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Smith Prairie Groundwater Quality Assessment

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Smith Prairie Groundwater Quality Assessment

by
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Watershed Ecology Section

Conducted for the Department of Ecology
Water Quality Program Southwest Regional Office
and the Thurston Conservation District

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Abstract

A groundwater quality assessment was conducted to determine the source(s) of nitrates and other contaminants in groundwater in an area near Smith Prairie Road and 161st Way SE about eight miles southwest of Yelm, Washington. In particular, since 1995 the discharge of one private water-supply well (WS1) showed elevated concentrations of nitrate+nitrite-N and intermittent green discoloration, fecal coliform bacteria, and particulate matter. A groundwater monitoring network, consisting of four monitoring wells and three private water-supply wells, was established and sampled monthly from September 1999 to May 2000. The hydrogeology and groundwater-flow patterns were characterized.

The findings suggest that two groundwater contamination issues exist in the study area:

- Nitrate loading to the uppermost aquifer from a source upgradient of the monitoring network.
- Hydraulic connection of well WS1 with infiltrating surface runoff during periods of heavy rainfall.

The primary source of nitrate is likely a dairy upgradient of the monitoring network. The dairy became inactive in 1999 and, provided there is no additional loading to groundwater, nitrate concentrations in groundwater should decrease over time. Based on the estimated groundwater flow rate and assuming nitrate loading to groundwater has ceased, it may take up to 20 years for nitrate levels to decline substantially at WS1. Recharge complexity and denitrification processes may reduce this period. Inspection of the status of the dairy waste storage pond is recommended.

Two potential hydrogeologic contaminant pathways to WS1 are identified. Additional investigations are needed to verify subsurface conditions for both pathways. The probable source of contaminants is infiltrated runoff, but the specific locations where infiltration occurred and where runoff originated were not determined. The sensitivity of groundwater to contamination dictates that runoff be minimized and controlled. To improve water quality at affected water-supply wells, one potential option for well owners is to drill wells to a deeper aquifer zone.

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Introduction

Purpose and Objectives

The purpose of this project was to identify the source(s) of groundwater contamination in the vicinity of 161st Way SE and Smith Prairie Road. Private water-supply wells in the area have shown elevated nitrate concentrations up to 41mg/L. One private water-supply well (WS1), in addition to elevated nitrate, has shown intermittent dark green discoloration and elevated chloride, fecal coliform bacteria, total dissolved solids, phosphorus and particulate matter. Potential contaminant sources include two dairies, onsite septic systems, and commercial poultry operations.

To identify the sources of contamination the following tasks were completed:

- Established a groundwater monitoring network consisting of four monitoring wells, five private water-supply wells and two surface water (ditch) stations.
- Characterized the hydrogeology of the study area including the groundwater flow direction and its seasonal variability and rates of movement.
- Sampled the monitoring network monthly from September 1999 to May 2000 to define temporal and spatial distribution of nitrate+nitrite-N, fecal coliform bacteria, and other parameters.
- Evaluated the integrity of WS1 using a downhole video camera.
- Reviewed historic air photos.

This report describes the results and findings of these tasks.

Previous Studies

In response to a well owner's complaint of intermittent dark green discoloration of well water, the Washington State Department of Ecology (Ecology) Southwest Regional Office (SWRO) conducted a groundwater investigation in the area. Nine wells were sampled a varying number of times (two to nine times) between April 1995 and May 1996. All samples were tested for nitrate+nitrite-N; in addition, most samples were tested for specific conductance, chloride, and fecal coliform bacteria. The results of this investigation are summarized in Garland (1996). Nitrate+nitrite-N concentrations in wells ranged from 0.5 to 41 mg/L over the study period. At WS1 nitrate+nitrite-N concentrations ranged from 10.0 to 33.4 mg/L. Chloride concentrations for all wells ranged about 4 to 46 mg/L. The highest chloride concentrations were observed at WS1. Fecal coliform bacteria were not detected in most wells; however, concentrations in WS1 averaged about five Colony Forming Units (CFU) between December 1995 and May 1996. Garland concluded that manure-rich runoff from the Plowman Dairy south of WS1 flowed northward onto adjacent private property (Bigler) and infiltrated into the ground and was the likely source of groundwater contamination seen at WS1.

Manure and wastewater handling at the Plowman Dairy improved after 1996 but water quality at WS1 continued to show intermittent discoloration in the winter. Marilou Pivirotto, SWRO dairy waste inspector, and Wym Matthews with the Thurston Conservation District requested that the Ecology Environmental Assessment Program further investigate to determine why groundwater quality was not improving. The Environmental Assessment Program sampled WS1 and another private well (WS2, Austen) 300 feet to the east in January, March, April, and May 1999. The target analytes included nitrate+nitrite-N, chloride, ammonia, total phosphorus, total dissolved solids, and fecal coliform bacteria. Nitrate+nitrite-N concentrations at WS1 ranged from 13.4 to 36.6 mg/L. Total phosphorus concentrations in WS1 were atypically high for groundwater ranging from 0.4 to 2.0 mg/L. Since phosphorus typically has low mobility in groundwater, the data suggest that the contamination source is close by. In June and August 1999 four monitoring wells were installed in the Upper Aquifer to define groundwater flow direction and quality for this project.

Study Area Description

The study area occupies an area of about one square mile and is located about eight miles southeast of Yelm (Figure 1). Land use consists of two dairies and low-density residential development. A commercial poultry operation exists about 3/4 mile northwest of the center of the study area. The topography has moderate relief ranging from an elevation of 530 to 560 feet and is rolling. Lackamus Creek lies southeast and east of the study area and drains northeastward to the Nisqually River. The Deschutes River lies about 1.5 miles south of the study area and drains westward.

Geology, Hydrogeology, and Soils

Geology

The study area geology is largely a product of multiple glacial advances and retreats, that occurred over the last hundreds of thousands of years (Mundorf, Weigle, and Holmberg, 1955; Wallace and Molenaar, 1961; and Noble and Wallace, 1966). The near-surface deposits are the product of the most recent glacial episode, the Vashon Stade of the Fraser Glaciation. The surficial geology of the study area is dominated by two deposits: Vashon till deposited directly by glacial ice and recessional outwash deposited by the meltwater of the Vashon Glacier during glacial recession. Vashon till, consisting of a compacted mixture of clay, silt, sand and gravel, covers a majority of the study area. Recessional outwash deposits, consisting of a loose mixture of silt, sand, and gravel, crop out in the northwestern portion of the study area (Noble and Wallace, 1966).

Hydrogeology

The study area hydrogeology is known from drillers' logs for private wells on file with Ecology and geologic logs of subsurface soils observed during the installation of four study area monitoring wells. The hydrogeology is characterized by multiple water-bearing sandy gravel layers (aquifers) sandwiched between silty and clayey units (aquitards) with low permeability.

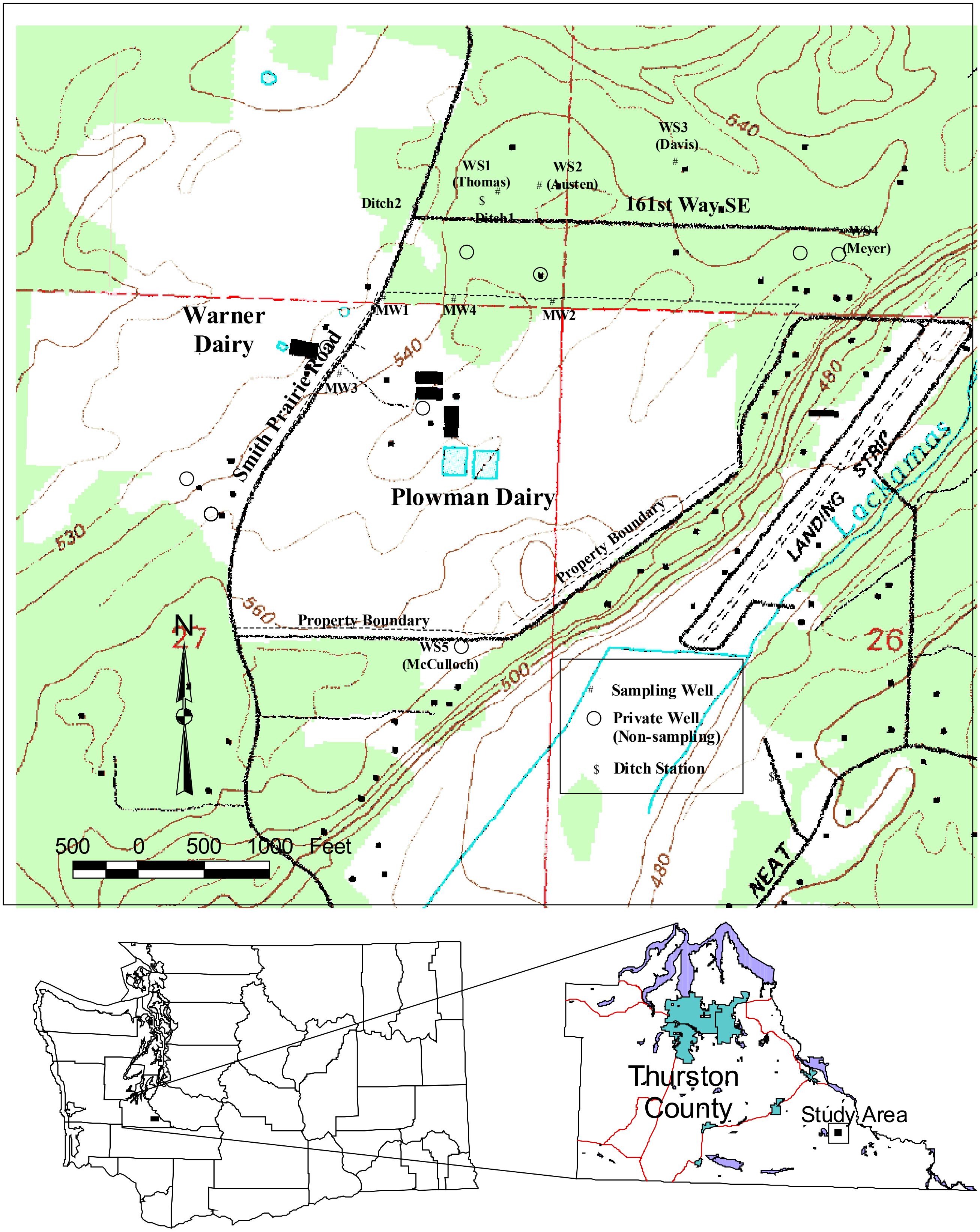

Figure 1. Smith Prairie Vicinity and Well Location Map.

Six hydrogeologic units were identified to a depth of about 200 feet: the Vashon Till, Upper Aquifer, Upper Aquitard, Lower Aquifer, Lower Aquitard and Deep Aquifer. The subsurface relationship of the units is shown in the Hydrogeologic Profiles, Figure 2 and Figure 3. The Vashon Till consists of a compacted mixture of clay, silt, sand, and gravel with a low permeability that appears to continuously underlie the study area. Till thickness is variable ranging from 20 to 95 feet. The Upper Aquifer underlies the till and is the target aquifer for this project. The groundwater flow direction of the Upper Aquifer is discussed in the *Results* section of this report. The Upper and Lower Aquifers are separated by the Upper Aquitard. However, as shown in Figures 2 and 3, the Upper Aquitard is thin and discontinuous; therefore, the Upper and Lower Aquifers are interconnected in some locations.

Well drillers described the occurrence of coarse gravel deposits including boulders and cobbles in drill logs of a number of study area wells. These deposits are depicted as "Gravel" on Hydrogeologic Profiles, Figures 2 and 3. The occurrence of coarse gravel with cobbles and boulders is potentially significant because, if present at the ground surface, laterally continuous, and thick, they could act as a high permeability contaminant pathway to the Upper Aquifer. Also, because pore sizes of these deposits could be large, contaminants (including particulate materials) could be readily transported through this media. However, because of variability of drillers' logs and the difficulty of identifying matrix materials in unsaturated coarse gravel deposits with the air rotary drilling method, it is not known how well the descriptions represent actual conditions.

Soils

Four soil types are mapped in the study area: Kapowsin silt loam, Baldhill very stony loam, Norma silt loam, and Skipopa silt loam (Pringle, 1990).

The dominant soil type is the Kapowsin silt loam. It is a moderately deep, moderately well-drained silt loam that derived from till parent material. It has moderate permeability above the till but very slow permeability through the till. As a result the unit typically has a seasonal high water table at 12 to 24 inches between December to June.

Baldhill very stony loam soils occur north of the study area. Baldhill very stony loam is a well-drained soil associated with recessional outwash deposits. The near surface has moderate permeability with rapid permeability at depth.

Norma silt loam and Skipopa silt loam occur in the western portion of the study area. Norma silt loam is a very deep, poorly drained soil associated with depressions on till plains. It is typically formed over alluvium. It consists of gray silty loam overlying mottled sandy loam and has moderately rapid permeability. Skipopa silt loam is a moderately deep, somewhat poorly drained soil associated with volcanic ash and loess over glaciolacusterine sediment. It consists of 15 inches of silt loam overlying silty clay loam and mottled silt and clay. The permeability is moderate in the silt loam but is slow in the substratum. The unit has a seasonal high water table at 12-24 inches during the winter and spring.

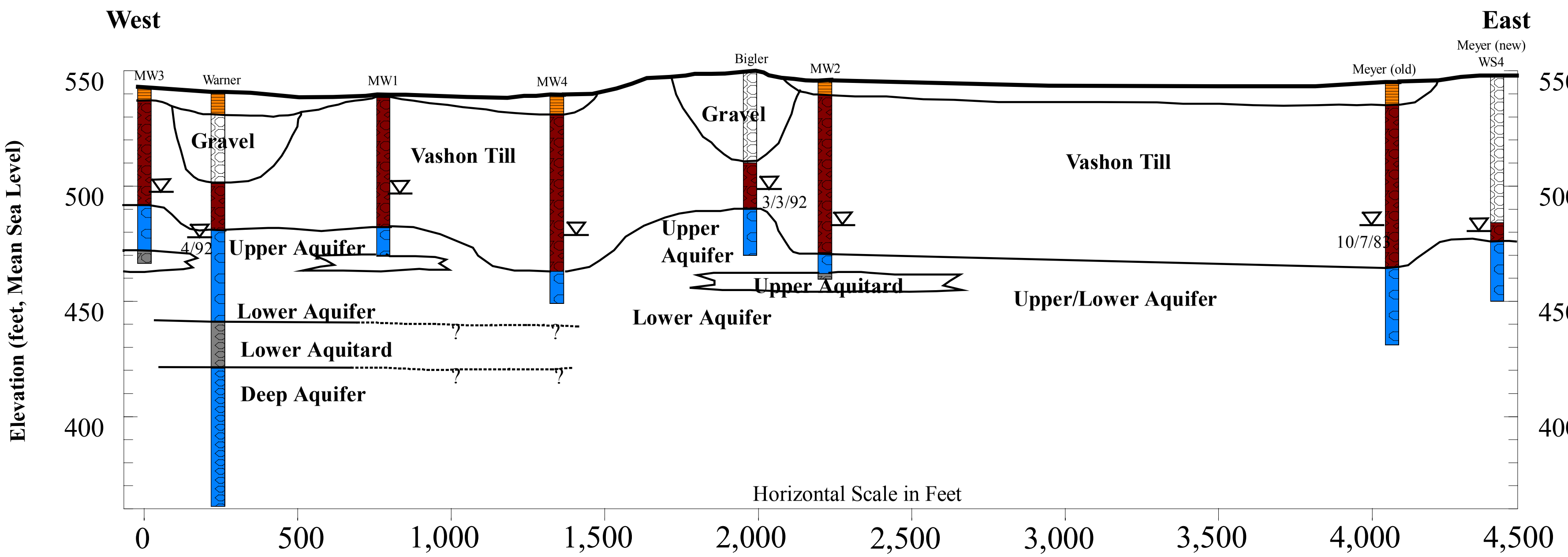

Figure 2. Smith Prairie Groundwater Quality Assessment West-East Hydrogeologic Profile.

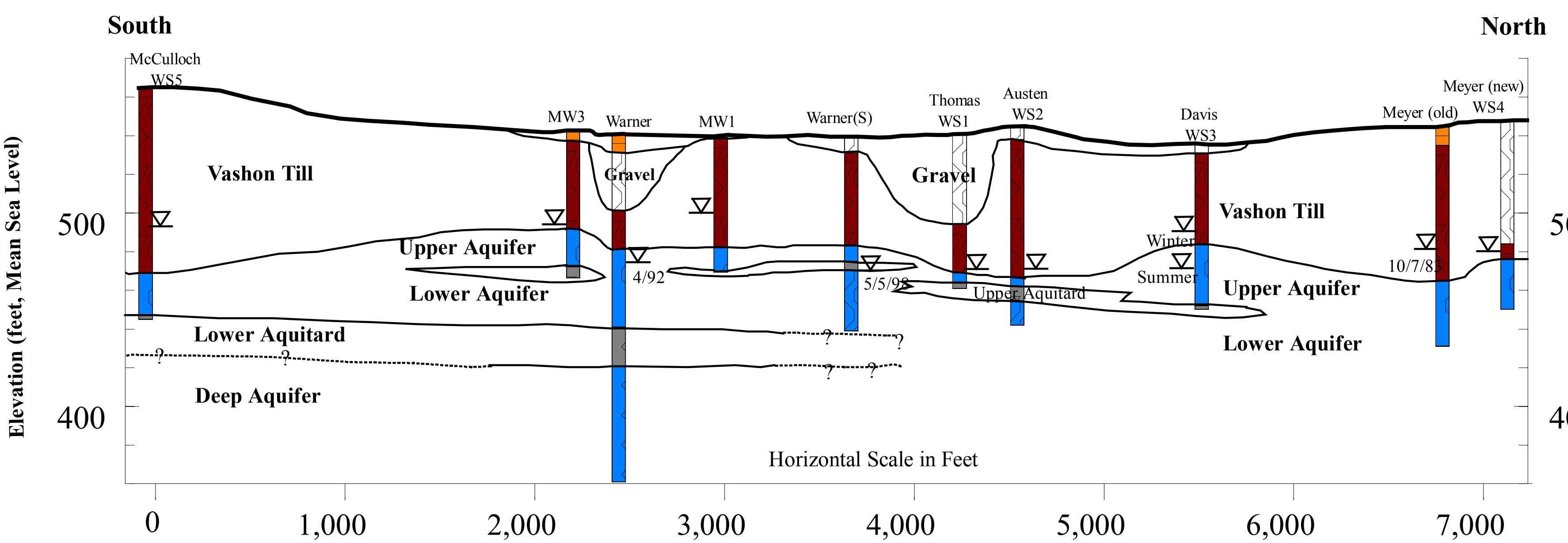

Figure 3. Smith Prairie Groundwater Quality Assessment, South-North Hydrogeologic Profile.

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Methods

Monitoring Network

The monitoring network consisted of four monitoring wells, five private wells, and two surface water stations. The locations of sampling stations are shown in Figure 1. Two of the private wells were used mostly for water-level monitoring but also were sampled twice. Two monitoring wells were installed at June 1999 and two additional wells were installed in August 1999. All of the wells in the monitoring network are completed in the Upper Aquifer with the exception of one private well (WS2) which is completed in the Lower Aquifer. Geologic logs for all wells, along with as-built drawings for the monitoring wells, are shown in Appendix A. Well construction data are summarized in Table A-1. WS2 was included in the network because it had shown elevated nitrate+nitrite-N in the past. The monitoring network was sampled monthly from September 1999 through May 2000. A number of private wells and property parcels were not accessible for this project. The lack of access to these areas resulted in a less than ideal distribution of sampling points in the monitoring network.

The Ditch1 station was established at the north end of the culvert under 161st Way SE. Ditch1 results represent the water quality of the ponded water closest to WS1. In the past the source for this water may have been runoff from adjacent properties and possibly from the north side of the Plowman Dairy. However, development including the excavation of a 4-to 5-foot-deep, north-south trench the entire length of the intervening property (Bigler) altered this drainage pattern. As a result the source of water at Ditch1 was the product of runoff and flooding of adjacent land areas, with no contribution from the Plowman Dairy. The source of water at the Ditch2 station was runoff from the west side of Plowman Dairy.

Sampling Procedures

Detailed sampling procedures are discussed in Appendix B. Water-supply wells were sampled from an outside tap located as close to the wellhead as possible. Monitoring wells were sampled using either dedicated submersible pumps or cleaned Teflon bailers. All wells were purged until field parameters including pH, temperature, specific conductance, and dissolved oxygen stabilized. Grab samples of surface water were obtained by directly filling pre-cleaned bottles.

