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Reno County Swine Facility Report

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Abstract

This cooperative study was undertaken at the request of the Board of Directors, Equus Beds Groundwater Management District #2 and the Kansas Department of Health and Environment Confined Animal Feeding Operations section to demonstrate the use of the nitrogen-15 isotope analysis method as a means to determine if an animal waste lagoon at a swine facility in Reno County was leaking and affecting the water quality of the Equus Beds aquifer.

Eleven samples were collected in December 1999 from supply and monitoring wells at the facility and from three domestic wells that the facility operator had requested be sampled. Additional samples were collected from the supply and monitoring wells at the facility in March 2000.

The results of the December sampling showed a fertilizer signature (<+8‰) for all of the wells at the facility except for a monitoring well in the downgradient-flow direction from the waste lagoon. The monitoring well located downgradient from the facility showed an animal-waste signature (+12.8‰) similar to the value measured from the lagoon (+18‰). Monitoring wells located to the east and northeast of the facility showed fertilizer at the northeast site and animal waste to the south. Three domestic wells sampled at this time all showed animal waste as a probable source. All three domestic wells had animal feedlots or septic tanks located near the wells and were probably influenced by these sources. All domestic wells were upgradient or away from the downgradient-flow direction of the facility.

The March 2000 sampling showed that the supply well and three of the monitoring wells had nitrate-nitrogen of fertilizer origin. The area surrounding the facility to the south and west is dry-land farming. Evaluation of rainfall records for the area indicates that there was sufficient rainfall and warm temperature to permit nitrification and movement of spring-applied nitrogen fertilizer. The monitoring well downgradient of the facility continued to show an animal waste d ^{15}N signature of +12.8‰.

Evaluation of the water chemistry from the area showed a background level of 3 to 25 mg/L of chloride. The chloride value from the lagoon was 547 mg/L, and the monitoring well downgradient from the lagoon had a chloride value of 159 mg/L. Bicarbonate values of 437 mg/L were significantly higher for the downgradient monitoring well versus 50 to 200+ mg/L at the other monitoring and domestic wells.

Nitrate-N at the down gradient monitoring well was 4 to 5 mg/L as opposed to the other monitoring wells which always had values above the drinking-water limit of 10 mg/L. Use of the chloride ratio showed that approximately 30% of the water contributing to the well sample was from the lagoon. The d ^{15}N and chloride values strongly support the idea that the lagoon is leaking and affecting the ground water. The bicarbonate and lower nitrate-N values suggest the possibility that the sampled water is a mixture of denitrified regional ground water plus lagoon water resulting in a high d ^{15}N value and a lower nitrate-N value.

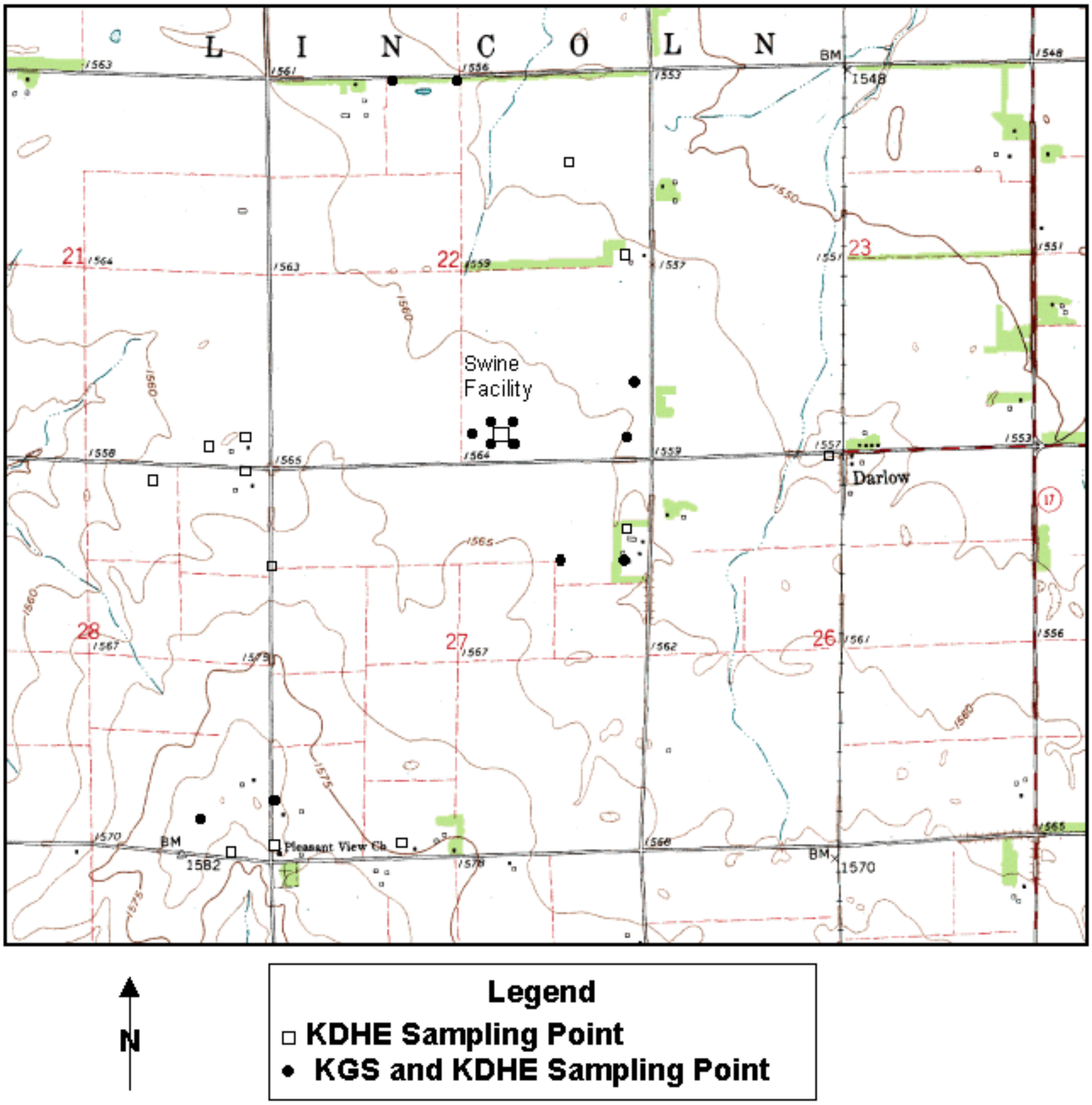
Introduction

This study was requested by the Board of Directors, Equus Beds Groundwater Management District #2, and the Kansas Department of Health and Environment Confined Animal Feeding Operations section to determine if an active swine facility in Reno County is affecting the water chemistry of the Equus Beds aquifer underlying the area. The groundwater management district requested that the nitrogen-15 isotope method be used to determine likely sources for high nitrate concentrations in monitoring wells surrounding the swine waste-storage lagoon. A map of the study area is presented in figure 1.

Figure 1. Location map of swine facility and other sampling points for September and December, 1999 and March, 2000 sampling by

KDHE and/or KGS.

Reno County Water Quality Sampling Sites T24S R6W



Methods

Personnel from the Kansas Geological Survey (KGS), the Kansas Department of Health and Environment Confined Animal Feeding Operations (KDHE), and Equus Beds Groundwater Management District #2 (GMD2) met at the swine facility located in T24S-R6W-Sec 22 on December 9, 1999, to sample the monitoring wells surrounding the lagoon, the facility water-supply well, the lagoon, two monitoring wells located east of the facility, and three domestic wells that the facility owner requested be tested.

The water level was measured at each monitoring well and then the well was purged using an airlift pump system provided by GMD2 personnel or a small 2" submersible pump used by KDHE personnel. The monitoring wells were purged until the temperature, pH, and specific conductance of each well had stabilized, generally after 10 to 15 minutes of pumping. The water-supply well for the facility was pumped until the parameters stabilized. The sample from the lagoon was collected using a 1" PVC screw-joint sampler with smaller diameter polyethylene tubing inserted inside. The sampler is approximately 10 feet long with a support on the leading edge to keep the sampler off the bottom of the lagoon. The internal tube was connected to a peristaltic pump that pumped the sample into the collecting bottle. KDHE laboratories analyzed the sample.

Samples were collected for both KDHE and KGS analyses. KGS samples for each well were collected in a 500-ml unacidified polyethylene bottle, a 200-ml polyethylene bottle acidified with 2-ml 6M HCl, and a 125-ml polyethylene bottle for the nitrogen-15 isotope sample. The samples were iced and cooled until analyzed at the water-chemistry laboratory.

Samples for KDHE were collected in 1000-ml containers that were either unacidified or pretreated with acid for samples used in the metals analyses.

