WASHINGTON STATE DEPARTMENT OF ECOLOGY

Effects of Land Application of Manure on Groundwater at Two Dairies over the Sumas-Blaine Surficial Aquifer

Implications for Agronomic Rate Estimates

March 2002

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Effects of Land Application of Manure on Groundwater at Two Dairies over the Sumas-Blaine Surficial Aquifer

Implications for Agronomic Rate Estimates

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Abstract

The Washington State Department of Ecology (Ecology) monitored groundwater, soil pore liquid, and soil at two diary farms over the Sumas-Blaine Surficial Aquifer from 1997-2000. At the same time, Ecology compared manure and commercial fertilizer application with recommended agronomic rates.

Fifteen monitoring wells and 12 soil pore-liquid samplers were installed within and upgradient of two spray fields. Monitoring wells and soil pore-liquid samplers were sampled monthly for ammonia-nitrogen, nitrate+nitrite-nitrogen (nitrate+nitrite-N), total nitrogen, chloride, total dissolved solids, total organic carbon, dissolved oxygen, temperature, pH, and specific conductivity. Composite soil samples were collected at each site in September to estimate residual nitrate and ammonia at the end of the growing season.

Measured application rates exceeded agronomic rates by 10-600 lb/acre/year at Site 1, with the exception of one year when part of the site received close to the agronomic rate. At Site 2 the measured application rate ranged from below the agronomic rate to 140 lb/acre/year above the rate. The median groundwater nitrate+nitrite-N concentrations in downgradient wells at Site 1 (15.4 mg/L in the North Field and 19.6 mg/L in the South Field) were higher than the downgradient median at Site 2 (10.6 mg/L). The mean downgradient nitrate+nitrite-N concentration at Site 1, where nitrogen application exceeded the agronomic rate by a factor of 2 in most cases, was significantly greater than that upgradient at the 95% confidence level using the Student's t-test. There was no difference between upgradient and downgradient nitrate+nitrite-N at Site 2, where the nitrogen application rate was close to the agronomic rate. The non-growing season mean nitrate+nitrite-N concentrations in groundwater were 24.3 mg/L at Site 1 and 9.8 mg/L at Site 2.

The soil nitrate concentration at Site 1 (200-380 lb/acre) was up to three times higher than the "very high" level defined in Sullivan (1994) and was within the "medium" to "high" range at Site 2 (50-110 lb/acre).

Acknowledgements

The author would like to thank the following people for their generous contributions to this study.

- Two dairy farmers allowed the Department of Ecology to drill monitoring wells and install lysimeters in their fields and to monitor their operations for two to three years. We also appreciate the farmers' willingness to take time to discuss details of their manure application and fertilization techniques and occasionally to collect and store manure samples.

- Craig Cogger, Andy Bary, and Liz Myhre of Washington State University, Puyallup, collected and analyzed soil nitrate samples at Site 1 in September 1997.

- Dave Garland of Ecology's Northwest Regional Office initiated and helped design this study. He also chose the study sites, fostered good communication between Ecology and the participating dairymen, provided field assistance, and reviewed the report. Dave's commitment to understanding and improving the nitrate situation in the Sumas-Blaine Aquifer was the guide for this study.

- Andrew Craig and Mak Kaufman of Ecology's Bellingham Field Office provided field assistance.

- These staff from Ecology's Environmental Assessment Program:
    - Denis Erickson assisted in designing the study and provided valuable input during the study. Denis's experience in studying agricultural influences on groundwater, especially in this location, was very helpful.
    - Robert Garrigues and Pam Marti oversaw drilling of monitoring wells and lysimeters at Site 2 and logged the boreholes.
    - Kirk Sinclair and Charles Pitz collected soil nitrate samples during September 1998.
    - Chris Evans, Robert Garrigues, Katina Kapantais, Pam Marti, Charles Pitz, Kirk Sinclair, Bernard Strong, and John Summers provided field assistance.
    - Becky Bogaczyk, Michelle Dhee, Debby Lacroix, Casey Maggart, Meredith Osborn, Aileen Richmond, and Jim Ross conducted laboratory analyses at the Manchester Environmental Laboratory.
    - Pam Covey maintained and tracked samples and prepared contracts for soil samples.
    - Joan LeTourneau formatted and edited the report.

- Ken Johnson of the King County Department of Natural Resources provided field assistance.

Executive Summary

Ecology conducted a hydrogeologic study at two dairy sprayfields near Lynden, Washington. The purpose of the study was to provide information to assess the effectiveness of prescribed agronomic rate calculations (WSU, 1995) for minimizing leaching of manure-related nitrate to groundwater under different soil and hydrogeologic conditions.

The primary findings of the study are:

- Monitoring well borings indicate that both sites are underlain by shallow, unconfined groundwater. The depth to water at Site 1 was 0-10 feet. At Site 2 it was 18-25 feet to water. Site 1 soils consist of silty sand and fine to medium grained sand. The soils at Site 2 consist of mixed sand and gravel. The coarser materials at Site 2 allow more rapid flow of percolating water to the water table than at Site 1. Flooded winter-time conditions and low dissolved oxygen concentrations at Site 1 provide a suitable environment for denitrification.

- Nitrogen application (manure plus commercial fertilizer) at Site 1 was double the suggested agronomic rate (WSU, 1995) during much of the study, while application at Site 2 ranged from below to 35% above the agronomic rate.

- At Site 1 the median groundwater nitrate+nitrite-N concentrations, 15.4 and 19.6 mg/L, were higher than upgradient (0.75 mg/L) at the 95% confidence level using the Student's t-test.

- At Site 2 the downgradient median groundwater nitrate+nitrite-N, 10.6 mg/L, was not statistically different from that upgradient (12.4 mg/L).

- Median groundwater nitrate concentrations beneath Site 1 were 1.5 to 2 times the drinking water standard, 10 mg/L, and significantly higher than upgradient. At Site 2 both upgradient and downgradient groundwater nitrate+nitrite-N concentrations were at or slightly above the drinking water standard.

- The mean non-growing season (March-November) groundwater nitrate+nitrite-N concentrations at Site 1 were 26.6-31.0 mg/L. At Site 2 the non-growing season mean nitrate+nitrite-N was 9.5-10.0 mg/L. Most leaching of nutrients occurs during the winter non-growing season.

- The median groundwater nitrate+nitrite-N values were three to five times greater than the aquifer-wide median of 3.8 mg/L at both sites, indicating substantial land use effects.

- Estimated residual nitrate in the top two feet of soil at Site 1 was 25-240% higher than the "very high" criterion in Sullivan (1994). At Site 2 residual nitrate in the top two feet was "high" in 1998 and "medium" in 1999.

- Soil ammonia concentrations in the fall were substantial at both sites. The estimated two-foot residuals for ammonia were 61-96 lb/acre at Site 1 and 35-81 lb/acre at Site 2. Similar studies in British Columbia found that virtually all nitrate and ammonia in the soil was lost in the winter, most to leaching (about 80%) and the remainder to denitrification (about 20%).

- Major decreases in nitrogen application at Site 1 did not translate into immediate improvements in soil or groundwater nitrate concentrations. However, the second year of lowered application at the South Field corresponded to a 10% decrease in soil nitrate compared to the previous year. Accumulated organic matter in the soil mineralizes gradually over time and can cause a lag in soil and groundwater quality improvements.

- Concentrations of soil pore-liquid nitrate+nitrite-N were similar to those in groundwater in three of five lysimeters at Site 1. However, the relationship between the concentrations in the other two lysimeters and groundwater was obvious. Variability in soil pore-liquid movement over time and spatially make it difficult for use as an indicator of groundwater impacts.

- Based on results of this study, applying manure above the agronomic rate can lead to long-term contamination of groundwater, because organic nitrogen from manure that accumulates in soil gradually mineralizes to nitrate. If not biologically taken up, nitrate from mineralized organic nitrogen is available for leaching.

- To help reduce leaching of excess nitrate to groundwater, mineralizable nitrogen should be accounted for when planning nitrogen application rates in manured fields.

Introduction

Widespread nitrate contamination has been documented in the Sumas-Blaine Surficial Aquifer, the principal aquifer of the Nooksack River basin in northwestern Whatcom County (Erickson, 2000; Erickson, 1998; Cox, 1999). The aquifer covers much of rural Whatcom County and is vulnerable to contamination due to the shallow depth to water and permeable soils. The Sumas-Blaine Aquifer is the southern part of the larger Abbottsford-Sumas Aquifer that extends into British Columbia, Canada (Figure 1).

Nitrate contamination is extensive in the Sumas-Blaine Aquifer and is associated with agricultural practices including dairy waste management (Cox and Kahle, 1999; Erickson, 1998). In 1997, 21% of 258 wells contained nitrate+nitrite-nitrogen (nitrate+nitrite-N) concentrations exceeding the drinking water standard of 10 mg/L (Erickson, 1998). In a smaller study focused on areas where elevated nitrate had been observed previously, more than half of 53 wells sampled in the aquifer exceeded 10 mg/L (Erickson, 2000). Using existing data from across the aquifer, Cox and Kahle (1999) found 21% of wells in the Sumas Aquifer exceeded the drinking water standard for nitrate.

Erickson (1998) found that dairy waste and raspberry production were associated with elevated nitrate concentrations in groundwater across the Sumas-Blaine Aquifer. The density of dairy cows in the Nooksack River basin is among the highest in the U.S. and has increased by almost 50% between 1978 and 1997, from 44,000 to 65,000 milk cows (Gillies, 2000). At the same time that the number of cows has increased, the amount of acreage used for land application of manure has decreased by about 7%. The net increase in loading rate of manure to the remaining farmed acreage in the past 20 years is about 60%.

Although sufficient data are not available to evaluate changes in nitrate concentrations over time in recharge over the U.S. portion of the aquifer, estimated nitrate concentrations in recharge to the portion of the aquifer that extends into British Columbia, where agricultural practices are prevalent, have increased from nondetectable in 1971 to 6 mg/L in 1991 (Vizcarra et al., 1997). The increase on the Canadian side is mainly attributed to animal manure application and fertilizer.

Hermanson et al. (2000) defined agronomic application rate as the recommended rate of nitrogen addition to the soil that is needed to produce an expected yield, while minimizing adverse environmental effects. Farmers have been encouraged to apply up to one-third of their annual agronomic manure application in the fall, followed by another application in early spring to improve the next year's first harvest (Sullivan et al., 2000). Local studies in the Whatcom County area have been conducted to test the effectiveness of recommended nitrogen application rate on crop yield and soil nitrogen remaining at the end of the growing season (Cogger et al., 1998). However, little information is available regarding the effects on underlying groundwater of applied manure relative to estimated agronomic rates and recommended timing.

Purpose of the Study

The Washington State Department of Ecology (Ecology) conducted this study to evaluate the effects on groundwater, soil, and soil pore liquid of typical manure and inorganic fertilizer application at two grass fields overlying the Sumas-Blaine Aquifer over a two-year period. Another objective of the study was to compare nitrogen application rates used at the study sites with application rates recommended in manure management guidelines (WSU, 1995). To the extent possible, Ecology also wanted to evaluate the relationship of nitrogen application rates and timing to fall soil nitrogen and groundwater nitrate concentrations.

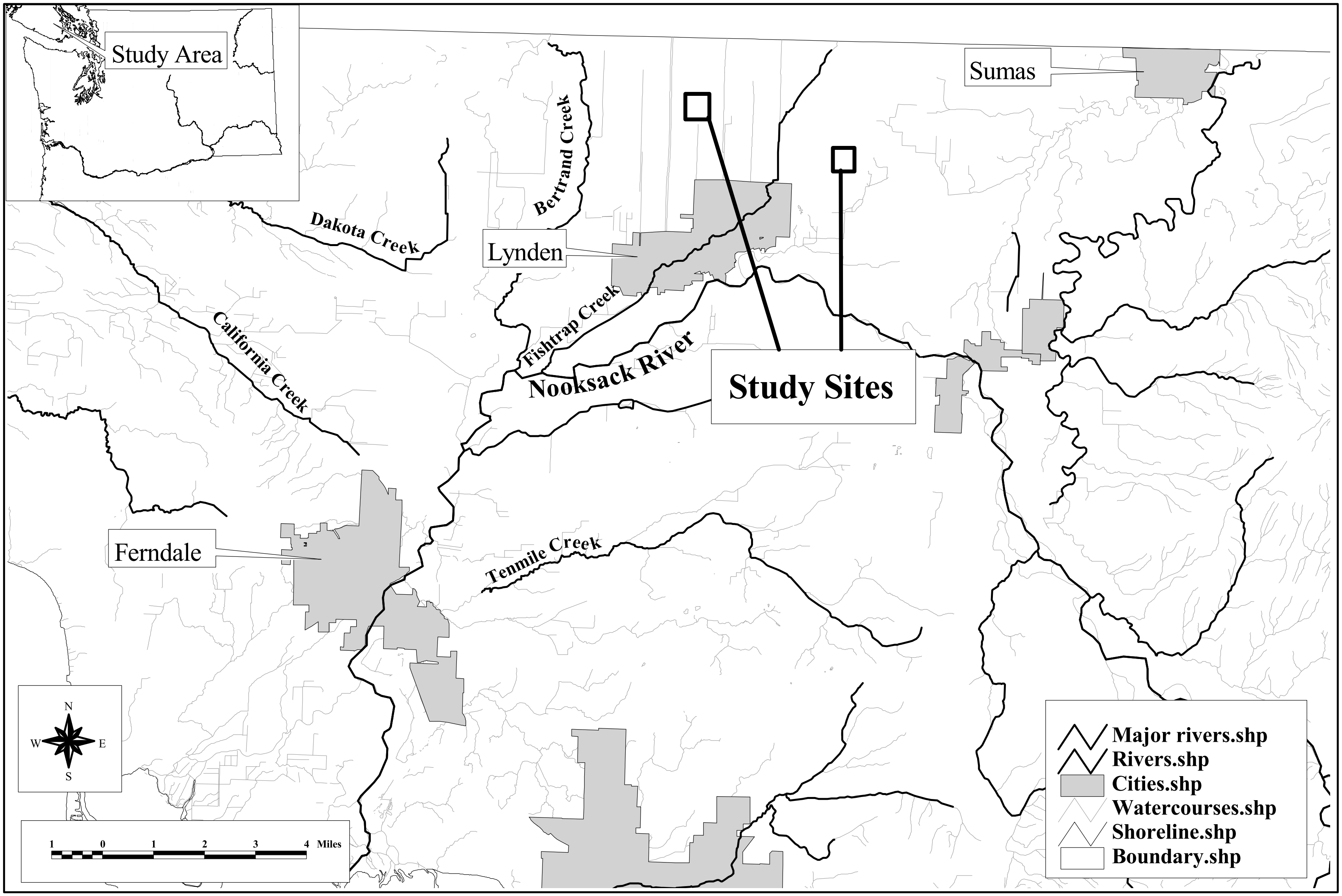


Figure 1. Study site locations.

Site Description

Location

The study area is located in northern Whatcom County north of the town of Lynden and near the border with British Columbia, as shown in Figures 2 and 3. The Canadian border is one to two miles north of the study sites. The study area is located on the extensive, flat Lynden Terrace, a glacial outwash plain that slopes gradually southward toward the Nooksack River. Surface and groundwater drainage is toward the river one to two miles south of the study sites. A system of ditches and tile drains has been constructed in much of the area, including Site 1, to control high water table conditions and facilitate agricultural land use. These ditches discharge to the river. Site 2 is not artificially drained.

Agriculture, especially dairy farms, is the predominant land use in the county. Approximately one-third of Washington dairies are located in Whatcom County. Grass and corn are commonly grown on land operated by the dairies. Other major crops grown in the area include raspberries, blueberries, strawberries, and seed potatoes.

Poultry production is a major agricultural activity across the international border in Abbottsford, British Columbia. Similar to dairy farms, poultry farming involves land application of large volumes of organic waste. Berries and other crops are also grown in the Abbottsford area.

Geology

A number of studies were synthesized by Cox and Kahle (1999) to describe the geology and hydrogeology of the study area (Figure 4). Their interpretation is summarized here.

The study site lies in the Fraser-Whatcom Lowlands and is part of the larger Georgia Basin that was formed by tectonic activity. Mountain building that occurred during the tectonic period in the eastern part of the area created the Coast and Cascade ranges. Weathering and erosion of the mountain areas left large deposits of sediment as well as plant and organic material in the Georgia Basin. The resulting sediment deposits became consolidated into sandstone, mudstone, and conglomerate following the depositional period. Coal deposits were also formed from organic material. The consolidated bedrock deposits then underwent folding and faulting, resulting in an irregular bedrock surface.

Pleistocene glaciation that began 18,000 years ago eroded and smoothed the irregular bedrock surface. Over the next 8,000 years, sediments left by repeated glacial advances and retreats and associated meltwaters were deposited over the area to depths of 1,000 to 2,000 feet. Outwash from the last glacial episode left deposits of gravel and cobbles near the Canadian border which grade finer southward to sand with some clay layers near Lynden.

During the past 10,000 years, the Nooksack River has eroded the glacial deposits resulting in the current flat terrace flood plain. The river has rearranged alluvial material similar to the glacial distribution with gravel in upstream areas and sand and silt in downstream areas. These recent sediments can be divided into two major units: *coarse-grained alluvium* which contains mainly sand, gravel, and cobbles, and *fine-grained alluvium* which contains more silt and clay (Cox and Kahle, 1999).

Hydrogeology

The study area is located over the Sumas-Blaine Surficial Aquifer, which is unconfined and composed of recent sediments of glacial and alluvial origin (Erickson and Tooley, 1996; Erickson, 1998) (Figure 5). The Sumas-Blaine Aquifer covers about 150 square miles and consists mostly of sand and gravel deposits with areas containing more silt and clay. The aquifer is the major drinking water source for the rural community.

In the vicinity of the study area, the aquifer is about 25-50 feet thick based on a detailed characterization of the aquifer by Erickson and Tooley (1996). Depth to water is less than ten feet over much of the aquifer, making it highly susceptible to contamination. Groundwater flow in the aquifer is generally south toward the Nooksack River and its tributaries.

Recharge to the aquifer is from precipitation over the aquifer and from upgradient groundwater flow. Average annual precipitation is 40-46 inches/year (NOAA, 1990). The average estimated recharge is 26-30 inches/year (Cox and Kahle, 1999). The actual recharge may be lower, however, because this estimate does not take into account extensive drainage of water from the fields for water table management.

Hydraulic conductivity varies widely over the aquifer, based on specific capacity estimates from well logs by Cox and Kahle (1999). The range for 164 wells in the aquifer was 7-7,800 feet/day. The geometric mean for the 11 wells nearest the study area was 200 feet/day and ranged from 26 to 4,800 feet/day. Stasney (2000) estimated the groundwater flow velocity for the Judson Lake area, a few miles east of the study site, as 25 feet/day using a groundwater model. Erickson (1991) estimated the velocity of groundwater close to the study site as 5 feet/day, based on specific capacity data for eight nearby wells.

Soils

Soil types found at the study site and some of their physical and hydrologic properties are shown in Table 1. These soils are derived from underlying glacial outwash and alluvial materials. The shallow soils also contain accumulated volcanic ash and organic material. In most of the area, soil permeability increases with depth as clay content decreases (Cox and Kahle, 1999).

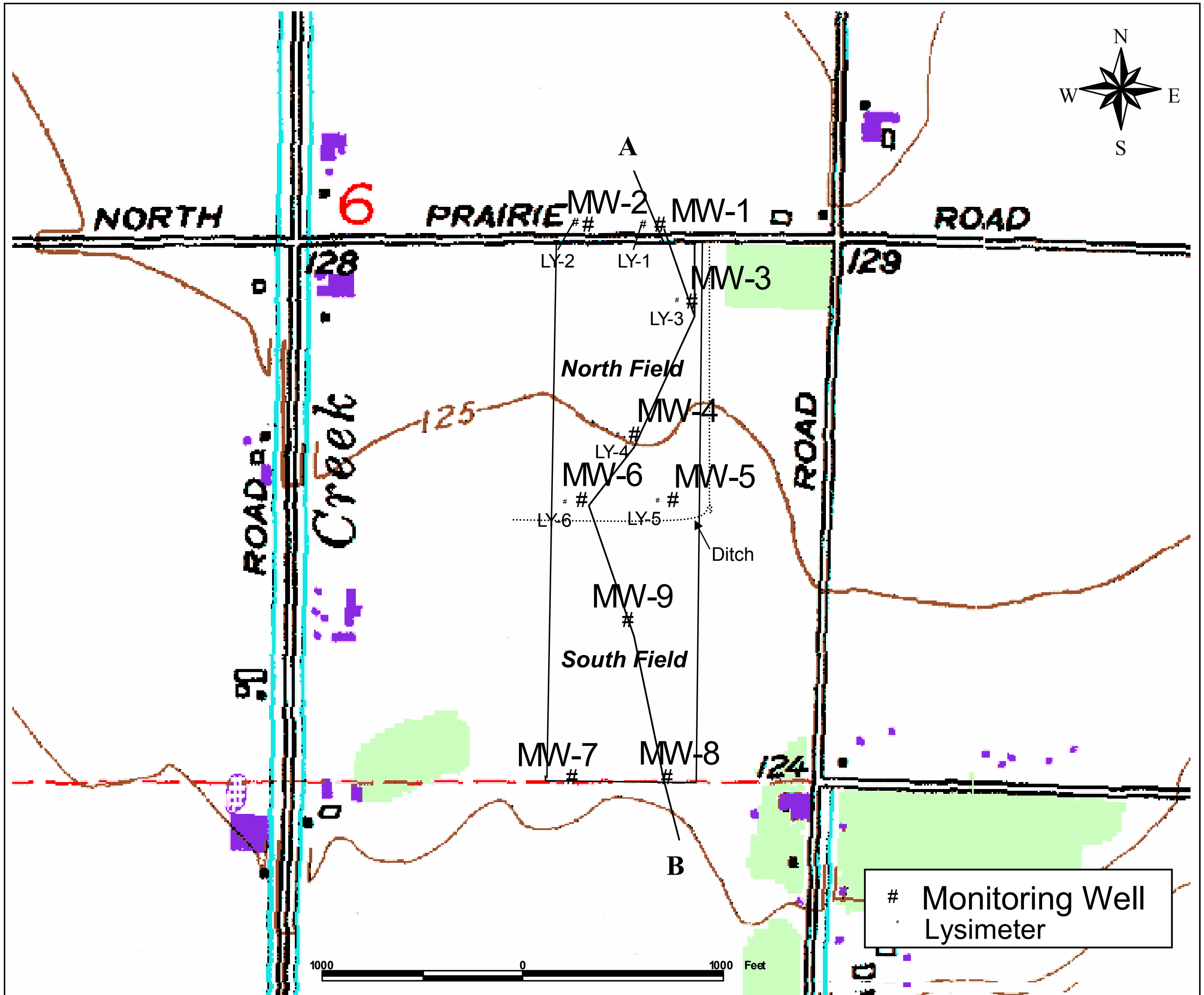


Figure 2. Site 1 showing the North and South fields, monitoring wells, and lysimeter locations.

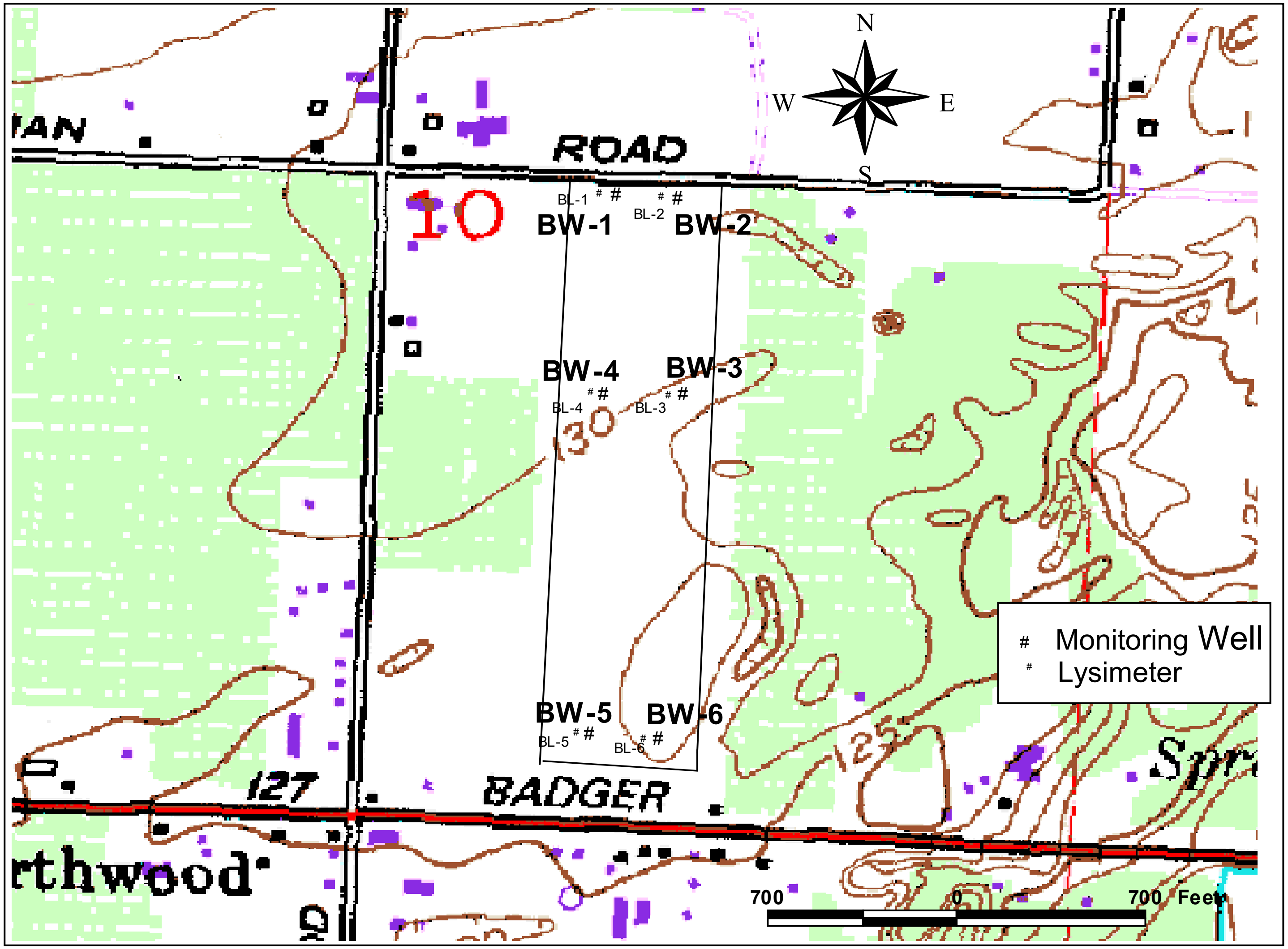


Figure 3. Site 2 showing the study field, monitoring wells, and lysimeter locations.

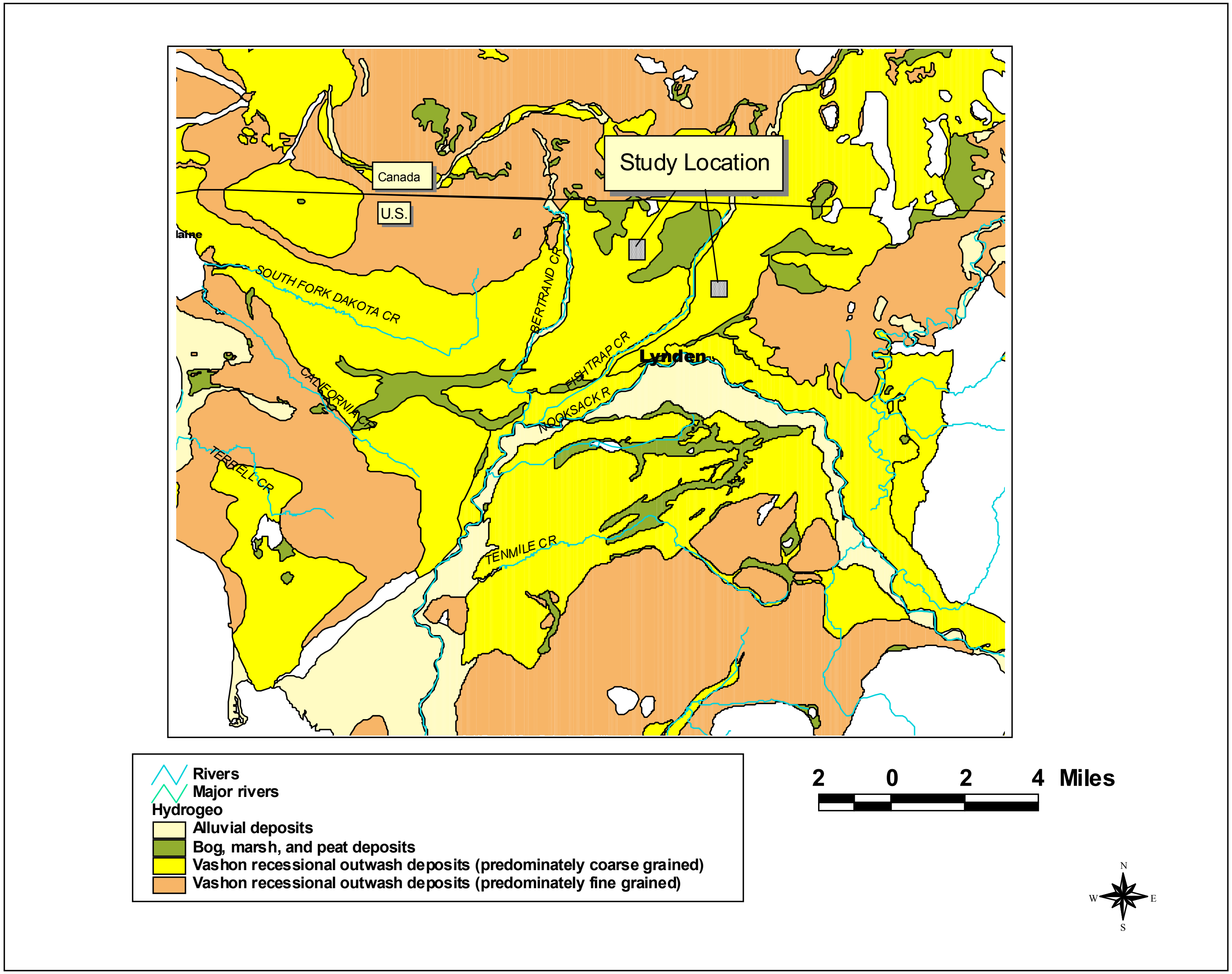


Figure 4. Surficial hydrogeologic units of the Upper Nooksack River Basin and study site location (from Jones, 1999).

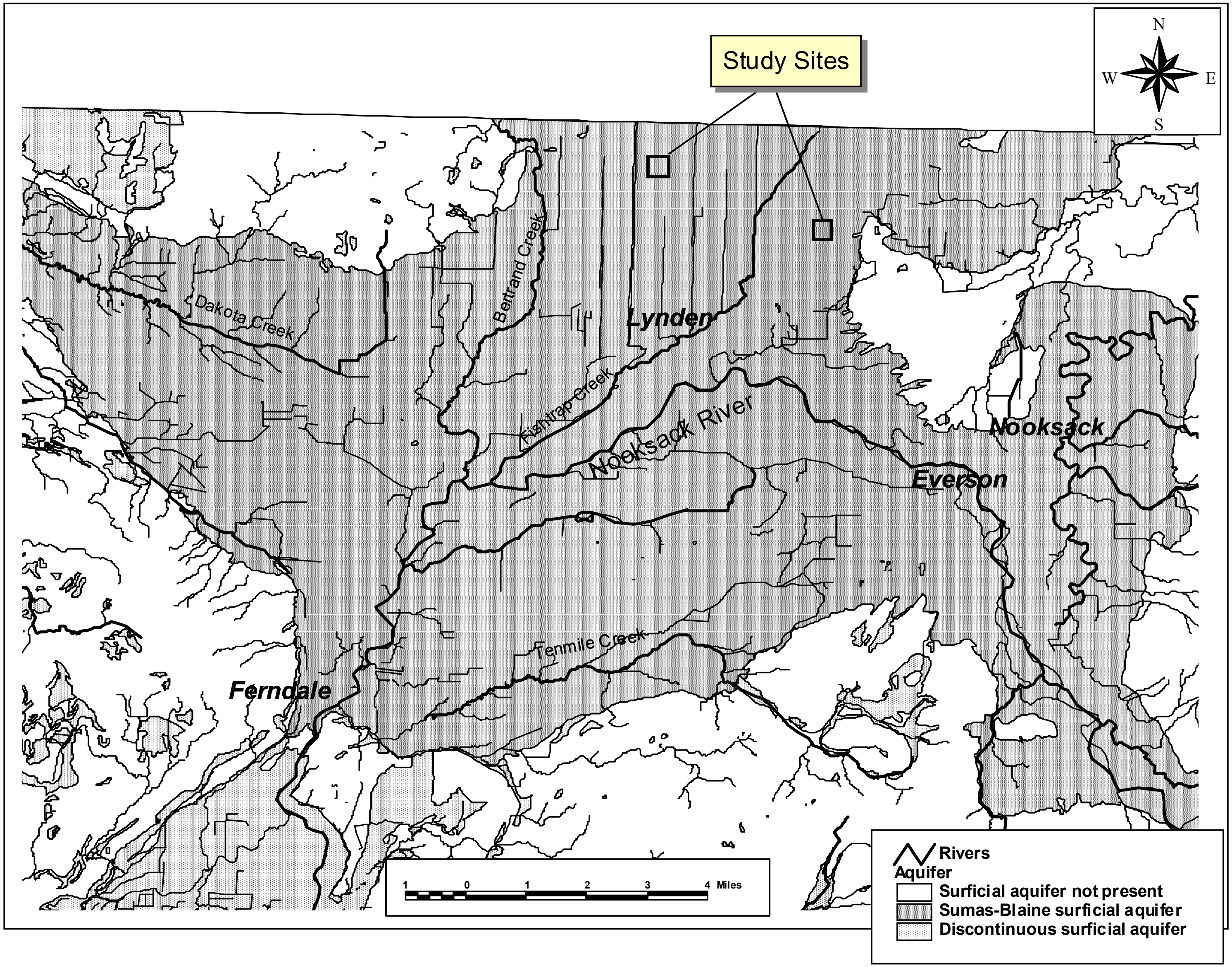


Figure 5. Sumas Blaine Surficial Aquifer (from Tooley and Erickson, 1996).

Table 1. Physical and hydrologic properties of soils at the study sites (SCS, 1992).

Soil type	Soil texture	Depth (inches)	Clay (percent)	Available water capacity (inches)	Permeability rate (inches/hour)	Organic matter (percent)
Site 1						
Hale	Silt loam	0-10	10-18	0.19-0.21	0.6-2.0	1-4
Clipper	Silt loam	0-9	10-18	0.25-0.35	0.6-2.0	2-9
Site 2						
Kickerville	Silt loam	0-9	--	0.25-0.35	0.6-2.0	3-9
		9-22	--	0.20-0.30	0.6-2.0	--
Lynden	Sandy loam	0-8	--	0.15-0.25	2-6	3-9
		8-18	--	0.10-0.15	2-6	--

-- No data

Study Site 1 is mapped as *Hale silt loam* except for the northernmost 20% of the field and a small part southwest of the ditch which are both classified as *Clipper silt loam* (U.S. Soil Conservation Service, 1992). Both of these poorly drained soils have moderate permeability in the upper 15-30 inches and very rapid permeability in the lower soil. The upper soil zone in both soils is often mottled, and the deeper soil zone in the Clipper soil (to 60 inches) can be mottled. Both soils are subject to seasonal high water table which, at this site, leads to standing water during the winter.

Most of the soils at Site 2 are mapped as *Kickerville silt loam*, with the middle quarter of the field mapped as *Lynden sandy loam* (U.S. Soil Conservation Service, 1992). These soils are well drained and contain more gravel than the Site 1 soils, especially below 14-36 inches. Permeability is moderate in the upper Kickerville soil and moderately rapid in the upper Lynden. Both Kickerville and Lynden soils have very rapid permeability below three feet. The water table was at least eight feet below the surface at Site 2.

Land Application

Site 1

Site 1 is part of one of the largest dairies in the area, with over 2,000 head of cattle. Manure is held in a large, double-cell storage lagoon and transported through an underground pipeline to a number of fields in the area. The Site 1 field has been used for manure application since 1990, when the pipeline was completed. The 40-acre Site 1 field is bisected by a 5-foot deep drainage ditch running west to east and about 150 feet south of monitoring wells MW-5 and MW-6 (Figure 2).

The halves of the field above and below the ditch received different treatment during the study and are therefore analyzed separately in this report. The half north of the ditch is referred to as the North Field and that south of the ditch as the South Field. The upper 20 acres of the field and the field upgradient on the north side of Prairie Road were planted in orchardgrass during the study. The lower 20 acres started out as grass in 1997, was replanted in corn in 1998, and planted back to grass in 1999. Corn has a lower nitrogen application rate than grass and can only receive manure early in the growing season. The crop rotation for the field is generally five years in grass followed by one year in corn, and the pattern is repeated.

Upgradient monitoring wells MW-1 and MW-2 were located about ten feet north of another drainage ditch along the north side of Prairie Road. These ditches probably intercept and remove some of the groundwater flow when the water table is less than five feet below ground surface. Manure was applied using a traveling gun at about 350 gallons/minute. Liquid manure was applied from May until October or November during the study. Inorganic nitrogen fertilizer was also applied. A light application of solid manure was applied to the South Field in 1998 (about 35 lb/acre).

Site 2

With 245 total cows (100 adults and 145 juvenile and dry cows), the Site 2 dairy is smaller than Site 1 (see Figure 3). The Site 2 field was planted in orchardgrass during the study, while the upgradient field north of Haveman Road was in corn. A slurry wagon was used to apply liquid manure as the vehicle is driven back and forth across the field. Manure was applied from April until November during the study. Inorganic fertilizer was also applied at Site 2 and the upgradient field.

Since 1986 the crop rotation at Site 2 has been four years in grass and two years in corn after which the pattern is repeated. Little manure is applied during the years when corn is grown. Solid manure is usually not used on these fields, and was not used during the study.

Methods

Ecology selected two dairy farms located over the Sumas-Blaine Aquifer. The study goal was to sample groundwater, soil pore liquid, and soil at grass fields where liquid manure was land-applied at rates and using methods that are representative for the area. The dairy operator was asked to record the amount and timing of manure and fertilizer application for two years.

The two sites are located north of Lynden as shown in Figure 1. The sites are both located in areas mapped as predominantly coarse-grained Vashon recessional deposits (Cox and Kahle, 1999). However the two sites differ in soil type, depth to water, application rates, and application methods as shown in Table 2.

Table 2. Comparison of site characteristics.

Characteristic	Site 1	Site 2
Soil type - SCS classification[1]	Hale silt loam/Clipper silt loam	Kickerville silt loam/ Lynden sandy loam
Soil type based on grain size	Poorly graded sand with silt	Poor to well graded sand with gravel
Aquifer description based on grain size	Poorly graded sand with silt in the north and with gravel in the south	Poorly graded sand with gravel
Mean d_{10} (um) for boring samples (diameter at which 10% of particles pass in a sieve analysis)	0.12	0.32
Depth to water (feet)	0-10	18-25
Manure application method	Traveling big gun	Tank spreader
Nitrogen application rate from manure (lb/acre/year total N)	900-1,000 [2]	225-350
Nitrogen application rate from inorganic fertilizer (lb/acre/year N)	100-160	125-150
Total nitrogen application in manure + fertilizer (lb/acre total N)	1,000-1,100[2]	350-500

[1] SCS, 1992. Soil Survey of Whatcom County Area, Washington.

[2] Represents normal grass-growing. In 1998 the south end of the field was converted to corn and manure application reduced to about 300 lb/acre. A new grass planting the following year also received a low application of nitrogen (about 350 lb/acre total N).

Monitoring Wells

Nine two-inch diameter monitoring wells were installed at Site 1 in May 1997, two upgradient of the field and seven downgradient within the field. Six monitoring wells were installed at Site 2 in May 1998, two at the upgradient end of the field and four downgradient within the field. All wells were installed using as 4-1/4-inch diameter hollow stem auger by Tacoma Pump and Drilling Co., Inc., Spanaway, Washington. The wells were drilled to about five feet below the water table in an attempt to allow the well screen to span the range of elevations of the top of the water table where concentrations of percolating contaminants are easiest to detect. Well logs and geologic observations during drilling are shown in Appendix A. A summary of well location and construction information is shown in Appendix B.

The wells were two-inch diameter Schedule 40, flush-threaded PVC casing with caps and screens. The wells at Site 1 were about ten feet deep. Those at Site 2 were 20-25 feet deep. The screens were seven feet long at Site 1 and ten feet long at Site 2, all with a slot size of 20. Sand packs consisted of 10-20 Colorado silica sand installed continuously over the screened interval to two feet above the screen at Site 2 and ½- foot above the screen at Site 1. The shallow depths at Site 1 precluded the normal extension of sand to two feet above the screen. Annular well seals were emplaced using bentonite chips from the top of the sand to three feet below ground surface at Site 2 and to one foot below ground at Site 1. The PVC casings were cut off a few inches below ground and fitted with locking compression caps. Protective flush-mounted steel monuments were installed in concrete to cover the well heads and to facilitate normal operation of farm equipment.

During well drilling, details of stratigraphy, blow counts, soil characteristics of 1.5-inch diameter split spoon samples collected every 2-1/2 to five feet, well construction, and other observations were recorded and are summarized in Appendix A. Samples were placed in labeled, heavy-duty, plastic, zip-lock sampling bags for grain size analysis. Soil samples were then taken to the Ecology/EPA Manchester Environmental Laboratory and transported to Rosa Environmental and Geotechnical Laboratory, Seattle, Washington for grain size analysis.

The drillers developed the wells by bailing until the well discharge was clear. Well development occurred one to two days after drilling at Site 1 and two weeks after drilling at Site 2. Monitoring well MW-9 was redeveloped using a submersible pump on February 27, 1998 after leakage into the well from above ground was discovered.

Lysimeters

Model 1920 ceramic-cup vacuum lysimeters 24-inch long were installed beside six wells at each site (Soilmoisture Equipment Corp., Santa Barbara, CA). See Figure 6. The samplers were installed at about three feet depth beside the six wells north of the ditch at Site 1 and beside each well at Site 2 (Figures 2 and 3). Lysimeter installation procedures are described in Appendix C.

Water Table Elevations

Wellhead elevations were surveyed to the nearest 0.01 foot using a Top Con surveyor's level and rod. Elevations are referenced to a visual estimate of the elevation of one well at each site from the U.S. Geological Survey 7.5 minute topographic quadrangle. The elevation estimate for ground surface at MW-2 is 128.00 feet above mean sea level (AMSL) at Site 1. The elevations at Site 2 are based on the assumption that the elevation of BW-2 is 130.00 feet AMSL. The depth of the top of the casing below ground was subtracted from the well head elevation when calculating water table elevations.

The depth to water was measured monthly in the monitoring wells using a commercial electric well probe. Measurements were made to the nearest 0.01-foot before purging and water quality sampling. The probe was rinsed with de-ionized water between wells.