Target Analytes and Test Methods

Test methods and detection limits for target analytes are listed in Table 1. All analytes were tested monthly from September 1999 to May 2000 with the exception of MBAS and caffeine. MBAS were sampled in all wells during one sampling event in September 1999. Caffeine was tested in WS1 in January 2000. All analyses were conducted at Manchester Environmental Laboratory with the exception of MBAS which were tested by Sound Analytical in Fife, Washington.

Table 1. Test Methods and Detection Limits.

Parameter	Test Methods[1]	Target Detection Limit
pH (Field)	Orion Model 250A	NA
Temperature (Field)	Orion Model 250A	0.1°C
Specific Conductance (Field)	Beckman Meter	10 umhos/cm
Dissolved Oxygen (Field)	VWR Meter	0.1 mg/L
Total Dissolved Solids	2540C	1 mg/L
Ammonia-N	4500 NH3 D	0.01 mg/L
Nitrate+Nitrite-N	4500 NO3 F	0.01 mg/L
Total Phosphorus	4500-P F	0.01 mg/L
Total Kjeldahl Nitrogen	4500-Norg	0.1 mg/L
Chloride	4110B	0.1 mg/L
Total Organic Carbon	5310B	1 mg/L
Methylene Blue Active Substances	5540 C	0.025 mg/L
Caffeine	SW846 Method 8270	1-5 ug/L
Fecal Coliform Bacteria	MF 9222D	1 CFU/100mL

[1] Manchester Environmental Laboratory, 1994, and APHA, 1992.

Microscopic Particle Identification

Four samples were collected and submitted to Manchester Environmental Laboratory for microscopic particle identification. The sample locations are listed as follows:

- Pre-filter of the WS1 water treatment system
- WS1 well water
- Ditch1 water
- Ditch2 water

The pre-filter sample was collected October 26 by scraping the reddish-brown residue from the filter into a pre-cleaned two-ounce glass bottle using a cleaned spatula. The water samples were collected in pre-cleaned one-gallon jars November 30.

Hydrologic Testing

Three private wells and the four monitoring wells were tested to estimate the hydraulic conductivity of the aquifer. Hydraulic conductivity is a measure of how easily water is transmitted through the aquifer; the higher the hydraulic conductivity, the more readily water moves through the aquifer.

Hydrologic tests consisted of measuring the water-level response to constant-rate pumping. Existing installed pumps were used to discharge water from private wells. At MW3 the dedicated 2-inch Purger submersible pump used for sampling was used to pump water for the test; and at MW1, MW2, and MW4 a Grunfos Redi-Flo 2-inch stainless steel submersible pump was used to discharge water. Pumping rates were measured and maintained for a minimum of one hour or until the pumping water level stabilized. Pumping rates ranged from 0.7 to 10.9 gallons per minute. Water levels were measured to 0.01 feet using an electric tape. Hydraulic conductivity was estimated using the method described by Bradbury and Rothschild (1985). This method is a iterative solution to the Theis equation with corrections for partial penetration and hydraulic efficiency. The Upper Aquifer is confined and the storage coefficient was assumed to be 0.001. Headloss due to well inefficiency was assumed to be negligible. These hydrologic test results should be considered approximate values.

Air Photo Review

Air photos of the study area taken between 1972 and 1993 were obtained from the Washington State Department of Natural Resources. Nine-by-nine-inch pairs were examined stereoscopically to identify past drainage conditions, land use practices and features that may have affected groundwater quality. The scale of these photos was about one inch to 1000 feet. Dates of photos examined are listed as follows: August 27, 1972; May 19, 1978; June 25, 1981; June 18, 1985; September 3, 1989, and August 30, 1993.

Quality Assurance of Field Parameter Results

The overall precision of sampling and testing for field parameters was estimated using relative percent differences (RPDs) of duplicate samples. Duplicate results and RPDs are shown in Table C-1 and summarized in Table 2 below. The overall precision for field results averaged from 4 to 6.5%.

Table 2. Summary of Field Duplicate Results for Field Parameters.

	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
Minimum RPD=	0.0	0.3	0.0	0.7
Maximum RPD=	16	8.2	13	14
Mean RPD=	6.3	4.9	4.0	4.9

Quality Assurance of Laboratory Results

Quality assurance results for the data obtained for this project are discussed below. The quality assurance for samples collected during previous studies is assumed to be comparable.

Laboratory Quality Control Procedures

Laboratory staff conducted a quality assurance review of all analytical data generated at Manchester Environmental Laboratory prior to releasing the data for this project. Laboratory quality control tests were done on each set of 20 or fewer samples and consisted of duplicate blanks, duplicate samples, spiked samples, and check standards (Ecology, 1988). Analytical precision was estimated from check standards and duplicate sample analyses. Analytical bias was estimated from matrix spikes and check standards. Recoveries from check standards provided an estimate of bias due to calibration. Mean percent recoveries of spiked sample analyses provide an estimate of bias due to interference. Based on the internal laboratory review, all results are considered acceptable for use except as qualified in Table E-2 (Appendix E).

Field Duplicate Samples

The RPD of field duplicate samples provide an estimate of overall sampling and analytical precision. The RPD of a duplicate sample set is the ratio of the difference of the sample results and the mean of sample results expressed as a percentage. Duplicate results and RPDs are shown in Table C-2 (Appendix C) and summarized in Table 3 below.

Table 3. Summary of Field Duplicate Results for Laboratory Analytes.

Analyte	Minimum RPD	Maximum RPD	Mean RPD
NO2+NO3-N	1.9	9.8	6.9
Total Kjeldahl Nitrogen	1.6	2.1	1.8
NH3-N	18	45	32
Total Phosphorus	0.0	10	2.8
Chloride	0.2	8.1	2.0
Total Dissolved Solids	0.0	18	5.2
Total Organic Carbon	0.0	14	7.2
Fecal Coliform	3.3	33	18
Bromide	5.6	5.6	5.6
MBAS	29	29	29

Overall sampling and analytical precision for most parameters (excluding ammonia-N, MBAS, and fecal coliform bacteria) ranged from 2 to 7%. Ammonia-N showed a mean RPD of 31.5% based on two duplicate sets. MBAS showed an RPD of 29% based on one duplicate set. Both ammonia-N and MBAS results were close to the detection limit where RPDs are least representative of precision. Fecal coliform bacteria results had a mean RPD of 18% based on two duplicate sets.

Results

Hydrogeology

Hydrologic Testing

The hydrologic test data and calculated hydraulic conductivities for each well are listed in Table D-1 (Appendix D) and summarized below in Table 4. The hydraulic conductivity values of the Upper Aquifer range from 1 to 200 feet per day. The higher values are associated with the private water-supply wells, and the lower values are associated with the monitoring wells. Often water-supply wells are selectively installed in the most productive zones of an aquifer; this potentially could account for the higher hydraulic conductivity values. However, the thin nature of the Upper Aquifer does not support this conjecture. Most likely the results reflect the distribution of hydraulic conductivity in the Upper Aquifer. Hydraulic conductivity is generally considered to be lognormally distributed, and the geometric mean is considered a good measure of central tendency (Freeze, 1975). The geometric mean of all Upper Aquifer hydraulic conductivity test results is about 20 feet/day.

Table 4. Summary of Hydrologic Test Results.

Well ID	Aquifer	Hydraulic Conductivity (ft/d)
WS1	Upper	181
WS2(A)	Upper/Lower	170
WS2 (B)[1]	Upper/Lower	59
WS3	Upper	107
MW1	Upper	1.1
MW2	Upper	23
MW3(A)	Upper	7.7
MW3(B)	Upper	8.2
MW4	Upper	5.6
WS4(New)[1]	Upper	200
Meyers(Old)[1]	Lower	54
Upper Aquifer Geometric Mean=		21
Upper Aquifer Minimum=		1.1
Upper Aquifer Maximum=		200

[1]Test results calculated from data reported on drill log.

Direction and Rates of Groundwater Flow

Water level measurements are listed in Table D-2 (Appendix D). Hydrographs for selected wells are shown in Figure 4. Daily precipitation values measured at Olympia Airport through

March 30, 2000 are shown in Figure 5. The pattern of groundwater flow in the Upper Aquifer is complex and varies seasonally in response to precipitation. Water levels in private wells along the north portion of the study area rose dramatically in response to the onset of winter rainfall beginning the last week of October. The water level in WS3 rose 19.5 feet between October 26 and November 30. The seasonal variation of the water levels in monitoring wells was much more subdued, ranging from three to five feet.

The summer and winter groundwater flow patterns are shown in potentiometric maps Figures 6 and 7, respectively. These contour maps are based on water-level elevations measured at each of the wells. Potentiometric contour line locations were determined with the Surfer software package using a kriging algorithm. The large arrows on the figures are drawn perpendicular to the contour lines and show the approximate groundwater flow direction. In the summer groundwater flows primarily eastward. The hydraulic gradient appears to be fairly steep between MW1 and MW4 and flatter over most of the study area. In the winter the flow direction in the north portion of the study area changes showing a strong southward component of flow. This pattern persists through the winter; the summer pattern was restored in June 2000.

Groundwater velocity can be estimated using Darcy's Law:

$v = - K_h (dh/dL)/n_e$

where,

v = the average linear groundwater velocity (feet/day)

K_h = horizontal hydraulic conductivity (feet/day)

dh/dL = hydraulic gradient (dimensionless)

n_e = effective porosity (dimensionless)

Table 5 summarizes the input parameters to estimate groundwater flow velocity for the Upper Aquifer in the study area. Summer, winter, and average hydraulic gradients were determined from Figures 5 and 6 for two areas: 1) the Plowman fields which are representative of the study area and 2) the high hydraulic gradient area between MW1 and WS1. An effective porosity of 0.25 was used for all estimates. Based on these parameters the average groundwater flow is expected to range between 0.01 and 5 feet/day. The best estimate for the average velocity of the Upper Aquifer is about 0.3 feet/day or about 100 feet/year.

Table 5. Estimated Groundwater Flow Velocities.

Area		**Hydraulic Gradient**		**Hydraulic Conductivity (ft/d)**		**Average Linear Velocity (ft/d)**
Plowman Fields	Summer=	0.0046	Minimum=	1	Minimum=	0.01
(Typical Conditions)	Winter=	0.0033	Maximum=	200	Maximum=	4
	Average=	0.0040	Geomean=	20	**Mean=**	**0.3**
MW1 to WS1	Summer=	0.0073	Minimum=	1	Minimum=	0.03
(High gradient)	Winter=	0.0067	Maximum=	180	Maximum=	5
	Average=	0.0070	Geomean[1]=	10	**Mean=**	**0.3**

[1] Geometric mean of MW1, WS1, and MW4

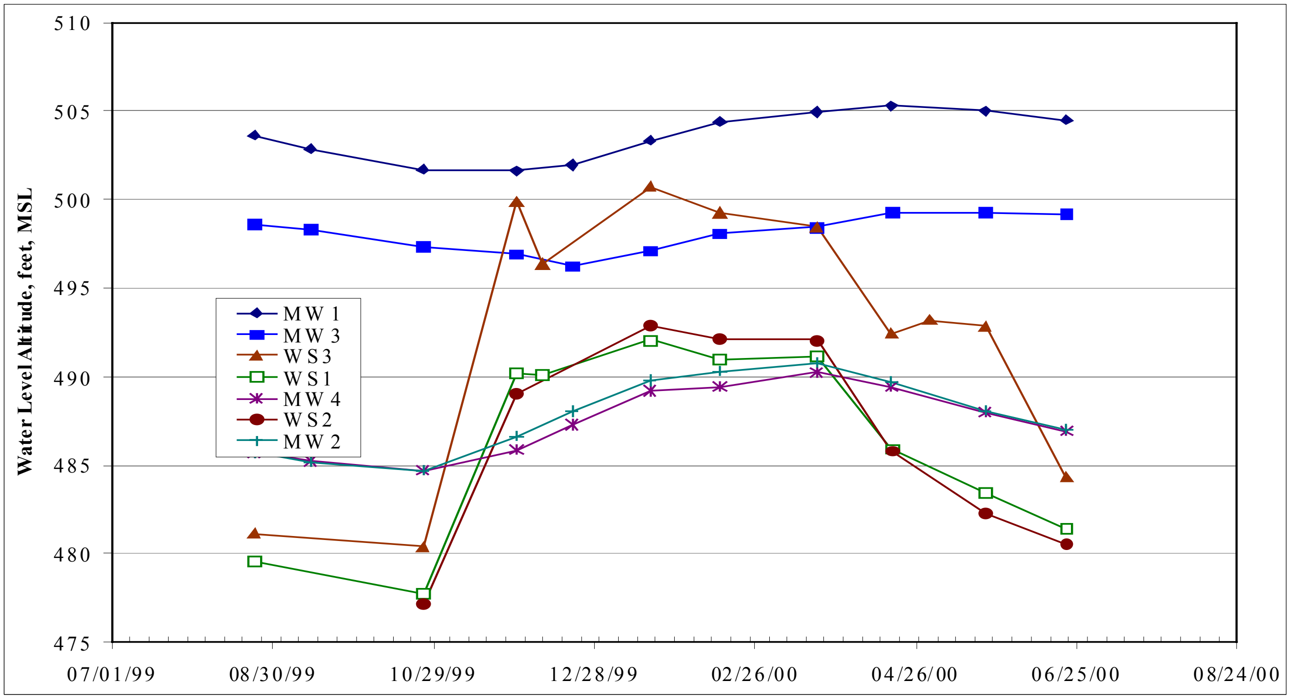


Figure 4. Hydrographs for Selected Wells, Smith Prairie Groundwater Quality Assessment.

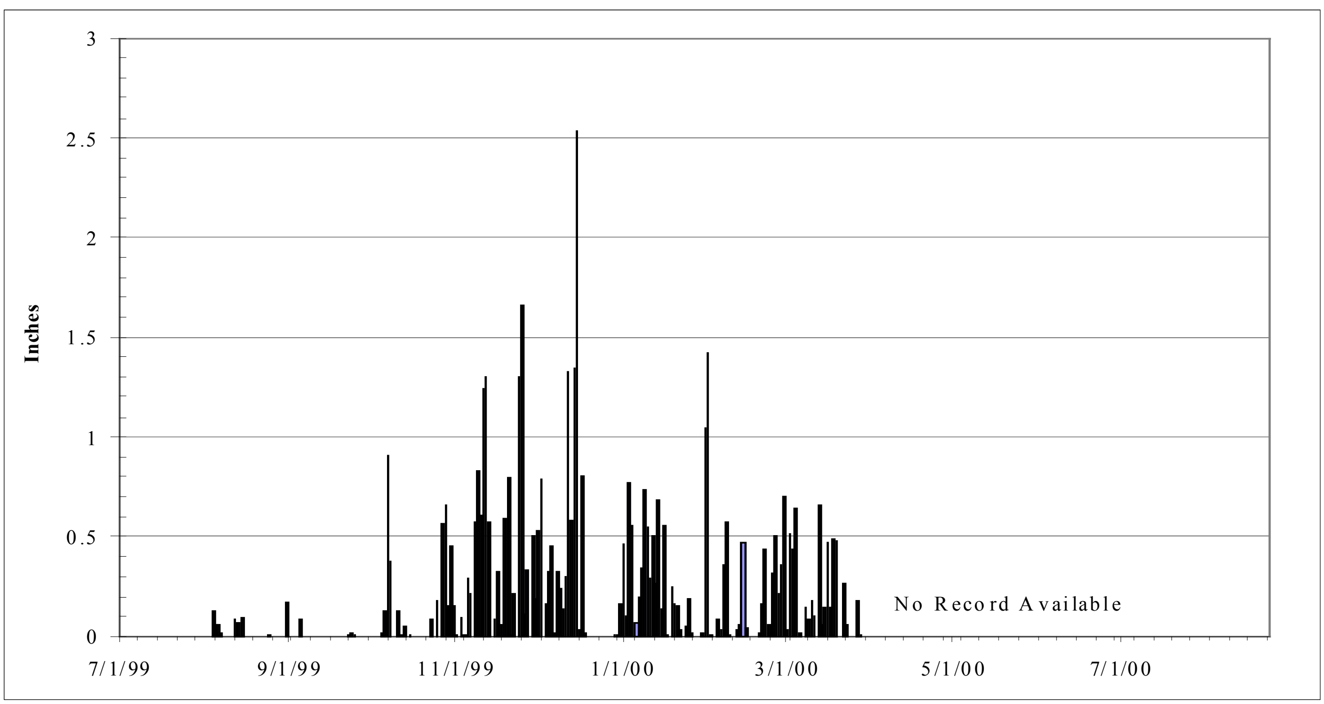


Figure 5. Daily Precipitation at Olympia Airport, August 1, 1999 to March 30, 2000(National Climatic Data Center, 2000).

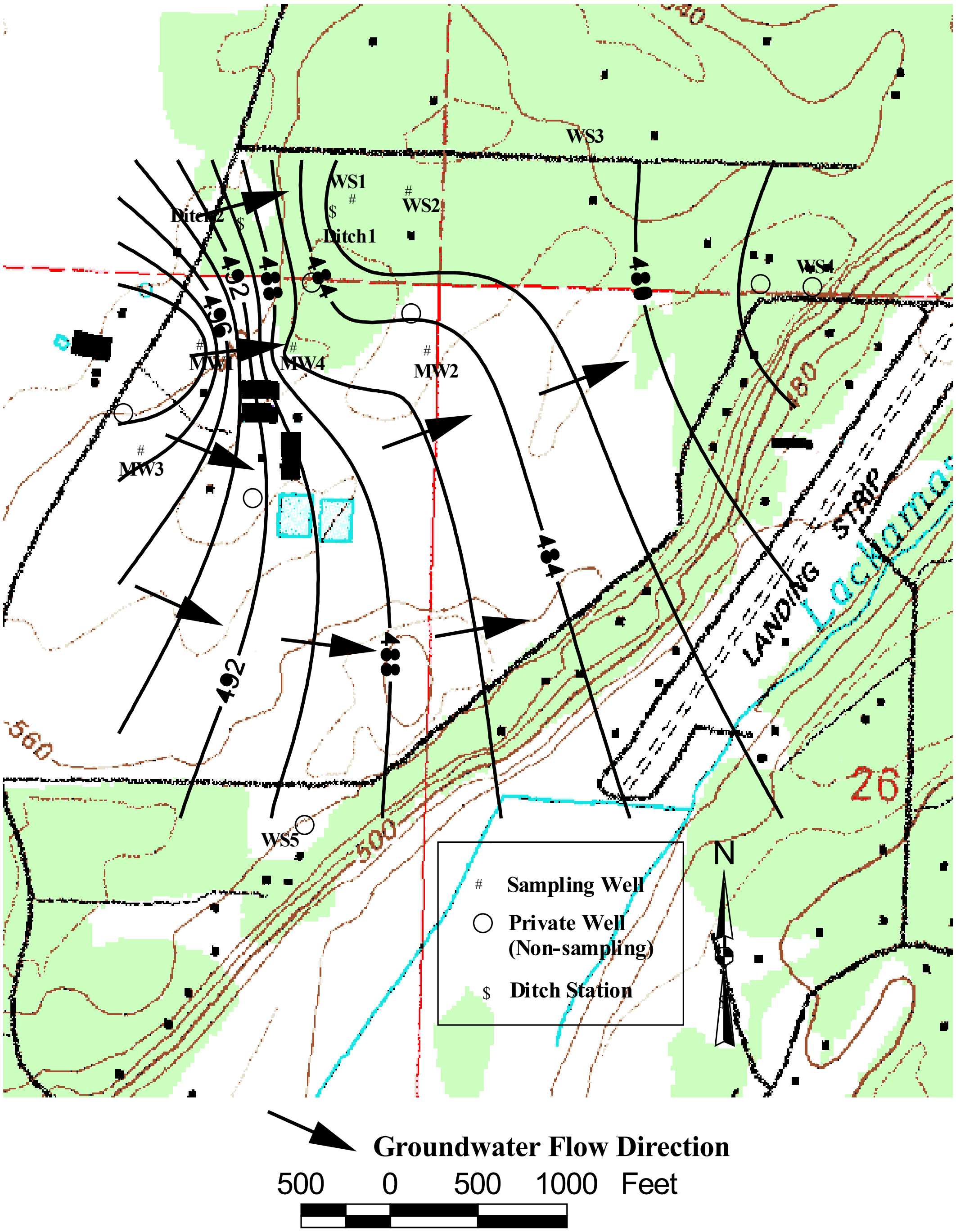


Figure 6. Smith Prairie Groundwater Quality Assessment, Upper Aquifer Potentiometric Map, August 1999.

