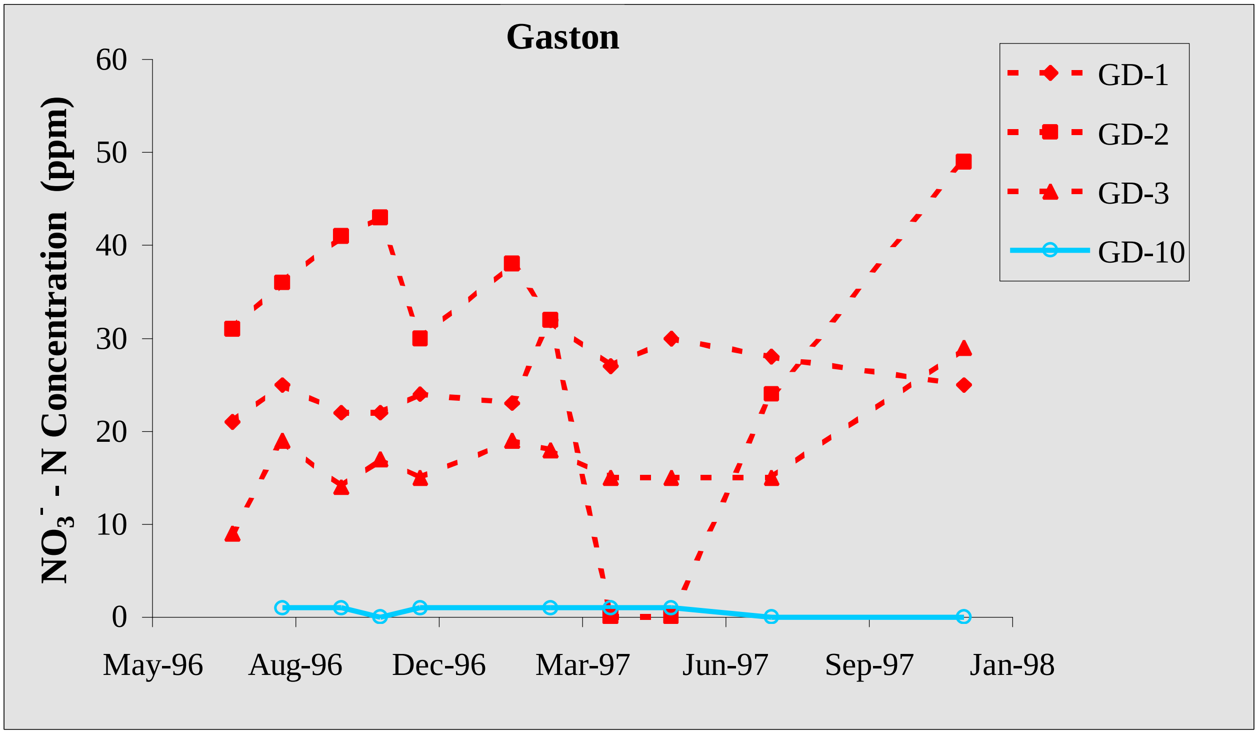
The separation distance between the lagoon bottom and the water table was estimated to be more than 6 feet. Based on this limited information, the Gaston site would generally be considered to have moderate potential for lagoon seepage to contaminate ground water.

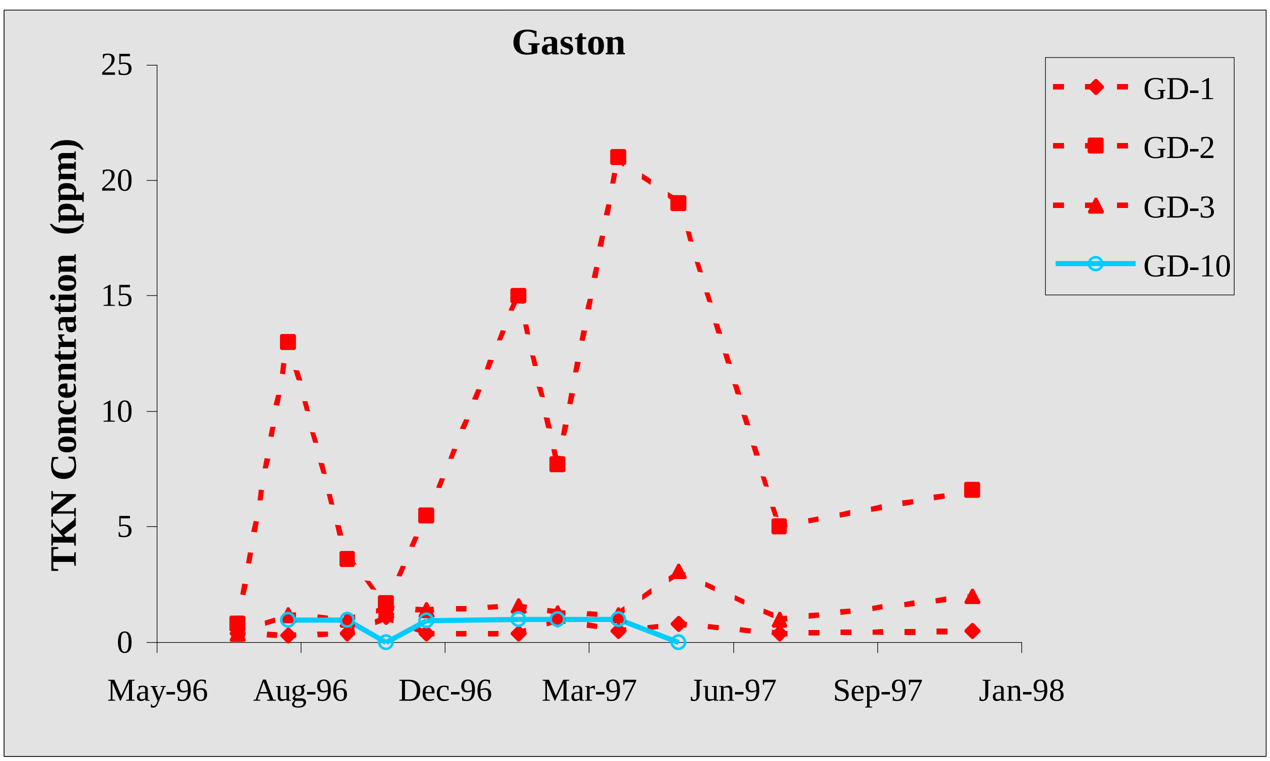
All three of the shallow downgradient wells have some indication that lagoon seepage occurred during the study. The wells had elevated concentrations of nitrate-nitrogen for the entire study period. The source of this nitrate-nitrogen in ground water cannot be determined with certainty but may be related to the animals having access to the area where the wells were constructed before the study began. Before the wells were constructed, a fence was installed and vegetation planted to create a riparian buffer along the course of the stream. The wells are located inside this fenced area so there was no impact from the animals during the study.

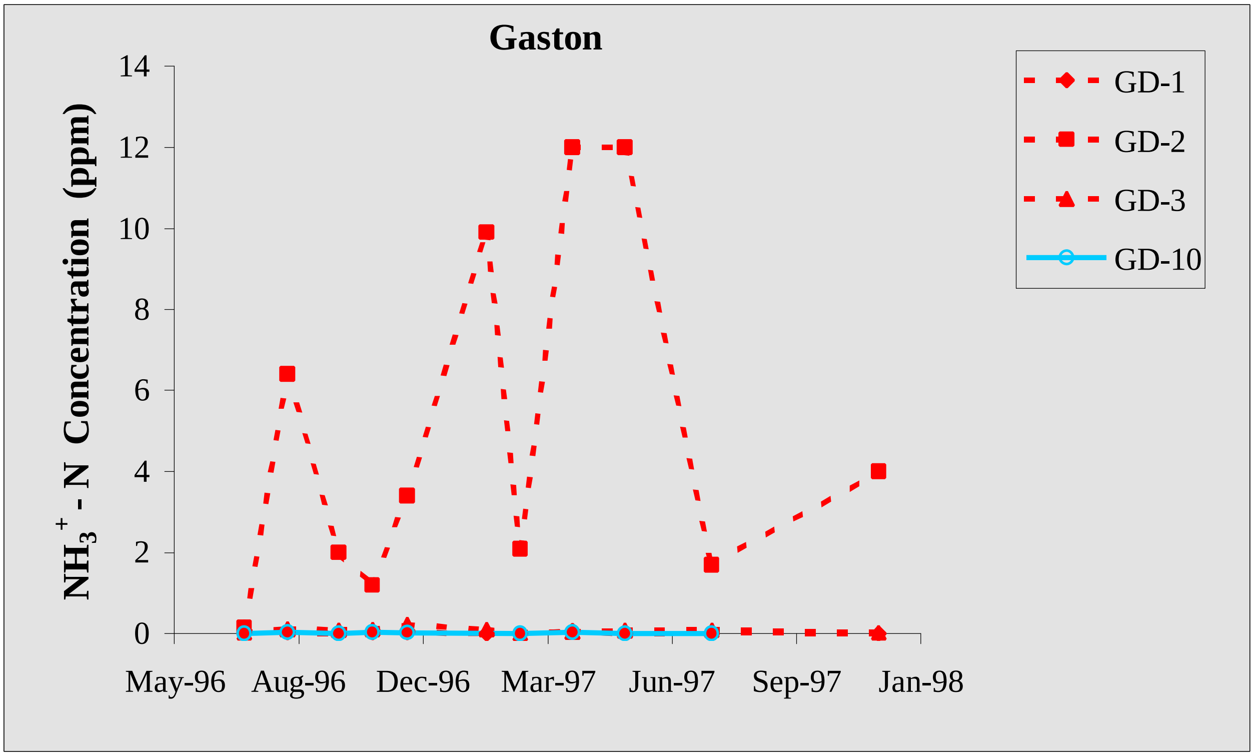
The wells also have elevated concentrations of chloride, which are increasing or trending upward. Two of the wells have elevated concentrations of potassium and an upward trend. One well has elevated concentrations of two of the nitrogen species, ammonia-nitrogen and organic nitrogen, and an upward trend for both constituents. The increasing trends began in November 1996. This appears to be due to lagoon seepage at a rate high enough to contaminate ground water.

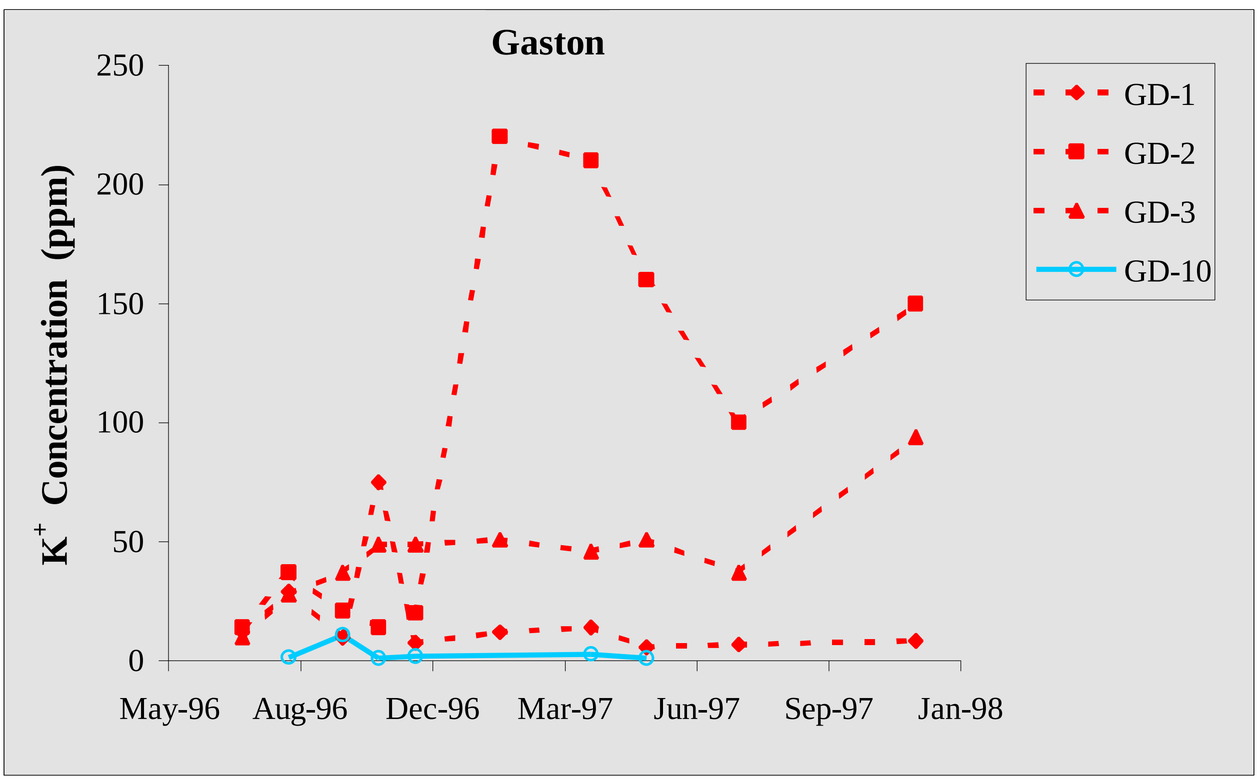
The one well with increasing ammonia and organic nitrogen also had a corresponding decreasing concentration trend for nitrate-nitrogen for two sampling periods, followed by a gradual return to the background concentration for nitrate-nitrogen. This could be explained by a change in oxygen concentration in the subsurface environment. Anaerobic conditions would favor the presence of ammonia-nitrogen in ground water. Aerobic conditions would favor the presence of nitrate-nitrogen in ground water.

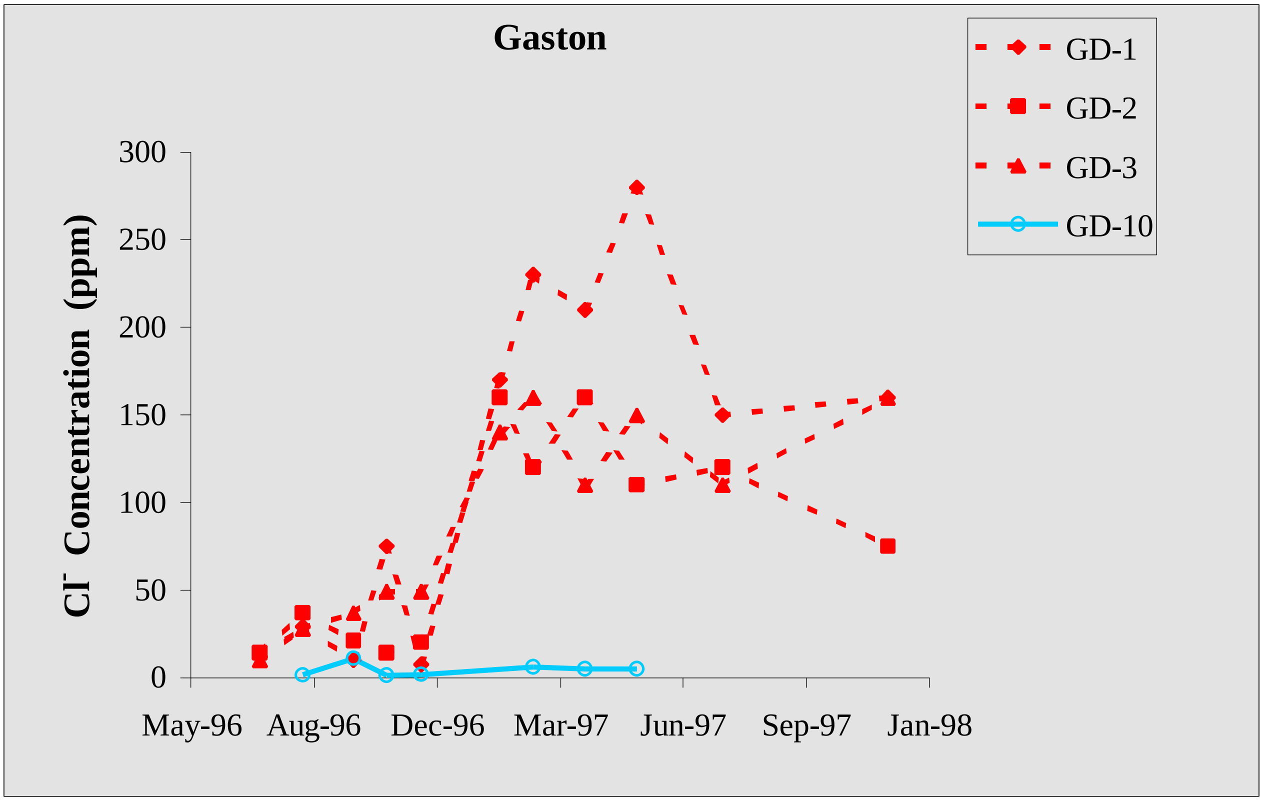
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:


Gaston
60
50
40
30
20
10
0
NO_3^- - N Concentration (ppm)
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
GD-1
GD-2
GD-3
GD-10


Gaston
25
20
15
10
5
0
TKN Concentration (ppm)
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
GD-1
GD-2
GD-3
GD-10


Gaston
NH_3^+ - N Concentration (ppm)
14
12
10
8
6
4
2
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
GD-1
GD-2
GD-3
GD-10


Gaston
K^+ Concentration (ppm)
250
200
150
100
50
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
GD-1
GD-2
GD-3
GD-10


Gaston
GD-1
GD-2
GD-3
GD-10
300
250
200
150
100
50
0
Cl⁻ Concentration (ppm)
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98

Nahunta Site (Wayne County)

The Nahunta site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are fine to medium textured.

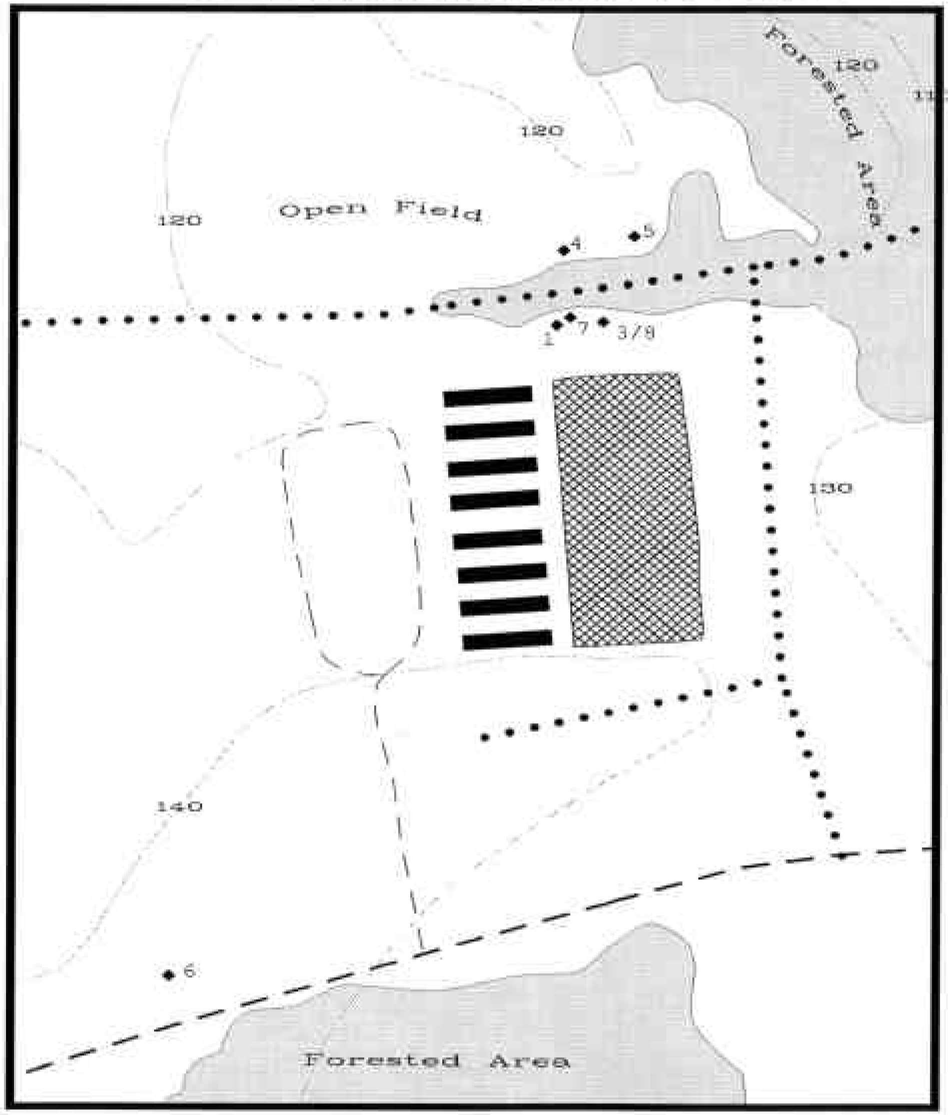
The lagoon was constructed on a broad, nearly flat hilltop. The method of construction was excavation into the subsurface several feet and then building up the berm around the hole using the excavated material. A site map is included for reference.