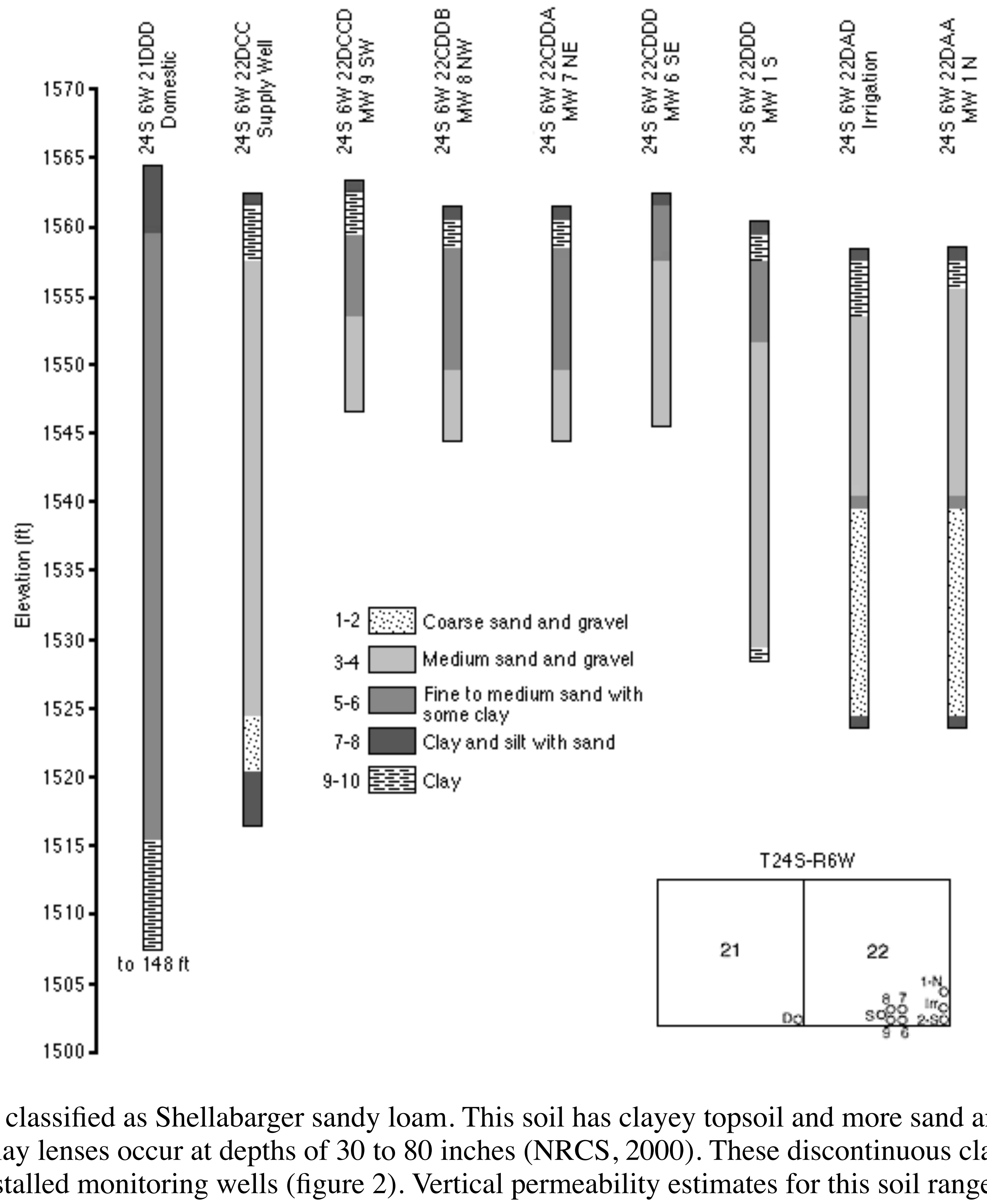
Nitrogen-15 isotope samples were sent to the University of Virginia for analysis. Samples were frozen and sent on ice by Federal Express to the laboratory. Samples were thawed and a known aliquot of sample was dried and the residue burned to determine the nitrogen-15 ratio with a known standard (air). Results are reported in per mil units (parts per thousand) and are represented by ‰. Values are reported as enriched (+, greater than 0) or depleted (-, less than 0).

Geology

The study site is located in Reno County, Kansas, T24S-R6W-Sec 22 and is in the Great Bend Prairie physiographic region of the state. The area is nearly flat with little topographic variation (figure 1).

This area is approximately 5 miles north of the North Fork of the Ninnescah River and underlain by Permian-age bedrock. The depth to bedrock is approximately 20-40 feet. The overlying units consist of silts, clays, and fine to coarse sands of Quaternary age as shown by the cross section of wells at and near the site (figure 2).

Figure 2. Cross section of wells in T24S-R6W-Sec 22. Note variation in thickness of clay and clay silt zones in upper portions of section. Circles represent locations of wells.



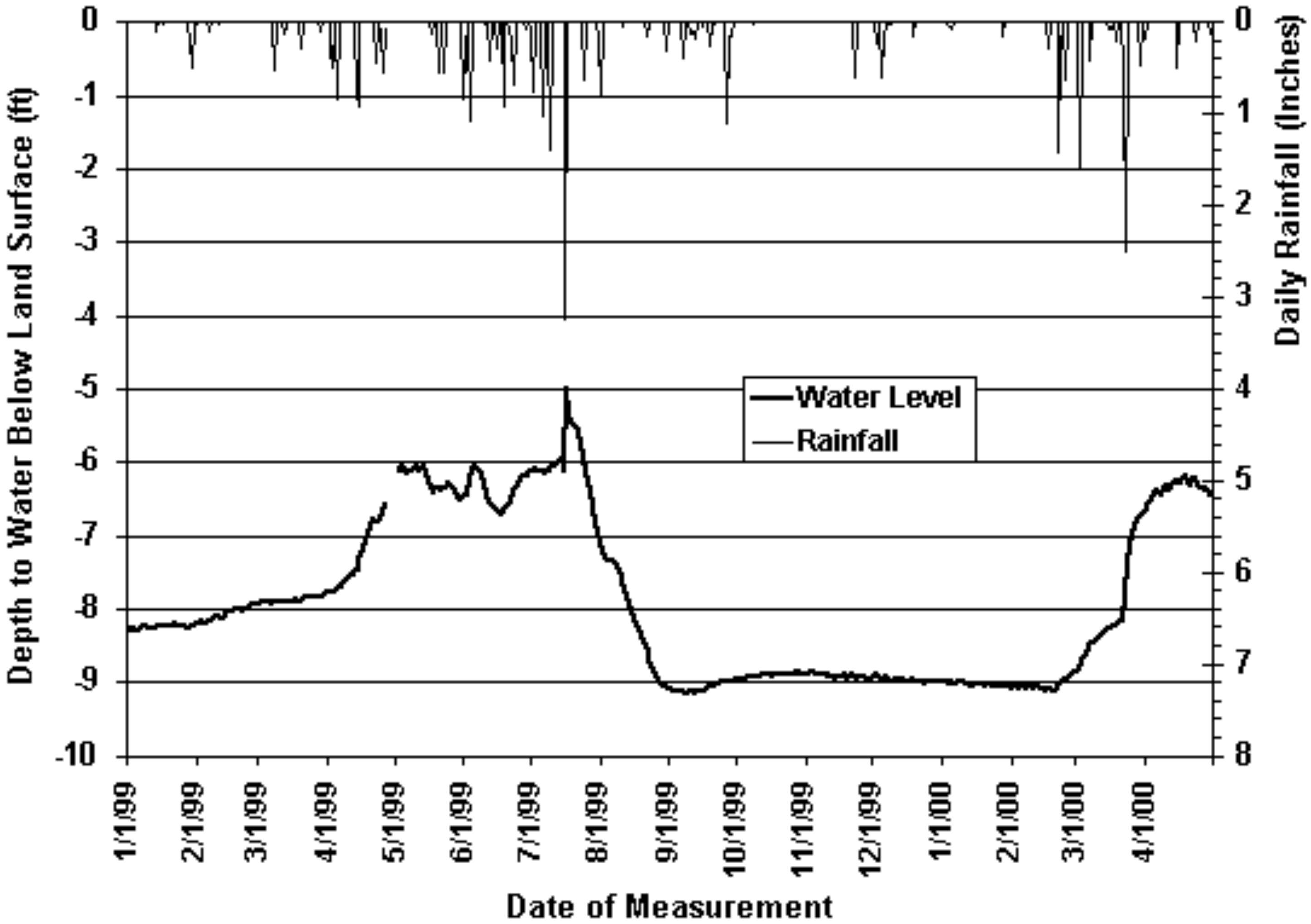
Soils near the facility are classified as Shellabarger sandy loam. This soil has clayey topsoil and more sand and silt in the subsoil. In this area discontinuous clay lenses occur at depths of 30 to 80 inches (NRCS, 2000). These discontinuous clay lenses are indicated on the well logs from the installed monitoring wells (figure 2). Vertical permeability estimates for this soil range from 0.6 to 2 inches/hour depending upon the presence or absence of clay zones in the soil profile.

Ground Water

Except for lesser water-bearing Permian rocks, the principal source of fresh and usable water in the study area is the Equus Beds aquifer. The Equus Beds aquifer is part of the High Plains regional aquifer system (Weeks and Gutentag, 1981; Watts and Stulken, 1985). Water level data indicate the aquifer is unconfined.