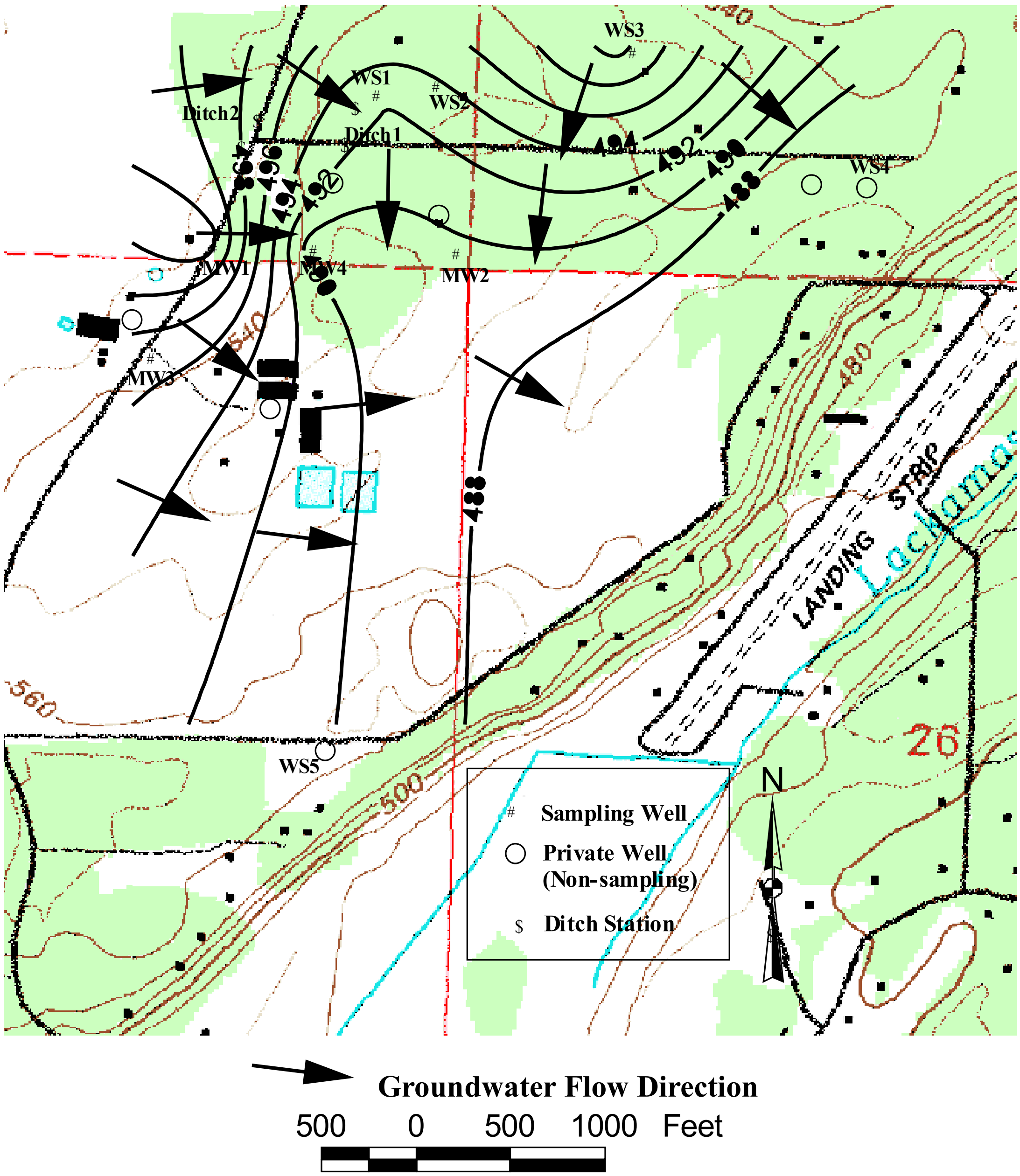


Figure 7. Smith Prairie Groundwater Quality Assessment, Upper Aquifer Potentiometric Map, January 2000.

Air Photo Review

Examination of air photos identified a remnant drainage channel that extends northward from the Plowman Dairy, crosses the Bigler property, and enters Thomas property about 100 feet west of WS1. The remnant channel continues northwestward onto the Cloran property where it becomes indistinguishable. The channel was formed either by meltwater during glacial recession or a post-glacial stream. In the past, the channel may have acted as a pathway for runoff from Plowman Dairy that eventually crossed beneath 161st Way SE. But development and drainage control activities on the Bigler property including the four-to-five-feet deep, north-south trench have altered the drainage pattern, and runoff from the dairy no longer reaches 161st Way SE.

Photos also revealed one gravel pit located on Port Blakely Tree Farm property 1300 feet north of WS1. This pit was excavated between 1972 and 1978. A field inspection of the pit did not show any signs of dumping or placement of materials would serve as a source of contamination. Most of the cutslopes of the pit were covered with vegetation but coarse sandy gravel cropped out in some locations. No other pits or potential sources of contamination were identified.

Downhole Well Inspection of WS1

A downhole inspection of WS1 was conducted on March 22, 2000 by Mark Ader of Ecology's Eastern Regional Office. The purpose of the inspection was to determine if the well casing showed any breaks that would allow water to enter from shallow depths. The downhole camera was slowly lowered down the entire depth of the well while video images were continuously recorded. The inspection revealed a steel casing with considerable flaking and weathering of the inner surface but did not identify any breaks in the casing.

Water Quality

Field Parameters

Field parameter results are listed in Table E-1 (Appendix E). The range and mean value for each sampling station are summarized in Table 6. For groundwater, specific conductance ranged from 155 to 800 umhos/cm with a mean of 355 umhos/cm; pH ranged from 5.18 to 6.90 Standard Units with a mean of 5.95 Standard Units; temperature ranged from a 7.2 and 13.1°C with a mean of 10.6 °C; dissolved oxygen ranged from 0.2 to 9.2 mg/L with a mean of 3.7 mg/L. The highest mean specific conductance values, which typically is proportional to total dissolved solids, were observed in MW1 (442 umhos/cm), MW3 (609 umhos/cm), and WS1 (534 umhos/cm) and values decreased eastward. The lowest groundwater temperature was observed at WS1 in February 2000 with a reading of 7.2°C. This temperature was over 2°C cooler than the minimum temperatures at other groundwater stations.

Table 6. Summary of Field Parameter Results.

Station ID	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
WS1				
Minimum=	373	5.47	7.3	0.5
Maximum=	690	6.57	10.8	5.34
Mean=	534	5.91	9.1	1.9
WS2				
Minimum=	183	5.21	9.6	2.0
Maximum=	341	6.23	11.7	9.25
Mean=	254	5.75	10.3	4.7
WS3				
Minimum=	155	5.18	9.3	0.2
Maximum=	255	6.19	11.8	6.2
Mean=	210	5.58	10.6	2.4
MW1				
Minimum=	425	5.53	10.5	3.3
Maximum=	460	6.18	12.5	6.81
Mean=	442	5.89	11.4	4.8
MW2				
Minimum=	177	6.38	10.1	2.7
Maximum=	190	6.90	11.3	5.2
Mean=	182	6.64	10.6	3.9
MW3				
Minimum=	480	5.52	11.1	0.9
Maximum=	800	6.32	13.1	4.85
Mean=	609	5.90	11.9	2.7
MW4				
Minimum=	226	5.42	9.4	3.8
Maximum=	287	6.43	11.3	7.98
Mean=	253	6.00	10.2	5.3
Overall Groundwater				
Minimum=	155	5.18	7.3	0.2
Maximum=	800	6.90	13.1	9.25
Mean=	355	5.95	10.6	3.7
Ditch1				
Minimum=	183	NA	5.6	2.7
Maximum=	310	NA	10.5	9.3
Mean=	229	NA	7.9	6.3
Ditch2				
Minimum=	362	6.04	3.7	3.2
Maximum=	910	7.06	18.5	7.44
Mean=	546	6.61	9.5	5.2

Laboratory Analytes

All laboratory results obtained for this project including results from previous studies are compiled and listed in Table E-2 (Appendix E). In addition the results for each analyte for selected stations are shown separately in Tables E-3 through E-10 (Appendix E). The results are summarized in Table 7 and discussed below.

Nitrate+Nitrite-N

Nitrate+nitrite-N results are summarized in Table 7 and listed for selected stations in Table E-3. Nitrate+nitrite-N, the target analyte for this study, showed concentrations in groundwater ranging from 0.14 to 41.7 mg/L. The maximum concentration (41.7 mg/L) was observed at WS1. Mean nitrate+nitrite-N concentrations for wells over the study period ranged between 0.7 mg/L at MW2 and 24.4 mg/L at WS1. The mean nitrate+nitrite-N concentration for all wells over the study period was 9.6 mg/L

Time-series plots of nitrate+nitrite-N results, including data from previous studies, are shown in Figure 8. For clarity, private wells, monitoring wells, and ditch samples are shown separately. Nitrate+nitrite-N concentrations at WS1 fluctuated seasonally with concentrations exceeding 30 mg/L in the summer and decreasing to about 15 mg/L in the winter. Maximum concentrations observed in 1999-2000 were higher than in 1995-6.

Nitrate+nitrite-N concentrations in the monitoring wells show substantially less fluctuation than WS1 (with the exception of the October 1999 sample at WS3). MW1 and MW3 located on the upgradient border of Plowman Dairy showed the highest concentrations of the four monitoring wells with means of 21.4 and 14.7 mg/L, respectively.

Nitrate+nitrite-N concentrations were much higher in Ditch2 than in Ditch1. Over the winter concentrations in Ditch 2 decreased continuously from nearly 40 mg/L to 0.2 mg/L. Likewise, concentrations at Ditch1 decreased continuously over the winter from 3mg/L to 0.02 mg/L.

Nitrate is significant because it has a drinking water standard and a groundwater quality criterion of 10 mg/L (Washington State Department of Health, 1994; and Washington State Department of Ecology, 1990). The test method used for this study determined the sum of nitrate and nitrite in samples. However, nitrite is seldom present in groundwater and when present usually occurs at low concentrations (Matthess, 1982). It is assumed for this study that the amount of nitrite-N in samples is negligible relative to the nitrate fraction.

Chloride and TDS

Chloride concentration distributions were similar to nitrate+nitrite-N and are listed in Table E-4. Concentrations in groundwater ranged from 3.3 mg/L at MW2 to 49.4 mg/L at WS1. Time-series plots for private wells, monitoring wells, and ditch samples are shown in Figure 9. WS1 showed widely fluctuating chloride concentrations that ranged from 19.5 to 49.4 mg/L and had a mean of 34.7 mg/L. For monitoring wells, the highest concentrations were observed at MW1

Table 7. Laboratory Results Summary, Smith Prairie Groundwater Quality Assessment. (Units in mg/L unless shown otherwise.)

Station ID		Nitrate+ Nitrite-N	Chloride	TDS	Fecal Coliform Bacteria[1]	NH3-N	Total Phos.	TKN	Total Organic Nitrogen	TOC
WS1	Minimum=	10.0	19.5	300	1U	0.01U	0.13	0.5U	0.5U	2.4
	Maximum=	41.7	49.4	654	152	0.03	2.05	2.54	2.54	19.3
	Mean=	24.4	34.7	407	22	0.01	0.76	1.13	1.12	11.0
WS2	Minimum=	6.8	11.8	150	1U	0.01U	0.03	0.5U	0.5U	1.6
	Maximum=	17.0	21.3	233	1U	0.02	0.10	0.58	0.56	4.4
	Mean=	11.4	16.5	192	1U	0.01	0.07	NA	NA	3.0
WS3	Minimum=	1.0	7.2	153	1U	0.01U	0.07	0.5U	0.5U	1.8
	Maximum=	12.3	14.7	190	1100J	0.14	0.32	1.65	1.60	6.2
	Mean=	7.0	10.9	170	146	0.05	0.11	0.41	0.385	2.9
WS4	Minimum=	0.6	3.7	146	1U	0.01U	0.12	0.5U	0.5U	1.0U
	Maximum=	1.6	6.1	156	1U	0.01	0.13	0.5U	0.5U	1.0U
	Mean=	1.1	4.5	151	NA	0.01	0.12	0.5U	NA	1.0U
WS5	Minimum=	0.5	4.2	192	1U	0.01U	0.13	0.5U	0.5U	1.0U
	Maximum=	0.7	5.2	195	1U	0.01	0.15	0.5U	0.5U	1.0U
	Mean=	0.6	4.6	194	1U	0.01	0.14	0.5U	NA	1.0U
MW1	Minimum=	19.7	29.4	315	1U	0.01U	0.11	0.5U	0.5U	1.0U
	Maximum=	22.8	32.0	348	1U	0.23	0.45	0.5U	0.5U	1.3
	Mean=	21.4	30.4	329	1U	0.03	0.16	0.5U	NA	0.7
MW2	Minimum=	0.1	3.3	132	1U	0.01U	0.12	0.5U	0.5U	1.0U
	Maximum=	1.6	4.7	187	1U	0.03	0.19	0.5U	0.5U	1.0
	Mean=	0.7	4.0	159	1U	0.01	0.14	0.5U	NA	0.6
MW3	Minimum=	7.1	21.5	328	1U	0.01U	0.12	0.5U	0.5U	1.0U
	Maximum=	41.3	39.9	500	6	0.01U	0.19	0.5U	0.5U	2.2
	Mean=	14.7	31.1	415	NA	0.01U	0.15	0.5U	NA	1.5
MW4	Minimum=	2.6	9.0	185	1U	0.01U	0.09	0.5U	0.5U	1.0U
	Maximum=	7.4	17.1	220	1U	0.02	0.16	0.5U	0.5U	1.1
	Mean=	5.2	12.3	202	1U	0.01	0.11	0.5U	NA	0.6
Groundwater Summary	Minimum=	0.1	3.3	132	1U	0.01U	0.03	0.5U	0.5U	1.0U
	Maximum=	41.7	49.4	654	1100J	0.23	2.05	2.54	2.54	19.3
	Mean=	9.6	16.6	246	NA	NA	0.20	NA	NA	2.4
Ditch1	Minimum=	0.02	10.6	129	3U	0.01	0.49	1.00	0.982	11.2
	Maximum=	3.1	13.8	225	640J	0.12	1.55	1.92	1.81	18.7
	Mean=	1.3	11.8	164	137	0.04	1.05	1.36	1.32	13.7
Ditch2	Minimum=	0.2	8.6	312	46	0.08	2.54	3.79	3.51	32.9
	Maximum=	39.3	51.3	664	3800J	3.51	6.02	8.97	5.59	42.2
	Mean=	12.4	25.0	421	1803	0.89	4.51	5.55	4.61	37.7

[1] Units in Colony Forming Units/100mL.

U= Analyte not detected at or above value shown.

J= Analyte was positively identified. The listed value is an estimate.

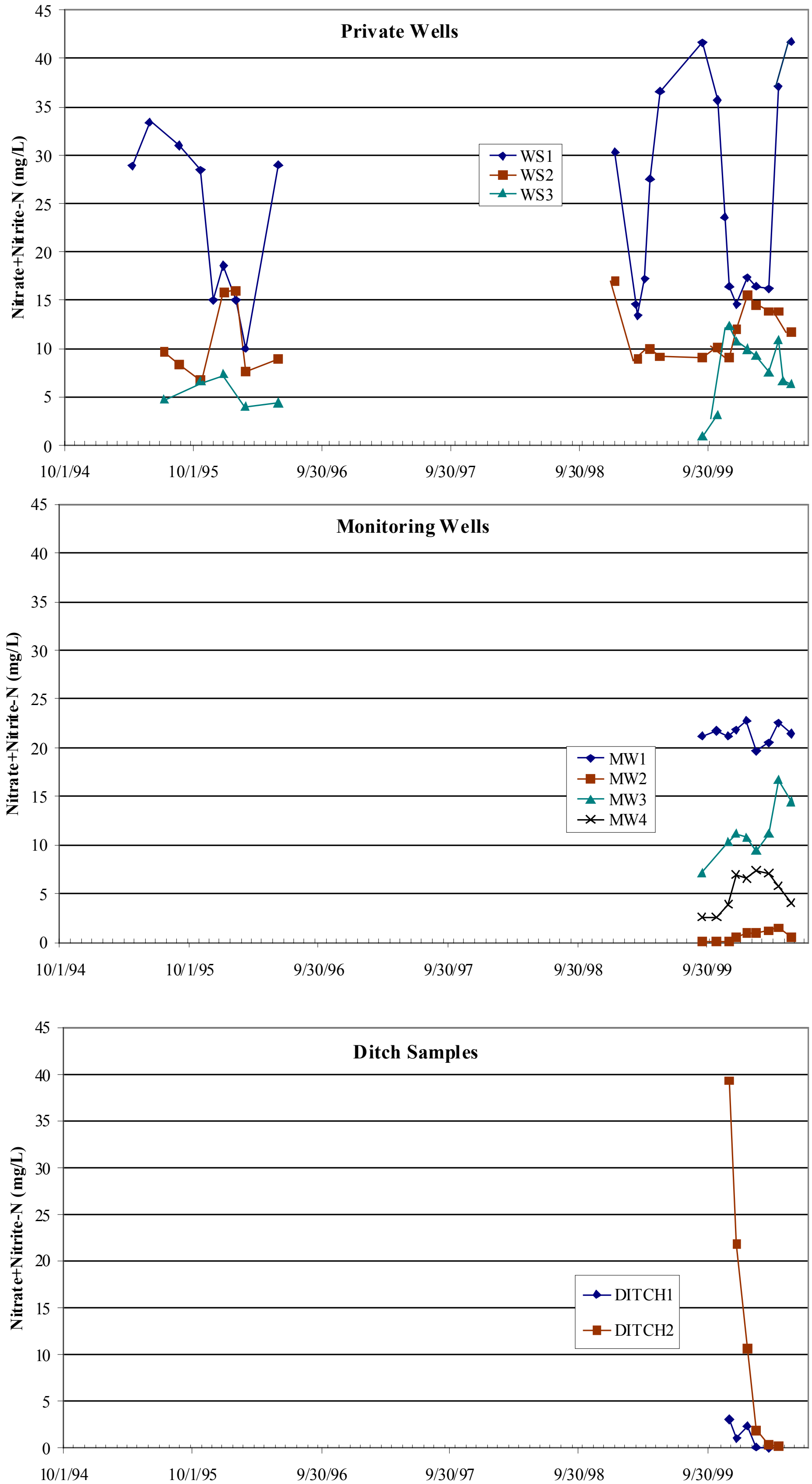


Figure 8. Nitrate+Nitrite-N Results, Smith Prairie Groundwater Quality Assessment.

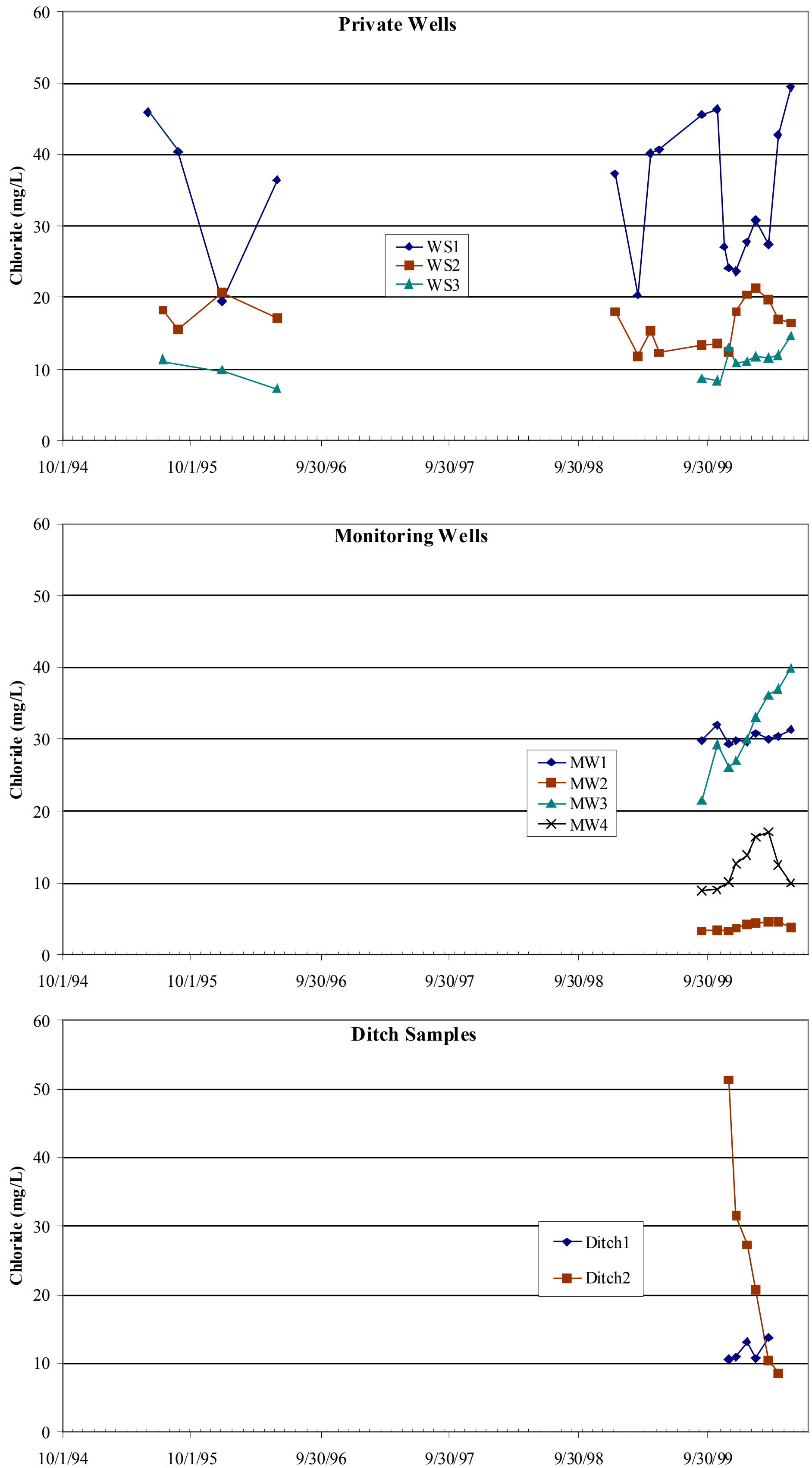


Figure 9. Chloride Results, Smith Prairie Groundwater Quality Assessment.

and MW3 with means of 30.4 and 31.1 mg/L chloride, respectively. Ditch2 samples showed higher chloride concentrations than Ditch1, and concentrations at Ditch2 decreased continuously over the winter.