This site was previously used for row crop agriculture and no clearing of vegetation was required prior to the conversion to an animal operation. Monitoring well construction was completed in December 1995. Wells were sited on the downgradient side of the lagoon based on topography.

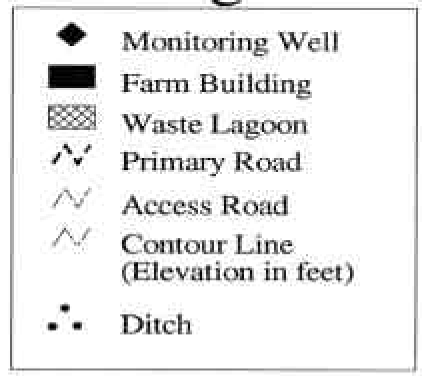
Depths of the top of the well screens ranged from about 8 to13 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 3 to 8 feet below the ground surface.

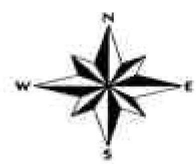
Soil and sediment textures encountered during drilling of the four wells were generally medium to fine textured. The site's stratigraphy is presented in the 'fence diagram' on page 59.

Nahunta Site



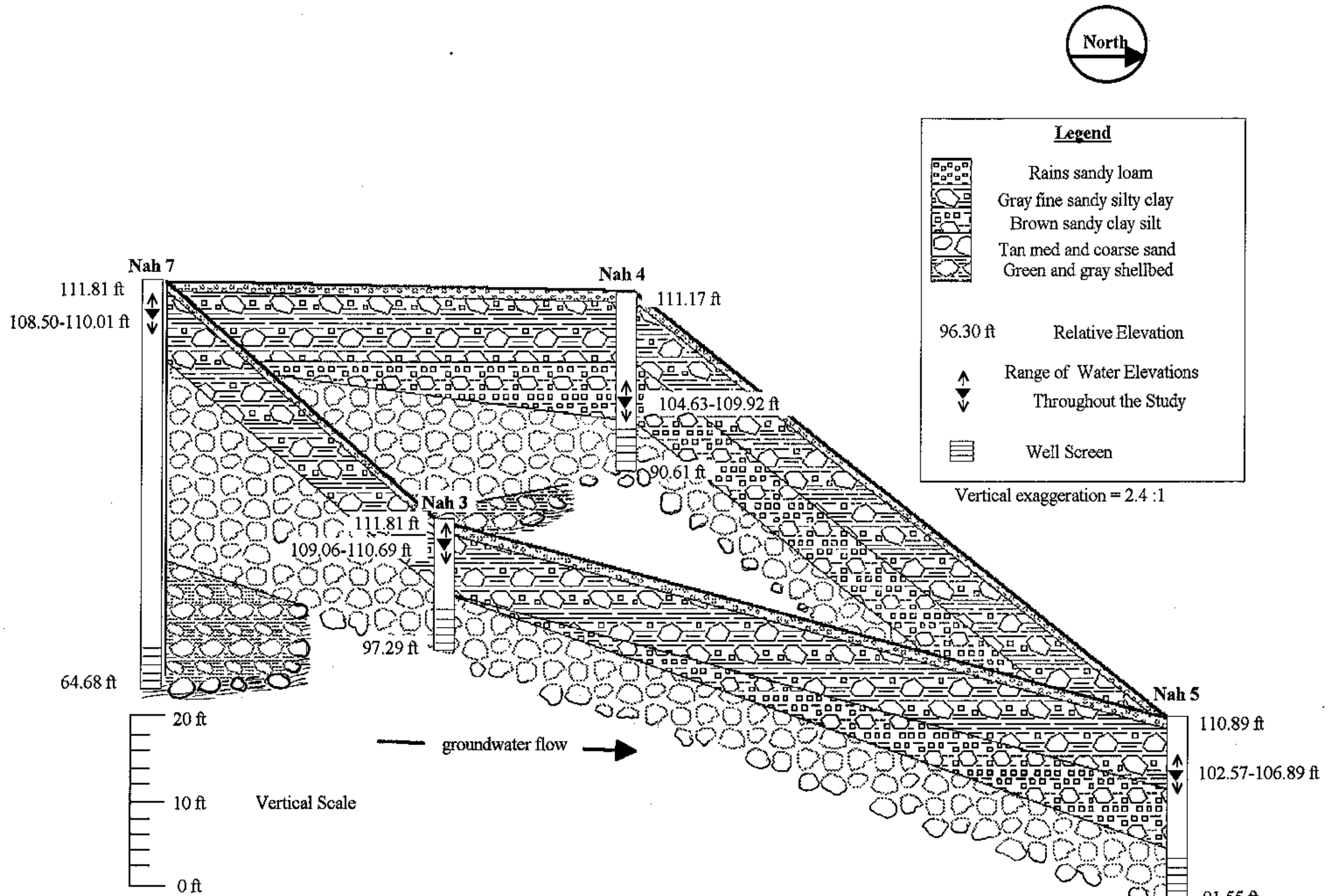
Legend





Scale: 1" = 450 feet
(approximately)

Borehole Stratigraphy of the Nahunta Site in Wayne County



Note: The orientation of the view is such that the lagoon is to the left

Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 1,500 feet.

Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is possible that the variability of the clay in the subsurface was such that the EM meter was unable to distinguish between higher conductive ground water and more conductive clay sediments.

The separation distance between the lagoon bottom and the water table was estimated to be less than 4 feet. Based on this limited information, the Nahunta site would generally be considered to have moderate potential for lagoon seepage to contaminate ground water.

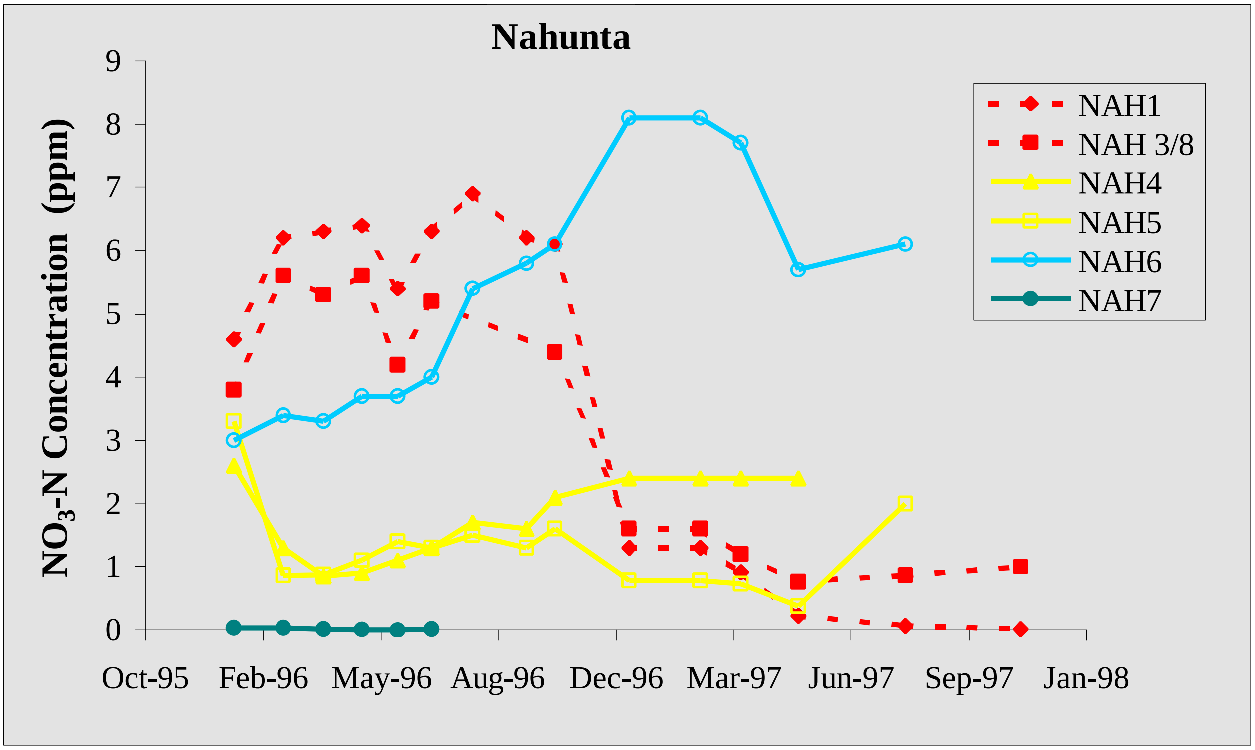
In February 1997 during a routine sampling event, an accidental waste release was discovered from the discharge pipes connected to one of the swine houses to the ground surface in the area where the closest monitoring wells were located. The cooperator was notified immediately and took actions to seal off the leak. No further discharge has been noted.

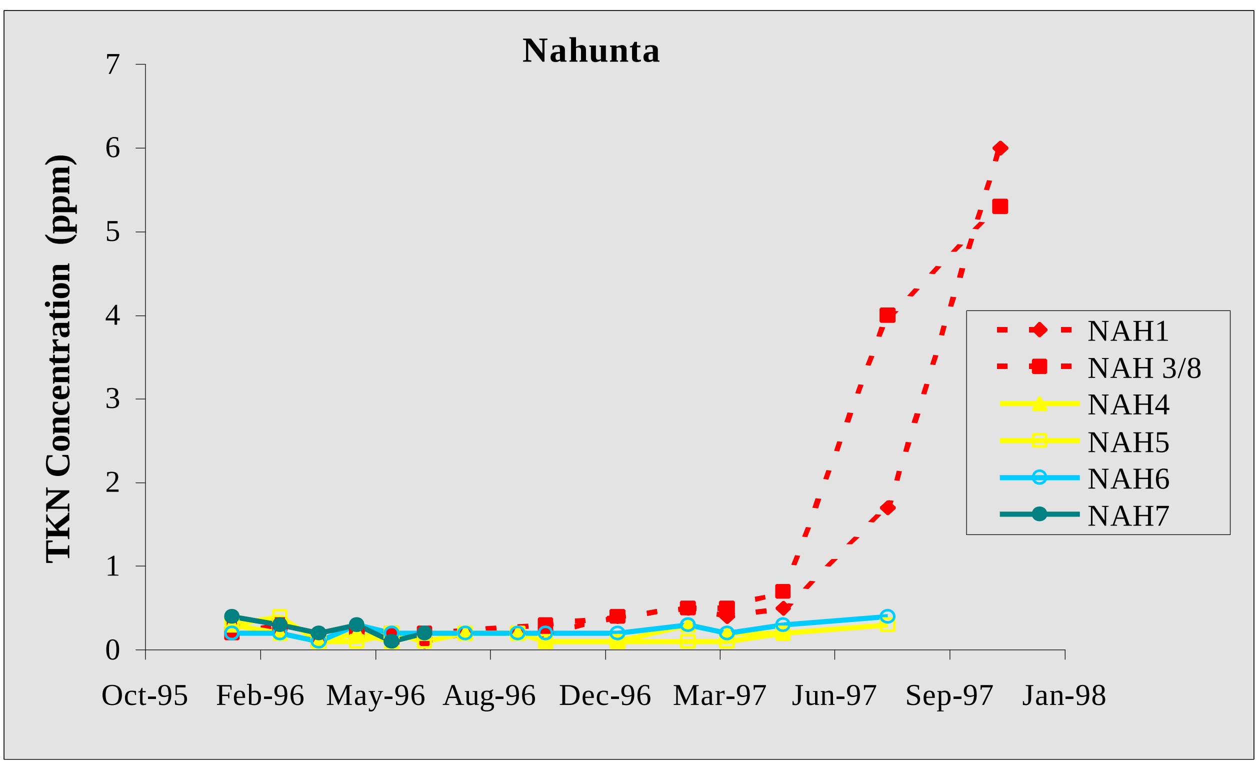
Two of the shallow wells were affected by this waste release. Chloride is the first constituent to be detected at high concentrations in the shallow ground water. Potassium, ammonia-nitrogen and TKN-nitrogen are showing an increasing concentration trend as well. These wells also show a corresponding decreasing nitrate-nitrogen trend over the same sampling period. This appears to indicate a change in the subsurface environmental conditions where dissolved oxygen has been depleted. Further monitoring of the wells should show a decrease in lagoon seepage indicator constituents since the source of the waste has been eliminated.

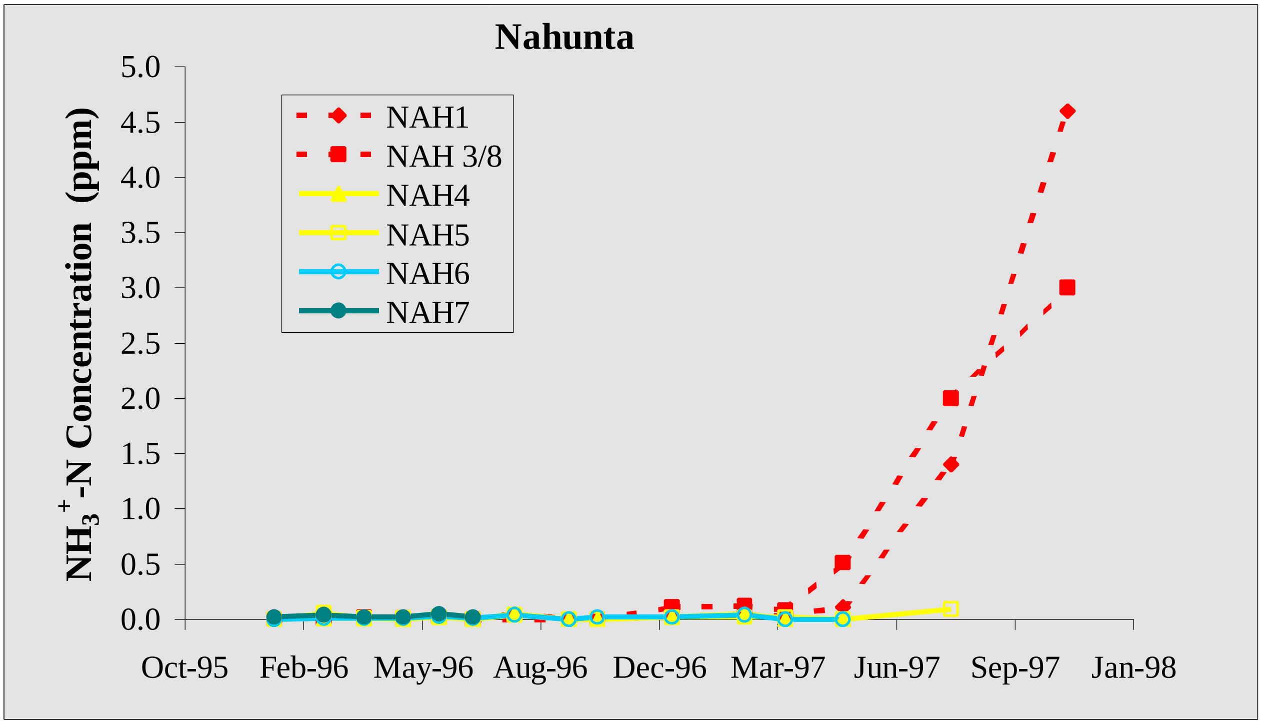
The upgradient well has slightly elevated concentrations of nitrate. This may be related to agricultural activities over the last 20 years on adjacent farm fields. There was not another suitable location for this upgradient well on the property.

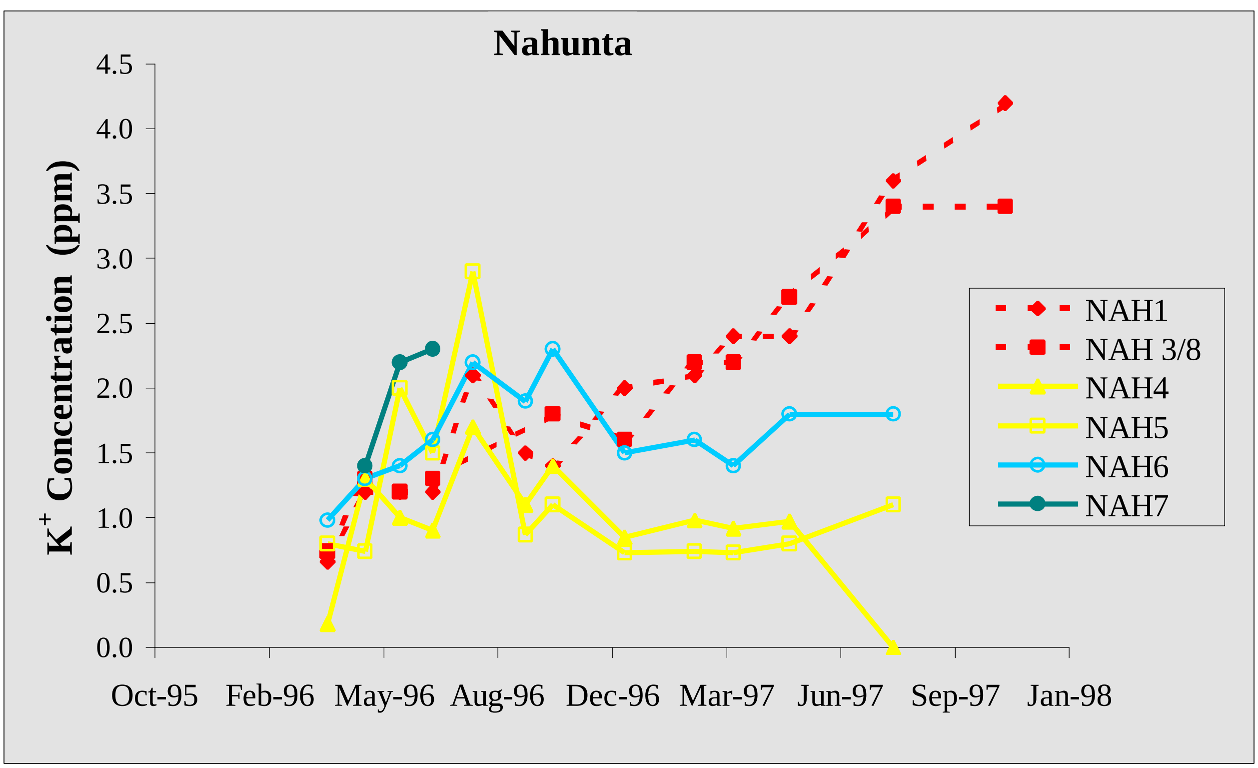
In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

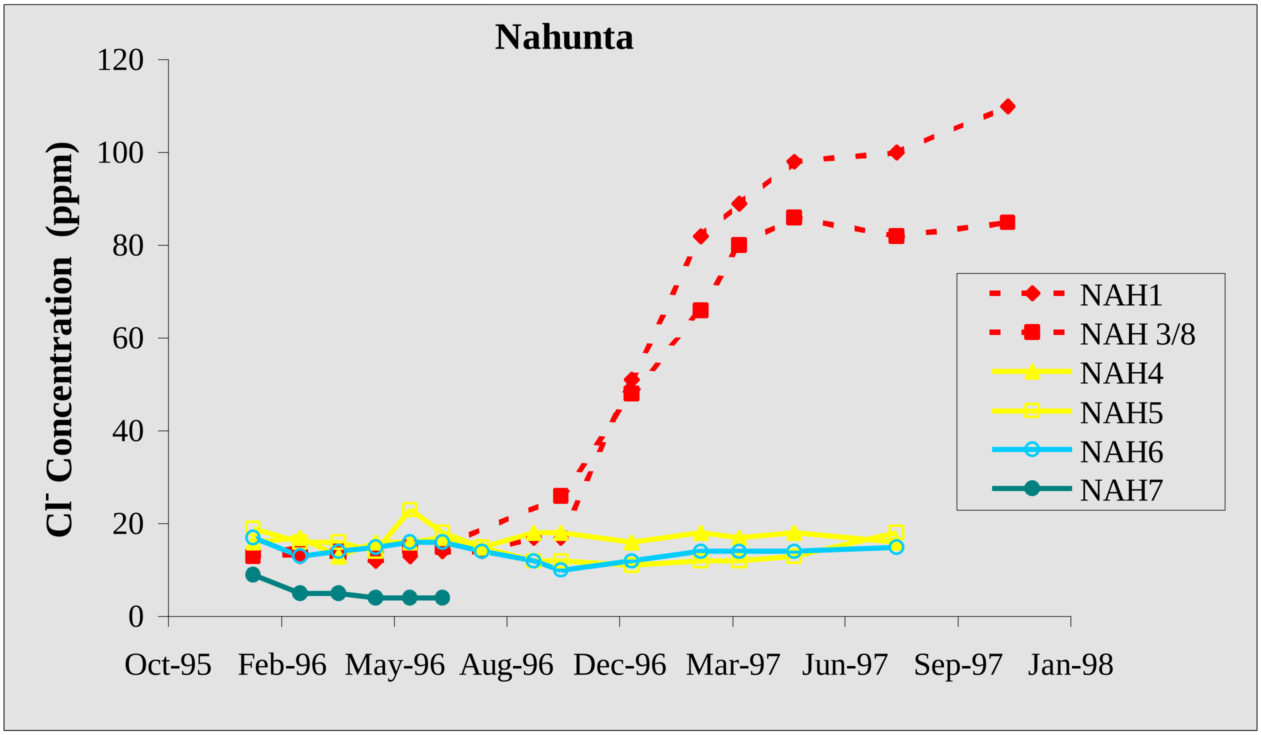
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:


Nahunta
NO3-N Concentration (ppm)
9
8
7
6
5
4
3
2
1
0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
NAH1
NAH 3/8
NAH4
NAH5
NAH6
NAH7


Nahunta
TKN Concentration (ppm)
7
6
5
4
3
2
1
0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
NAH1
NAH 3/8
NAH4
NAH5
NAH6
NAH7


Nahunta
NH3+-N Concentration (ppm)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
NAH1
NAH 3/8
NAH4
NAH5
NAH6
NAH7


Nahunta
K+ Concentration (ppm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
NAH1
NAH 3/8
NAH4
NAH5
NAH6
NAH7


Nahunta
Cl⁻ Concentration (ppm)
120
100
80
60
40
20
0
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
NAH1
NAH 3/8
NAH4
NAH5
NAH6
NAH7

McDaniels Site (Samson County)

The McDaniels site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are medium to fine textured.