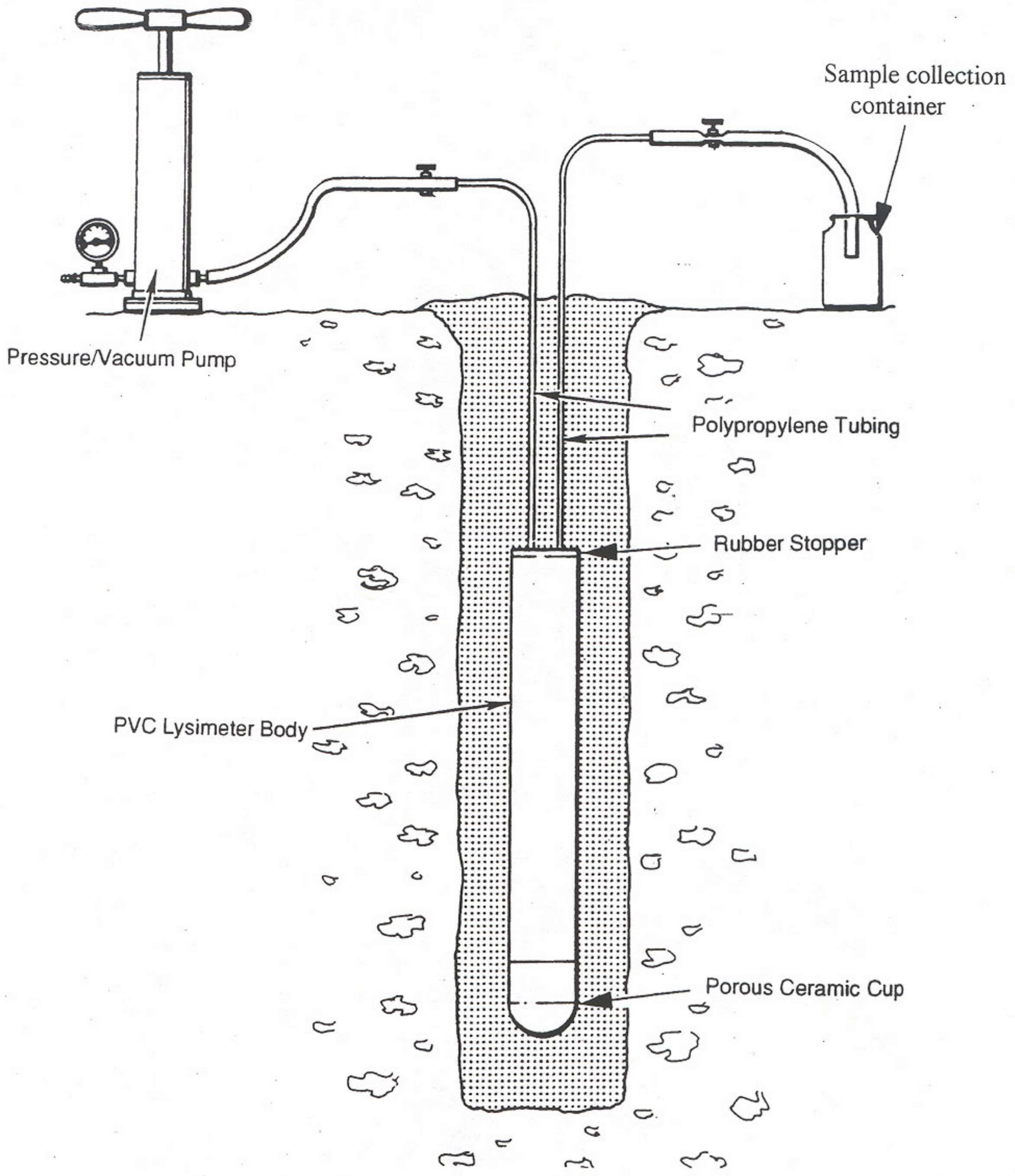


Figure 6. Diagram of a ceramic cup lysimeter similar to those used in this study.

Water Quality Sampling and Analysis Procedures

Monitoring Wells

Ecology sampled monitoring wells every four to six weeks for two years. Sampling procedures are described in Appendix D. Groundwater samples were analyzed for temperature, pH, specific conductivity, ammonia-nitrogen (ammonia-N), nitrate+nitrite-nitrogen (nitrate+nitrite-N), total persulfate nitrogen (TPN), chloride, total dissolved solids (TDS), and total organic carbon (TOC) (for one year only). Analytical methods are described in Appendix D, Table D.1.

Lysimeters

Lysimeters were sampled at the same frequency as wells. Lysimeters were sampled for ammonia-N, nitrate+nitrite-N, total N, chloride, and TDS using the analytical methods described in Appendix D, Table D.1.

Manure

At Site 1 most of the initial manure samples collected in 1997 and spring 1998 were from the storage lagoon that supplied the traveling gun applicator. A sample bottle attached to a long pole was used to scoop the sample from about three to four feet from the side of the lagoon. Most samples, however, were collected directly from a spigot on the traveling gun applicator by the dairyman while Ecology observed. A few samples were collected by the dairy operator when Ecology was not present. These samples were refrigerated and picked up within one to two weeks for analysis.

At Site 2 the dairy operator collected samples when he applied manure and kept them refrigerated until Ecology picked them up. Samples collected at Site 2 sometimes exceeded recommended holding times, but because total N, rather than the individual nitrogen species, was of most interest for loading estimates, the data were assumed to be usable. A few Site 2 manure samples were collected from the storage lagoon.

Manure samples were analyzed for specific conductivity, ammonia-N, nitrate+nitrite-N, total Kjeldahl N (TKN), chloride, and total solids as described in Appendix D, Table D.1.

Soil Sampling

Composite soil samples were collected in September of 1997, 1998, and 1999 to quantify the inorganic nitrogen not used by the crop. This is referred to as “Report Card Testing” (Sullivan, 1994). The results are used to adjust farm management practices, including manure and fertilizer application, the following year.

In 1997, Dr. Craig Cogger and associates of the Washington State University (WSU) Puyallup Research Station collected and analyzed soil samples at Site 1. A total of 12 soil subsamples was collected at both the North and South fields. Six samples were composited from the top one foot of soil after removing the top 2-3 inches of grass material, and were analyzed for nitrate and ammonia analysis. The six samples were collected along two transects in the field. The other six samples at each location were composited from the 1-2 -foot depth. The 1-2 foot samples were collected along the same transects as the shallow samples.

In 1998 and 1999, soil sampling was conducted by Ecology at Sites 1 and 2. Eight samples were collected at each of the two locations sampled in 1997 as well as at Site 2. The eight sample locations were chosen as midpoints between monitoring wells and spaced throughout the fields. All soil samples collected for the study were analyzed by Agri-Check Laboratory in Umatilla, Oregon.

Specific Capacity Tests

Specific capacity tests were conducted at Site 1 wells, MW-2, MW-7, and MW-8, as well as at Site 2 well BW-2, on January 20-21, 2001. Specific capacity can be used to estimate hydraulic conductivity (K_s) which is a measure of the ability of the screened zone of a well to transmit water. K_s is also used to estimate the velocity of groundwater flow.

Water was pumped from each well with a submersible pump at a rate of 2.2-2.5 gallons/minute until the water level was stable, about 30-45 minutes. Water level measurements were recorded for use in a computer program that estimates K_s developed by Bradbury and Rothschild (1985). The program takes into account the effect of partial penetration of the aquifer and well loss. The estimates from this method are considered approximate and reliable to within an order of magnitude. The saturated aquifer thickness was assumed to be 50 feet (Cox and Kahle, 1999; Erickson, 1998).

Quality Assurance

Groundwater

Blind duplicate groundwater samples were submitted from one well at each site on most sampling dates to estimate combined analytical and field precision. The quality assurance results are shown in Appendix E, Table E.1, in terms of relative percent difference (RPD). The RPD is the difference between the duplicate results divided by their mean.

The quality of groundwater data was generally good. The mean RPDs for nitrate+nitrite-N and total N were 12.9% and 18.4%, respectively, including one outlier for nitrate+nitrite-N (158%) and two outliers for total N (174% and 184%). The outliers did not occur on the same date, and the reason for the large discrepancies could not be determined. Ammonia-N values were mostly below detection. Chloride, TDS, and specific conductivity had consistently low RPDs of 0-4.4%.

A discrepancy frequently occurred when comparing TPN results with those for nitrate+nitrite-N in samples where the nitrate+nitrite-N was above 20 mg/L, although not obvious in RPDs. TPN represents the sum of ammonia-N, nitrate+nitrite-N, and organic nitrogen (organic N); therefore, TPN values should be at least as high as the sum of ammonia-N and nitrate+nitrite-N. However, in several samples the TPN value was less than that for nitrate+nitrite-N. The cause of the discrepancy is not known.

Soil Pore Liquid

Twelve two-inch diameter pressure-vacuum soil water samplers (ceramic cup lysimeters) were cleaned and tested for leaks and contaminants prior to installation. Before preparing the samplers, polypropylene tubing (1/4-inch diameter) was attached to the two exit ports at the top of the samplers, with color-coding for pressure/vacuum on one side (black) and sample tubing on the other side (green).

The outside of the samplers was cleaned with tap water and a clean brush. The samplers were sealed in the factory, so that the only access to the inside was through the pores of the ceramic cup and the fittings at the top of the samplers for internal tubing. Samplers were rinsed with tap water and soaked in an acid-washed bucket with de-ionized water for one week (Site 2 samplers) to one month (Site 1 samplers). A vacuum of 60 centibars (cb), the same as used in the field, was then applied to the samplers using a pressure-vacuum pump with a vacuum dial gauge.

Four to five pore volumes were then discarded from the lysimeters using a pressure/vacuum hand pump. The vacuum was set once more for the Site 1 lysimeters, and the resulting sample water was analyzed for ammonia-N, nitrate+nitrite-N, TPN, TDS, and chloride. Blank samples were not collected for the lysimeters used at Site 2. The ranges in results from the six lysimeters and the de-ionized water in the soaking bucket are shown in Appendix E. (Table E.2).

Blank samples from the lysimeters were in the same range as the de-ionized water samples for all constituents. Chloride, TDS, and ammonia-N values from the lysimeters were similar to those from the de-ionized water in which the lysimeters were soaked. Nitrate+nitrite-N concentrations were slightly higher in the de-ionized water than in the lysimeters, but are insignificant compared to the concentrations found in the soil pore liquid during the study. The TPN concentration in one of the lysimeters was higher than the de-ionized water, but was also small compared to most soil pore-liquid concentrations observed.

Soil Nitrogen

The September 1999 soil sample collected at Site 1 South Field was split and submitted to the laboratory as two blind duplicates. The results are shown in Appendix E, Table E.3. The RPD for nitrate, 0.9%, was very low. The RPD for ammonia was 9% higher than for nitrate, but was well within the 15% acceptance limit for precision specified in the Quality Assurance Project Plan (Carey, 1996).

Split samples were not analyzed in 1998. However, the same sample collection and subsampling methods were used in 1998 as in 1999, and precision is likewise assumed to have been similar.

Results

Hydrogeology

Aquifer and Vadose Zone Materials

Split spoon samples were analyzed for grain size from three well borings at Site 1 (MW-3, MW-4, MW-9) and two wells at Site 2 (BW-1, BW-4). The grain size results are shown in Appendix F. Grain size analyses were used to classify soil samples according to ASTM Method 247-92 (ASTM, 1994) as shown in Table 3. Effective grain size, or $d_{10,}$ values are also shown in Table 3. Effective grain size is the sieve diameter through which 10% of particles pass and can be extrapolated from the grain size distribution curve. The lower the d_{10} value, the more fine-grained material is in the sample.

Table 3. Soil classifications and effective grain size (d_{10}) based on grain size analyses for Sites 1 and 2 split spoon samples.

Site	Lab No.	Well	Depth (ft)	Soil Class	Description	d_{10}[1]
Site 1						
	21-8105	MW-3	2.5	SP-SM	Poorly graded sand w/ silt and gravel	0.075
	21-8106	MW-3	5.0	SM	Silty sand	0.04
	21-8107	MW-3	10.0	SM	Silty sand w/ gravel	0.04
	21-8108	MW-4	Topsoil	SC-SM	Silty, clayey sand w/ gravel-- borderline sandy organic silt w/ gravel	0.019
	21-8109	MW-4	2.5	SC-SM	Silty, clayey sand w/ gravel	0.055
	21-8110	MW-4	5.0	SP	Poorly graded sand	0.25
	21-8111	MW-4	7.5	SP	Poorly graded sand	0.16
	21-8112	MW-4	10.0	SP	Poorly graded sand	0.18
	21-8113	MW-9	Topsoil	SP-SM	Poorly graded sand with silt	0.09
	21-8114	MW-9	2.5	SM	Poorly graded sand w/ silt	0.07
	21-8115	MW-9	5.0	SP	Poorly graded sand w/ gravel	0.18
	21-8116	MW-9	7.5	SP	Poorly graded sand w/ gravel	0.16
	21-8117	MW-9	10.0	SP	Poorly graded sand w/ gravel	0.24
Site 2						
	21-8118	BW-1	5.0	SP	Poorly graded sand w/ gravel	0.27
	21-8124	BW-1	7.5	SP	Poorly graded sand w/ gravel	0.42
	21-8119	BW-1	12.5	SP	Poorly graded sand w/ gravel	0.16
	21-8122	BW-1	15.0	GP	Poorly graded gravel w/ sand	0.50
	21-8120	BW-1	17.5	SP	Poorly graded sand w/ gravel	0.32
	21-8126	BW-4	5.0	SW	Well graded sand	0.25
	21-8121	BW-4	10.0	SP	Poorly graded sand w/ gravel	0.42
	21-8122	BW-4	15.0	SP	Poorly graded sand	0.27
	21-8123	BW-4	20.0	SP	Poorly graded sand	0.28

[1] Effective grain size: sieve size (µm) which 10% of sample particles pass.

Site 1

Split spoon samples from the North Field at Site 1, represented by MW-1, MW-2, and MW-3, indicate that the top five feet consisted of silty sand with fine-to medium-sized gravel (Figure 7). Mottling was observed in the topsoil at MW-2. These characteristics coincide with the SCS (1992) Clipper silt loam designation for the northern one-fifth of the site, except that mottling was not observed below the top two feet as is typical for Clipper soils.

Below five feet at MW-1 and MW-3, split spoon samples indicate continued silty sand. MW-3 also contained fine gravel. The MW-2 samples collected below five feet contained medium to coarse sand and fine gravel as well as a two-inch thick fine-grained layer at ten feet. Effective grain size values at MW-3 are relatively low at 2.5-, 5.0-, and 10-foot depths, consistent with drilling observations of silt mixed with sand.

Samples from the top five feet of the middle and South Field of Site 1, represented by MW-4, MW-5, MW-6, MW-7, MW-8, and MW-9, consisted of sand with silt and about 10% fine gravel. Mottling was observed in the topsoil at MW-4, consistent with the Hale silt loam designation (SCS, 1992). Samples from MW-8 in the southeast corner of the site did not contain silt below the topsoil; at MW-9 in the middle-south area, silt was not observed below 2.5 feet.

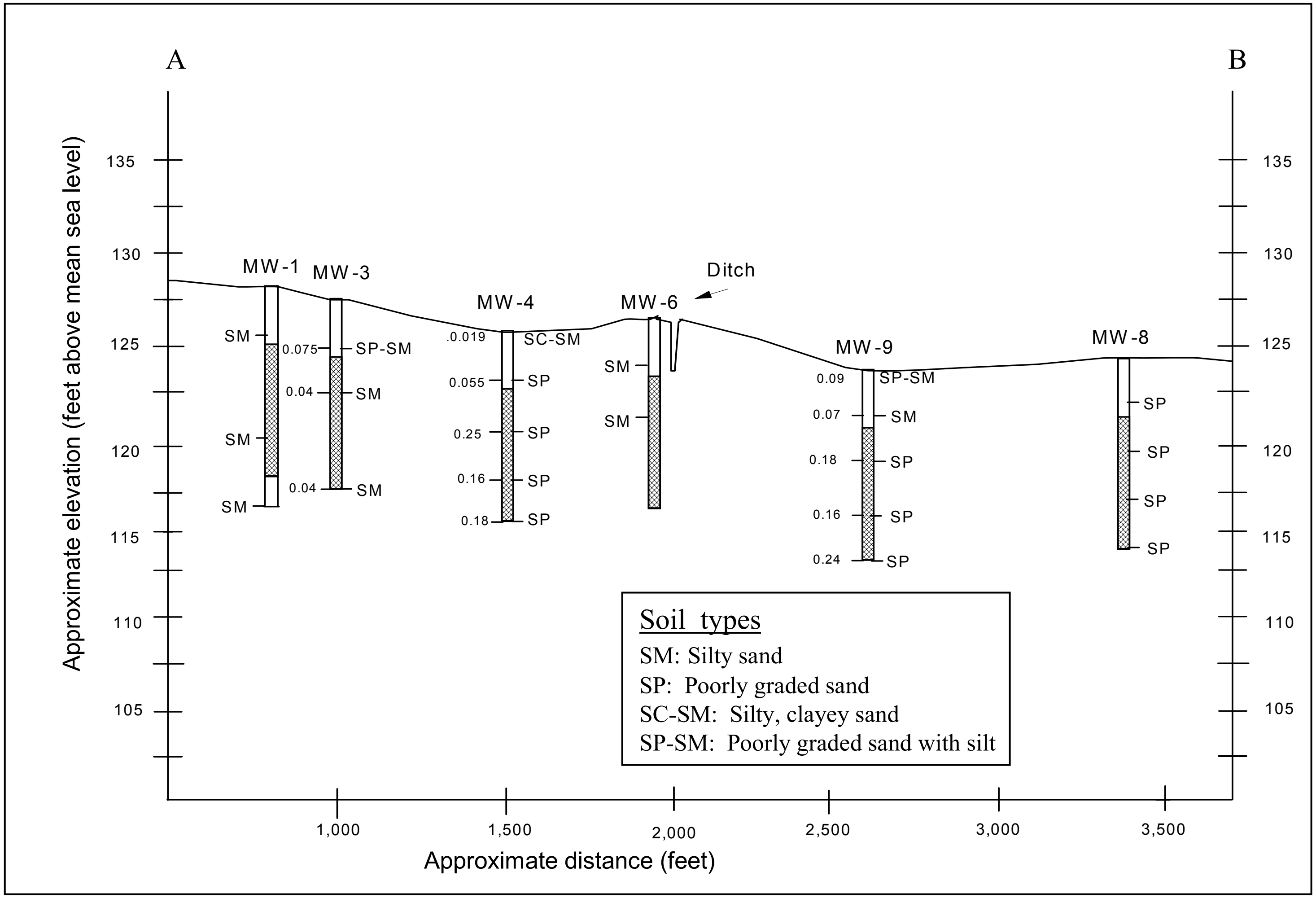
Samples collected below five feet in the middle and southern parts of Site 1 contained less silt and more sand and fine gravel (MW-4, MW-5, MW-6, MW-7, MW-8, and MW–9). Table 3 shows that the d_{10} values for MW-4 and MW-9 were three to five times higher at 5 feet and below, than at 2.5 feet.. Increasing d_{10} values with depth is indicative of decreasing fine-grained material and increasing larger-sized particles.

Based on the monitoring well logs, sands from the southern and eastern locations tended toward medium to coarse sizes, while those from the northern and western areas tended toward fine to medium sizes.

Site 2

Drilling samples at Site 2 indicate that the subsurface consists mostly of poorly graded sand with 15-40% gravel (Figure 8). The gravel ranged from pea-sized to about 1.5-inch diameter, the maximum size that fits inside the 1.5-inch opening of the split spoon sampler. The percentage of gravel varied with depth in some wells. In BW-3 the percentage increased with depth. In BW-4 gravel decreased with depth.

The range of d_{10} values for BW-1 and BW-4, the two wells where grain size samples were analyzed, was 0.16-0.50 µm. These values are higher than those from Site 1, reflecting the much coarser materials at Site 2. Figure 9 shows the d_{10} values versus depth for both sites.



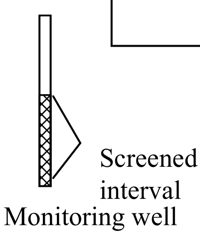
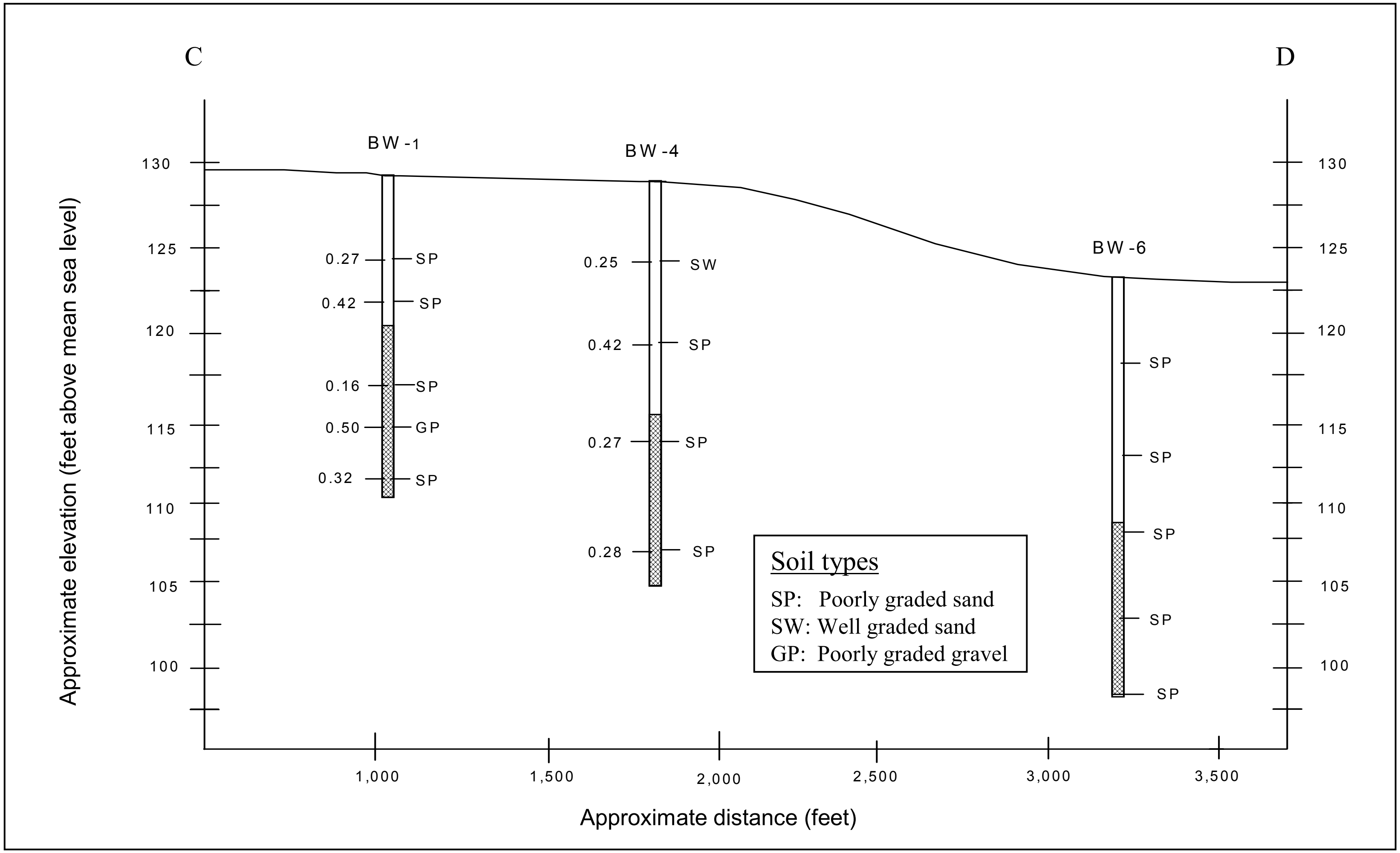


Figure 7. Cross-section A-B showing ASTM (1994) soil classifications and d_{10} values for soil samples at Site 1. Elevations are estimated based on the assumption that the ground surface at MW-4 is 125.00 feet above mean sea level. The ground surface is approximated.



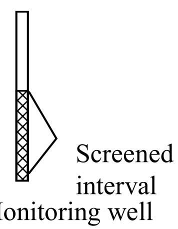


Figure 8. Cross-section C-D showing ASTM (1994) soil classifications and d_{10} values for soil samples at Site 2. Elevations are estimated based on the assumption that the ground surface at BW-2 is 130.00 feet above mean sea level. The ground surface is approximated.

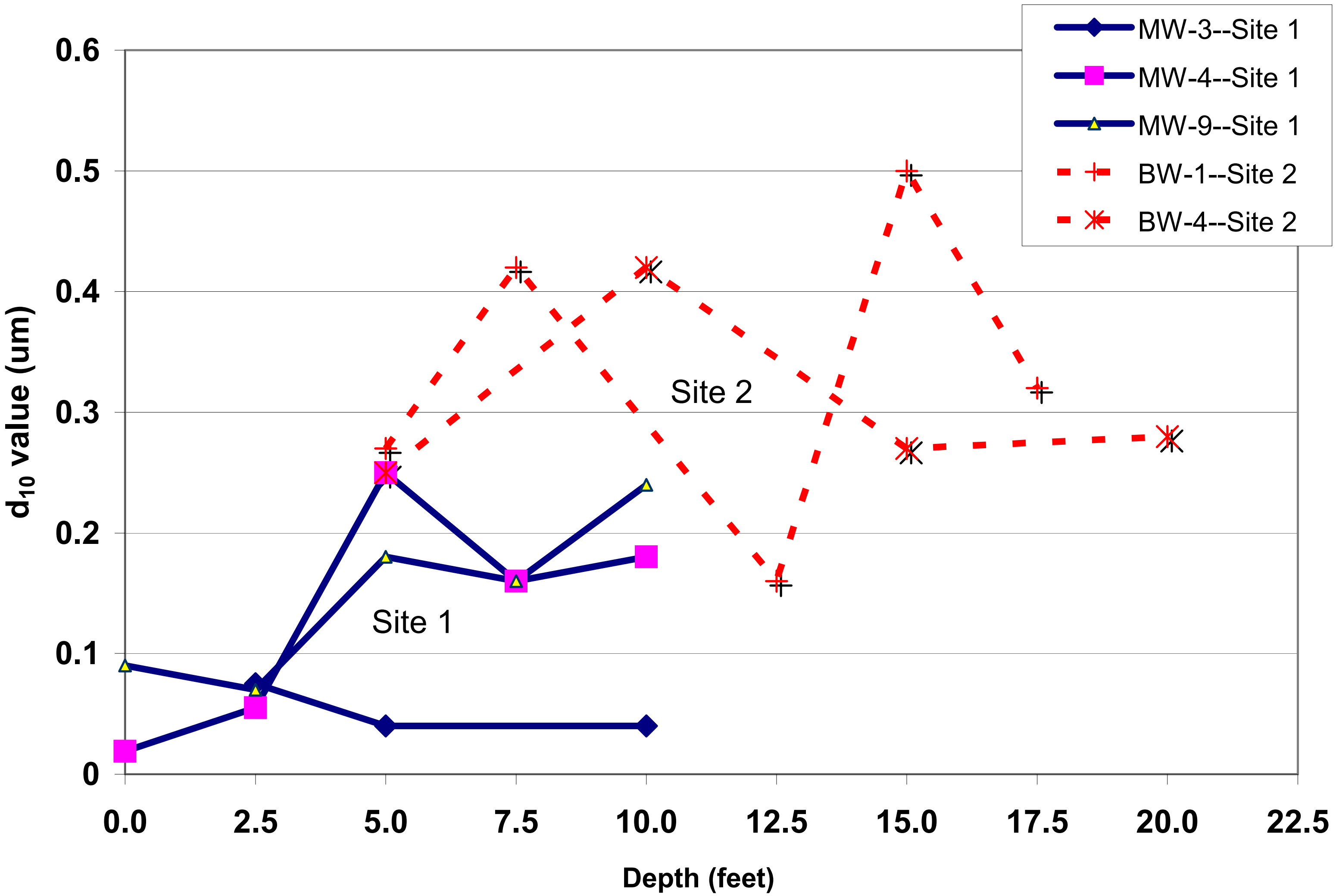


Figure 9. Effective grain size (d_{10}) values for well boring samples.

Specific Capacity

The specific capacity results and estimated hydraulic conductivities are shown in Table 4. The K_s value found at the Site 2 well (300 feet/day) is approximately 10 times higher than those found at Site 1 (30-90 feet/day). This is consistent with drilling observations of significantly more gravel and coarse-grained material at Site 2 than at Site 1.

Table 4. Hydraulic conductivity (K_s) estimates based on specific capacity. (Bradbury and Rothschild, 1985).

Site	Well I.D.	Static water level (feet)	Pumping water level (feet)	Pumping rate (gpm)	Screen length (feet)	Storage coefficient	Aquifer thickness (feet)	K_s (feet/sec)	K_s (feet/day)
1	MW-2	2.02	2.87	2.5	7	0.25	50	6.98E-04	57
1	MW-7	2.24	3.57	2.5	7	0.25	50	4.21E-04	36
1	MW-8	2.91	3.38	2.2	7	0.25	50	1.06E-03	92
2	BW-2	13.23	13.35	2.2	10	0.25	50	3.45E-03	293

The geometric mean is considered most representative of the K_s values which are typically lognormally distributed (Freeze, 1975). The geometric mean for K_s at for the three Site 1 wells is 57 feet/day. The geometric mean for Site 2 could not be determined, because only one value was available.

Groundwater Flow Direction and Velocity

Water level measurements in the monitoring wells are shown in Appendix G. Hydrographs based on water level elevations are shown in Figure 10 for Site 1 and Figure 11 for Site 2 with monthly precipitation measurements at Blaine, Washington (NOAA, 1997, 1998, and 1999). Water levels at both sites are lowest in the fall, and increase with fall and winter rains.

Water level contours typical for high and low water table conditions at Site 1 are shown in Figures 12 and 13. Figures 14 and 15 show water level contours for high and low water table conditions at Site 2. The flow direction at both sites was generally northwest to southeast toward the Nooksack River. However, at Site 1 the summer and fall groundwater flow in the northern part of the field is strongly affected by the irrigation well near MW-3.

The hydraulic gradient was calculated for each site as the difference in water table elevation between the two wells furthest apart in the direction of flow. The Site 1 gradient was 0.0012 -0.0023, with a mean of 0.0017. At Site 2 the gradient was 0.0028-0.0034, with a mean of 0.0031.

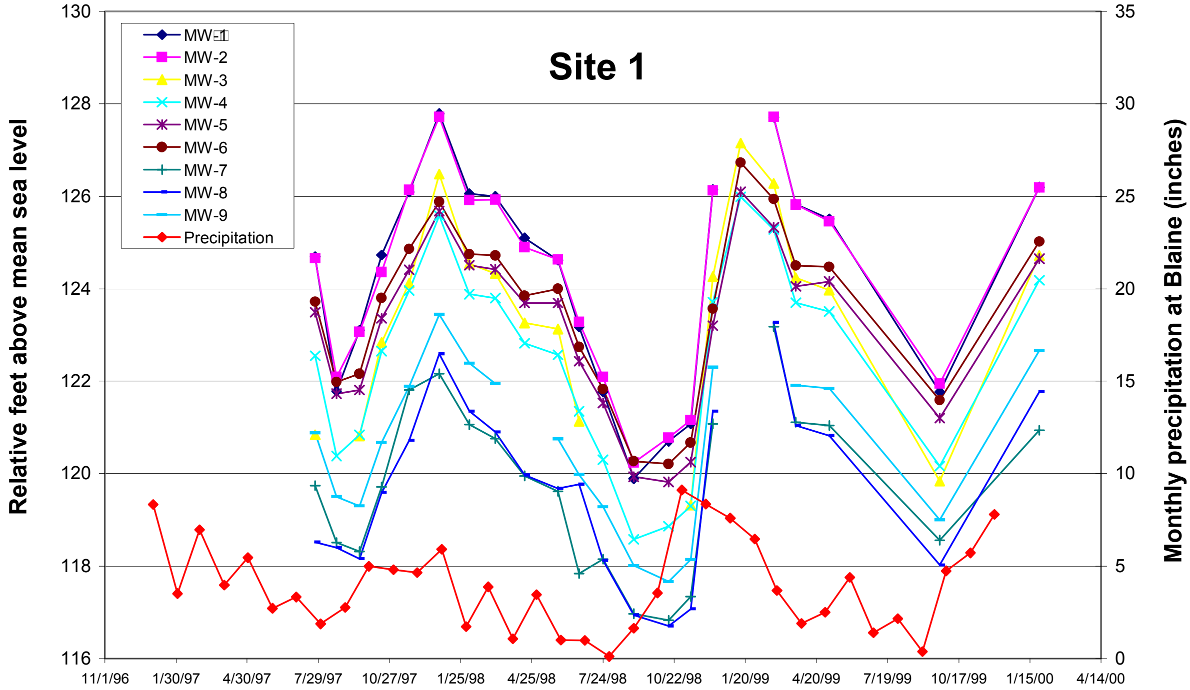


Figure 10. Water table elevations at Site 1 and monthly precipitation at Blaine, Washington (NOAA, 1997, 1998, 1999.)

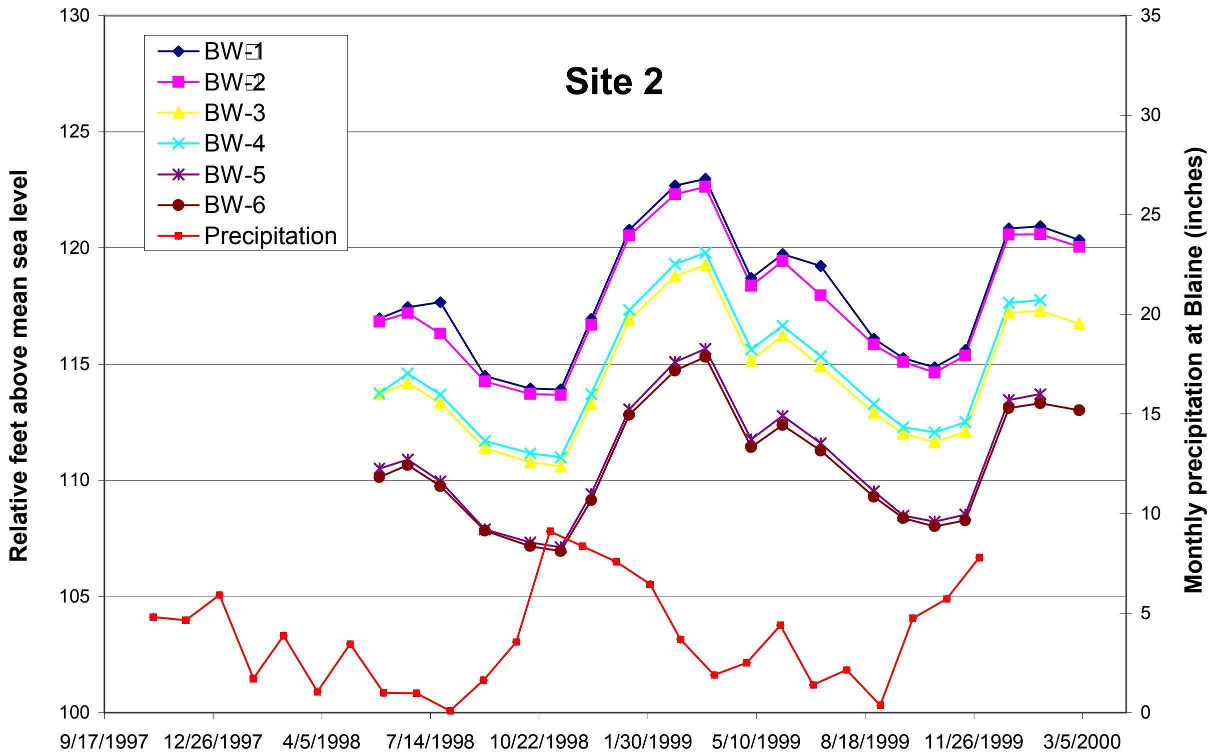


Figure 11. Water table elevations at Site 2 and monthly precipitation at Blaine, Washington (NOAA, 1997, 1998, 1999).

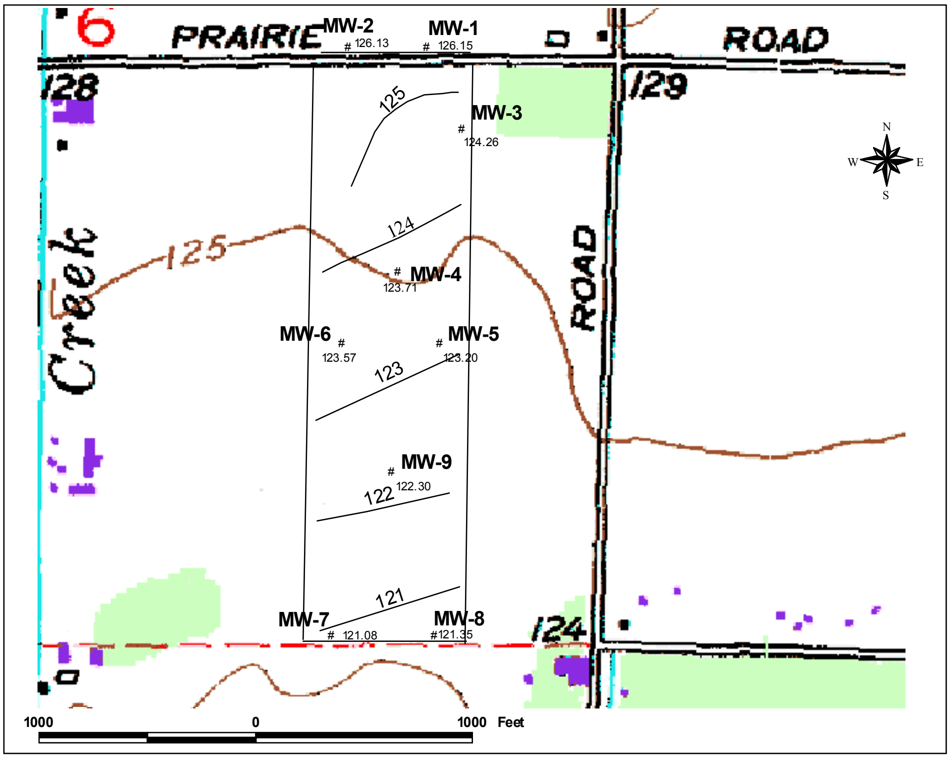


Figure 12. Water table contours at Site 1 on December 10, 1998, demonstrating the flow direction when the water table was high, but the field was not flooded.

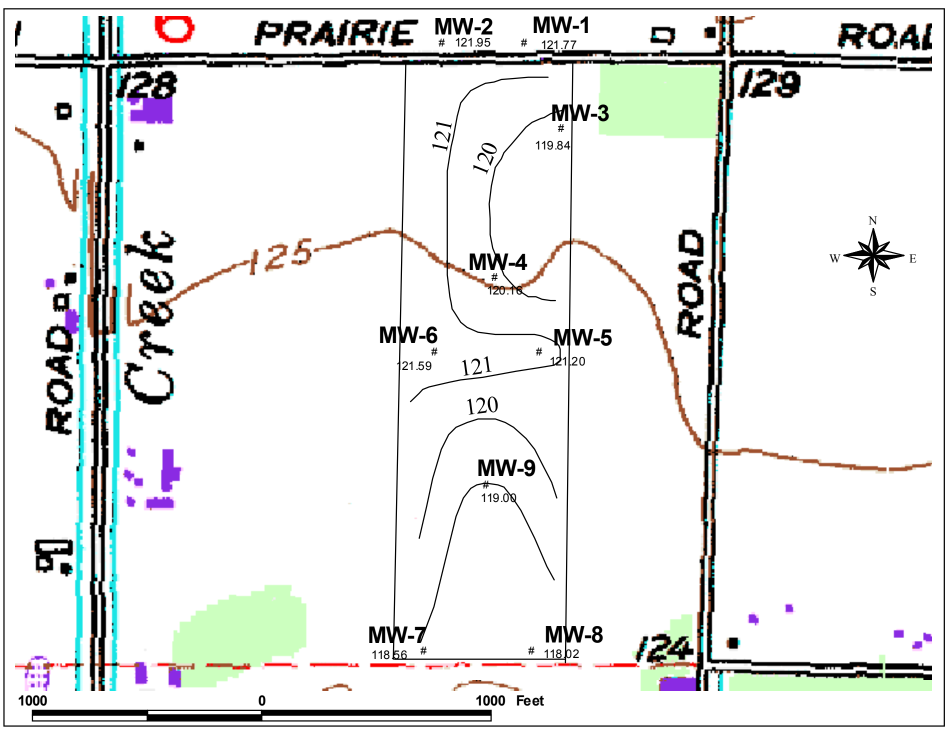


Figure 13. Water table contours at Site 1 on September 23, 1999 when the water table is typically lowest. The irrigation well near MW-3 causes a cone of depression in the summer and fall in the northern part of the field.

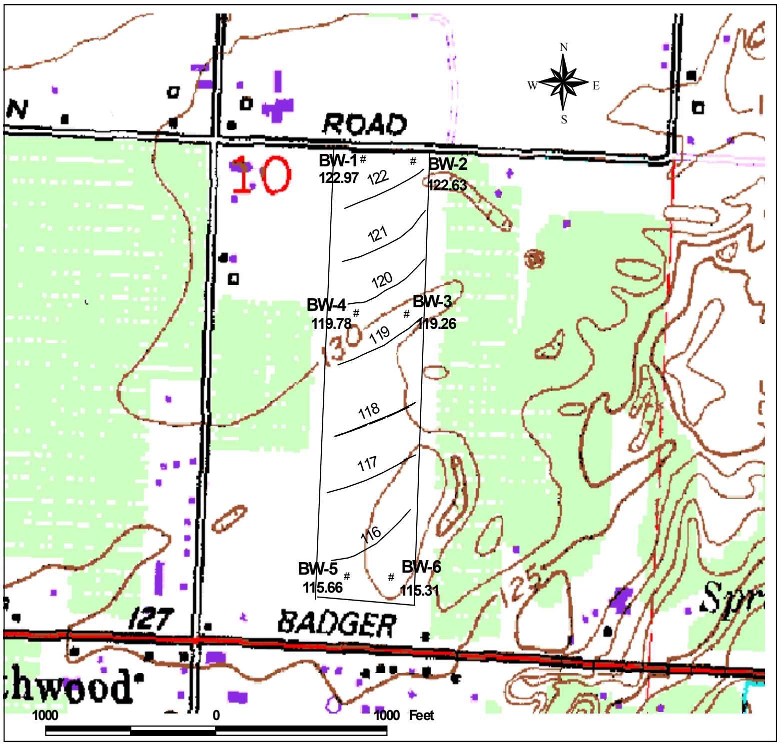


Figure 14. Water table contours at Site 2 on March 24, 1999 when the water table was relatively high.

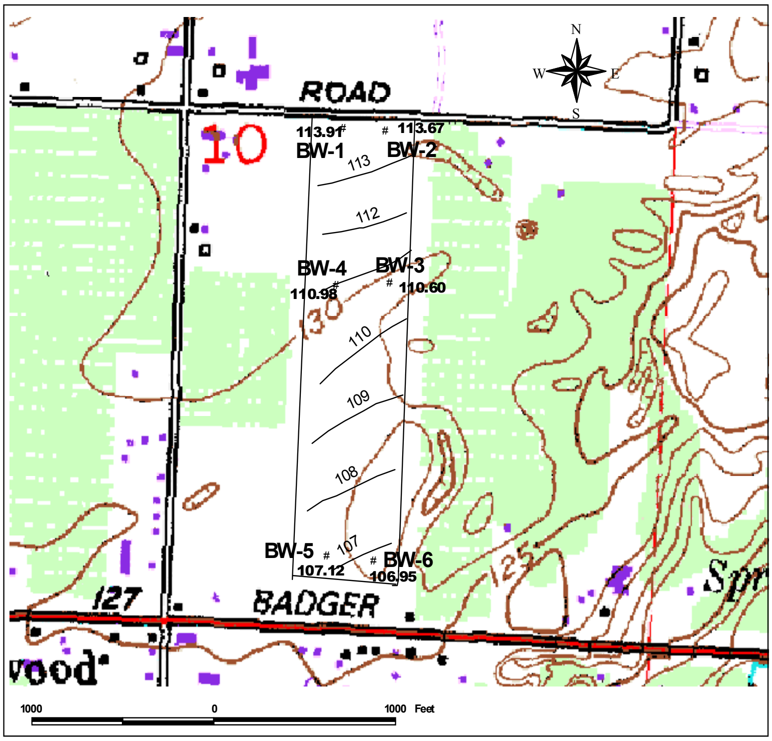


Figure 15. Water table contours at Site 2 on November 11, 1998 when the water table was relatively low.

The velocity of groundwater flow was estimated using Darcy's Law:

$$v = -K_H \, (dh/dl)/n_e$$

where,
v = average linear velocity (feet/day)
K_H = horizontal hydraulic conductivity (feet/day)
dh/dl = hydraulic gradient (dimensionless)
n_e = effective porosity (ratio of the volume of voids/total volume of material)

The data used to estimate average linear velocity of groundwater are shown in Table 5. Minimum values are based on the lowest hydraulic conductivity values and lowest gradient observed. Maximum values are based on the maximum hydraulic conductivity and gradient values observed. At Site 1 the geometric mean of the three hydraulic conductivity values, 60 feet/day, is used to calculate average linear velocity. At Site 2 the only hydraulic conductivity measurement, 300 feet/day, was used. The effective porosity was assumed to be 0.25 at Site 2 and 0.30 at Site 1 to account for the higher silt content.