Total dissolved solids (TDS) concentrations are listed in Table E-5. TDS concentration distributions were similar to nitrate+nitrite-N and chloride. Concentrations in groundwater ranged from 132 mg/L at MW2 to 654 mg/L at WS1 with a mean of 246 mg/L TDS. TDS concentrations in Ditch2 averaged 421 mg/L and were substantially higher than Ditch1 concentrations, showing a mean of 164 mg/L.

Total Phosphorus

Total phosphorus results are shown in Table E-6. Concentrations in groundwater ranged from 0.03 mg/L at WS2 to 2.05 mg/L at WS1 with a mean of 0.20 mg/L. Time-series plots of results are shown in Figure 10. Phosphorus concentrations in wells WS2, WS3, and all monitoring wells are fairly uniform seasonally. At WS1, however, concentrations fluctuated seasonally with high values in the winter and low values in the summer. This seasonal pattern is the opposite of the one observed for nitrate+nitrite-N, chloride, and TDS with highs occurring in the summer and concentrations decreasing in the winter. Mean phosphorus concentrations in monitoring wells showed a narrow range of 0.11 to 0.16 mg/L. Ditch2 phosphorus concentrations were consistently higher than Ditch1, with means of 4.51 and 1.05 mg/L total phosphorus, respectively.

Fecal Coliform Bacteria

Fecal coliform bacteria results are shown in Table E-7. Fecal coliform bacteria were detected primarily in private wells WS1 and WS3 and the ditch stations. At WS1, concentrations ranged from less than the detection limit (1 CFU/100mL) to 152 CFU/100mL. WS3 showed high fecal coliform counts (650 CFU/100mL) in April and May 2000 (115 and 1100 CFU/100mL). Ditch2 concentrations, ranging from 46 to 3800 CFU/100mL, were much higher than Ditch1. Time-series plots of bacteria results are shown in Figure 11. As with total phosphorus, fecal coliform bacteria concentrations showed a seasonal pattern with high values in the winter and low values in the summer.

Other Parameters

Ammonia-N, Total Kjeldahl Nitrogen (TKN), organic nitrogen, and Total Organic Carbon (TOC) results are shown in Tables E-8 through E-10. Similar to fecal coliform bacteria and total phosphorus, these analytes were detected primarily at the ditch stations and in water-supply wells WS1 and WS3. The highest concentrations for each analyte were observed at WS1 with the exception of ammonia-N. The concentrations at WS1 varied seasonally with high values occurring in the winter and low values occurring in the summer. This seasonal pattern is the opposite of the pattern for nitrate+nitrite-N, chloride, and total dissolved solids which showed high values in the summer and low values in the winter. The highest ammonia-N concentration (0.23 mg/L) was observed at MW1.

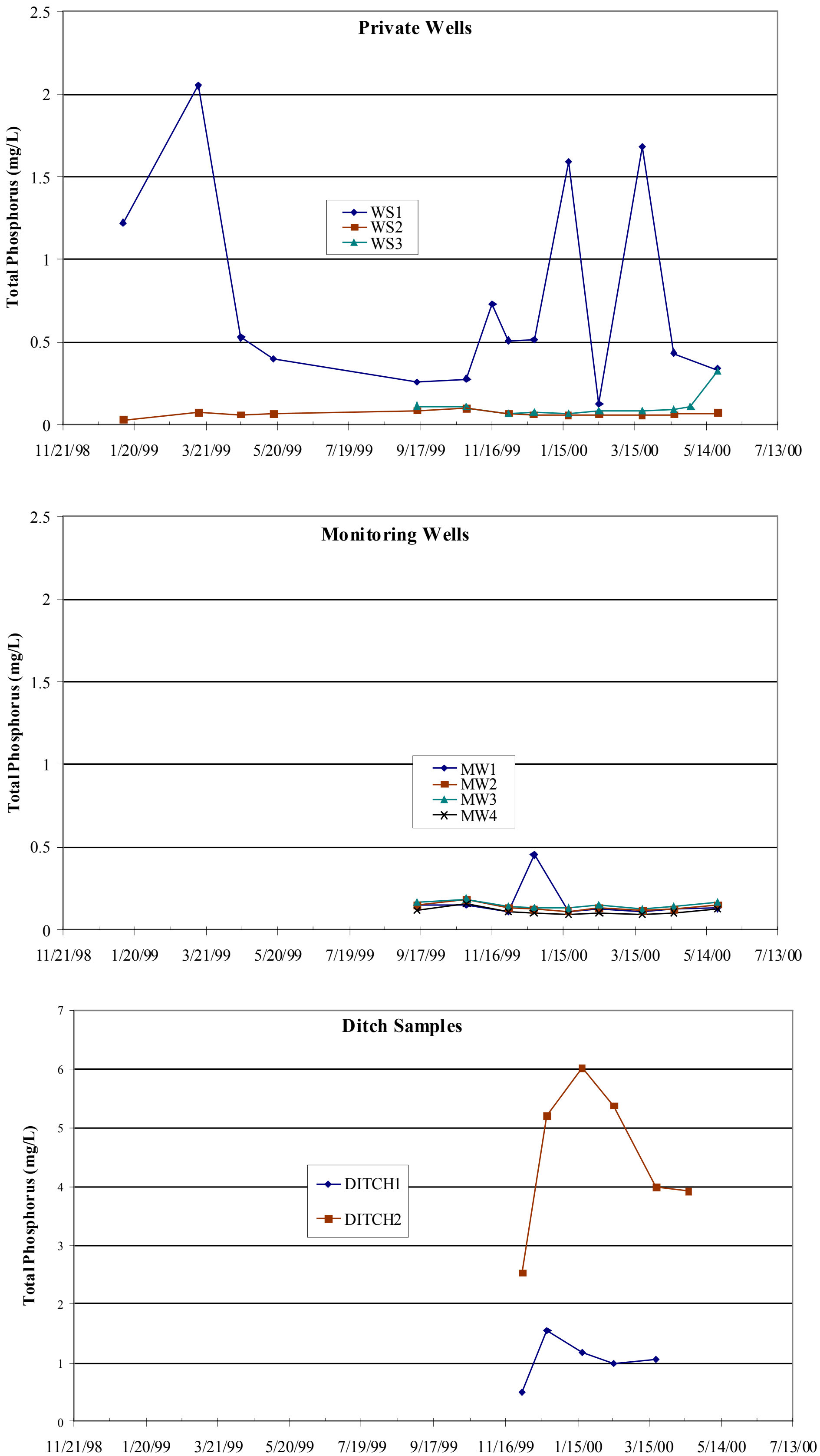
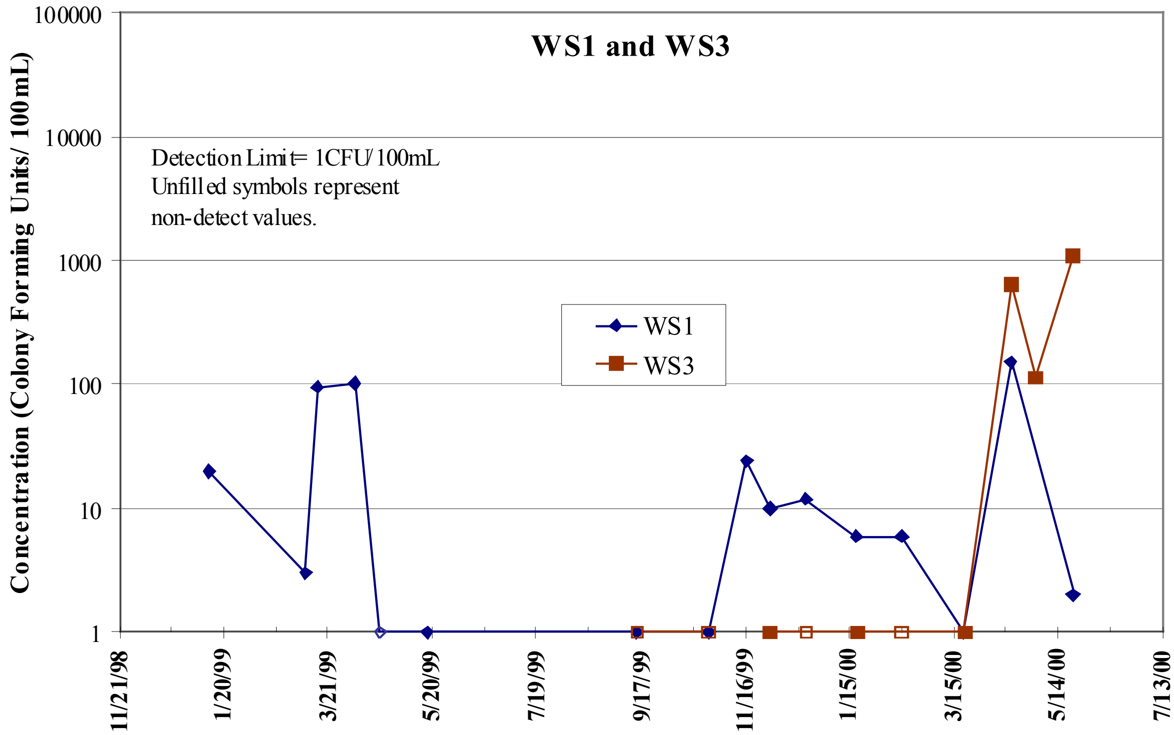


Figure 10. Total Phosphorus, Smith Prairie Groundwater Quality Assessment.



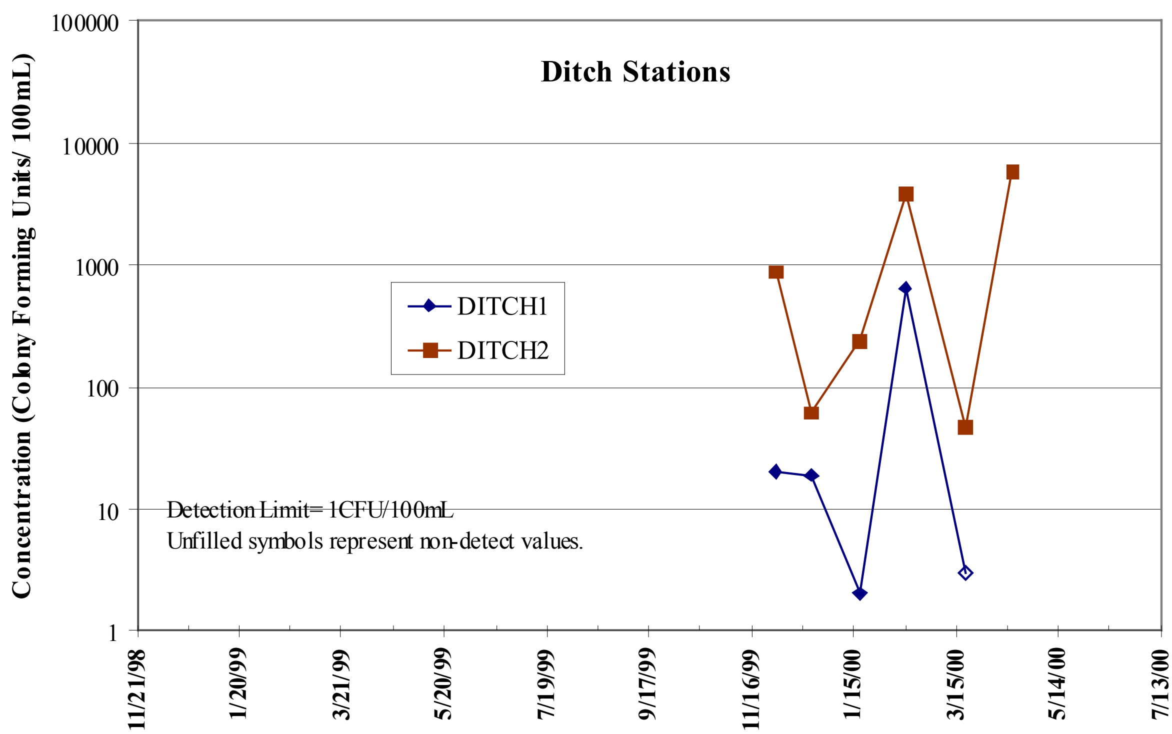


Figure 11. Fecal Coliform Bacteria Results, Smith Prairie Groundwater Quality Assessment.

Bromide was tested in the monitoring network on November 29-30 and December 20-21,1999. Bromide concentrations were less than the detection limit at all stations except MW3, MW4 and Ditch1. The detection limit ranged from 0.03 to 0.15 mg/L depending on the station. The maximum observed concentration was 0.054 mg/l bromide at MW3.

Methylene Blue Active Substances (MBAS) were tested in the monitoring network on September 13-14, 1999. Concentrations ranged from less than the detection limit (0.05 mg/L) to 0.27 mg/L. The highest concentrations were observed in WS1 (0.27 mg/L), MW3 (0.19 mg/L) and MW1 (0.18 mg/L) and decreased eastward. This spatial pattern for MBAS is similar to the pattern shown by nitrate+nitrite-N, chloride, and total dissolved solids.

Microscopic Particle Identification

The results of the Microscopic Particle Identification are described in a December 20 memorandum from Dickey Huntamer to Denis Erickson. The memorandum is included in Appendix E of this report. Highlights of the memorandum are summarized as follows. The pre-filter sample showed abundant living pigmented diatoms and chlorophyll containing flagellate algae. A frequently observed diatom was tentatively identified as *Nitzschia*, an organism commonly associated with polluted surface water. Ditch1 water samples showed a wide variety of microorganisms including diatoms similar to organisms seen in the pre-filter sample as well as flagellate and filamentous algae and spores. The Ditch2 sample also showed the same microorganisms but in lesser numbers. The results strongly suggest a hydraulic connection of the well with surface water. From the microscopist's perspective, of the two ditch samples, Ditch1 more closely resembled the flora observed on the filter but the data were not conclusive.

Maximum Contaminant Levels and Groundwater Quality Criteria

Maximum Contaminant Levels (MCLs), commonly referred to as drinking water standards, and groundwater quality criteria for target analytes are listed in Table 8. Primary MCLs are based on potential adverse health effects and Secondary MCLs are based on aesthetics such as taste, odor, or staining. MCLs are applicable to public water-supply systems but are provided as a basis for comparison with observed results. Primary MCLs were exceeded for nitrate (10 mg/L) and fecal coliform bacteria (1 Colony Forming Unit/100mL). Nitrate+nitrite-N concentrations exceeded 10 mg/L in five of nine wells in the network, and in four of the wells averaged over 10 mg/L over the study period. Coliform bacteria exceeded the MCL in two private water supply wells and one monitoring well. Secondary MCLs were exceeded for TDS (500mg/L) and specific conductance (700 micromhos per centimeter). The TDS standard was exceeded in two wells (WS1 and MW3) and the specific conductance standard was exceeded in one well (MW3). Concentrations in WS1, the most contaminated well in the network, exceeded the MCLs for nitrate, coliform bacteria, and TDS. The distribution of contaminant concentrations and seasonal variations are discussed in detail in the following section.

Table 8. Maximum Contaminant Levels and Groundwater Quality Criteria.

Parameter	Primary Maximum Contaminant Levels[1]	Secondary Maximum Contaminant Levels[1]	Groundwater Quality Criteria[2]
pH (Field)	None	None	**6.6-8.5 Std Units**
Temperature (Field)	None	None	None
Specific Conductance (Field)	None	**700 umhos/cm**	None
Dissolved Oxygen (Field)	None	None	None
Total Dissolved Solids	None	**500mg/L**	**500 mg/L**
Ammonia-N	None	None	None
Nitrate+Nitrite-N	**10 mg/L**	None	**10 mg/L**
Total Phosphorus	None	None	None
Total Kjeldahl Nitrogen	None	None	None
Chloride	None	**250 mg/L**	**250 mg/L**
Total Organic Carbon	None	None	None
Methylene Blue Active Substances	None	None	None
Caffeine	None	None	None
Fecal Coliform Bacteria	**1CFU/100mL[3]**	None	**1CFU/100mL[3]**

[1] Washington State Department of Health, 1994.
Primary Maximum Contaminant Levels are based on adverse health effects.
Secondary Maximum Contaminant Levels are based on esthetics such as taste, odor, or staining.

[2] Washington State Department of Ecology, 1990.

[3] Coliform Bacteria

CFU= Colony Forming Units

Discussion

Nitrate Contamination

Nitrate+nitrite-N concentrations in the Upper Aquifer are elevated in much of the study area. Nitrate+nitrite-N distributions in the Upper Aquifer for September 1999 and January 2000 are shown in Figures 12 and 13, respectively. The locations of contour lines for these figures were determined with the Surfer software package using a kriging algorithm. The contour line locations should be considered approximate and the pattern shown should be considered diagrammatic rather than a detailed depiction of actual nitrate+nitrite-N concentrations. The highest concentrations were observed in wells WS1, MW1, and MW3 in the northwest portion of the study area. Concentration gradients in both figures consistently decrease toward the southeast. The arrows on the figures represent the groundwater flow directions defined for August 1999 (from Figure 6) and January 2000 (from Figure 7). The contour pattern appears to represent the south limb of a northeastward trending plume.

The plume appears to extend from the Warner Dairy at least 2000 feet to the vicinity of WS3. The area of highest nitrate+nitrite-N concentrations is downgradient of Warner Dairy. Considering the westward extent of the Warner property, it appears the Warner Dairy is the source of the nitrate+nitrite-N. However, without monitoring wells on Warner Dairy and upgradient of the dairy, it is not possible to identify the source with absolute certainty.

Leakage from the ditch along the east side of Smith Prairie Road is also a potential source of nitrate+nitrite–N. The ditch is directly upgradient of the MW1, MW3, and WS1. However, water level data at MW1 and MW3, adjacent to the ditch, suggest that the ditch is not directly interacting with the Upper Aquifer. If the ditch were hydraulically connected to the Upper Aquifer, water levels in MW1 and MW3 would be expected to rise rapidly in response to leakage from the ditch once the ditch began to carry water in the winter. Instead, the hydrographs of MW1 and MW3 (Figure 4) show a gradual seasonal rise of water levels that is more characteristic of an aquifer receiving regional recharge.

Chloride and total dissolved solids concentrations show a similar pattern as nitrate+nitrite-N; highest concentrations were observed at WS1, MW1 and MW3 and concentrations decreased toward the east. The source for these contaminants is likely also the Warner Dairy.

Because of the complexity of groundwater movement in the Upper Aquifer, the poor understanding of source concentrations, and the uncertainties of denitrification rates in the Upper Aquifer, it not possible to estimate with high reliability how long the nitrate plume will persist. However, a simplistic approach based solely on the average groundwater flow velocity can provide a rough estimate of the time for groundwater quality to improve at WS1. Implicit in this approach is the assumption that nitrate loading to groundwater at the source has ceased. Using this method and assuming a travel distance of about 2000 feet and an average groundwater flow velocity of 100 feet per year it would take about 20 years for groundwater to improve. However, the complex recharge pattern to the aquifer and denitrification processes could substantially reduce this estimate.