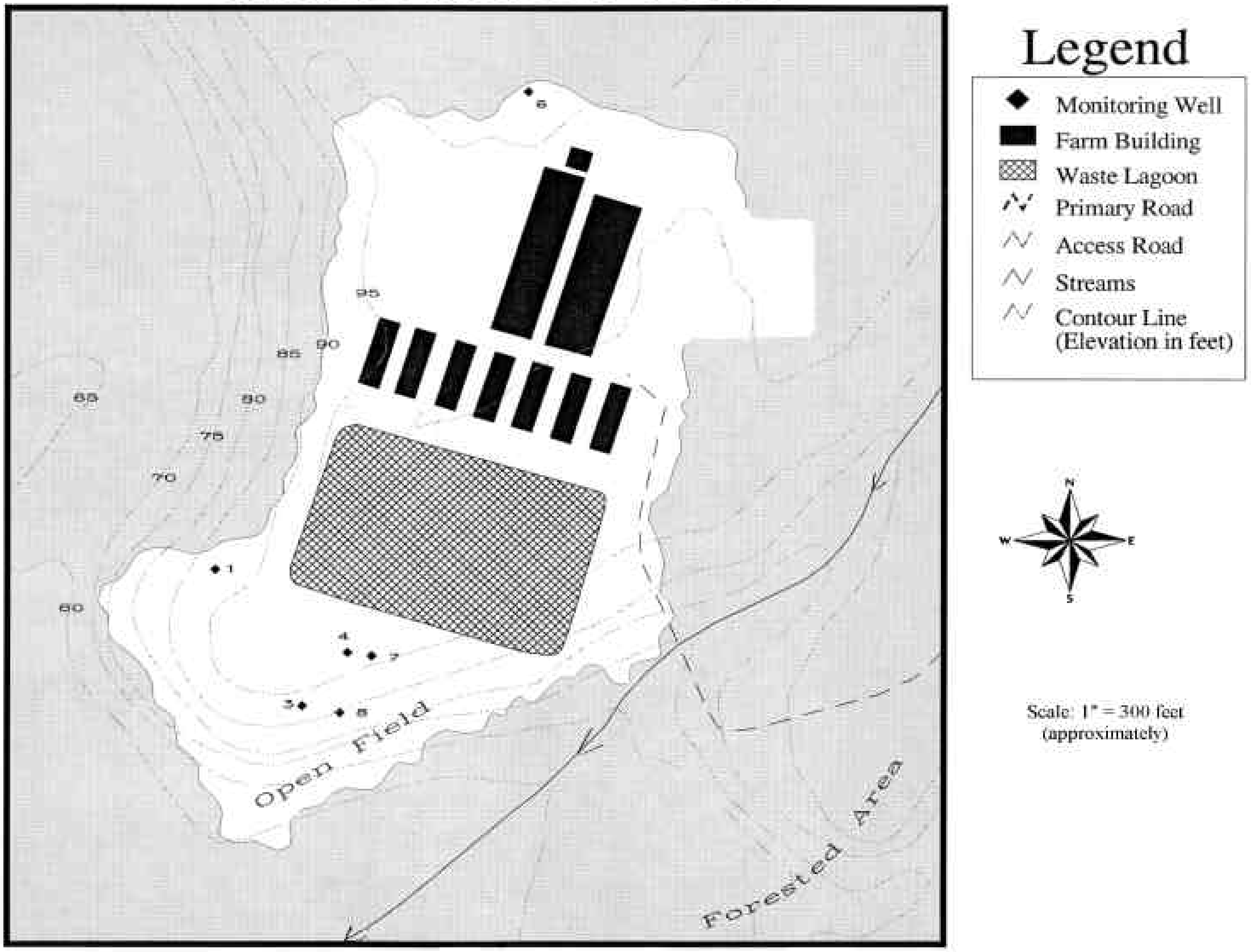
The lagoon was constructed by excavation into the side slope of the topographic high area on the site. The excavated material was used for building the berm around the hole. A site map is included on the next page for reference.

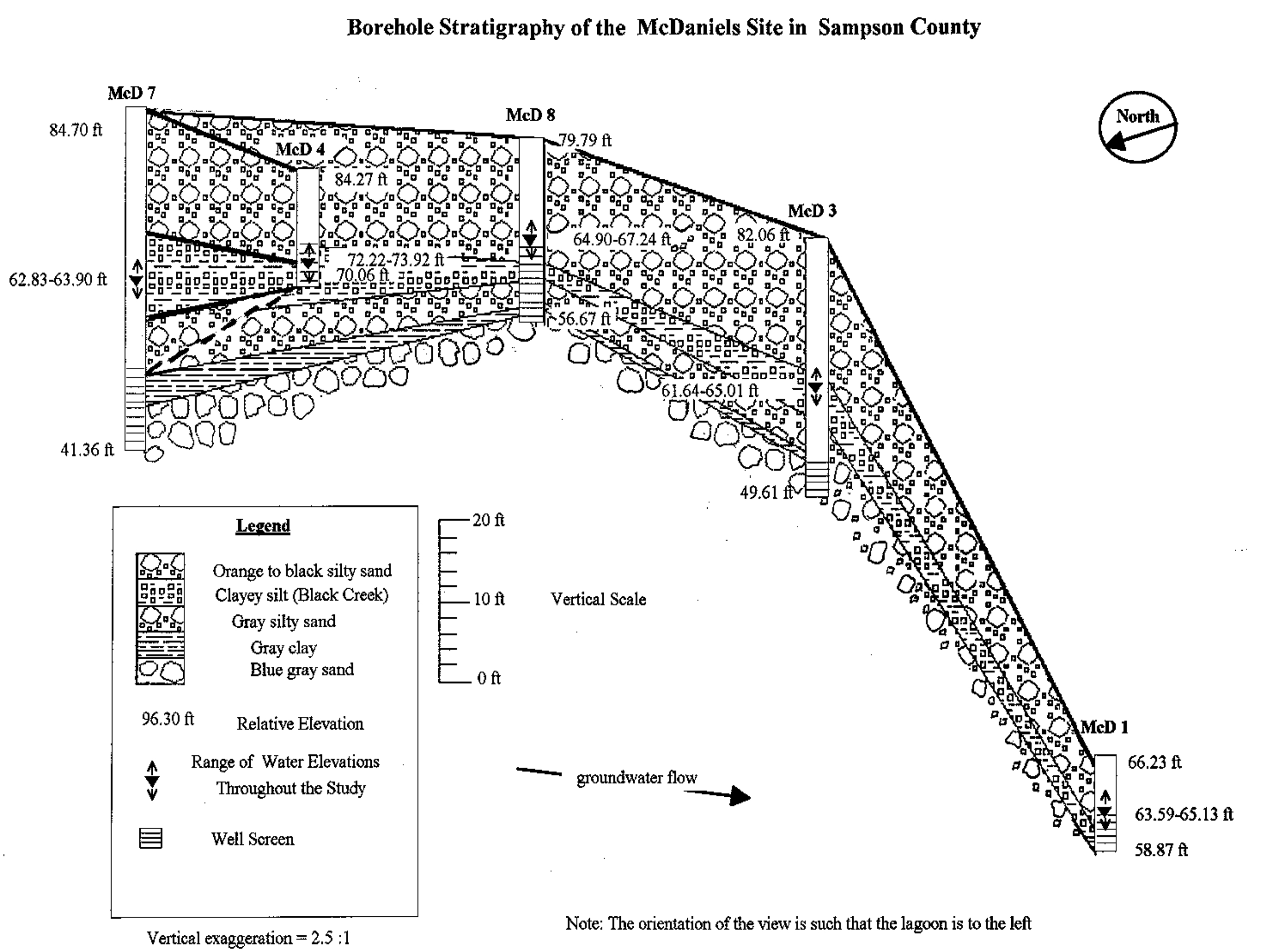
The area of the site where the lagoon was constructed was cleared of the existing vegetation, primarily a mixed stand of pine and hardwood. Monitoring well construction was completed in February 1996. Wells were sited on the downgradient side of the lagoon based on topography.

Depths to the top of the well screens ranged from 4 to 28 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 5 to 20 feet below the ground surface.

Soil and sediment textures encountered during drilling of the four wells were medium to fine textured in general. The site's stratigraphy is presented in the 'fence diagram' on page 66.

McDaniel Site




Borehole Stratigraphy of the McDaniels Site in Sampson County
McD 7
84.70 ft
62.83-63.90 ft
41.36 ft
McD 4
84.27 ft
72.22-73.92 ft
70.06 ft
McD 8
79.79 ft
64.90-67.24 ft
56.67 ft
McD 3
82.06 ft
61.64-65.01 ft
49.61 ft
McD 1
66.23 ft
63.59-65.13 ft
58.87 ft
North
Legend
Orange to black silty sand
Clayey silt (Black Creek)
Gray silty sand
Gray clay
Blue gray sand
96.30 ft
Relative Elevation
Range of Water Elevations
Throughout the Study
Well Screen
20 ft
10 ft
0 ft
Vertical Scale
groundwater flow
Vertical exaggeration = 2.5 :1
Note: The orientation of the view is such that the lagoon is to the left

Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 2,000 feet.

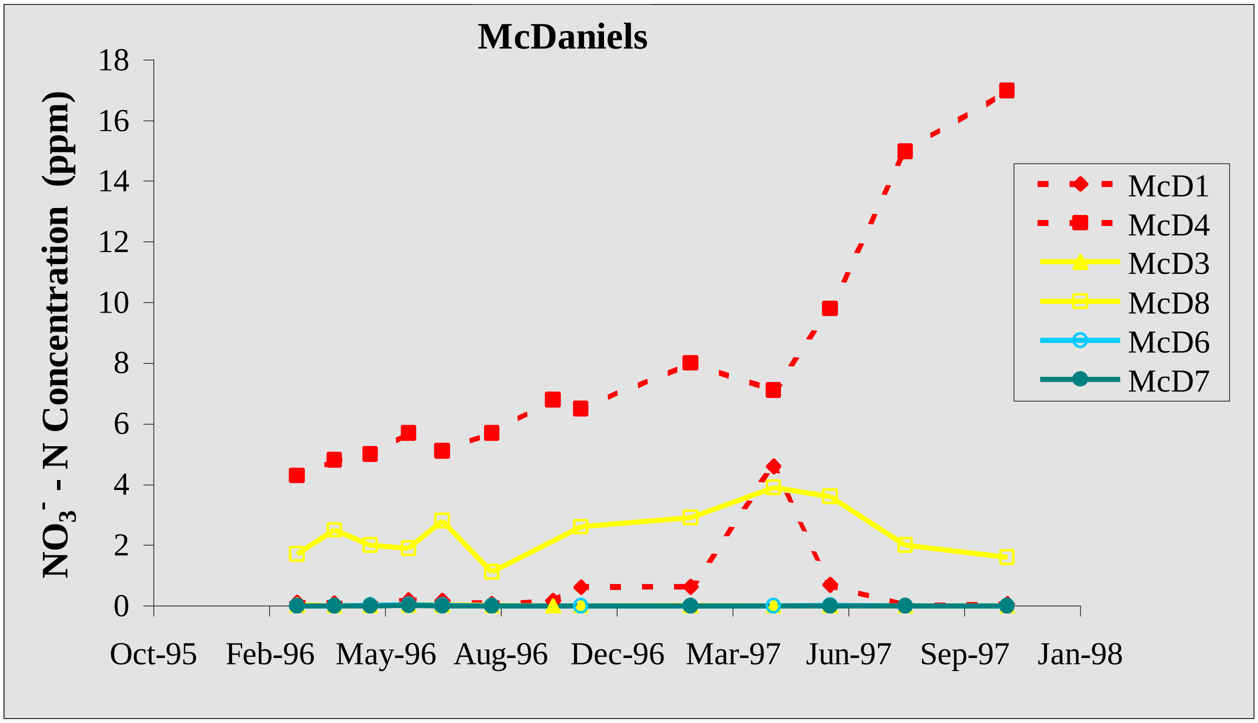
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is possible that the amount of clay in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

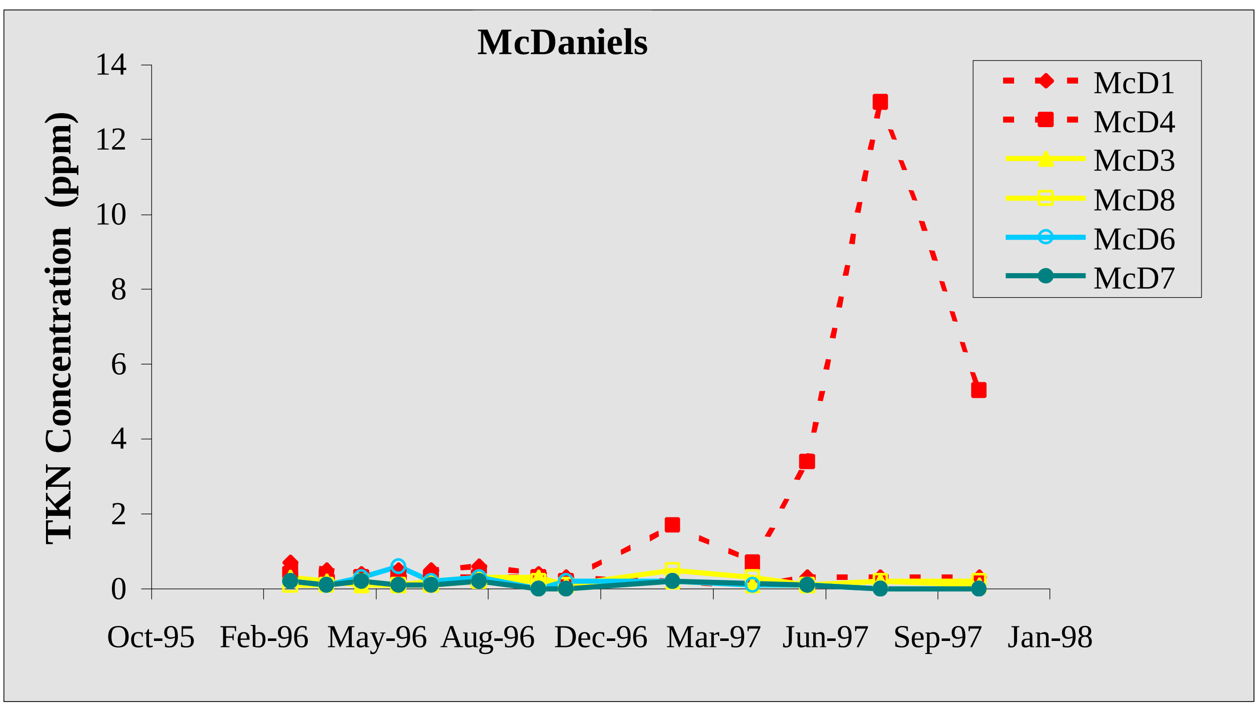
The separation distance between the lagoon bottom and the water table was estimated to be more than 5 feet. Stratigraphy data collected indicated a somewhat thin and discontinuous clay layer at approximately 15 to 20 feet below the surface. Based on this limited information, the McDaniels site would generally be considered to have moderate potential for lagoon seepage to contaminate ground water.

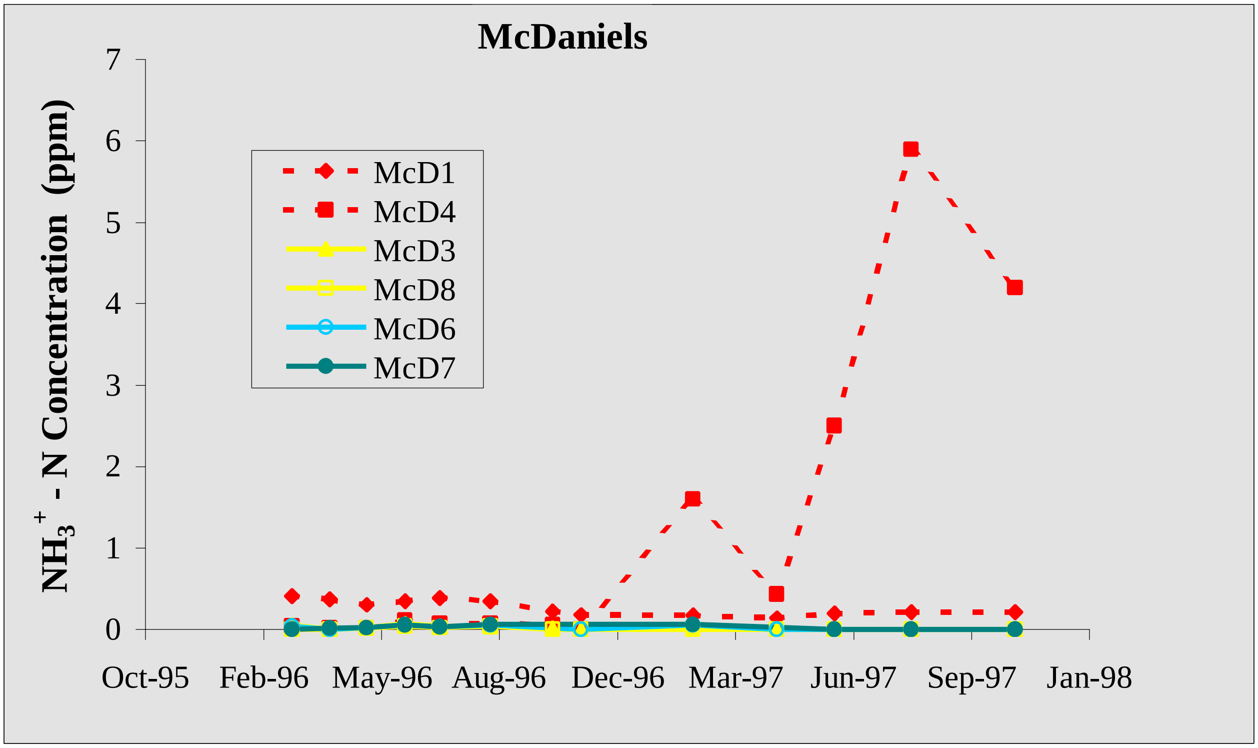
One well, McD-4, located approximately 114 feet downgradient from the lagoon berm, has increasing trends in concentration over the last three sampling periods for all of the lagoon seepage indicators. Concentrations are not very high overall. However, since the early sampling data indicated no presence of contamination it appears that the concentrations are the result of lagoon seepage. No distinct clay layer was described in the well boring log of this well or the well McD-7, which is located only 10 feet away and was drilled to a depth of 43 feet below the surface.