Table 5. Groundwater velocity estimates and data used in calculations.

Site		K_H (feet/day)		Hydraulic Gradient	n_e		v (feet/day)
1	Minimum:	30	Minimum:	0.0012	0.30	Minimum:	0.12
1	Maximum:	90	Maximum:	0.0023	0.30	Maximum:	0.69
1	Geometric Mean:	60	Mean:	0.0017	0.30	Mean:	0.34
2		300	Minimum:	0.0028	0.25	Minimum:	3.36
2			Maximum:	0.0034	0.25	Maximum:	4.08
2			Mean:	0.0031	0.25	Mean:	3.72

The mean linear groundwater velocity at Site 1, 0.3 feet/day, was about one-tenth of that at Site 2. On an annual basis, the Site 1 mean velocity estimate is approximately 110 feet/year. The Site 2 annual estimate is 1,300 feet/year.

Nitrogen Application Rate

The application rate for nitrogen was estimated for the upgradient and downgradient fields at both sites as the sum of manure nitrogen and inorganic nitrogen fertilizer applied over the calendar year. For each application episode, the manure nitrogen application rate was calculated as:

Manure nitrogen applied (lb/acre) = Volume of manure applied (L/acre) x Concentration of TKN in the effluent (mg/L) x 2.205 $\times 10^{-6}$ (lb/mg)

Appendices H and I show the estimated nitrogen application rates for each episode of manure and inorganic fertilizer application. As shown in these summaries, both sites received 100-150 lb/acre of inorganic nitrogen fertilizer each year in addition to manure nitrogen. Figure 16 shows the total nitrogen application for 1997-99 at each site.

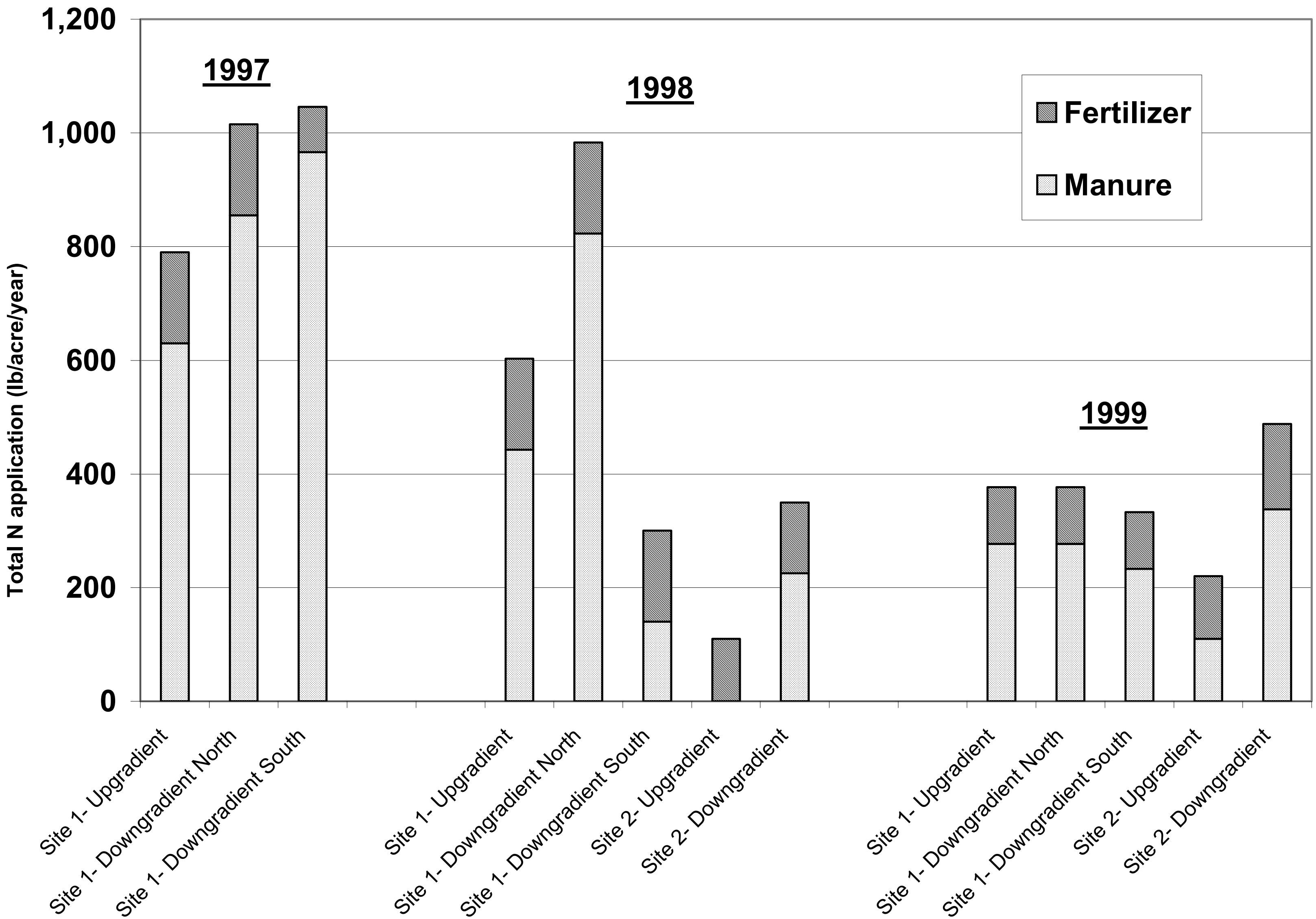


Figure 16. Total nitrogen application rates for 1997-99 showing manure and inorganic fertilizer components.

The volume of manure applied was estimated based on information recorded by the dairymen operating the sites. At Site 1 the volume of manure was estimated by multiplying the number of hours that the big gun applicator was operated by the manufacturer's suggested nozzle capacity and divided by the acreage receiving manure. The dairyman reported good comparison between estimated and actual application rates (+/- 10%). At Site 2 the dairyman recorded the volume of manure applied based on the capacity of the delivery wagon and the number of loads delivered to the field.

Nitrogen concentration in the applied manure is based on samples of manure collected when manure was being applied or the next closest date for which a sample was available. The results for major constituents in manure samples are shown in Appendix J.

Site 1 - 1997

Because no TKN measurements were available for manure nitrogen when applied in April, May, and October 1997 at Site 1, data for the same times in 1998 were used. In April and May 1999 ammonia-N data for manure on those dates was used to estimate TKN values. The mean fraction of ammonia in TKN for all manure gun samples for which both ammonia-N and TKN were available, 0.64, was used. The ammonia-N values for April and May 1999 were divided by the mean ammonia fraction to estimate the TKN (or total N) value.

The highest nitrogen application rate was found at Site 1 in 1997, about 1,000 lb/acre total N in both the North and South fields as shown in Table 6a. Manure comprised about 85% of nitrogen applied in 1997 (Table 6b). The application rate at the field upgradient of Site 1 was about 790 lb/acre, about 70-80% of this in manure nitrogen. According to the dairyman, these rates are typical of those applied to mature grass at this field.

Table 6a. Estimates of annual nitrogen loading (manure + inorganic fertilizer) for 1997-99 (lb/acre total N).

Field	Wells represented	1997	1998[1]	1999
Site 1- Upgradient	MW-1, -2	790	*603*	*380*
Site 1- Downgradient North	MW-3, -4, -5, -6	1,015	*983*	377
Site 1- Downgradient South	MW-7, -8, -9	1,046	*300*	333
Site 2- Upgradient	BW-1, -2		143	149
Site 2- Downgradient	BW-3, -4, -5, -6		350	488

[1]*Italicized numbers are rough estimates, due to incomplete records.*

Table 6b. Percent of nitrogen applied in the form of manure.

Field	1997	1998[1]	1999
Site 1- Upgradient	80	*73*	73
Site 1- North Field	84	*84*	73
Site 1- South Field	85	*47*	70
Site 2- Upgradient		25	29
Site 2- Downgradient		64	69

[1]*Italicized numbers are rough estimates, due to incomplete records.*

Site 1 - 1998

The 1998 record for manure application is incomplete at Site 1. The estimates in Tables 6a and 6b and Figure 16 do not include all the manure applied. In the spring of 1998 the South Field was converted from grass to corn which requires less manure and total N than grass. Therefore the estimate provided for the South Field, 300 lb/acre/year in 1998, may be close to the actual application rate. Some of the manure applied to the South cornfield was in the form of solid manure (about 35 lb/acre). The dairyman stated that the North Field, still planted in grass, probably received similar loading in 1998 as in 1997, or about twice the 500 lb/acre/year recorded.

Site 1 - 1999

The 1999 application rate for nitrogen at Site 1 was only about 35% of the rate typically applied to mature grass by this dairy. The South Field had just been replanted back to grass and required less nitrogen than a mature grass field.

Site 2 - 1998 and 1999

At Site 2 the downgradient nitrogen application rate was approximately 350 lb/acre/year in 1998 and 500 lb/acre/year in 1999. Manure nitrogen comprised roughly 65-70% of the applied N. The upgradient field was planted in corn during the study and received about 150 lb/acre/year of nitrogen, mostly in the form of inorganic fertilizer.

Water Quality

Groundwater

The groundwater quality results are shown in Appendix K. Time series graphs of monitoring well data are shown for nitrate+nitrite-N, chloride, TDS, and dissolved oxygen in Figures 17-24. Summary statistics for each analyte are described below.

The groundwater data record contains a few gaps. For example, no data were available for MW-3 on August 21, 1997 and July through October, 1998, because the well was dry. On April 16, 1998, Ecology could not locate MW-9 in the tall grass; and on January 14, 1999 and February 25, 1999, the top of the well was submerged due to high water.

The values for MW-9 on February 5, 1998 may not be representative of groundwater from the screened zone due to leakage at the top of the well. Mud was visible in the well which was redeveloped on February 27, 1998.

Nitrate+nitrite-nitrogen

Nitrate+nitrite-N concentrations in groundwater samples are shown in Figure 17 and 18. Table 7 shows summary statistics for nitrate+nitrite-N at the two sites.

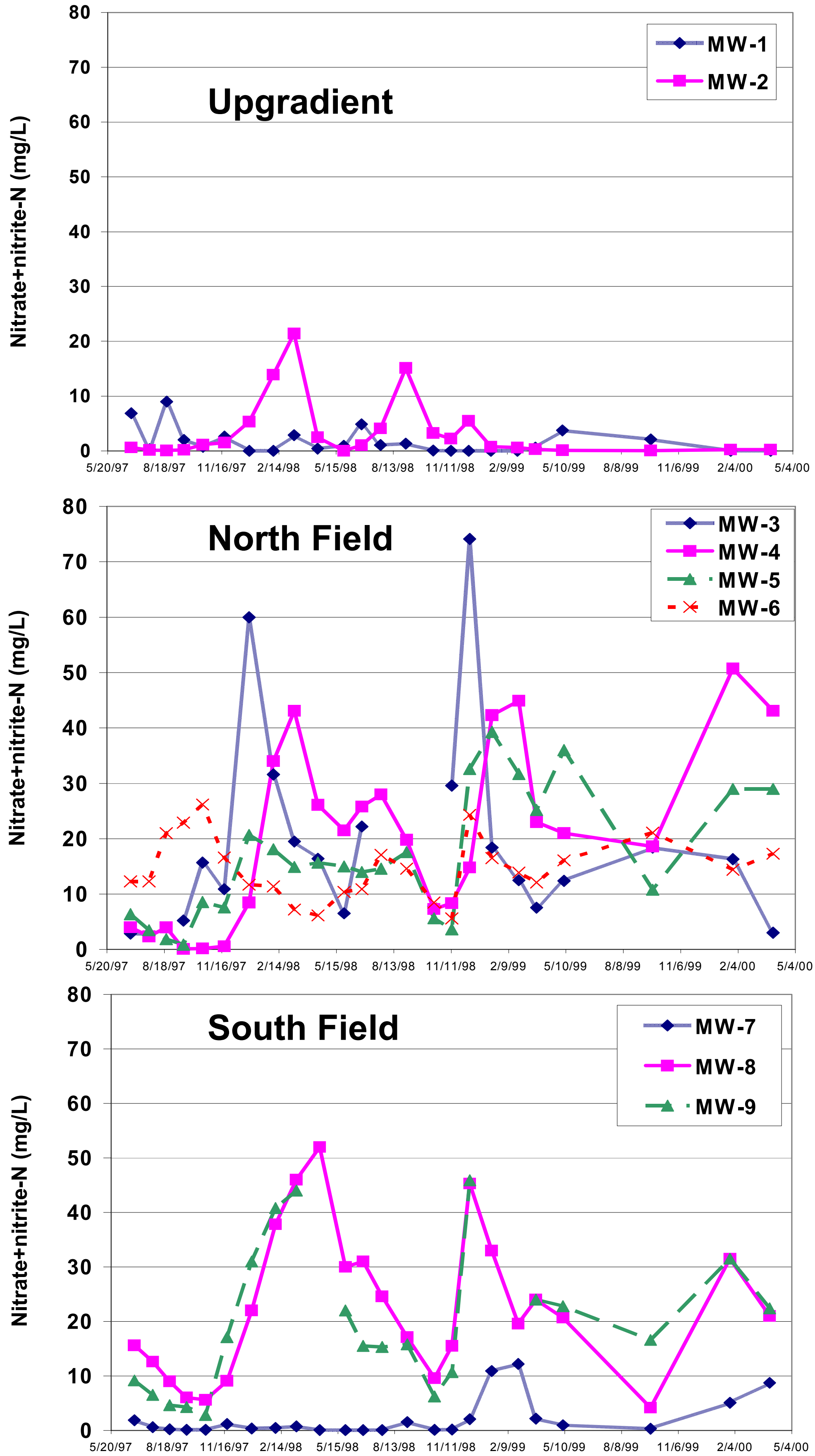


Figure 17. Nitrate+nitrite-N concentrations in Site 1 monitoring wells.

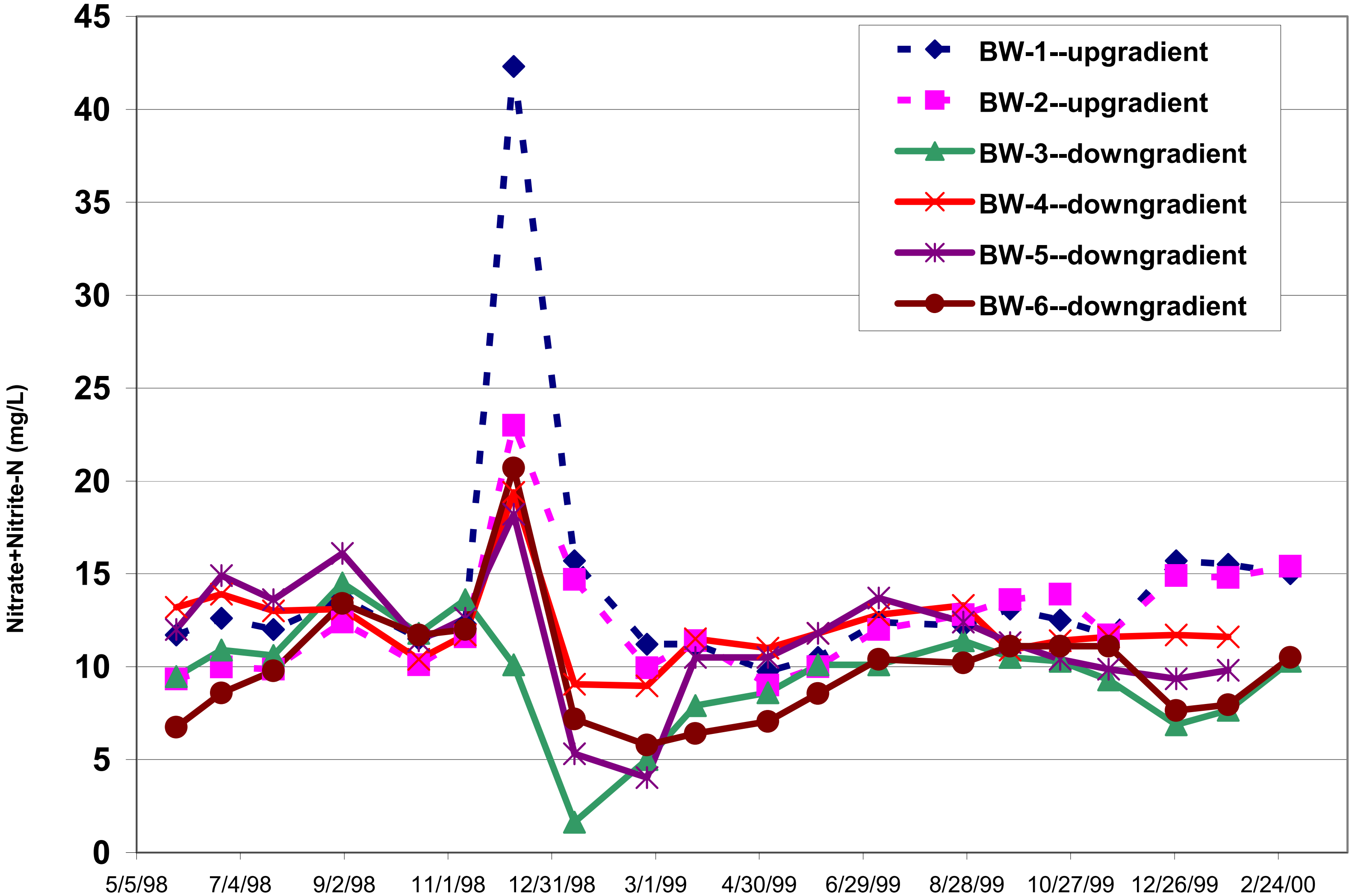


Figure 18. Nitrate+nitrite-N concentrations in Site 2 monitoring wells.

Table 7. Summary statistics for nitrate+nitrite-nitrogen (mg/L)

	Field	Mean	Standard Deviation	Median	Maximum	Minimum	Number of values
Site 1							
	Upgradient	2.5	4.3	0.75	21.4	<0.01	48
	North Field	17.7	13.5	15.4	74.1	0.092	92
	South Field (not including MW-7)	21.2	13.2	19.6	52.0	2.82	45
Site 2							
	Upgradient	13.4	5.2	12.4	42.3	9.0	42
	Downgradient	10.7	3.1	10.6	20.7	1.6	80

At Site 1 the upgradient nitrate+nitrite-N values ranged from less than 0.01 mg/L to 21.4 mg/L. The upgradient median was 0.75 mg/L. The downgradient range was 0.092 –74.1 mg/L. The downgradient means and medians exceeded those upgradient by a factor of 3 to 7. MW-7 was excluded from the South Field statistics, because Ecology learned that it had probably been affected by a heavy manure treatment just upgradient of the well that was not upgradient of the rest of the field.

The Site 2 upgradient median for nitrate+nitrite-N was 12.4 mg/L. The range was 9.0-42.3 mg/L. The downgradient median at Site 2 was 10.6 mg/L, and the range was 1.6 to 20.7 mg/L. The peak nitrate+nitrite-N concentrations for most wells at Site 2 occurred on December 9, 1998 following heavy precipitation. The nitrate concentration in drinking water wells in the Site 2 area had been in the range of 10-12 mg/L for some time according to local land owners, and helps explain the higher upgradient median and mean.

Ammonia-nitrogen

Ammonia-N concentrations were below detection in more than 80% of the samples in well at both sites as shown in Appendix L. The maximum ammonia-N concentration was 2.07 mg/L at Site 1 at MW-9 on February 5, 1998. This was probably not representative of the groundwater, because the top of the casing was muddy and the well water was turbid. The water table presumably rose above the top of the well, which was not sealed tightly enough to prevent water from seeping into the well. The well was redeveloped three weeks later using a submersible pump. The range of values excluding the anomalous value was less than 0.010 to 0.053 mg/L.

The total number of sample detections for ammonia-N was 20%. Ammonia-N was detected in most or all of the wells at Site 1 on four of 24 dates: June 26 and August 21, 1997, December 10, 1998, and May 7, 1999. Detections occurred in 24 other samples during the study.

Ammonia-N at Site 2 was detected in 16% of the samples and occurred mainly on two of 20 dates: July 8 and September 22, 1999. The range of values was less than 0.010 to 0.050 mg/L.

Total nitrogen and organic nitrogen

Many TPN values were screened out of the data set used to estimate organic N, because they exceeded nitrate+nitrite-N values. If the total N concentration was more than 0.3 mg/L higher than the nitrate+nitrite-N value for the same date or if the sum of ammonia and nitrate+nitrite-N was more than 102% of the total N value, then the value was not used to estimate organic N. Appendix L shows the screened organic N values.

The estimated concentration of organic N was low in all wells, ranging from 0 to 15.7 mg/L, as shown in Table 8. The median concentrations at the two sites were 0.26-0.60 mg/L. The median percent organic N of the total N was 3-11% in most wells as shown in Table 9. Exceptions were the two upgradient wells at Site 1 (MW-1 and MW-2) with approximately 28-32% organic N, as well as downgradient MW-7 with 35%. Although the percent organic N was higher in the three exceptional wells, the actual concentration was similar to that in the majority of monitoring wells.

Table 8. Summary statistics for organic nitrogen estimates (mg/L).

	Field	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Site 1							
	Upgradient	0.28	0.21	0.26	1.24	0	42
	North Field	1.46	2.28	0.40	9.50	0	65
	South Field (excluding MW-7)	2.03	3.74	0.40	15.68	0	32
Site 2							
	Upgradient	1.15	1.31	0.60	6.30	0	31
	Downgradient	0.87	1.06	0.50	5.20	0	55

Table 9. Median values for percent organic nitrogen of total nitrogen and organic nitrogen concentrations in monitoring wells.

Monitoring Well	Organic N %	Organic N mg/L
Site 1		
MW-1	31.9	0.31
MW-2	28.4	0.17
MW-3	10.6	0.60
MW-4	5.2	0.25
MW-5	4.6	0.30
MW-6	3.7	0.59
MW-7	35.2	0.24
MW-8	3.1	0.40
MW-9	4.4	0.36
Site 2		
BW-1	5.5	0.60
BW-2	5.7	0.65
BW-3	8.4	0.87
BW-4	4.1	0.54
BW-5	4.9	0.50
BW-6	3.8	0.39

Chloride

Results for chloride, TDS, and specific conductivity followed similar patterns during the study. Summary statistics are shown in Table 10. Times series graphs for chloride and TDS are shown in Figure 19-22.

Table 10. Summary statistics for chloride (mg/L), total dissolved solids (mg/L), and specific conductivity (µmhos/cm).

		Field	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Chloride								
	Site 1							
		Upgradient	13.9	4.2	14.1	23.4	7.05	47
		N downgradient	19.0	9.1	19.6	38	0.8	68
		S downgradient[1]	21.7	11.3	20.4	56.8	6.69	45
	Site 2							
		Upgradient	10.0	1.3	10.1	12.8	7.3	42
		Downgradient	9.6	1.3	9.8	13.4	6.0	80
TDS								
	Site 1							
		Upgradient	250	90	256	453	115	46
		N downgradient	333	102	337	632	114	89
		S downgradient[1]	322	81	302	583	212	43
	Site 2							
		Upgradient	164	22.4	167	197	64	40
		Downgradient	155	28.6	158	290	103	78
Specific Conductivity								
	Site 1							
		Upgradient	365	118	379	532	202	33
		N downgradient	479	144	492	878	155	46
		S downgradient[1]	482	123	481	840	290	27
	Site 2							
		Upgradient	248	16	248	274	209	39
		Downgradient	230	30	235	302	161	75

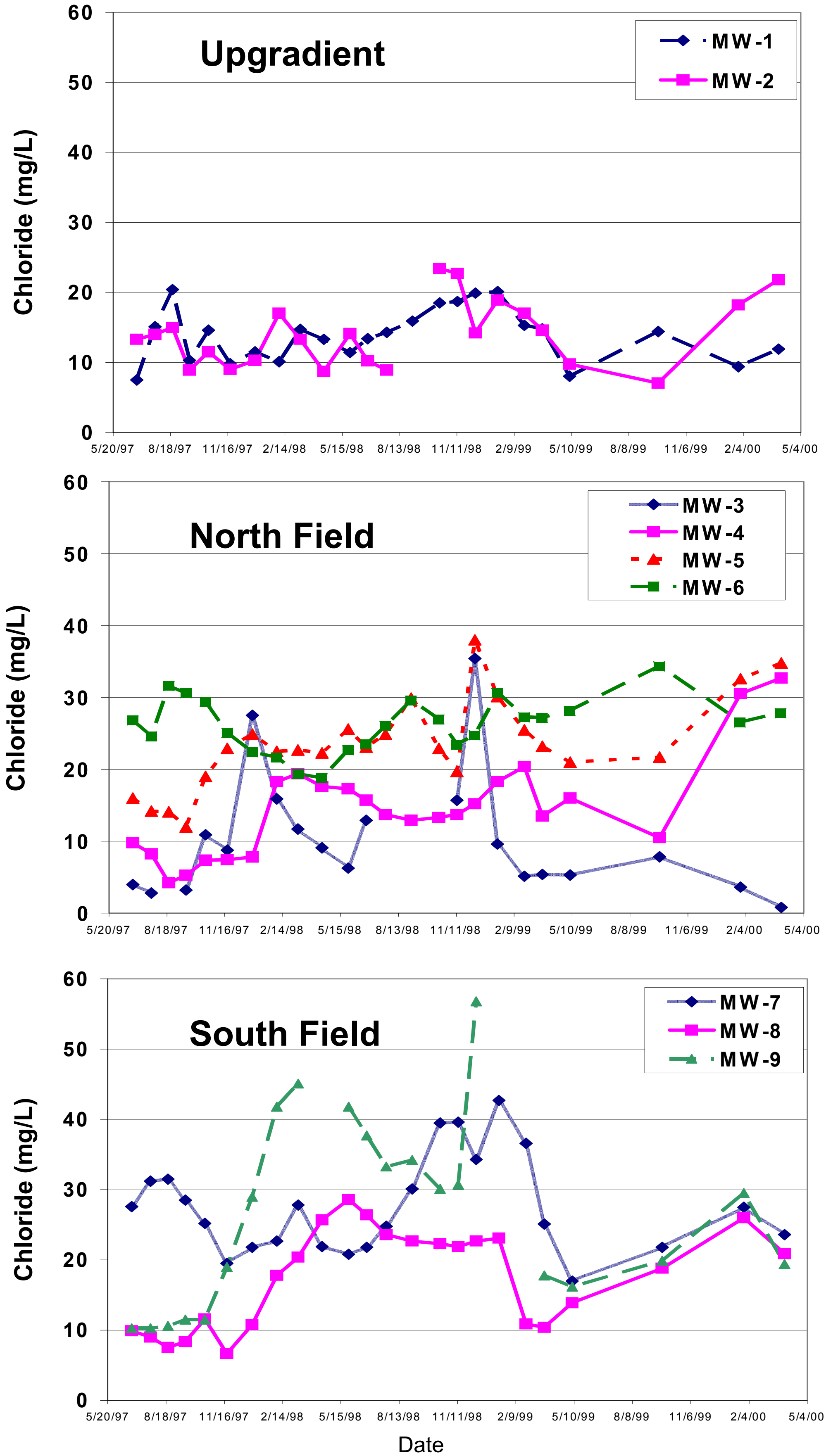


Figure 19. Chloride concentrations in Site 1 monitoring wells.

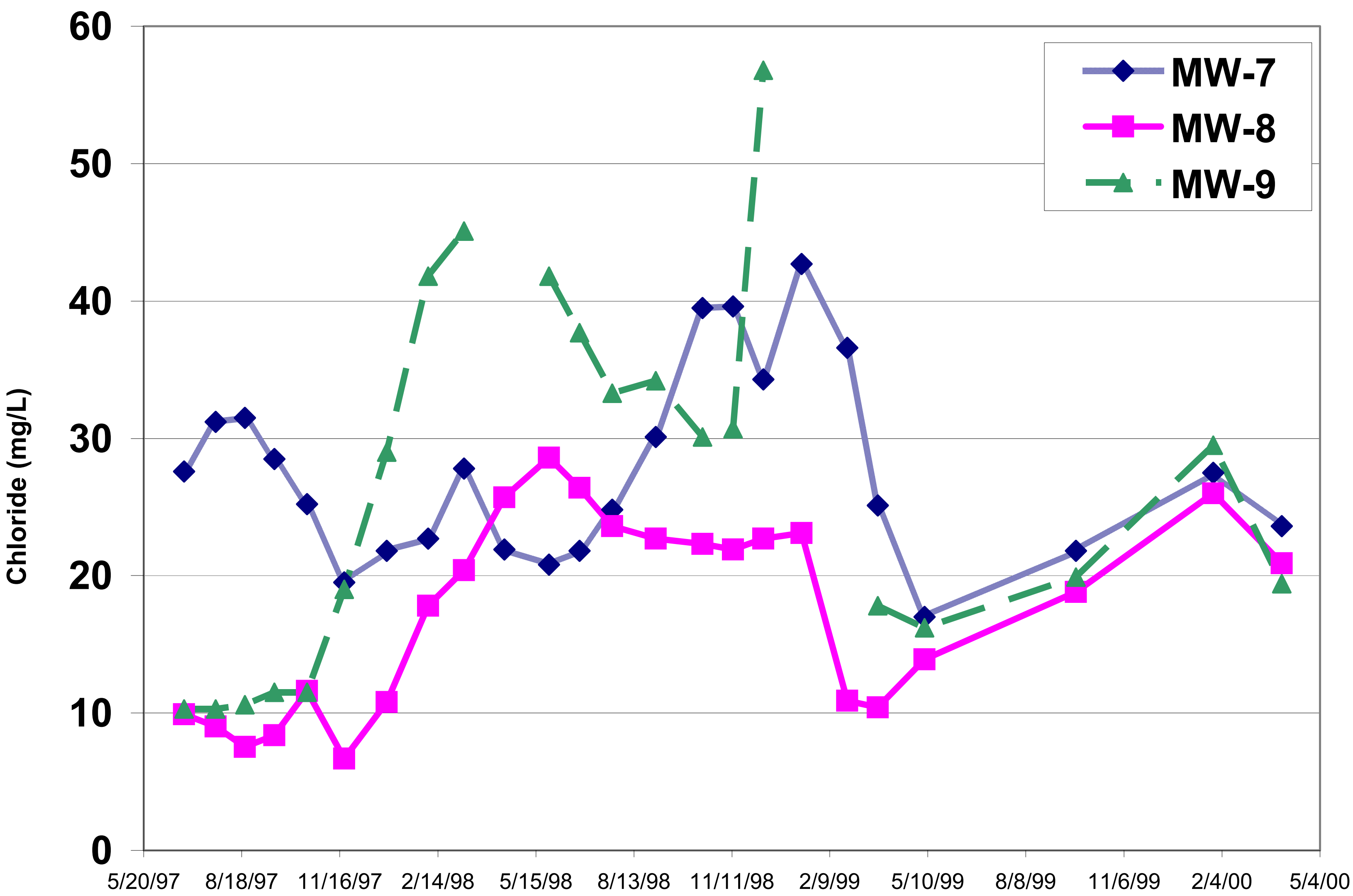


Figure 20. Chloride concentrations in Site 2 monitoring wells.

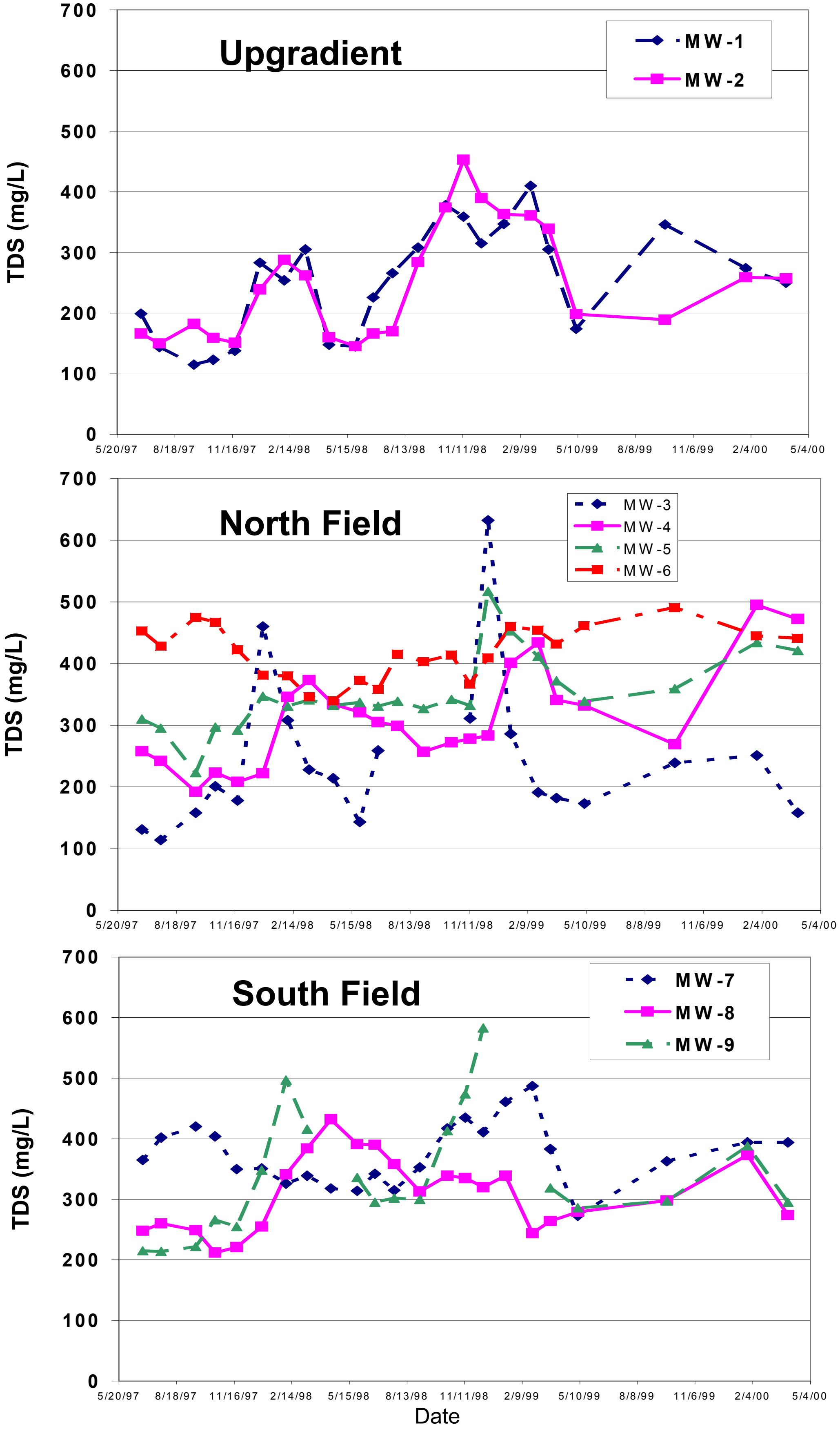


Figure 21. TDS concentrations in Site 1 monitoring wells.

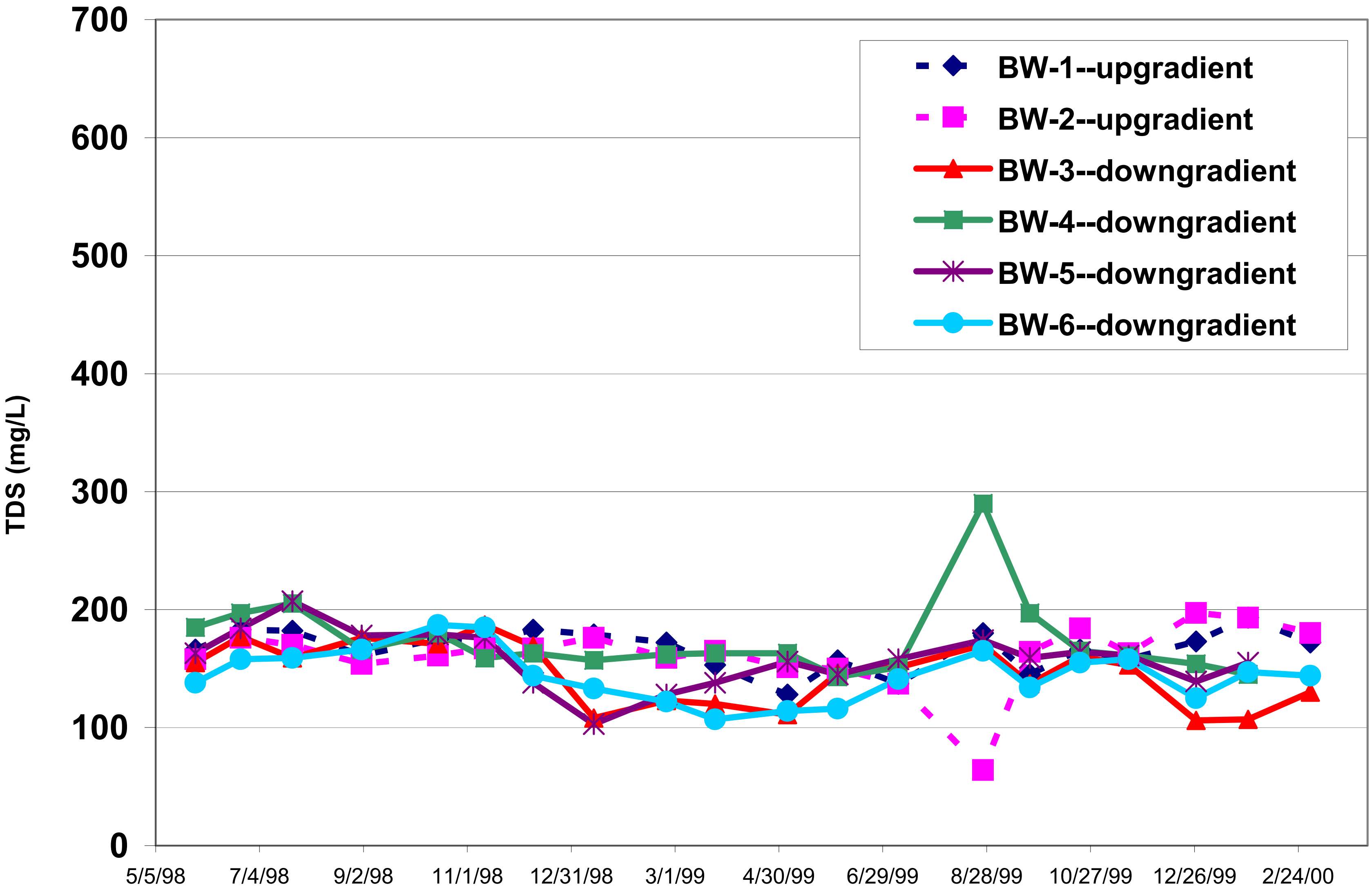


Figure 22. TDS concentrations in Site 2 monitoring wells.

Dissolved oxygen

Dissolved oxygen concentrations in well samples at both sites are shown in Figures 23-24. Table 11 shows summary statistics for dissolved oxygen concentrations. The dissolved oxygen concentrations were consistently higher at Site 2 than at Site 1. The Site 1 dissolved oxygen was often at or below the meter's lower detection limit.

Table 11. Summary statistics for dissolved oxygen (mg/L).

	Field	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Site 1							
	Upgradient	0.90	1.55	0.25	6.10	0.10	38
	North Field	1.25	2.04	0.30	7.90	0.10	77
	South Field (excluding MW-7)	1.70	2.00	0.56	7.20	0.10	36
Site 2							
	Upgradient	6.98	1.42	6.95	10.80	4.20	38
	Downgradient	7.41	1.47	7.05	11.30	4.20	73

Total organic carbon

TOC concentrations in well samples at both sites are shown in Table 12. TOC was analyzed on seven dates at Site 1 and on eight dates at Site 2. TOC results were below detection at all Site 2 wells on six of eight sampling dates as shown in Appendix M.

Table 12. Summary statistics for total organic carbon in groundwater (mg/L).

	Field	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Site 1							
	Upgradient	3.4	1.3	3.6	6.0	1.9	14
	North Field	4.7	2.4	3.9	10.2	2.3	21
	South Field (excluding MW-7)	4.4	3.0	3.4	14.1	2.6	13
Site 2							
	Upgradient	0.67	0.32	0.50	1.30	< 1	16
	Downgradient	0.64	0.31	0.50	1.52	< 1	29

1 For non-detects, one-half of the detection limit, 0.5 mg/L, was used.

TOC results that were below detection were assumed to be half of the detection limit, or 0.5 mg/L for TOC. Because most of the values at Site 2 were below detection, both the upgradient and downgradient medians for TOC were 0.5 mg/L. The upgradient range was less than 1 to 1.23 mg/L. The downgradient range was less than 1 to 1.52 mg/L.

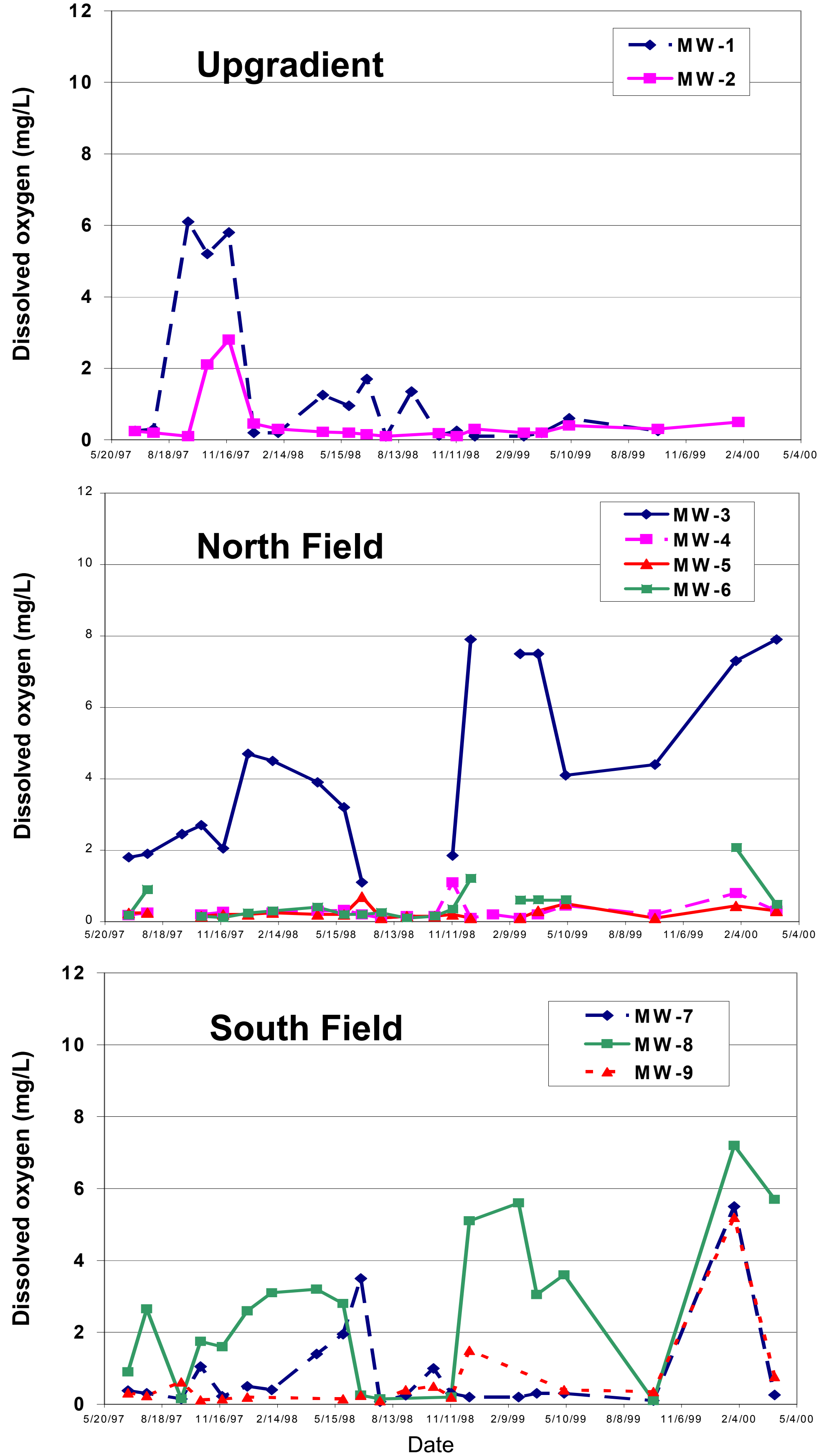


Figure 23. Dissolved oxygen concentrations in Site 1 monitoring wells.