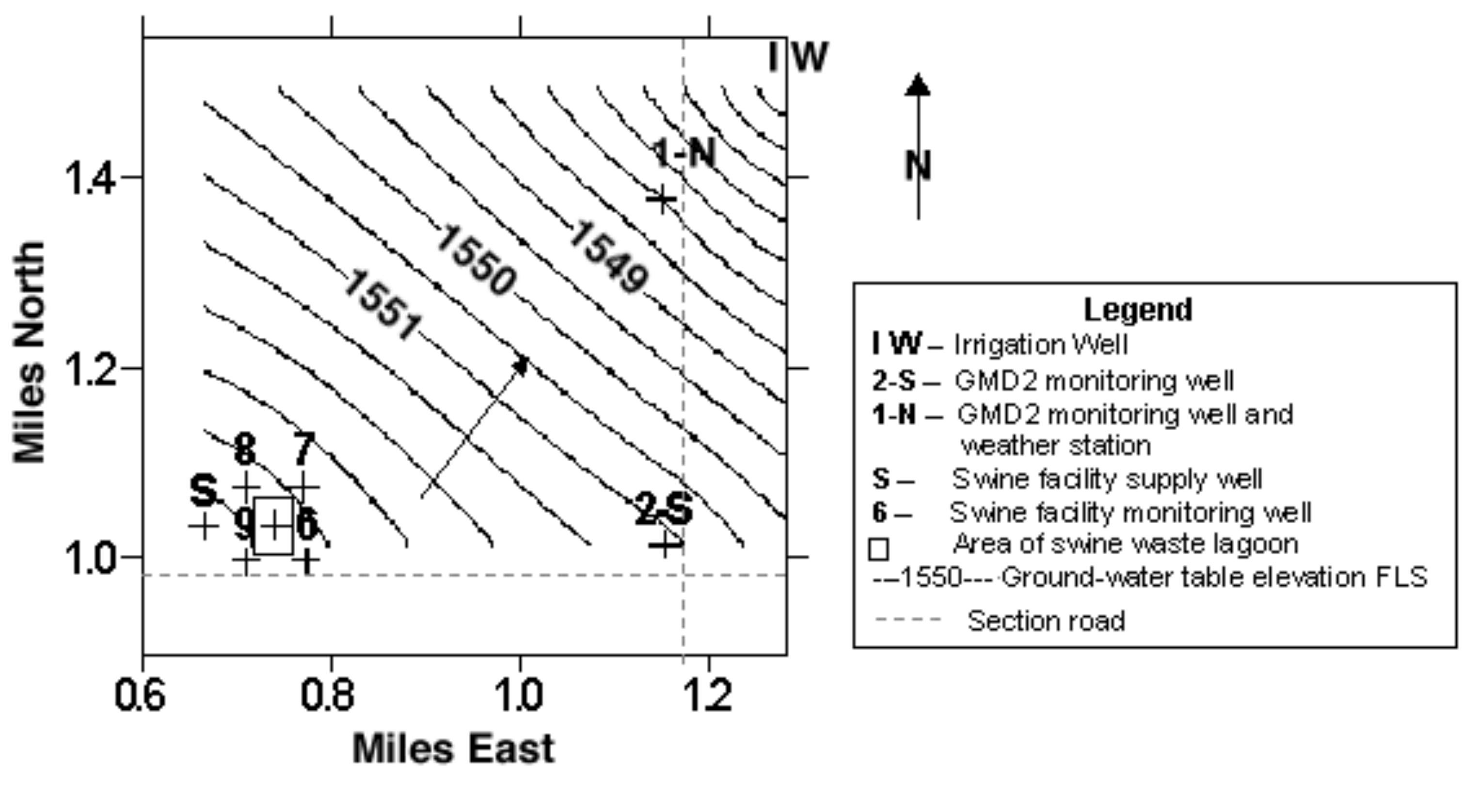
Average precipitation in the area is approximately 28.5 inches per year. Most of the rainfall occurs during the growing season from April to September. Depth to water at the lagoon site was 10 ft below land surface (bls) at the time of facility construction in 1994. Because of the permeable soils throughout the study area ground-water recharge and water table response is rapid. Figure 3 shows the change in the water table throughout 1999 into 2000. A rain-gage and water-level recording site operated by GMD2 is located to the east of the swine facility near monitoring well 1N (figure 3). Rapid infiltration through the soil profile means that any contaminants also will move rapidly from the land surface to the water table.

Figure 3. Precipitation and ground-water level record for 1999 and 2000 at site in T24S-R6W-Sec 22. Data from GMD2 data collection station to the east of site.



Land-surface elevation used to calculate water-table elevation and ground-water flow direction was determined by several accepted survey methods. Measurements from all land survey methods were in agreement. The survey was performed by geography students at Kansas State University campus, Salina, Kansas, and supervised by Professor Steven R. Thompson, P.E, Civil Engineering Technology, Kansas State University campus, Salina, Kansas. Ground-water flow direction was determined by GMD2 staff to be to the northeast as shown by the arrow in figure 4.

Figure 4. Ground-water elevation and flow direction (shown by arrow in figure) in the vicinity of swine facility in Reno County.



Lagoon

The lagoon covers an area of approximately 96,000 ft^2. The lagoon is approximately 311 ft in length per side, and 4 ft deep from the top of the berm surrounding the lagoon. The lagoon is lined with 2 ft of compacted bentonite covering an area of 127,000 ft^2, which includes covering part of the berm banks.

A monitoring well is located at each corner of the lagoon (figure 4). The wells are 17 ft deep. Depth to water was approximately 10 ft in depth at the time of installation in 1994. A production well for use in the facility is located to the west of the lagoon and the swine-housing facilities. As indicated in the cross section of wells in the area (figure 2), the major portion of the aquifer is of fine to coarse sand. Horizontal hydraulic conductivity estimates from the county report (Bayne, 1956) indicate values from 12 to 72 ft/day.

Work by Kansas State University personnel (Ham and others, 2000) showed that the leakage rate from the lagoon was 0.03125 inches/day. This is equivalent to a **maximum** discharge of 11.4 inches/year or 0.95 ft/year. The leakage is not confined to a specific point below the lagoon so the maximum discharge rate must be evaluated over the area of the lagoon (96,000 ft^2): 96,000 ft^2 x 0.95 ft/year = 91,200 ft^3/year. Converting this to acre-ft: 91,200 (ft^3/year)/43,560 (ft^3/acre-ft) = 2.09 acre-ft/year (681,029 gallons) of potential leakage from the lagoon. The rate of leakage should be **less** than this amount because the lagoon is drained, and the effluent is used to irrigate cropland when a maximum depth is reached as specified in the swine facility operational permit issued by KDHE.

Water Chemistry

The general water chemistry type for the area is calcium bicarbonate. Many of the samples collected in the area had nitrate-N above the drinking-water limit of 10 mg/L. Land uses vary surrounding the swine facility. Dry-land farming dominates in the area west and south of the site. The land directly north and northeast of the facility is used for irrigated spray disposal of hog-lagoon waste and crop production. Irrigated farming occurs to the east and northeast of the facility. A dairy is located to the northwest of the facility. The rest of the sampled sites are long-time residences and small farm homesteads. Chemical analyses for the three sampling periods during this study are in Appendix A.

Figure 5 shows a nitrate-N contour of the various sites sampled by KDHE in September 1999. In general the entire area surrounding the swine facility is high in nitrate-N probably due to the presence of many sources in the area including fertilizer application and animal waste from both barnyard and septic-tank sources.

Figure 5. Contour map of nitrate-N concentration from KDHE sampling in September 1999 and KGS/KDHE sampling in December 1999. Note the general high nitrate-N throughout the area. Lower nitrate-N at monitoring well #7 (4.8 mg/L) indicated by hachure marks.