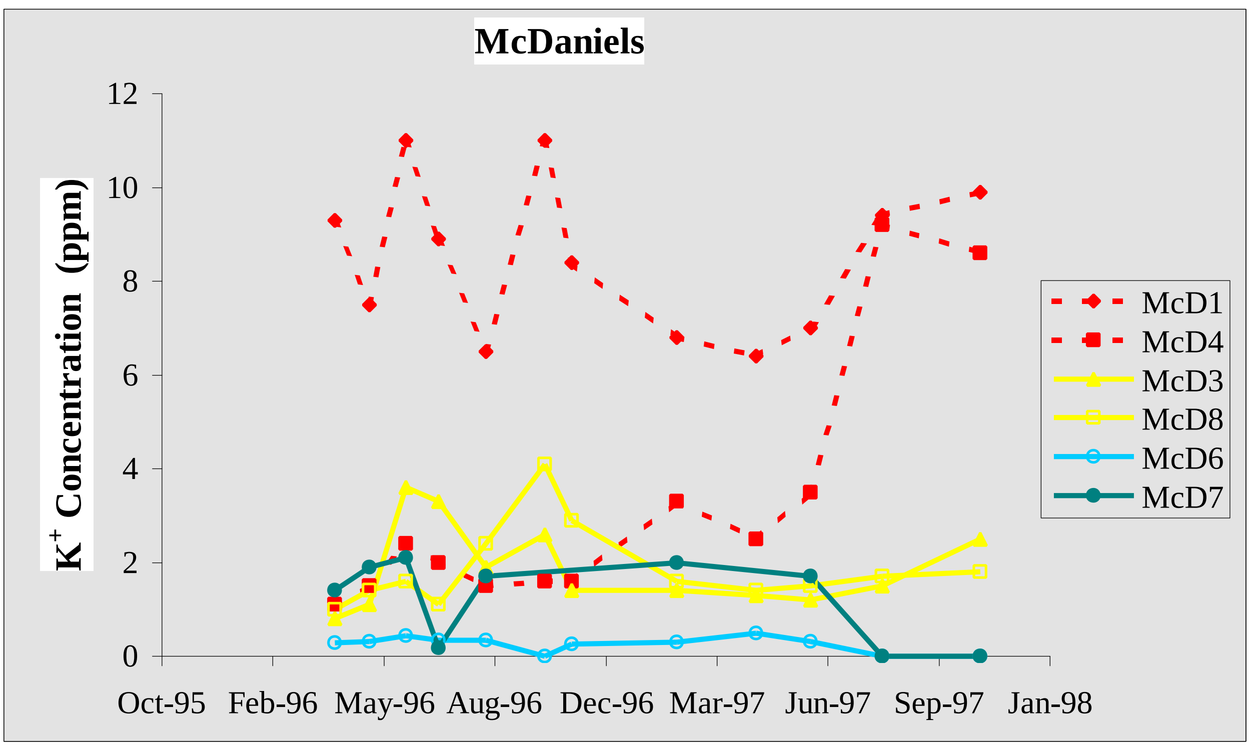
In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

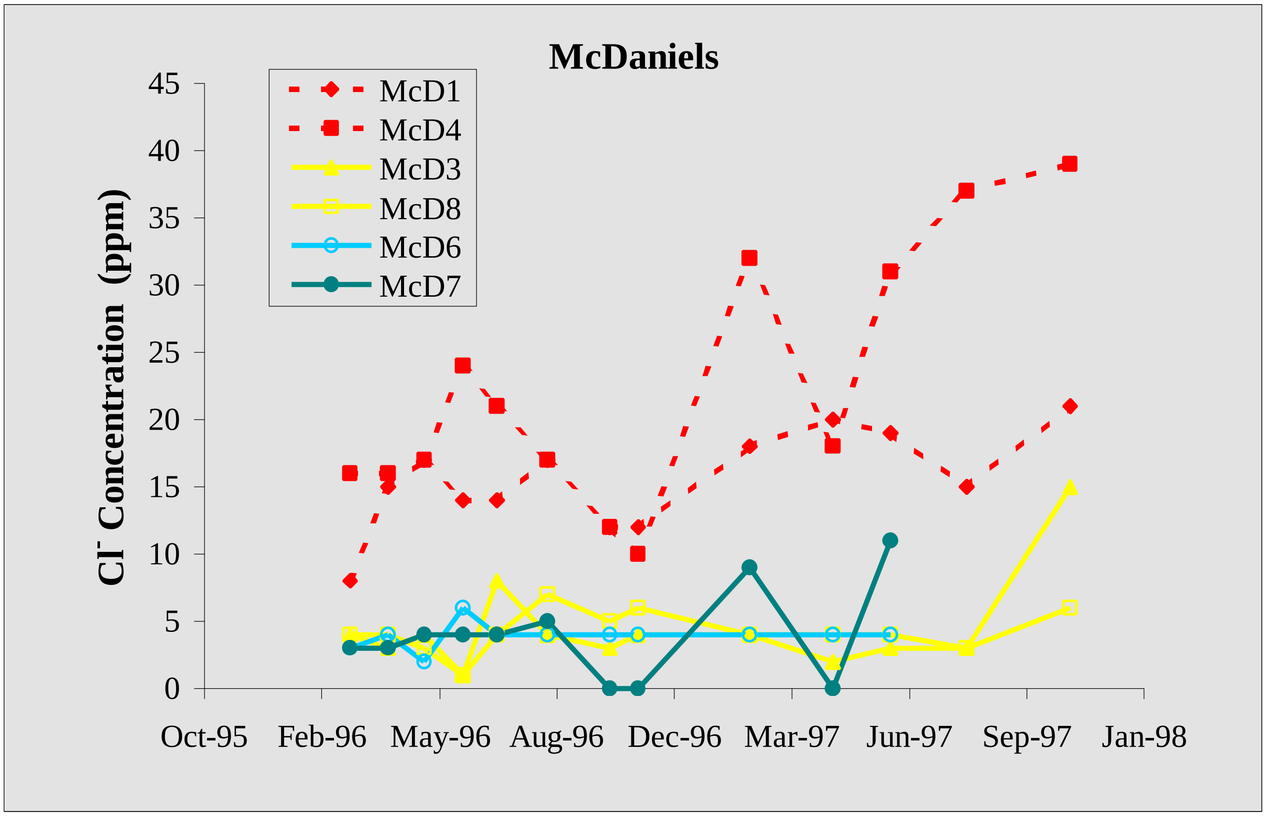
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:


McDaniels
NO_3^- - N Concentration (ppm)
0
2
4
6
8
10
12
14
16
18
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
McD1
McD4
McD3
McD8
McD6
McD7


McDaniels
TKN Concentration (ppm)
0
2
4
6
8
10
12
14
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
McD1
McD4
McD3
McD8
McD6
McD7


McDaniels
NH3+ - N Concentration (ppm)
McD1
McD4
McD3
McD8
McD6
McD7
0
1
2
3
4
5
6
7
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98


McDaniels
K+ Concentration (ppm)
McD1
McD4
McD3
McD8
McD6
McD7
0
2
4
6
8
10
12
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98


McDaniels
Cl⁻ Concentration (ppm)
45
40
35
30
25
20
15
10
5
0
McD1
McD4
McD3
McD8
McD6
McD7
Oct-95
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98

Grantham Site (Wayne County)

The site known as the Grantham site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are medium to fine textured.

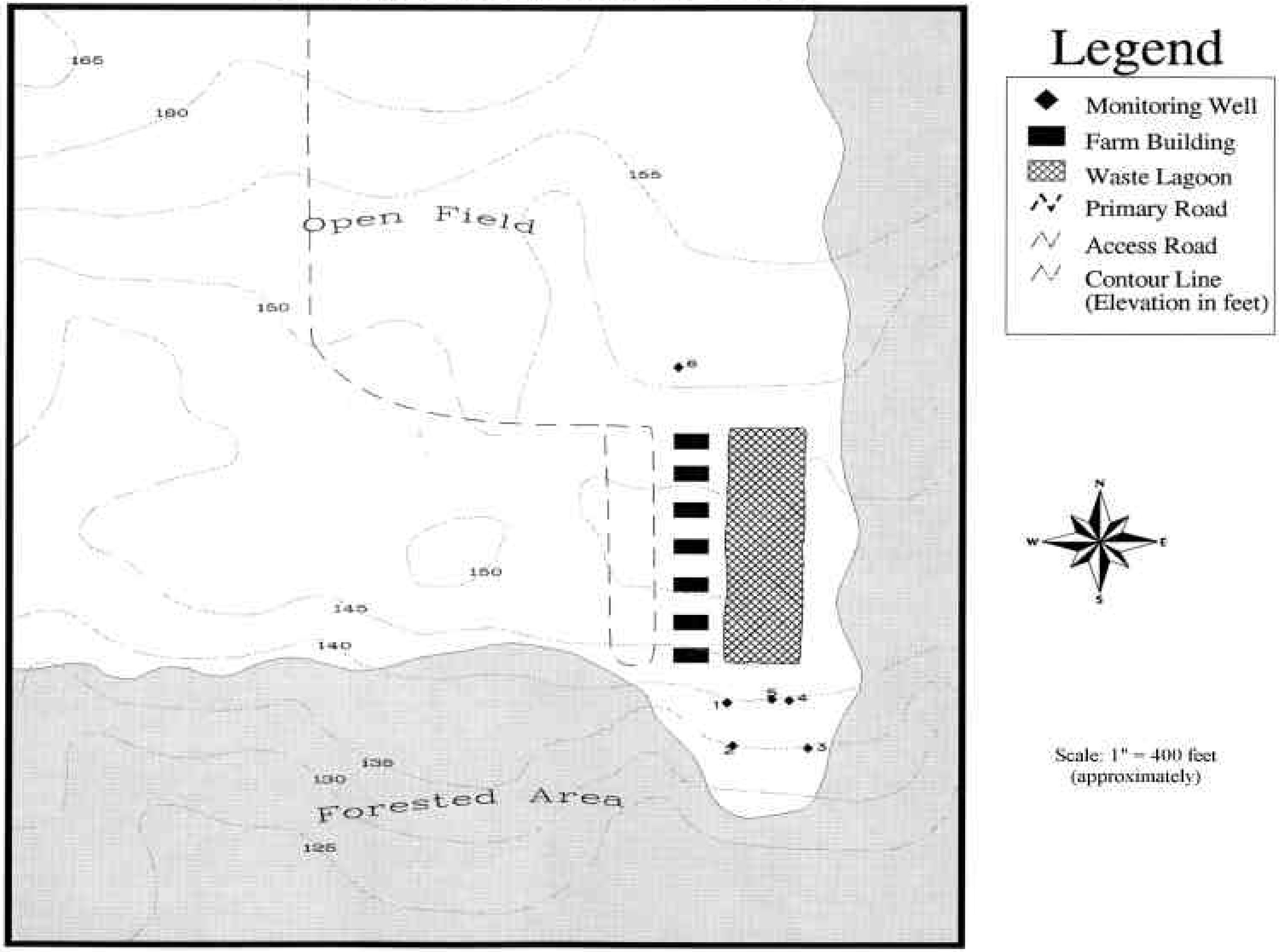
The lagoon was constructed by excavation into the gently sloping to mostly flat section of the site. The excavated material was used for building the berm around the hole. A site map is included on the following page for reference.

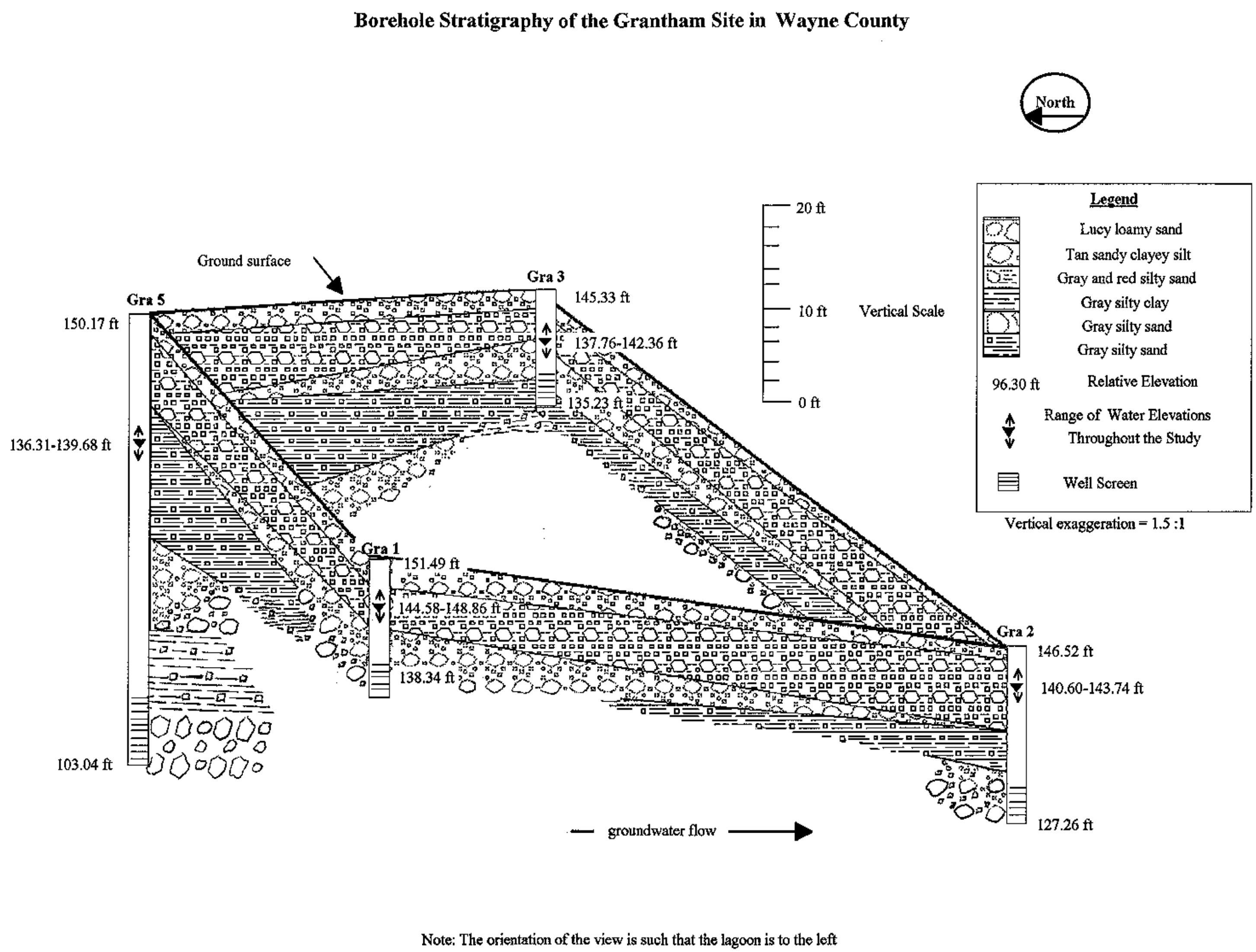
The area of the site where the lagoon was constructed was previously used for traditional row-crop agricultural production. Monitoring well construction was completed in May 1996. Wells were sited on the downgradient side of the lagoon based on topography.

Depths to the top of the well screens ranged from 5 to 20 feet below surface in the four shallow downgradient wells. Water table depth in the shallow downgradient wells ranged from approximately 6 to 11 feet below the ground surface.

Soil and sediment textures encountered during drilling of the four wells on this site were medium textured in general. The site's stratigraphy is presented in the 'fence diagram' on page 73.

Grantham Site




Borehole Stratigraphy of the Grantham Site in Wayne County
North
Legend
Lucy loamy sand
Tan sandy clayey silt
Gray and red silty sand
Gray silty clay
Gray silty sand
Gray silty sand
96.30 ft
Relative Elevation
Range of Water Elevations Throughout the Study
Well Screen
Vertical exaggeration = 1.5 :1
20 ft
10 ft
0 ft
Vertical Scale
Ground surface
Gra 5
150.17 ft
136.31-139.68 ft
103.04 ft
Gra 3
145.33 ft
137.76-142.36 ft
135.23 ft
Gra 1
151.49 ft
144.58-148.86 ft
138.34 ft
Gra 2
146.52 ft
140.60-143.74 ft
127.26 ft
groundwater flow
Note: The orientation of the view is such that the lagoon is to the left

Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 500 feet.

Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. It is likely that the amount of fine textured sediments in the subsurface was such that the EM meter would not be able to distinguish between the higher conductive ground water and more conductive clay sediments.

The separation distance between the lagoon bottom and the water table was estimated to be less than 5 feet. Stratigraphy data collected indicated a somewhat thin and discontinuous clay layer at approximately 15 to 20 feet below the surface. Based on this limited information, the Grantham site would generally be considered to have moderate potential for lagoon seepage to contaminate ground water.

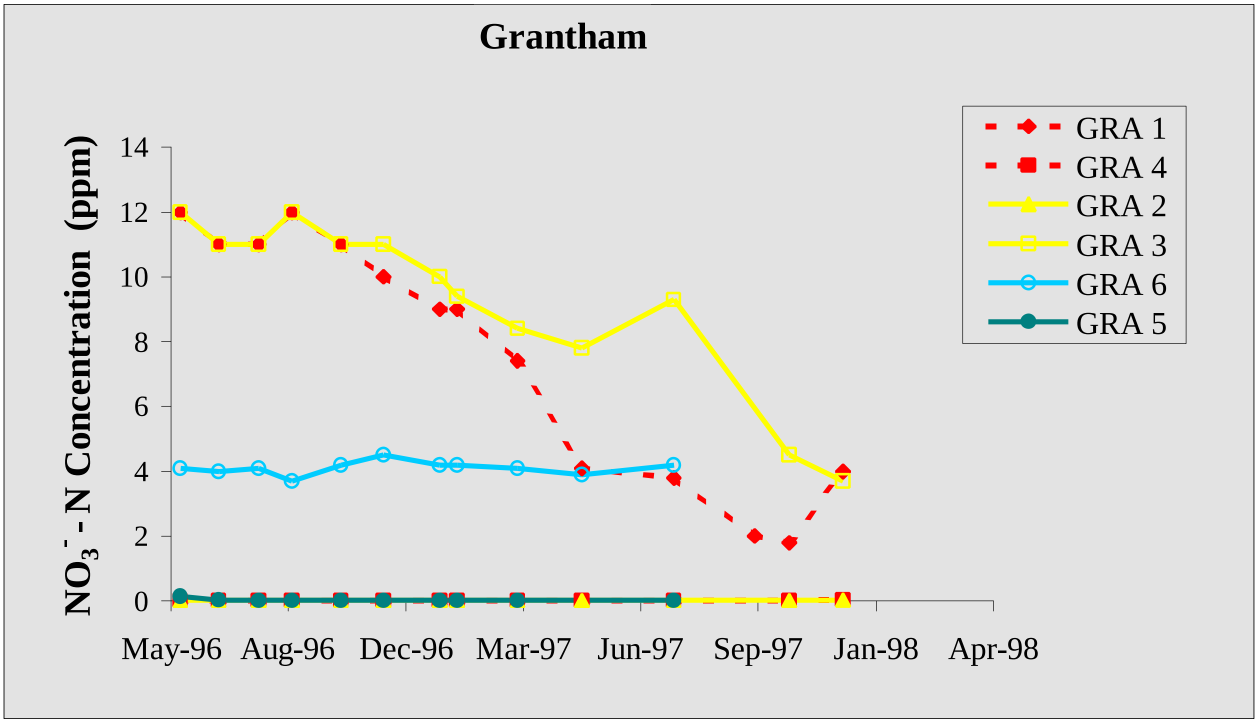
Nitrate-nitrogen concentrations in one well, GRA-1 located approximately 125 feet downgradient from the lagoon berm, began in the 10 to 12 ppm range and now are in the 2 to 4 ppm range. The other nitrogen species have had increasing trends for four sampling periods, followed by a decreased value for the final sampling period of the study. This could be explained by the presence of lagoon seepage and an associated change in oxygen concentration in the subsurface environment. Anaerobic conditions would favor the presence of ammonia-nitrogen in ground water.

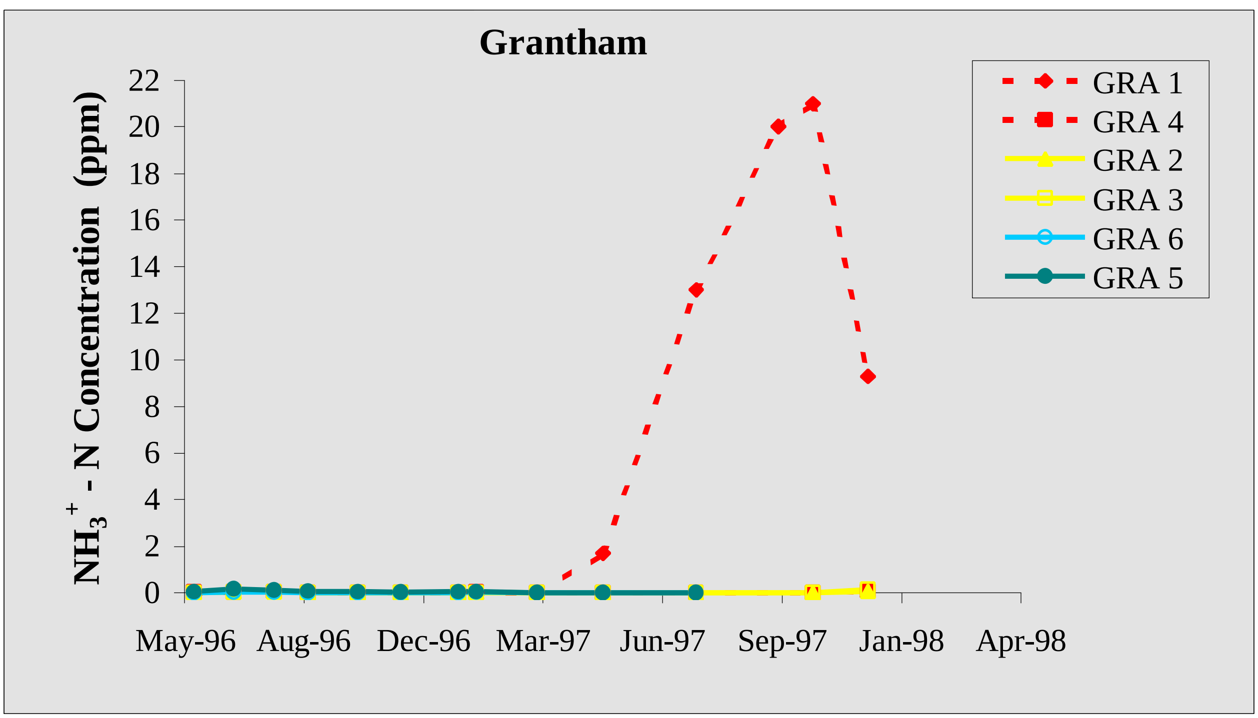
Aerobic conditions would favor the presence of nitrate-nitrogen in ground water. Chloride has been increasing in this well over the last six sampling periods to a level that is just under one half that of the lagoon waste concentration. Potassium was extremely low until the final sampling period when it was found at a concentration that is one third as high as the lagoon waste itself.