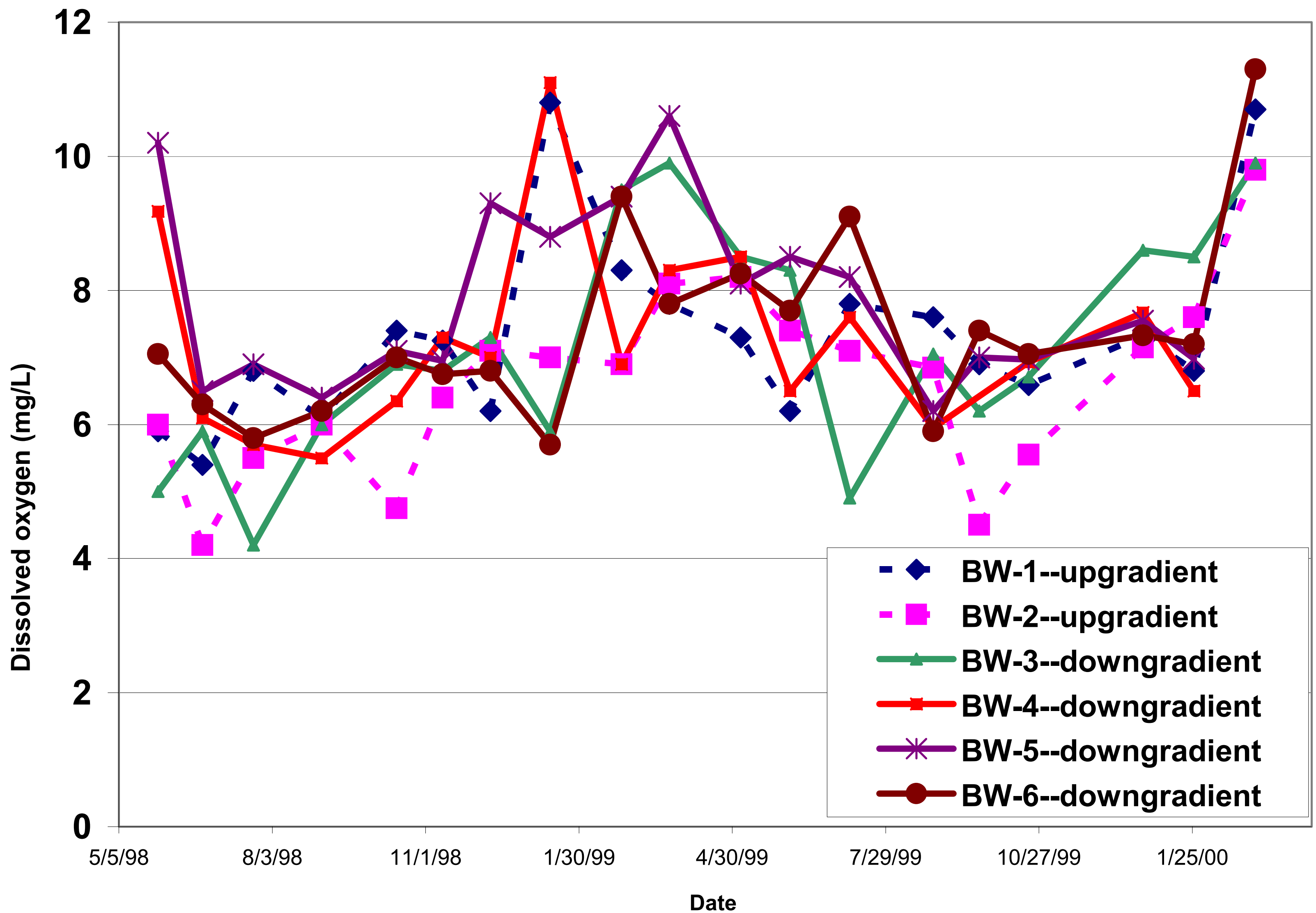


Figure 24. Dissolved oxygen concentrations in Site 2 monitoring wells.

Soil Pore Liquid

The soil pore-liquid results for ammonia-N, nitrate+nitrite-N, TPN, chloride, TDS, and specific conductivity are shown in Appendix N. The ceramic cup intakes for the lysimeters at Site 1 were below the water table during about half the year (October 17, 1997 - April 16, 1998 and December 10, 1998 – summer 1999). Therefore, results during these times reflect groundwater conditions more than soil pore-liquid conditions.

Four of six lysimeters at Site 1 functioned throughout the study, but only one of six functioned consistently at Site 2. Leaks compromised the two failed samplers at Site 1. The coarse texture of the soils in all but one location at Site 2 apparently caused very rapid flow of water through the vadose zone. Even on occasions during and shortly after rain events, the lysimeters at Site 2 (except for BL-6) were usually empty.

Nitrate+nitrite-nitrogen

Figures 25 and 26 show nitrate+nitrite-N values at Site 1 and 2, respectively. Table 13 shows the summary statistics for nitrate+nitrite-N in the lysimeters at each site. The upgradient and downgradient data were combined for Site 2, because most of the results were from BL-6.

Table 13. Summary statistics for nitrate+nitrite-N in soil pore liquid (mg/L).

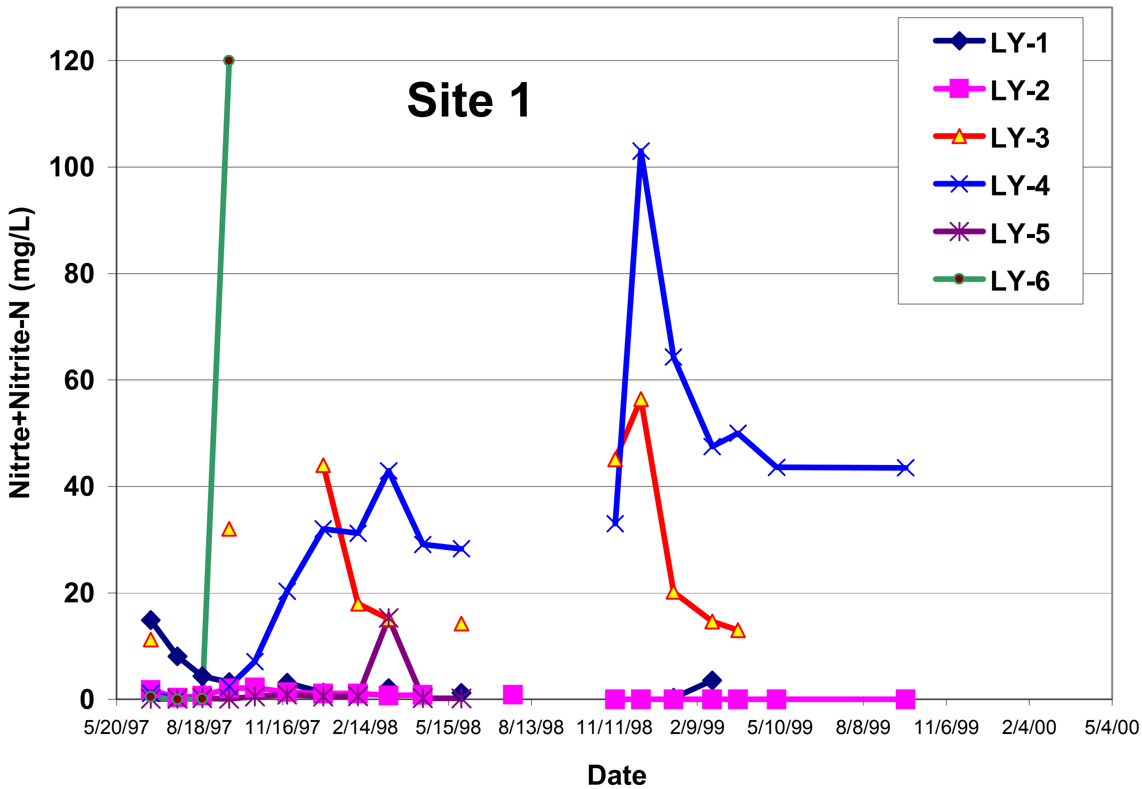
	Lysimeters	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Site 1	LY-1, -2	1.73	2.95	0.82	14.9	0.010	32
	LY-3, -4, -5, -6	24.4	26.9	15.3	120	0.010	47
Site 2	All lysimeters (mostly BL-6)	27.7	29.5	24.6	111	0.064	19

The range of values for Site 1 was 0.010-120 mg/L nitrate+nitrite-N. Similar to Site 1, the range at Site 2 was 0.064-111 mg/L. The medians at Site 1 were 0.82 mg/L in the upgradient field and 15.3 mg/L in the downgradient field. At Site 2 the median was 24.6 mg/L.

Ammonia-nitrogen, TPN, and organic nitrogen

A summary of the basic soil pore-liquid statistics for ammonia-N and TPN is shown in Table 14. At Site 1 the mean and median for all the constituents was greater in the downgradient field (near MW-3 through MW-9) than in the upgradient field (near MW-1 and MW-2). Site 2 data represent only 5-12 samples depending on the analyte, compared to 25-47 samples for lysimeters at Site 1 in the downgradient field.

Ammonia-N soil pore-liquid concentrations were low at both sites. The medians for Site 1 and 2 were less than 0.04 mg/L. Non-detect values were considered as one-half the detection limit for statistical calculation (i.e., 0.005 mg/L for ammonia-N). The maximum ammonia-N concentration was 5.02 mg/L at Site 1.



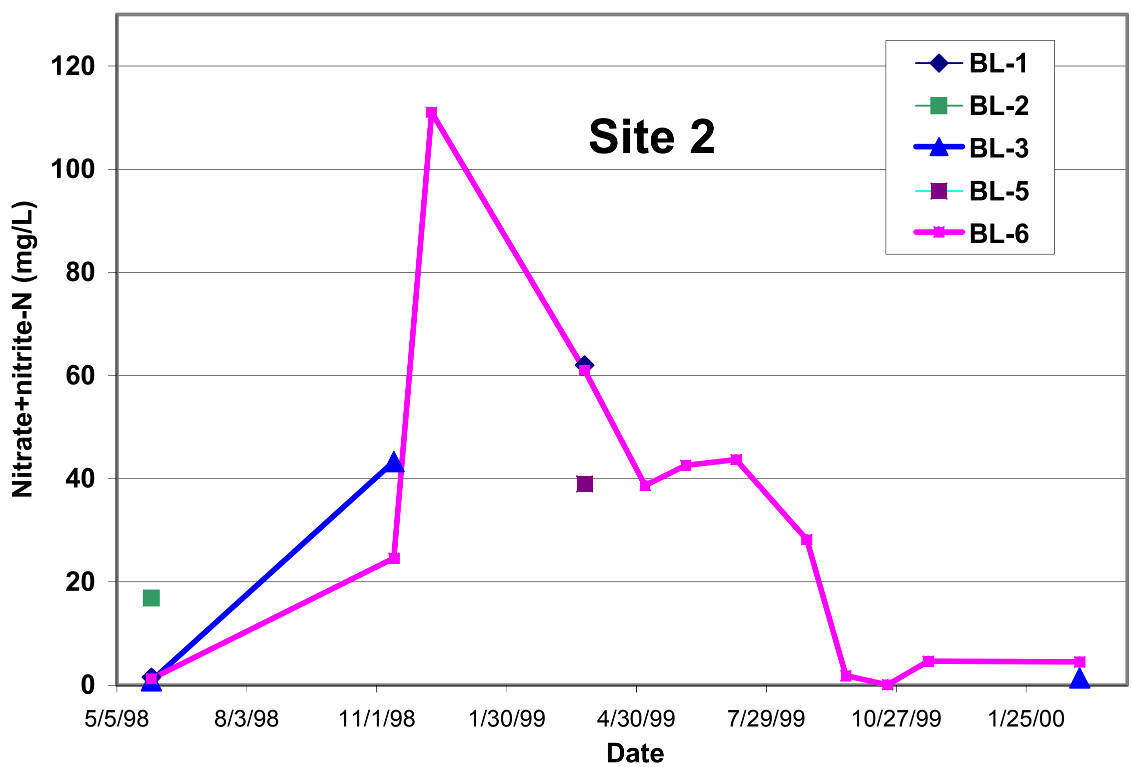


Figure 25. Soil pore-liquid nitrate+nitrite-N concentrations at Site 1 and Site 2.

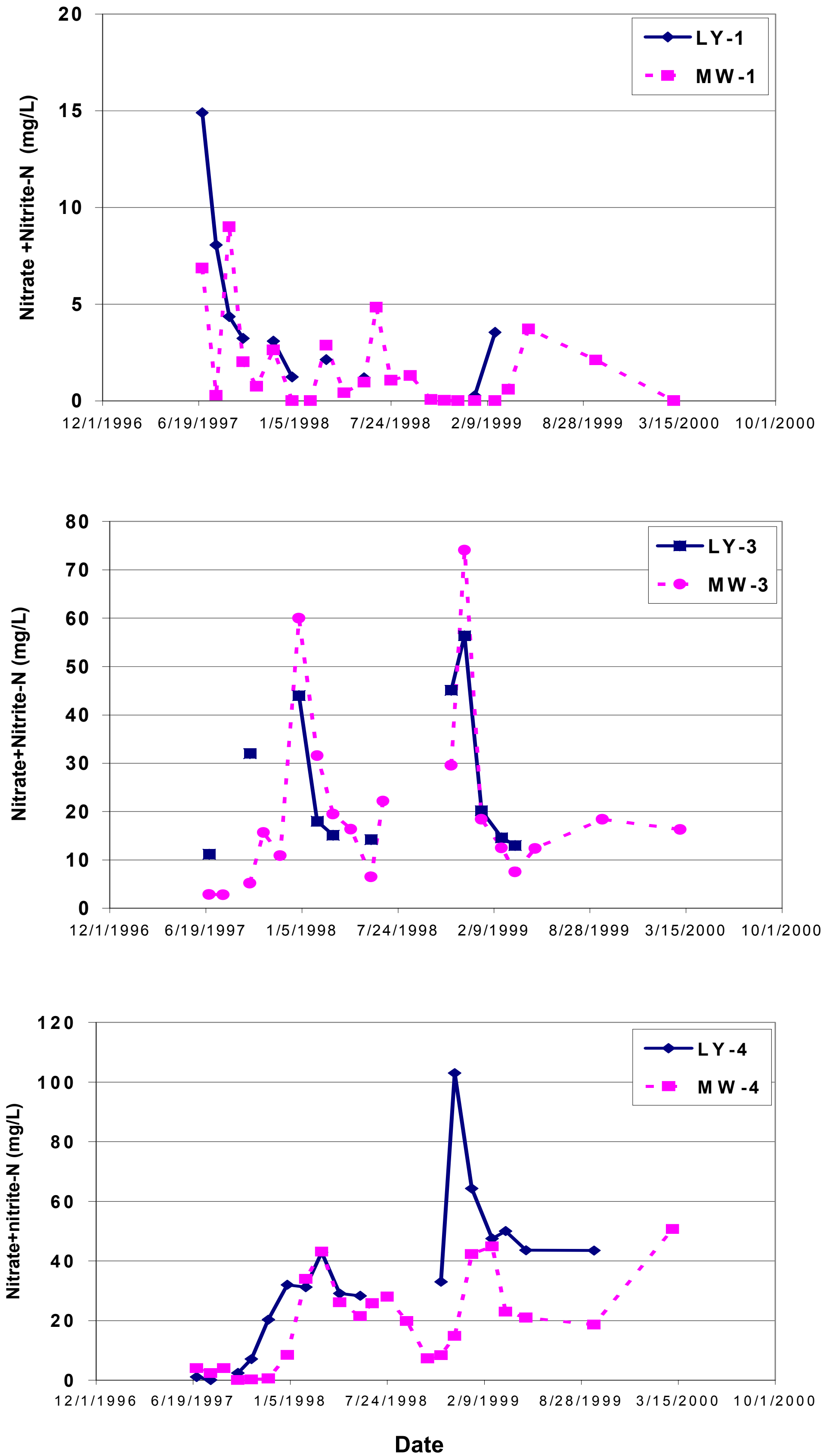


Figure 26. Soil pore-liquid and groundwater nitrate+nitrite-N concentrations at Site 1 at locations where soil pore-liquid and groundwater patterns were similar.

Table 14. Summary statistics for soil pore-liquid ammonia and TPN (mg/L).

	Lysimeters	Mean	Standard Deviation	Median	Maximum	Minimum	Number of Values
Site 1							
Ammonia	LY-1, -2	0.033	0.047	0.0175	0.187	0.005	30
	LY-3, -4, -5, -6	0.314	0.808	0.039	5.02	0.005	47
TPN	LY-1, -2	1.47	2.90	1.315	15.1	0.355	32
	LY-3, -4, -5, -6	23.5	24.1	20.1	120	0.711	46
Site 2							
Ammonia (BL-6 only)		0.070	0.194	0.005	0.685	0.005	12
TPN (BL-6 only)		13.2	21.8	3.68	64	0.838	8

Soil Nitrogen

The soil nitrate results ranged from 10.5 mg/kg at Site 2 to 84 mg/kg at Site 1 and are shown in Appendix O, Table O.1. The 1997 WSU samples were collected at two depths (0-1 foot and 1-2 foot). In 1998 and 1999 Ecology sampled soils at 0-1 foot only. Figure 27 shows the nitrate-N results for each year in the top one foot of soil. Soil ammonia in the top one foot was also analyzed in the 1998 and 1999 samples as shown in Appendix O, Table O.2. Soil ammonia concentrations ranged from 7.5 mg/kg at Site 2 to 20.0 mg/kg at Site 1. Figure 28 shows the soil ammonia concentrations. Soil samples were collected in September each year, one to two months before the last application of manure.

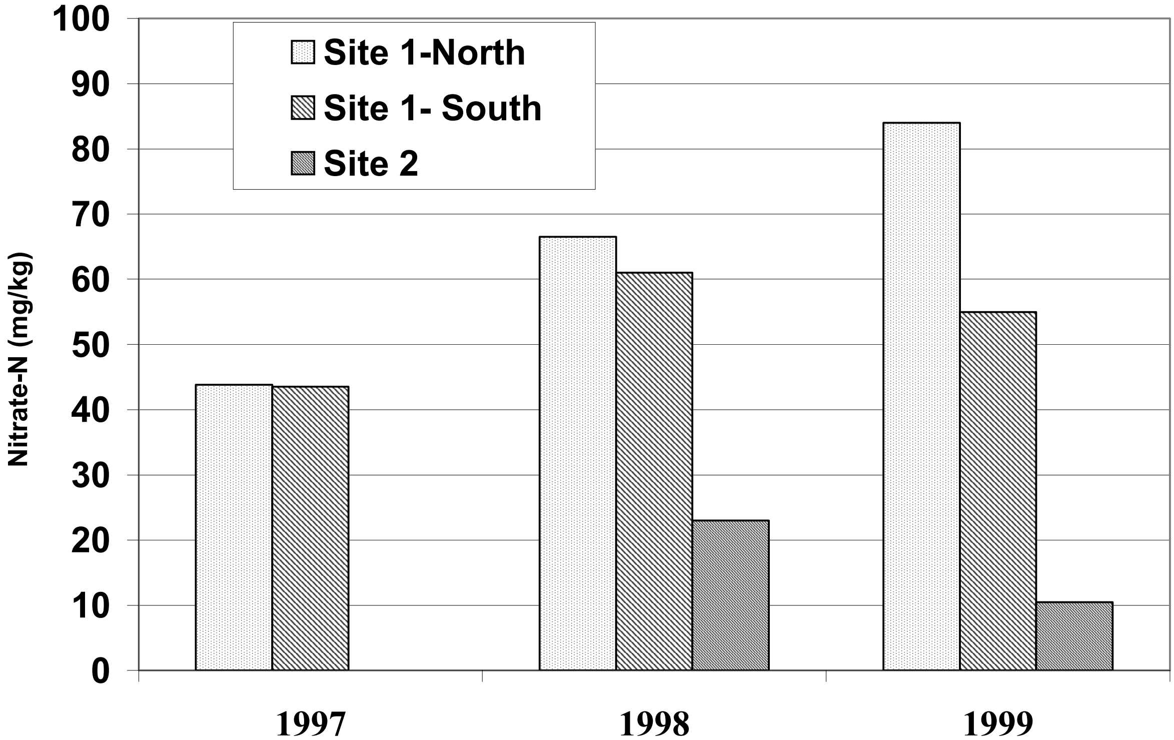


Figure 27. Soil nitrate concentrations in the top one foot of soil.

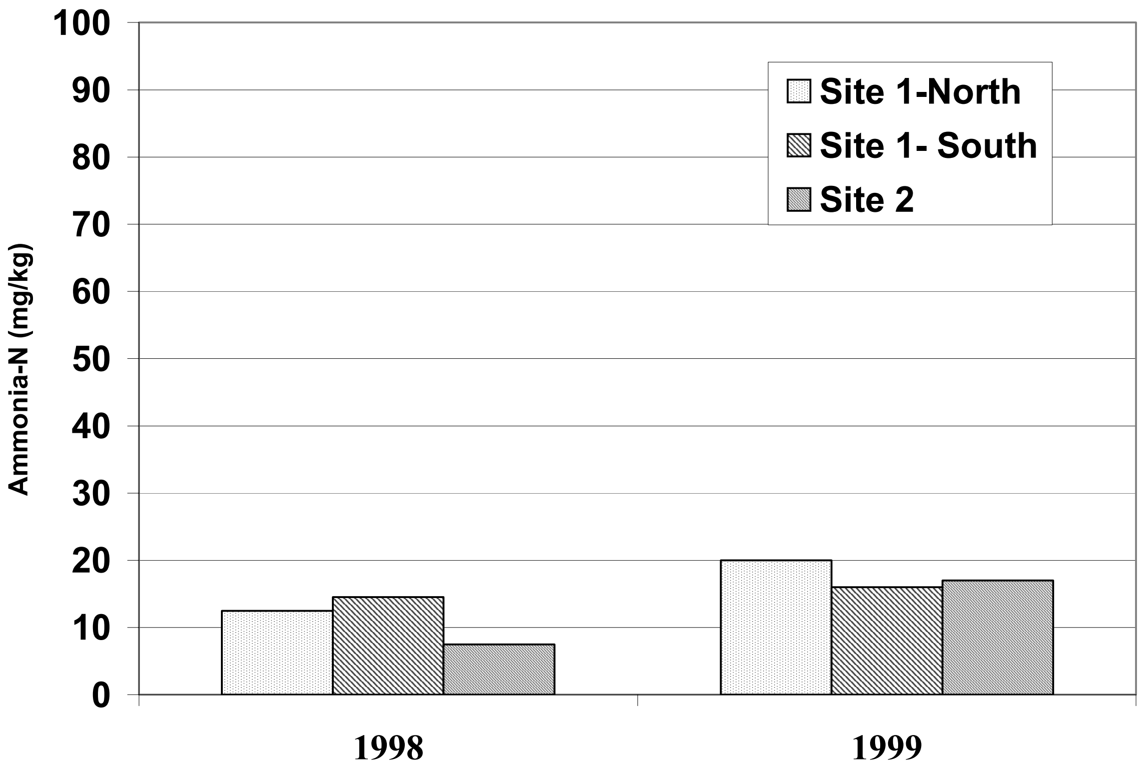


Figure 28. Soil ammonia in the top one foot of soil.

Discussion

Hydrogeology

Aquifer and Vadose Zone Materials

The top five feet at Site 1 is composed of silty sand and fine to medium grained sand, based on drilling observations and grain size distributions. In the northern one-third of the site, this material continues to the bottom of the wells, about 10 feet. In the southern two-thirds of the site, materials at five feet depth and below contain more gravel and medium grained sand. The mean effective grain size (d_{10}) for split spoon samples collected at 2.5-10 feet at Site 1 was 0.14 µm (n=10).

Site 2 materials were generally coarser than at Site 1, consisting mainly of mixed sand and gravel. The gravel ranged from 15-40%. The d_{10} value for split spoon samples from 5-20 feet depth was 0.32 µm (n=9), about twice the size at Site 1. The higher d_{10} values at Site 2 indicate generally coarser materials.

Although the transport of nitrate and other manure-related solutes through the vadose zone to the groundwater was faster in the coarser vadose materials at Site 2, the shallow depth to water at Site 1 also allows rapid transport of nitrate to groundwater. As shown in Table 15, the water table in many parts of Site 1 is at the surface during the winter. In contrast, the minimum depth to water at Site 2 was eight feet below ground surface.

Table 15. Maximum, minimum, and mean depth to water in feet below ground surface.

Location	Maximum	Minimum	Mean
Site 1	8.7	0	3.8
Site 2	23.2	7.8	16.1

The estimated hydraulic conductivity at Site 2 (300 feet/day) was about five times that at Site 1 (62 feet/day). This is consistent with grain size and well log information indicating coarser materials at Site 2. However, the estimate for Site 2 is based on only one specific capacity test at BW-2. The well log for BW-2 indicates that it is similar to the other wells, although the gravel content in the screened zone was lower in BW-2 than in most of the other wells. A grab sample from the screened zone also contained about 5% silt or clay which was not observed at that depth in other wells. Therefore, the estimate for K_s at Site 2 may be somewhat low compared to that at other wells.

Hydraulic conductivity estimates for both sites are close to 200 feet/day, the geometric mean estimated by Cox and Kahle (1999) for 11 wells in the area.

Groundwater Flow

Due to the higher K_s, the mean estimated velocity of groundwater flow is roughly ten times higher at Site 2 (4 feet/day) than at Site 1 (0.4 feet/day) (Table 5). The Site 2 velocity may be an underestimate for the site, because it is based on one K_s measurement in a well containing more fine-grained material in the screened zone than the other five wells.

Erickson (1991) and Stasney (2000) estimated similar groundwater flow velocities for this area. Using specific capacity data for eight wells near Site 1, Erickson (1991) estimated flow at 5 feet/day. Stasney (2000) estimated that groundwater flow in the Judson Lake area northeast of the study areas to be 25 feet/day.

The direction of groundwater flow at Site 2 was consistently northwest to southeast as shown in Figure 14 and 15. This is consistent with the flow direction that Erickson (1998) found in this area using existing water level and stream elevations.

At Site 1 the flow was also northwest to southeast during the winter (Figure 12). However, the irrigation well near MW-3 exerts a major effect on the groundwater flow direction in the northern half of the field above the drainage ditch during the summer and fall (Figure 13). Although the irrigation well pumped for only about three months in the summer each year, the cone of depression causes the flow lines to bend east-northeast for nine months of the year.

Another factor possibly contributing to the east-northeast flow direction in the northern half of the field at Site 1 during much of the year is that the coarser materials near MW-4 allow faster flow through this area and cause an erroneous depression in the water table. Soil samples from MW-4 at 5.0 feet and below were classified as poorly graded sand with effective grain sizes (d_{10}) of 0.16-0.25 mm, while soil samples from MW-3 at the same depths were classified as silty sand with d_{10} values of 0.04 mm.

The ditch that cuts through the middle of Site 1 likewise affects groundwater flow, intercepting groundwater when the water table is less than five feet below ground surface. This occurred in all but three months during the study. Thus the ditch serves as a sink for nitrate from the northern part of the field. Surface runoff would also tend to flow toward the ditch; however, the flat topography minimizes surface flow. Drainage to the ditch would prevent water and nitrate picked up from the soil in runoff from reaching the groundwater.

The hydraulic gradient at Site 2 was slightly higher than at Site 1 and less variable during the year. The mean at Site 1 was 0.0017; the mean at Site 2 was 0.0031. The difference between the maximum and minimum gradient at Site 2 was 0.0006; the difference at Site 1 was 0.0011. The effects of these differences on the velocity estimate is not significant compared with the difference in K_s values.

The slower velocity at Site 1 would tend to keep nitrate in the groundwater at the site longer and allow more nitrate buildup than at Site 2. Large-scale pumping from the irrigation well at Site 1 not only prevents downgradient flow of nitrate but also removes nitrate from the groundwater and reapplies it to the surface at one of many fields in the area.

Nitrogen Application Rates

Agronomic Rate Calculations

The agronomic rate for nitrogen in this study refers to the total rate of nitrogen application in the form of manure and inorganic fertilizer needed to produce an expected yield while minimizing leaching of nitrogen to groundwater. The method used for calculating agronomic rate is described in WSU (1995). The expected crop yield is multiplied by the nitrogen uptake rate to estimate the amount of nitrogen needed by the crop. Nitrogen from sources other than manure and fertilizer, such as residual soil nitrogen and irrigation water are also taken into account as well as loss of ammonia-N due to volatilization. The steps for calculating the agronomic rates for nitrogen application at the study sites are shown below.

1. Set yield goals for the crop

Orchardgrass was grown at both sites except for Site 1 in 1998 when corn was grown. According to the manual (WSU, 1995), the typical yield range for orchardgrass in western Washington is 3-8 tons/acre/year dry matter. The yields provided by the dairymen for the study period were: 7-7.5 tons/acre/year dry matter at Site 1 for mature fields, and 6.5 tons/acre/year dry matter at Site 2.

Ecology used 6-7 tons/acre/year dry matter for the crop yield goal for Site 1, 5-6 tons/acre/year dry matter for Site 2. For the newly establishing grass field at the Site 1 in 1999 and the North Field in 2000, the yield goal used was 4-5 tons/year dry matter.

Ecology assumed a yield of 6 tons/acre/year for the 1998 corn crop at the South Field of Site 1.

2. Determine the crop nutrient content

Typically orchardgrass contains about 2.9% nitrogen by weight, and corn contains 1.2%, according to WSU (1995). The next step is to calculate nutrient uptake by multiplying yield goal by percent nitrogen of the dry crop yield. This converts to 406 lb/acre/year for Site 1 orchardgrass and 348 lb/acre/year for Site 2 of nitrogen theoretically taken up by the crop. The estimated nitrogen uptake for corn at the Site 1 South Field is 144 lb/acre/year.

3. Adjust for nitrogen from other sources (irrigation water and residual soil nitrate)

Determine the amount of nitrogen applied through irrigation water using the following equation:

NO3-N (mg/L) in irrigation water x 2.7 x inches water applied / 12 = lb N/acre applied

Ecology used the mean groundwater nitrate+nitrite-N value for all the wells at each site for the concentration in irrigation water, because irrigation water originated from nearby wells at both sites. The mean NO3+NO2-N concentration was 13 mg/L for Site 1, and 12 mg/L for Site 2. The resulting amounts of nitrogen added through irrigation water were 9 lb/acre/year for Site 1 and 27 lb/acre/year for Site 2.

Residual nitrate in the soil was assumed to be negligible following leaching by winter rains.

4. Adjust for nitrogen loss due to ammonia-N volatilization

Ecology assumed a 30% loss of nitrogen due to ammonia-N volatilization, because at least 10% of the nitrogen applied is commercial fertilizer which does not contain volatile ammonia. The resulting approximate agronomic application rates for the study period are shown in Table 16. For Site 1 the agronomic rate estimate is 440-520 lb/acre/year of nitrogen; for Site 2, 340-420 lb/acre/year.

Table 16. Agronomic rate calculations based on WSU (1995) (lb/acre/year).

Location	1997	1998	1999
Site 1- Downgradient North	440-520	440-520	290-370
Site 1- Downgradient South	440-520	180	290-370
Site 2- Downgradient	340-420	340-420	340-420

Comparison of Estimated Application Rates with Agronomic Rates

Site 1

A comparison of the amount of nitrogen applied with the agronomic rate estimate for the location indicates that nitrogen was being excessively applied at Site 1 in 1997 and 1998 as shown in Table 17. In 1997 both downgradient fields at Site 1 received more than double the amount of nitrogen required for good crop growth. Incomplete records of manure application in 1998 indicate that the application may have been even greater than shown here. In 1999 both North and South downgradient fields at Site 1 received close to the estimated agronomic rate for nitrogen.

Table 17. Differences between agronomic rate and estimated total nitrogen application rates.*

Location	1997	1998[1]	1999
Site 1- North Field	500-580	470-540	10-90
Site 1- South Field	530-600	120	-30+40
Site 2- Downgradient[2]		-70-(+10)	70-150

* Positive values represent the amount over-applied relative to the agronomic rate estimate. Negative values represent under-application.

[1] Site 1 over-application may be underestimated for 1998 due to incomplete manure application records.

[2] For estimating agronomic rates, upgradient soil N is assumed to be the same as downgradient.

Site 2

The Site 2 estimated nitrogen application rate for 1998 was at or slightly below the agronomic rate for the site (Table 17). However, in 1999 the application was somewhat above that recommended for the field.

Missing Element in Agronomic Rate Estimate

A significant factor not considered in the WSU (1995) agronomic rate calculation method is organic nitrogen that mineralizes to nitrate in the soil. Fields that have received manure over a period of time can accumulate organic nitrogen that gradually mineralizes to nitrate, especially during the warm growing season. This pool of nitrate should be taken into consideration when planning appropriate manure application, especially where previous testing has shown high fall soil nitrate residual.

Comparison of Manure Application Methods

Uniformity

The more uniform the application of manure, the better for nutrient conservation and plant growth. At Site 1 the trailing gun method applies a large volume of water in a relatively short time. However, wind can affect the uniformity of application, and the circular spray distribution pattern does not apply manure equally to all areas. Margins of the field and areas near ditches are also not covered by the trailing gun due to set-back requirements. Other methods are used in these areas or inorganic fertilizer is applied. Variability estimates for irrigation-based systems are typically 15-34% (Bittman et al., 1999).

Wind is less of a concern for the tank spreader used at Site 2 than for the trailing gun, because manure is discharged closer to the ground. Margins of the field can be covered, and the linear pattern of application is more controllable than that of the trailing gun. Bittman et al. (1999) reported 21% variability with a conventional tank spreader.

Timing

Manure application began in March at Site 2, about one month earlier in the season than at Site 1. This was possible due to faster drying of the coarser soils and deeper water table at Site 2. The manure application schedule during this study is shown in Table 18. Manure is applied beyond the growing season at both sites. The latest application was in early October to mid-November.

Table 18. Manure application timing.

Site	1997	1998	1999
1	April 7-November 13	Unknown	May 5-October 1
2	NA	March 1-November 2	March 30-October 25

Residual nitrate and ammonia in the soil are available for leaching in the winter based on similar studies in southwest British Columbia (Paul and Zebarth, 1997; Kowalenko, 1987). Therefore, application of manure during the non-growing, high-precipitation season is not protective of groundwater.

Groundwater, Soil Pore Liquid, and Soil Quality

Groundwater

Nitrate+nitrite-nitrogen

Site 1

A statistical paired t-test indicated that nitrate+nitrite-N concentrations were significantly higher downgradient than upgradient at Site 1 at the 95% confidence level, excluding MW-7 (Table 19). The mean upgradient concentration was compared with each downgradient well result on 20-24 dates. The MW-7 data are considered erroneous due to effects of a nearby heavy solid manure application early in the study.

Table 19. Results of paired t-test for upgradient and downgradient groundwater nitrate+nitrite-nitrogen concentrations.

Monitoring well	Mean difference	Standard deviation of differences	n	t	df	alpha=0.05
Site 1						
MW-3	17.15	17.95	20	4.274	19	2.093
MW-4	18.00	15.97	24	5.523	23	2.069
MW-5	14.26	12.17	24	5.741	23	2.069
MW-6	12.11	6.82	24	8.701	23	2.069
MW-7	-0.41	5.19	24	-0.386	23	2.069
MW-8	20.12	12.85	24	7.668	23	2.069
MW-9	16.73	12.09	21	6.340	20	2.086
Site 2						
BW-3	3.89	5.65	21	3.16	20	2.086
BW-4	1.09	5.31	19	0.90	18	2.101
BW-5	1.77	4.76	19	1.62	18	2.101
BW-6	3.60	3.27	21	5.05	20	2.086

Higher downgradient nitrate+nitrite-N values in groundwater at Site 1 correspond with higher nitrogen application rates than upgradient during 1997 and 1998 in the North Field (Figure 16). If the same trend in nitrogen application occurred during the life of the site (6-8 years) as occurred during the study, the reservoir of organic nitrogen in the soil downgradient is probably somewhat higher than that upgradient. This organic nitrogen mineralizes gradually over time to nitrate which is available for plant uptake as well as leaching. Therefore, in addition to higher nitrogen application downgradient than upgradient, higher accumulated soil nitrogen probably contributes more nitrate to groundwater through leaching downgradient than upgradient.

At Site 1 the downgradient nitrate+nitrite-N medians for the North and South fields, 15.4 and 19.6 mg/L, respectively, exceeded the drinking water standard for nitrate-N of 10 mg/L (Chapter 264-290 WAC, 1999). Nitrate+nitrite-N is virtually equivalent to nitrate-N, because nitrite-N is usually negligible in groundwater.

At Site 1 maximum nitrate+nitrite-N concentrations in downgradient wells tended to occur in the winter, with peaks in November and December following the onset of winter precipitation as shown in Figure 29. Minimum concentrations usually occurred in the summer. This pattern is similar to the findings of Paul and Zebarth (1997) that inorganic nitrogen not used by the crop during the growing season leaches from the soil during the winter months due to heavy precipitation.

Site 2

No statistically significant difference was observed at Site 2 between upgradient and downgradient nitrate+nitrite-N concentrations in groundwater. The nitrogen application rate at the field upgradient of the site was probably below the agronomic rate during the study, although lack of soil nitrate information precludes an accurate assessment. The application rate at the downgradient field was close to the agronomic rate in 1998, and 25% above the recommended rate in 1999.

Despite nitrogen application close to or somewhat above the agronomic rate at Site 2, the median nitrate+nitrite-N concentration in both upgradient and downgradient wells, 12.4 and 10.6 mg/L, exceeded the drinking water standard.

At Site 2 only one large nitrate+nitrite-N peak was observed on December 9, 1998. This occurred following 9.1 inches of precipitation in November at Blaine, Washington (NOAA, 1999) and is higher than precipitation during the same period in 1999 (Figure 30). During the rest of the study, groundwater nitrate+nitrite-N concentrations were 7-15 mg/L. On December 9, 1998, however, all but one well at Site 2 was in the 17-42 mg/L range. This peak was followed by lower than normal nitrate+nitrite-N concentrations at most of the wells. The fact that most of the wells followed the same trend may indicate a substantial flush of residual nitrate from the soil, followed by dilution with water of lower nitrate concentration due to the large volume of recharge (Gerhart, 1986).

Comparison of Sites 1 and 2

Although the median nitrate+nitrite-N concentrations were higher at Site 1 than at Site 2, the difference is disproportional to the difference in nitrogen application rates. Over-application by 400-600 lb/acre/year of nitrogen for at least two years at Site 1 as shown in Table 17 would seem to have a large effect on nitrate concentrations in groundwater, compared to 0-150 lb/acre/year over-application at Site 2. However, the difference in downgradient median groundwater nitrate+ nitrite-N concentrations for the whole year was only 3-9 mg/L between the two sites. When only winter months (November through March) are considered, the difference in downgradient medians is more pronounced: 24.3 mg/L at Site 1 (excluding MW-7) compared to 9.8 mg/L at Site 2. Most recharge and leaching of solutes to groundwater occur during the winter months.

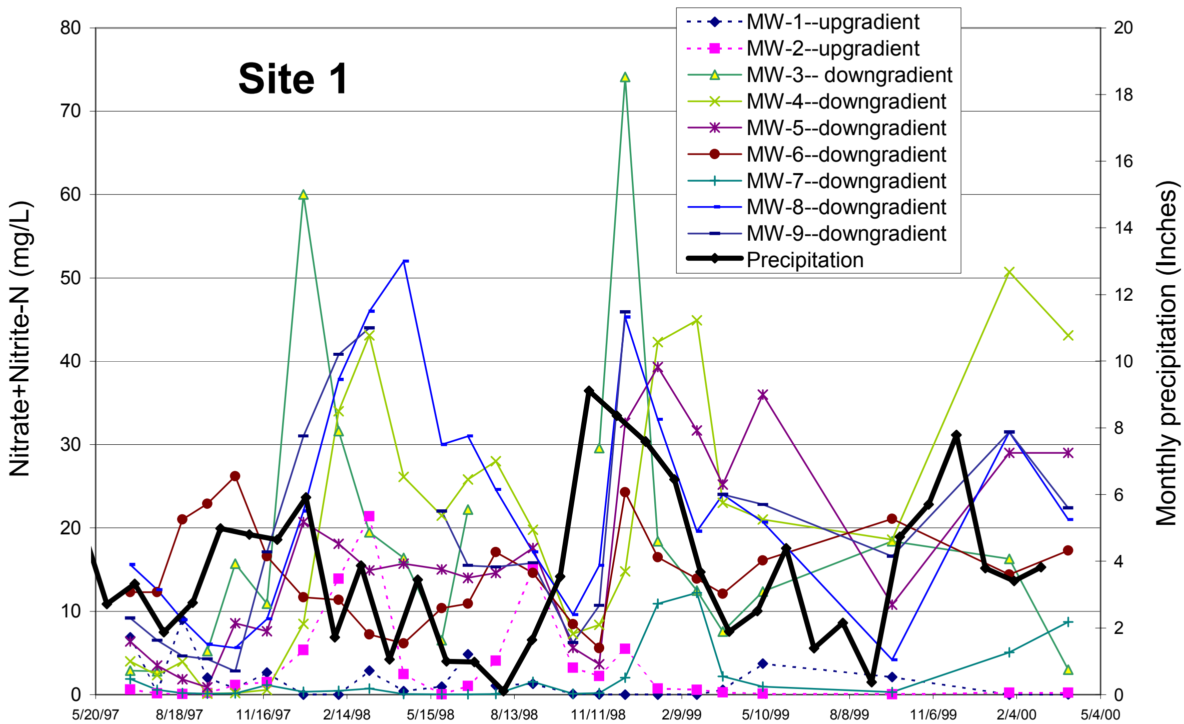


Figure 29. Nitrate+nitrite-N concentrations in monitoring wells at Site 1 and monthly precipitation at Blaine, Washington.

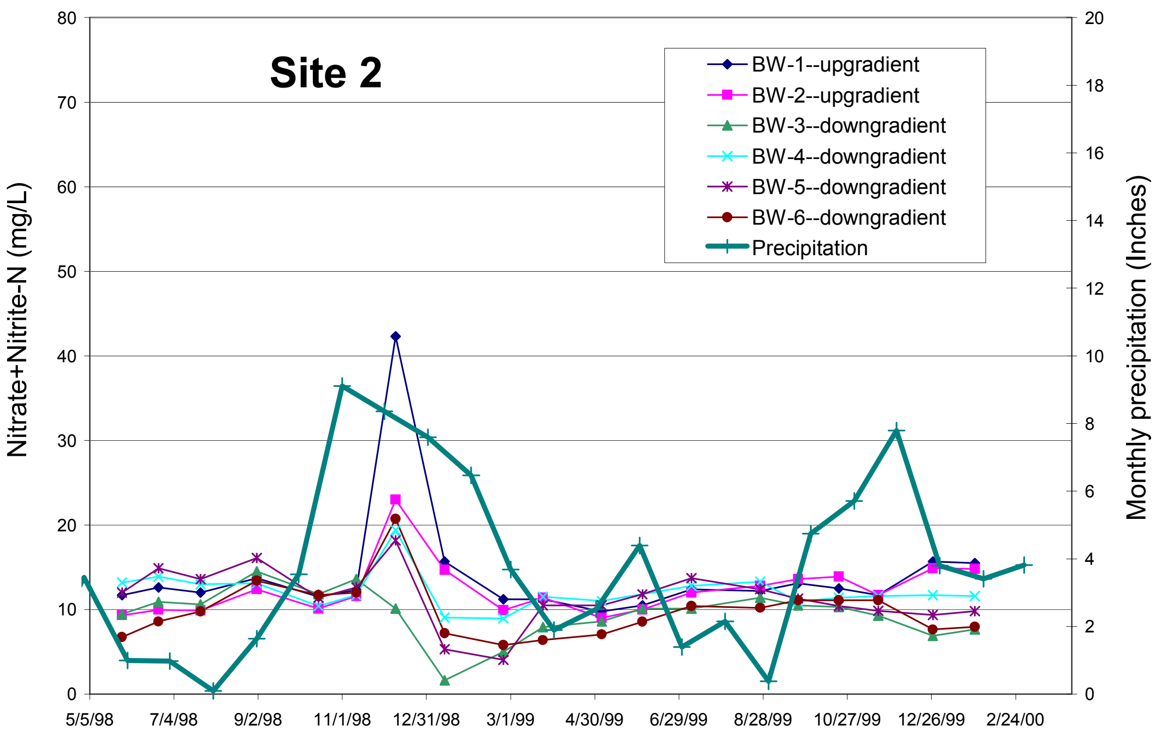


Figure 30. Nitrate+nitrite-N concentrations in monitoring wells at Site 2 and monthly precipitation at Blaine, Washington.