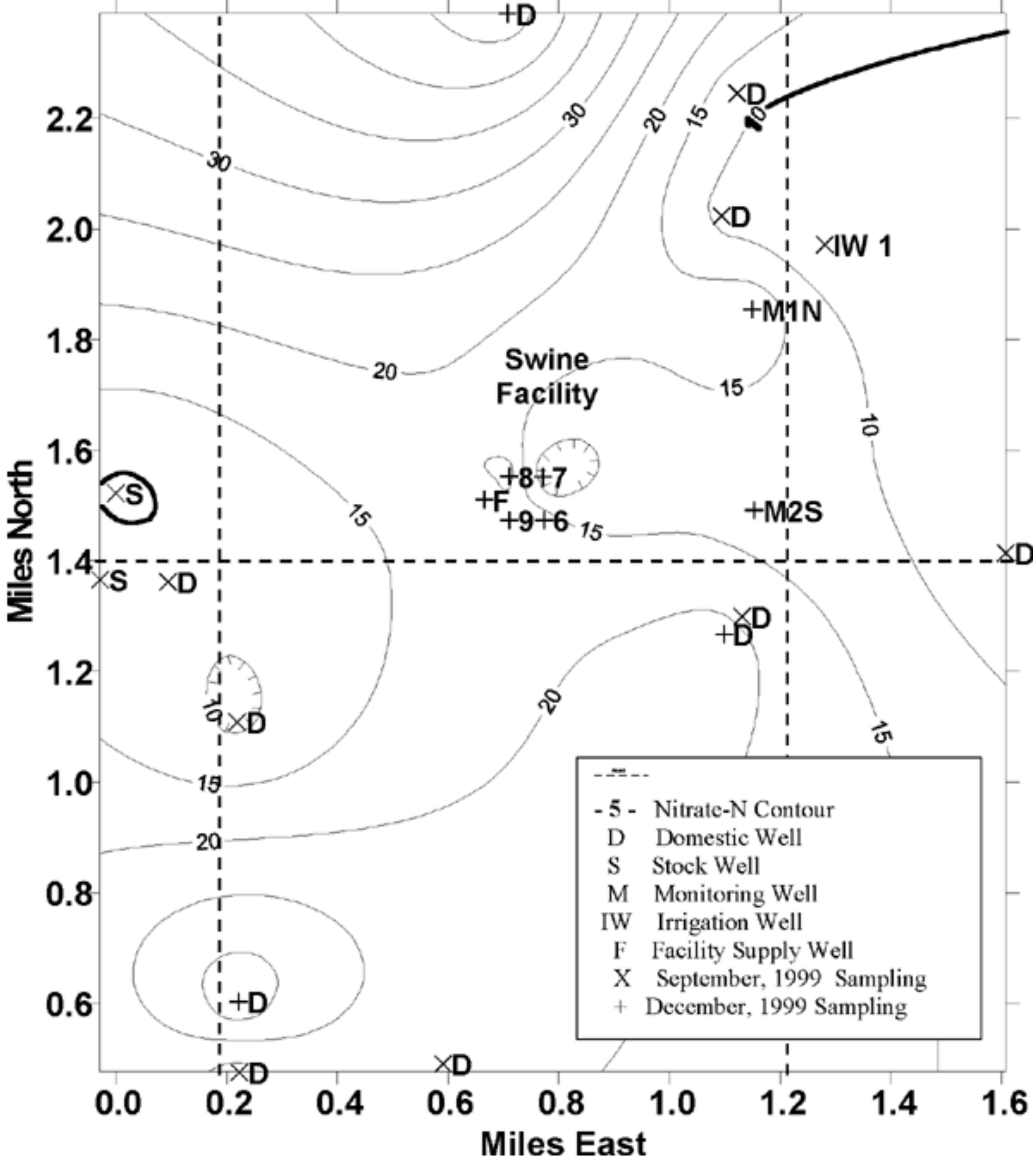
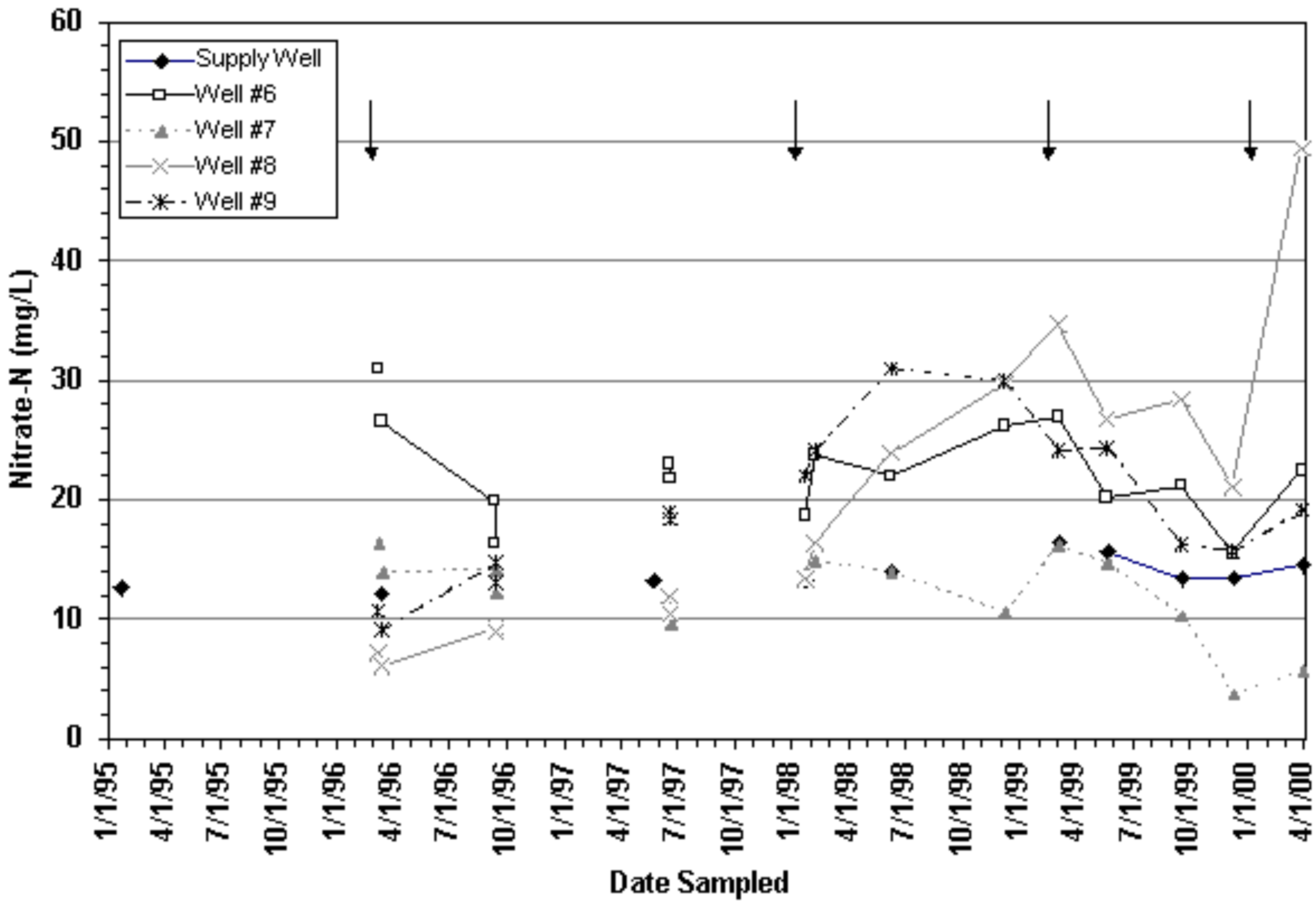


Figure 6 shows the variability of nitrate-N at the swine facility with time. Arrows indicate the probable fertilizer application times to the dry-land farms surrounding the facility. The seasonal high nitrate values at the monitoring wells appear to coincide with fertilizer application several months earlier. The nitrogen-15 isotope values measured in March 2000 (discussed in Nitrogen isotope section) strongly support this observation. Because of the rainfall amount and the highly permeable nature of the soils and aquifer materials in the area, it appears that chemicals applied at the surface move rapidly to the subsurface. This has been observed in other studies in the Reno County area and in other parts of south-central Kansas (Townsend, 1997; Townsend, 1999).

Figure 6. Graph of variation of nitrate-N concentration with time. Arrows indicate probable periods of fertilizer application. Note general increase in nitrate concentration during spring as indicated by arrows.