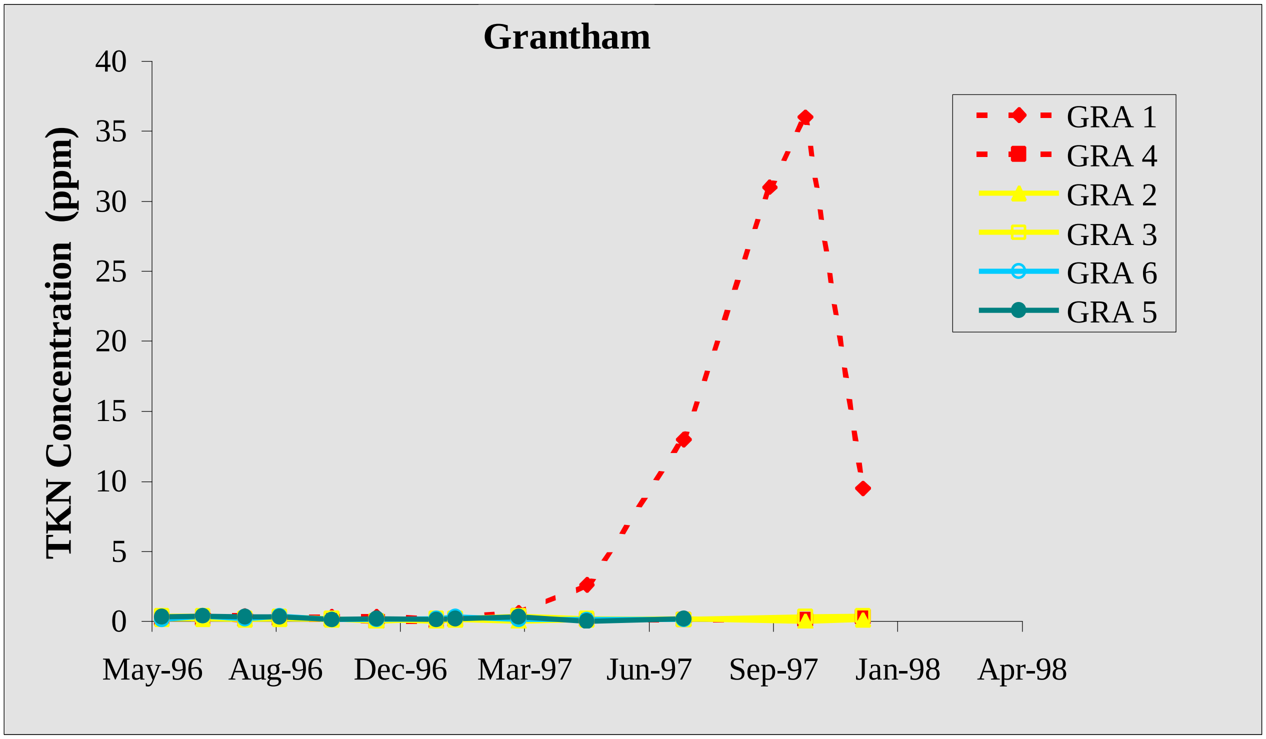
Concentrations are not very high overall, with the exception of the final potassium value. However, since the early sampling data indicated no presence of the seepage indicators, it appears that the elevated concentrations of ammonia-nitrogen, organic nitrogen and chloride are the result of lagoon seepage.

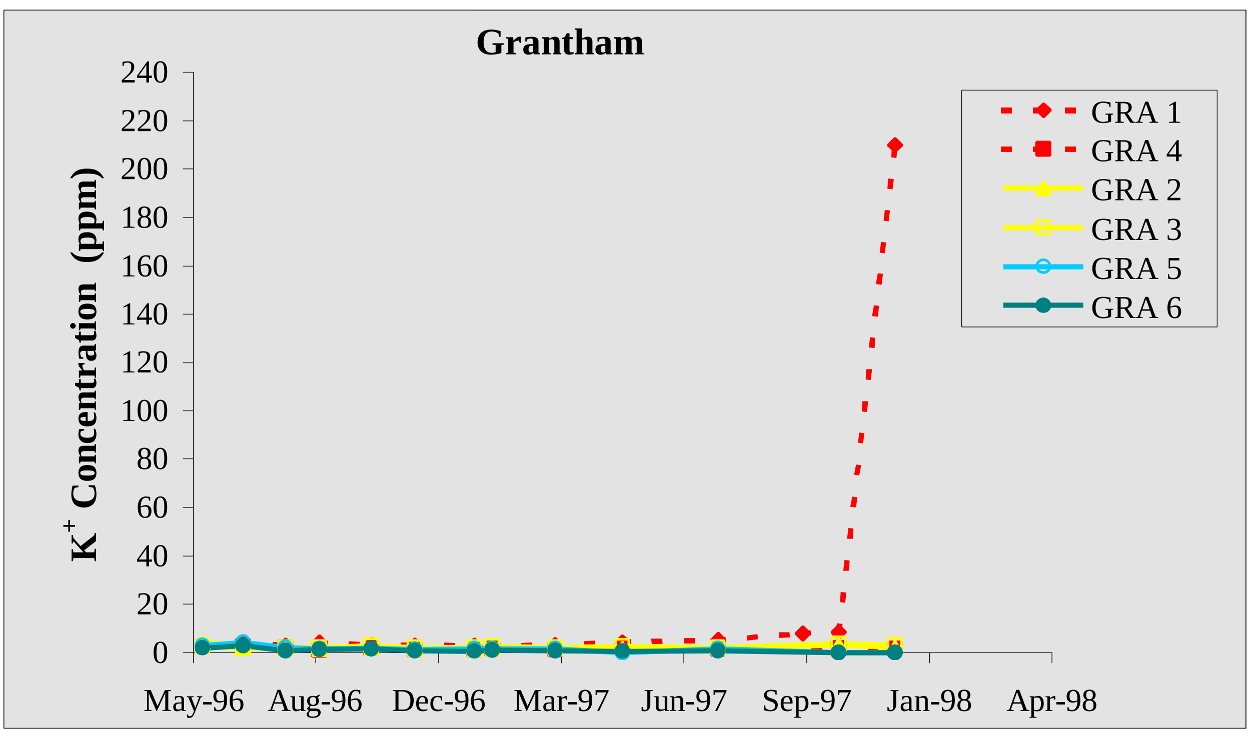
Three of the seepage indicators -- ammonia-nitrogen, organic nitrogen and chloride -- had decreasing values for the last sampling event while nitrate was slightly increasing. This may indicate that seepage rate has declined, except that the potassium value was quite high in the final sampling period. In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells.

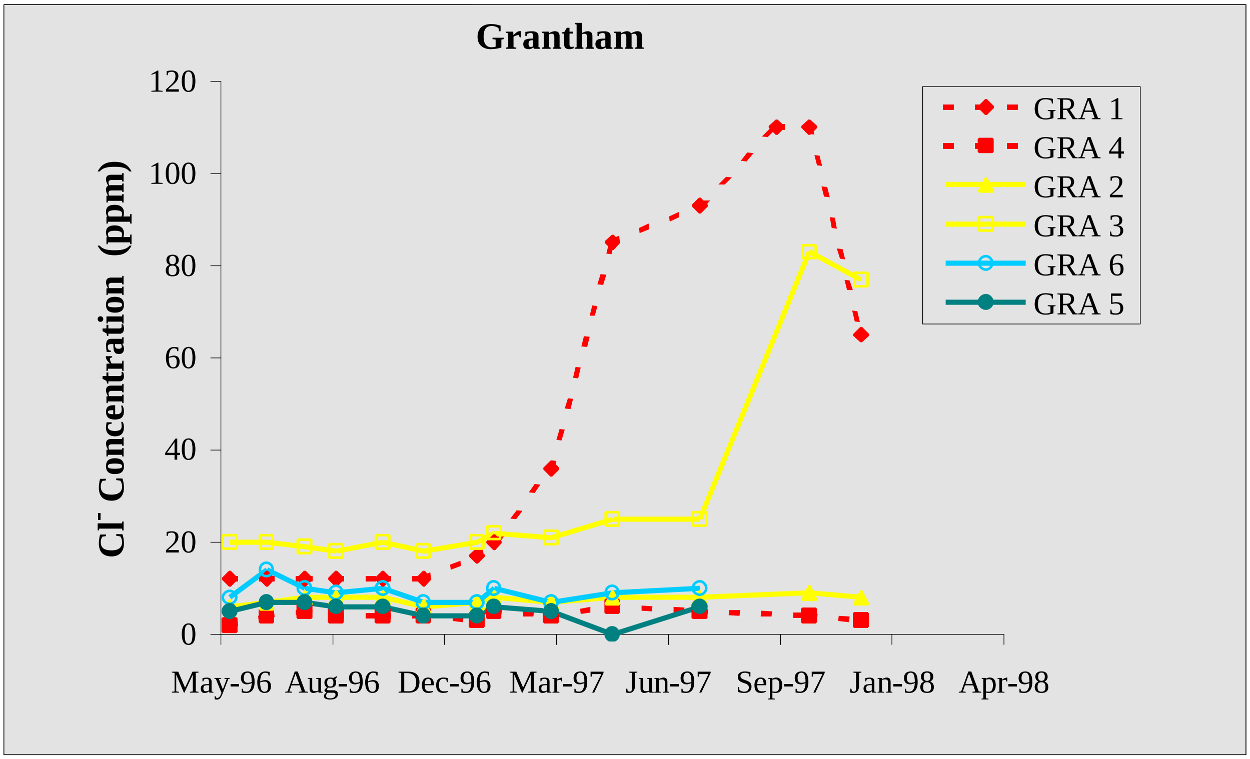
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:


Grantham
NO3- - N Concentration (ppm)
14
12
10
8
6
4
2
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
GRA 1
GRA 4
GRA 2
GRA 3
GRA 6
GRA 5


Grantham
NH3+ - N Concentration (ppm)
22
20
18
16
14
12
10
8
6
4
2
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
GRA 1
GRA 4
GRA 2
GRA 3
GRA 6
GRA 5


Grantham
TKN Concentration (ppm)
0
5
10
15
20
25
30
35
40
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
GRA 1
GRA 4
GRA 2
GRA 3
GRA 6
GRA 5


Grantham
K+ Concentration (ppm)
0
20
40
60
80
100
120
140
160
180
200
220
240
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
GRA 1
GRA 4
GRA 2
GRA 3
GRA 5
GRA 6


Grantham
Cl⁻ Concentration (ppm)
0
20
40
60
80
100
120
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
GRA 1
GRA 4
GRA 2
GRA 3
GRA 6
GRA 5

Well Site (Sampson County)

The Well site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are coarse textured.

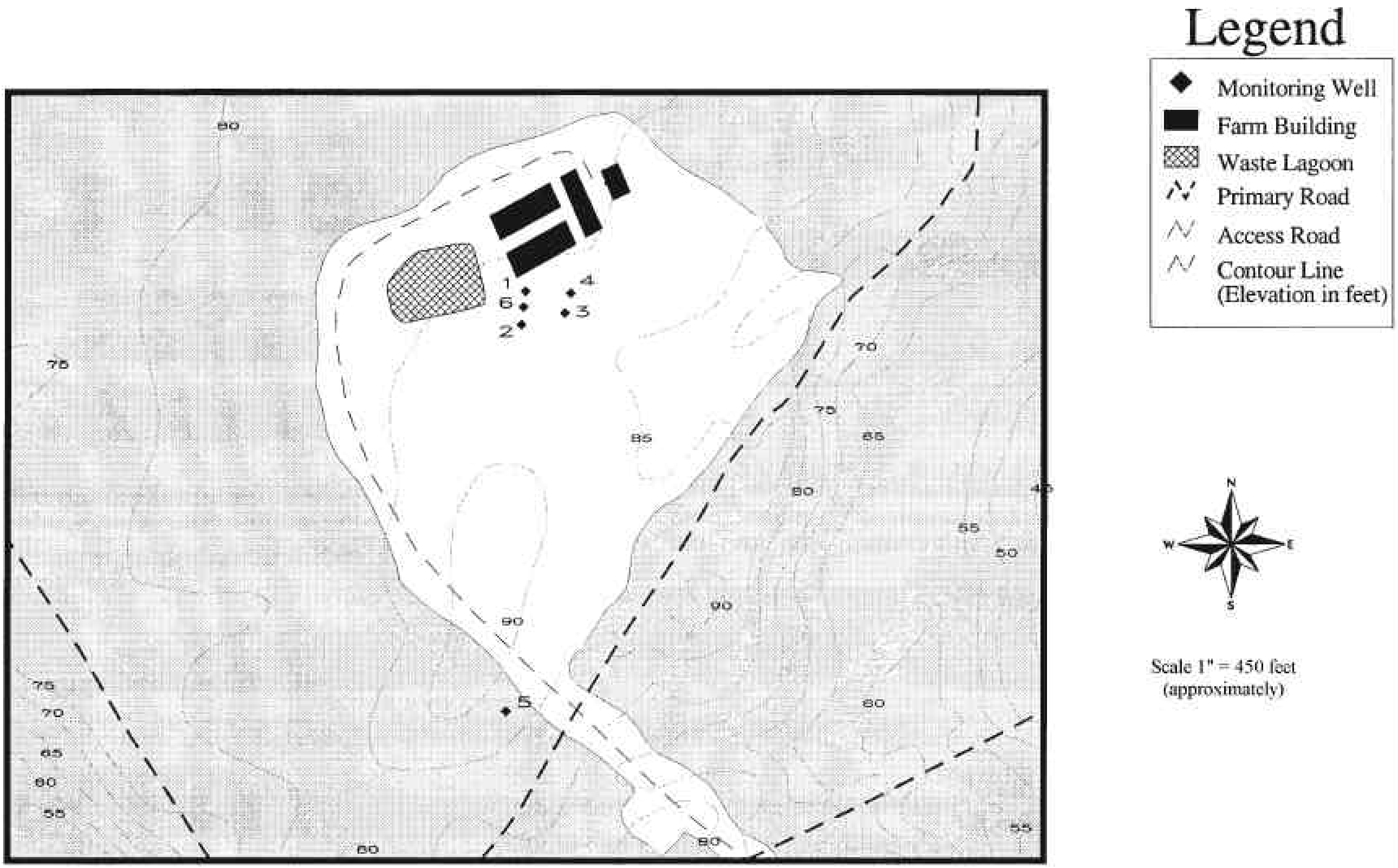
The lagoon was constructed by excavation into the topographic high area on the site. The material used for the lagoon liner had to be hauled in from off site since no suitable materials were found during the excavation. The excavated material was used for building the berm around the hole. A site map is included on the next page for reference.

This site was cleared of the existing vegetation, primarily a mixed stand of pine and hardwood trees. Monitoring well construction was completed in May 1996. Wells were sited on the downgradient side of the lagoon based on topography.

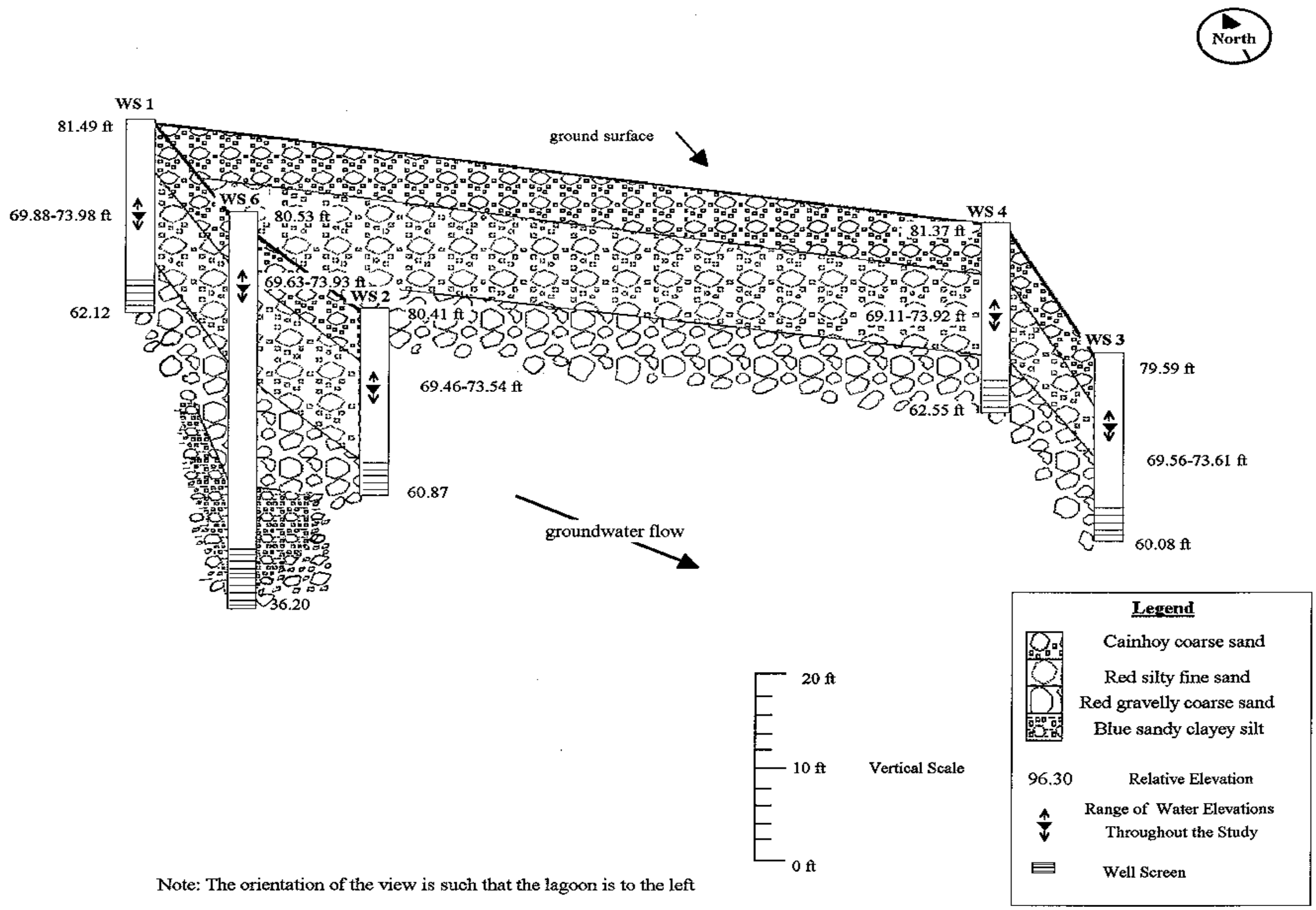
Depth to the top of the well screens was 13 feet below surface in all four of the shallow downgradient wells. The water table depth in the shallow downgradient wells ranged from approximately 10 to 14 feet below the ground surface.

Soils and sediment textures encountered during drilling of the four shallow downgradient monitoring wells were very coarse textured to a depth of about 25 feet below the ground surface. The site's stratigraphy is presented in the fence diagram' on page 80.

Well Site


Legend
Monitoring Well
Farm Building
Waste Lagoon
Primary Road
Access Road
Contour Line
(Elevation in feet)
N
W
E
S
Scale 1" = 450 feet
(approximately)
1
2
3
4
5
6

Borehole Stratigraphy of the Well Site in Sampson County



Note: The orientation of the view is such that the lagoon is to the left

Vertical exaggeration = 1.6

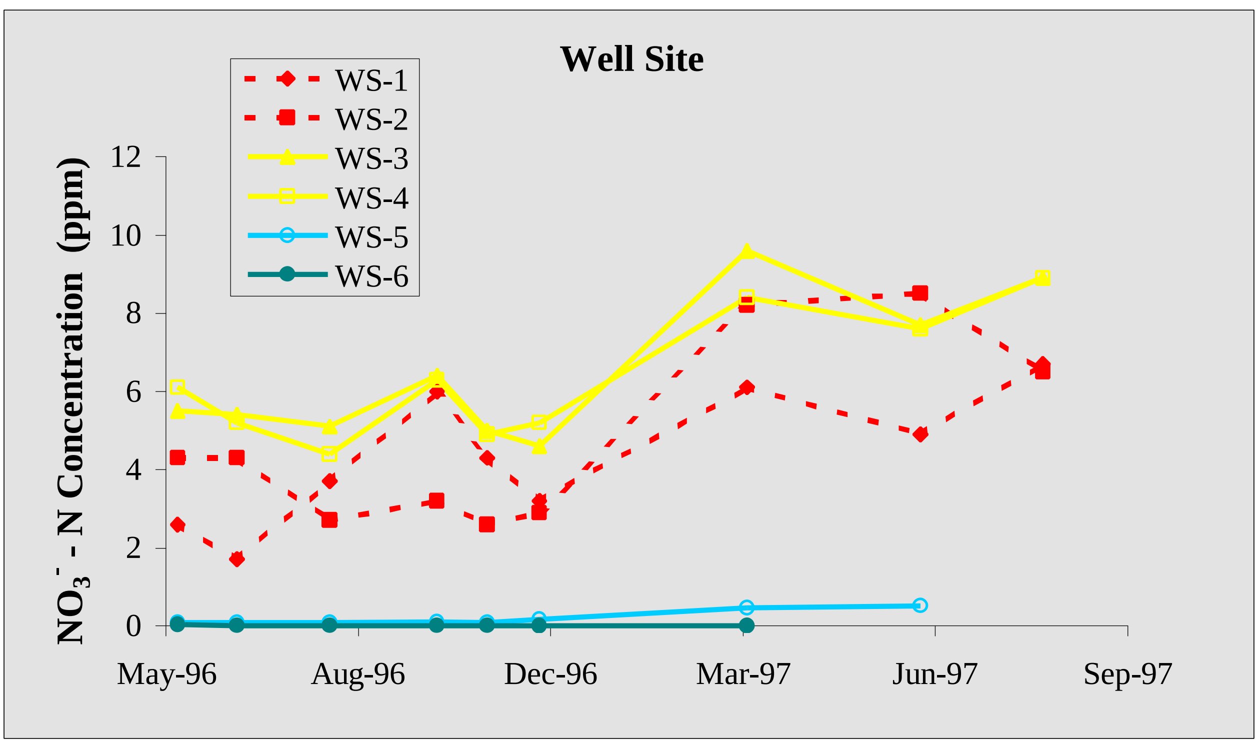
Measured elevations of the water table in the wells show a general flow direction from the lagoon in a southerly direction with a few exceptions. However, the shallow downgradient monitoring wells were located southeast of the lagoon because the cooperator denied a request for a southerly location. Distance from the wells to the nearest discharge feature is approximately 500 feet.