Median nitrate+nitrite-N values at both sites exceed the median for 230 samples collected in the Sumas Aquifer (Sumas-Blaine Aquifer plus the Canadian continuation of the aquifer) of 3.8 mg/L (Cox and Kahle, 1999). This indicates that groundwater at both sites in this study is affected by land uses, especially agriculture.

Ammonia-nitrogen

Ammonia-N concentrations were very low at both sites in the 20% of monitoring well samples where it was detected. The highest representative value at both sites is about 0.05 mg/L nitrogen. Most of the detections occurred during the spring-summer manure application season. Because a large fraction of the nitrogen in liquid manure is in the form of ammonia-N (64% in Site 1 samples), these low concentrations probably represent a portion of the applied manure ammonia-N that moved more quickly than typical. Precipitation or irrigation soon after application can hasten soil pore-liquid movement.

Organic nitrogen

The very low concentration of organic N found in groundwater indicates that most organic N is not moving to the water table at either site (Appendix L). Organic N typically mineralizes in the soil to ammonia-N and nitrate-N which are either taken up biologically or are susceptible to leaching with recharge water.

Chloride, total dissolved solids, and specific conductivity

Downgradient mean and median chloride, TDS, and specific conductivity values at Site 1 were about two times higher than the same values at Site 2 (Table 10). This difference is proportionally larger than the nitrate+nitrite-N difference between the sites and is consistent with other studies, indicating that denitrification causes significant loss of nitrogen from groundwater in low permeability soil where the water table is high and sufficient organic carbon is available (Nolan, 2000).

MW-7 at Site 1 may be an example of an especially active denitrification zone, as indicated by the relatively high concentrations of chloride and TDS compared to upgradient and even to other downgradient wells (Figures 19 and 21), while nitrate +nitrite-N concentrations were below 1 mg/L for most samples (Figures 17). Nitrate+nitrite-N concentrations in other downgradient monitoring wells were 5-74 mg/L.

A paired t-test of upgradient and downgradient chloride and TDS at Site 1 indicates that downgradient concentrations were significantly different from upgradient at all wells, except MW-4 at the 95% confidence level (Appendices P and Q). Downgradient chloride was higher than upgradient at all wells where there was a significant difference, except MW-3 where downgradient chloride was lower than upgradient. This tends to distinguish chloride at MW-1, -2, -3, and -4 as lower than that at the further downgradient wells (MW-5, -6, -7, -8, and -9) (Figure 19).

At Site 2 the upgradient and downgradient chloride, TDS, and specific conductivity means and medians were virtually the same. Concentrations were generally less variable and ranges were less than at Site 1 (Figures 20 and 22).

Dissolved oxygen

The dissolved oxygen concentration was very low in most wells at Site 1 on at least a few occasions. In several wells dissolved oxygen rarely if ever exceeded 1 mg/L, indicative of oxygen depletion due to bacterial activity associated with manure (Figure 23 and Table 11). When dissolved oxygen is absent and other conditions are suitable, microorganisms convert nitrate to nitrogen gas.

At Site 2 dissolved oxygen was in good supply with a minimum of 4.2 mg/L and medians both upgradient and downgradient of about 7 mg/L, a situation unfavorable for denitrification and indicative that bacteria from manure were not depleting oxygen.

Total organic carbon

Like low dissolved oxygen, TOC affects groundwater nitrogen chemistry and is needed by microorganisms for denitrification. TOC was above the detection limit in all samples at Site 1 and in 29% of samples at Site 2 as shown in Appendix M. TOC concentrations were highest at MW-6, and did not seem to have seasonal trends. However, the data record for TOC is too limited for basing conclusions about seasonality. No significant difference was found between upgradient and downgradient concentrations at either site.

Soil Pore Liquid

Soil pore-liquid quality is difficult to characterize due to variability over time and space, both in quantity and quality. Downward flow tends to be episodic and highly variable over a small area due to precipitation, irrigation, manure application, and soil properties. Soil pore-liquid data were collected to test the effectiveness of a limited effort to augment the groundwater analysis and provide an indicator of leaching below the root zone. The number of samplers used was insufficient to accurately characterize conditions at either site. Flux of water was not analyzed.

Suction lysimeters functioned well at Site 1 where the soil contained sufficient silt to allow relatively slow downward flow, compared to Site 2 where the soil is coarse and gravelly. Evidently flow through the vadose zone at Site 2 was either too rapid and/or too spatially variable to track with suction lysimeters.

Nitrate+nitrite-nitrogen

At Site 1 the median downgradient nitrate+nitrite-N concentration in the downgradient field, 15.3 mg/L, exceeded that upgradient as shown in Table 13. This is similar to the results for groundwater, and probably reflects the higher nitrogen application rate at the downgradient field. The median at Site 2, 24.6 mg/L, was greater than that at Site 1. However, the Site 2 value represents only 19 values, mostly from one sampler, compared to 47 samples from six samplers at Site 1. These values are concentrations and do not take into account the volume of water and, thereby, the total amount of nitrate leaching below the root zone.

Soil pore-liquid and groundwater nitrate+nitrite-N samples collected on the same date showed similar trends and concentrations at LY-1, LY-3, and LY–4 over time (Figure 26). However, no relationship was evident between samples from LY-2 and LY-5 and their corresponding monitoring wells. Monitoring well concentrations at MW-2 and MW-5 usually exceeded those in the lysimeters. The difference may be due to differences in lysimeter sampling representativeness that are affected by installation, soil structure, location relative to preferential flow paths, and other factors that are difficult to detect. Representativeness of lysimeter samples may also vary over time with some studies showing bias in newly installed samplers and others showing bias in older samplers (Debyle et al., 1988).

A major weakness of suction lysimeters is that, unless sampling is constant, important episodes of drainage water movement are missed. Ecology sampled on only one day per month without regard to irrigation or precipitation events, the main influences on recharge. Therefore, samples may not have been indicative of the bulk of water draining to the water table.

Significantly higher than normal nitrate+nitrite-N values occurred on three dates at Site 2 in lysimeter BL-6 (Appendix N). The highest value, 111 mg/L, occurred on December 9, 1998 at the same time that the monitoring wells also reached their peak concentrations. At Site 2 in the fall of 1998, the soil nitrate value, 109 lb/acre, indicated a “high” amount of nitrate residual according to WSU (1995). The heavy November precipitation (9.1 inches) probably induced movement of a slug of residual nitrate from the vadose zone to the groundwater.

Ammonia-nitrogen

Ammonia-N was generally less than 0.1 mg/L in the lysimeters at both sites with a few exceptions at Site 1. Ammonia-N concentrations were generally lower in groundwater than in soil pore liquid. Some of the ammonia in the soil pore liquid probably oxidizes to nitrate, and the remainder that reaches the water table probably becomes diluted and oxidized to nitrate if sufficient oxygen is available.

Organic nitrogen

Organic N concentrations were generally less than 1 mg/L in the upgradient lysimeters at Site 1 (Appendix L). Concentrations were 1-2 mg/L in LY-5 and in the first half of the study at LY-3 and LY-4. However, concentrations at LY-3 increased to 3-5 mg/L and at LY-4 to 13-14 mg/L in the last half of the study. The higher organic N concentrations indicate that organic material may have been moving more rapidly than previously.

At Site 2 soil pore-liquid organic N concentrations were generally less than 1 mg/L (Appendix L). On two of three dates when soil pore-liquid nitrate+nitrite-N was higher than normal, organic N was also higher than normal. On December 9, 1998 organic N was 189 mg/L in BL-6, and on May 6, 1999 it was 17.6 mg/L. Residual soil N was high (109 lb/acre) when recharge events occurred in November 1998, according to the soil nitrate analysis for the field. High organic N in soil pore liquid indicates a significant amount of organic N was available in the soil for leaching. The high organic N value at BL-6 on May 6, 1999, 17.6 mg/L, occurred following two applications of manure (50 lb/acre each) one month apart and after one inch of precipitation during the preceding 11 days. The third instance of high nitrate that did not result in high organic N in soil pore liquid occurred on March 25, 1999, before the first manure application of 1999.

Soil Nitrogen

Soil nitrate at Site 1

Soil nitrate concentrations in the top foot of soil were about equal in the North and South fields at Site 1 in 1997 (43 mg/kg) as shown in Figure 27. This coincided with an excess of about 500-600 lb/acre/year nitrogen applied relative to the estimated agronomic rate at both fields. Concentrations of nitrate increased at both sites in 1998, by 53% in the North Field and 40% in the South. The increase in the South Field occurred despite a decrease of 700 lb/acre nitrogen applied in 1998, compared to 1997 (Table 6a). This application was about 100 lb/acre/year above the agronomic rate (Table 17). The application rate in the North Field was about the same in 1997 and 1998.

The increase in soil nitrogen in the South Field, despite lower nitrogen application, could be due to plowing and aeration of deeper soils when the field was converted from grass to corn in 1998. This may have enhanced mineralization of organic nitrogen to nitrate. Different methods for soil sampling in 1998 and 1999, compared to 1997 (see Methods section), may also have biased the results somewhat.

In 1999 the nitrate concentration in the top foot of the North Field increased by an additional 25% over the 1998 increase, despite a 60% decrease in applied nitrogen (Figure 31b). This application rate was about the same as the estimated agronomic rate (Table 17).

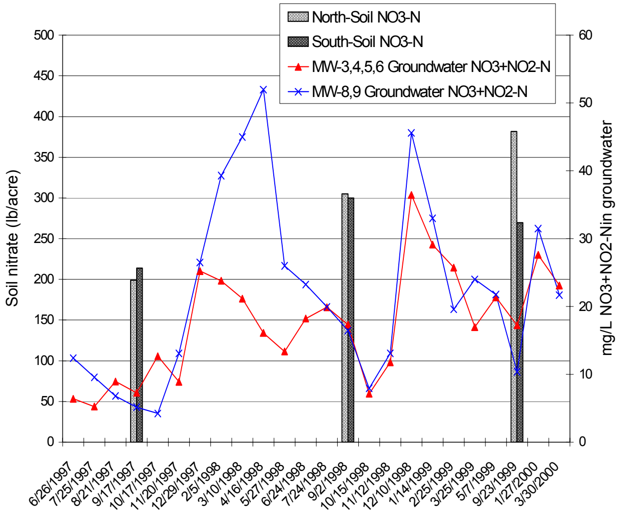
In the South Field, a 10% decrease in soil nitrate was found in 1999, the second year of lowered nitrogen application. The application rate was close to or below the agronomic rate in 1999 (Table 17). A lag between reduced nitrogen application rate and lower soil nitrate concentrations has been found in other studies, and is at least partially attributable to ongoing mineralization of organic nitrogen in the soil. Hall (1992) found a lag of 4-19 months in groundwater nitrate decreases following lowered application of manure nitrogen.

Soil nitrate at Site 2

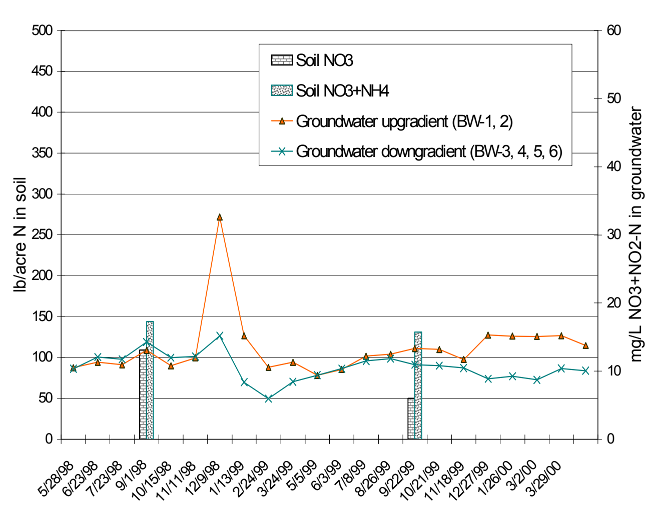
At Site 2 soil nitrate in the top one foot decreased by 54% from 1998 to 1999, although the total nitrogen application rate increased from close to the agronomic rate in 1998 to 70-150 lb/acre above the agronomic rate in 1999 (Figure 31c). This suggests that nitrate should have been higher in the soil in 1999 than in 1998, assuming that crop uptake was the same. Factors other than nitrogen application rate, such as crop uptake, may have had more influence in the soil nitrate concentration.

Site 1

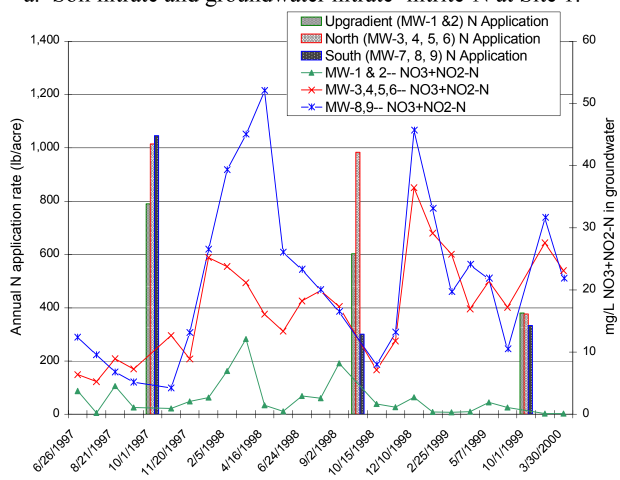
Site 2



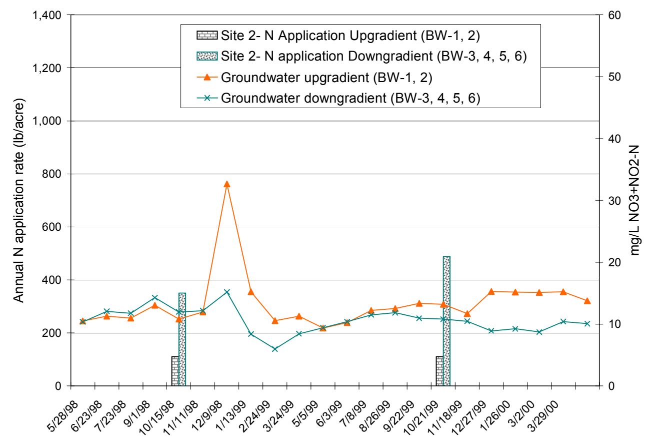
a. Soil nitrate and groundwater nitrate+nitrite-N at Site 1.



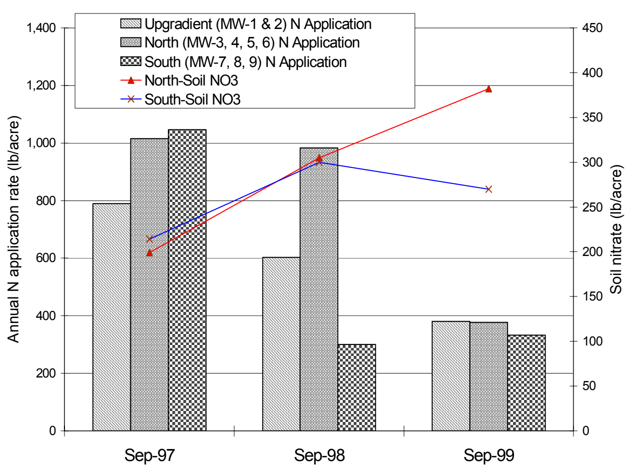
d. Soil nitrate and groundwater nitrate+nitrite-N at Site 2.



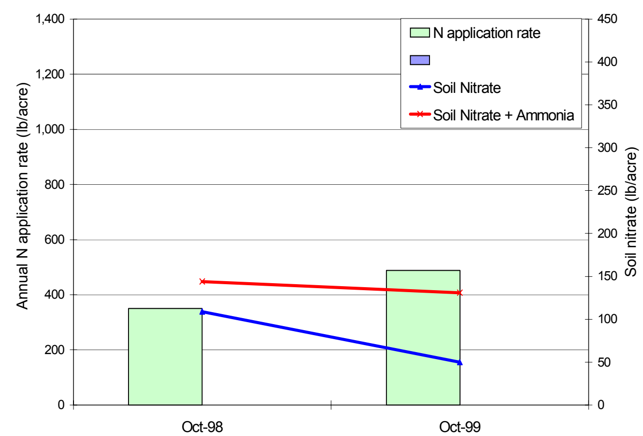
b. Nitrogen application rate and groundwater nitrate+ nitrite-Nat Site 1.



e. Nitrogen application rate and groundwater nitrate+nitrite-N at Site 2.



c. Annual nitrogen application rate and soil nitrate at Site 1.



f. Annual nitrogen application rate and soil nitrate at Site 2.

Figure 31. Nitrogen application rates, soil nitrogen, and groundwater nitrate+nitrite-N concentrations at Site 1(a, b, c) and Site 2 (d, e, f).

Soil nitrate values compared to criteria

Soil nitrate values in the top two feet of soil for 1997 were converted to lb/acre for comparison with "report card" criteria for nitrate in soils (Sullivan, 1994). The bulk density in the top one foot of soil was assumed to be 1.0 in the top one foot and 1.3 in the 1-2-foot strata. The lower bulk density in the top one foot takes into account the high organic matter content of volcanic ash in the local soils (Cogger, 2001). The nitrate concentration in mg/kg was then multiplied by 2.8 for the top foot and 3.5 for the second foot to convert to lb/acre as shown in Table 20 The nitrate values for the two depths were then added to get the total for the two-foot zone. Figure 32 shows the two-foot nitrate data in lb/acre compared with the report card criteria.

Table 20. Nitrogen in the top two feet of soil in September 1997 (lb/acre).

Soil nitrate	1997	1998	1999
Site 1- North Field[1]	199	305	382
Site 1- South Field[2]	214	300	270
Site 2[3]		109	50
Soil ammonia		1998	1999
Site 1- North Field[1]		61	94
Site 1- South Field[2]		71	76
Site 2[3]		35	81
Total inorganic nitrogen		1998	1999
Site 1- North Field[1]		366	476
Site 1- South Field[2]		371	346
Site 2[3]		144	131

[1] Monitoring wells in the area are MW-3, 4, 5, 6.
[2] Monitoring wells in the area are MW-7, 8, 9.
[3] Monitoring wells in the area are BW-1 through BW-6.

The 1997 results represent a composite of 12 subsamples, six at one foot and six at two feet. In 1998 and 1999, each sample represents eight subsamples collected at one-foot depth and composited. The concentration in the second foot was estimated as the same fraction of one-foot sample as found in 1997.

Because there were no data for the 1-2-foot interval for 1998-1999 and all samples were collected between September 1 and 23, it was assumed at Site 1 that the difference between the 1- and 2-foot samples in 1997 was proportional to the difference in 1998 and 1999. Concentrations for nitrate at two-feet in 1998 and 1999 were therefore estimated as the same percentage of the concentration in the top foot as was found in 1997 (50% for the North Field and 60% for the South Field).

The assumption that the percentage of nitrate in the first and second foot was consistent from year to year may have biased the 1998 and 1999 results somewhat high, because precipitation just prior to the 1997 sampling may have transported more of the residual nitrate downward than in 1998 and 1999. Blaine received one inch of rain in the three days prior to sampling in 1997, while no precipitation was reported for at least three weeks prior to sampling in 1998 and 1999.

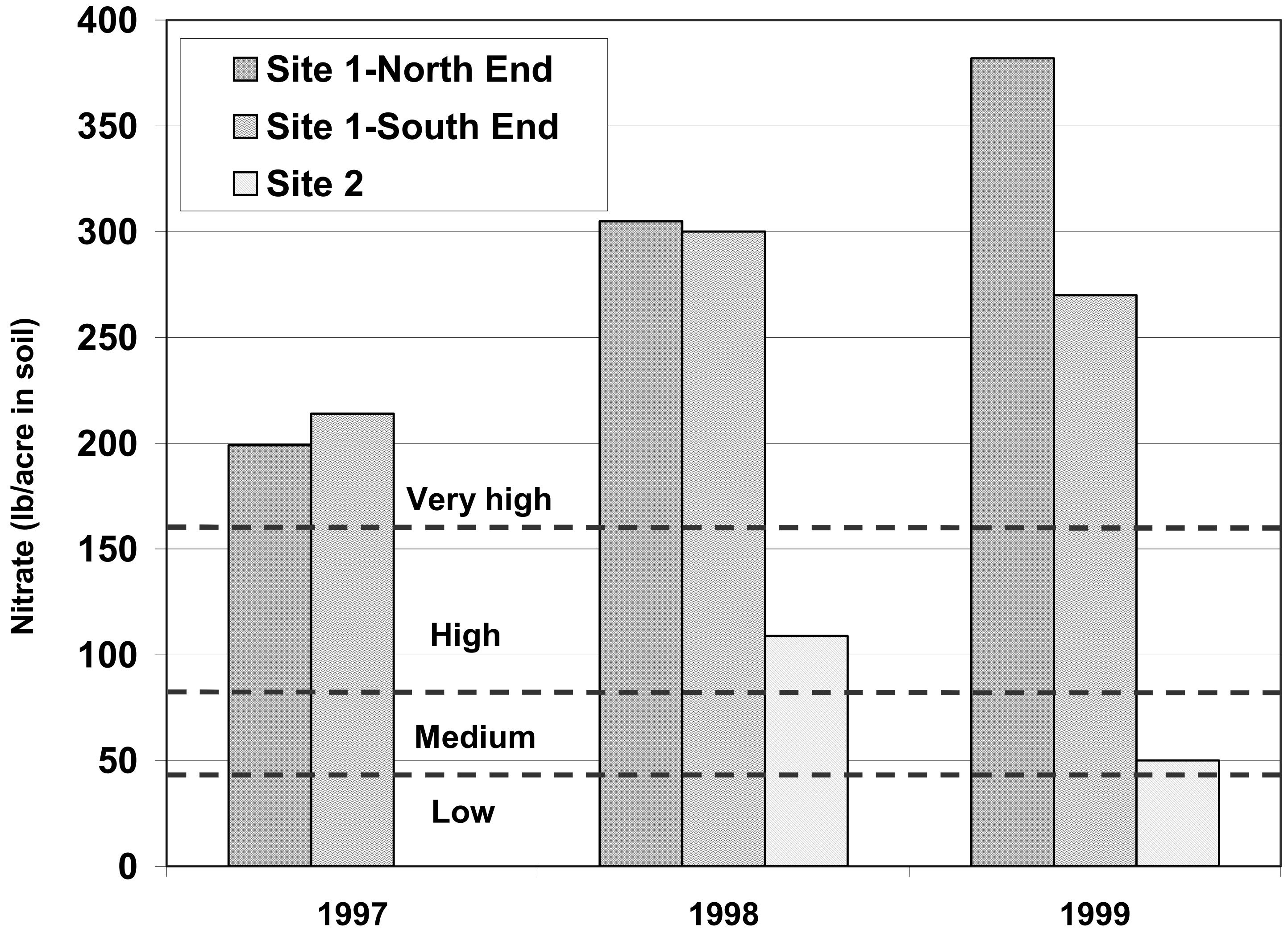


Figure 32. Fall soil nitrate values for 1997-99 for the top two feet. Results for 1998 and 1999 at two-foot depth are projected based on 1997 results. Low, medium, and high criteria are from Sullivan (1994).

For Site 2 it was assumed that the nitrate concentration at 1-2 feet was the same as the fraction of the top foot as at Site 1 (55%). The 0-1-foot nitrate concentrations at Site 2 were therefore multiplied by 0.55 to estimate the 1-2-foot concentrations. The Site 2 concentrations for the top two feet were then converted to lb/acre using the same method as used for the 1997 samples at Site 1.

At Site 1 all 2-foot soil nitrate values exceeded the "very high" criterion of 160 lb/acre. The values exceeded the criterion by 40-220 lb/acre. The maximum estimated nitrate concentration, 380 lb/acre, was 2.5 times the criterion. When soil nitrate exceeds the "very high" limit, Sullivan (1994) recommends major farm management changes and consultation with a qualified agronomist. SCS (1993) suggests considering moving manure or other high nitrogen organic inputs off the farm when the soil nitrate exceeds 160 lb/acre.

Site 2 soil nitrate was in the "high" range (80-160 lb/acre) in 1998. When soil nitrate is in this range, Sullivan (1994) recommends decreasing nitrogen application rates or improving management of water and other nitrogen inputs to increase crop nitrogen removal. In 1999 soil nitrate at Site 2 decreased to the "medium" range. Sullivan (1994) recommends continuing the same nitrogen application rate for medium range soil. Similar to Site 1, the soil nitrate concentrations may not represent the maximum soil nitrate values for the year, because the last manure application occurred one to two months after soil sampling (Appendix I).

In similar studies most of the nitrate in the soil in the fall is lost before the next spring. Paul and Zebarth (1997) found that essentially all the nitrate in soil beneath a manured field was lost before the following spring, 17% to denitrification and the remaining 83% to groundwater leaching.

Sullivan et al. (2000) recommend applying up to one-third of annual manure loading to grass fields in the late fall and another application in early spring, in order to maximize the first cutting yield. However, their results indicate only slightly higher yield in the first cutting after fall and early spring application compared to early spring only. Late fall manure application does not seem to be agronomically justified where (1) the surficial aquifer is extremely vulnerable to nitrate leaching, (2) the surficial aquifer already exceeds the drinking water standard for nitrate in many locations, and (3) fall application of manure may not be critical for good crop growth.

Soil ammonia and total inorganic nitrogen

The residual soil ammonia concentrations (Figure 28) were converted to lb/acre using the same method as used for soil nitrate. Soil ammonia is not included in "report card" evaluation of soil or in agronomic rate calculations (WSU, 1995). However, Paul and Zebarth (1997) and Kowalenko (1987) found that virtually all ammonia-N in the soil profile mineralized to nitrate within three to five weeks of manure application in cornfields located in nearby southern British Columbia. The leaching process beneath a grass field may be slower than that beneath a cornfield, but nonetheless significant.

If soil ammonia concentrations, which were 20-60% of soil nitrate, were added to the nitrate concentrations, the resulting total inorganic nitrogen concentrations in the soil would be more representative of the total amount of nitrogen likely to leach below the root zone. The total inorganic nitrogen (ammonia plus nitrate) was 370-470 lb/acre at Site 1 and 130-145 lb/acre at Site 2 in 1998-1999 (Table 20). Ammonia concentrations in soils at both sites in this study would fall into the medium to high range according to the "report card" criteria.

Relationships between nitrogen application rate, soil nitrate, and groundwater nitrate+nitrite-nitrogen

Site 1

Changes in nitrogen application rate at Site 1 provide an opportunity to evaluate the connection between application rate and nitrate concentrations in soil and groundwater. In the South Field, the decrease from 800 lb/acre/year over the agronomic rate in 1997 to 120 lb/acre/year in 1998 and close to the agronomic rate in 1999 coincided with a soil nitrate increase in 1998 and a slight decrease in 1999 (Figure 31a,b,c). The soil nitrate value increased by 80 lb/acre the first fall after decreased nitrogen application. Mineralization of organic nitrogen was probably enhanced when the field was plowed and replanted in 1998. Soil nitrate decreased 30 lb/acre the second year of lowered nitrogen application when the application rate was close to the agronomic rate.

Groundwater nitrate+nitrite-N concentrations during the non-growing season (November-March) when concentrations usually peaked in the South Field, however, showed no improvement in terms of mean nitrate+nitrite-N concentration at the 90% confidence level using the Student's t-test following the reduction of nitrogen application by 500 lb/acre/year. The mean non-growing season nitrate+nitrite-N concentrations were 31.0 mg/L in 1997, 28.3mg/L in 1998, and 26.6 mg/L in 1999.

Decreased nitrogen application rate in the North Field in 1999, where grass was grown continuously during the study, likewise did not show an immediate effect on soil nitrate or groundwater nitrate+nitrite-N concentrations (Figure 31a). Soil nitrate concentrations increased each year (Figure 31b,c). The non-growing season mean nitrate+nitrite-N values in groundwater when the application rate was around 1,000 lb/acre/year were 19.8 mg/L and 25.8 mg/L. The winter following nitrogen application at only 300 lb/acre (close to the agronomic rate), the mean groundwater nitrate+nitrite-N was 25.4 mg/L Because the application rate decrease occurred near the end of the study, there was not enough time to evaluate long-term effects.

Erickson (2001) also found that soil nitrate and groundwater nitrate+nitrite-N concentrations were not necessarily correlated at fields receiving heavy applications of dairy manure in Thurston County, Washington. Soil nitrate at one field increased from 88 to 270 lb/acre from one year to the next during the non-growing season, while nitrate+nitrite-N in groundwater decreased from 37 to 29 mg/L. The nitrogen application rate on the field was about 490 lb/acre/year above the agronomic rate during both years.

Site 2

Small changes in nitrogen application rate that are close to the agronomic rate range did not seem to affect either soil total inorganic nitrogen or groundwater nitrate+nitrite-N concentrations at Site 2, as shown in Figure 31d,e,f. An increase of 140 lb/acre/year of nitrogen applied in 1999 compared to 1998 coincided with a decrease in soil nitrate but an increase in soil ammonia, such that the total inorganic nitrogen concentration (nitrate plus ammonia) was about the same both years. Downgradient groundwater nitrate+nitrite-N concentrations during the non-growing season of 1998 and 1999 (10.0 mg/L in 1998-99 and 9.5 mg/L in 1999-2000) likewise were not statistically different at the 95% confidence level following the application increase when the Student's t-test was applied.

Conclusions

Hydrogeology

The two study sites are underlain by shallow, unconfined groundwater that is susceptible to contamination from surface activities. The top five feet of material at Site 1 consists of silty sand and fine to medium grained sand that becomes somewhat coarser with depth. The materials at Site 2 consist of mixed sand and gravel. The coarser materials at Site 2 allow more rapid flow of percolating water to the water table than at Site 1. However, the shallower depth to water at Site 1 probably offsets the slower flow rate.

Plant uptake is the main loss mechanism for nitrate at Site 2, while the high water table and lower permeability conditions at Site 1 are favorable for denitrification, as well as plant uptake, during much of the year.

Groundwater movement is roughly 13 times faster at Site 2 (4 feet/day) than at Site 1 (0.3 foot/day), due to the higher hydraulic conductivity at Site 2 (300 feet/day) compared to Site 1 (60 feet/day). The flatter groundwater gradient at Site 1 than at Site 2 also contributes to the velocity difference. The more rapid flow of groundwater below Site 2 does not allow for as much accumulation of nitrate and manure-related solutes along the flowpath as at Site 1.

Groundwater flow was southeast toward the Nooksack River at both sites, although at Site 1 flow was highly affected by summer pumping of an irrigation well in the northeast corner of the field. The resulting flow direction at Site 1 was toward the pumping well during much of the year. This may divert a portion of groundwater and associated nitrate that would have been moving in the southward direction.

A surface drain bisecting the downgradient field at Site 1 may also have directed a portion of groundwater flow away from the south half of the field, resulting in less nitrogen from the upgradient North Field being transported to the South Field.

Nitrogen Application Rate

The nitrogen application rate, which includes manure and inorganic fertilizer, exceeded the agronomic rate at Site 1 by a factor of 2 in 1997, and ranged from below the agronomic rate to over 500 lb/acre above in 1998 and 1999. At Site 2 the nitrogen application rate ranged from below the agronomic rate to 140 lb/acre/year above the agronomic rate in 1998.

Groundwater Quality

Nitrate+nitrite-N values were statistically higher downgradient than upgradient at Site 1, where the nitrogen application rate had substantially exceeded the agronomic rate. No statistical difference was observed between upgradient and downgradient nitrate+nitrite-N values at Site 2.

Median downgradient nitrate+nitrite-N concentrations at Site 1 (15.4 mg/L in the North Field and 19.6 mg/L in the South Field) exceeded the drinking water standard of 10 mg/L for nitrate-N. However, the upgradient median (0.75 mg/L) was far below the standard. Both upgradient and downgradient median nitrate+nitrite-N concentrations at Site 2 (12.4 and 10.6 mg/L) exceeded the drinking water standard for nitrate-N.

The mean non-growing season (November-March) nitrate-nitrite-N concentrations at Site 1 were 31.0 mg/L in 1997-98, 28.3 mg/L in 1998-99, and 26.6 mg/L in 1999-2000. At Site 2 the concentrations were 10.0 mg/L in 1998-99 and 9.5 mg/L in 1999-2000.

Despite substantially reduced nitrogen application at Site 1 for two years in the South Field and one season in the North, groundwater nitrate+nitrite-N concentrations were not lower during the non-growing seasons. Fall soil nitrogen concentrations likewise remained very high at both sites, with a slight decrease the second year at the South Field. A likely reason for the delay in groundwater and soil improvement is ongoing mineralization of accumulated organic nitrogen. Also, the application rate was still at least 100 lb/acre above the agronomic rate the first year of decreased application.

Conditions were favorable for denitrification at Site 1 but not at Site 2. Median groundwater dissolved oxygen concentrations were below 1 mg/L, TOC median values were 3.4-3.9 mg/L, and the water table was close to the surface. The median dissolved oxygen concentration in Site 2 wells was 7.0 mg/L, TOC concentrations were mostly below detection, and the water table was greater than 15 feet below ground surface.

The median downgradient nitrate+nitrite-N for Site 1 is greater than that for Site 2. However, the difference in medians, 5-9 mg/L, is disproportional to the difference in nitrogen application rates (2-3 times higher at Site 1 than Site 2 on grass). The relatively small difference in groundwater nitrate+nitrite-N concentration may be partially due to denitrification at Site 1 and not at Site 2. Studies conducted under similar conditions have indicated 10-17% nitrogen loss due to denitrification. Larger seasonal fluctuations in nitrate+nitrite-N concentrations at Site 1 than at Site 2 also tend to mute the difference in medians.

The median nitrate+nitrite-N values in the monitoring wells were three to five times greater than the aquifer-wide median of 3.8 mg/L, indicating substantial land use effects.

Similar to nitrate+nitrite-N, Site 1 downgradient chloride and TDS values were statistically different from upgradient values (except chloride at MW-4). No statistical difference was observed between Site 2 upgradient and downgradient values.

Soil Nitrogen

High nitrate concentrations in the top one foot of soil at Site 1 did not decrease immediately following a reduction in applied manure of 600-700 lb/acre/year. In the South Field, however, soil nitrate decreased by about 10% after two years of nitrogen applied at close to the agronomic rate.

Estimated residual nitrate in the top two feet of soil at Site 1 was 25-240% higher than the "very high" criterion (160 lb/acre) in Sullivan (1994).

Assuming the estimate for nitrate in the second foot of soil is valid, residual nitrate in the top two feet of soil at Site 2 was in the "high" range in 1998 (80-160 lb/acre) and in the "medium" range (40-80 lb/acre) in 1999. The "high" value was observed following nitrogen application at or below the agronomic rate, while the "medium" value was observed following application of about 100 lb/acre more than the estimated agronomic rate, the reverse of what would be expected. However, the soil total inorganic nitrogen concentrations (including ammonia) for both years were about the same.

A two-year time lag occurred between lowered nitrogen application at the South Field at Site 1 and slightly lower (10%) nitrate concentration in soil.

Soil ammonia concentrations in the fall were substantial at both sites. The estimated two-foot residuals for ammonia were 61-96 lb/acre at Site 1 and 35-81 lb/acre at Site 2.

The total of residual soil nitrate plus ammonia nitrogen was approximately 370-470 lb/acre at Site 1 and 130-140 lb/acre at Site 2. Similar studies in British Columbia found that virtually all nitrate and ammonia in the soil was lost in the winter, most to leaching (about 80%) and some to denitrification (about 20%). Soil ammonia was a substantial component of the total inorganic nitrogen in this study and is considered available for leaching during the winter after oxidizing to nitrate, although it is not included in fall "report card " soil testing.

Fields receiving very heavy manure application can rapidly become major, long-term sources of nitrate to groundwater. Site 1 had been in use for only six years before this study and, because manure application had exceeded the agronomic rate, organic nitrogen presumably provided an ongoing source of mineralizable nitrogen, even after application was decreased substantially. Median groundwater nitrate concentrations beneath the field were 1.5 to 2 times the drinking water standard and significantly higher than upgradient. On the other hand, at Site 2 where nitrogen had been applied at rates close to the agronomic rate for 20 years, soil nitrate concentrations were only somewhat higher than recommended in Sullivan (1994). Groundwater nitrate concentrations at Site 2 were also not higher than those upgradient.

Soil Pore Liquid

Suction lysimeters were reliable at Site 1 presumably due to finer textured soils, but only one of six lysimeters in the coarser textured soils at Site 2 functioned reliably. Infrequent sampling did not allow for meaningful evaluation of soil pore liquid.

Median soil pore-liquid nitrate+nitrite-N concentrations at Site 1 were similar to those in groundwater. The median in the North and South fields (LY-3, -4, -5, -6) was 15.3 mg/L, while the median in LY-1 and -2 was 0.82 mg/L. The Site 2 median concentration was 24.6 mg/L, based mainly on one sampler.

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Recommendations

- Late fall application of manure to grass fields over the Sumas-Blaine Aquifer should be discouraged. Plants have little opportunity to take up nitrogen before fall and winter rains begin leaching nitrate and ammonia below the root zone.

- Farmers should be assisted in monitoring soil nitrate and ammonia, and adjusting manure and fertilizer applications accordingly.

- Farmers should be encouraged and assisted in spring soil sampling for mineralizable nitrogen. Manure application rates should take this pool of available nitrate into account to decrease loss of nitrate to groundwater.

- In order to accurately determine actual nitrogen application rates, farmers should measure manure total nitrogen concentrations and the volume applied.

- Continue to educate local dairy operators and the public about the fact that overapplication of nitrate causes groundwater quality degradation, directly contributing to long-term nitrate contamination in their very vulnerable drinking water source.

- Develop alternatives to over-application of manure to cropland. Encourage dairies to more fully embrace sustainable practices that optimize crop production for cattle nutrition.

- For future studies of manure impacts on groundwater, soil, and soil pore liquid, application rates should be measured accurately, and total nitrogen (ammonia, nitrate, and organic nitrogen) should be analyzed in manure from each application.

- Evaluate use of tracers to compare nitrogen loss between the time manure is applied and the residual mixes with groundwater.

- Estimate the impact of high nitrate groundwater on surface water in the Nooksack River basin in terms of ammonia, nitrate for algal growth, and resulting reduction in dissolved oxygen.

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Appendices

Appendix A. Construction logs for monitoring wells.

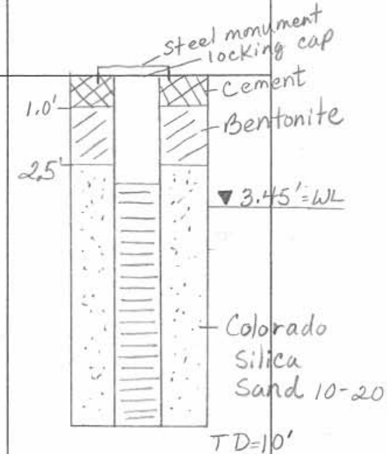
MW-1 (Well I.D.: AAF-282)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drill
Date Completed: 5/20/97
Altitude Ground Surface: 127.56 feet

GEOLOGIC LOG	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)
GROUND SURFACE				0
Brown silty SAND to sandy SILT, with gravel. Gravelly, till-like material		6/50		
Silty SAND to sandy SILT with gravel. Wet.				5
		50 for 4"		
				10
		65 for 4"		
				15

AS-BUILT DATA

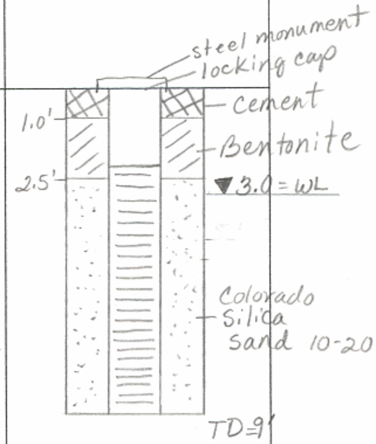


MW-2 (Well I.D.: AAF-281)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drill
Date Completed: 5/20/97
Altitude Ground Surface: 127.01 feet

GEOLOGIC LOG	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)	AS-BUILT DATA
GROUND SURFACE				0	
Topsoil orange and dark brown SILT. Below topsoil, dark brown SILT with sand and gravel to 1/2."					
Medium to coarse grey SAND and fine gravel to 1/4." wet at 7.5.' Wet silt lens about 2" wide in 10' sample		8/15/20 for 1½" 6/38/35		5	
		4/28/20 for 1"		10	
				15	



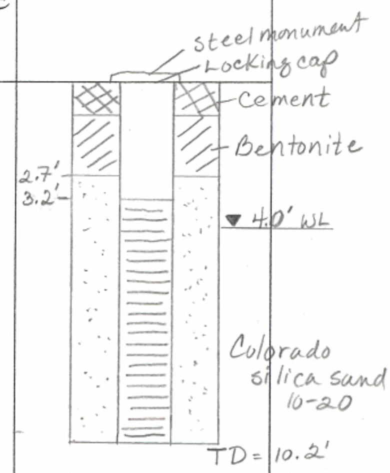
MW-3 (Well I.D.: AAF-286)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drilling
Date Completed: 5/20/97
Altitude Ground Surface: 126.43 feet

GROUND SURFACE

Description	d_{10} (mm)	Blow Counts		Depth (feet)	AS-BUILT DATA
Topsoil dark brown SILT, damp with gravel to 1." Below topsoil sandy SILT w/ small amount of sand and gravel. Wet at 4.' Drilled to 12.'	0.075	30/50 for 5.5"		0	
	0.04	9/30/50 for 3.5"		5	
	0.04	4/8/20		10	
				15	



MW-4 (Well I.D. : AAF-285)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drilling
Date Completed: 5/21/97
Altitude Ground Surface: 125.00 feet

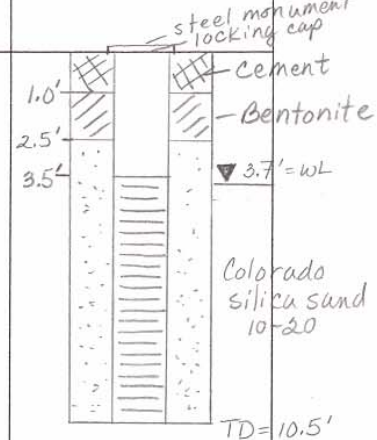
GROUND SURFACE

Topsoil brown and orange, cloddy SILT, mottled. Below topsoil brown and grey SILTY SAND with fine gravel.

wet, coarse, grey SAND with gravel. Drilled to 12' to prevent heaving.

d_{10} (mm)	Blow Counts	Depth (feet)
0.019		0
0.055	9/16/16	
0.25	10/40/50 for 5"	5
0.16	30/50 for 4½"	
0.18	30/50 for 5½"	10
		15

AS-BUILT DATA



MW-5 (Well I.D.: AAF: 283)

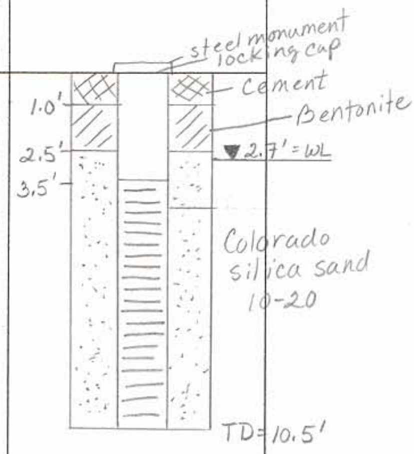
GEOLOGIC LOG

Drilling Contractor: Tacoma Pump & Drilling
Date Completed: 5/12/97
Altitude Ground Surface: 125.33 feet

GROUND SURFACE

Description	d_{10} (mm)	Blow Counts		Depth (feet)
				0
Fine to medium SAND, grey, with silty layer at 5 feet. Small amount of silt at 2.5 feet and some gravel at 7.5 feet.		7/14/20		
Heaving sand in logged boring necessitated re-drilling 4 feet east. First hole abandoned up to 3 feet and lysimeter installed.		5/15/30 for 2"		5
		12/28/50 for 4"		
		5/14/18		10
				15

AS-BUILT DATA



MW-6 (Well I.D. : AAF: 284)

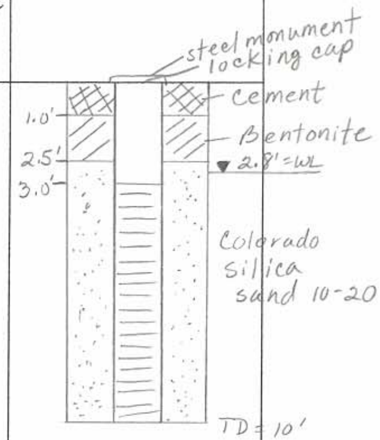
GEOLOGIC LOG

Drilling Contractor: Tacoma Pump & Drilling
Date Completed: 5/21/97
Altitude Ground Surface: 125.74'

GROUND SURFACE

Description	d_{10} (mm)	Blow Counts		Depth (feet)
Topsoil brown SILT, moist. Below topsoil fine to medium grey SAND with silt at 2.5 feet. No silt deeper.				0
		6/10/20		
		8/12/24		5
Heavy rain storm began in the middle of drilling and property owner asked that we remove vehicles from the field immediately. Hence fewer details on boring.				10
				15

AS-BUILT DATA



MW-7 (Well I.D.: AAF-278)

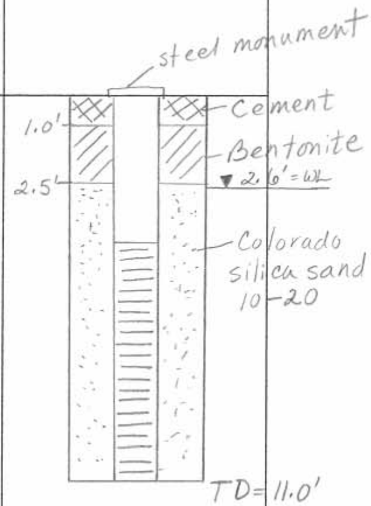
GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drilling
Date Completed: 5/22/97
Altitude Ground Surface: 122.90 feet

GROUND SURFACE

Description	d_{10} (mm)	Blow Counts		Depth (feet)
				0
Dark brown SILT turning to SILTY SAND with depth.		8/11/14		
Medium to coarse SAND with gravel (10%) to 1/2."		8/20/30 for 2"		5
		5/24/50 for 5"		
				10
				15

AS-BUILT DATA



MW-8 (Well I.D.: AAF-280)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump + Drilling
Date Completed: 5/22/97
Altitude Ground Surface: 123.44 feet

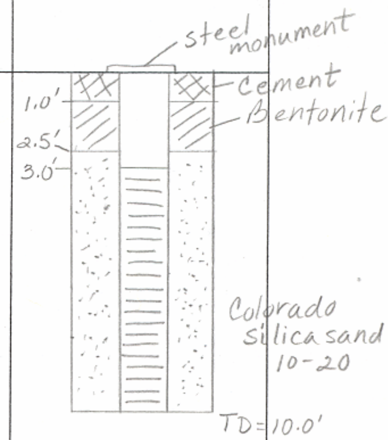
GROUND SURFACE

Topsoil dark brown SILT with sand and gravel. Below topsoil, grey SAND with gravel (10-25%) to 1" diameter.
Wet at 5.'