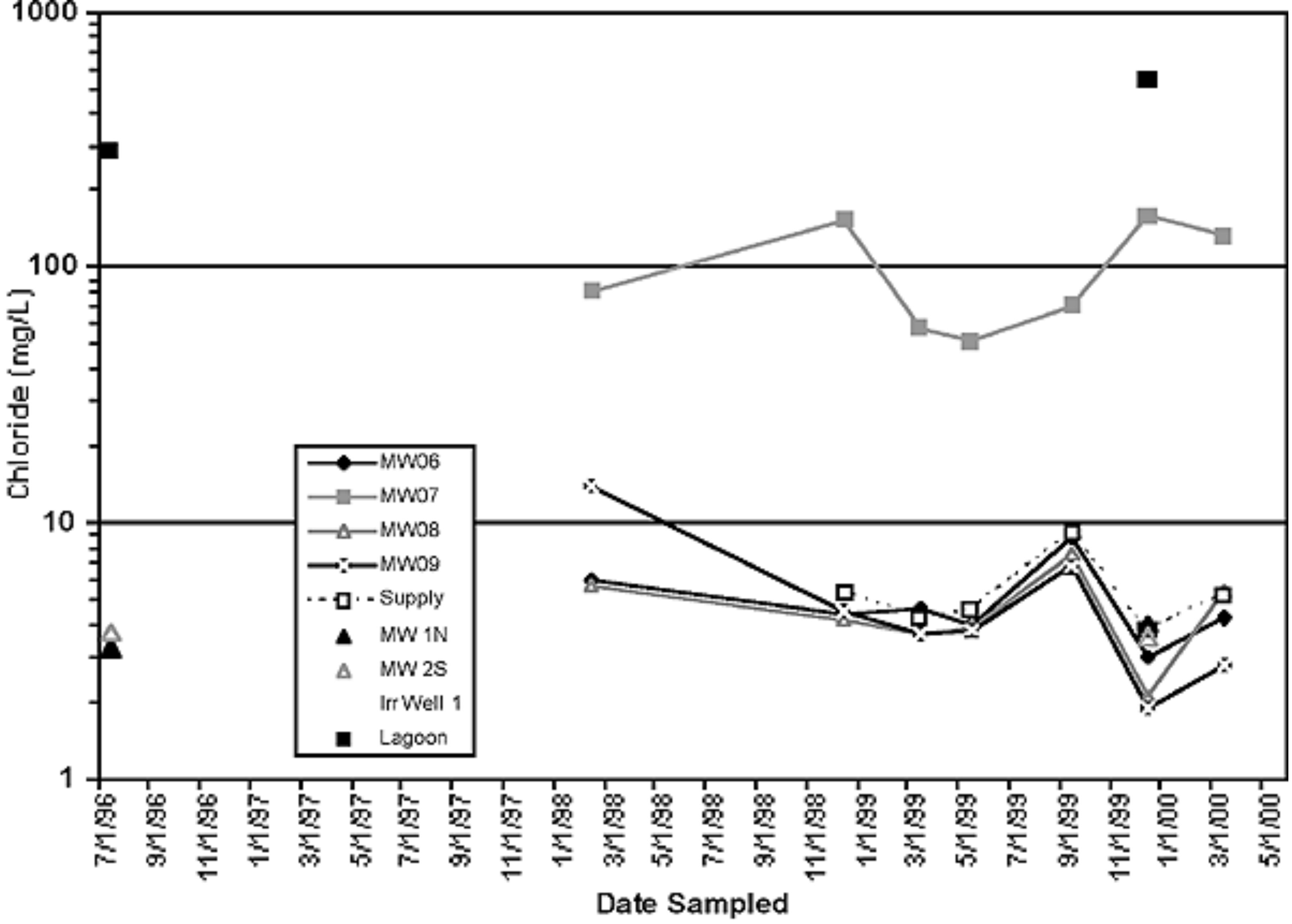


Chloride

Chloride is considered a reliable and stable tracer because it is not transformed by chemical or biological processes (Davis et al., 1985). Because chloride is a stable ion, the ratio of chloride from two different wells should provide an indicator of the percent of mixing of waters from two sources.

The chloride concentration of most of the observation wells around the facility (wells 6, 8, and 9) and the supply well have similar chemistry at any given sampling event (1.9 to 22 mg/L, Appendix A, figure 7). Monitoring well #7 has a higher concentration of chloride than the regional ground-water chemistry. The chloride concentration in well #7 was 159 mg/L in December 1999 and the concentration in the lagoon was 547 mg/L.

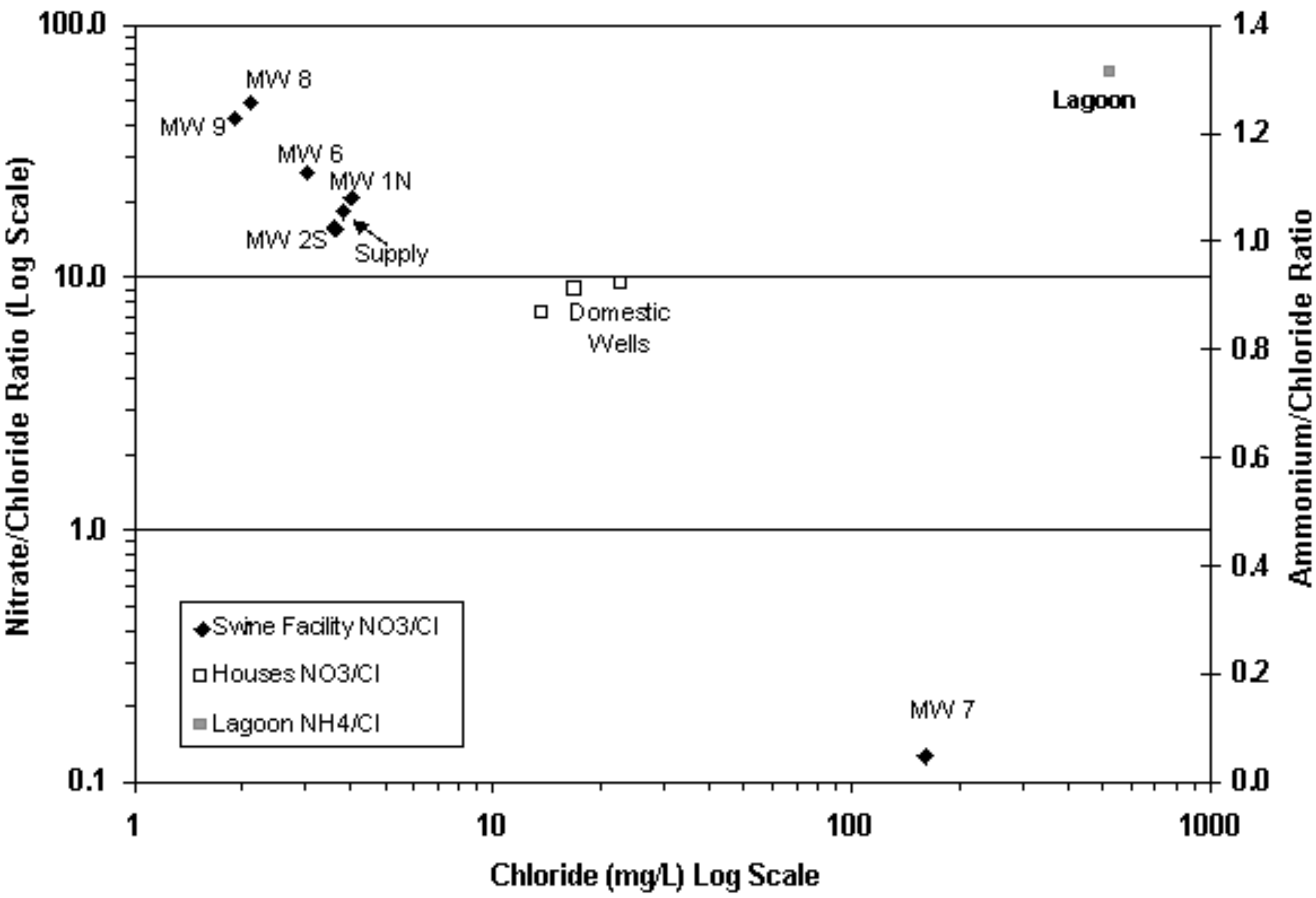
Figure 7. Chloride concentration for wells near swine facility plus waste lagoon. Note similarity of chloride concentration from all monitoring wells except well #7. Well #7 has concentrations between that of the lagoon and the regional water chemistry, indicating probable mixing of waters.



Because of the stability of chloride in ground water, the chloride ratio between the quantity measured in the lagoon and that measured in well #7 should give an estimate of the proportion of lagoon water entering well #7. In this case the ratio of chloride in well #7 to the amount measured in the lagoon (159/547mg/L) is approximately 30%. A similar ratio is noted from the July 1996 measurements (Appendix A). This simplification of the situation at the site assumes that the water from the lagoon is being diluted by the regional water chemistry, which has a range of about 2 to 25 mg/L chloride (Appendix A). The occurrence of higher chloride at well #7 (downgradient of the lagoon) suggests the probable movement of chloride with the ground-water flow direction as shown previously in figure 4. Further work is needed to evaluate the overall effects of mixing of water types to determine the possible effects of dilution of lagoon water by regional ground water.

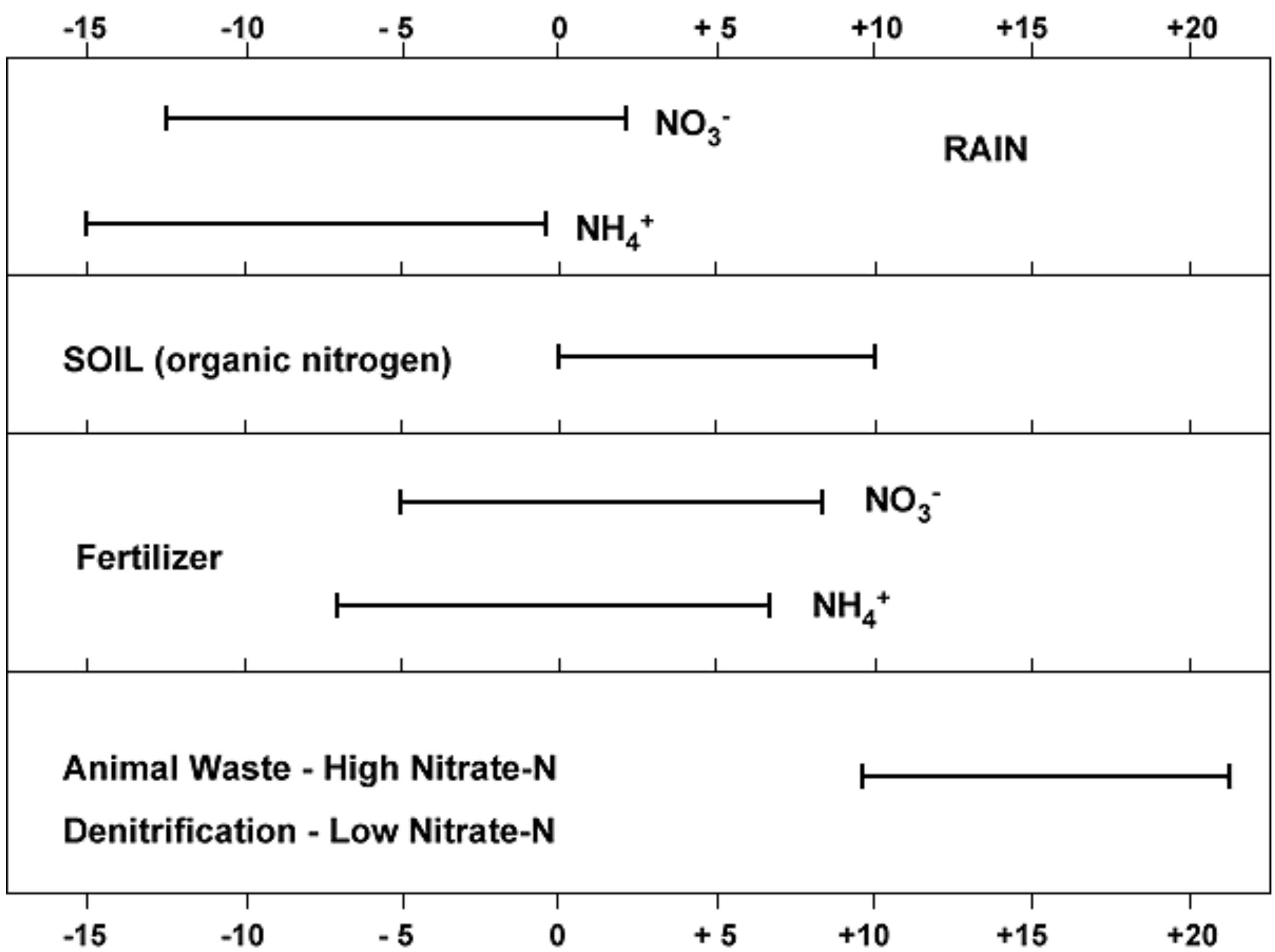
The ratio of nitrate/chloride is another tool for determining sources of nitrate (Williams et al., 1998). Figure 8 shows the similarity of the nitrate/chloride ratio for the majority of wells near the swine facility sampled in December 1999. The domestic wells sampled in December 1999 show different ratios than the swine facility wells and monitoring well #7 shows an even larger difference from all of the other wells. The lagoon sample represents ammonium/chloride ratio because the nitrate-N concentration is negligible. The difference in the ratios suggests that different sources are responsible for the chemical values. As discussed previously the wells around the facility represent water that has been impacted by dry-land farming practices for the most part. The domestic wells represent the impact of human and/or other confined animal waste facilities near the wells. Monitoring well #7 appears to represent the mixing of the regional ground water with leakage from the lagoon.