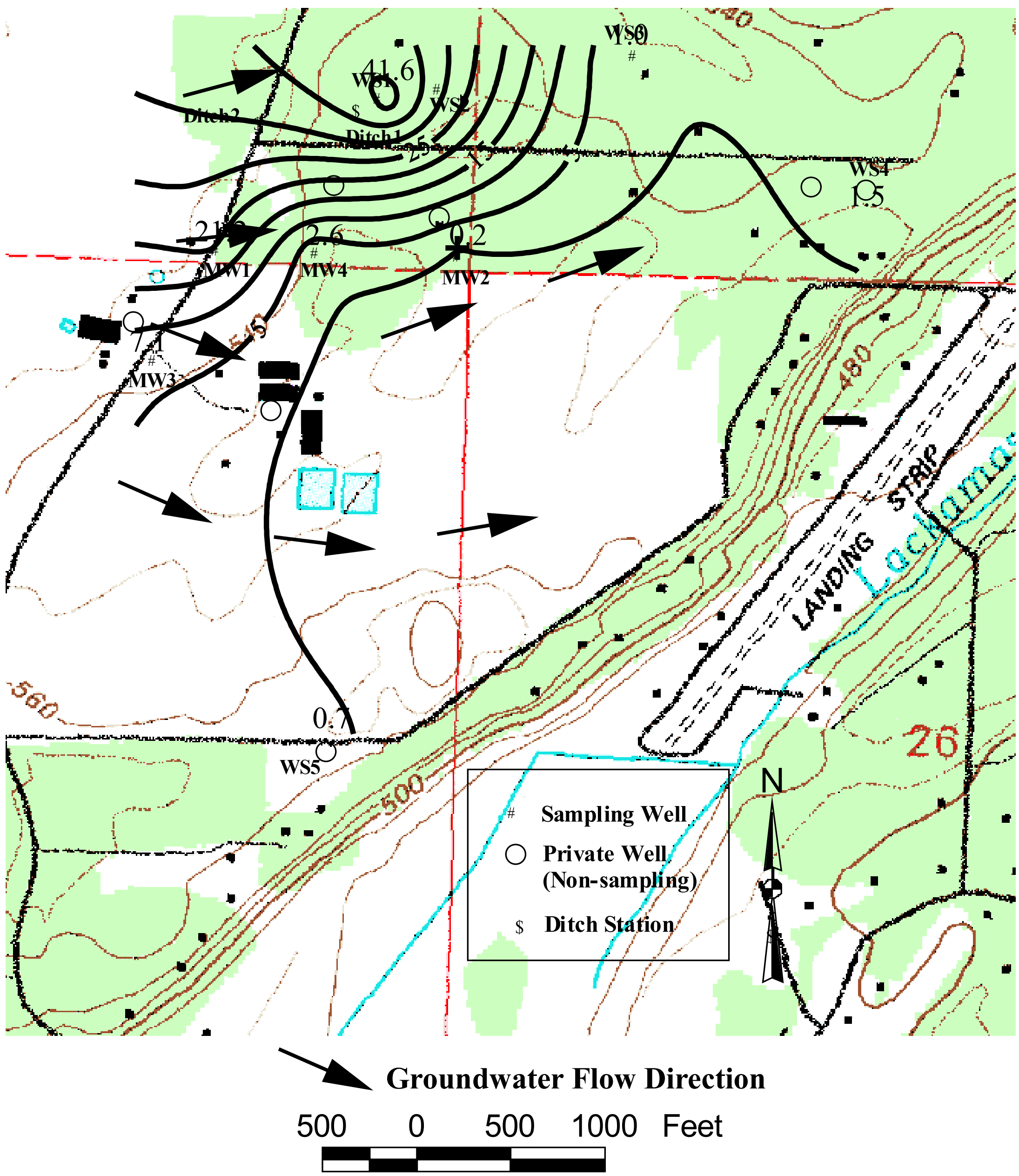


Figure 12. Nitrate+Nitrite-N Concentration Contours, September 1999, Smith Prairie Groundwater Quality Assessment. (Contour Interval 5 mg/L)

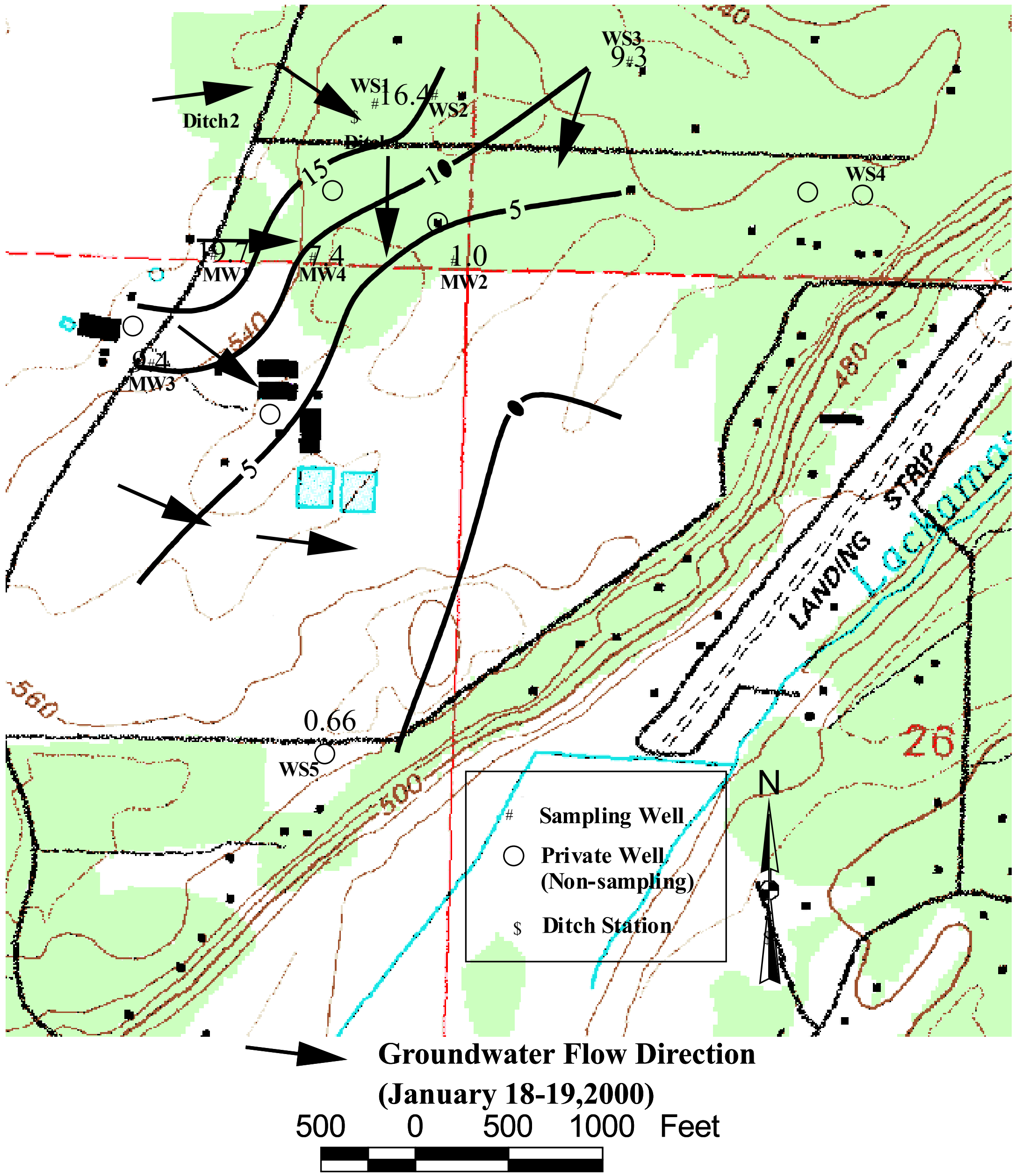


Figure 13. Nitrate+Nitrite-N Concentration Contours, February 2000, Smith Prairie Groundwater Quality Assessment. (Contour interval 5 mg/L)

Water Quality Degradation at WS1

Contamination Mechanisms

The water quality at WS1 appears to be affected by two contamination mechanisms:

- Dissolved nitrate contamination of the Upper Aquifer.
- Near-direct hydraulic connection with surface water.

The distribution and source of the nitrate contamination in the study area are discussed in the previous section of this report. Evidence that WS1 also has a near-direct hydraulic connection with surface water is listed as follows:

- Living pigmented diatoms and chlorophyll-containing flagellate algae were observed on the pre-filter of the water treatment system.
- The well water level rose 12.49 feet between October 26 and November 29 in response to the onset of fall rainfall.
- Water quality in WS1 reportedly deteriorated within a few days after heavy rainfall. Changes in water quality at WS1 consisted of increased turbidity and/or dark green discoloration, increased concentrations of fecal coliform bacteria, total phosphorus, organic nitrogen, and total organic carbon; a pulse of increased total dissolved solids followed by a decrease of total dissolved solids concentrations; and decreased nitrate and chloride concentrations.
- The minimum temperature of water in WS1 recorded over the winter was over 2.0°C colder (7.2°C in February 2000) than any of the other wells in the monitoring network.

Near-Direct Contaminant Pathways

Potential contaminant pathways for a near-direct hydraulic connection of surface water to WS1 include the following:

- Compromised well integrity resulting from breaks in the well casing or leakage along the outside of the casing due to improper surface seal installation.
- Artificial conduits – e.g., improperly abandoned wells, dry wells (vertical drains) – in the immediate vicinity of the well.
- Naturally occurring hydrogeologic pathways consisting of highly transmissive zones (preferred flow paths) that connect the surface with the aquifer.

These pathways are discussed below as they relate to WS1.

Compromised Well Integrity

WS1 was drilled and installed by a licensed well driller. The well report describes that an annular surface seal was installed to a depth of 18 feet as required by the Minimum Standards for Construction and Maintenance of Wells (Washington State Department of Ecology, 1990). The well is situated on well-drained ground with no standing water in the immediate vicinity, and direct flow from the ground surface along the outside of the casing is unlikely. The downhole video inspection verified the integrity of the well casing.

Artificial Conduits

No features were observed from the examination of historical air photos that would indicate the presence of well sites or vertical structures in the immediate vicinity of WS1. A manhole exists at the corner of Smith Prairie Road and 161st Way SE which is used to house the culvert that transfers water from the east side of Smith Prairie Road to the west side. This manhole is located about 750 feet west and hydraulically upgradient of WS1. The ownership or construction of the manhole was not determined.

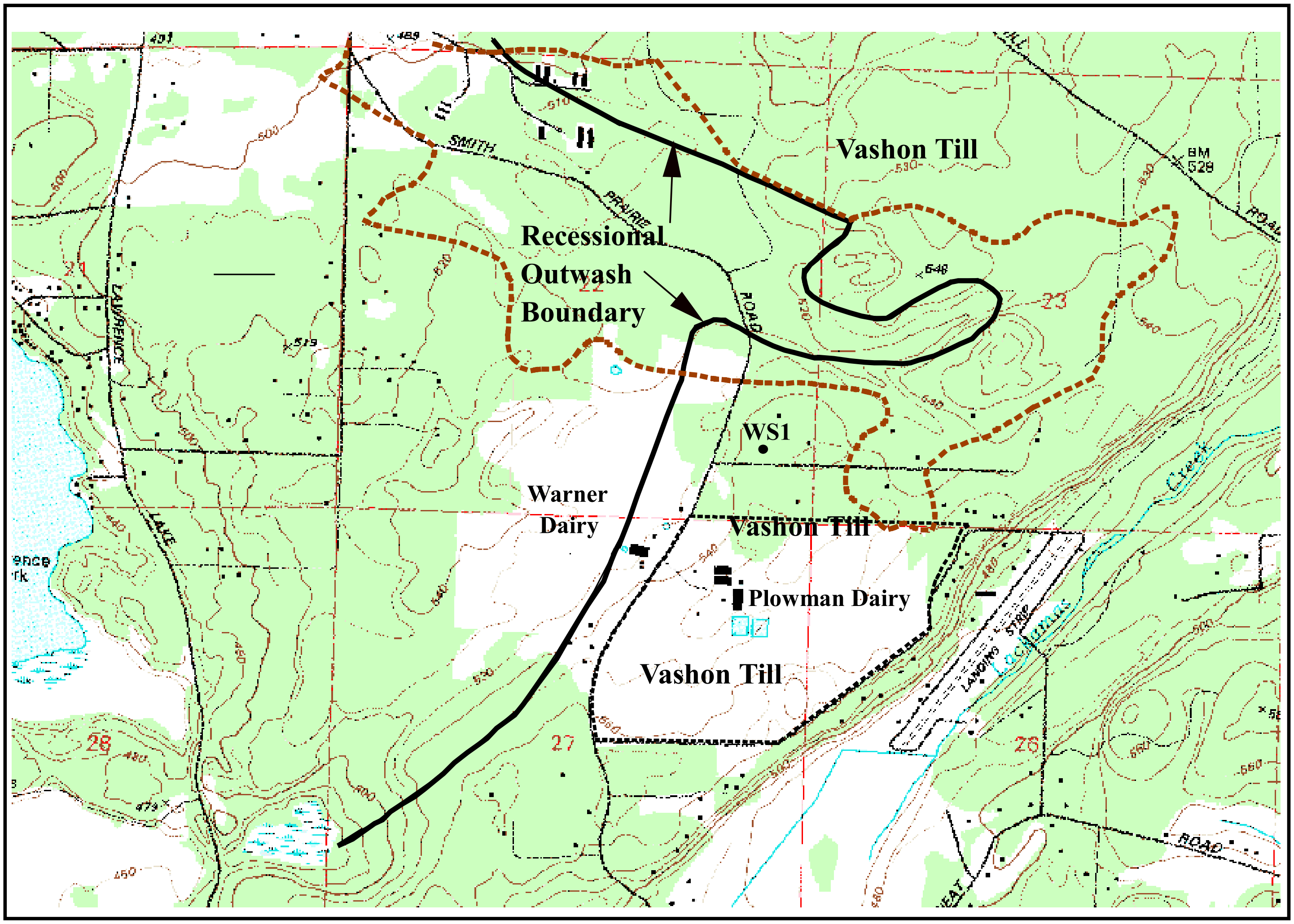
Hydrogeologic Pathways

Conceptually, a hydrogeologic pathway would consist of high hydraulic conductivity deposits that connect the ground surface with the Upper Aquifer drafted by WS1. Also, to transport particulate matter, diatoms, and bacteria through the medium to the WS1 well intake, large pore sizes would be required. Considering the geology of the study area, coarse gravel outwash deposited by high-flow, glacial meltwater streams represent the most likely potential hydrogeologic pathway with these characteristics. Hydraulic conductivity values up to 7000 feet/day have been reported for outwash deposits in the Puget Sound region (Vaccaro et al, 1998). Two potential hydrogeolgic pathways exist in the area, recessional outwash deposits and onsite gravel deposits, and are discussed below.

Recessional Outwash Deposits

Recessional outwash deposits crop out at the ground surface north of the study area. Figure 14 shows the occurrence of recessional outwash deposits based on two sources: regional geologic mapping by Noble and Wallace (1966) and more detailed soil mapping by Pringle (1990). The extent of the recessional outwash from soil mapping was based on the occurrence of the Baldhill Very Stony Sandy Loam, a soil unit associated with recessional outwash deposits. The detailed soil mapping is probably more representative of the distribution of the recessional outwash.

In response to the onset of fall rains, water levels in wells WS1, WS2, and WS3 on the north boundary of the study area rose rapidly (Figures 4 and 5). The water level in WS3, the well showing the greatest water-level fluctuation, rose 19.5 feet over about 35 days. This suggests that a major component of recharge to the Upper Aquifer occurs north of the study area. Infiltration of runoff and precipitation through the recessional outwash deposits is the probable source of the recharge. It is conceivable that contaminants associated with this recharge enter the Upper Aquifer and are transported to WS1. The source of the contaminants in the runoff and the specific areas where infiltration is occurring were not identified.



Baldhill Very Stony Sandy Loam

Recessional Outwash/Vashon Till Boundary

Scale 1"=2000'

Figure 14. Recessional Outwash/Vashon Till Boundary (Nobel and Wallace, 1966) and Baldhill Very Stony Sandy Loam Soils (Pringle, 1990).

Onsite Gravel Deposits

A second potential hydrogeologic pathway consists of the onsite, bouldery and cobbly gravel described in well drillers' logs. These deposits are designated as "Gravel" in hydrogeologic profiles Figures 2 and 3. Coarse gravel reportedly occurred at WS1 from the ground surface to a depth of 47 feet and another water-supply well (Bigler) 700 feet south of WS1 to a depth of 40 feet. The gravel deposits overlie till. A structural contour map of the top of the till underlying the coarse gravel is shown in Figure 15. The contours represent lines of equal elevation on the surface of the till. The locations of the contours were determined using the contouring package in the Rockware software suite. Provided the well log descriptions are representative of actual conditions, Figure 15 defines a potential area infiltration of surface water may be occurring. The pathway is described as follows:

> Water infiltrates into the surficial gravel and percolates vertically downward to the top of the till. The till, with a low hydraulic conductivity, limits vertical downward percolation. The bottom of the gravel deposits becomes saturated locally, and water flows "downhill" along the top of the till interface eventually accumulating in the areas where the elevation of the till is lowest.

This condition is analogous to an elongate, gravel-filled bowl with the till acting as the interior surface of the bowl. Water entering the gravel at the surface would accumulate at the bottom of the bowl. A well drilled at the location where the till is lowest could create a pathway for contaminated water to move downward which could contaminate the well and also the Upper Aquifer. It may not be coincidental that the lowest elevation of the till occurs near WS1, the well showing the most severe contamination.

In 1996 Garland observed runoff from a ditch in the north-central portion of Plowman Dairy flowing onto the Bigler property and infiltrating into the subsurface. The location of the infiltration, shown on Figure 15, is close to the lateral limit of the coarse gravel and the depression in the till. In 1996 Garland concluded that the infiltration site was the source of contaminants at WS1. However, the quantity of water observed moving offsite from this ditch during the winter of 1999-2000 was small. The ditch was observed monthly during sampling episodes and standing water was present but not flowing. However, it is possible that flows may have occurred during times of heavy rainfall but were not observed. Also, during the current study the drainage from Plowman Dairy that Garland observed to be infiltrating was disrupted by the north-south trench excavated on Bigler property.

Potential Sources of Near-Direct Contamination

The presence of living diatoms and algae on the pre-filter of WS1 suggests that the well has a near-direct connection with surface water. There are no nearby perennial sources of surface water in the study area. The only surface water occurs in the winter in ditches, and shallow standing water resulting from runoff from adjacent properties.

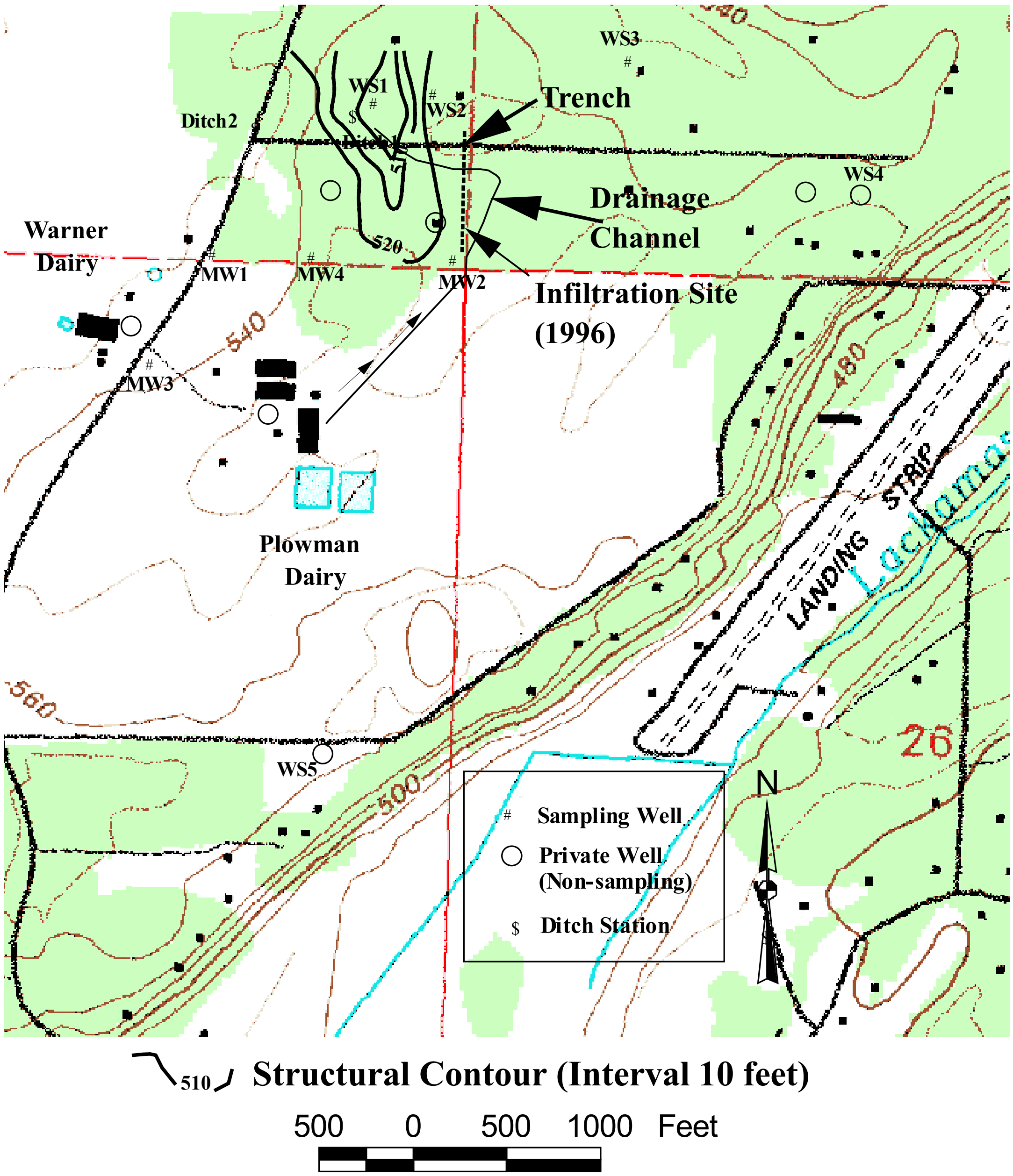


Figure 15. Structural Contour Map, Top of Vashon Till Near WS1, Smith Prairie Groundwater Quality Assessment.