Drilled to 11.' Water added to prevent heaving.

d_{10} (mm)	Blow Counts	Depth (feet)
		0
	10/14/18	
	14/30/50	5
	30/50 for 4"	
	10/20/50 for 5.5"	10
		15

AS-BUILT DATA



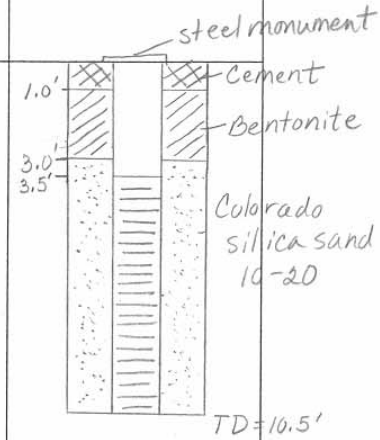
MW-9 (Well I.D.: AAF-279)

GEOLOGIC LOG

Drilling Contractor: Tacoma Pump & Drilling
Date Completed: 5/22/97
Altitude Ground Surface: 123.01 feet

GROUND SURFACE	d_{10} (mm)	Blow Counts		Depth (feet)
	0.09			0
Light brown SANDY SILT, compact, moist.				
	0.07	4/12/22		
Fine to medium grey SAND with gravel and occasimal silt. Gravel 10-25%, up to 1" diameter.	0.18	10/35/38		5
Added water to prevent heaving.	0.16	40/50 for 3"		
	0.24	15/15/18		10
				15

AS-BUILT DATA



BW-1 (Well ID: AAF-272)

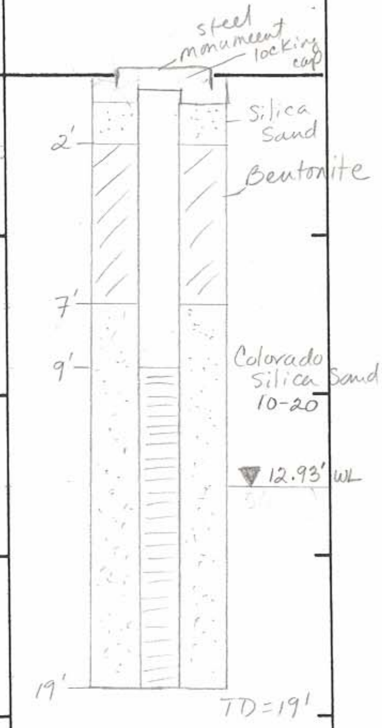
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump + Drill
DATE COMPLETED: 5/11/98
ALTITUDE GROUND SURFACE: 129.46 ft

GROUND SURFACE (0)

Geologic Log	d_{10}	Blow Counts	Graphic Log (depth)
Poorly sorted fine to coarse SAND and gravel to 1/2" diameter.		30/40/31	
	0.27	23/21/19	5'
Coarse SAND and gravel — granitic gravel to 1 1/2", mostly pea gravel and sand.	0.42	23/50 for 5 inches	
		50 for 5 inches	10'
same as above, WET	0.16	23/31/40	
	0.50	11/23/30	15'
	0.32		
		9/30/50	20'

AS-BUILT DATA



BW-2 (Well ID: AAF 275)

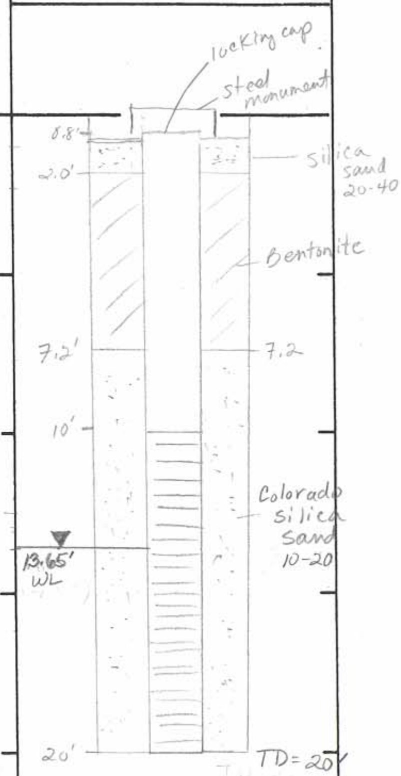
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump + Drill
DATE COMPLETED: 5/12/98
ALTITUDE GROUND SURFACE: 130.00ft

GROUND SURFACE

Description	Blow Counts	Graphic Log (depth)
		0
Brown silty SAND with gravel to 1" diameter. Minor clay 5'-7.5' from grab sample.	8/11/10	5'
Light grey, fine to medium grain SAND with minor amount of gravel – SAND well sorted. (Grab sample more gravel: 25% and brown clay-silt 5% or less.)	25/50 for 3"	10'
Light grey, very poorly sorted fine to coarse SAND with 20-25% gravel, pea sized to 1½" diameter.	27/30/30	15'
	30/50 for 3"	20'

AS-BUILT DATA



BW-3 (Well ID: AAF-274)

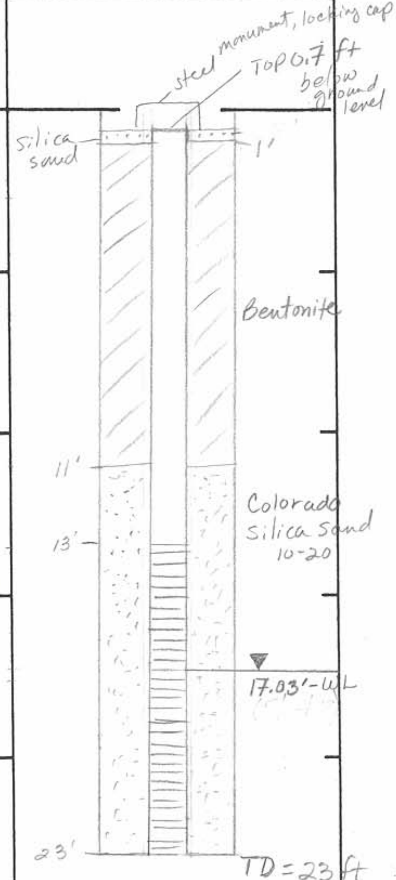
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump + Drill
DATE COMPLETED: 5/12/98
ALTITUDE GROUND SURFACE: 130.07 ft

— GROUND SURFACE —

Description	Blow Counts	Graphic Log (depth)
		0
Brown SAND very poorly sorted grading to coarse, grey SAND with 5% gravel to 1" diameter. Small fraction of silt.	4/11/23	5'
Same as above but 20% gravel.	20/50 for 5"	10'
	20/50 for 6"	15'
SAND same as above but gravel 40% up to 2" diameter		
SAND same as above with small amount of gravel to 1/2" diameter.	9/31/50 for 4"	20'
		25'

AS-BUILT DATA



BW-4 (Well ID: AAF-273)

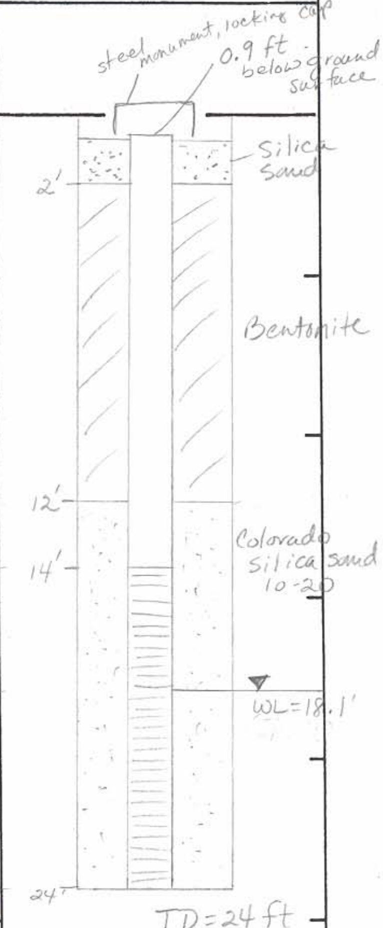
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump + Drill
DATE COMPLETED: 5/12/98
ALTITUDE GROUND SURFACE: 129.20 ft

GROUND SURFACE

Geologic Log	Blow Counts	d_{10}	Depth (GRAPHIC LOG)
Brown silty SAND			0
Very poorly sorted fine- to coarse-grained SAND with gravel. (Grab sample: gravel ranging from pea-sized to 2" diameter.)	20/25/27	0.25	5'
	28/50 for 6"	0.42	10'
Grey SAND same as above with 20% gravel raning from pea-sized to. ½" diameter. (Grab sample: gravel pea-sized to 2" diameter.)	7/10/15	0.27	15'
Same as above except gravel pea-sized.			
	10/15/35	0.28	20'
Fine-grained grading to very coarse-grained SAND and pea gravel (about 10% gravel)			
			25'

AS-BUILT DATA



BW-5 (Well ID: AAF-276)

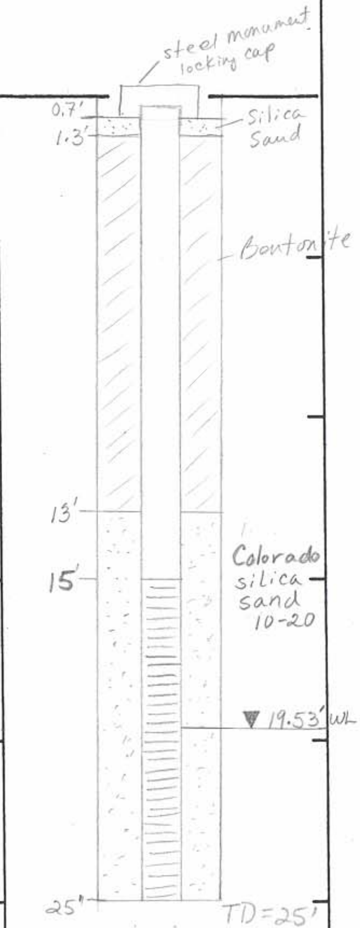
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump + Drill
DATE COMPLETED: 5/13/98
ALTITUDE GROUND SURFACE: 129.14 ft

GROUND SURFACE

Graphic Log (depth)	Geologic Log	Blow Counts
0	Dirty, very poorly sorted SAND with silt and gravel to 1½" diameter. About 10% silt; very fine to very coarse SAND 70%; gravel 20%.	
5'		16/25/33
10'	Same as above but gravel up to 2"	50/50 for 3"
15'		35/50 for 3"
20'	Grey, clean very coarse SAND with gravel, 30%, to 2½" diameter.	21/50 for 5"
25'		

AS-BUILT DATA



BW-6 (Well I.D. AAF-277)

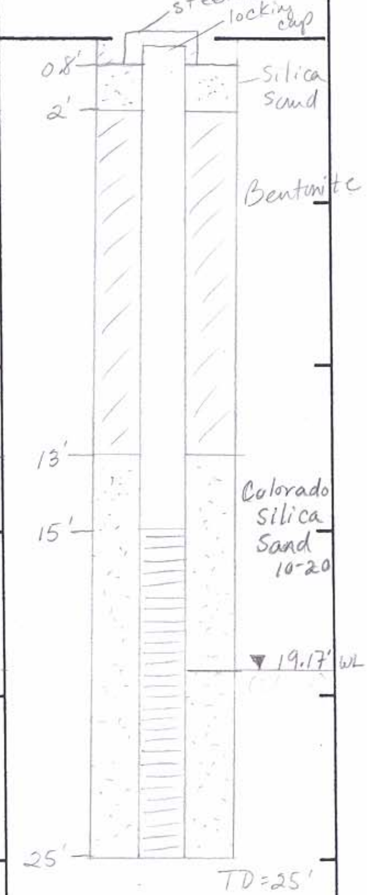
GEOLOGIC LOG

DRILLING CONTRACTOR: Tacoma Pump & Drill
DATE COMPLETED: 5/13/98
ALTITUDE GROUND SURFACE: 128.57 ft

GROUND SURFACE

Geologic Log	Blow Counts	Graphic Log (depth)
		0
Brown SAND grading downward to grey-brown poorly sorted fine to coarse SAND with 15-20% gravel. Gravel ranging from pea-sized to 1" diameter. Minor clay content.	20/27/46	5'
	50 for 5"	10'
Grey-brown, fairly clean fine to very coarse SAND with 15% gravel from pea-sized to ½" diameter.	33/50 for 4"	15'
Same as above but gravel to 1" diameter.	20/33/35	20'
Same as above but gravel to ½" diameter.		25'

AS-BUILT DATA



Appendix B. Summary of monitoring well construction information.

Measurements are in feet.

Well ID	Unique well ID	Latitude N	Longitude W	Elevation of ground surface	Depth of casing below ground	Well elevation (TOC[1])	Well depth (from TOC[1])	Open interval
MW-1	AAF282	48^{0} 59.165'	122^{0} 27.977'	127.56	0.10	127.46	10	3-10
MW-2	AAF281	48^{0} 59.162'	122^{0} 28.004'	127.01	0.14	126.87	9	2-9
MW-3	AAF286	48^{0} 59.053'	122^{0} 27.947'	126.43	0.17	126.26	10.2	3.2-10.2
MW-4	AAF285	48^{0} 59.005'	122^{0} 27.971'	125.00	0.19	124.81	10.5	3.5-10.5
MW-5	AAF283	48^{0} 59.015'	122^{0} 27.988'	125.33	0.15	125.18	10.5	3.5-10.5
MW-6	AAF284	48^{0} 59.000'	122^{0} 28.038'	125.74	0.19	125.55	10	3-10
MW-7	AAF278	48^{0} 58.75'	122^{0} 27.93'	122.90	0.73	122.17	11	4-11
MW-8	AAF280	48^{0} 58.760'	122^{0} 27.976'	123.44	0.35	123.09	10	3-10
MW-9	AAF279	48^{0} 58.822'	122^{0} 28.017'	123.01	0.22	122.79	10.5	3.5-10.5
BW-1	AAF272	48^{0} 58.265'	122^{0} 24.209'	129.46	0.64	128.82	19	9-19
BW-2	AAF275	48^{0} 58.247'	122^{0} 24.163'	130.00	0.56	129.44	20	10-20
BW-3	AAF274	48^{0} 58.129'	122^{0} 24.168'	130.07	0.61	129.46	23	13-23
BW-4	AAF273	48^{0} 58.157'	122^{0} 24.180'	129.20	0.80	128.40	24	14-24
BW-5	AAF276	48^{0} 58.018'	122^{0} 24.210'	129.14	0.58	128.56	25	15-25
BW-6	AAF277	48^{0} 58.063'	122^{0} 24.203'	128.57	0.62	127.95	25	15-25

Datum: NAD27

[1] Top of casing.

Appendix C. Ceramic cup lysimeter installation procedures.

Borings at Site 1 were drilled 3 to 3-1/2 feet deep using a 4-1/14-inch diameter hollow stem auger at a distance of about four feet west of wells MW-1, MW-2, MW-3, MW-4, MW-5, and MW-6. At Site 2 lysimeters were installed four feet west of each of the wells. A slurry of 200-um silica flour and water (1-2 gallons or 4-6 inches depth) was poured into each empty hole at Site 1 to provide a good contact between the ceramic cup and the soil. At Site 2 the slurry consisted of water and seived native soil. The lysimeters were placed in the slurry and allowed to set undisturbed for one to three hours.

After the bottom slurry had adequately solidified, about six inches of silica sand was added, followed by a layer of bentonite chips ½ to one foot thick. Silica sand was placed above the bentonite up to about four inches below the ground surface. A 2-foot long piece of 4-inch diameter PVC pipe with a compression cap was pushed into the ground over the lysimeter installation for protection. The two access tubes for the samplers were wound up and placed inside the protective cover with caps over the ends of the tubing to prevent contamination.

Appendix D. Water quality sampling and analysis procedures.

Wells

Monitoring wells were purged and sampled using a peristaltic pump. Dedicated tubing was used in each well to prevent cross-contamination. The pump intake was set at about one foot below the top of the water table and run for at least 20 minutes at a rate of 600 ml/minute. The purging procedure was intended to draw water from the top of the aquifer without disturbing the entire column of water in the well casing.

The purge water discharged directly to a YSI flow cell equipped with temperature, pH, and specific conductance probes. The pH probe was calibrated with pH 4 and 7 buffers before sampling. Dissolved oxygen (D.O.) was monitored with a separate YSI probe without a stirrer lowered into the well to the same depth as the intake for the peristaltic pump before October 1999. Measurements for field parameters were recorded every four minutes. If field parameters had not stabilized within 20 minutes, Ecology continued purging until there was less than a 10% change in each parameter.

The measuring technique and equipment used for D.O. measurement changed on October 21, 1999. The new device, a Geotech flow cell, was similar to the YSI flow cell previously used with the addition of a port for a D.O. probe. Samples were pumped into an air-tight chamber with the peristaltic pump from a dedicated tube in the well. Special care was taken to prevent bubbles from entering the flow cell which could interfere with D.O. readings. The data obtained before and after October 21, 1999 indicate that results from the new measurement technique were consistent with previous data. Temperature, pH, D.O., and specific conductivity were all calibrated before sampling with the Geotech flow cell.

When purging was complete, the discharge to the flow cell was redirected to the sample bottles. Samples were placed on ice and kept at 4ºC until delivered to the Manchester Environmental Laboratory in Port Orchard, Washington. The methods for analysis and holding times are shown in Table D.1.

Lysimeters

Neoprene tubing was attached to the end of the polypropylene exit tubing for applying vacuum and pressure on each lysimeter. The sample tubing was stoppered. A vacuum of 60 cb was applied using a pressure/vacuum pump, and samples were collected the following day by applying pressure with the same pump. Samples were collected directly into sample bottles from the discharge tubing. The maximum sample volume was about 600 ml which sometimes limited the number of analyses possible. When sample volume was limited, ammonia-N, nitrate+nitrite-N, and TPN were the highest priority. Chloride and TDS were also analyzed when possible.

Table D.1. Parameters, test methods, quantitation limits, holding times, and preservatives.

Parameter	Test Method: ASTM [3]	Quantitation Limit	Matrix	Holding Time	Preservative
pH (Field)	YSI Probe or WTW Probe[5]	0.1 Std Unit	G, M		
Specific conductivity (Field or lab)	YSI Probe or WTW Probe[5] /2510[2]	1 µmhos/cm	G, M, SP		
Dissolved oxygen (Field)	YSI Probe or WTW Probe[6]	0.1 mg/L	G	None	None
Chloride	EPA 330.0/4110B	0.1 mg/L	G, M, SP	28 days	Cool to 4^0C
Total dissolved solids	EPA 160.1/2540	1 mg/L	G, M, SP	7 days	Cool to 4^0C
Total solids	EPA 160.3/2540B	1 mg/L	G, M	7 days	Cool to 4^0C
Ammonia-N	EPA 350.1/4500 NH3 D	0.01 mg/L	G, M, SP	28 days	Cool to 4^0 C, acidify to pH<2
Nitrate+nitrite-N	EPA 353.2/4500 NO3 F	0.01 mg/L	G, M, SP	28 days	Cool to 4^0 C, acidify to pH<2
Total persulfate N	EPA 353.2 (Modified)/4500 NO3 F Modified	0.01 mg/L	G, M, SP	28 days	Cool to 4^0 C, acidify to pH<2
Total Kjeldahl N	/4500-N_{org}B	0.01 mg/L	G, M	28 days	Cool to 4^0 C, acidify to pH<2
Total organic carbon (TOC)	EPA 415.1/5201B	1 mg/L	G	28 days	Cool to 4^0 C, acidify to pH<2
Grain size	ASTM D422-63 (Reapproved 1990)		S		

[1] EPA, 1983. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020. Revised March 1983.

[2] American Public Health Association, 1995. Methods for the Examination of Water and Wastewater, 19th Edition.

[3] ASTM, 1994. ASTM Standards on Ground Water and Vadose Zone Investigations, 2nd Ed. Philadelphia.

[4] Matrix Codes: G=Ground water, M=Manure, SP=Soil pore liquid, S=Soil.

[5] YSI Flow cell and Orion probes used until October 1999 when Wissenshaftlich-Technishce Werkstatten, GmBH probes and flow cell used.

Appendix E. Quality assurance results.

Table E.1. Relative percent difference between duplicate samples.
(Concentrations are in mg/L unless specified otherwise.)

Well	Date	NH4-N		NO2+NO3-N	TPN		Chloride	TDS	Specific Conductance (µmhos/cm)	TOC
Site 1										
MW-3	11/20/1997	0.010	U	10.9	11.0		8.75	178	260	3.9
	11/20/1997	0.010	U	11.9	12.8		8.02	167	253	4.0
	RPD (%)	0.0		8.8	15.1		8.7	6.4	2.7	2.5
	5/29/1998	0.010	U	6.54	7.14		6.28	143	205	
	5/29/1998	0.010	U	6.95	7.41		6.21	150	205	
	RPD (%)	0.0		6.1	3.7		1.1	4.8	0.0	
MW-4	10/17/1997	0.010	U	0.191	0.029		7.36	223		
	10/17/1997	0.010	U	0.232	0.429		7.27	227		
	RPD (%)	0.0		19.4	174.7		1.2	1.8		
	10/15/1998	0.010	U	7.30	7.52		13.3	272	394	
	10/15/1998	0.010	U	7.31	7.63		13.1	269	393	
	RPD (%)	0.0		0.1	1.5		1.5	1.1	0.3	
	3/25/1999	0.010	U	23	26.9		13.5	341	494	
	3/25/1999	0.010	U	30	0.528	J	14.0	332	497	
	RPD (%)	0.0		26.4	192		3.6	2.7	0.6	
MW-6	6/26/1997	0.038		12.3	12.5		26.8	453		
	6/26/1997	0.045		14.2	14.1		27.5	428		
	RPD (%)	16.9		14.3	12.0		2.6	5.7		
	9/1/1998	0.010	U	14.6	15.1		29.6	403	595	
	9/1/1998	0.010	U	13.9	14.1		29.8	409	594	
	RPD (%)	0.0		4.9	6.8		0.7	1.5	0.2	
	2/25/1999	0.010	U	13.9	16.4		27.3	454	647	
	2/25/1999	0.010	U	15.0	17.2		26.6	444	655	
	RPD (%)	0.0		7.6	4.8		2.6	2.2	1.2	
	5/6/1999	0.029		16.1	17.7		28.2	461		
	5/6/1999	0.029		14.9	18.5		28.1	457		
	RPD (%)	0.0		7.7	4.4		0.4	0.9		
MW-8	2/6/1998	0.010	U	37.8	37.8		17.8	341	481	4.3
	2/6/1998	0.010	U	37.6	38.5		17.4	337	483	4.4
	RPD (%)	0.0		0.5	1.8		2.3	1.2	0.4	2.3

Table E.1 (cont.)

Well	Date	NH4-N		NO2+NO3-N	TPN	Chloride	TDS	Specific Conductance (µmhos/cm)	TOC
	7/24/1998	0.010	U	24.6	24.2	23.6	358	519	
	7/24/1998	0.010	U	23.3	24.9	23.6	348	519	
	RPD (%)	0.0		5.4	2.9	0.0	2.8	0.0	
	1/27/2000	0.010	U	31.5	32.5	26.0	373		
	1/27/2000	0.010	U	32.8	32.3	26.6	399		
	RPD (%)	0.0		4.0	0.6	2.3	6.7		
MW-9	9/19/1997	0.010	U	4.29	4.31	11.5	222		
	9/19/1997	0.010	U	4.41	4.46	11.8	213		
	RPD (%)	0.0		2.8	3.4	2.6	4.1		
	5/23/1999	0.028		16.6	16.3	19.9	297	421	
	5/23/1999	0.027		16.6	16.3	20.0	286	420	
	RPD (%)	3.6		0.0	0.0	0.5	3.8	0.2	
Site 2									
BW-2	10/15/1998	0.010	U	10.1	10.4	10.7	161	254	
	10/15/1998	0.010	U	10.5	10.5	10.7	165	252	
	RPD (%)	0.0		3.9	1.0	0.0	2.5	0.8	
	3/24/1999	0.010	U	11.4	10.4	10.3	165	235	
	3/24/1999	0.010	U	8.50	10.4	10.3	171	235	
	RPD (%)	0.0		29.1	0.0	0.0	3.6	0.0	
	11/18/1999	0.010	U	11.7	12.4	10.4	163	257	
	11/18/1999	0.010	U	12.2	12.6	10.3	188	257	
	RPD (%)	0.0		4.2	1.6	1.0	14.2	0.0	
	3/2/2000	0.010	U	14.6	14.9	11.8	185	274	
	3/2/2000	0.338		15.4	14.8	10.5	180	274	
	RPD (%)	189		5.3	0.7	11.7	2.7	0.0	
BW-3	9/22/1999	0.028		10.5	10.3	10.5	137	220	
	9/22/1999	0.028		10.4	9.85	10.6	142	220	
	RPD (%)	0.0		1.0	4.5	0.9	3.6	0.0	
	9/2/1998	0.010	U	13.1	11.1	9.67	166	264	
	9/2/1998	0.010	U	13.0	11.0	9.67	180	264	
	RPD (%)	0.0		0.8	0.9	0.0	8.1	0.0	
	7/8/1999	0.021		12.8	12.0	9.71	151	241	
	7/8/1999	0.020		12.1	12.7	8.91	158	241	
	RPD (%)	4.9		5.6	5.7	8.6	4.5	0.0	

Table E.1 (cont.)

Well	Date	NH4-N		NO2+NO3-N	TPN	Chloride	TDS	Specific Conductance (µmhos/cm)	TOC
	1/26/2000	0.010	U	11.6	11.8	9.75	145		
	1/26/2000	0.010	U	11.2	11.3	9.28	161		
	RPD (%)	0.0		3.5	4.3	4.9	10.5		
	5/5/1999	0.028		10.5	13.1	9.96	156		0.50
	5/5/1999	0.030		11.2	13.5	9.32	153		0.52
	RPD (%)	6.9		6.5	3.0	6.6	1.9		3.9
	6/3/1999	0.010	U	11.8	13.5	9.62	145		
	6/3/1999	0.010	U	1.40	12.3	10.1	140		
	RPD (%)	0.0		158	9.3	4.9	3.5		
	8/26/1999	0.010	U	12.4	12.4	8.67	174	237	
	8/26/1999	0.010	U	11.4	12.1	8.69	160	238	
	RPD (%)	0.0		8.4	2.4	0.2	8.4	0.4	
	10/21/1999	0.010	UJ	10.4	10.2	10.2	164	227	
	10/21/1999	0.010	UJ	10.3	9.8	10.4	155	227	
	RPD (%)	0.0		1.0	4.0	1.9	5.6	0.0	

U: Below detection limit.

J: Estimated value.

Table E.2. Sample blank results for lysimeters at Site 1 prior to installation (mg/L).

Constituent	Lysimeters	De-ionized Water Blank
Ammonia-N	0.025-0.038	0.035
Nitrate+nitrite-N	0.053-0.077	0.120
TPN	0.070-0.200	0.089
Chloride	<0.100	<0.100
TDS	3-14 (estimates)	3 (estimate)

Table E.3. Soil nitrogen split sample results at Site 1 (South Field) 1999 for the top one foot.

	Nitrate (mg/kg)	Ammonia (mg/kg)
Sample 1	55.0	16.0
Sample 2	55.5	17.5
Relative percent difference	0.9	9.0

Appendix F. Grain size results.

State of Washington Department of Ecology
Manchester Environmental Laboratory
7411 Beach Dr. East Port Orchard WA. 98366

July 23, 1998

Project: Nooksack Agronomic

Samples: 21-8105-26

Laboratory: Columbia Analytical

By: Pam Covey

Case Summary

These samples required twenty-two (22) Grain Size analyses on sediment using Puget Sound Estuary Protocol (PSEP) method for sieve fractions only. Three of the samples also required hydrometer analysis for silt and clay. The samples were received at the Manchester Environmental Laboratory on May 21, 1998 and transported to the contract lab the same day for Grain Size analyses.

The analyses were reviewed for qualitative and quantitative accuracy, validity and usefulness.

The results are acceptable for use as reported.

Acronyms

ASTM	American Society for Testing and Materials
A2LA	American Association for Laboratory Accreditation
CARB	California Air Resources Board
CAS Number	Chemical Abstract Service registry Number
CFC	Chlorofluorocarbon
CFU	Colony-Forming Unit
DEC	Department of Environmental Conservation
DEQ	Department of Environmental Quality
DHS	Department of Health Services
DOE	Department of Ecology
DOH	Department of Health
EPA	U. S. Environmental Protection Agency
ELAP	Environmental Laboratory Accreditation Program
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
J	Estimated concentration. The value is less than the method reporting limit, but greater than the method detection limit.
LUFT	Leaking Underground Fuel Tank
M	Modified
MCL	Maximum Contaminant Level is the highest permissible concentration of a substance allowed in drinking water as established by the USEPA.
MDL	Method Detection Limit
MPN	Most Probable Number
MRL	Method Reporting Limit
NA	Not Applicable
NAN	Not Analyzed
NC	Not Calculated
NCASI	National Council of the Paper Industry for Air and Stream Improvement
ND	Not Detected at or above the MRL
NIOSH	National Institute for Occupational Safety and Health
PQL	Practical Quantitation Limit
RCRA	Resource Conservation and Recovery Act
SIM	Selected Ion Monitoring
TPH	Total Petroleum Hydrocarbons
tr	Trace level is the concentration of an analyte that is less than the PQL but greater than or equal to the MDL.

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept of Ecology	**Service Request:**	K9803281
Project:	Nooksack Agronomic	**Date Collected:**	5/21/98
Sample Matrix:	Soil	**Date Received:**	5/1/55
		Date Analyzed:	6/4/98

Particle Size Determination
ASTM Method D 422

Sample Name: 21-8108 — MW-4 (topsoil)
Lab Code: K9803281-004

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No. 1"(25.4 mm)	0.0000	100
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.1/2"(12.7 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	8.2216	89.7
Medium Gravel	No.4 (4.75 mm)	5.7067	82.7
Fine Gravel	No.10 (2.00 mm)	4.0695	77.7
Very Coarse Sand	No.20 (0.850 mm)	3.2284	73.4
Coarse Sand	No.40 (0.425 mm)	5.1896	66.7
Medium Sand	No.60 (0.250 mm)	6.3741	58.4
Medium-Fine Sand	No.80 (0.180 mm)	2.6912	54.9
Fine Sand	No.100 (0.150 mm)	1.0512	53.5
Very Fine Sand	No.200 (0.0750 mm)	3.4532	49.0

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	35.7
0.005 mm	17.4
0.001 mm	6.44

Approved By: [signature] Date: 6/26/98

1A/102094

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Washington Dept of Ecology
Project: Nooksack Agronomic
Sample Matrix: Soil

Service Request: K9803281
Date Collected: 5/21/98
Date Received: 5/1/55
Date Analyzed: 6/4/98

Particle Size Determination
ASTM Method D 422

Sample Name: 21-8108 (duplicate)
Lab Code: K9803281-004d

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No. 1"(25.4 mm)	0.0000	100
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.1/2"(12.7 mm)	2.8805	96.7
Gravel	No.3/8"(9.50 mm)	3.8382	92.4
Medium Gravel	No.4 (4.75 mm)	9.2624	82.0
Fine Gravel	No.10 (2.00 mm)	5.7187	75.6
Very Coarse Sand	No.20 (0.850 mm)	3.6146	71.3
Coarse Sand	No.40 (0.425 mm)	6.2871	63.8
Medium Sand	No.60 (0.250 mm)	6.2174	56.4
Medium-Fine Sand	No.80 (0.180 mm)	2.5633	53.4
Fine Sand	No.100 (0.150 mm)	1.1960	51.9
Very Fine Sand	No.200 (0.0750 mm)	3.4821	47.8

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	32.9
0.005 mm	14.7
0.001 mm	3.88

Approved By: [signature] Date: 6/26/98

1A/102094

3281-4DH.XLS/6/26/98

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept of Ecology	**Service Request:**	K9803281
Project:	Nooksack Agronomic	**Date Collected:**	5/21/98
Sample Matrix:	Soil	**Date Received:**	5/1/55
		Date Analyzed:	6/4/98

Particle Size Determination
ASTM Method D 422

Sample Name: 21-8109 – MW-4, 2.5 ft
Lab Code: K9803281-005

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No. 1"(25.4 mm)	0.0000	100
Gravel	No.3/4"(19.0 mm)	16.3123	85.6
Gravel	No.1/2"(12.7 mm)	10.1947	76.6
Gravel	No.3/8"(9.50 mm)	3.4052	73.6
Medium Gravel	No.4 (4.75 mm)	5.6850	68.5
Fine Gravel	No.10 (2.00 mm)	6.7027	62.6
Very Coarse Sand	No.20 (0.850 mm)	3.6739	59.1
Coarse Sand	No.40 (0.425 mm)	7.1741	52.2
Medium Sand	No.60 (0.250 mm)	8.6095	43.9
Medium-Fine Sand	No.80 (0.180 mm)	3.3054	40.7
Fine Sand	No.100 (0.150 mm)	1.1769	39.6
Very Fine Sand	No.200 (0.0750 mm)	3.6269	36.1

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	22.5
0.005 mm	9.29
0.001 mm	1.43

Approved By: ______________ Date: 6/8/98

1A/102094

3281-5H.XLS/6/8/98

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept of Ecology	**Service Request:**	K9803281
Project:	Nooksack Agronomic	**Date Collected:**	5/22/98
Sample Matrix:	Soil	**Date Received:**	5/1/55
		Date Analyzed:	6/4/98

Particle Size Determination
ASTM Method D 422

Sample Name: 21-8114 – MW-9, 2.5 ft
Lab Code: K9803281-010

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No. 1"(25.4 mm)	0.0000	100
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.1/2"(12.7 mm)	3.7616	95.2
Gravel	No.3/8"(9.50 mm)	0.0000	95.2
Medium Gravel	No.4 (4.75 mm)	3.5267	90.8
Fine Gravel	No.10 (2.00 mm)	6.4985	82.7
Very Coarse Sand	No.20 (0.850 mm)	7.5278	73.3
Coarse Sand	No.40 (0.425 mm)	25.6006	41.3
Medium Sand	No.60 (0.250 mm)	5.5542	34.3
Medium-Fine Sand	No.80 (0.180 mm)	1.3899	32.6
Fine Sand	No.100 (0.150 mm)	0.6550	31.7
Very Fine Sand	No.200 (0.0750 mm)	1.9563	29.3 ←

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	9.68
0.005 mm	3.90
0.001 mm	0.44

Approved By: [signature] Date: 6/26/98

1A/102094

3281-10H.XLS/6/26/98

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept. of Ecology	**Date Collected:**	5/20/98
Project:	Nooksack Agronomic	**Date Received:**	5/22/98
Sample Matrix:	Soil	**Service Request:**	K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

Sample:	21-8105 (mw3, 2.5 ft)	21-8105	21-8106 (mw-3, 5 ft)
Sample #:	3281-001	3281-001d	3281-002
Wet Weight	100.3789	100.0263	100.1706
Tare	85.4518	77.6841	79.0807
Dry + Tare	172.9686	164.4597	154.0138
Dry Weight	87.5168	86.7756	74.9331
% Solids	87.2%	86.8%	74.8%

Sieve Size	Dry Weight	% Passing	Dry Weight	% Passing	Dry Weight	% Passing
1 in.	0.0000	100	0.0000	100	0.0000	100
3/4 in.	14.4874	83.4	0.0000	100	0.0000	100
1/2 in.	4.9436	77.8	12.5992	85.5	0.0000	100
3/8 in	3.1221	74.2	2.5480	82.5	0.0000	100
No.4	5.9574	67.4	6.6801	74.8	1.2539	98.3
No. 10	5.0687	61.6	6.4348	67.4	3.8520	93.2
No. 20	7.8460	52.7	10.8339	54.9	10.8056	78.8
No. 40	12.4260	38.5	17.3947	34.9	13.5661	60.7
No. 60	12.4371	24.3	12.4114	20.6	13.1826	43.1
No. 80	5.6557	17.8	3.8797	16.1	7.0611	33.6
No. 100	2.8796	14.5	2.0018	13.8	8.2773	22.6
No. 200	4.3116	9.58	4.1892	8.99	5.3477	15.5
Pan	8.2359	--	7.8290	--	11.7531	--

	21-8105 (3281-001)	21-8105 (3281-001d)	21-8106 (3281-002)
Total Weight =	87.3711	86.8018	75.0994
% Recovered =	99.8	100	100

Approved By: [signature] Date: 6/26/98

3ADW/061694

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept. of Ecology	**Date Collected:**	5/20/98
Project:	Nooksack Agronomic	**Date Received:**	5/22/98
Sample Matrix:	Soil	**Service Request:**	K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

Sample:	21-8107	Sample:	21-8110	Sample:	21-8111
	mw-3, 10 ft		mw-4, 5 ft		mw-4, 7.5 ft
Sample #:	3281-003	Sample #:	3281-006	Sample #:	3281-007
Wet Weight	104.9016	Wet Weight	100.8323	Wet Weight	100.5178
Tare	81.6628	Tare	79.9508	Tare	82.3043
Dry + Tare	160.9743	Dry + Tare	164.5469	Dry + Tare	171.7509
Dry Weight	79.3115	Dry Weight	84.5961	Dry Weight	89.4466
% Solids	75.6%	% Solids	83.9%	% Solids	89.0%

Sieve Size	Dry Weight	% Passing	Sieve Size	Dry Weight	% Passing	Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100	1 in.	0.0000	100	1 in.	0.0000	100
3/4 in.	0.0000	100	3/4 in.	0.0000	100	3/4 in.	0.0000	100
1/2 in.	16.5975	79.1	1/2 in.	0.0000	100	1/2 in.	7.6159	91.5
3/8 in	0.0000	79.1	3/8 in	0.0000	100	3/8 in	0.0000	91.5
No.4	2.6535	75.7	No.4	5.6935	93.3	No.4	6.3249	84.4
No. 10	8.2625	65.3	No. 10	8.4069	83.3	No. 10	6.4268	77.2
No. 20	10.5418	52.0	No. 20	13.3699	67.5	No. 20	15.9775	59.4
No. 40	12.4141	36.4	No. 40	32.1447	29.5	No. 40	18.9457	38.2
No. 60	8.6999	25.4	No. 60	15.1401	11.6	No. 60	14.5005	22.0
No. 80	3.1577	21.4	No. 80	3.9759	6.93	No. 80	7.6929	13.4
No. 100	1.8709	19.1	No. 100	1.4089	5.27	No. 100	2.8453	10.2
No. 200	3.9816	14.0	No. 200	2.4466	2.38	No. 200	6.2452	3.21
Pan	11.0357	--	Pan	1.8525	--	Pan	2.7082	--

Total Weight =	79.2152	Total Weight =	84.4390	Total Weight =	89.2829
% Recovered =	99.9	% Recovered =	99.8	% Recovered =	99.8

Approved By: [signature] Date: 7/14/98

3ADW/061694

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Washington Dept. of Ecology
Project: Nooksack Agronomic
Sample Matrix: Soil

Date Collected: 5/20/98
Date Received: 5/22/98
Service Request: K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

mw-4, 10 ft

Sample:	21-8112
Sample #:	3281-008
Wet Weight	100.7734
Tare	80.9876
Dry + Tare	170.4839
Dry Weight	89.4963
% Solids	88.8%

Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100
3/4 in.	0.0000	100
1/2 in.	0.0000	100
3/8 in	2.7304	96.9
No.4	6.3201	89.9
No. 10	12.6834	75.7
No. 20	16.1996	57.6
No. 40	24.8699	29.8
No. 60	12.8796	15.4
No. 80	5.1172	9.72
No. 100	2.1024	7.37
No. 200	3.7888	3.13
Pan	2.5426	--

Total Weight = 89.2340

% Recovered = 99.7

mw-9, topsoil

Sample:	21-8113
Sample #:	3281-009
Wet Weight	100.5432
Tare	77.3756
Dry + Tare	159.3144
Dry Weight	81.9388
% Solids	81.5%

Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100
3/4 in.	0.0000	100
1/2 in.	0.0000	100
3/8 in	0.0000	100
No.4	0.0000	100
No. 10	0.2984	99.6
No. 20	3.1205	95.8
No. 40	20.9509	70.3
No. 60	28.6757	35.3
No. 80	8.7290	24.6
No. 100	6.1970	17.0
No. 200	7.2562	8.19
Pan	7.2915	--

Total Weight = 82.5192

% Recovered = 101

mw-9, 5 ft

Sample:	21-8115
Sample #:	3281-011
Wet Weight	100.9609
Tare	85.3589
Dry + Tare	176.8120
Dry Weight	91.4531
% Solids	90.6%

Sieve Size	Dry Weight	% Passing
1 in.	36.5676	60.0
3/4 in.	0.0000	60.0
1/2 in.	0.0000	60.0
3/8 in	4.6872	54.9
No.4	2.8223	51.8
No. 10	1.2728	50.4
No. 20	4.3723	45.6
No. 40	18.6277	25.3
No. 60	10.7707	13.5
No. 80	3.1399	10.1
No. 100	1.6801	8.21
No. 200	3.5701	4.31
Pan	4.0830	--

Total Weight = 91.5937

% Recovered = 100

Approved By: [signature] Date: 6/26/98

3ADW/061694

3281DRY.XLS6/26/98

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Washington Dept. of Ecology
Project: Nooksack Agronomic
Sample Matrix: Soil

Date Collected: 5/20/98
Date Received: 5/22/98
Service Request: K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