Figure 8. Nitrate/chloride and ammonium/chloride ratios for December 1999 sampling at swine facility. Monitoring well #7 and the domestic well samples show very different ratios than the other monitoring wells and the supply well.



Nitrogen-15 isotope analysis is a method to assist in determining sources of nitrogen in ground water. The isotope analysis evaluates the ratio of nitrogen-14 (what is present in the air we breathe) to the amount of nitrogen-15 present in the water or whatever is being analyzed. This ratio is compared to a standard based on the ratio of $^{14}N/^{15}N$ present in air. Comparisons of these values indicates if there is more (a positive value +) or less (negative value -) than the standard. The plus or minus sign indicates whether the sample is enriched (+) or depleted (-) in relation to the standard. Units of nitrogen-15 isotope values are in per mil (‰) and are equal to parts per thousand. Researchers have found that sources of nitrogen in ground water fall into various categories. These are illustrated in figure 9.

Figure 9. Range of nitrogen-15 values and probable sources from multiple studies (adapted from Heaton, 1986).



Values of d ^{15}N that range from negative values up to +8‰ generally indicate sources from atmospheric nitrogen (rain), fertilizer, or soil organic nitrogen (figure 9). Rainwater has very low nitrogen content as nitrate (NO_3 -N) or ammonium (NH_4-N), usually less than

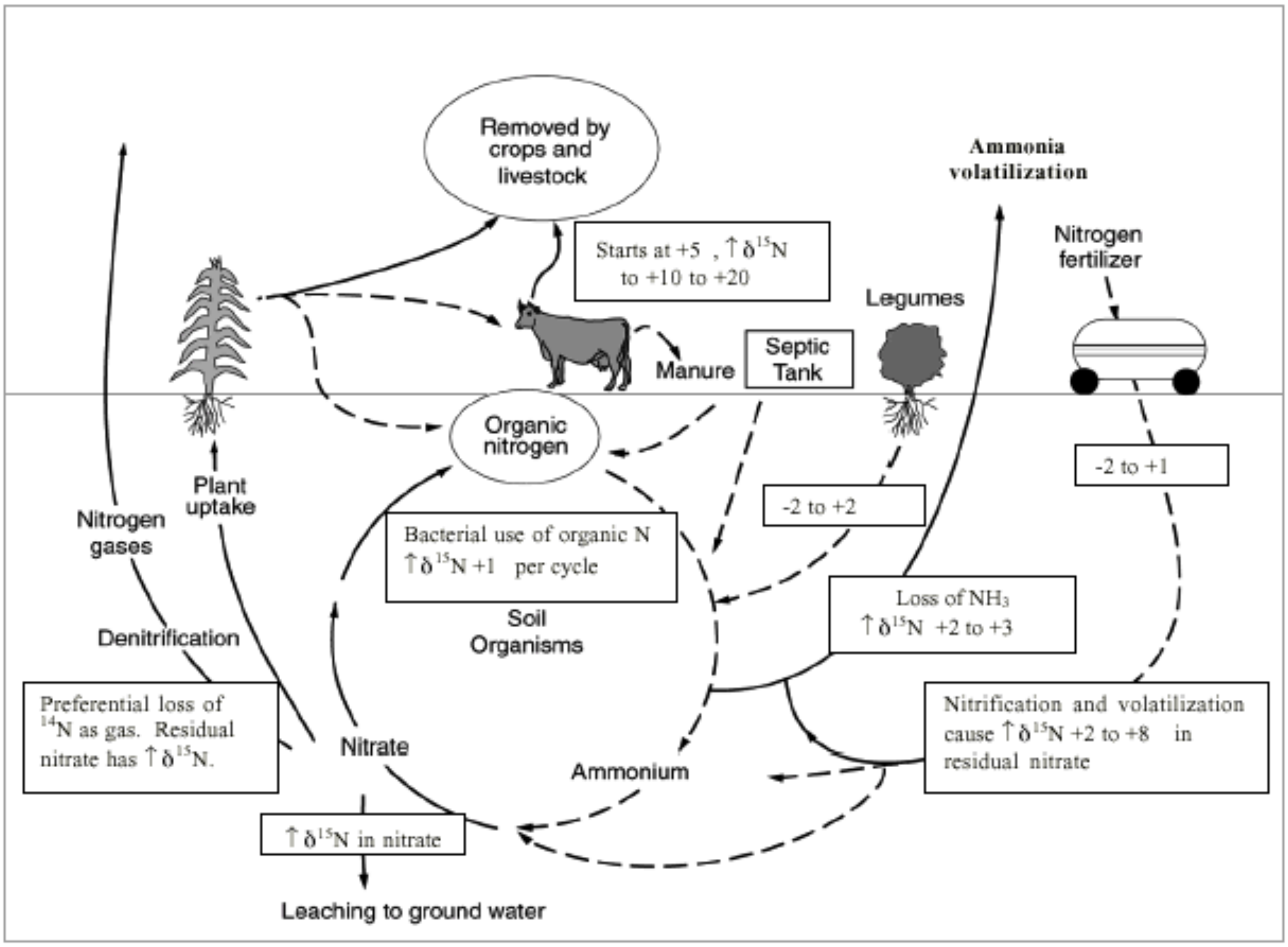
1 or 2 mg/L. Fertilizer and soil organic nitrogen samples are frequently above 2 mg/L nitrate-N, which is considered a "background level" of pristine areas that are not affected by human activities (Mueller and Helsel, 1996). Generally, if fertilizer is a source, the nitrate-N concentration is above 2 mg/L and often over 10 mg/L (drinking-water limit), and the d ^{15}N signature is between +0 and +8‰.

Animal-waste sources have a signature that is generally greater than +10‰. Nitrate-nitrogen concentrations often are above the drinking-water limit of 10 mg/L. Another possibility for an enriched value (greater than +10‰) is called denitrification. This occurs when bacteria break down the nitrate-N to nitrogen gas. This process usually results in nitrate-N concentration of below 1 mg/L as well as a high d ^{15}N value (greater than +10‰).

The effects of various processes of the nitrogen cycle on the enrichment of d ^{15}N are shown in figure 10. The figure illustrates the various sources of nitrogen to the environment and gives an indication of processes that result in changes in the d ^{15}N signature of products from the various reactions. In general if biological processes occur such as bacterial use of nitrogen or animal use of plant material with the end product of manure or urea, the process preferentially uses the available ^{14}N isotope. The net result is that the ^{15}N isotope is concentrated in the remaining form of nitrogen. In the case of the study at Reno County, the dominant form of nitrogen in the ground water is nitrate.

As can be seen from the diagram (figure 10), animal waste starts as a +5‰ value. Any volatilization process of ammonia from the urea or manure will result in an additional increase of up to +3‰. Any biological intervention such as nitrification of ammonium in the barnyard will also increase the d ^{15}N value of the resulting nitrate. Any biological use of the organic nitrogen in the system will also result in an increase in d ^{15}N. The resulting nitrate will be high in concentration (usually if coming from a point source such as a confined feeding operation or septic system) with an enriched d ^{15}N signature.