Runoff Water Quality

Runoff water quality was monitored at two locations designated as Ditch1 and Ditch2 stations. The locations of ditch stations are shown on Figure 1. The source of water for Ditch1 represents runoff from the Scott Warner and Thomas properties. Water in Ditch2 represents runoff from the western side of the Plowman Dairy. Flow was present in Ditch2 from November 1999 through April 2000 at rates that ranged from 0.06 to 1.3 cubic feet per second (cfs) and a mean of 0.5 cfs. Flow was observed at Ditch1 on one occasion on November 30, 1999 estimated at about one gallon per minute.

Concentrations of all parameters were substantially higher in Ditch 2 than in Ditch 1 (Tables 6 and 7). With the exception of fecal coliform bacteria and total organic carbon, concentrations at Ditch2 declined continuously over the winter (Tables E-3 through E-10). Fecal coliform bacteria concentrations fluctuated widely with no particular trend. Total organic carbon concentration remained fairly constant, ranging between 33 to 42 mg/L.

The water quality at WS1 changed dramatically after the onset of the fall rains. By comparing the changes in water quality observed at WS1 before and after rainfall, it is possible to bracket the upper or lower bounds of parameter concentrations of the water affecting WS1. These concentration bounds can be compared to the observed ditch water quality to assess whether the ditch is contributing water to WS1. This method assumes that the observed changes were solely a function of mixing of infiltrated water with the aquifer.

Fall rains began near the end of October 1999 (Figure 5). On November 16 the well owner reported that the well water was beginning to discolor. A sample was obtained from the well on November 17. The results for October 26 and November 17 for WS1 are shown in Table 9. The upper or lower bounds of the mixing water are estimated based on the change observed (whether the concentration increased or decreased) and the concentration in the November 17 sample. For example, for nitrate+nitrite-N the concentration decreased from 35.7 on October 26 to 23.6 mg/L on November 17. Therefore, the concentration of the mixing water must be less than 23.6 mg/L. The values for each parameter were determined similarly and are listed in the column. The values for each parameter for the mixing water are compared with values for the ditch samples taken on November 30. As shown in Table 9, results suggest that neither of the ditches appears to be the source of the water affecting the WS1 at least without some additional modification of chemistry. Only six of the 12 parameters match for Ditch1, and seven parameters match for Ditch2.

Onsite Treatment (Septic) System

The onsite septic system at the WS1 site is a potential source of nitrate, fecal coliform bacteria, ammonia-N, chloride, total dissolved solids, total phosphorus, and total organic carbon. In the summer when groundwater flow is northeastward, the onsite system is about 150 feet upgradient of WS1. In the winter the groundwater flow direction is southeastward and the onsite system is not upgradient of the well. It is unlikely that algae and diatoms would originate from septic effluent. Also the onsite system was specially designed and constructed to meet the requirements of Thurston County Environmental Health for areas susceptible to groundwater contamination. The onsite treatment system is probably not the source of contaminants in WS1.

Table 9. Comparison of Pre- and Post-Rainfall Water Quality Changes at WS1 with Ditch Water Quality.

Parameter	WS1 Pre-Rainfall 10/26/99	WS1 Post-Rainfall 11/17/99	Change at WS1	Quality of Mixing Water	Ditch1 11/30/99	Ditch1 Matches Mixing Water	Ditch2 11/30/99	Ditch2 Matches Mixing Water
NO2+NO3-N (mg/L)	35.7	23.6	-12.1	<23.6	3.05	Yes	39.3	No
TKN (mg/L)	0.5U	1.52	1	>1	1.48	Yes	5.67	Yes
NH3-N (mg/L)	0.01U	0.01U	NA	0	0.012	?	0.08	No
Total Phosphorus (mg/L)	0.279	0.728	0.449	>0.728	0.494	No	2.54	Yes
Chloride (mg/L)	46.3	27.1	-19.2	<27.1	10.6	Yes	51.3	No
TDS (mg/L)	447	654	207	>654	158	No	664	Yes
TOC (mg/L)	2.7	8.4	5.7	>8.4	12.7	Yes	41	Yes
Fecal Coliform (CFU/100mL)	1U	24	24	>24	20	No	870	Yes
SpecificConductance (umhos/cm)	645	550	-95	<550	218	Yes	910	No
pH (Std Units)	5.47	5.89	0.42	>5.89	5.66	No	6.64	Yes
Temperature (C)	9.1	9.3	0.2	>9.3	10	Yes	9.8	Yes
Dissolved Oxygen (mg/L)	1.46	5.34	3.88	>5.34	2.74	No	3.59	No

< = less than listed value   > = greater than listed value   U= Analyte not detected above listed value.

Comparison Summary:	Ditch 1	Ditch2
Agree	6	7
Disagree	5	5
Uncertain	1	0

WS3 Water Quality Degradation

In April 2000 the owner of well WS3 (Davis) reported a dark green discoloration of the well discharge that changed over about two weeks to a light gray discharge. Samples in April and May identified substantial increases in fecal coliform bacteria of 650, 115, and 1100 CFU/100mL. Previously the highest reported fecal coliform count was 32 CFU/100 mL in May 1996. In addition to high fecal coliform counts, organic-N concentration increased to 1.6 mg/L, total phosphorus increased to 0.324 mg/L, and total organic carbon jumped to 6.2 mg/L. These results are similar to the pattern of contamination at WS1 but do not have immediate correlation with heavy rainfall. The source of contamination at WS3 is probably related to infiltrated precipitation or runoff through the recessional outwash deposits north of the well.

Conclusions

Groundwater in the study area shows extensive contamination, with nitrate at levels that exceed drinking water standards and groundwater quality criteria. WS1, a domestic well showing the highest levels of contamination, is situated in the nitrate plume but is also affected in the winter by infiltration of runoff. In addition to nitrate, concentrations at WS1 exceed drinking water standards and groundwater quality criteria for fecal coliform bacteria and total dissolved solids. Specific conclusions are discussed below.

- The hydrogeology of the study area consists of multiple water-bearing sand and gravel layers (aquifers) with depth sandwiched between silty and/or clayey non-water-bearing layers. The Upper Aquifer, the uppermost sand and gravel layer and the target aquifer for this study, occurs at a depth of about 70 feet below the ground surface and ranges in thickness from 5 to 30 feet. The groundwater flow direction in the Upper Aquifer is eastward and northeastward in the summer, and southeastward and eastward in the winter. The change of flow direction is due to increased recharge in the winter through recessional outwash deposits north of the study area. The average groundwater flow rate in the Upper Aquifer is about 0.3 feet per day.

- Elevated nitrate+nitrite-N, chloride, and total dissolved solids concentrations occur in the Upper Aquifer and hydraulically connected portions of the Lower Aquifer in the northwestern portion of the study area. Although concentrations vary seasonally, elevated values persist through the year. Nitrate+nitrite-N concentrations exceeded the primary Maximum Contaminant Level and groundwater quality criterion of 10 mg/L in five of nine wells in the network. The primary source of dissolved constituents in groundwater originates upgradient of the monitoring network and is most likely the Warner Dairy, a dairy that became inactive in 1999.

- Maximum nitrate+nitrite-N concentrations observed at WS1, the private well showing the most severe groundwater contamination, increased from 33.4 mg/L in 1995-6 to 41.6 mg/L in 1999. If the Warner Dairy is the source of the dissolved contaminants, then nitrate+nitrite-N, chloride, and total dissolved solids concentrations should decrease over time. The rate of decline will depend largely on existing nitrate concentrations in groundwater and excess available nitrogen in the soil. Based on the estimated groundwater flow rate, once nitrate loading to groundwater ceases, up to 20 years may be required for nitrate concentrations to be substantially reduced. However, the complex recharge pattern of the aquifer and denitrification processes may substantially reduce this period.

- WS1, in addition to nitrate+nitrite-N contamination, appears to have a near-direct hydraulic connection to runoff in the winter. Evidence of this connection includes: the presence of living pigmented diatoms and chlorophyll containing flagellated algae on the pre-filter of the water treatment system, particulate organic matter and fecal coliform bacteria in the well water, and anomalously cold water temperatures.

- Potential hydrogeologic contaminant pathways to WS1 consist of infiltration of runoff and precipitation through 1) recessional outwash deposits north of the study area or 2) onsite coarse gravel deposits immediately north of Plowman Dairy. Additional subsurface investigations are needed to verify conditions in both areas.

- This study did not identify the original source of the runoff affecting WS1 or the specific location(s) where infiltration is occurring. The water quality at two ditch stations could not account directly for water quality changes observed at WS1. In 1996 an investigator had observed infiltration of runoff at a location about 100 feet north of the Plowman Dairy boundary. The runoff originated from a ditch draining the north portion of Plowman Dairy. The infiltration site is located near the lateral limit of the onsite coarse gravel deposits. Although standing water was present during this 1999-2000 study, no offsite flow was observed from the drainage ditch on the north side of Plowman Dairy.

- In April 2000 another private well, WS3, showed discolored discharge and elevated fecal coliform bacteria, total organic nitrogen, and total organic carbon concentrations similar to WS1. WS3 is located within a few hundred feet of where recessional outwash deposits crop out at the surface. The contamination is probably the result of infiltration of contaminated runoff through the outwash deposits to the north, but the source of the contaminants is unknown.

- Runoff from the west and possibly the north side of Plowman Dairy poses a potential threat to groundwater quality. The water quality of runoff from the west portion of Plowman Dairy shows elevated concentrations for nitrate+nitrite-N, chloride, total dissolved solids, fecal coliform bacteria, total phosphorus, ammonia-N, total organic nitrogen, and total organic carbon. Concentrations of contaminants in ditch samples decreased continuously during the winter. Flow rates in the ditch draining the west side of the dairy (Ditch2) ranged up to 1.3 cfs, with a mean of 0.5 cfs between November and April.

Recommendations

1. Warner Dairy appears to be the source of nitrate in groundwater in the northwestern portion of the study area. The Warner Dairy reportedly has been inactive since the fall of 1999, and provided the land receives no additional nitrogen loading, nitrate concentrations in groundwater should begin to decline over time. The rate of decline will depend largely on the upgradient nitrate concentrations in groundwater, groundwater flow rate, nitrogen content of the soil, and the presence of onsite accumulations of manure and wastewater. At the time of this study, the dairy was the subject of an Ecology no-contact policy. If the site becomes accessible the following actions should be taken:

   ◊ The status of the dairy waste storage pond should be verified by a site inspection. If the pond is still being used to hold manure and wastewater, the contents should be removed and spread so as not to result in a localized loading of nitrate to groundwater. Ideally the material could be transported offsite and applied agronomically in an area where nitrate loading to groundwater is not an issue.

   ◊ Soil samples should be obtained to determine hydraulic properties and nitrogen content to estimate nitrate loading to groundwater

2. The study area hydrogeology is characterized by multiple aquifers with depth. The two private wells showing a near-direct hydraulic connection with surface water, WS1 and WS3, are completed in the Upper Aquifer, the uppermost water-bearing zone. It is likely that uncontaminated groundwater exists in deeper aquifers at these well locations. WS1 and WS3 should be deepened to obtain uncontaminated water from these deeper aquifers. However, if the wells are deepened, annular well seals should be installed from the surface to at least the top of the Upper Aquitard or ideally the top of the Lower Aquitard, because of the potential for near-direct hydraulic connection with runoff.

3. Considering the sensitivity of groundwater to contamination in this area, the Thurston County Environmental Health may consider special water well construction requirements that could include:

   ◊ Water-supply wells should be constructed to a minimum depth of 120 feet in order to obtain water from the Deep Aquifer.

   ◊ Surface seals for water-supply wells should be installed to the top of the deepest aquitard penetrated during well installation.

4. Runoff from Plowman Dairy must be minimized. Ecology, the Thurston Conservation District, and the Natural Resource Conservation Service should provide technical assistance to identify and implement management practices to reduce runoff, particularly in the north and west portions of the dairy.

5. Additional subsurface studies are needed to verify the presence of coarse gravel deposits identified on well logs and, if present, define the lateral and vertical extent. Studies should include:

   - ◊ Detailed mapping of the surficial geology.
   - ◊ Geophysical surveys (electromagnetic or resistivity surveys).
   - ◊ Installation of additional monitoring wells north and west of the study area.

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Appendices

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Appendix A

Table A-1. Well Construction Data.

Well Logs and As-Built Drawings for Wells.

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Table A-1. Smith Prairie Groundwater Quality Assessment Well Data.

Well ID	Type	State Plane Coordinate X	Y	Measuring Point Elevation	Aquifer	Well Depth (ft)	Open Interval (ft)	Date Drilled
WS1 (Thomas)	Domestic	1492270	560720	540.70[1]	Upper	76.5	76.5	6/22/94
WS1 (Thomas)	Domestic	1492270	560720	539.35	Upper	76.5	76.5	6/22/94
WS1 (Thomas)	Domestic	1492270	560720	539.06[2]	Upper	76.5	76.5	6/22/94
WS2 (Austen)	Domestic	1492570	560770	545.14	Lower	100	100	8/18/81
WS3 (Davis)	Domestic	1493510	561020	536.00[3]	Upper	84	84	10/1/91
WS4 (Meyer, new)	Domestic	1494800	560140	547.30	Upper	98	98	5/30/95
Warner	Domestic	1490887	559582	540.58	Deep	180	180	4/4/92
WS5 (McCulloch)	Domestic	1491887	557299	564.80	Upper	118	118	4/30/90
Carroll	Domestic	1490021	558315	549.96	No Log			
Warner (Scott)	Domestic	1491954	560365	543	Lower	100.5	100.5	5/5/98
MW1	Monitoring	1491280	559950	541.88	Upper	69	59-69	6/23/99
MW2	Monitoring	1492630	559930	547.24	Upper	85.3	75.3-85.3	6/30/99
MW3	Monitoring	1490890	559350	543.42	Upper	61	51-61	8/19/99
MW4	Monitoring	1491850	559930	546.48	Upper	89.2	79.2-89.2	8/23/99

MP= Measuring Point.

[1]MP for Thomas well before 7/12/99.

[2]MP for Thomas well after 3/22/00.

[3] Assumed elevation.

Well Logs and As-Built Drawings for Wells are not available in electronic form.

For a printed copy, call the Ecology Publications Office at 360-407-7472 and ask for Publication No. 00-03-043.

Appendix B

Sampling Procedures.

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Sampling Procedures

Prior to sampling, water levels were measured in each well using a commercial electric probe. Measurements were recorded to 0.01 feet and were accurate to 0.03 feet. For private wells the well probe was decontaminated with sequential rinses of 10% bleach solution and de-ionized water between wells. For monitoring wells the probe was rinsed with de-ionized water only. Well volumes were calculated using the height of water in the well casing above the bottom of the well.

The pH and dissolved oxygen meters were calibrated and operated as described in their respective manuals. The pH meter was calibrated using a two-point calibration. The DO meter was calibrated to saturated conditions.

Private wells were purged and sampled using existing pumps and plumbing. All private wells sampled are equipped with submersible pumps. Samples were obtained from a tap as close to the wellhead as possible. Samples were obtained when the pump was operating to minimize the effects of obtaining water from storage tanks. To do this a "Y" fitting was attached to the tap sampling (Figure B-1). Samples were obtained from one "Y" outlet while most of the discharge is directed through the other outlet. A hose was attached to the primary "Y" discharge outlet to direct discharge to a suitable location. A hose-bib adapter was attached to the second "Y" discharge outlet and was used to direct flow to the sample bottle. Temperature, pH, specific conductance, and dissolved oxygen were measured every five to ten minutes during purging. Monitoring wells were

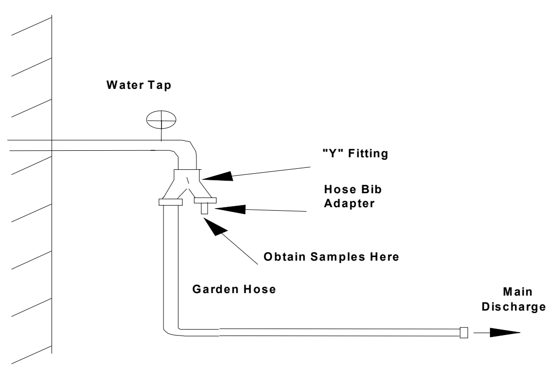

Figure B-1. Water Tap Sampling Configuration.

purged and sampled with either cleaned Teflon bailers or dedicated submersible pumps. Bailers were cleaned with a Liquinox tap water wash and triple de-ionized water rinses, air dried, and wrapped in tin foil. Wells were purged until pH, specific conductance, temperature, and dissolved oxygen stabilized (change less than 10%) for two consecutive well volumes.

Once purging was completed, samples were placed in pre-cleaned bottles provided by Manchester Environmental Laboratory. Grab samples of surface water were obtained by directly filling bottles. Bottle materials, preservatives, and holding times for target analytes are listed in Table B-1. Samples were placed in coolers with ice and transported to the Ecology Headquarters Building in Lacey. The Ecology laboratory courier transported samples to the Ecology/EPA Manchester Environmental Laboratory in Manchester, Washington. MBAS samples were transported directly to Sound Analytical in Fife, Washington by the sampler.

Table B-1. Bottle Materials, Holding Times, and Preservatives for Smith Prairie Groundwater Quality Assessment.

Parameter	Bottle	Holding Time	Preservative
Total Dissolved Solids	500 mL w/m polyethylene	7 Days	Cool to 4°C
Ammonia-N	125 mL clear wide mouth, polyethylene	28 Days	Sulfuric Acid to pH<2 Cool to 4°C
Nitrate+Nitrite-N	125 mL clear wide mouth, polyethylene	28 Days	Sulfuric Acid to pH<2 Cool to 4°C
Total Kjeldahl Nitrogen	125 mL clear wide mouth, polyethylene	28 Days	Sulfuric Acid to pH<2 Cool to 4°C
Total Phosphorus	125 mL clear wide mouth, polyethylene	28 Days	Sulfuric Acid to pH<2 Cool to 4°C
Chloride	500 mL polyethylene	28 Days	Cool to 4°C
Total Organic Carbon	60 mL narrow mouth, polyethylene	28 Days	Sufuric Acid to pH<2 Cool to 4°C
Methylene Blue Active Substances	500 mL wide polyethylene (Not Rinsed)	48 hours	Cool to 4°C
Caffeine	1gallon glass jar w/ Teflon lined lids	7 Days	Cool to 4°C
Fecal Coliform Bacteria	250 mL glass, autoclaved	30 Hours	Cool to 4°C

Manchester Environmental Laboratory, 1994.

Appendix C

(Quality Assurance)

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Table C-1. Field Parameter Quality Assurance Results, Smith Prairie Groundwater Quality Assessment.

Date	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
9/13/99	460	6.18	12.5	4.27
9/13/99	442	6.16	12.3	4.93
RPD=	4.0	0.3	1.6	14.3
10/25/99	560	5.95	12.0	4.58
10/25/99	600	6.24	11.9	4.85
RPD=	6.9	4.8	0.8	5.7
11/29/99	550	5.78	12.1	2.63
11/29/99	580	6.02	12.1	2.59
RPD=	5.3	4.1	0.0	1.5
12/20/99	525	5.66	11.1	2.79
12/20/99	580	6.04	11.2	2.81
RPD=	10.0	6.5	0.9	0.7
1/18/00	590	5.52	11.4	2.33
1/18/00	585	5.99	11.5	2.11
RPD=	0.9	8.2	0.9	9.9
2/14/00	510	5.56	7.4	2.81
2/14/00	510	5.99	7.2	2.9
RPD=	0.0	7.4	2.7	3.2
3/21/00	418	5.74	9.1	0.97
3/21/00	490	6.20	10.4	0.98
RPD=	15.9	7.7	13.3	1.0
4/17/00	650	5.73	9.7	1.32
4/17/00	650	5.91	10.8	1.26
RPD=	0.0	3.1	10.7	4.7
5/22/00	690	5.80	10	1.55
5/22/00	600	5.91	10.5	1.51
RPD=	14.0	1.9	4.9	2.6
Minimum R	0	0.3	0	0.7
Maximum R	15.9	8.2	13.3	14.3
Mean RPD=	6.3	4.9	4.0	4.9

Table C-2. Laboratory Analytes, Field Duplicate Results.