	MW-9, 7.5 ft	MW-9, 10 ft	BW-1, 5 ft
Sample:	21-8116	21-8117	21-8118
Sample #:	3281-012	3281-013	3281-014
Wet Weight	101.5857	100.4048	100.6261
Tare	82.7539	77.4880	77.5609
Dry + Tare	173.0780	165.8318	174.1583
Dry Weight	90.3241	88.3438	96.5974
% Solids	88.9%	88.0%	96.0%

Sieve Size	Dry Weight (21-8116)	% Passing (21-8116)	Dry Weight (21-8117)	% Passing (21-8117)	Dry Weight (21-8118)	% Passing (21-8118)
1 in.	0.0000	100	0.0000	100	0.0000	100
3/4 in.	0.0000	100	15.8280	82.1	0.0000	100
1/2 in.	17.7163	80.4	0.0000	82.1	15.4555	84.0
3/8 in	5.0247	74.8	0.0000	82.1	3.3060	80.6
No.4	3.9790	70.4	4.5352	77.0	9.2685	71.0
No. 10	6.3969	63.3	6.8957	69.1	8.7869	61.9
No. 20	10.4360	51.8	14.3532	52.9	9.8894	51.6
No. 40	19.8702	29.8	23.0808	26.8	19.8339	31.1
No. 60	10.2566	18.4	14.0199	10.9	21.4588	8.90
No. 80	5.3472	12.5	4.3854	5.94	4.8313	3.90
No. 100	2.2063	10.1	1.2732	4.50	0.9182	2.95
No. 200	5.0942	4.42	2.0972	2.12	1.5175	1.38
Pan	3.6614	--	1.6726	--	1.3158	--

	21-8116	21-8117	21-8118
Total Weight =	89.9888	88.1412	96.5818
% Recovered =	99.6	99.8	100

Approved By: [signature] Date: 6/26/98

3ADW/061694

00010

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept. of Ecology	**Date Collected:**	5/20/98
Project:	Nooksack Agronomic	**Date Received:**	5/22/98
Sample Matrix:	Soil	**Service Request:**	K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

Sample:	21-8119 (BW-1, 12.5ft)	21-8120 (BW-1, 17.5ft)	21-8121 (BW-4, 10 feet)
Sample #:	3281-015	3281-016	3281-017
Wet Weight	100.3499	101.0939	100.1040
Tare	82.3481	86.3762	86.7501
Dry + Tare	170.7502	175.2107	183.8073
Dry Weight	88.4021	88.8345	97.0572
% Solids	88.1%	87.9%	97.0%

Sieve Size	Dry Weight (21-8119)	% Passing (21-8119)	Dry Weight (21-8120)	% Passing (21-8120)	Dry Weight (21-8121)	% Passing (21-8121)
1 in.	0.0000	100	0.0000	100	0.0000	100
3/4 in.	0.0000	100	0.0000	100	0.0000	100
1/2 in.	0.0000	100	13.4673	84.8	24.9925	74.2
3/8 in	2.3403	97.4	2.1912	82.4	4.2829	69.8
No.4	7.5468	88.8	8.6625	72.6	18.8012	50.5
No. 10	17.5687	68.9	12.8501	58.2	12.8422	37.2
No. 20	17.3747	49.3	17.3278	38.7	11.7134	25.2
No. 40	15.9415	31.3	21.9106	14.0	14.5704	10.2
No. 60	11.3010	18.5	6.6993	6.45	5.8476	4.13
No. 80	6.6155	11.0	2.0065	4.19	1.3290	2.76
No. 100	1.3348	9.48	0.7740	3.32	0.4097	2.34
No. 200	5.2514	3.54	1.7196	1.38	0.9744	1.33
Pan	2.8833	--	1.0276	--	1.0109	--

	21-8119	21-8120	21-8121
Total Weight =	88.1580	88.6365	96.7742
% Recovered =	99.7	99.8	99.7

Approved By: [signature] Date: 6/26/98

3ADW/061694

00011

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Washington Dept. of Ecology
Project: Nooksack Agronomic
Sample Matrix: Soil

Date Collected: 5/20/98
Date Received: 5/22/98
Service Request: K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

BW-4, 15 ft

Sample:	21-8122
Sample #:	3281-018
Wet Weight	100.4118
Tare	80.1139
Dry + Tare	167.0111
Dry Weight	86.8972
% Solids	86.5%

Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100
3/4 in.	0.0000	100
1/2 in.	0.0000	100
3/8 in	0.0000	100
No.4	6.1143	93.0
No. 10	13.0858	77.9
No. 20	15.6648	59.9
No. 40	29.7299	25.7
No. 60	14.3147	9.19
No. 80	3.0354	5.70
No. 100	0.8545	4.72
No. 200	1.6376	2.83
Pan	1.5186	--

Total Weight = 85.9556
% Recovered = 98.9

BW-4, 20 ft

Sample:	21-8123
Sample #:	3281-019
Wet Weight	100.2559
Tare	81.9197
Dry + Tare	163.5495
Dry Weight	81.6298
% Solids	81.4%

Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100
3/4 in.	0.0000	100
1/2 in.	0.0000	100
3/8 in	0.0000	100
No.4	0.1717	99.8
No. 10	1.3828	98.1
No. 20	12.3738	82.9
No. 40	41.0461	32.7
No. 60	19.3201	8.99
No. 80	3.7036	4.45
No. 100	1.0958	3.11
No. 200	1.4628	1.31
Pan	0.4328	--

Total Weight = 80.9895
% Recovered = 99.2

BW-1, 7.5 ft

Sample:	21-8124
Sample #:	3281-020
Wet Weight	100.3585
Tare	78.3782
Dry + Tare	175.9388
Dry Weight	97.5606
% Solids	97.2%

Sieve Size	Dry Weight	% Passing
1 in.	0.0000	100
3/4 in.	23.1102	76.3
1/2 in.	7.3287	68.8
3/8 in	1.1711	67.6
No.4	8.9599	58.4
No. 10	11.5938	46.5
No. 20	12.7427	33.5
No. 40	22.5605	10.3
No. 60	6.0461	4.15
No. 80	1.2439	2.87
No. 100	0.4855	2.38
No. 200	0.9809	1.37
Pan	1.1529	--

Total Weight = 97.3762
% Recovered = 99.8

Approved By: [signature] Date: 6/26/98

3ADW/061694

3281DRY.XLS6/26/98

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Washington Dept. of Ecology	**Date Collected:**	5/20/98
Project:	Nooksack Agronomic	**Date Received:**	5/22/98
Sample Matrix:	Soil	**Service Request:**	K9803281

Dry Sieve Analysis

PSEP

Units: Percent Passing

Sample:	21-8125	Sample:	21-8126
Sample #:	3281-021	Sample #:	3281-022
Wet Weight	100.1144	Wet Weight	100.2425
Tare	83.5562	Tare	81.6797
Dry + Tare	176.1088	Dry + Tare	176.5893
Dry Weight	92.5526	Dry Weight	94.9096
% Solids	92.4%	% Solids	94.7%

BW-1, 15 ft | BW-4, 5 ft

Sieve Size	Dry Weight	% Passing	Sieve Size	Dry Weight	% Passing
1 in.	39.7955	57.0	1 in.	0.0000	100
3/4 in.	0.0000	57.0	3/4 in.	0.0000	100
1/2 in.	0.0000	57.0	1/2 in.	2.8210	97.0
3/8 in	2.6890	54.1	3/8 in	0.0000	97.0
No.4	13.9672	39.0	No.4	6.0699	90.6
No. 10	13.6901	24.2	No. 10	8.5759	81.6
No. 20	8.9616	14.5	No. 20	14.9915	65.8
No. 40	5.5107	8.58	No. 40	35.5092	28.4
No. 60	2.8562	5.49	No. 60	16.3104	11.2
No. 80	1.3117	4.07	No. 80	3.3321	7.69
No. 100	0.8102	3.20	No. 100	1.1510	6.48
No. 200	1.8793	1.17	No. 200	3.4597	2.83
Pan	0.9755	--	Pan	3.1239	--

Total Weight = 92.4470 | Total Weight = 95.3446

% Recovered = 99.9 | % Recovered = 100

Approved By: [signature] Date: 6/26/98

3ADW/061694

00013

3281DRY.XLS6/26/98

Appendix G. Depth to water measurements in monitoring wells.

Table G.1. Depth to water measurements at Site 1 in feet below ground surface. Values are corrected for depth of the casing below ground.

	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9
07/25/97	3.96	3.48	6.75	3.63	2.98	3.20	4.88	6.26	3.34
08/21/97	6.77	5.91	NA	5.61	4.59	4.75	5.38	6.03	4.50
09/19/97	5.45	4.93	6.61	5.15	4.51	4.57	5.58	6.27	4.70
10/17/97	3.82	3.64	4.58	3.34	2.96	2.93	4.18	4.84	3.33
11/21/97	2.46	1.86	3.30	2.03	1.91	1.87	2.08	3.71	2.11
12/29/97	0.76	0.28	0.94	0.41	0.64	0.85	1.73	1.84	0.56
02/05/98	2.49	2.08	2.88	2.11	1.81	1.98	2.83	3.08	1.61
03/10/98	2.55	2.07	3.09	2.19	1.90	2.01	3.13	3.53	2.05
04/16/98	3.45	3.10	4.16	3.17	2.63	2.88	3.94	4.46	na
05/27/98	3.93	3.37	4.29	3.42	2.63	2.73	4.27	4.75	3.25
06/24/98	5.38	4.72	6.29	4.64	3.89	3.99	6.05	4.66	4.02
07/24/98	6.78	5.91	NA	5.69	4.79	4.90	5.74	6.31	4.72
09/02/98	8.66	7.76	NA	7.41	6.39	6.46	6.92	7.49	5.99
10/15/98	7.85	7.22	NA	7.13	6.50	6.52	7.06	7.73	6.34
11/12/98	7.47	6.84	8.10	6.69	6.07	6.06	6.55	7.36	5.86
12/10/98	2.40	1.87	3.16	2.28	3.12	3.16	2.81	3.08	1.70
01/14/99	NA	NA	0.44	0.19	0.37	0.19	NA	NA	NA
02/25/99	0.94	0.42	1.31	0.90	1.14	0.98	1.44	1.51	NA
03/25/99	2.82	2.32	3.35	2.48	2.42	2.42	3.51	3.74	2.31
05/06/99	3.14	2.68	3.62	2.67	2.31	2.45	3.58	3.96	2.38
09/23/99	6.88	6.19	7.75	6.02	5.27	5.33	6.06	6.76	5.22
01/27/00	2.45	1.95	2.87	2.00	1.82	1.90	3.68	3.01	1.56
03/30/00	2.73	2.33	3.25	2.37	2.03	2.18	3.10	3.36	1.89

NA: Wells were either not accessible due to flooding or difficulty locating in tall grass or corn, or the well was dry.

Table G.2. Depth to water measurements at Site 2 in feet below ground surface. Values are corrected for depth of the casing below ground.

	BW-1	BW-2	BW-3	BW-4	BW-5	BW-6
05/28/98	12.49	13.17	16.34	15.46	18.63	18.44
06/23/98	13.29	13.93	17.10	16.21	19.41	19.16
07/23/98	13.08	14.81	17.97	17.11	20.34	20.06
09/02/98	16.25	16.87	19.90	19.11	22.40	21.98
10/14/98	16.79	17.40	20.50	19.64	22.98	22.64
11/11/98	16.83	17.45	20.69	19.82	23.18	22.86
12/09/98	13.81	14.42	18.00	17.09	20.89	20.67
01/13/99	9.96	10.59	14.39	13.47	17.25	16.99
02/24/99	8.06	8.81	12.50	11.49	15.21	15.09
03/24/99	7.77	8.49	12.03	11.02	14.64	14.50
05/05/99	12.04	12.75	16.13	15.17	18.54	18.38
06/03/99	11.01	11.69	15.05	14.15	17.53	17.43
07/08/99	11.52	13.16	16.38	15.46	18.70	18.53
08/26/99	14.65	15.28	18.39	17.53	20.77	20.51
09/22/99	15.48	16.03	19.29	18.51	21.82	21.44
10/21/99	15.88	16.48	19.64	18.73	22.08	21.79
11/18/99	15.14	15.76	19.20	18.30	21.78	21.53
12/28/99	9.90	10.54	14.07	13.16	16.84	16.70
01/26/00	9.81	10.53	13.99	13.05	16.59	16.50
03/02/00	10.40	11.07	14.54	NA	NA	16.80
03/30/00	9.27	9.91	10.61	NA	NA	14.09

NA: Wells were abandoned.

Appendix H. Nitrogen application at Site 1 by episode for 1997-99.

The application rate is assumed to be 350 gallons/minute based on the nozzle capacity.

1997

Upgradient near MW-1, -2

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure N lb applied	Manure N lb/acre applied	Commercial Fertilizer N applied (lb/acre)	Total N applied (lb/acre)	
04/12/97	3	63,000	238,455	*1,600*	841	22	80	102	
05/21/97	11	231,000	874,335	*1,600*	3,085	154		154	
06/19/97	7	147,000	556,395	*1,000*	1,227	61		61	
07/18/97	3	63,000	238,455	1,000	526	26	80	106	
07/21/97	6	115,500	437,168	1,000	964	48		48	
07/29/97	12	241,500	914,078	1,000	2,016	101		101	
07/31/97	11	231,000	874,335	1,000	1,928	96		96	
10/23/97	13	262,500	993,563	*1,100*	2,410	120	0	120	
		1,354,500				630	160	**790**	**Total**

Downgradient near MW-3, -4, -5

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
04/07/97	6	126,000	476,910	*1,600*	1,683	84	80	164	
06/17/97	9	189,000	715,365	*1,000*	1,577	79		79	
7/26-28/97	14	294,000	1,112,790	1,000	2,454	123	80	203	
07/31/97	12	252,000	953,820	1,000	2,103	105		105	
08/23/97	14	294,000	1,112,790	*1,000*	2,454	123		123	
08/28/97	14	294,000	1,112,790	*1,000*	2,454	123		123	
09/08/97	14	294,000	1,112,790	*1,000*	2,454	123		123	
10/21/97	10	210,000	794,850	*1,100*	1,928	96	0	96	
		1,953,000				855	160	**1,015**	**Total**

Downgradient near MW-7, -8, -9

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
04/08/97	6	115,500	437,168	*1,600*	1,542	77	80	157	
05/20/97	8	168,000	635,880	*1,600*	2,243	112		112	
06/17/97	11	231,000	874,335	*1,000*	1,928	96		96	
7/23-24/97	6	115,500	437,168	1,000	964	48	80	128	
07/29/97	6	126,000	476,910	1,000	1,052	53		53	
07/31/97	12	252,000	953,820	1,000	2,103	105		105	
08/22/97	14	294,000	1,112,790	*1,000*	2,454	123		123	
08/28/98	14	294,000	1,112,790	*1,000*	2,454	123		123	
09/08/97	14	294,000	1,112,790	*1,000*	2,454	123		123	
10/21/97	12	252,000	953,820	*1,100*	2,313	116		116	
11/13/97	7	147,000	556,395	*1,100*	1,350	67	0	67	
		2,289,000				966	80	**1,046**	**Total**

1998

The 1998 data record is incomplete. The following are estimates of nitrogen application recorded.

Upgradient near MW-1, -2

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
04/23/98		252,000	953,820	1600	3,365	89		89	
06/20/98		504,000	1,907,640	1600	6,730	177		177	
07/25/98		504,000	1,907,640	1600	6,730	177		177	
							80	80	
							80	80	
Not all applications recorded.						443	160	**603**	**Total**

Downgradient near MW-3, -4, -5

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
04/24/98		126,000	476,910	1600	1,683	84		84	
05/26/98		210000	794,850	1600	2,804	140		140	
1/9/00		298800	1,130,958	1600	3,990	200		200	
09/03/98		597600	2,261,916	1600	7,980	399		399	
							80	80	
							80	80	
Not all applications recorded.						823	160	**983**	**Total**

Downgradient near MW-7, -8, -9

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
05/01/98		210,000	794,850	*1,600*	2,804	140	80	220	
							80	80	
Solid manure applied at unknown rate.						140	160	**300**	**Total**

1999

Upgradient near MW-1 and MW-2 - Assumed to be the same as at the MW-3, -4, -5, and -6 locations (350 lb/acre total) based on the dairyman's assessment that loading was the same at both sites.

Downgradient near MW-3, -4, -5, -6

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
5/5/99	4	84,000	317,940	*1,780*	1,248	62		62	
6/7/99	3	63,000	238,455	*1,160*	610	30	100	130	
6/16/99	5	105,000	397,425	*1,160*	1,017	51		51	
7/13/99	4	84,000	317,940	540	379	19		19	
7/16/99	4	84,000	317,940	540	379	19		19	
8/20/99	6	126,000	476,910	680	715	36		36	
8/24/99	5	105,000	397,425	680	596	30		30	
10/1/99	5	105,000	397,425	680	596	30	0	30	
		756,000				277	100	**377**	**Total**

Downgradient near MW-7, -8, -9

Date	Hours applied	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure lb applied	Manure N lb/acre applied	Commercial Fertilizer applied (lb/acre)	Total N applied (lb/acre)	
4/23/99	4	84,000	317,940	*1,780*	1,248	62		62	
4/30/99	4	84,000	317,940	*1,780*	1,248	62		62	
6/1/99							100	100	
8/2/99	8	168,000	635,880	540	757	38		38	
8/6/99	8	168,000	635,880	540	757	38		38	
9/6/99	3	63,000	238,455	680	358	18		18	
10/3/99	2.5	52,500	198,713	680	298	15	0	15	
		619,500				233	100	**333**	**Total**

[1] Most of the values in italics represent the measured TKN concentration from the manure gun on the nearest date. The measured value for October 14, 1998 was used for October 21, 1997, because there was no measured value close to that date. Likewise, the April 1998 TKN ma
lagoon value was used for April and May 1997 estimates. The April and May 1999 values represent the ammonia -N manure value for that date divided by the mean fraction of ammonia in TKN. The June 1999 value is the value half-way between the estimate for May 5 and July 15, 1999.

Appendix I. Nitrogen application at Site 2 by episode for 1998-99.

1998

Downgradient

Date	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)[1]	Manure N lb applied	Commercial fertilizer applied (lb/acre)	Total N applied (lb/acre)	
3/1/98	6,000	22,710	860	43		43	
5/9-11/98	5000	18,925	*640*	27		27	
6/8/98	5000	18,925	640	27		27	
8/19/98	5000	18,925	1,250	52	125	177	
11/2/98	4000	15,140	2,275	76	0	76	
				225	125	350	Total

Upgradient

Date	Manure applied (gallons/acre)	Manure Liters applied	Manure TKN (mg/L)	Manure lb applied	Commercial fertilizer applied (lb/acre)	Total N applied (lb/acre)	
Spring					60	60	
Summer					50	50	
					110	110	Total

1999

Downgradient

Date	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)	Manure N lb applied	Commercial fertilizer applied (lb/acre)	Total N applied (lb/acre)	
3/30/99	7000	26,495	*860*	50		50	
4/30/99	7000	26,495	*860*	50		50	
6/21/99	8000	30,280	1,350	90		90	
8/14/99	5000	18,925	*1,250*	52	150	202	
10/25/99	5000	18,925	*2,275*	95	0	95	
				338	150	488	Total

Upgradient

Date	Manure applied (gallons/acre)	Manure applied (liters)	Manure TKN (mg/L)	Manure lb applied	Commercial fertilizer applied (lb/acre)	Total N applied (lb/acre)	
Spring					60	60	
Summer					50	50	
					110	110	Total

[1] Numbers in italics represent the TKN sample concentration for the closest date (1998 data) or for the same date in 1998 (1999 data). In 1999 only one sample was collected on June 3. The TKN concentrations for 1998 were used for all other dates in 1999. However, the ammonia-n value was used instead of TKN for 3/1/98, because the TKN value was suspect.

Appendix J. Water quality results for manure samples (mg/L).

Sample Site	Date	Ammonia-N	Nitrate+ nitrite-N	Total Per-sulfate N	Total Kjeldahl N	Chloride	Total Dissolved Solids	Total Solids	Specific Conductance (µmhos/cm)	TKN (mg/kg)	% Solids
Site 1											
Lagoon	7/25/97	360	0.014 J		968 JH				11,400	1,450 JH	30.8
	8/21/97	760	3.56			317					
	8/21/97	530	1.83								
	3/11/98	680 J	0.010 UJ		1600	422		19,700			
	4/17/98	90	0.010 U		1,610	441		21,000	12,300		
	6/23/98	340	0.076		834	212					
Manure Gun	8/21/97	580	2.44	0.17							
	5/29/98	920	4.83		1,630	375			10,400		
	05/29/1998(dup)				1,710						
	6/24/98	444 J	1.13		1,600	230.0		10,000			
	9/3/98	330	2.00 J		397	153	5,300		6,530		
	10/14/98	590	0.337 J		1,100	309		19,100	20,100		
	5/5/99	1,140	0.05	677		424		21,800			
	7/15/99	440	0.010 UJ		539	239		10,500			
	8/26/99	548	0.010 U		677	652		10,900			
Site 2											
Pit	3/11/98	860 J	0.010 UJ		208	497			62,400	3,330	
	11/7/98	410 J	0.849		2,275	707			59,500	13,200	
Lagoon	6/12/98	632 H	3.87 J		613	480			49,000		
	6/3/99	830	0.018		1,350 J						
Manure	8/30/98	722	4 J		1,250	587	6,210			13,000	

( ): Small sample volume.
J: Estimate
H: Holding time exceeded
(TKN measurements for some manure samples in mg/kg dry wt are converted to mg/L using total solids (converted to % solids)).

Appendix K. Groundwater quality data.

"MW" sites are wells at Site 1. "BW" sites are wells at Site 2. Values are in mg/L or as specified.

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul- fate N		Total Kjel- dahl N		Chloride	Total Dis- solved Solids	Total Organic Carbon	Specific Conduc- tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc- tivity (not temper- ture-corrected before 10/99) (umhos/cm)	D.O.
Site 1																	
MW-1	6/26/97	0.016		6.87		7.62				7.50	199		275	14.4	5.51	215	0.3
MW-1	7/25/97	0.010	U	0.290		0.676				15.1	144		202	17.8	5.53	163	0.3
MW-1	8/21/97	0.032		9.00		9.43				20.4	na		512				
MW-1	9/17/97	0.010	U	2.02		2.63				10.3	115			15.2	5.13	127	6.1
MW-1	10/17/97	0.039		0.753		1.13				14.6	123			12.6	5.29	36	5.2
MW-1	11/20/97	0.010	U	2.63		2.89				9.8	138	6.0	211	8.7	5.54	117	5.8
MW-1	12/29/97	0.010	U	0.010	U	0.29				11.50	283	3.7	430				0.2
MW-1	2/5/98	0.010	U	0.010	U	0.361				10.10	254	4.0	379	9.9	5.63	224	0.2
MW-1	3/10/98	0.010	UJ	2.880		3.13				14.7	305	4.3	441	8.9	5.50		
MW-1	4/16/98	0.010	U	0.415		0.57		0.5	U	13.3	148	4.4	222	10.5	5.62	144	1.3
MW-1	5/27/98	0.010	U	0.966		1.56				11.4	145	5.1	231	12.8	5.29	164	1.0
MW-1	6/24/98	0.010	U	4.84	J	4.48	J			13.4	226	3.9	323	13.1	4.82	250	1.7
MW-1	7/24/98	0.010	U	1.07		1.36				14.3	266		378	14.1	5.09	300	0.1
MW-1	9/2/98	0.010	U	1.31		1.470				15.9	308		454	13.9	4.96	301	1.4
MW-1	10/15/98	0.010	U	0.066		0.321				18.5	378		504	13.1	5.19	400	0.1
MW-1	11/12/98	0.010	U	0.020		0.394				18.7	359		474	12.0	5.15	372	0.3
MW-1	12/10/98	0.010	UJ	0.010	U	0.377				19.9	315			10.4	6.13	344	0.1
MW-1	1/14/99	0.010	U	0.010	U	0.323				20.1	347		523	10.6	5.90	320	
MW-1	2/25/99	0.012		0.010	U	0.299				15.3	410			9.5	5.76	330	0.1
MW-1	3/25/99	0.022		0.601		0.915				14.8	305		454	9.3	5.57	322	0.2
MW-1	5/7/99	0.038		3.72		5.00				8.02	174			10.2	6.58	201	0.6
MW-1	9/23/99	0.033		2.11		2.45				14.4	346		495	13.8		395	0.3
MW-1	1/27/00	0.010	U	0.010	U	0.319				9.39	274		415			344	
MW-1	3/30/00	0.010	U	0.014		0.317				11.90	250						
MW-2	6/26/97	0.011		0.615		0.874				13.30	166		234	14.5	5.44	186	0.2
MW-2	7/25/97	0.010	U	0.153		0.373				14.0	150			16.5	5.25	135	0.2
MW-2	8/21/97	0.041		0.080		0.178				15.0			225				
MW-2	9/17/97	0.010	U	0.169		0.326				8.89	182			15.2	4.86	162	0.1
MW-2	10/17/97	0.010	U	1.15		1.31				11.50	159			13.5	4.60	47	2.1
MW-2	11/20/97	0.010	U	1.51		1.60				9.01	151	3.4	210	10.4	5.04	138	2.8
MW-2	12/29/97	0.010	U	5.35		4.95				10.30	239	1.9	326				0.5
MW-2	2/5/98	0.010	U	13.9		13.6				17.0	288	2.0	411	8.0	5.04	64	0.3
MW-2	3/10/98	0.010	UJ	21.4		20.7				13.3	262	1.9	367	7.8	4.6	320	
MW-2	4/16/98	0.022		2.46		2.65		0.973		8.7	160	2.9	225	9.4	5.12	100	0.2
MW-2	5/27/98	0.010	U	0.032		0.207				14.1	145	2.1	217	12.3	4.93	147	0.2
MW-2	6/24/98	0.010	U	1.02		1.07				10.2	166	2.0		13.4	4.52	166	0.2
MW-2	7/24/98	0.010	U	4.09		4.04				8.89	170		217	14.8	4.58	177	0.1
MW-2	9/2/98	0.010	U	15.1	J	13.30	J				284		406	15.1	4.43	317	
MW-2	10/15/98	0.010	U	3.23		3.22				23.4	374		498	13.4	4.61	403	0.2
MW-2	11/12/98	0.010	U	2.22		2.65				22.7	453			12.0	4.59	469	0.1
MW-2	12/10/98	0.032		5.48		2.86				14.2	390		532	9.6	5.43	386	0.3
MW-2	1/14/99	0.010	U	0.753		1.01				18.9	363		513	9.4	5.40	320	
MW-2	2/25/99	0.010	U	0.602		0.750				17.0	361			8.3	5.58	356	0.2
MW-2	3/25/99	0.012		0.284		0.502				14.6	339		492	8.3	5.18	342	0.2
MW-2	5/7/99	0.029		0.102		0.343				9.77	198			9.8	6.46	217	0.4
MW-2	9/23/99	0.029		0.060		0.263				7.05	189		257	14.3		204	0.3
MW-2	1/27/00	0.010	U	0.243		0.441				18.2	259			8.8	5.19	312	0.5
MW-2	3/30/00	0.010	U	0.226		0.399				21.8	257						
MW-3	6/26/97	0.014		2.87		3.11				4.00	131			12.4	5.75	137	1.8
MW-3	7/25/97	0.010	U	2.79		3.13				2.80	114		155	13.6	5.66	120	1.9
MW-3	8/21/97	dry		dry		dry				dry			dry				
MW-3	9/18/97	0.010	U	5.23		5.46				3.23	158			14.4	5.47	161	2.5
MW-3	10/17/97	0.010	U	15.7		16.2				10.90	201			13.3	5.27	127	2.7
MW-3	11/20/97	0.010	U	10.9		11.0				8.75	178	3.9	260	11.4	5.63	78	2.1
MW-3	11/20/97-dup	0.010	U	11.9		12.8				8.02	167	4.0	253				
MW-3	12/29/97	0.010	U	60	J	53	J			27.5	460	3.8	638				4.7
MW-3	2/5/98	0.010	U	31.6		32				15.9	308	7.0	422	7.2	5.48	77	4.5
MW-3	3/10/98	0.010	UJ	19.5		19.2				11.7	228	4.3	337	7.5	5.6	290	na

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul-fate N		Total Kjel-dahl N		Chloride	Total Dis-solved Solids	Total Organic Carbon	Specific Conduc-tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc-tivity (not temper-ture-corrected before 10/99) (umhos/cm)	D.O.
MW-3	4/16/98	0.010	U	16.4		14.8	J	0.5	U	9.09	214	4.4	289	8.7	5.34	150	3.9
MW-3	5/29/98	0.010	U	6.54		7.14				6.28	143	3.3	205	10.9	5.33	149	3.2
MW-3	5/29/98-dup	0.010	U	6.95		7.41				6.21	150		205	10.9	5.33	149	3.2
MW-3	6/24/98	0.010	U	22.2		20.4				12.9	259	2.6	349	11.8	5.18	251	1.1
MW-3	7/24/98																
MW-3	9/1/98																
MW-3	10/15/98																
MW-3	11/12/98	0.010	U	29.6		33.1				15.7	311			12.3	5.37	340	1.9
MW-3	12/10/98	0.011		74.1		68.2				35.4	632		878	10.4	5.43	680	7.9
MW-3	1/14/99	0.010	U	18.4		27.9		0.5	U	9.61	286		407				
MW-3	2/25/99	0.010	U	12.5		16.4				5.15	191			7.0	5.86	183	7.5
MW-3	3/25/99	0.010	U	7.56		14.8				5.40	182		265	7.7	5.50	176	7.5
MW-3	5/6/99	0.035		12.4		14.5				5.30	173			8.6	5.69	170	4.1
MW-3	9/23/99	0.027		18.4		18.0				7.83	239		348	13.0		275	4.4
MW-3	1/27/00	0.010	U	16.3		18.8				3.63	251			7.3	5.74	228	7.3
MW-3	3/31/00	0.038		3.01		8.4				0.80	158		203	7.7	4.94	206	7.9
MW-4	6/26/97	0.010	U	4.01		4.00				9.79	258		379	11.2	5.76	198	0.2
MW-4	7/25/97	0.010	U	2.36		2.63				8.25	242		356	12.3	5.62	180	0.3
MW-4	8/21/97	0.010	U	3.98		4.20				4.25			280				
MW-4	9/19/97	0.010	U	0.092		0.288				5.26	192				5.4	280	
MW-4	10/17/97	0.010	U	0.191		0.029				7.36	223			13.0	5.30	231	0.2
MW-4	10/17/97-dup	0.010	U	0.232		0.429				7.27	227						
MW-4	11/21/97	0.010	U	0.563		0.727				7.44	208	3.2	320	11.1	4.38	180	0.3
MW-4	12/29/97	0.010	U	8.48		7.99				7.80	222	2.7	325				
MW-4	2/5/98	0.010	U	34		35				18.3	346	2.3	518	8.0	5.36	315	0.3
MW-4	3/11/98	0.010	UJ	43.1		34.4				19.4	373	2.3	543	9.5	5.4	450	na
MW-4	4/16/98	0.010	U	26.1		22.4	J	0.5	U	17.6	334	3.1	484	9.5	5.38	267	0.3
MW-4	5/27/98	0.011		21.5		23.9				17.3	321	2.5	485	10.1	4.85	357	0.3
MW-4	6/24/98	0.010	U	25.8		23.1				15.7	305	2.6		11.5	5.09	349	0.2
MW-4	7/24/98	0.010	U	28.0		28.2				13.7	299		413	13.6	5.24	336	0.1
MW-4	9/1/98	0.010	U	19.8	J	18.2	J			12.9	257		399	14.4	5.30	305	0.2
MW-4	10/15/98	0.010	U	7.30		7.52				13.3	272		394	13.2	5.40	314	0.2
MW-4	10/15/98-dup	0.010	U	7.31		7.63				13.1	269		393				
MW-4	11/12/98	0.010	U	8.36		8.68				13.7	278			12.0	5.48	317	1.1
MW-4	12/10/98	0.016		14.8		8.20				15.2	283		425	10.5	5.53	314	0.1
MW-4	1/14/99	0.010	U	42.3		43.5		0.5	U	18.3	401		575	8.8	5.74	403	0.2
MW-4	2/25/99	0.010	U	44.9				0.5	UJ	20.4	434			7.8	5.74	420	0.1
MW-4	3/25/99	0.010	U	23		26.9		0.5	U	13.5	341		494	8.0	5.10	342	0.2
MW-4	03/25/99-dup	0.010	U	30		0.528	J	0.5	U	14.0	332		497				
MW-4	5/6/99	0.034		21.0		27.1				16.0	354			8.8	5.54	372	0.5
MW-4	9/23/99	0.029		18.6		18.4				10.5	269		390	12.9		306	0.2
MW-4	1/27/00	0.010	U	50.7		48.3		0.5	U	30.5	495			8.0	5.41	563	0.8
MW-4	3/30/00	0.010	U	43.1		51.9		0.5	U	32.7	472			8.4	4.75	723	0.3
MW-5	6/26/97	0.010	U	6.38		6.45				16.0	310		444	12.5	5.62	267	0.2
MW-5	7/25/97	0.010	U	3.50		3.79				14.2	295		421	13.7	5.61	182	0.3
MW-5	8/21/97	0.010	U	1.85		2.17				14.1			386				
MW-5	9/19/97	0.010	U	0.89		1.09				12.0	223			15.1	5.30	310	
MW-5	10/17/97	0.010	U	8.57		8.91				19.0	297			14.4	5.10	270	0.2
MW-5	11/21/97	0.010	U	7.59		7.74				22.9	292	4.0	427	11.5	4.28	84	0.2
MW-5	12/29/97	0.010	U	20.7		19.4				24.9	347	3.3	508				0.2
MW-5	2/5/98	0.010	U	18.1		17.8				22.5	331	3.6	496	7.6	5.34	322	0.3
MW-5	3/11/98	0.010	UJ	14.9		14.8				22.7	341	3.3	504	8.9	5.3	440	
MW-5	4/16/98	0.010	U	15.7		14.7		0.5	U	22.3	332	4.1	487	9.1	5.36	290	0.2
MW-5	5/27/98	0.043		15		17.7				25.6	337	4.5	496	10.6	4.73	308	0.2
MW-5	6/24/98	0.010	U	14.0		13.0				23.1	331	3.6	492	12.3	5.19	378	0.7
MW-5	7/24/98	0.010	U	14.6		14.9				24.9	339		495	14.2	5.25	394	0.1
MW-5	9/1/98	0.010	U	17.6		17.1				29.9	327		493	15.4	5.26	413	0.2
MW-5	10/15/98	0.010	U	5.62		5.88				22.9	342		473	14.1	5.32	385	0.2
MW-5	11/12/98	0.010	U	3.65		3.91				19.7	332			12.3	5.39	374	0.2
MW-5	12/10/98	0.014		32.6		41.7				38.0	517		751	10.4	5.39	552	0.1
MW-5	1/14/99	0.010	U	39.3		41.2		13.0		30.1	453		671				
MW-5	2/25/99	0.010	U	31.7				0.500	UJ	25.5	412			7.4	6.07	410	0.1

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul-fate N	Total Kjel-dahl N		Chloride	Total Dis-solved Solids	Total Organic Carbon	Specific Conduc-tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc-tivity (not temper-ture-corrected before 10/99) (umhos/cm)	D.O.
MW-5	3/25/99	0.010	U	25.2		23.7	0.5	U	23.2	372		563	7.8	5.21	385	0.3
MW-5	5/6/99	0.019		36.0		17.9	0.689		21.0	339			9.0	5.50	365	0.5
MW-5	9/23/99	0.036		10.8		10.5			21.7	359		511	13.7		409	0.1
MW-5	1/27/00	0.010	U	29.0		30.1	0.5	U	32.6	434			8.0	5.48	501	0.4
MW-5	3/30/00	0.010	U	29.0		28.1	0.5	U	34.8	421			8.2	4.78	646	0.3
MW-6	6/26/97	0.038		12.3		12.5			26.8	453		650	12.7	5.97	488	0.2
MW-6	6/26/97-dup	0.045		14.2		14.1			27.5	428						
MW-6	7/25/97	0.010	U	12.3		13.1			24.6	427		608	14.0	5.93	427	0.9
MW-6	8/21/97	0.031		21		23.2			31.6			709				
MW-6	9/19/97	0.010	U	22.9		23.7			30.6	475				5.40	620	
MW-6	10/17/97	0.010	U	26.2		26.6			29.4	467			13.6	5.48	205	0.2
MW-6	11/21/97	0.010	U	16.6		16.7			25.1	422	9.2	593	10.8	4.62	270	0.1
MW-6	12/30/97	0.010	U	11.7		11.6			22.4	381	10.2	532				0.2
MW-6	2/5/98	0.010	U	11.4		11.6			21.7	380	7.5	528	7.6	5.66	285	0.3
MW-6	3/11/98	0.010	UJ	7.21		8.05			19.4	346	8.0	491	9.0	5.8	380	na
MW-6	4/16/98	0.010	U	6.16		5.89	0.7		18.8	340	8.6	491	9.5	5.58	278	0.4
MW-6	5/27/98	0.010	U	10.4		12			22.7	373	8.8	546	11.3	4.95	388	0.2
MW-6	6/24/98	0.010	U	10.9		10.4			23.5	358	6.2		12.8	5.43	440	0.2
MW-6	7/24/98	0.010	U	17.1		17.1			26.1	415		582	14.5	5.39	480	0.3
MW-6	9/1/98	0.010	U	14.6		15.1			29.6	403		595	15.3	4.95	488	0.1
MW-6	9/1/98-dup	0.010	U	13.9		14.1			29.8	409		594				
MW-6	10/15/98	0.010	U	8.46		8.59			27.0	414		575	13.9	5.36	463	0.2
MW-6	11/12/98	0.010	U	5.60		6.18			23.5	367			12.2	5.42	410	0.4
MW-6	12/10/98	0.029		24.3		22.5			24.8	409		578	10.0	5.96	431	1.2
MW-6	1/14/99	0.010	U	16.5		17.40			30.7	460		665				
MW-6	2/25/99	0.010	U	13.9		16.4			27.3	454		647	7.3	5.77	474	0.6
MW-6	2/25/99-dup	0.010	U	15.0		17.2			26.6	444		655				
MW-6	3/25/99	0.010	U	12.1		14.9			27.2	432		641	8.0	5.47	448	0.6
MW-6	5/6/99	0.029		16.1		17.7			28.2	461			9.6	5.80	491	0.6
MW-6	5/6/99-dup	0.029		14.9		18.5			28.1	457			13.7	na	551	0.2
MW-6	9/23/99	0.026		21.1		20.6			34.4	491		688				
MW-6	1/27/00	0.010	U	14.4		15.0			26.6	445		631	7.5	5.76	487	2.1
MW-6	3/30/00	0.010	U	17.3		14.3			27.9	441			9.0	5.27	634	0.5
MW-7	6/26/97	0.025		1.88		2.06			27.6	365			11.8	5.70	329	0.4
MW-7	7/25/97	0.010	U	0.593		0.815			31.2	402		574	13.7	5.70	340	0.3
MW-7	7/25/97-dup	0.010	U	0.655		0.864			31.2	404		573				
MW-7	8/21/97	0.019		0.216		0.467			31.5			602				
MW-7	9/19/97	0.010	U	0.140		0.384			28.5	420			14.3	5.48	430	0.2
MW-7	10/16/97	0.016		0.142		0.281			25.2	404			13.8	5.52	354	1.1
MW-7	11/21/97	0.010	U	1.16		1.40			19.5	350	3.5	493	11.7	4.49	375	0.2
MW-7	12/30/97	0.010	U	0.343		0.579			21.8	351	2.5	496				0.5
MW-7	2/6/98	0.010	U	0.466		0.663			22.7	326	2.7	474	8.1	4.99	283	0.4
MW-7	3/11/98	0.010	UJ	0.736	J	1.00			27.8	339	3.0	499	8.8	5.4		na
MW-7	4/17/98	0.019		0.089		0.238	0.5	U	21.9	318	3.2	458	9.2	4.79	296	1.4
MW-7	5/28/98	0.032		0.043		0.680			20.8	314	2.7	459	11.2	5.44	344	2.0
MW-7	6/24/98	0.010	U	0.050		0.288			21.8	342	2.8		12.1	5.07	420	3.5
MW-7	7/24/98	0.024		0.066		0.364			24.8	315		475	14.0	5.38	376	0.1
MW-7	9/2/98	0.017		1.54		1.80			30.1	353		515	15.0	5.34	387	0.3
MW-7	10/15/98	0.012		0.096		0.407			39.5	417		597	14.5	5.51	489	1.0
MW-7	11/12/98	0.010	U	0.169		0.608			39.6	435			12.9	5.52	478	0.3
MW-7	12/10/98	0.053		2.05		1.28			34.3	411		592	11.1	5.52	444	0.2
MW-7	1/14/99	0.010	U	10.9		12.4			42.7	461		680	9.4	na	390	
MW-7	2/25/99	0.010	U	12.2		15.7			36.6	487			7.9	5.67	483	0.2
MW-7	3/26/99	0.010	U	2.17		2.19			25.1	383		564	7.6	5.48	381	0.3
MW-7	5/6/99	0.030		0.959		1.31			17.0	273			9.3	5.69	299	0.3
MW-7	9/23/99	0.037		0.300		0.617			21.8	363		520	13.7		411	0.1
MW-7	1/27/00	0.010	U	5.09		5.41			27.5	394			9.0	5.50	474	5.5
MW-7	3/30/00	0.010	U	8.73		7.21			23.6	394			9.2	5.15	577	0.3
MW-8	6/26/97	0.010	U	15.6		15.8			9.91	248			11.7	5.97	185	0.9
MW-8	7/25/97	0.010	U	12.6		13.0			9.01	260			13.2	5.66	278	2.7
MW-8	8/21/97	0.011		8.98		9.27			7.54			355				