Figure 10. Effects of processes in the nitrogen cycle on d ^{15}N values for different forms of nitrogen, particularly nitrate.



Nitrate from a fertilizer source also will have some changes because of nitrification changes from ammonium to nitrate, but the resulting d ^{15}N value is lower because the original value of the fertilizer is much lower. In this case too, the nitrate concentration also will be high if the soil is sufficiently permeable to permit movement of the nitrate before plants utilize it or bacteria can degrade it to nitrogen gas.

Nitrogen-15 isotope values at the Reno County site

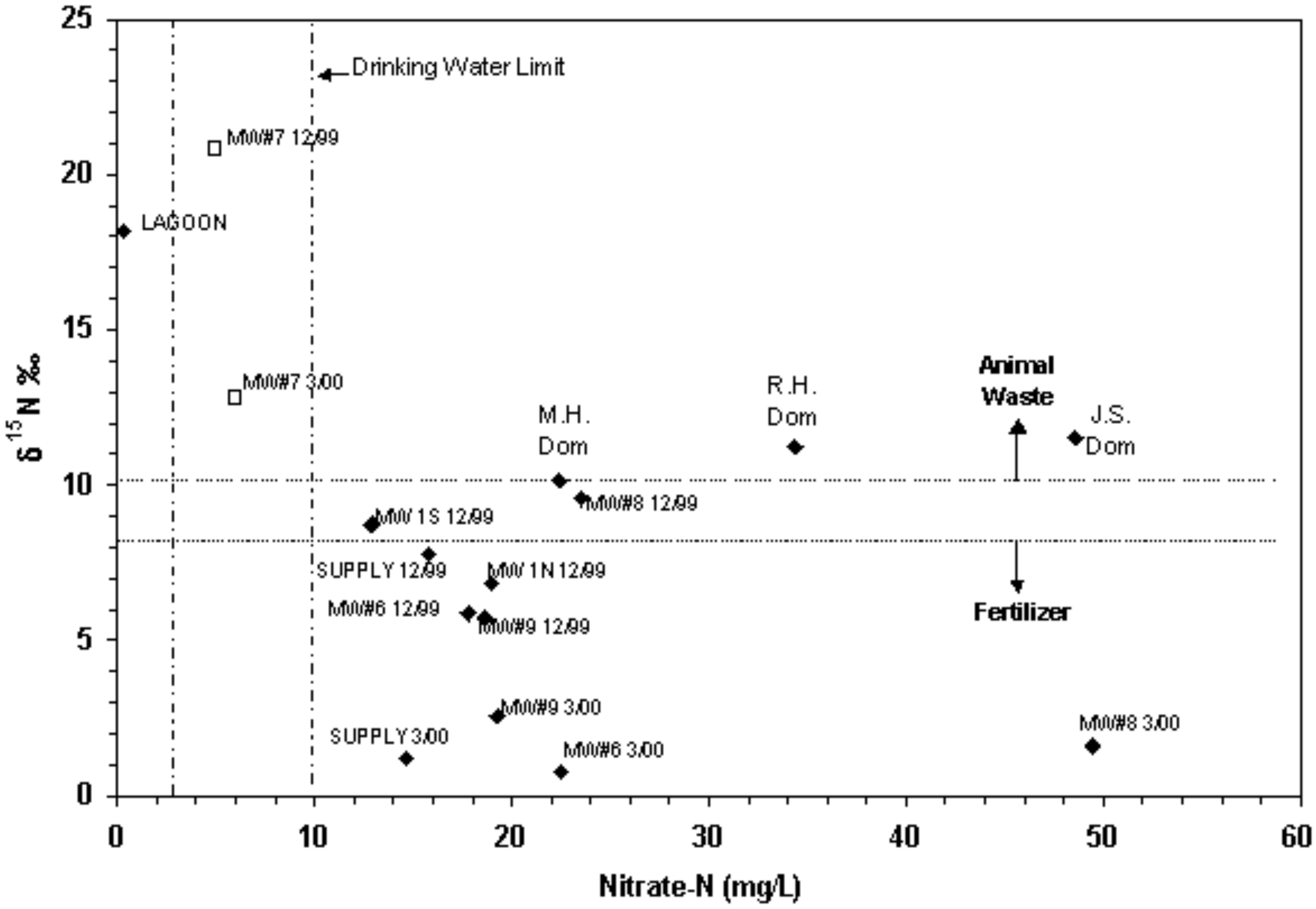
Nitrogen-15 was used in the current study as a means to determine if a waste-storage lagoon at a swine facility was leaking. Based on the information presented previously, an animal waste source from the lagoon would have an enriched d ^{15}N value above +10‰. If the contamination was widespread away from the lagoon, other wells sampled in the area should have similar d ^{15}N values.

Figure 11 shows the range of values of samples collected in December 1999 from monitoring wells around the lagoon, the lagoon, the supply well, and several homes in the area. The values from monitoring wells 6, 8, and 9 indicate that a fertilizer source is responsible for the high nitrate in these wells. The values from the lagoon and monitoring well #7 (downgradient along the flow path from the lagoon) both show d ^{15}N values in the animal-waste range.

Figure 11 also shows the nitrate-n concentration and d ^{15}N values for samples collected in March 2000. The nitrate-N values are higher in all wells and the d ^{15}N values are in the fertilizer range for all wells except monitoring well #7. The lagoon was not sampled in March 2000, and the d ^{15}N value was not determined for this period.

Figure 6 showed the variation in the nitrate-N concentration in the vicinity of the swine facility since 1995. Nitrate concentration has definitely increased in the wells in the spring. The fertilizer signature for the d ^{15}N associated with these values strongly indicates rapid ground-water recharge in the area.

Figure 11. Nitrogen-15 and nitrate-N values for wells at swine facility and surrounding domestic wells. Samples collected in December, 1999 and March 2000.



The increased nitrate-N concentration during springtime with d ^{15}N values in the fertilizer range strongly suggests that rapid infiltration of nitrified anhydrous ammonia fertilizer into the water table has occurred in the area. The land use surrounding the facility is mainly dry-land farming. Irrigation directly to the north and east of the facility is responsible for application of waste from the lagoon. Irrigated farming occurs in section 23 east of the facility.

The cross section of well logs from the area (figure 2) showed the presence of mostly fine to coarse sands within the aquifer with overlying sandy to clayey loam soil. The distance between well logs is a minimum of 300 feet (monitoring wells at site) up to 1 mile. The presence of seasonal high nitrate-N and variation in d ^{15}N values suggests that the overlying thin silty clays to clays may not be continuous and do not prevent nitrification of ammonium sources to nitrate.

The rainfall data and depth to ground water (figure 4) show that there is a rapid response and subsequent rise in the ground-water table when certain types of rainfall events occur. This rapid response indicates that any dissolvable material applied to the surface will quickly reach the ground water if sufficient water is available. The time lag is probably minimal, on the order of weeks to months at the most.

Conceptual Model

The presence of high nitrate in all of the wells at the facility (except well #7 downgradient of the site) and in the surrounding area indicates regional and multiple nitrate sources. The lower nitrate-N concentration at well #7 is indicative of a chemical reaction occurring in the vicinity of the subsurface area of the lagoon.

The swine facility has been in operation since 1994. The bottom and sides of the lagoon are sealed with bentonite to a depth of 2 feet and compacted. In spite of this barrier zone, a seepage investigation by KSU researchers found that the lagoon leaks at a rate of 0.03125 inches/day. This is equivalent to a maximum discharge of 11.4 inches/year. The rate of leakage will be less than this amount because the lagoon is drained and the effluent used to irrigate cropland when a maximum depth is reached as specified in the swine-facility operational permit issued by KDHE.

The bentonite used in the lagoon has a specified cation-exchange capacity that is in the range of 78 to 100 centimoles of negative charge per kg of bentonite. This means the bentonite has a finite ability to absorb the ammonium that is produced by the swine and is discharged with the wastewater to the lagoon. If the ammonium reaches the unsaturated zone, it is available either to be nitrified by bacterial processes to nitrate or if a reducing zone exists beneath the lagoon then the ammonium will most likely be stored in the limited clay and silt available in the upper unsaturated zone beneath the lagoon.

The lagoon has a measured rate of leakage. The chloride concentration of both the lagoon and well #7 (downgradient) is much higher than any of the other monitoring wells, the supply well, or any of the other wells sampled in the area. The only exception is one domestic well which is located downgradient from a small feedlot located in T24S-R6W-Sec 21 (Appendix A). The high chloride and very low ammonium-N (0.85 mg/L) at this well probably indicates an impact from the underlying Permian bedrock aquifer. A nitrogen-15 sample was not collected at this site.

The δ^{15}N of well #7 also is similar to that measured in the lagoon although it is lower in value. The chloride ratio of well #7 and the lagoon water suggests that approximately 30% of the water reaching well #7 is from the lagoon. This means that mixing of regional ground water and lagoon water has likely occurred. Because the nitrate-n value in well #7 is low (4 to 5 mg/L), the δ^{15}N value is enriched relative to the other monitoring wells, and the chloride value is high. This suggests that leakage of the lagoon water may have caused a reducing water-chemistry zone in the subsurface that permits some denitrification of the nitrate-N in the regional ground water (13.6 mg/L nitrate-N in well 9 upgradient from the lagoon, fig. 4). The bicarbonate level in well #7 (447 mg/L) helps to support the idea of leakage from the lagoon but also may be an indicator that denitrification could be occurring in the subsurface, particularly if there is a reducing water chemistry below the lagoon.