Date	NO2+NO3 as N (mg/L)	TKN (mg/L)	NH3-N (mg/L)	Total Phos. (mg/L)	Cl^- (mg/L)	TDS (mg/L)	TOC (mg/L)	Fecal Colif. CFU/100ml	Br^- (mg/L)	MBAS (mg/L)
9/13/99	20.5	0.500U	0.030	0.15	29.7	305	1U	1U	NT	0.15
9/13/99	22.6	0.500U	0.019	0.138	29.8	314	1U	**1**	NT	0.20
RPD=	9.7	NA	44.9	8.3	0.3	2.9	NA	NA	NA	28.6
10/25/99	39.8	0.500U	0.010U	0.187	28.6	403	1.1	1U	NT	NT
10/25/99	42.8	0.500U	0.010U	0.189	29.3	483	1.2	**1**	NT	NT
RPD=	7.3	NA	NA	1.1	2.4	18.1	8.7	NA	NA	NA
11/29/99	9.96	0.5U	0.01U	0.145	25	374	1.0U	1U	0.09U	NT
11/29/99	10.6	0.5U	0.01U	0.145	27.1	392	1.0U	1U	0.09U	NT
RPD=	6.2		NA	0.0	8.1	4.7	NA	NA	NA	NA
12/20/99	10.7	0.5U	0.01U	0.139	26.5	360	1.8	1U	0.052	NT
12/20/99	11.7	0.5U	0.01U	0.135	27.4	371	1.9	1U	0.055	NT
RPD=	8.9	NA	NA	2.9	3.3	3.0	5.4	NA	5.6	NA
1/18/00	10.9	0.5U	0.01U	0.133	29.9	412	1.6	1U	NT	NT
1/18/00	10.7	0.5U	0.01U	0.131	30	414	1.6	1U	NT	NT
RPD=	1.9	NA	NA	1.5	0.3	0.5	0.0	NA	NA	NA
2/14/00	15.6	1.46	0.014	0.135	30.7	363	13.7	7	NT	NT
2/14/00	17.2	1.43	0.01U	0.122	31	340	15.8	5	NT	NT
RPD=	9.8	2.1	NA	10.1	1.0	6.5	14.2	33.3	NA	NA
3/21/00	16.5	1.9	0.01	1.67	27.3	364	18.5	1U	NT	NT
3/21/00	15.8	1.87	0.012	1.68	27.5	365	19.4	1U	NT	NT
RPD=	4.3	1.6	18.2	0.6	0.7	0.3	4.7	NA	NA	NA
4/17/00	38.9	0.5U	0.01U	0.438	42.7	475	4.6	155	NT	NT
4/17/00	35.4	0.5U	0.01U	0.438	42.8	426	4.9	150	NT	NT
RPD=	9.4	NA	NA	0.0	0.2	10.9	6.3	3.3	NA	NA
5/22/00	40.7	0.5U	0.01U	0.343	49.1	462	3.5	1U	NT	NT
5/22/00	42.7	0.5U	0.01U	0.342	49.8	462	3.9	4	NT	NT
RPD=	4.8	NA	NA	0.3	1.4	0.0	10.8	NA	NA	NA
Minimum=	1.9	1.6	18.2	0.0	0.2	0.0	0.0	3.3	5.6	28.6
Maximum=	9.8	2.1	44.9	10.1	8.1	18.1	14.2	33.3	5.6	28.6
Mean=	6.9	1.8	31.5	2.8	2.0	5.2	7.2	18.3	5.6	28.6

NT= Not Tested. U= Analyte not detected above listed value. NA= Not Applicable.

Appendix D

Table D-1. Hydrologic Test Results.

Table D-2. Depth-to-Water Measurements.

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Table D-1. Hydrologic Test Results, Smith Prairie Groundwater Quality Assessment.

Well ID	Aquifer	Dia. (In)	Static Water Level (Ft)	Test Water Level (Ft)	Test Length (Hr)	Rate (GPM)	Aquifer Thick. (Ft)	Open Interval (Ft)	Sc	Well Loss Coeff.	Kh (ft/d)
WS1	Upper	6	55.65	59.13	0.60	8.0	5	0.5	0.001	1	181
WS2(A)	Upper/Lower	6	62.85	68.56	0.38	10.9	12	0.5	0.001	1	170
WS2 (B)[1]	Upper/Lower	6	75	90	1.0	10	12	0.5	0.001	1	59
WS3	Upper	6	43.15	51.90	0.55	7.3	32	0.5	0.001	1	107
MW1	Upper	2	36.93	46.82	1.0	0.7	12	10	0.001	1	1.1
MW2	Upper	2	59.36	63.19	1.0	3.9	9	10	0.001	1	23
MW3(A)	Upper	2	45.17	47.68	0.12	1.25	19.5	10	0.001	1	7.7
MW3(B)	Upper	2	45.17	47.68	0.33	1.25	20	10	0.001	1	8.2
MW4	Upper	2	58.63	65.71	1.0	2.2	14	10	0.001	1	5.6
WS4(New)	Upper	6	70	74	1.0	7	26	0.5	0.001	1	200
Meyers(Ol	Lower	6	60	95	1.0	20	14	0.5	0.001	1	54
[1]Test results calculated from data reported on drill log.							Upper Aquifer Geometric Mean=				21
							Upper Aquifer Minimum=				1.1
							Upper Aquifer Maximum=				200

Table D-2. Depth-To-Water Measurements, Smith Prairie Groundwater Quality Assessment. (Units in feet).

Well ID	MP Elev.	8/23/99	9/13/99	10/25-26/99	11/29-30/99	12/9/99	12/20-21/99	1/18-19/00	2/13-14/00	3/20-21/00
WS1 (Thomas)	539.35	59.82	NM	61.64	49.15	49.25	NM	47.27	48.41	48.22
WS2 (Austen)	545.14	NM	NM	68.00	56.13	NM	NM	52.25	53.04	53.05
WS3 (Davis)	536.00	54.88	NM	55.62	36.11	39.66	NM	35.26	36.75	37.54
WS4 (Meyer, new)	547.30	70.50	NM	71.87	68.44	NM	NM	65.18	64.68	64.2
WS5 (McCulloch)	564.80	75.27	NM	74.63	74.61	NM	NM	74.49	74.01	74.18
MW1	541.88	38.26	39.03	40.18	40.22	NM	39.92	38.53	37.49	36.9
MW2	547.24	61.52	62.03	62.56	60.64	NM	59.18	57.48	56.97	56.46
MW3	543.42	44.84	45.16	46.11	46.52	NM	47.20	46.32	45.35	44.98
MW4	546.48	60.80	61.25	61.80	60.65	NM	59.19	57.28	57.05	56.27

Well ID	MP Elev.	4/16-17/00	5/1/00	5/22-23/00	6/21/00
WS1 (Thomas)	539.06	53.16	NM	55.65	57.70
WS2 (Austen)	545.14	59.35	NM	62.85	64.61
WS3 (Davis)	536.00	43.59 (R)	42.81	43.15	51.66
WS4 (Meyer, new)	547.30	65.3	NM	67.14	68.97
WS5 (McCulloch)	564.80	73.74	NM	73.81	73.94
MW1	541.88	36.56	NM	36.85	37.40
MW2	547.24	57.51	NM	59.13	60.22
MW3	543.42	44.16	NM	44.1	44.24
MW4	546.48	57.06	NM	58.51	59.54

Note: MP for WS1 after 3/22/00 = 539.06

NM= Not Measured.

Appendix E

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Table E-1. Field Parameter Results, Smith Prairie Groundwater Quality Assessment. Page 1 of 4.

Well ID	Date	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
WS1	4/11/95				
(Thomas)	5/31/95	593			
	8/23/95	575			
	10/23/95	541			
	11/27/95	487			
	12/27/95	441			
	1/31/96	515			
	2/27/96	435			
	5/29/96	560			
	1/11/99	560	6.08	8.6	
	3/8/99				
	3/15/99	373	6.57	7.8	0.5
	4/5/99				
	4/20/99	510	6.2	8.5	0.6
	5/17/99	545	5.96	9.4	1.0
	9/14/99	680	5.98	10.6	1.8
	10/26/99	645	5.47	9.1	1.46
	11/17/99	550	5.89	9.3	5.34
	11/30/99	442	5.9	8.9	3.16
	12/21/99	425	5.83	8.3	4.01
	1/19/00	490	5.79	7.6	1.81
	2/14/00	510	5.56	7.4	2.81
	2/14/00	510	5.99	7.2	2.9
	3/21/00	418	5.74	9.1	0.97
	3/21/00	490	6.2	10.4	0.98
	4/17/00	650	5.73	9.7	1.32
	4/17/00	650	5.91	10.8	1.26
	5/22/00	690	5.8	10	1.55
	5/22/00	600	5.91	10.5	1.51
WS2	7/11/95	286			
(Austen)	8/23/95	262			
	10/23/95	239			
	12/27/95	321			
	1/31/96	341			
	2/27/96	202			
	5/29/96	258			
	1/11/99	262	5.76	10.5	
	3/15/99	183	6.23	9.8	5.0
	4/20/99	231	6.14	10.1	2.0
	5/17/99	235	6.15	10.4	2.0
	9/14/99	228	6.19	11.7	3.9
	10/26/99	220	5.62	10.2	3.32
	11/30/99	215	5.21	10.3	5.27

Table E-1. Field Parameter Results, Smith Prairie Groundwater Quality Assessment. Page 2 of 4.

Well ID	Date	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
	12/21/99	241	5.65	9.9	9.25
	1/19/00	290	5.59	9.8	5.29
	2/14/00	325	5.37	9.6	9.06
	3/21/00	268	5.66	10.7	4.34
	4/17/00	250	5.64	10.9	3.88
	5/22/00	229	5.62	10.3	2.89
WS3	7/11/95	224			
(Davis)	10/23/95	255			
	12/27/95	213			
	2/27/96	155			
	5/29/96	180			
	9/14/99	185	6.19	11.5	1.37
	10/26/99	180	5.6	10.2	0.3
	11/30/99	252	5.62	10.3	3.81
	12/21/99	218	5.43	9.3	2.81
	1/19/00	210	5.64	9.8	3.44
	2/14/00	222	5.18	9.5	6.2
	3/21/00	205	5.59	11.2	2.17
	4/17/00	212	5.51	11.8	1.33
	5/1/00	218	5.55	11	2.48
	5/22/00	228	5.52	10.9	0.2
WS4	7/11/95	140			
(Meyers, new)	8/23/95	139			
	10/23/95	144			
	12/27/95	144			
	1/31/96	144			
	2/27/96	139			
	5/29/96	145			
	9/14/99	150	6.36	11.5	4.81
	10/26/99	150	5.98	10.3	3.01
WS5	5/31/95	276			
(McCulloch)	8/23/95	274			
	10/23/95	276			
	12/27/95	276			
	1/31/96	282			
	2/27/96	276			
	5/29/96	275			
	9/14/99	265	6.78	12.2	6.61
	2/14/00	280	>4.64	8.3	7.66

Table E-1. Field Parameter Results, Smith Prairie Groundwater Quality Assessment. Page 3 of 4.

Well ID	Date	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
MW1	9/13/99	460	6.18	12.5	4.27
	9/13/99	442	6.16	12.3	4.93
	10/25/99	442	6.07	11.8	6.81
	11/29/99	445	6.00	11.5	3.93
	12/20/99	442	5.99	10.5	4.65
	1/18/00	430	5.86	11.2	3.84
	2/13/00	425	5.61	11.2	3.32
	3/20/00	440	5.53	10.8	5.2
	4/16/00	440	5.64	10.8	5.32
	5/22/00	450	5.86	11.5	5.43
MW2	9/13/99	183	6.76	11.2	3.01
	10/25/99	180	6.5	10.5	5.2
	11/29/99	180	6.67	10.6	2.98
	12/20/99	178	6.38	10.1	2.68
	1/18/00	181	6.71	10.2	3.8
	2/13/00	180	6.5	10.1	3.53
	3/20/00	190	6.5	10.6	5.08
	4/16/00	185	6.9	10.5	4.65
	5/22/00	177	6.86	11.3	4.5
MW3	9/13/99	480	6.32	13.1	4.07
	10/25/99	560	5.95	12.0	4.58
	10/25/99	600	6.24	11.9	4.85
	11/29/99	550	5.78	12.1	2.63
	11/29/99	580	6.02	12.1	2.59
	12/20/99	525	5.66	11.1	2.79
	12/20/99	580	6.04	11.2	2.81
	1/18/00	590	5.52	11.4	2.33
	1/18/00	585	5.99	11.5	2.11
	2/13/00	625	5.82	11.6	2.79
	3/20/00	700	5.84	12	1.92
	4/16/00	740	5.78	12.1	0.88
	5/22/00	800	5.73	12.6	1.3
MW4	9/13/99	236	6.43	11.3	4.87
	10/25/99	226	5.97	10.5	7.98
	11/29/99	230	5.42	10.1	4.98
	12/20/99	258	6.18	9.7	4.34
	1/18/00	262	6.00	9.4	3.82
	2/13/00	282	5.9	10	4.73
	3/20/00	287	5.42	10.1	5.5
	4/16/00	252	6.37	10.2	5.51
	5/22/00	240	6.37	10.8	5.95

Table E-1. Field Parameter Results, Smith Prairie Groundwater Quality Assessment. Page 4 of 4.

Well ID	Date	Specific Conductance (umhos/cm)	pH (Std Units)	Temperature (°C)	Dissolved Oxygen (mg/L)
DITCH1	11/30/99	218	5.66	10	2.74
	12/21/99	183	>5.43	7.6	4.3
	1/19/00	240	>4.93	5.6	9.3
	2/14/00	193	NT	5.9	9.22
	3/21/00	310	>5.7	10.5	6.13
	4/17/00	DRY			
	5/22/00	DRY			
DITCH2	11/30/99	910	6.64	9.8	3.59
	12/21/99	610	6.33	6.4	3.19
	1/19/00	575	6.04	3.7	5.85
	2/14/00	445	>4.92	5.2	7.44
	3/21/00	362	7.06	13.4	6.06
	4/17/00	372	6.99	18.5	5.1
	5/22/00	Shallow discontinuous standing water - no sample			

Table E-2. Laboratory Results, Smith Prairie Groundwater Quality Assessment.
(Units = mg/L unless shown otherwise.) Page 1 of 4.

Well ID	Date	NO2+NO3 as N	TKN	NH3 as N	Total Phos.	Cl^-	TDS	TOC	Fecal Colif (CFU /100mL)	MBAS	Br^-
WS1	4/11/95	28.9									
(Thomas)	5/31/95	33.4				45.9					
	8/23/95	31				40.4					
	10/23/95	28.4							1U		
	11/27/95	15									
	12/27/95	18.6				19.5			4		
	1/31/96	15							6		
	2/27/96	10							5		
	5/29/96	29				36.4			6		
	1/11/99	30.3	0.671	0.011	1.22	37.3	362		20		
	3/8/99	14.6							3		
	3/15/99	13.4	2.34	0.027	2.05	20.3	300		95		
	4/5/99	17.2							103		
	4/20/99	27.5	0.5U	0.01U	0.528	40.1	395		1U		
	5/17/99	36.6	0.5U	0.021	0.402	40.6	424		1		
	9/14/99	41.6	0.5U	0.011	0.26	45.6	487	2.4	1U	0.27	
	10/26/99	35.7	0.5U	0.01U	0.279	46.3	447	2.7	1U		
	11/17/99	23.6	1.52	0.01U	0.728	27.1	654	8.4	24		
	11/30/99	16.4	2.54	0.01U	0.509	24.1	331	17.3	10		0.09U
	12/21/99	14.6	1.98	0.021	0.513	23.7	313	19.3	12		0.15U
	1/19/00	17.3	1.91	0.021	1.59	27.8	354	17.9	6		
	2/14/00	16.4	1.44	0.012	0.128	30.8	352	14.8	6		
	3/21/00	16.2	1.88	0.011	1.68	27.4	364	19	1U		
	4/17/00	37.1	0.5U	0.01U	0.438	42.7	450	4.8	152		
	5/23/00	41.7	0.5U	0.01U	0.342	49.4	462	3.7	2		
WS2	7/11/95	9.7				18.2					
(Austen)	8/23/95	8.4				15.6			1U		
	10/23/95	6.8									
	12/27/95	15.8				20.7			1U		
	1/31/96	16							1U		
	2/27/96	7.6							1U		
	5/29/96	8.9				17.2			1U		
	1/11/99	17	0.5U	0.01	0.031	18	210		1U		
	3/15/99	8.9	0.575	0.01U	0.075	11.8	150		1U		
	4/20/99	10	0.067	0.01U	0.061	15.3	173		1U		
	5/17/99	9.18	0.5U	0.02	0.064	12.3	166		1U		
	9/14/99	9.1	0.5U	0.015	0.086	13.3	206	1.7	1U	0.1	
	10/26/99	10.2	0.5U	0.01U	0.101	13.6	205	1.6	1U		
	11/30/99	9.1	0.5U	0.01U	0.069	12.4	167	3.2	1U		0.15U
	12/21/99	12	0.5U	0.01U	0.062	18	159	4.4	1U		0.15U
	1/19/00	15.6	0.5U	0.01U	0.055	20.4	227	3.6	1U		

Table E-2. Laboratory Results, Smith Prairie Groundwater Quality Assessment.
(Units = mg/L unless shown otherwise.) Page 2 of 4.

Well ID	Date	NO2+NO3 as N	TKN	NH3 as N	Total Phos.	Cl^-	TDS	TOC	Fecal Colif (CFU /100mL)	MBAS	Br^-
	2/14/00	14.6	0.5U	0.01U	0.062	21.3	233	3.5	1U		
	3/21/00	13.9	0.5U	0.01U	0.058	19.7	222	4.2	1U		
	4/17/00	13.9	0.5U	0.01U	0.062	17	192	2.5	1U		
	5/23/00	11.7	0.5U	0.01U	0.072	16.4	183	2.4	1U		
WS3	7/11/95	4.8				11.3					
(Davis)	10/23/95	6.7									
	12/27/95	7.4				9.86			1U		
	2/27/96	4							1U		
	5/29/96	4.4				7.2			32		
	9/14/99	0.954	0.5U	0.062	0.115	8.7	159	2.5	1U	0.08	
	10/26/99	3.16	0.5U	0.052	0.11	8.36	153	2	1U		
	11/30/99	12.3	0.5U	0.046	0.07	13.1	188	1.8	1		0.09U
	12/21/99	10.8	0.5U	0.144	0.075	10.8	154	2.8	1U		0.03U
	1/19/00	9.93	0.5U	0.06	0.067	11.1	172	2.3	1		
	2/14/00	9.28	0.5U	0.01U	0.086	11.7	182	2.1	1U		
	3/21/00	7.55	0.5U	0.01U	0.084	11.5	170	3.8	1		
	4/17/00	10.9	0.5U	0.039	0.095	11.9	162	2.5	650J		
	5/1/00	6.74		0.01U	0.11				115		
	5/23/00	6.35	1.65	0.054	0.324	14.7	190	6.2	1100J		
WS4	7/11/95	0.6				3.74					
(Meyers, new)	8/23/95	0.9				3.85			1U		
	10/23/95	1.1									
	12/27/95	0.9				3.83			1U		
	1/31/96	1.1							1U		
	2/27/96	1.1							1U		
	5/29/96	1.1				4.05			1U		
	9/14/99	1.49	0.5U	0.013	0.122	5.37	156	1.0U	1U	0.05U	
	10/26/99	1.64	0.5U	0.01U	0.127	6.11	146	1.0U	1U		
WS5	5/31/95	0.5				4.26					
(McCulloch)	8/23/95	0.55				4.18			1U		
	10/23/95	0.62									
	12/27/95	0.51				4.2			1U		
	1/31/96	0.53							1U		
	2/27/96	0.55							1U		
	5/29/96	0.57				4.52			1U		
	9/14/99	0.743	0.5U	0.013	0.147	5.12	195	1.0U	1U	0.05U	
	2/14/00	0.658	0.5U	0.01U	0.132	5.2	192	1.0U	1U		

Table E-2. Laboratory Results, Smith Prairie Groundwater Quality Assessment. (Units = mg/L unless shown otherwise.) Page 3 of 4.