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul-fate N		Total Kjel-dahl N		Chloride	Total Dis-solved Solids	Total Organic Carbon		Specific Conduc-tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc-tivity (not temper-ture-corrected before 10/99) (umhos/cm)	D.O.
MW-8	9/19/97	0.010	U	6.02		6.38				8.39	249				13.9	5.42	218	0.2
MW-8	10/16/97	0.010	U	5.61		6.01				11.6	212				13.3	5.42	218	1.8
MW-8	11/21/97	0.010	U	9.09		9.14				6.69	221	3.9		328	11.3	4.53	58	1.6
MW-8	12/30/97	0.010	U	22		20.4				10.80	255	5.9		371				2.6
MW-8	2/6/98	0.010	U	37.8		37.8				17.8	341	4.3		481	7.6	4.94	287	3.1
MW-8	2/6/98-dup	0.010	U	37.6		38.5				17.4	337	4.4		483				
MW-8	3/11/98	0.010	UJ	46		40.3				20.4	384	3.4		534	8.2	5.4	na	na
MW-8	4/18/98	0.010	U	52		50.1		0.5	U	25.7	432	3.4		607	8.6	4.46	356	3.2
MW-8	5/28/98	0.010	U	30		38				28.6	391	2.8		583	11.2	5.32	442	2.8
MW-8	6/24/98	0.010	U	31		27.3	J			26.4	390	2.8			12.1	5.28	373	0.3
MW-8	7/24/98	0.010	U	24.6		24.2				23.6	358			519	13.2	5.23	410	0.2
MW-8	7/24/98-dup	0.010	U	23.3		24.9				23.6	348			519				
MW-8	9/2/98	0.010	U	17.1		17.4				22.7	313			494				
MW-8	10/15/98	0.010	U	9.60		9.81				22.3	339			491				
MW-8	11/12/98	0.010	U	15.5		16.0				21.9	335				12.4	5.37	387	0.2
MW-8	12/10/98	0.018		45.3		22.4				22.7	320			471	10.3	5.68	346	5.1
MW-8	1/14/99	0.010	U	33.0		35.2		0.5	U	23.1	339			507	7.8			
MW-8	2/25/99	0.010	U	19.6		19.9				10.9	244				7.0	6.14	223	5.6
MW-8	3/26/99	0.010	U	24		26.3		0.5	U	10.4	264			376	7.8	5.91	254	3.1
MW-8	5/6/99	0.032		20.7		26.9		0.5	U	13.9	279				9.3	5.63	291	3.6
MW-8	9/23/99	0.028		4.17		17.3				18.8	298			441	13.2	na	347	0.1
MW-8	1/27/00	0.010	U	31.5		32.5		0.5	U	26.0	373				8.0	5.78	415	7.2
MW-8	1/27/00-dup	0.010	U	32.8		32.3		0.5	U	26.6	399							
MW-8	3/30/00	0.010	U	21.0		20.9				20.9	274				8.3	5.13	424	5.7
MW-9	6/26/97	0.010	U	9.17		8.91				10.3	215				13.5	5.50	179	0.3
MW-9	7/25/97	0.010	U	6.52		6.68				10.3	214			290	14.9	5.40	224	0.2
MW-9	8/21/97	0.015		4.63		5.00				10.6				295				
MW-9	9/19/97	0.010	U	4.29		4.31				11.5	222				15.0	5.10	216	0.6
MW-9	9/19/97-dup	0.010	U	4.41		4.46				11.8	213							
MW-9	10/16/97	0.010	U	2.82		3.45				11.5	266				13.6	5.17	236	0.1
MW-9	11/21/97	0.010	U	17.1		17.2				19.0	255	4.2		365	10.9	4.22	208	0.2
MW-9	12/30/97	0.010	U	31		29.8				29.0	348	2.6		490				0.2
MW-9	2/6/98	2.07		40.8		41.9				41.8	497	14.1		707	7.0	5.48	458	n/a
MW-9	3/11/98	0.029	J	44	J	40.8				45.1	416	2.9		616	8.0	5.0		
MW-9	4/17/98																	
MW-9	5/28/98	0.010	U	22		25.1				41.8	336	3.3		503	12.7	4.98	395	0.2
MW-9	6/24/98	0.010	U	15.5		13.6				37.7	295	3.6			13.5	4.84	359	0.3
MW-9	7/24/98	0.010	U	15.3		15.4				33.3	302			443	15.2	4.96	358	0.1
MW-9	9/2/98	0.010	U	15.8		14.2				34.2	300			445	15.5	5.02	359	0.4
MW-9	10/15/98	0.010	U	6.24		6.51				30.1	413			568	13.6	5.01	463	0.5
MW-9	11/12/98	0.010	U	10.7		11.6				30.7	474				11.8	5.08	508	0.2
MW-9	12/10/98	0.019		45.9		61.6				56.8	583			840	9.8	5.04	621	1.5
MW-9	1/14/99	na		na		na				na	na			na				
MW-9	2/25/99	na		na		na				na	na			na				
MW-9	3/26/99	0.010	U	24		25.1		0.5	U	17.8	319			472				
MW-9	5/6/99	0.025		22.8		27.2		0.5	U	16.2	286				9.7	5.37	306	0.4
MW-9	9/23/99	0.027		16.6		16.3				19.9	297			421	14.2		340	0.4
MW-9	9/23/99-dup	0.028		16.6		16.3				20.0	286			420				
MW-9	1/27/00	0.010	U	31.5		30.8		0.5	U	29.5	388				7.6	5.12	438	5.2
MW-9	3/30/00	0.010	U	22.4		22.4				19.4	295				8.7	4.72	448	0.8
Site 2																		
BW-1	5/28/98	0.010	U	11.7		13.2				9.21	166	1.0	U	258	10.2	6.05	168	5.9
BW-1	6/23/98	0.010	U	12.6		11.0				9.23	183	1.0	U	248	10.5	5.98	182	5.4
BW-1	7/23/98	0.010	U	12.0		12.6				9.12	182	1.0	U	251	11.8	6.84	190	6.8
BW-1	9/1/98	0.010	U	13.7	J	12.4	J			9.13	161			248	11.9	5.92	186	6.1
BW-1	10/15/98	0.010	U	11.5		11.5				9.28	175			246	11.7	6.08	183	7.4
BW-1	11/11/98	0.010	U	12.3		12.4				9.38	172				11.4	6.13	184	7.3
BW-1	12/9/98	0.010	U	42.3		48.6				10.9	183	1.3		258	10.9	6.29	193	6.2
BW-1	1/13/99	0.010	U	15.7		15.9				10.9	179	1.0	U	266	9.9	6.13	182	10.8
BW-1	2/24/99	0.010	U	11.2		11.8									9.4	6.90	168	8.3
BW-1	3/24/99	0.010	U	11.2		10.5				7.85	153			224	9.2	6.07	160	7.8
BW-1	5/5/99	0.010	U	9.8		11.1				7.31	128	0.68		225	9.7	6.12	160	7.3

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul-fate N		Total Kjel-dahl N	Chloride	Total Dis-solved Solids	Total Organic Carbon		Specific Conduc-tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc-tivity (not temper-ture-corrected before 10/99) (umhos/cm)	D.O.
BW-1	6/3/99	0.010	U	10.5		11.3			7.66	157			228	10.4	6.03	165	6.2
BW-1	7/8/99	0.022		12.4		14.1			8.32	137			234	11.2	6.06	173	7.8
BW-1	8/26/99	0.010	U	12.2		12.8			8.99	180			239	12.1	5.84	180	7.6
BW-1	9/22/99	0.030		13.1		11.7				145			241	12.3		183	6.9
BW-1	10/21/99	0.010	UJ	12.5		12.0			10.1	166			244	11.9	6.14	na	6.6
BW-1	11/18/99	0.010	U	11.7		12.4			9.3	158			240	9.6	6.32	250	na
BW-1	12/27/99	0.010	U	15.7		16.1			10.2	173			264	9.9	6.12	188	7.3
BW-1	1/26/00	0.010	U	15.5		16.0			10.1	193			269	9.0	6.18	220	6.8
BW-1	3/2/00	0.010	U	15.1		18.0			9.50	181			263	10.9	5.58	263	10.7
BW-1	3/29/00	0.010	U	15.0		15.0			9.37	172				10.9	5.58	263	10.7
BW-2	5/28/98	0.010	U	9.33		10.6			10.3	158	1.0	U	247	10.2	5.89	167	6.0
BW-2	6/23/98	0.010	U	9.99		8.32			10.3	176	1.0	U	244	10.2	5.85	178	4.2
BW-2	7/23/98	0.010	U	9.87		10.2			10.0	170	1.0	U	249	11.7	6.38	184	5.5
BW-2	9/2/98	0.010	U	12.4	J	10.8	J		10.4	154			255	12.0	5.81	192	6.0
BW-2	10/15/98	0.010	U	10.1		10.4			10.7	161			254	11.9	6.07	190	4.8
BW-2	10/15/98-dup	0.010	U	10.5		10.5			10.7	165			252				
BW-2	11/11/98	0.010	U	11.6		11.6			10.6	167				11.3	6.10	188	6.4
BW-2	12/9/98	0.010	U	23.0		12.4			10.9	167	1.23		243	11.1	6.16	182	7.1
BW-2	1/13/99	0.010	U	14.7		14.6			12.8	176	1.4		273	10.3	6.15	195	7.0
BW-2	2/24/99	0.010	U	9.94		12.0								9.6	6.53	179	6.9
BW-2	3/24/99	0.010	U	11.4	J	10.4	J		10.3	165			235	9.5	6.12	166	8.1
BW-2	3/24/99-dup	0.010	U	8.50		10.4			10.3	171			235				
BW-2	5/5/99	0.010	U	9.01		10.5			7.66	151	0.84		226	9.9	6.69	159	8.2
BW-2	6/3/99	0.010	U	10.0		10.6			8.5	150			229	10.4	6.07	167	7.4
BW-2	7/8/99	0.024		12.0		12.6			9.33	137			242	11.1	6.01	180	7.1
BW-2	8/26/99	0.010	U	12.8		13.1			10.8	64			260	12.1	5.61	192	6.9
BW-2	9/22/99	0.027		13.6		12.8				164			269	14.1		203	4.5
BW-2	10/21/99	0.010	UJ	13.9		17.3			12.8	184			274	12.3	6.09		5.6
BW-2	11/18/99	0.010	U	11.7		12.4			10.4	163			257		6.15	261	
BW-2	11/18/99-dup	0.010	U	12.2		12.6			10.3	188			257				
BW-2	12/27/99	0.010	U	14.9		15.5			11.6	197			274	10.4	6.14	197	7.2
BW-2	1/27/00	0.010	U	14.8		16.0			11.8	193				9.6	6.14	224	7.6
BW-2	3/2/00	0.010	U	15.1		18.0			11.8	191			274				
BW-2	3/02/00-dup	0.338		14.6		14.9			11.8	185			274				
BW-2	3/29/00	0.010	U	15.4		14.8			10.5	180				11.2	5.69	268	9.8
BW-3	5/28/98	0.010	U	9.47		10.3			9.26	155	1.0	U	237	10.5	5.66	161	5.0
BW-3	6/23/98	0.010	U	10.9		9.2	J		10.0	177	1.0	U	239	10.3	5.6	175	5.9
BW-3	7/24/98	0.010	U	10.6		11.3			9.81	159			242	11.7	6.02	181	4.2
BW-3	9/3/98	0.010	U	14.5	J	12.2	J		10.8	176			264	11.1	5.86	194	6.0
BW-3	10/15/98	0.010	U	11.8		12.1			11.1	171			267	10.7	5.92	198	6.9
BW-3	11/11/98	0.010	U	13.6		13.8			11.2	187				10.5	5.94	196	6.8
BW-3	12/9/98	0.012		10.1		10.6			10.0	169	1.39		235	10.5	5.95	174	7.3
BW-3	1/13/99	0.010	U	1.63		4.2			9.28	108	1.0	U	176	10.1	5.89	125	5.9
BW-3	2/24/99	0.010	U	5.00		5.30								9.1	6.41	129	9.5
BW-3	3/24/99	0.010	U	7.91	J	3.51	J			120			200	9.1	5.86	138	9.9
BW-3	5/5/99	0.010	U	8.60		9.85			11.0	111	0.93		210	9.8	6.35	150	8.5
BW-3	6/3/99	0.030		10.1		9.71			10.2	146			213	10.7	5.79	154	8.3
BW-3	7/8/99	0.028		10.1		11.1			10.1	151			217	10.9	5.68	156	4.9
BW-3	8/26/99	0.010	U	11.4		16.6	J		10.7	170			219	11.8	5.33	161	7.1
BW-3	9/22/99	0.028		10.5		10.3			10.5	137			220	11.7		165	6.2
BW-3	9/22/99-dup	0.028		10.4		9.85			10.6	142			220				
BW-3	10/21/99	0.010	UJ	10.3		9.43			9.77	160			220	11.6	5.89		6.7
BW-3	11/18/99	0.010	U	9.29		9.37			8.68	153			218	10.3	5.99	220	
BW-3	12/27/99	0.010	U	6.88		7.87			6.54	106			169	10.0	5.88	120	8.6
BW-3	1/26/00	0.010	U	7.65		9.50			7.64	107				9.0	5.97	147	8.5
BW-3	3/2/00	0.010	U	9.29		10.2			7.95	127			196				
BW-3	3/29/00	0.010	U	10.3		9.7			8.8	130				11.0	5.34	202	9.9
BW-4	5/28/98	0.010	U	13.2		14.4			10.7	185	1.0	U	277	10.6	5.85	205	9.2
BW-4	6/23/98	0.010	U	13.9		12.8			10.4	197	1.0	U	278	10.3	5.72	194	6.1
BW-4	7/24/98	0.010	U	13.0		13.5			10.0	205	1.0	U	275	11.6	6.07	204	5.7
BW-4	9/2/98	0.010	U	13.1		11.1			9.67	166			264	11.7	5.85	196	5.5

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persul-fate N		Total Kjel-dahl N	Chloride	Total Dis-solved Solids	Total Organic Carbon		Specific Conduc-tivity (umhos/cm)	Temp (field) ^{0}C	pH (field) (SU)	Specific Conduc-tivity (not temper-ture-corrected before 10/99) (umhos/cm)	D.O.
BW-4	9/2/98-dup	0.010	U	13.0		11.0			9.67	180			264				
BW-4	10/15/98	0.010	U	10.4		10.7			9.79	180				10.8	6.02	192	6.4
BW-4	11/11/98	0.010	U	11.7		11.8			9.9	159				10.5	6.04	186	7.3
BW-4	12/9/98	0.027		19.4		10.2					1.52			10.3	6.04	182	7.0
BW-4	1/13/99	0.010	U	9.05		10.1			10.2	157	1.0	U	237	9.9	6.09	171	11.1
BW-4	2/24/99	0.010	U	8.97		9.69			9.94	163			246	9.8	6.31	170	6.9
BW-4	3/24/99	0.010	U	11.5	J	10.8	J		11.5	163			245	9.8	5.96	176	8.3
BW-4	5/5/99	0.050		11.0		13.1			10.6	163	0.77		248	9.9	6.04	179	8.5
BW-4	6/3/99	0.010	U	11.8		12.8			10.2	143			244	10.9	5.99	177	6.5
BW-4	7/8/99	0.021		12.8		12.0			9.71	151			241	11.3	5.91	177	7.6
BW-4	7/08/99-dup	0.020		12.1		12.7			8.91	158			241				
BW-4	8/26/99	0.010	U	13.3		17.2	J		9.27	290			237	11.5	5.57	172	6.0
BW-4	9/22/99	0.027		10.9		10.7				197			239	11.8		179	
BW-4	10/21/99	0.010	UJ	11.4		11.2			10.10	165			243	11.7	6.07		6.9
BW-4	11/18/99	0.010	U	11.6		11.4			9.64	161			243	10.4	6.13	247	
BW-4	12/27/99	0.013		11.7		11.9			9.93	154			242	10.4	6.21	173	7.7
BW-4	1/26/00	0.010	U	11.6		11.8			9.75	145				9.3	6.15	195	6.5
BW-4	1/26/00-dup	0.010	U	11.2		11.3			9.28	161							
BW-5	5/28/98	0.010	U	12		13.8			9.90	163	1.0	U	253	10.7	5.77	168	10.2
BW-5	6/23/98	0.010	U	14.9		12.6			10.4	184	1.0	U		10.2	5.65	184	6.5
BW-5	7/24/98	0.010	U	13.6		14.7			9.31	207	1.0	U	269	11.4	5.99	200	6.9
BW-5	9/3/98	0.010	U	16.1		13.4			9.70	178			267	11.1	5.66	195	6.4
BW-5	10/15/98	0.010	U	11.4		11.5			9.22	179			258	10.6	5.22	193	7.1
BW-5	11/13/98	0.010	U	12.6		12.8			9.08	176				10.6	6.54	191	7.0
BW-5	12/9/98	0.010	U	18.2		8.93			6.94	138	1.34		213	10.3	6.06	158	9.3
BW-5	1/13/99	0.010	U	5.31		5.33			6.01	103	1.0	U	161	10.5	6.49	117	8.8
BW-5	2/26/99	0.010	U	4.03		7.24								9.4	6.63	128	9.4
BW-5	3/25/99	0.010	U	10.5		10.6			8.33	138			199	9.3	5.82	142	10.6
BW-5	5/5/99	0.028		10.5		13.1			9.96	156	0.50		224	9.7	5.89	160	8.1
BW-5	5/5/99-dup	0.030		11.2		13.5			9.32	153	0.52		224				
BW-5	6/3/99	0.010	U	11.8		13.5			9.62	145			238	10.8	5.79	173	8.5
BW-5	6/03/99-dup	0.010	U	1.4		12.3			10.1	140			239				
BW-5	7/8/99	0.022		13.7		12.7			8.91	158			236	11.3	6.16	175	8.2
BW-5	8/26/99	0.010	U	12.4		12.4			8.67	174			237	11.7	5.57	174	6.2
BW-5	8/26/99-dup	0.010	U	11.4		12.1			8.69	160			238				
BW-5	9/22/99	0.028		11.3		10.8				159			235	11.0		175	7.0
BW-5	10/21/99	0.010	UJ	10.4		10.2			10.2	164			227	11.4	6.09		7.0
BW-5	10/21/99-dup	0.010	UJ	10.3		9.8			10.4	155			227				
BW-5	11/18/99	0.010	U	9.86		10.2			7.89	161			231	10.5	6.16	234	
BW-5	12/27/99	0.010	U	9.35		10.1			11.0	139			223	10.6	5.98	161	7.6
BW-5	1/26/00	0.010	U	9.80		10.3			10.3	155				9.8	6.0	183	7.0
BW-6	5/28/98	0.010	U	6.74		7.51			7.31	138	1.0	U	209	11.0	5.76	153	7.1
BW-6	6/23/98	0.010	U	8.59		7.5			8.24	158	1.0	U		10.3	5.67	163	6.3
BW-6	7/24/98	0.010	U	9.78		10.0			8.87	159	1.0	U	238	11.1	5.90	174	5.8
BW-6	9/3/98	0.010	U	13.4		10.9			10.1	166			259	11.2	5.71	193	6.2
BW-6	10/15/98	0.010	U	11.7		12.1			10.1	187			261	10.7	5.93	195	7.0
BW-6	11/13/98	0.010	U	12.0		11.7			9.88	185				10.7	6.16	185	6.8
BW-6	12/9/98	0.010	U	20.7		8.36			9.54	144	1.23		230	10.2	5.98	168	6.8
BW-6	1/14/99	0.010	U	7.18		8.16			8.05	133	1.0	U	197	10.5	6.30	142	5.7
BW-6	2/26/99	0.010	U	5.78		5.93								10.2	6.57	125	9.4
BW-6	3/25/99	0.010	U	6.40		5.84			7.40	107			170	9.7	5.80	120	7.8
BW-6	5/5/99	0.018		7.05		7.99			8.48	114	0.46		180	9.7	5.91	129	8.3
BW-6	6/3/99	0.010	U	8.56		8.99			9.20	116			196	10.5	6.02	143	7.7
BW-6	7/8/99	0.021		10.4		10.6			9.80	141			213	11.3	5.67	155	9.1
BW-6	8/26/99	0.010	U	10.2		10.4			10.5	165			227	11.4	5.47	168	5.9
BW-6	9/22/99	0.028		11.1		10.1	J			134			229	11.2		170	7.4
BW-6	10/21/99	0.010	UJ	11.1		10.6	J		10.0				302	11.5	5.99		7.1
BW-6	11/18/99	0.010	U	11.1		10.1			9.07	158			223	10.9	6.11	224	
BW-6	12/28/99	0.010	U	7.64		8.47			8.05	125			197	9.9	6.12	188	7.3
BW-6	1/26/00	0.010	U	7.95		7.47			8.72	147			198	10.2	6.11	167	7.2
BW-6	3/2/00	0.010	U	8.16		8.53			9.71	130			200	9.9	6.12	201	7.4
BW-6	3/29/00	0.010	U	10.5		9.68			10.7	144				9.9	5.32	215	11.3

Appendix L. Estimated organic nitrogen concentrations in groundwater and soil pore liquid.

Sample Site	Date	Organic N (mg/L)[1]	% Organic N[2]
Site 1			
MW-1	6/26/97	0.73	9.6
MW-1	7/25/97	0.39	57.1
MW-1	8/21/97	0.40	4.2
MW-1	9/17/97	0.61	23.2
MW-1	10/17/97	0.34	29.9
MW-1	11/20/97	0.26	9.0
MW-1	12/29/97	0.28	96.5
MW-1	2/5/98	0.35	97.2
MW-1	3/10/98	0.25	8.0
MW-1	4/16/98	0.16	27.2
MW-1	5/27/98	0.59	38.1
MW-1	7/24/98	0.29	21.3
MW-1	9/2/98	0.16	10.9
MW-1	10/15/98	0.26	79.4
MW-1	11/12/98	0.37	94.9
MW-1	12/10/98	0.37	97.3
MW-1	1/14/99	0.31	96.9
MW-1	2/25/99	0.28	92.6
MW-1	3/25/99	0.29	31.9
MW-1	5/7/99	1.24	24.8
MW-1	9/23/99	0.31	12.5
MW-1	1/27/00	0.31	96.9
MW-1	3/30/00	0.30	95.6
MW-2	6/26/97	0.25	28.4
MW-2	7/25/97	0.22	59.0
MW-2	8/21/97	0.06	32.0
MW-2	9/17/97	0.16	48.2
MW-2	10/17/97	0.16	12.2
MW-2	11/20/97	0.09	5.6
MW-2	4/16/98	0.17	6.3
MW-2	5/27/98	0.18	84.5
MW-2	6/24/98	0.05	4.7
MW-2	7/24/98	-0.05	-1.2
MW-2	10/15/98	-0.01	-0.3
MW-2	11/12/98	0.43	16.2
MW-2	1/14/99	0.26	25.4
MW-2	2/25/99	0.15	19.7
MW-2	3/25/99	0.21	41.0
MW-2	5/7/99	0.21	61.8
MW-2	9/23/99	0.17	66.2
MW-2	1/27/00	0.20	44.9
MW-2	3/30/00	0.17	43.4
MW-3	6/26/97	0.23	7.3
MW-3	7/25/97	0.34	10.9
MW-3	9/18/97	0.23	4.2
MW-3	10/17/97	0.50	3.1
MW-3	11/20/97	0.10	0.9
MW-3	2/5/98	0.40	1.3
MW-3	3/10/98	-0.30	-1.6
MW-3	5/29/98	0.60	8.4
MW-3	11/12/98	3.50	10.6
MW-3	1/14/99	9.50	34.1
MW-3	2/25/99	3.90	23.8
MW-3	3/25/99	7.24	48.9
MW-3	5/6/99	2.07	14.2
MW-3	1/27/00	2.50	13.3
MW-3	3/31/00	5.37	63.8
MW-4	6/26/97	-0.01	-0.2
MW-4	7/25/97	0.27	10.3
MW-4	8/21/97	0.22	5.2
MW-4	9/19/97	0.20	68.1
MW-4	10/171997	0.20	45.9

Sample Site	Date	Organic N (mg/L)[1]	% Organic N[2]
MW-4	11/21/97	0.16	22.6
MW-4	2/5/98	1.00	2.9
MW-4	5/27/98	2.40	10.0
MW-4	7/24/98	0.20	0.7
MW-4	10/15/98	0.22	2.9
MW-4	11/12/98	0.32	3.7
MW-4	1/14/99	1.20	2.8
MW-4	2/25/99	0.25	0.6
MW-4	3/25/99	3.90	14.5
MW-4	5/6/99	6.10	22.5
MW-4	9/23/99	-0.20	-1.1
MW-4	3/30/00	8.80	17.0
MW-5	6/26/97	0.07	1.1
MW-5	7/25/97	0.29	7.7
MW-5	8/21/97	0.32	14.7
MW-5	9/19/97	0.20	18.0
MW-5	10/17/97	0.34	3.8
MW-5	11/21/97	0.15	1.9
MW-5	5/27/98	2.66	15.0
MW-5	7/24/98	0.30	2.0
MW-5	10/15/98	0.26	4.4
MW-5	11/12/98	0.26	6.6
MW-5	12/10/98	9.09	21.8
MW-5	1/14/99	1.90	4.6
MW-5	1/27/00	1.10	3.7
MW-6	6/26/97	0.16	1.3
MW-6	7/25/97	0.80	6.1
MW-6	8/21/97	2.17	9.3
MW-6	9/19/97	0.80	3.4
MW-6	10/17/97	0.40	1.5
MW-6	11/21/97	0.10	0.6
MW-6	12/30/97	-0.10	-0.9
MW-6	2/5/98	0.20	1.7
MW-6	3/11/98	0.84	10.4
MW-6	5/27/98	1.60	13.3
MW-6	7/24/98	0.00	0.0
MW-6	9/1/98	0.50	3.3
MW-6	9/1/98--dup	0.20	1.4
MW-6	10/15/98	0.13	1.5
MW-6	11/12/98	0.58	9.4
MW-6	1/14/99	0.90	5.2
MW-6	2/25/99	2.50	15.2
MW-6	3/25/99	2.80	18.8
MW-6	5/6/99	1.57	8.9
MW-6	1/27/00	0.60	4.0
MW-7	6/26/97	0.16	7.5
MW-7	7/25/97	0.22	27.2
MW-7	8/21/97	0.23	49.7
MW-7	9/19/97	0.24	63.5
MW-7	10/16/97	0.12	43.8
MW-7	11/21/97	0.24	17.1
MW-7	12/30/97	0.24	40.8
MW-7	2/6/98	0.20	29.7
MW-7	3/11/98	0.26	26.4
MW-7	4/17/98	0.13	54.6
MW-7	5/28/98	0.61	89.0
MW-7	6/24/98	0.24	82.6
MW-7	7/24/98	0.27	75.3
MW-7	9/2/98	0.24	13.5
MW-7	10/15/98	0.30	73.5
MW-7	11/12/98	0.44	72.2
MW-7	1/14/99	1.50	12.1
MW-7	2/25/99	3.50	22.3
MW-7	3/26/99	0.02	0.9
MW-7	5/6/99	0.32	24.5
MW-7	9/23/99	0.28	45.4
MW-7	1/27/00	0.32	5.9
MW-8	6/26/97	0.20	1.3
MW-8	7/25/97	0.40	3.1

Sample Site	Date	Organic N (mg/L)[1]	% Organic N[2]
MW-8	8/21/97	0.28	3.0
MW-8	9/19/97	0.36	5.6
MW-8	10/16/97	0.40	6.7
MW-8	11/21/97	0.05	0.5
MW-8	2/6/98	0.00	0.0
MW-8	2/6/1998-dup	0.90	2.3
MW-8	5/28/98	8.00	21.1
MW-8	7/24/98--dup	1.60	6.4
MW-8	9/2/98	0.30	1.7
MW-8	10/15/98	0.21	2.1
MW-8	11/12/98	0.50	3.1
MW-8	1/14/99	2.20	6.3
MW-8	2/25/99	0.30	1.5
MW-8	3/26/99	2.30	8.7
MW-8	5/6/99	6.17	22.9
MW-8	9/23/99	13.10	75.7
MW-8	1/27/00	1.00	3.1
MW-9	7/25/97	0.16	2.4
MW-9	8/21/97	0.36	7.1
MW-9	9/19/97	0.02	0.5
MW-9	10/16/97	0.63	18.3
MW-9	11/21/97	0.10	0.6
MW-9	5/28/98	3.10	12.4
MW-9	7/24/98	0.10	0.6
MW-9	10/15/98	0.27	4.1
MW-9	11/12/98	0.90	7.8
MW-9	12/10/98	15.68	25.5
MW-9	3/26/99	1.10	4.4
MW-9	5/6/99	4.38	16.1
MW-9	3/30/00	0.00	0.0
LY-1	6/26/97	0.10	0.7
	7/25/97	0.03	0.4
	8/21/97	0.69	13.6
	9/19/97	0.42	11.4
	11/21/97	1.10	25.7
	12/30/97	0.48	27.8
	3/11/98	0.03	1.4
	5/29/98	0.56	32.0
	1/14/99	0.58	68.8
	2/25/99	0.91	20.4
	3/3/00	0.38	62.9
	3/30/00	0.51	80.8
LY-2	6/26/97	0.25	11.6
	7/25/97	0.66	57.2
	8/21/97	0.56	42.1
	9/19/97	0.26	11.0
	10/17/97	0.41	15.8
	11/21/97	0.48	26.1
	12/30/97	0.39	26.9
	2/6/98	0.32	23.2
	3/11/98	0.28	28.2
	4/17/98	0.11	11.9
	7/24/98	0.44	33.8
	11/12/98	0.53	98.2
	12/10/98	0.54	94.3
	1/14/99	0.67	98.4
	2/25/99	0.59	97.8
	3/25/99	0.54	95.1
	5/6/99	0.74	92.7
	9/23/99	0.45	89.5
	3/3/00	0.40	97.6
	3/30/00	0.34	96.1
LY-3	6/26/97	0.58	4.1
	6/27/97	1.52	10.1
	8/21/97	0.27	1.1
	12/30/97	-5.61	-14.6
	2/6/98	1.96	9.8
	3/11/98	0.88	5.5
	5/29/98	0.77	5.1

Sample Site	Date	Organic N (mg/L)[1]	% Organic N[2]
	11/12/98	3.08	6.4
	1/14/99	4.98	19.8
	2/25/99	5.44	26.9
	3/25/99	2.99	18.7
	3/3/00	5.40	20.8
LY-4	6/26/97	0.95	43.7
	7/25/97	0.57	80.6
	9/19/97	0.76	23.2
	10/17/97	1.17	14.1
	11/21/97	1.36	6.3
	5/29/98	1.30	4.4
	11/13/98	-3.32	-11.2
	1/14/99	0.80	1.2
	3/25/99	14.00	21.9
	5/6/99	12.96	22.9
	9/23/99	1.07	2.4
	3/3/00	13.70	20.5
LY-5	6/26/97	0.18	17.6
	7/25/97	0.94	51.4
	8/21/97	1.15	57.5
	9/19/97	0.65	62.9
	10/17/97	0.70	45.2
	11/21/97	0.65	37.7
	12/30/97	0.58	41.3
	2/6/98	0.71	44.1
	4/17/98	0.60	57.0
	5/29/98	0.78	67.4
LY-6	6/26/97	1.23	67.7
	7/25/97	1.95	28.0
	9/19/97	-1.07	-0.9
Site 2			
BW-1	5/28/98	1.50	11.4
BW-1	7/23/98	0.60	4.8
BW-1	11/11/98	0.10	0.8
BW-1	12/9/98	6.30	13.0
BW-1	1/13/99	0.20	1.3
BW-1	2/24/99	0.60	5.1
BW-1	5/5/99	1.35	12.2
BW-1	6/3/99	0.80	7.1
BW-1	7/8/99	1.68	11.9
BW-1	8/26/99	0.60	4.7
BW-1	11/18/99	0.70	5.6
BW-1	12/27/99	0.40	2.5
BW-1	1/26/00	0.50	3.1
BW-1	3/2/00	2.90	16.1
BW-1	3/29/00	0.00	0.0
BW-2	5/28/98	1.27	12.0
BW-2	7/23/98	0.33	3.2
BW-2	10/15/98	0.30	2.9
BW-2	11/11/98	0.00	0.0
BW-2	1/13/99	-0.10	-0.7
BW-2	2/24/99	2.06	17.2
BW-2	3/24/1999(dup	1.90	18.3
BW-2	5/5/99	1.49	14.2
BW-2	6/3/99	0.60	5.7
BW-2	7/8/99	0.58	4.6
BW-2	8/26/99	0.30	2.3
BW-2	10/21/99	3.40	19.7
BW-2	11/18/99	0.70	5.6
BW-2	12/27/99	0.60	3.9
BW-2	1/27/00	1.20	7.5
BW-2	3/2/00	2.90	16.1
BW-3	5/28/98	0.83	8.1
BW-3	7/24/98	0.70	6.2
BW-3	10/15/98	0.30	2.5
BW-3	11/11/98	0.20	1.4
BW-3	12/9/98	0.49	4.6
BW-3	1/13/99	2.60	61.5

Sample Site	Date	Organic N (mg/L)[1]	% Organic N[2]
BW-3	2/24/99	0.30	5.7
BW-3	5/5/99	1.25	12.7
BW-3	7/8/99	0.97	8.8
BW-3	8/26/99	5.20	31.3
BW-3	11/18/99	0.08	0.9
BW-3	12/27/99	0.99	12.6
BW-3	1/26/00	1.85	19.5
BW-3	3/2/00	0.91	8.9
BW-4	5/28/98	1.20	8.3
BW-4	7/24/98	0.50	3.7
BW-4	10/15/98	0.30	2.8
BW-4	11/11/98	0.10	0.8
BW-4	1/13/99	1.05	10.4
BW-4	2/24/99	0.72	7.4
BW-4	5/5/99	2.05	15.6
BW-4	6/3/99	1.00	7.8
BW-4	)7/08/1999dur	0.58	4.6
BW-4	8/26/99	3.90	22.7
BW-4	10/21/99	-0.20	-1.8
BW-4	11/18/99	-0.20	-1.8
BW-4	12/27/99	0.19	1.6
BW-4	1/26/00	0.20	1.7
BW-5	5/28/98	1.80	13.0
BW-5	7/24/98	1.10	7.5
BW-5	10/15/98	0.10	0.9
BW-5	11/13/98	0.20	1.6
BW-5	1/13/99	0.02	0.4
BW-5	2/26/99	3.21	44.3
BW-5	3/25/99	0.10	0.9
BW-5	5/5/99	2.57	19.6
BW-5	5/5/99(dup)	2.27	16.8
BW-5	6/3/99	1.70	12.6
BW-5	8/26/99	0.00	0.0
BW-5	10/21/99	-0.20	-2.0
BW-5	11/18/99	0.34	3.3
BW-5	12/27/99	0.75	7.4
BW-5	1/26/00	0.50	4.9
BW-6	5/28/98	0.77	10.3
BW-6	7/24/98	0.22	2.2
BW-6	10/15/98	0.40	3.3
BW-6	11/13/98	-0.30	-2.6
BW-6	1/14/99	0.98	12.0
BW-6	2/26/99	0.15	2.5
BW-6	5/5/99	0.92	11.5
BW-6	6/3/99	0.43	4.8
BW-6	7/8/99	0.18	1.7
BW-6	8/26/99	0.20	1.9
BW-6	12/28/99	0.83	9.8
BW-6	3/2/00	0.37	4.3
BL-1	5/29/98	0.81	35.0
BL-2	5/29/98	0.48	2.8
BL-3	5/29/98	0.36	30.9
BL-3	3/2/00	0.39	22.2
BL-5	3/25/99	0.00	0.0
BL-6	5/29/98	0.69	26.3
BL-6	12/9/98	188.97	63.0
BL-6	3/25/99	2.99	4.7
BL-6	5/6/99	17.57	31.2
BL-6	9/22/99	0.71	28.2
BL-6	10/21/99	0.76	91.2
BL-6	11/18/99	0.16	3.4
BL-6	3/2/00	1.85	29.2

[1] Organic N = (TPN)-(ammonia-N + nitrate-nitrite-N). Samples in which TPN exceeded the sum of nitrate+nitrite-N and ammonia-N by more than 0.2 mg/L were not included.

[2] Percent organic N = (organic N)/TPN x 100.

Appendix M. TOC results for monitoring wells (mg/L).

Site 1

	11/20/97	12/29/97	2/5/98	3/10/98	4/16/98	5/27/98	6/24/98
MW-1	6.0	3.7	4.0	4.3	4.4	5.1	3.9
MW-2	3.4	1.9	2.0	1.9	2.9	2.1	2.0
MW-3	3.9	3.8	7.0	4.3	4.4	3.3	2.6
MW-4	3.2	2.7	2.3	2.3	3.1	2.5	2.6
MW-5	4.0	3.3	3.6	3.3	4.1	4.5	3.6
MW-6	9.2	10.2	7.5	8.0	8.6	8.8	6.2
MW-7	3.5	2.5	2.7	3.0	3.2	2.7	2.8
MW-8	3.9	5.9	4.3	3.4	3.4	2.8	2.8
MW-9	4.2	2.6	14.1	2.9		3.3	3.6

Site 2

	5/28/98	6/23/98	7/23/98	11/11/98	12/9/98	1/13/99	2/24/99	5/5/99
BW-1	1.0 U	1.0 U	1.0 U	1.0 U	1.3	1.0 U	1.0 U	0.68
BW-2	1.0 U	1.0 U	1.0 U	1.0 U	1.23	1.4	1.0 U	0.84
BW-3	1.0 U	1.0 U		1.0 U	1.39	1.0 U	1.0 U	0.93
BW-4	1.0 U	1.0 U	1.0 U	1.0 U	1.52	1.0 U	1.0 U	0.77
BW-5	1.0 U	1.0 U	1.0 U	1.0 U	1.34	1.0 U		0.50
BW-6	1.0 U	1.0 U	1.0 U	1.0 U	1.23	1.0 U		0.46

Appendix N. Soil pore liquid results (mg/L).

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persulfate N	Total Kjeldahl N		Chloride	Dissolved Solids	Conductance (µmhos/cm)
Site 1											
LY-1	6/26/1997	0.101		14.9		15.1			18.7		
	7/25/1997	0.060		8.06		8.15					
	8/21/1997	0.040		4.36		5.09					
	9/19/1997	0.030		3.23		3.68			6.63	390	
	10/17/1997										
	11/21/1997	0.082		3.09		4.27					
	12/30/1997	0.017		1.24		1.74					
	2/6/1998										
	3/11/1998	0.010	UJ	2.13	J	2.16					
	4/17/1998										
	5/29/1998	0.010	U	1.19		1.75			3.20	144	
	6/23/1998										
	7/24/1998										
	11/12/1998										
	12/10/1998										
	1/14/1999			0.263		0.843					
	2/25/1999	0.016	J	3.54		4.470					
	3/25/1999										
	5/6/1999										
	9/23/1999										
	3/3/2000	0.010	U	0.225		0.607					
	3/30/2000	0.010	U	0.120		0.626			0.251	91	
LY-2	6/26/1997	0.187		1.74		2.18			10.5		
	7/25/1997	0.161		0.335		1.16			6.36	219	
	8/21/1997	0.110		0.660		1.33					
	9/19/1997	0.022		2.07		2.35			4.20	270	
	10/17/1997	0.017		2.18		2.61			3.70	250	
	11/21/1997	0.010	U	1.36		1.84			2.70	200	
	12/30/1997	0.010	U	1.06		1.45			2.15		
	2/6/1998	0.010	U	1.06		1.38			2.43	139	
	3/11/1998	0.010	UJ	0.710	J	0.989			2.73		178
	4/17/1998	0.030		0.800		0.942	0.5	U	2.8	136	
	5/29/1998										
	6/23/1998										
	7/24/1998	0.021		0.840		1.30					
	11/12/1998	0.010	U	0.010		0.542			0.618		255
	12/10/1998	0.023		0.010	U	0.576			0.499	184	
	1/14/1999			0.010	U	0.679			0.36		
	2/25/1999	0.010	U	0.013		0.601			0.923		
	3/25/1999	0.018		0.010	U	0.566			1.600	172	
	5/6/1999	0.048		0.010	U	0.799			1.95	197	
	9/23/1999	0.041		0.011		0.497					

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persulfate N	Total Kjeldahl N		Chloride	Dissolved Solids	Conductance (µmhos/cm)
	3/3/2000	0.010	U	0.010	U	0.410			0.58	158	212
	3/30/2000	0.010	U	0.014		0.355			0.609	144	
LY-3	6/26/1997	3.02		10.4		14.0					
	6/27/1997	2.380		11.2		15.1			11.2	330	
	7/25/1997										
	8/21/1997	0.528		23.9		24.7					
	9/19/1997	0.437		32		31.6					
	10/17/1997										
	11/21/1997										
	12/30/1997	0.012		44		38.4			20.3		
	2/6/1998	0.037		18		20					
	3/11/1998	0.017		15.1	J	16.0			5.89		
	4/17/1998										
	5/29/1998	0.034		14.2		15.0			2.95	339	
	6/23/1998										
	7/24/1998										
	11/12/1998	0.117		45.1		48.3					
	12/10/1998	0.060		56.4		31.6			26.2	656	
	1/14/1999	0.018		20.2		25.2	2.02				
	2/25/1999	0.159		14.6		20.2					
	3/25/1999	0.014		13		16.0					
	5/6/1999										
	9/23/1999										
	3/3/2000	0.010	U	20.6		26.0			4.50	313	406
	3/30/2000	0.010	U	14.3		13.9			3.09	268	
LY-4	6/26/1997	0.122		1.10		2.17					
	7/25/1997	0.046		0.092		0.711					
	8/21/1997	NA		NA		NA					
	9/19/1997	0.083		2.42		3.26			10.2	347	
	10/17/1997	0.037		7.09		8.30			12.3	372	
	11/21/1997	0.038		20.3		21.7			20.0	360	517
	12/30/1997	0.038		32		29.3			22.8		
	2/6/1998	0.033		31.2		29.8			23.5	374	
	3/11/1998	0.034		42.9	J	32.5			25.0		576
	4/17/1998	0.056		29.1		28.6	0.98		24.8	441	
	5/29/1998	0.010	U	28.3		29.6			24.8	444	
	6/23/1998										
	7/24/1998										
	11/13/1998	0.021		33.0		29.7			22.8	566	
	12/10/1998	0.039		103		29.4			38.1	677	
	1/14/1999	0.010	U	64.3		65.1	0.5	U	37.5		
	2/25/1999	0.018		47.5			0.5	U J	31.1		
	3/25/1999	0.010	U	50		64			28.6	521	
	5/6/1999	0.036		43.6		56.6	0.5	U	28.2	540	
	9/23/1999	0.034		43.5		44.6				553	785

Sample Site	Date	Ammonia-N		Nitrate+ nitrite-N		Total Persulfate N		Total Kjeldahl N		Chloride	Dissolved Solids	Conductance (µmhos/cm)
	3/3/2000	0.010	U	53.2		66.9				34.8	545	406
	3/30/2000	0.010	U	53.9		50.4		0.5	U	34.5	577	
LY-5	6/26/1997	0.749		0.075		1.00				24.5		
	7/25/1997	0.804		0.081		1.82						
	8/21/1997	0.645		0.206		2.00						
	9/19/1997	0.280		0.106		1.04				17.9	729	
	10/17/1997	0.296		0.548		1.54				22.1	677	
	11/21/1997	0.234		0.831		1.71				24.0	650	923
	12/30/1997	0.273		0.554		1.41				29.4		
	2/6/1998	0.304		0.591		1.60				31.5	659	
	3/11/1998	0.033		15.3	J	1.75				33.9		934
	4/17/1998	0.221		0.235		1.06		0.8		34.2	658	
	5/29/1998	0.179		0.199		1.16				46.2	650	
	6/23/1998											
LY-6	6/26/1997	0.146		0.438		1.81				15.9		
	7/25/1997	5.02		0.010	U	6.97						
	8/21/1997			0.109		?						
	9/19/1997	1.07		120		120				105	1,370	
	6/23/1998											
Site 2												
BL-1	5/29/1998	0.021		1.48		2.31				5.53		
	3/25/1999			62.0						14.7	155	
BL-2	5/29/1998	0.015		16.8		17.3						
BL-3	5/29/1998	0.010		0.799		1.17						
	11/13/1998	0.010	U	43.3		37.2						
	3/2/2000	0.010	U	1.37		1.76						
BL-5	3/25/1999	0.010	U	39		39		0.500	U			
BL-6	5/29/1998	0.685		1.23		2.6				11.1	105	174
	11/13/1998	0.010	U	24.6		22.9						
	12/9/1998	0.033		111		300	J			12.0	392	
	3/25/1999	0.015		61		64		1.06				
	5/6/1999	0.032		38.7				0.958		11.6	936	1,360
	6/3/1999	0.010	U	42.6				0.500				
	7/8/1999	0.035		43.7						8.3		
	8/26/1999			28.2				1.08				
	9/22/1999	0.010	U	1.80		2.52						
	10/21/1999	0.010	UJ	0.06		0.84						
	11/18/1999	0.010	U	4.59		4.76						
	3/2/2000	0.010	U	4.48		6.34				6.10	935	1340
	3/30/2000	0.010	U			1.35				1.60	855	

Appendix O. Soil nitrogen results.

Table O.1. Residual nitrate (mg/kg) in the top one foot of soil.

The 1997 samples were collected by WSU. The 1998 and 1999 samples were collected by Ecology. Each WSU sample represents a composite of 12 subsamples, while the Ecology samples represent a composite of eight subsamples.

	1997	1998	1999
Site 1-North			
0-1-foot	43.8	67	84
1-2-foot	21.8		
Site 1- South			
0-1-foot	43.5	61	55
1-2-foot	26.3		
Site 2			
0-1-foot		23	10.5

Table O.2. Residual ammonia-N (mg/kg) in the top one foot of soil.

	1998	1999
Site 1-North	13	20
Site 1- South	15	16
Site 2	7.5	17

Appendix P. Results of paired t-test for differences between upgradient and downgradient chloride concentrations at Site 1.

Downgradient monitoring well	Mean differences	Standard deviation of differences	n	t	df	alpha=0.05
MW-3	-4.06	8.87	21	-2.10	20	2.086
MW-4	0.57	7.03	24	0.40	23	2.069
MW-5	9.50	6.27	24	7.43	23	2.069
MW-6	12.27	4.93	24	12.18	23	2.069
MW-7	13.64	4.39	24	15.24	23	2.069
MW-8	3.52	7.00	24	2.46	23	2.069
MW-9	12.74	12.91	21	4.52	20	2.086

Appendix Q. Results of paired t-test for differences between upgradient and downgradient TDS concentrations at Site 1.

Downgradient monitoring well	Mean differences	Standard deviation of differences	n	t	df	alpha=0.05
MW-3	-2.58	107.54	20	-0.11	19	2.069
MW-4	60.80	95.10	23	3.07	22	2.093
MW-5	101.07	69.40	23	6.98	22	2.069
MW-6	167.67	98.91	23	8.13	22	2.069
MW-7	124.28	72.52	23	8.22	22	2.069
MW-8	59.15	100.09	23	2.83	22	2.069
MW-9	92.85	65.86	20	6.31	19	2.093