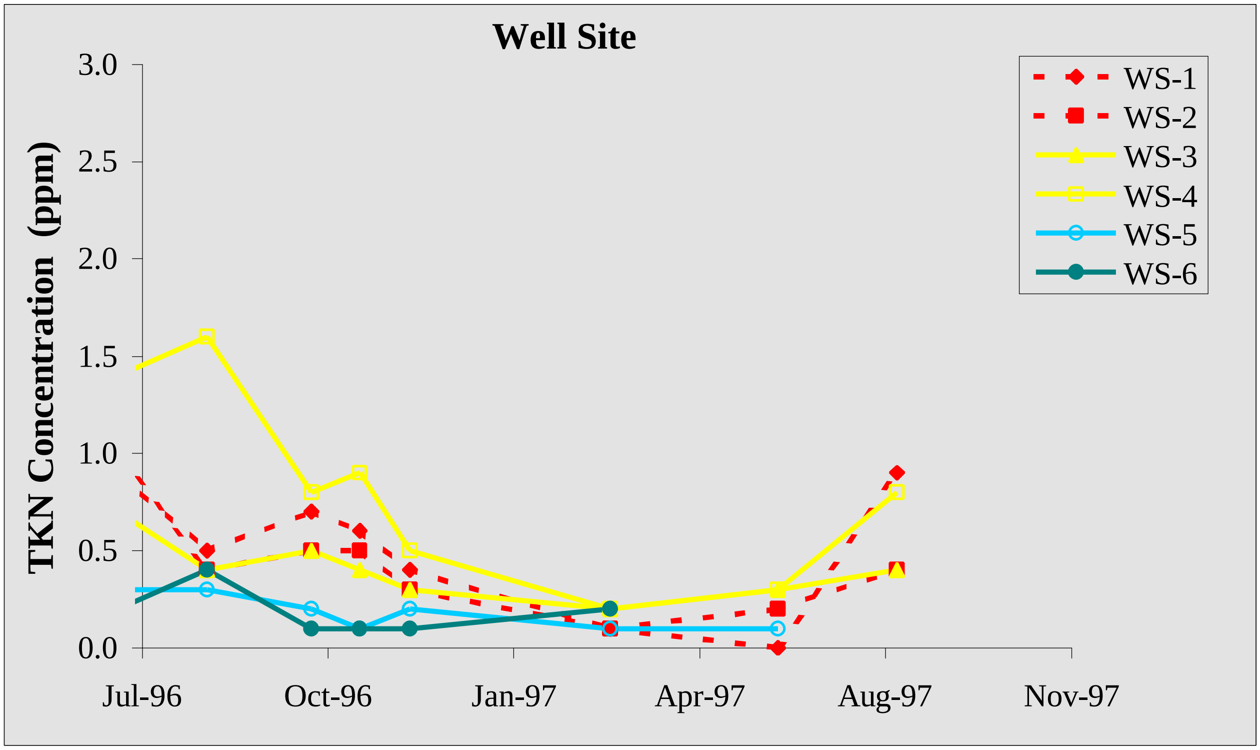
Results of the EM survey did not show any significant changes in conductivity in the subsurface that would be indicative of ground water contamination. The separation distance between the lagoon bottom and the water table was estimated to be about one foot or less. Based on this limited information, the Well site would generally be considered to have a high potential for lagoon seepage to contaminate ground water.

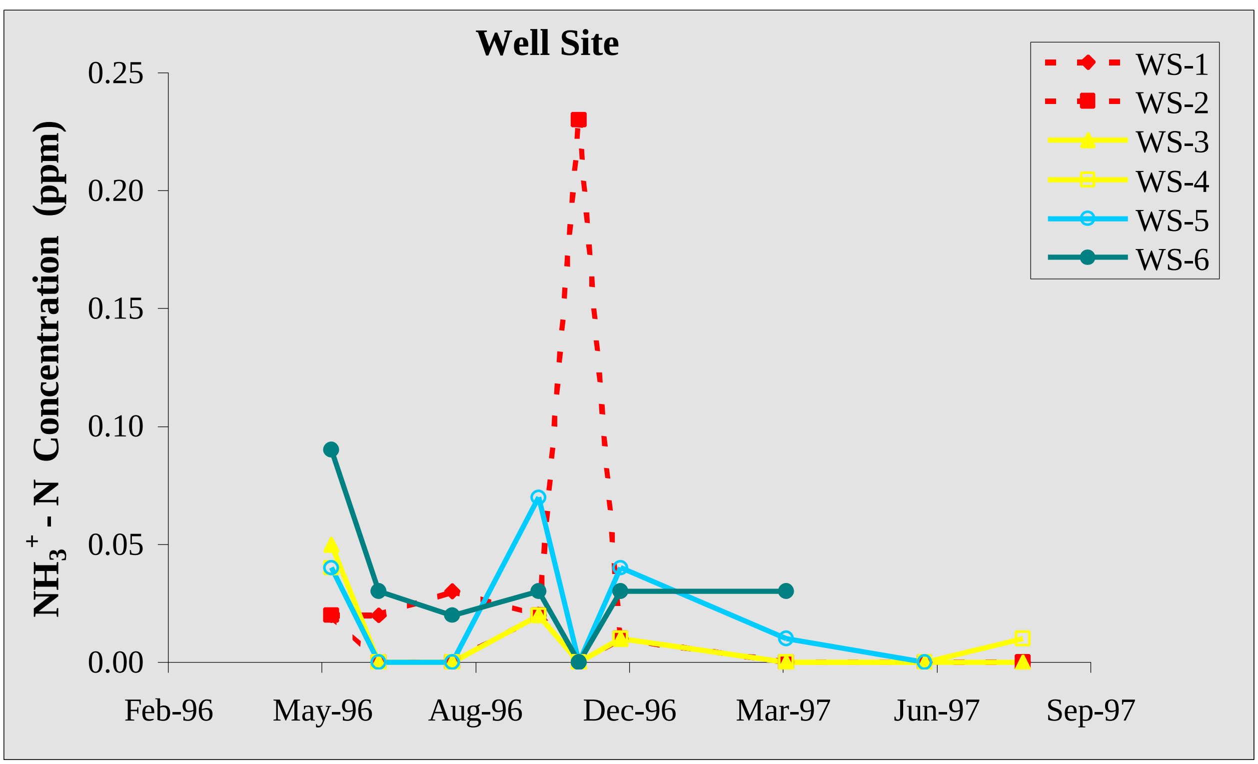
In order to form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells. The cooperator did not allow monitoring activities to continue after August 1997. Additionally, it appears that the monitoring wells are not properly located to determine if lagoon seepage has occurred.

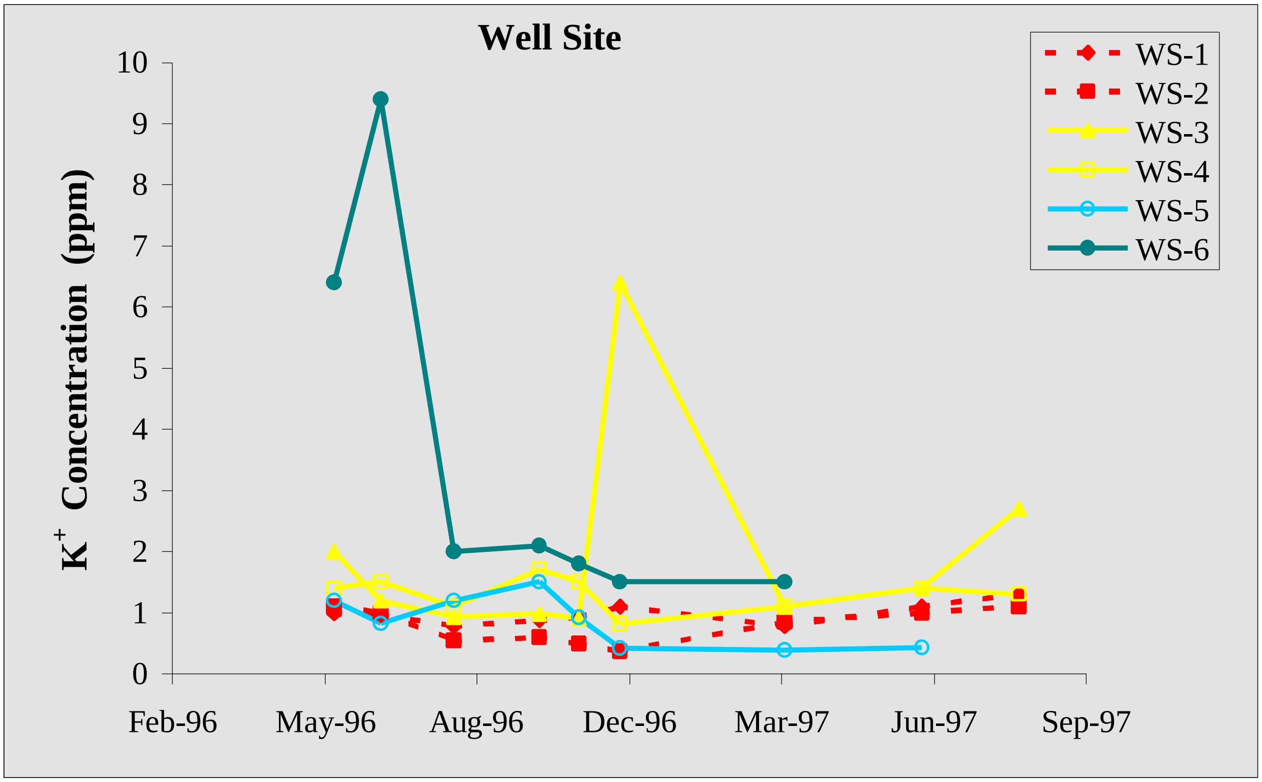
There does appear, however, to be possible increasing trends in both nitrate-nitrogen and chloride concentrations in a few of the wells. Without further site investigation, monitoring and cooperation the source of these increasing concentrations cannot be determined.

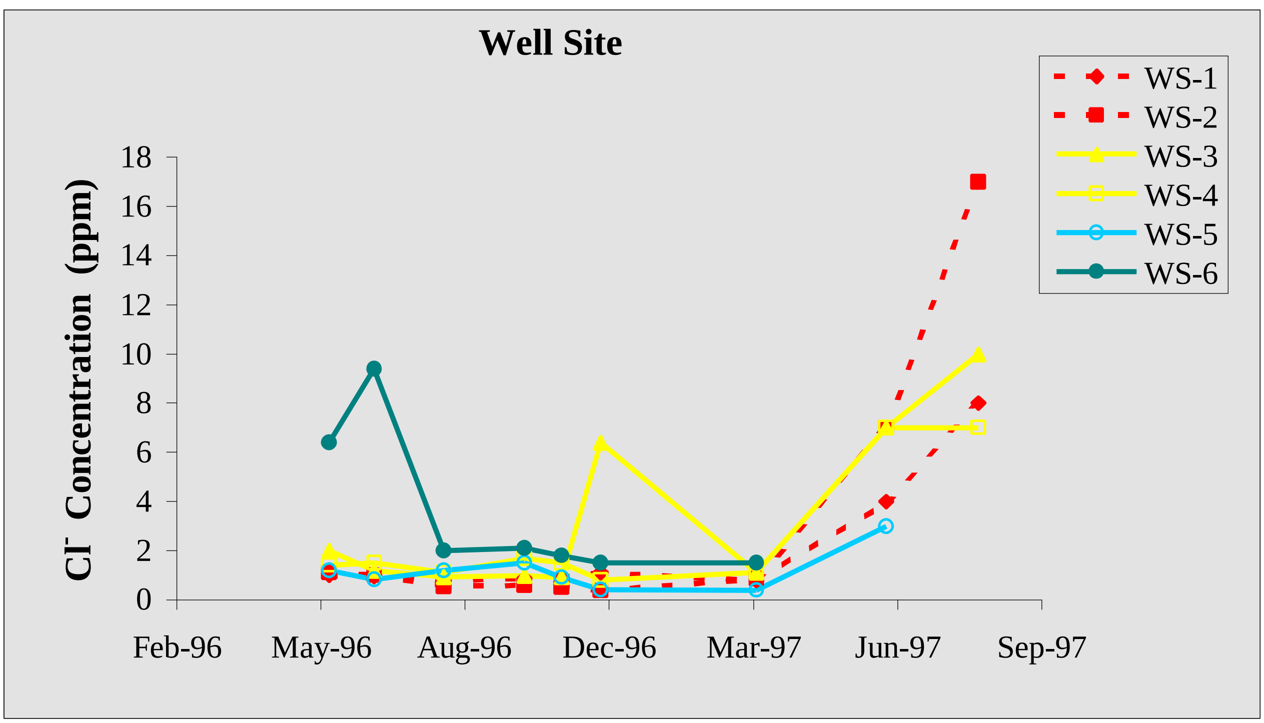
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:




Well Site
TKN Concentration (ppm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jul-96
Oct-96
Jan-97
Apr-97
Aug-97
Nov-97
WS-1
WS-2
WS-3
WS-4
WS-5
WS-6


Well Site
NH_3^+ - N Concentration (ppm)
0.25
0.20
0.15
0.10
0.05
0.00
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
WS-1
WS-2
WS-3
WS-4
WS-5
WS-6


Well Site
K+ Concentration (ppm)
10
9
8
7
6
5
4
3
2
1
0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
WS-1
WS-2
WS-3
WS-4
WS-5
WS-6


Well Site
Cl- Concentration (ppm)
18
16
14
12
10
8
6
4
2
0
Feb-96
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
WS-1
WS-2
WS-3
WS-4
WS-5
WS-6

Robeson Site (Robeson County)

The Robeson site is located in a topographically upland setting in the lower Coastal Plain physiographic province. The soils mapped are coarse to medium textured.

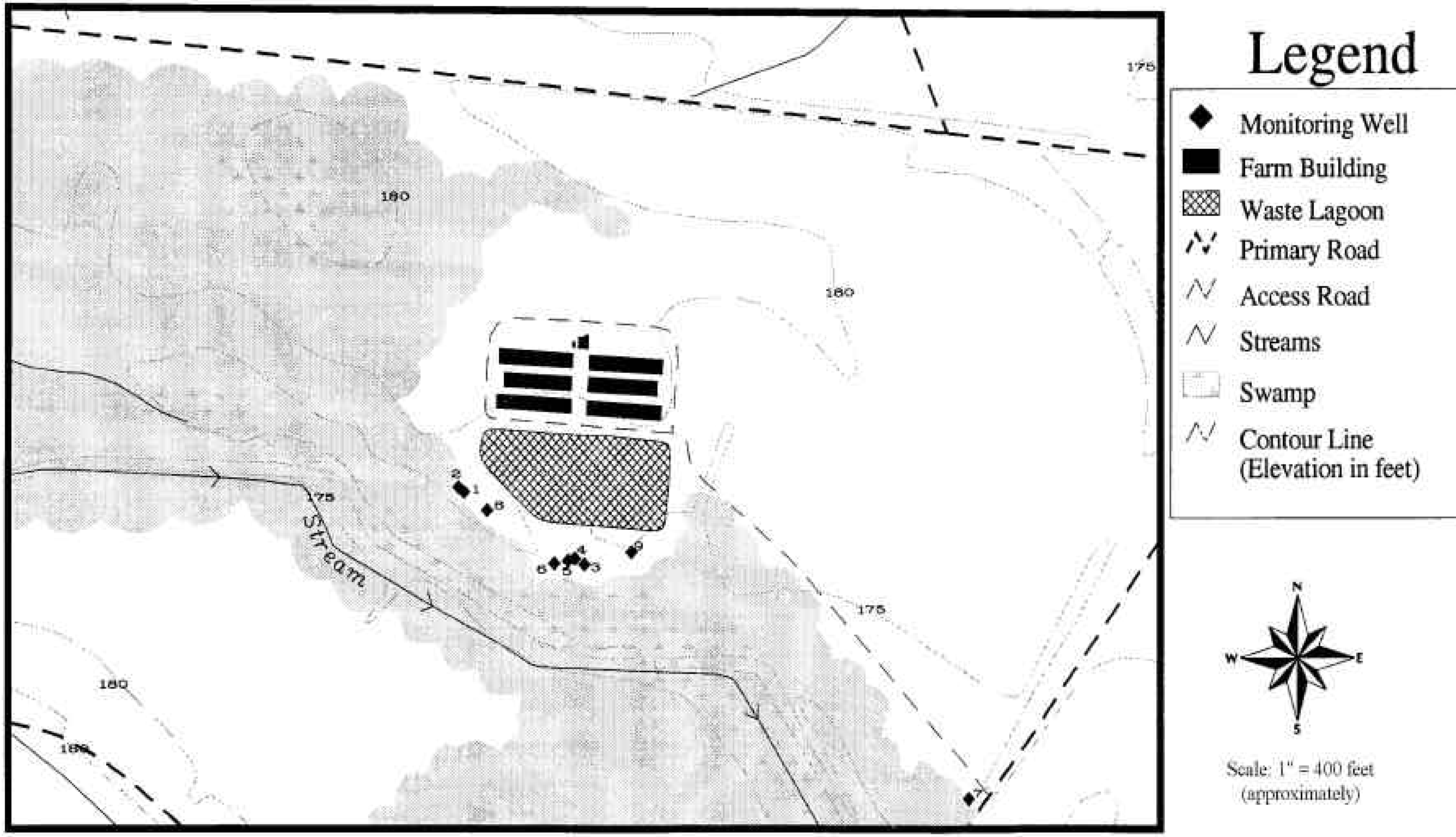
The lagoon was constructed by excavation into the gently sloping to mostly flat section of the site. There was an insufficient amount of fine textured material to complete the liner for this lagoon; so additional material had to be brought in from another location. The excavated material was used for building the berm around the hole. A site map is included for reference.