Conclusions

Results from this study show that the water chemistry of the area surrounding the swine facility is impacted by the facility. The chloride ratio of water collected downgradient of the facility indicates that approximately 30% of the lagoon water is migrating from the waste-lagoon area. Bicarbonate values, nitrate-N, and δ^{15}N values from a well downgradient of the lagoon indicate a possibility of denitrification of regional ground water as a source for the lower nitrate observed in this well. Other monitoring wells at the site show a strong δ^{15}N fertilizer signal as well as high nitrate-N values as has been observed in other agricultural areas in Reno County. Domestic wells in the area show high nitrate-N values and animal-waste-source signals for the measured δ^{15}N of these samples.

Recommendations for Additional Work

1. Work is under way to obtain permission for collection of water samples for nitrogen isotope analysis from irrigation wells associated with the facility and down-gradient from the site.
2. Construction of a conceptual model of the flow and mass movement through the area underlying the lagoon will continue.
3. Additional fieldwork such as collection of a core under the lagoon for chemical and physical soil properties would provide additional confirmation of the occurrence of denitrification under the waste lagoon.
4. Collection of cores and installation of a monitoring well in the field where the waste is irrigated onto the field for disposal would permit evaluation of possible problems from movement of animal-waste nitrogen into the ground water in a non-reducing water-chemistry environment. Nitrogen-isotope work on these samples would permit definition of a limit to the north of the site in terms of the dimension of a possible plume of waste in the area.
5. Continue monitoring ground-water levels, water quality, and atmospheric conditions at or near the swine facility.

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Acknowledgments

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Appendix A. Water-chemistry analyses from Reno County swine facility.

Samples collected by KDHE, KGS, and GMD2.

Sample Id	Date Sampled	Legal Location	d^{15}N ‰	SPCD micro-mhos/cm	pH	SiO_2 ppm	Calc TDS ppm	Ca ppm	Mg ppm	Na ppm	K ppm	HCO_3 ppm	SO_4 ppm	Cl ppm	F	B ppm	NO_3-N ppm
Supply	September-99	24S-6W-22 SW SW SE					97.5	30.9	5.8	8.2	1.1	58.2	13.4	9.2	0.25	0.049	13.4
Supply	December-99		7.79	280.0			189.0	31.3	5.8	8.1	1.1	59.0	14.8	3.8	0.25	25	15.7
Supply	March-00		1.24	264.0	6.57	26.12	157.6	31.0	5.6	8.3	1.3	57.9	12.8	5.3	0.21	0.066	14.6
MW6	September-99	24S-6W-22 SW SW SE					105.2	37.0	9.2	8.3	2.2	52.0	13.8	8.9	0.20	0.125	21.2
MW6	December-99		5.91				192.8	29.4	7.2	7.4	0.8	56.0	11.5	3.0	0.23	27	17.7
MW6	March-00		0.81	321.0	6.36	25.63	194.1	35.0	8.2	8.0	0.8	53.6	11.9	4.3	0.17	0.071	22.5

MW7	September-99	24S-6W-22 SW SW SE					246.5	48.0	10.9	7.0	1.1	188.7	15.6	70.9	0.20	0.063	10.4
MW7	December-99		20.81	1060.0			727.6	149.0	34.0	46.2	2.5	437.0	16.3	159.0	0.24	84	4.6
MW7	March-00		12.8	1205.0	6.5	20.647	645.2	129.1	32.1	70.1	1.6	485.5	14.4	133.6	0.12	0.071	5.7
MW8	September-99	24S-6W-22 SW SW SE					169.5	74.8	16.9	17.6	1.3	78.8	12.4	7.6	0.17	0.051	28.5
MW8	December-99		9.58	350.0			258.4	44.3	10.0	6.6	0.9	83.6	12.9	2.1	0.16	36	23.5
MW8	March-00		1.63	610.0	6.26	23.591	352.7	63.8	15.0	11.0	1.4	59.3	8.0	5.4	0.09	0.069	49.4
MW9	September-99	24S-6W-22 SW SW SE					96.6	34.0	7.8	5.6	1.2	58.5	12.0	6.7	0.23	0.276	16.3
MW9	December-99		5.74				198.3	31.0	7.8	5.7	0.7	58.8	9.7	1.9	0.18	30	18.6
MW9	March-00		2.59	290.0	6.3	25.207	179.8	33.1	7.6	5.6	0.7	74.2	8.3	2.8	0.15	0.069	19.2
MW1 N	July-96	24S-6W-22 NE NE SE		260.0			185.3	39.0	5.0	18.0	1.2	78.0	16.3	3.3			14.5
MW1 N	December-99		6.78	364.0			249.2	43.1	6.4	18.7	1.2	108.0	15.3	4.0	0.33	23	18.9
MW2 S	July-96	24S-6W-22 SE SE SE		270.0			195.0	40.0	6.0	17.0	1.1	82.0	17.3	3.7			15.7
MW2 S	December-99		8.78	342.0			226.1	40.4	5.8	16.6	1.0	112.0	20.2	3.6	0.37	26	12.8
Lagoon	July-99			5400.0	7.80		3469.0	80.0	30.0	170.0	655.0	4392.0	50.0	288.0		1	0.5
Lagoon	December-99		18.22		7.79	72.1	5603.7	79.5	10.6	216.6	814.0	3925.7	23.9	547.0	1.19	1.106	0.28
S. IW	July-96	24S-6W-23 NC NS NW SW		277.0	6.91			38.0	7.0	17.0	1.1	66.0	17.8	5.2			18.9
R.H.	September-99	24S-6W-27 SW			7.48		309.9	102.0	10.0	25.4	1.5	199.8	52.0	20.4	0.26	0.068	31.4
R.H.	December-99		11.29	735.0	7.25	25.9	467.6	106.0	10.0	26.5	1.6	201.0	55.2	16.9	0.32	0.044	34.3
J. S.	September-99	24S-6W-22 NE			7.26		402.2	116.9	15.2	57.6	1.3	341.6	19.2	23.5	0.33	0.166	41.1
J. S.	December-99		11.57	975.0	7.40	25.3	618.7	121.0	15.9	57.5	1.2	338.0	18.1	22.8	0.43	0.083	48.5

M. H.	September-99	24S-6W-27 NE			7.04		215.4	60.0	8.3	26.3	1.1	137.6	32.3	19.0	0.38	0.236	20.4
M. H.	December-99		10.21	491.0	6.60	26.0	304.4	58.9	8.1	26.0	1.0	131.0	32.5	13.7	0.42	0.029	22.4
J. H.	September-99	24S-6W-27 NE SE NE NE			6.99		200.7	55.8	7.6	24.0	0.8	132.9	33.6	13.2	0.33	0.051	18.6
C.M.	September-99	24S-6W-26 NE NW			7.54		439.3	98.4	10.0	62.6	1.0	428.3	30.7	25.5	0.57	0.138	6.2
A.U.	September-99	24S-6W-27 SW SW			7.37		265.6	84.3	7.6	20.7	1.3	218.7	27.5	16.4	0.23	0.097	17.2
A.M.	September-99	24S-6W-27 SE SW			7.33		327.1	101.5	7.4	25.9	1.1	195.2	53.4	41.7	0.23	0.057	22.0
P.H.	September-99	24S-6W-27 SW NW			7.37		149.6	40.3	4.9	16.9	1.0	114.8	21.8	8.1	0.23	0.06	8.9
G.R.--Stock	September-99	24S-6W-21 NE SW SE SE			7.72		455.6	56.8	17.2	85.8	2.1	201.6	147.3	46.5	0.42	0.37	8.7
G.R.	September-99	24S-6W-21 NW SE SE			7.73		1048.6	111.9	37.0	157.8	2.8	120.9	537.0	142.0	0.41	0.679	0.9
G.Y.	September-99	24S-6W-28 NE NE NE			7.09		305.7	95.5	9.9	62.6	1.0	143.3	48.2	17.6	0.44	0.138	10.8
G.Y.--Stock	September-99	24S-6W-28 NW NE NE			7.3		225.7	58.6	7.9	24.7	1.3	163.0	33.5	19.2	0.34	0.06	14.1
J.H.	September-99	24S-6W-22 SE SE NE NE			7.18		148.3	37.8	6.4	16.9	1.6	117.9	19.2	8.0	0.35	0.088	11.6
S.C.	September-99	24S-6W-22 SE NE			7.19		111.1	29.9	4.2	12.5	1.0	86.1	13.9	6.9	0.32	0.076	8.4
Sample Id	**Date Sampled**	**Legal Location**	**d^{15}N ‰**	**SPCD micro-mhos/cm**	**pH**	**SiO_2 ppm**	**Calc TDS ppm**	**Ca ppm**	**Mg ppm**	**Na ppm**	**K ppm**	**HCO_3 ppm**	**SO_4 ppm**	**Cl ppm**	**F**	**B ppm**	**NO_3-N ppm**

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