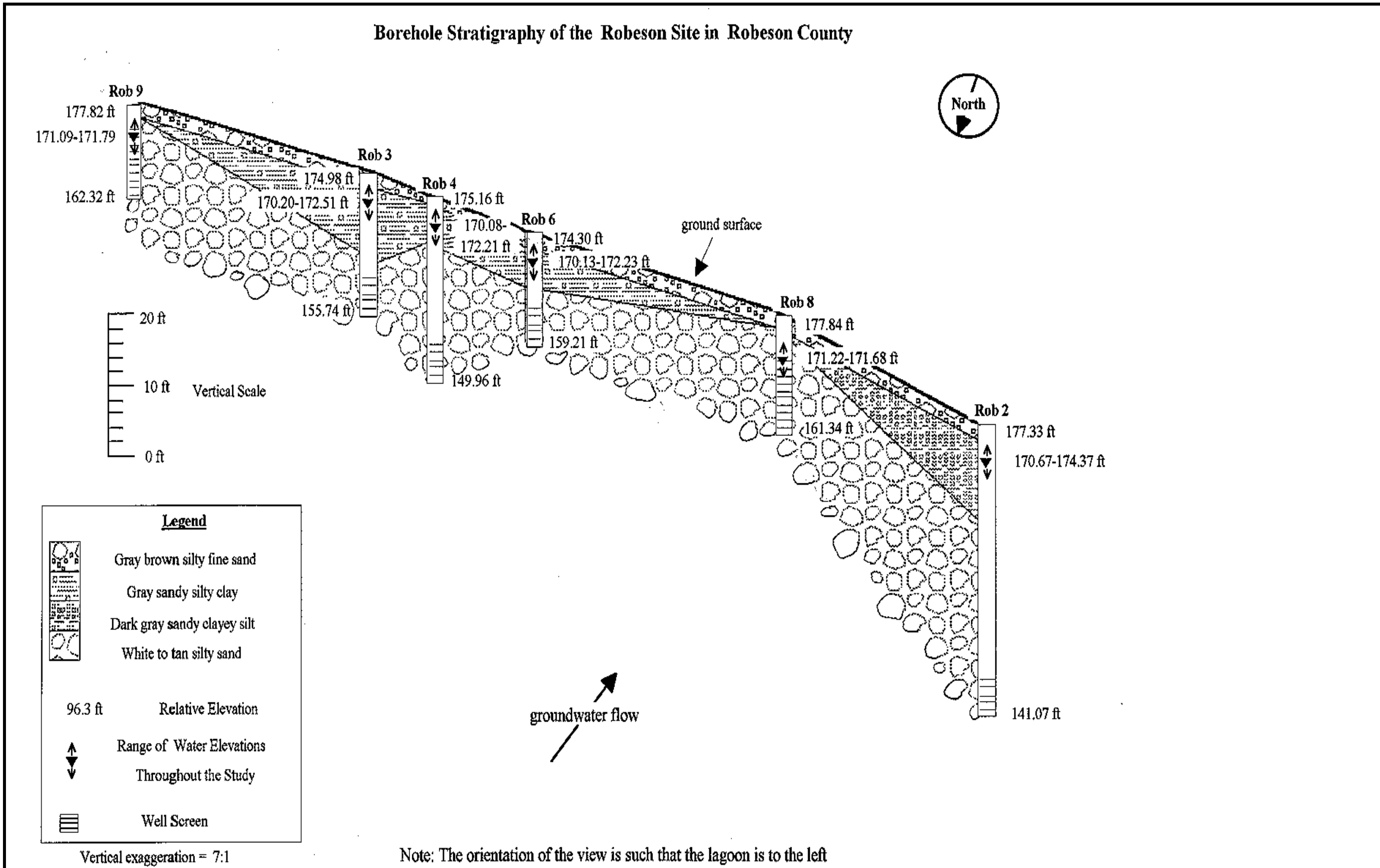
The area of the site where the lagoon was constructed was previously used for traditional row-crop agricultural production. Monitoring well construction was completed in July 1996. Wells were sited on the downgradient side of the lagoon based on topography. All six of the shallow downgradient wells were installed closer than 125 feet because the proximity of the woods would not allow for any more distance between the wells and the lagoon berm.

Depths to the top of the well screens ranged from 5 to 11 feet below surface in the six shallow downgradient wells. Water table depth in the wells ranged from approximately 5 to 8 feet below the ground surface.

Soil and sediment textures encountered during drilling of the six wells were generally coarse textured. The site's stratigraphy is presented in the 'fence diagram' on page 86.

Robeson Site



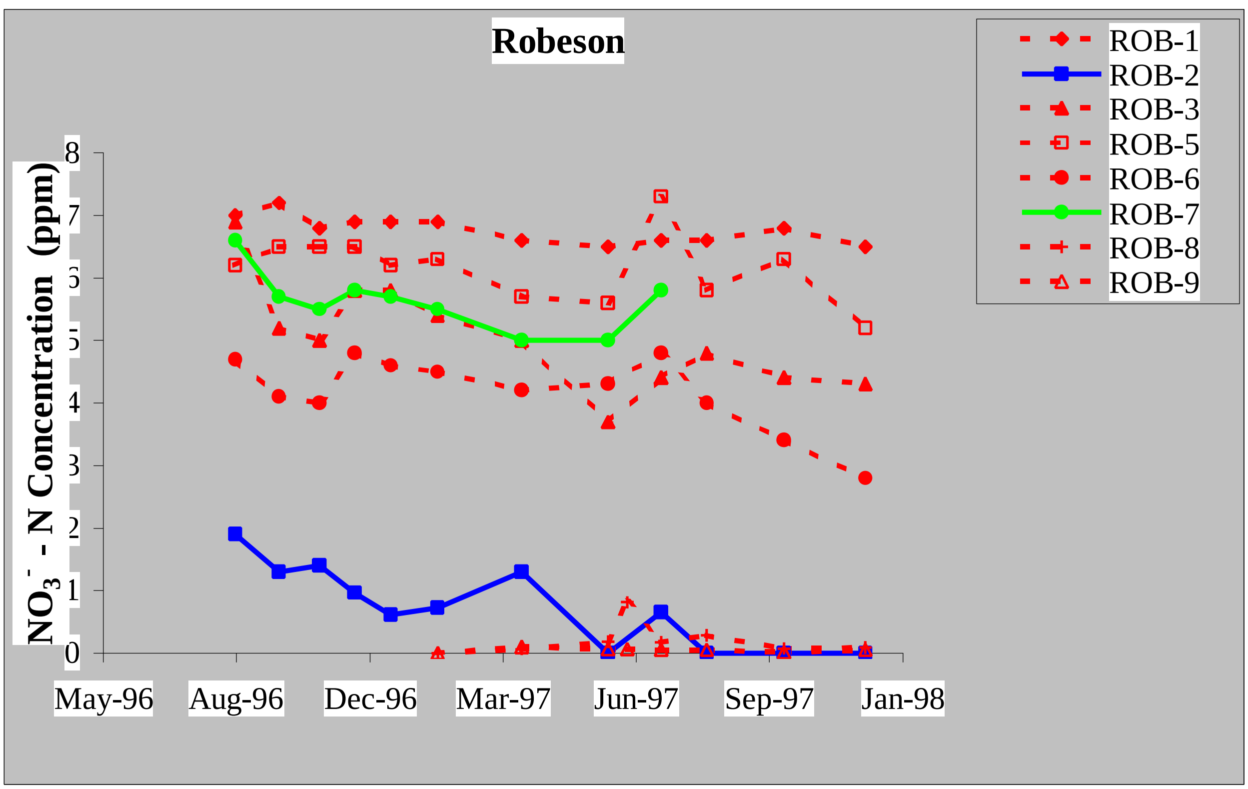

Borehole Stratigraphy of the Robeson Site in Robeson County
North
Rob 9
177.82 ft
171.09-171.79
162.32 ft
Rob 3
174.98 ft
170.20-172.51 ft
155.74 ft
Rob 4
175.16 ft
170.08-
172.21 ft
149.96 ft
Rob 6
174.30 ft
170.13-172.23 ft
159.21 ft
ground surface
Rob 8
177.84 ft
171.22-171.68 ft
161.34 ft
Rob 2
177.33 ft
170.67-174.37 ft
141.07 ft
20 ft
10 ft
Vertical Scale
0 ft
Legend
Gray brown silty fine sand
Gray sandy silty clay
Dark gray sandy clayey silt
White to tan silty sand
96.3 ft
Relative Elevation
Range of Water Elevations
Throughout the Study
Well Screen
Vertical exaggeration = 7:1
groundwater flow
Note: The orientation of the view is such that the lagoon is to the left

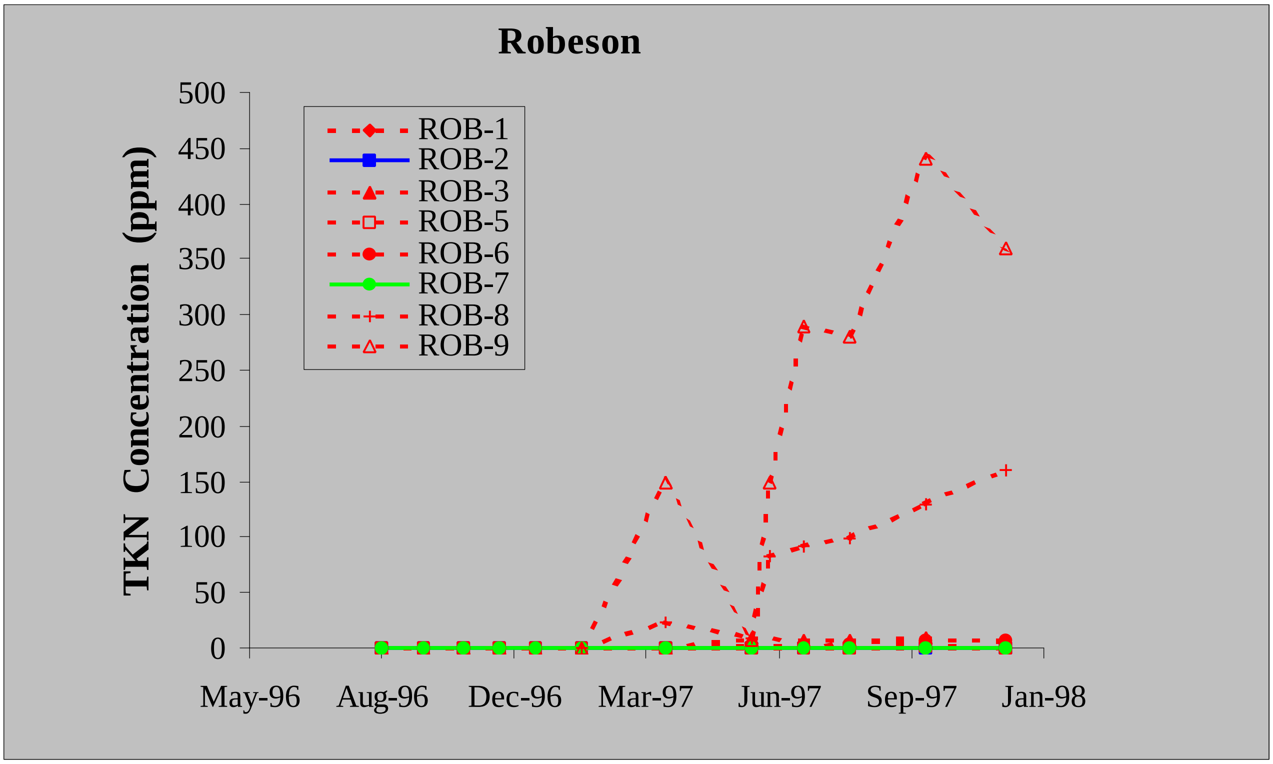
Measured elevations of the water table in the wells show a general ground water flow direction from the lagoon toward the shallow downgradient monitoring wells (also shown on the fence diagram). Water table elevations measured over time did not show significant variation in ground water flow direction. Distance from the shallow downgradient monitoring wells to the nearest discharge feature is approximately 150 feet.

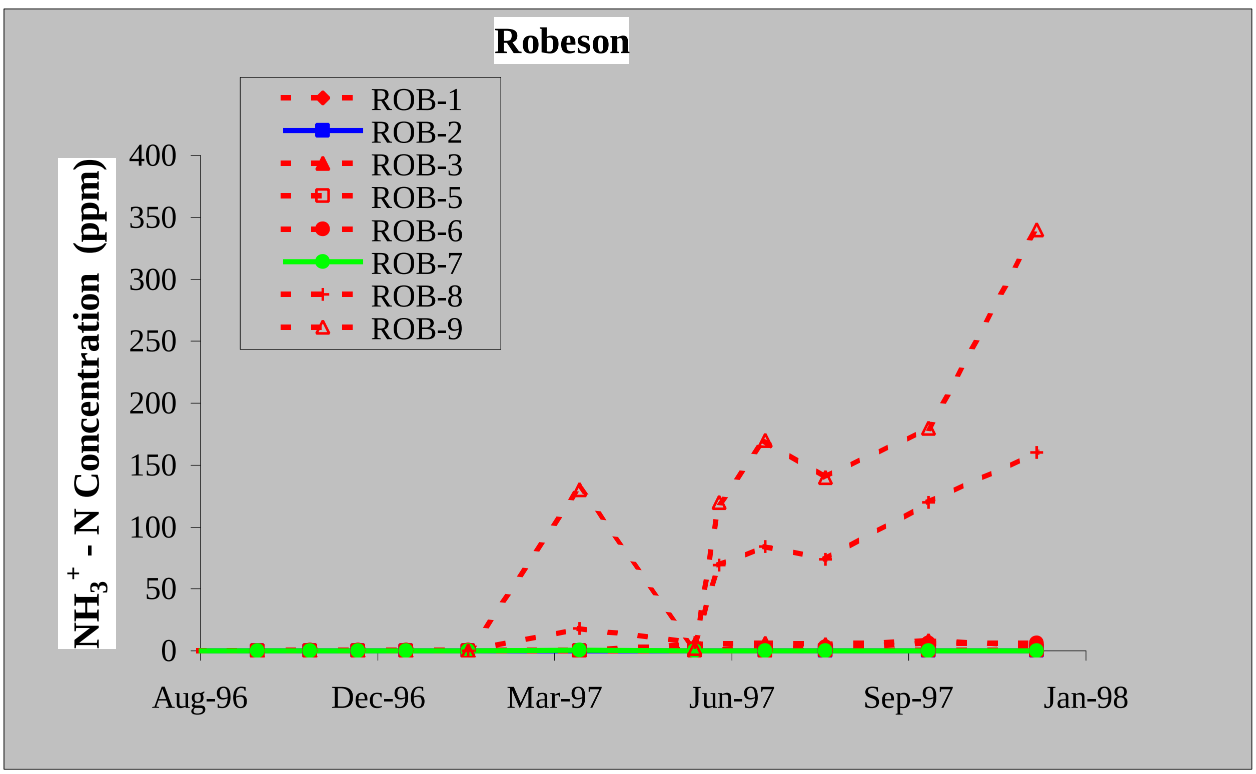
Results of the original EM survey in October 1996 showed two distinct linear anomalies coming from the lagoon in the general direction of ground water flow. In March 1997, these areas were resurveyed. Two wells were installed by hand and ground water samples were collected. Two grab samples showed high concentrations of lagoon seepage indicators, so monitoring wells were constructed with a drill rig in June 1997.

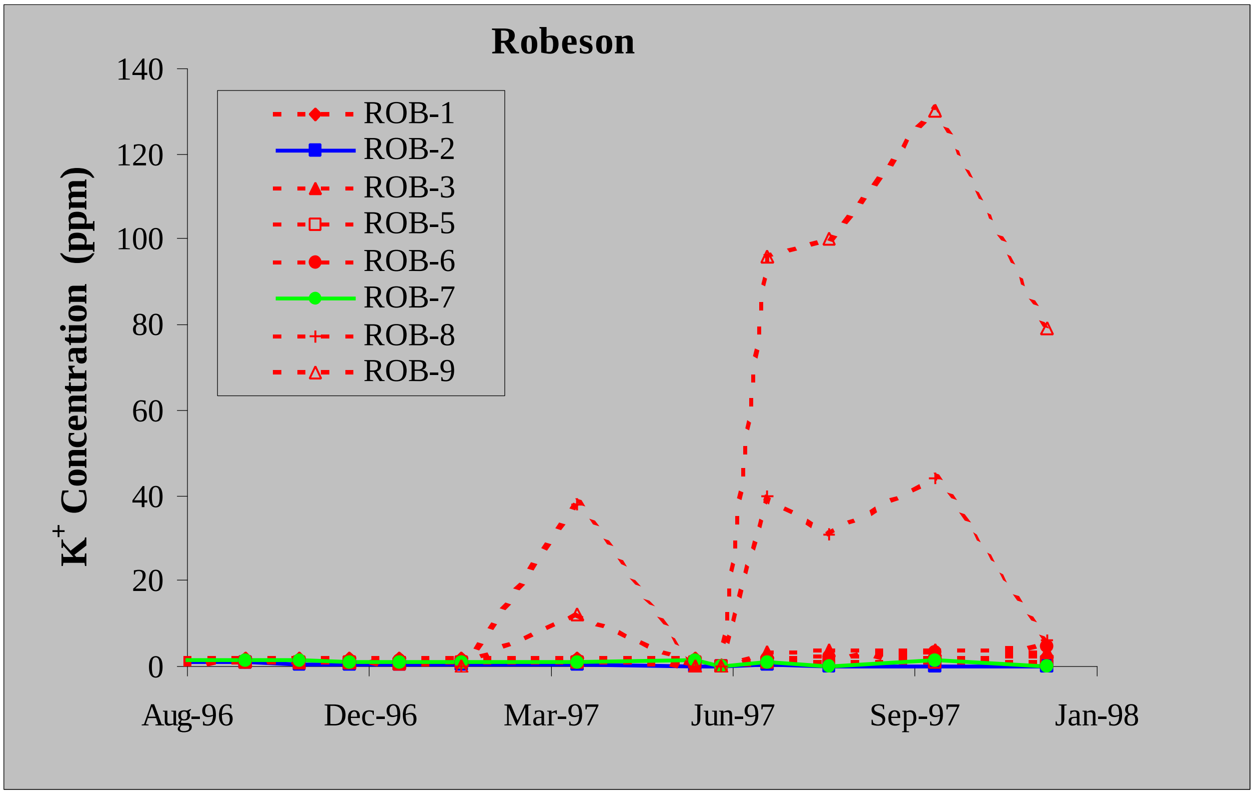
It was estimated that there was no separation distance between the lagoon bottom and the water table. Stratigraphy data collected indicate no significant clay layer below the first 10 feet down to 35 feet below the ground surface. Based on this limited information, the Robeson site would generally be considered to have high to very high potential for lagoon seepage to contaminate ground water.

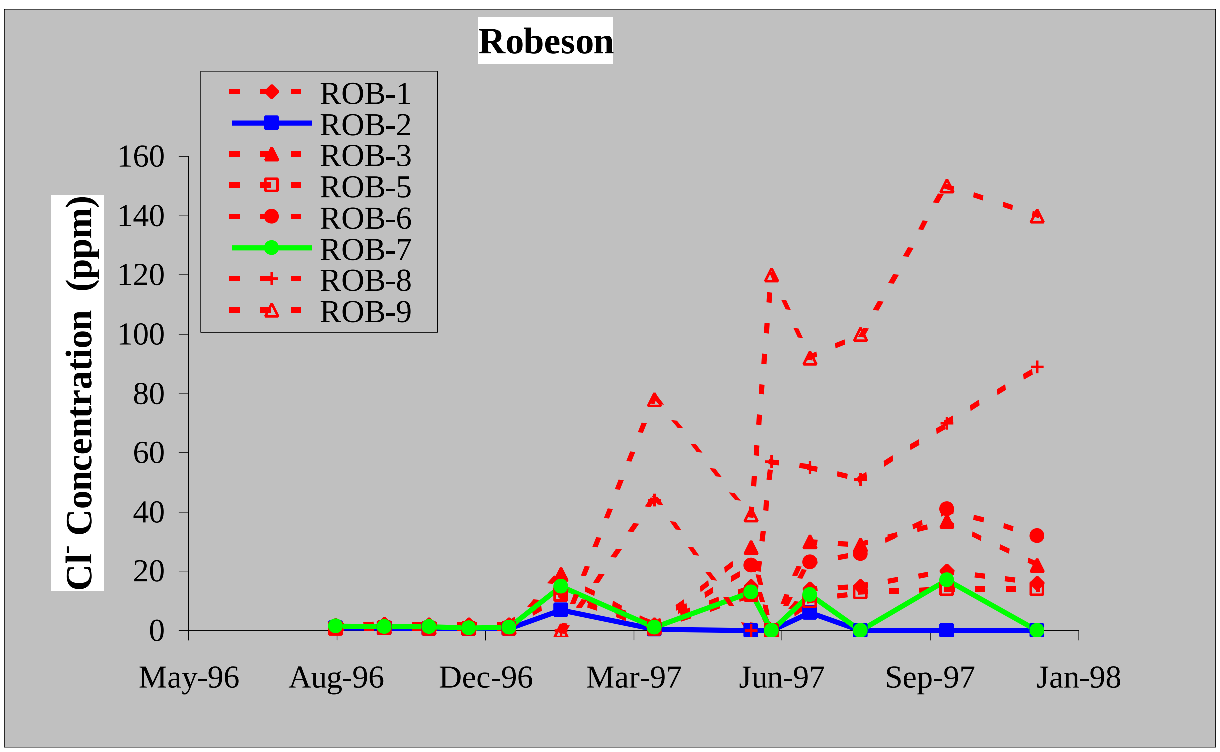
Results of the monitoring well analysis for the major seepage indicators are presented in the following five time-series graphs:



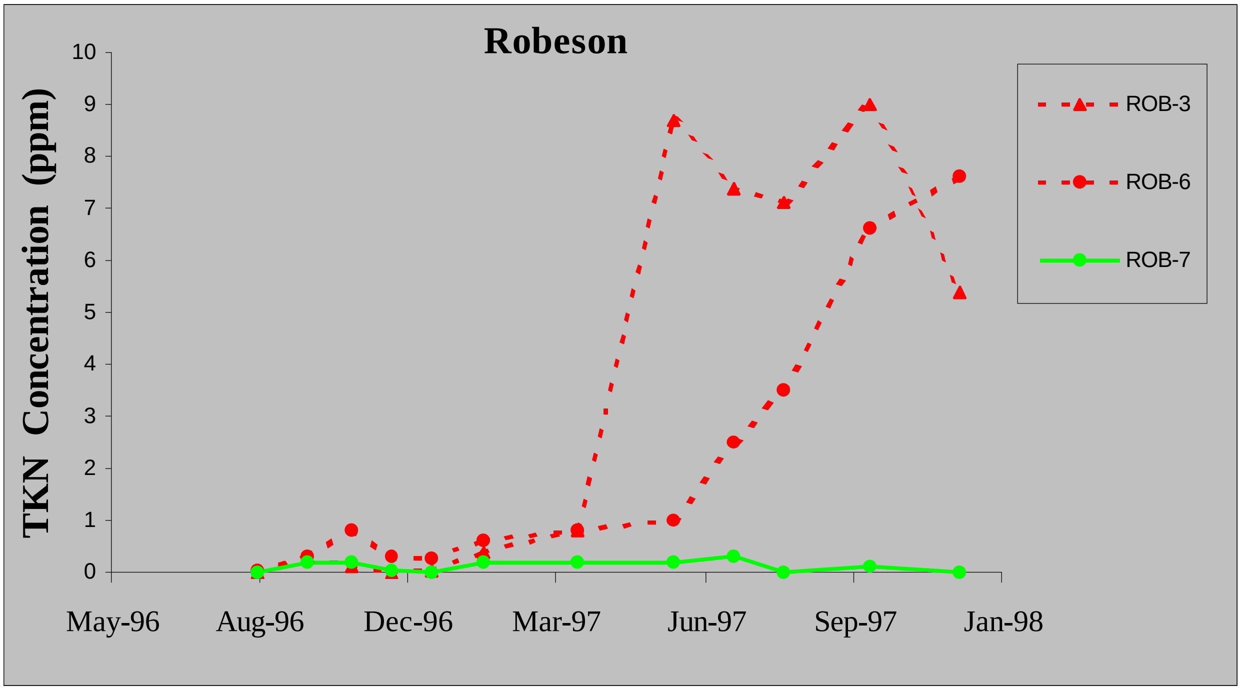

Robeson
TKN Concentration (ppm)
500
450
400
350
300
250
200
150
100
50
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
ROB-1
ROB-2
ROB-3
ROB-5
ROB-6
ROB-7
ROB-8
ROB-9

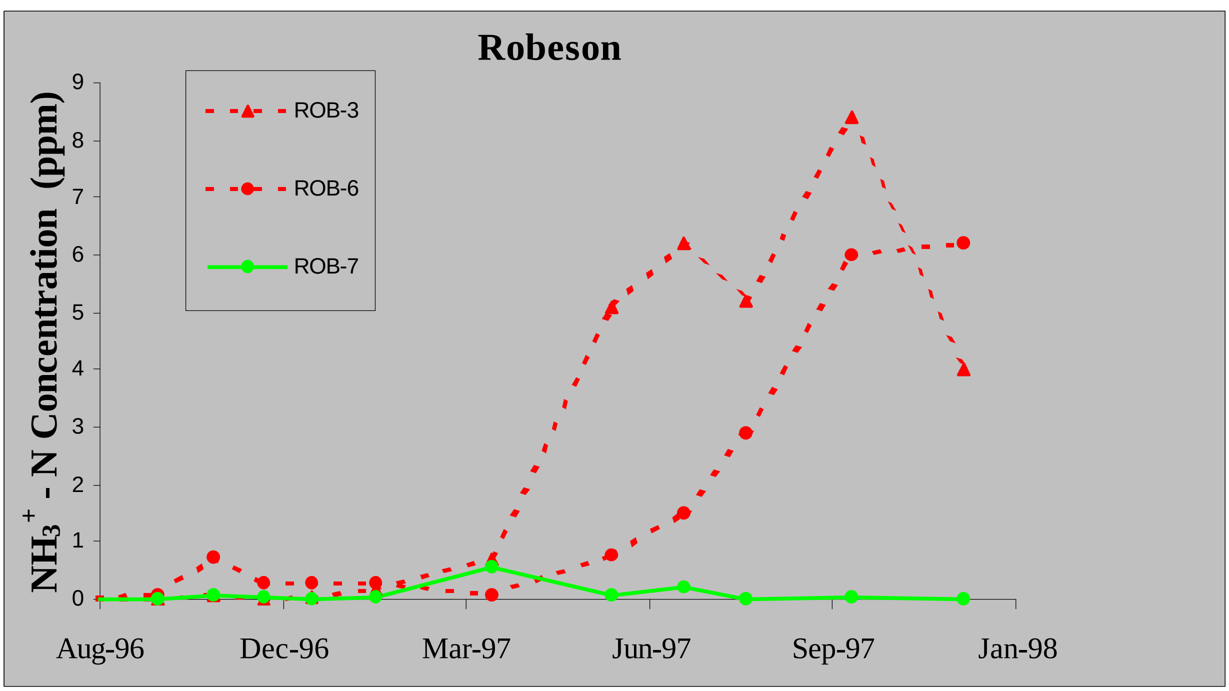

Robeson
NH_3^+ - N Concentration (ppm)
400
350
300
250
200
150
100
50
0
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
ROB-1
ROB-2
ROB-3
ROB-5
ROB-6
ROB-7
ROB-8
ROB-9


Robeson
ROB-1
ROB-2
ROB-3
ROB-5
ROB-6
ROB-7
ROB-8
ROB-9
K^+ Concentration (ppm)
0
20
40
60
80
100
120
140
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98


Robeson
ROB-1
ROB-2
ROB-3
ROB-5
ROB-6
ROB-7
ROB-8
ROB-9
Cl^- Concentration (ppm)
0
20
40
60
80
100
120
140
160
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98

Wells ROB-8 and ROB-9 were constructed in June1997, as previously mentioned. Concentrations of ammonia-nitrogen and organic nitrogen have been elevated each sampling period, and the levels in ROB-9 are currently close to that of the lagoon waste itself. Additional EM surveying has not shown any significant changes in the subsurface. However, concentrations of ammonia and organic nitrogen in two of the original monitoring wells have increased as shown in the following two time-series graphs (note different scale on y-axis):





The contamination appears to be spreading; however, the EM has not been able to detect the movement. Perhaps the concentration of the lagoon seepage constituents is still relatively low. This site exhibits the highest degree of lagoon seepage ground water contamination in the study.

Ground Water Vulnerability Assessment

Assessing farm operations for vulnerability to ground water contamination from lagoon seepage requires a detailed review of the stratigraphy and water table elevation data collected. Table 4 on the following page summarizes the results of the vulnerability assessment.

Based on the limited information that was collected while installing monitoring wells at each site, an assessment was made using the vulnerability criteria described in this report. Five of the subject farm operations are considered to be less vulnerable, four moderately vulnerable and two more vulnerable. One site in the study was not included in the assessment because the monitoring wells were not placed in the correct aquifer.

Of the five sites assessed less vulnerable, none of the downgradient shallow monitoring wells had concentrations of any of the five lagoon seepage indicators during the study. Some wells at three of the four moderately vulnerable sites showed increasing trends in concentrations of one or more seepage indicators. Those three sites were the Gaston, Grantham and McDaniels farms.

Of the two sites assessed most vulnerable, the Robeson site showed the most severe lagoon seepage contamination in shallow downgradient monitoring wells. The other site, Well Site, apparently did not have the monitoring wells placed in the proper location for the detection of lagoon seepage. The assessment of the vulnerability of the Well Site could not be completed because of inadequate useful monitoring well data.

Overall, the vulnerability assessment methodology appears to be adequate. However, sufficient time must be allowed for movement of ground water from beneath the lagoon to the monitoring well in order to form conclusions about the potential for lagoon seepage to contaminate ground water. It is possible that not enough time has been allowed for seepage to move through the ground water system at many of the sites included in the study, since the closest monitoring wells are generally 125 feet from the lagoons.

Also, since the number of sites included in this study was quite small, it would not be appropriate to transfer these findings to the entire population of animal waste lagoons. To aid in the vulnerability assessment of ground water at these types of animal waste facilities, more sites should be monitored for ground water quality.

The Groundwater Section has acquired additional funding to continue the monitoring at 11 sites to allow sufficient time for monitoring prior to assessing ground water vulnerability. Monitoring work will continue, assuming continued cooperation of the participating farm operators.

Table 2. Summary of Vulnerability Evaluation and Ground Water Quality Monitoring Results

Site Name	**Vulnerable Conditions Theoretically Exist Where:** 1. Insufficient separation distance exists between lagoon bottom and the seasonal high water table.	2. Coarse grained soils and sediments are dominant above the first significant clay layer in the subsurface.	3. Clay layers in the surficial aquifer are discontinuous and inter-bedded with coarse grained material.	Vulnerability Rating	Summary of Monitoring Results
Albertson	0	0	0	Low	No lagoon seepage detected.
Clarkton	0	0	0	Low	No lagoon seepage detected.
Lisbon	0	0	0	Low	No lagoon seepage detected
07 Site	0	0	0	Low	No lagoon seepage detected.
06 Site	0	0	0	Low	Monitoring results inconclusive.
PRS	0	0	0	Low	No lagoon seepage detected.
Gaston	X	0	0	Moderate	Three monitoring wells indicated lagoon seepage.
Nahunta	X	0	X	Moderate	No lagoon seepage detected.
McDaniels	0	X	X	Moderate	One monitoring well indicated lagoon seepage.
Grantham	X	0	X	Moderate	One monitoring well indicated lagoon seepage.
Well Site	X	X	X	High	Monitoring results inconclusive.
Robeson	X	X	X	High	Severe lagoon seepage detected in multiple monitoring wells.

X = Vulnerable; O = Not Vulnerable;

Demonstration Project Site

Robeson is the study site that has been determined to be the most vulnerable for ground water contamination from lagoon seepage. Sediment textures at the bottom of Robeson's constructed lagoon were generally coarse to medium textured. Insufficient natural fine textured material for a compacted liner was found during excavation of the lagoon. Additional excavation at another location on the farm had to be performed to provide enough suitable liner material.

No separation distance appears to exist between the lagoon bottom and the water table. No significant clay layer or significant fine textured material was generally found below about 10 feet or less in any of the downgradient shallow monitoring wells. These site conditions represent greater vulnerability for ground water contamination.

The site investigation techniques used, EM surveying and monitoring well installation, determined that lagoon seepage contamination has occurred.

The Groundwater Section plans to continue the investigation at this site. Planned activities include; characterization of surficial aquifer parameters such as ground water flow velocity, and hydraulic conductivity; and tracking of the contaminant plume in the shallow ground water system to study the changes in chemical concentrations over distance and time. The contaminant plume should be moving toward the vegetated riparian area adjacent to the creek. There are potential biological transformations of the chemical constituents that can occur in the ground water system as well as impact from the vegetation in the very shallow part of the subsurface.

Conclusions and Recommendations

Conclusions and recommendations based on the results of this study of animal waste facilities assessing lagoon seepage impact on ground water quality are constrained by several factors - namely, few sites were included, a relatively short time was available for collecting time-series monitoring data, and inadequate time and resources existed for site investigation activities prior to construction of monitoring wells. To form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water beneath the lagoon to the monitoring wells. The following conclusions and recommendations are presented.

1. The 1993 NRCS animal waste lagoon construction standards (or the process of implementing the standards) may be insufficient to prevent ground water contamination where substrate material underlying the lagoon is course or where there is little distance between the lagoon bottom and the water table. However, the State's ground water quality rules allow for an area at a permitted facility downgradient of a waste storage lagoon for treatment or dilution of contamination. This area is designated by the compliance boundary for a permitted facility. None of the lagoon seepage detected in this study was found to have migrated a distance from the lagoon equivalent to the compliance boundary (250 feet from the lagoon for the facility if it had been issued an individual permit by the State). Ground water monitoring should be considered a requirement on sites where it is believed that ground water is vulnerable to contamination. Unless further monitoring occurs on these farms and enough additional sites are included to make a more representative sample, a determination cannot be made of the adequacy of the construction standards to protect ground water quality standards.

2. Based on the limited results of this study the vulnerability assessment methodology appears to be adequate. To form conclusions about the potential for lagoon seepage to contaminate ground water, sufficient time must be allowed for movement of ground water from beneath the lagoon to the monitoring wells. More sites must be monitored for ground water quality impact to aid in the assessment of ground water vulnerability at these types of animal waste management facilities. Ground water monitoring requirements for animal waste management facilities could be considered during the permit review process for these facilities.

3. The greater the separation distance between the lagoon bottom and the water table, the less vulnerable the ground water will be to contamination from lagoon seepage. The area on the farm where the topographic high is located would be the preferred location for siting a lagoon rather than in the side-slope or stream terrace area adjacent to a surface water feature where the water table is closer to the ground surface. NRCS lagoon construction standards do not include a separation distance between the lagoon bottom and the water table.

4. When building lagoons, if natural fine-textured materials are not found in sufficient quantity and material must be collected from another location for the liner construction, great care should be taken and more oversight provided during the liner construction and the compacting process. During lagoon construction, the site with the greatest seepage problem – Robeson - required excavation of additional clay liner material since suitable material was not encountered during the

excavation process.

5. Electromagnetic ground conductivity surveying alone is not sufficient to detect lagoon seepage in ground water since subsurface fine-textured sediments can mask the signal of contaminated ground water. However, EM surveying in coarse-textured sediments can be effective, especially if surveying is repeated over time to show changes in subsurface conductivity.

APPENDIX

Annotated Bibliography

The first four papers reviewed in this annotated bibliography represent the current body of available literature on the impact of animal waste lagoons on ground water quality in North Carolina. Just one of these papers included limited ground water quality data collected from monitoring wells over about a one-year period. Another study is currently in the final stages and is looking into the ground water impact of older lagoons built prior to 1993.

Conducted by Dr. R. L. Huffman of N. C. State University's Department of Biological and Agricultural Engineering, the state-funded study is using direct push or "Hydropunch" technology for a one-time sampling of ground water, rather than time-series data collected from monitoring wells. Results from this study should be available soon.

The other six papers represent the results of an extensive literature review of research conducted on impacts of animal waste lagoons on ground water quality. Five of the six research projects included collection of ground water for quality analysis. The sixth examined soils and sediments collected from beneath the bottom of manure storage lagoons.

Seepage and Electromagnetic Terrain Conductivity Around New Swine Lagoons

Huffman, R. L. and P. W. Westerman**,** Presented at the 1991 International Summer Meeting. ASAE Paper No. 91-4016. American Society of Agricultural Engineers. St. Joseph, Mich.

This paper briefly explains the physics of electromagnetic terrain conductivity surveying. Three lagoons were monitored using wells and EM surveys. The two newest lagoons were built on deep sands while the oldest one was built on soil with high clay composition. Significant seepage was detected around the lagoons built on deep sands. EM surveys detected plumes that were confirmed with monitoring well data. No mention was made of liners being present in the animal waste lagoons. Parameters analyzed included, TKN, NH3, NO3, total P, orthophosphate, Cl, COD, pH, electrical conductivity, alkalinity, Na, K, Ca, Mg. Approximately one year of monitoring well data was reported. Of these, the best indicators of seepage were NH3, Cl, pH, electrical conductivity, Na and K. TKN data was not included in the reported data, however.

Modeling of Chemical Transport from Agricultural Waste Lagoons

Feng, J. S. , R. L. Huffman, and P. W. Westerman, Presented at the 1992 International Winter Meeting. ASAE Paper No. 92-2620. American Society of Agricultural Engineers. St. Joseph, Mich.

The authors calibrated and validated a model that predicts long-term behavior of contaminant plumes. The simulation was an "isothermal, two-dimensional mathematical model which solves the Richards equation and advection-dispersion-reaction equation for flow and chemical movement." Nitrogen species used in the simulation were NH4, NO3, and N2 or N2O. Field measurements of NH4 and NO3 show reasonable agreement with predicted concentrations. Parameters analyzed included, TKN, NH_4, NO_3, pH, Na, Ca, Mg, Cl, available phosphorus, and electrical conductivity.

Tracking Seepage with Terrain Conductivity Survey and Wells

Huffman, R. L. and P. W. Westerman, Presented at the 1993 International Summer Meeting. ASAE Paper No. 93-4016. American Society of Agricultural Engineers. St. Joseph, Mich.

The authors continue to study two leaking lagoons observed in their ASAE 91- 4016 paper. Two unlined lagoons -- three and four years old, constructed on deep sands -- were investigated using monitoring wells and EM surveying. The relationship between conductivity of well samples and EM conductivity values is briefly discussed. This paper explains the physics of electromagnetic terrain conductivity surveying. Parameters analyzed during this study were NH_3, NO_3, total P, orthophosphate, Cl, electrical conductivity, alkalinity, Na, K, Ca and Mg. However, ground water monitoring results were discussed in very limited detail and data was not provided in the report.

Estimated Seepage Losses from Established Swine Waste Lagoons in the Lower Coastal Plain of North Carolina

Huffman, R. L. and P. W. Westerman, 1995, Transactions of the American Society of Agricultural Engineers, Vol. 38 (2): 449-453.

Eleven unlined lagoons from 10 to 20 years old were evaluated to determine seepage loss rates in three soil systems along with construction styles. Monitoring was achieved with EM surveys and wells. It is unusual that soil pore water was analyzed instead of well water samples. No results of ground water quality sampling using monitoring wells were included in the report. The authors point out that lagoon orientation with respect to ground water flow direction may have an effect on contaminant concentration. Findings also determined that sediment material type used in lagoon construction was the most important factor determining seepage.

Accumulation of Nutrients in Soil Beneath Hog Manure Lagoons

M.H. Miller, J.B. Robinson, and D.W. Gallagher, *Journal of Environmental Quality,* Volume 5, No. 3, 1976

The study's objective was to determine the extent of accumulation of nitrogen and phosphorus in soil beneath manure storage lagoons. Study results indicated that large amounts of ammonium nitrogen accumulated below the lagoons in both medium-textured and coarse-textured soils. Data suggest that lagoons may be satisfactory on fine-textured soils although studies on older lagoons are required to determine whether further movement will occur.

Dairy Lagoon Effects on Groundwater Quality

John I. Sewell, *Transactions of the American Society of Agricultural Engineers* 1978, 948-952
Study objectives were to evaluate the effects of the lagoon system on nearby ground water quality and to determine changes in holding pond water quality with time. Piezometers were installed in order to sample ground water quality. Results indicated that little or no pollutants were found when the anaerobic dairy lagoon bottom was sealed within two months.

Pollutant Movement to Shallow Ground Water Tables from Anaerobic Swine Waste Lagoons

T.G. Ciravolo, D.C. Martens, D.L. Hallock, E.R. Collins, Jr., E.T. Kornegay, and H.R. Thomas, *Journal of Environmental Quality*, Volume 8, No. 1, 1979.

The purpose of the research was to determine the amount and distance of pollutant movement from three anaerobic swine waste lagoons. The sealing mechanism of anaerobic swine waste lagoons in high-water-table soils would be similar to that in well-drained soils. Disruptions in the seal could be caused by drying of embankment soil and by gas release from microbial activity in sediments beneath the seal. Concentrations of chloride, ammonia-nitrogen and nitrate-nitrogen indicated a greater amount of seepage to ground water from the lagoon located in the coarser textured soils and sediments than at two other sites where lagoons were constructed in finer-textured materials.

Effect of An Anaerobic Swine Lagoon on Groundwater Quality in Sussex County, Delaware

W. F. Ritter, E.W. Walpole & R.P. Eastburn, *Agricultural Wastes* 10 (1984) 267-284.

This study was conducted to determine if unlined lagoons in high water tables caused ground water contamination. Also key was collecting data on the impact of unlined lagoons on ground water quality, since none was available for the Delmarva Peninsula at the time. Lagoon constituent concentrations were relatively low because the lagoon was loaded at a rate much less than its design rate. The study concluded that the initial degree of contamination for an individual site will depend upon the loading rate to the lagoon. Additionally, biological sealing of unlined animal waste lagoons in coarse-textured soils will take place over a period of time. This biological sealing is caused by organisms producing organic compounds that clog the pores of the soil. However, complete sealing of the lagoon did not occur as indicated by increases in ammonia-nitrogen and chloride concentrations in one monitoring well.

Self-Sealing of Earthen Liquid Manure Storage Ponds: I. A Case Study

M.H. Miller, J.B. Robinson, and R.W. Gillham, *Journal of Environmental Quality*, Volume 14, No. 4, 1985.
Results of infiltration studies have indicated that ponds become effectively sealed on infiltration of liquid manure for time periods ranging from a few days on clay soils to as much as 100 days on loamy sands and sands. This study was conducted to determine the extent to which materials from this pond infiltrated into the soil and the effect of the pond on the quality of ground water in adjacent areas. Based on the soil moisture measurements and elemental analyses of ground water, it can be concluded that this pond became

effectively sealed to infiltration within 12 weeks of the addition of manure.

Impact of Animal Waste Lagoons on Ground-Water Quality

W.F. Ritter & A.E.M. Chirnside, *Biological Wastes* 34 (1990) 39 - 54.

Ground water quality was monitored for three years at two sites around clay-lined animal waste lagoons on the Delmarva Peninsula. Results show there is the potential for ammonium nitrogen to move through the soil profile to the ground water from an anaerobic lagoon in coarse textured soils and sediments. The swine waste lagoon site located in excessively well drained soils had a severe impact on ground water quality. At the second site, three lagoons were located in poorly drained soils and some seepage was occurring. Ground water samples were analyzed for ammonium-nitrogen, nitrate-nitrogen, chlorides and total dissolved solids.

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