Well ID	Date	NO2+NO3 as N	TKN	NH3 as N	Total Phos.	Cl^-	TDS	TOC	Fecal Colif (CFU /100mL)	MBAS	Br^-
MW1	9/13/99	21.2	0.5U	0.026	0.147	29.8	315	1.0U	1U	0.175	
	10/25/99	21.7	0.5U	0.01U	0.147	32	348	1.0U	1U		
	11/29/99	21.2	0.5U	0.01U	0.115	29.4	338	1.0U	1U		0.15U
	12/20/99	21.8	0.5U	0.225	0.454	29.8	333	1.3	1U		0.15U
	1/18/00	22.8	0.5U	0.01U	0.11	29.7	320	1.0U	1U		
	2/13/00	19.7	0.5U	0.01U	0.121	30.8	337	1.0U	1U		
	3/20/00	20.5	0.5U	0.01U	0.107	30	319	1.2	1U		
	4/16/00	22.6	0.5U	0.01U	0.124	30.4	325	1.0U	1U		
	5/22/00	21.4	0.5U	0.01U	0.13	31.4	323	1.0U	1U		
MW2	9/13/99	0.15	0.5U	0.028	0.148	3.31	160	1.0U	1U	0.05U	
	10/25/99	0.156	0.5U	0.01U	0.185	3.46	168	1U	1U		
	11/29/99	0.141	0.5U	0.01U	0.132	3.3	156	1.0U	1U		0.03U
	12/20/99	0.58	0.5U	0.01U	0.126	3.72	132	1	1U		0.03U
	1/18/00	1.03	0.5U	0.01U	0.115	4.31	161	1.0U	1U		
	2/13/00	0.992	0.5U	0.01U	0.13	4.34	156	1.0U	1U		
	3/20/00	1.19	0.5U	0.01U	0.118	4.58	151	1.0U	1U		
	4/16/00	1.55	0.5U	0.01U	0.128	4.66	187	1.0U	1U		
	5/22/00	0.572	0.5U	0.01U	0.152	3.87	163	1.0U	1		
MW3	9/13/99	7.14	0.5U	0.01U	0.17	21.5	328	1.0U	6	0.19	
	10/25/99	41.3	0.5U	0.01U	0.188	29.3	403	1.2	1		
	11/29/99	10.3	0.5U	0.01U	0.145	26.1	383	1.0U	1U		0.09U
	12/20/99	11.2	0.5U	0.01U	0.137	27	366	1.8	1U		0.054
	1/18/00	10.8	0.5U	0.01U	0.132	30	413	1.6	1U		
	2/13/00	9.4	0.5U	0.01U	0.152	33	427	1.5	1U		
	3/20/00	11.2	0.5U	0.01U	0.123	36.1	442	1.9	1U		
	4/16/00	16.7	0.5U	0.01U	0.145	37	476	1.9	1U		
	5/22/00	14.5	0.5U	0.01U	0.165	39.9	500	2.2	1U		
MW4	9/13/99	2.62	0.5U	0.017	0.119	8.95	185	1.0U	1U	0.06	
	10/25/99	2.63	0.5U	0.01U	0.156	9.11	200	1	1U		
	11/29/99	3.89	0.5U	0.01U	0.111	10.1	192	1.0U	1U		0.023
	12/20/99	6.94	0.5U	0.01U	0.101	12.7	189	1.0U	1U		0.021J
	1/18/00	6.6	0.5U	0.015	0.094	13.9	220	1.0U	1U		
	2/13/00	7.42	0.5U	0.01U	0.104	16.4	220	1.0U	1U		
	3/20/00	7.1	0.5U	0.01U	0.09	17.1	212	1.1	1U		
	4/16/00	5.78	0.5U	0.01U	0.106	12.5	200	1.0U	1U		
	5/22/00	4.05	0.5U	0.01U	0.128	10.0	196	1.0U	1U		

Table E-2. Laboratory Results, Smith Prairie Groundwater Quality Assessment. (Units = mg/L unless shown otherwise.) Page 4 of 4.

Well ID	Date	NO2+NO3 as N	TKN	NH3 as N	Total Phos.	Cl^-	TDS	TOC	Fecal Colif (CFU /100mL)	MBAS	Br^-
DITCH1	11/30/99	3.05	1.48	0.012	0.494	10.6	158	12.7	20		0.03U
	12/21/99	1.02	1.09	0.042	1.55	10.9	129	12.9	19		0.026J
	1/19/00	2.28	1.31	0.022	1.18	13.1	161	13.2	2		
	2/14/00	0.104	0.995	0.013	0.988	10.7	145	11.2	640J		
	3/21/00	0.018	1.92	0.115	1.06	13.8	225	18.7	3U		
DITCH2	11/30/99	39.3	5.67	0.08	2.54	51.3	664	41	870		0.15U
	12/21/99	21.9	4.08	0.315	5.21	31.5	437	32.9	62		0.15U
	1/19/00	10.6	8.97	3.51	6.02	27.3	414	36.9	240		
	2/14/00	1.89	5.24	0.384	5.38	20.7	382	42.2	3800J		
	3/21/00	0.308	3.79	0.281	3.99	10.4	319	36	46		
	4/16/00	0.186	5.29	0.788	3.92	8.61	312	37	5800J		

U= Analyte not detected above listed value.
J= Estimated value.

Table E-3. Nitrate+Nitrite-N Results, Smith Prairie Groundwater Quality Assessment. (Units in mg/L).

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
4/11/95	28.9								
5/31/95	33.4								
7/11/95		9.7	4.8						
8/23/95	31	8.4							
10/23/95	28.4	6.8	6.7						
11/27/95	15								
12/27/95	18.6	15.8	7.4						
1/31/96	15	16							
2/27/96	10	7.6	4						
5/29/96	29	8.9	4.4						
5/30/96									
1/11/99	30.3	17							
3/8/99	14.6								
3/15/99	13.4	8.9							
4/5/99	17.2								
4/20/99	27.5	10							
5/17/99	36.6	9.18							
9/14/99	41.6	9.1	0.954	21.2	0.15	7.14	2.62		
10/26/99	35.7	10.2	3.16	21.7	0.156	41.3	2.63		
11/17/99	23.6								
11/30/99	16.4	9.1	12.3	21.2	0.141	10.3	3.89	3.05	39.3
12/21/99	14.6	12	10.8	21.8	0.58	11.2	6.94	1.02	21.9
1/19/00	17.3	15.6	9.93	22.8	1.03	10.8	6.6	2.28	10.6
2/14/00	16.4	14.6	9.28	19.7	0.992	9.4	7.42	0.104	1.89
3/21/00	16.2	13.9	7.55	20.5	1.19	11.2	7.1	0.018	0.308
4/17/00	37.1	13.9	10.9	22.6	1.55	16.7	5.78		0.186
5/1/00			6.74						
5/23/00	41.7	11.7	6.35	21.4	0.572	14.5	4.05		
Minimum=	10	6.8	0.954	19.7	0.141	7.14	2.62	0.018	0.186
Maximum=	41.7	17	12.3	22.8	1.55	41.3	7.42	3.05	39.3
Mean=	24.4	11.4	7.0	21.4	0.7	14.7	5.2	1.3	12.4

Table E-4. Chloride Results (mg/L), Smith Prairie Groundwater Quality Assessment.

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
5/31/95	45.9								
7/11/95		18.2	11.3						
8/23/95	40.4	15.6							
12/27/95	19.5	20.7	9.86						
5/29/96	36.4	17.2	7.2						
1/11/99	37.3	18							
3/15/99	20.3	11.8							
4/20/99	40.1	15.3							
5/17/99	40.6	12.3							
9/14/99	45.6	13.3	8.7	29.8	3.31	21.5	8.95		
10/26/99	46.3	13.6	8.36	32	3.46	29.3	9.11		
11/17/99	27.1								
11/30/99	24.1	12.4	13.1	29.4	3.3	26.1	10.1	10.6	51.3
12/21/99	23.7	18	10.8	29.8	3.72	27	12.7	10.9	31.5
1/19/00	27.8	20.4	11.1	29.7	4.31	30	13.9	13.1	27.3
2/14/00	30.8	21.3	11.7	30.8	4.34	33	16.4	10.7	20.7
3/21/00	27.4	19.7	11.5	30	4.58	36.1	17.1	13.8	10.4
4/17/00	42.7	17	11.9	30.4	4.66	37	12.5		8.6
5/23/00	49.4	16.4	14.7	31.4	3.87	39.9	10.0		
Minimum=	19.5	11.8	7.2	29.4	3.3	21.5	8.95	10.6	8.6
Maximum=	49.4	21.3	14.7	32	4.66	39.9	17.1	13.8	51.3
Mean=	34.7	16.5	10.9	30.4	4.0	31.1	12.3	11.8	25.0

Table E-5. Total Dissolved Solids (mg/L), Smith Prairie Groundwater Quality Assessment.

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
1/11/99	362	210							
3/15/99	300	150							
4/20/99	395	173							
5/17/99	424	166							
9/14/99	487	206	159	315	160	328	185		
10/26/99	447	205	153	348	168	403	200		
11/17/99	654								
11/30/99	331	167	188	338	156	383	192	158	664
12/21/99	313	159	154	333	132	366	189	129	437
1/19/00	354	227	172	320	161	413	220	161	414
2/14/00	352	233	182	337	156	427	220	145	382
3/21/00	364	222	170	319	151	442	212	225	319
4/17/00	450	192	162	325	187	476	200		312
5/23/00	462	183	190	323	163	500	196		
Minimum=	300	150	153	315	132	328	185	129	312
Maximum=	654	233	190	348	187	500	220	225	664
Mean=	407	192	170	329	159	415	202	164	421

Table E-6. Total Phosphorus (mg/L), Smith Prairie Groundwater Quality Assessment.

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
1/11/99	1.22	0.031							
3/15/99	2.05	0.075							
4/20/99	0.528	0.061							
5/17/99	0.402	0.064							
9/14/99	0.26	0.086	0.115	0.147	0.148	0.17	0.119		
10/26/99	0.279	0.101	0.11	0.147	0.185	0.188	0.156		
11/17/99	0.728								
11/30/99	0.509	0.069	0.07	0.115	0.132	0.145	0.111	0.494	2.54
12/21/99	0.513	0.062	0.075	0.454	0.126	0.137	0.101	1.55	5.21
1/19/00	1.59	0.055	0.067	0.11	0.115	0.132	0.094	1.18	6.02
2/14/00	0.128	0.062	0.086	0.121	0.13	0.152	0.104	0.988	5.38
3/21/00	1.68	0.058	0.084	0.107	0.118	0.123	0.09	1.06	3.99
4/17/00	0.438	0.062	0.095	0.124	0.128	0.145	0.106		3.92
5/1/00			0.11						
5/23/00	0.342	0.072	0.324	0.13	0.152	0.165	0.128		
Minimum=	0.128	0.031	0.067	0.107	0.115	0.123	0.09	0.494	2.54
Maximum=	2.05	0.101	0.324	0.454	0.185	0.188	0.156	1.55	6.02
Mean=	0.762	0.066	0.114	0.162	0.137	0.151	0.112	1.05	4.51

Table E-7. Fecal Coliform Bacteria, Smith Prairie Groundwater Quality Assessment.
(Units in Colony Forming Units/100mL.)

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
8/23/95		1U							
10/23/95	1U								
12/27/95	4	1U	1U						
1/31/96	6	1U							
2/27/96	5	1U	1U						
5/29/96	6	1U	32						
1/11/99	20	1U							
3/8/99	3								
3/15/99	95	1U							
4/5/99	103								
4/20/99	1U	1U							
5/17/99	1	1U							
9/14/99	1U	1U	1U	1U	1U	6	1U		
10/26/99	1U	1U	1U	1U	1U	1	1U		
11/17/99	24								
11/30/99	10	1U	1	1U	1U	1U	1U	20	870
12/21/99	12	1U	1U	1U	1U	1U	1U	19	62
1/19/00	6	1U	1	1U	1U	1U	1U	2	240
2/14/00	6	1U	1U	1U	1U	1U	1U	640J	3800J
3/21/00	1U	1U	1	1U	1U	1U	1U	3U	46
4/17/00	152	1U	650J	1U	1U	1U	1U		46
5/1/00			115						
5/23/00	2	1U	1100J	1U	1	1U	1U		
Minimum=	1U	1U	1U	1U	1U	1U	1U	3U	46
Maximum=	152	1U	1100J	1U	1U	6	1U	640J	3800J

U=Not detected above listed value.   J= Estimated value.

Table E-8. Ammonia-N Results (mg/L), Smith Prairie Groundwater Quality Assessment.

Sample Date	WS1	WS2	WS3	MW1	MW2	MW3	MW4	Ditch1	Ditch2
1/11/99	0.011	0.01							
3/8/99									
3/15/99	0.027	0.01U							
4/5/99									
4/20/99	0.01U	0.01U							
5/17/99	0.021	0.02							
9/14/99	0.011	0.015	0.062	0.026	0.028	0.01U	0.017		
10/26/99	0.01U	0.01U	0.052	0.01U	0.01U	0.01U	0.01U		
11/17/99	0.01U								
11/30/99	0.01U	0.01U	0.046	0.01U	0.01U	0.01U	0.01U	0.012	0.08
12/21/99	0.021	0.01U	0.144	0.225	0.01U	0.01U	0.01U	0.042	0.315
1/19/00	0.021	0.01U	0.06	0.01U	0.01U	0.01U	0.015	0.022	3.51
2/14/00	0.012	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.013	0.384
3/21/00	0.011	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.115	0.281
4/17/00	0.01U	0.01U	0.039	0.01U	0.01U	0.01U	0.01U		0.788
5/1/00			0.01U						
5/23/00	0.01U	0.01U	0.054	0.01U	0.01U	0.01U	0.01U		
Minimum=	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.012	0.08
Maximum=	0.027	0.02	0.144	0.225	0.028	0.01U	0.017	0.115	3.51
Mean=	0.012	0.007	0.047	0.029	0.007	0.005	0.007	0.041	0.893

U= Analyte not detected above listed value.
Mean calculated using 0.01U equal to 0.005.

Table E-9. Total Kjeldahl Nitrogen and Total Organic Nitrogen (mg/L), Smith Prairie Groundwater Quality Assessment.

	Kjeldahl Nitrogen				Organic Nitrogen			
Sample Date	**WS1**	**WS3**	**Ditch1**	**Ditch2**	**WS1**	**WS3**	**Ditch1**	**Ditch2**
1/11/99	0.671				0.660			
3/15/99	2.34				2.31			
4/20/99	0.5U				0.5U			
5/17/99	0.5U				0.5U			
9/14/99	0.5U	0.5U			0.5U	0.5U		
10/26/99	0.5U	0.5U			0.5U	0.5U		
11/17/99	1.52				1.52			
11/30/99	2.54	0.5U	1.48	5.67	2.54	0.5U	1.47	5.59
12/21/99	1.98	0.5U	1.09	4.08	1.96	0.5U	1.05	3.77
1/19/00	1.91	0.5U	1.31	8.97	1.89	0.5U	1.29	5.46
2/14/00	1.44	0.5U	1.00	5.24	1.43	0.5U	0.982	4.86
3/21/00	1.88	0.5U	1.92	3.79	1.87	0.5U	1.81	3.51
4/17/00	0.5U	0.5U		5.29	0.5U	0.5U		4.50
5/23/00	0.5U	1.65			0.5U	1.596		
Minimum=	0.5U	0.5U	1.00	3.79	0.5U	0.5U	0.982	3.51
Maximum=	2.54	1.65	1.92	8.97	2.54	1.60	1.81	5.59
Mean=	1.13	0.41	1.36	5.55	1.12	0.385	1.32	4.61

U= Analyte not detected above listed value.
Mean calculated using non-detect values = 0.25mg/L.

Table E-10. Total Organic Carbon (mg/L), Smith Prairie Groundwater Quality Assessment.

Sample Date	**WS1**	**WS2**	**WS3**	**MW1**	**MW2**	**MW3**	**MW4**	**Ditch1**	**Ditch2**
9/14/99	2.4	1.7	2.5	1.0U	1.0U	1.0U	1.0U		
10/26/99	2.7	1.6	2	1.0U	1U	1.2	1		
11/17/99	8.4								
11/30/99	17.3	3.2	1.8	1.0U	1.0U	1.0U	1.0U	12.7	41
12/21/99	19.3	4.4	2.8	1.3	1	1.8	1.0U	12.9	32.9
1/19/00	17.9	3.6	2.3	1.0U	1.0U	1.6	1.0U	13.2	36.9
2/14/00	14.8	3.5	2.1	1.0U	1.0U	1.5	1.0U	11.2	42.2
3/21/00	19	4.2	3.8	1.2	1.0U	1.9	1.1	18.7	36
4/17/00	4.8	2.5	2.5	1.0U	1.0U	1.9	1.0U		37
5/23/00	3.7	2.4	6.2	1.0U	1.0U	2.2	1.0U		
Minimum=	2.4	1.6	1.8	1.0U	1.0U	1.0U	1.0U	11.2	32.9
Maximum=	19.3	4.4	6.2	1.3	1	2.2	1.1	18.7	42.2
Mean=	11.0	3.0	2.9	0.7	0.6	1.5	0.6	13.7	37.7

U= Analyte not detected above listed value.
Mean calculated using 1.0U equal to 0.5.

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Appendix E

MANCHESTER ENVIRONMENTAL LABORATORY

7411 Beach Drive E, Port Orchard Washington 98366

CASE NARRATIVE

December 20, 1999

Subject: Smith Prairie

Samples: 99-438114, -488085, -488088 and -488089

Officer: Dennis Erickson

By: Dickey D. Huntamer
Microscopist -Chemist

FORENSIC MICROANALYSIS

Summary

One sample 99438114 was submitted for microscopic particle identification. The sample consisted of scrapings from a fiber filter used to filter water from a private drinking water well. Microscopic examination revealed significant numbers of viable chlorophyll bearing diatoms and flagellate algae were reaching the 76-foot deep well. This indicates a direct surface water connection to the underground aquifer.

Water samples collected from nearby surface waters provide presumptive evidence that SPDITCH#1, 99488088, could be a source of the microorganisms but 99488089 SPDITCH#2 cannot be entirely ruled out. Microorganisms similar to the well filter sample 99438114 were present in both ditch water samples but in substantially fewer numbers than in 99488088, SPDITCH#1.

Sample Description

The filter sediment sample was collected on October 26, 1999, 99438114 (SPWS1) and received November 27, 1999 in an 8 oz translucent plastic bottle. Inside were scrapings from the fiber filter used to filter the well water.

A one gallon well water sample, 99488085 (SPWS1), and two one gallon ditch water samples, 99488088 (SPDITCH#1) and 99488089 (SPDITCH#2) were collected November 30, 1999, and received, December 1, 1999 at the Manchester Environmental Laboratory. The samples were kept refrigerated at four degrees Celsius until analysis.

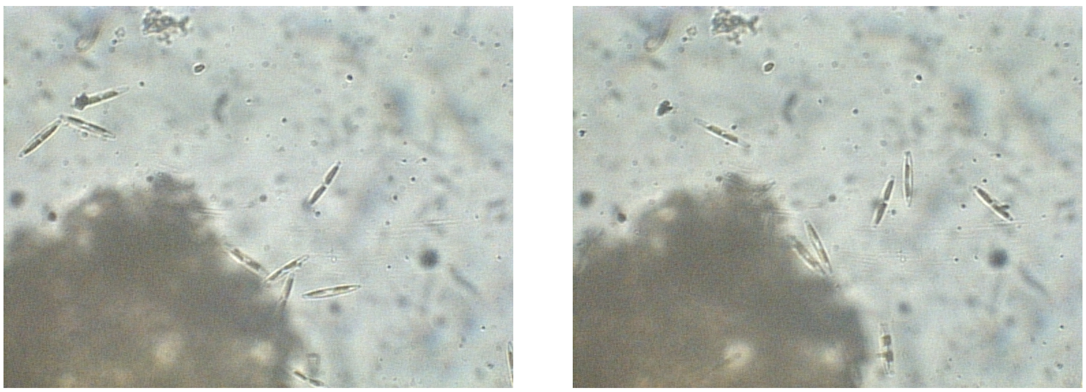
Analysis

The sediment sample were prepared for microscopical examination by placing a small amount on a clean microscope slide with 50% glycerol and water as a mounting media.

The water samples were first filtered using a 2.0-micrometer Nuclepore filter. Unfortunately the well water sample, 99488085 contains fine mineral grains and the volumes filtered were limited to as little as 70 milliliters of water. Volumes filtered for samples 99488088 and 99488089 were 610 and 325 milliliters respectively. Due to the small sample size filtered and the presence of the Nuclepore filter material these samples were of limited value.

Additional slide preparations were made after allowing the water to settle for a week in the refrigerator, 10 milliliters was pipetted from the sample container bottom and centrifuged at 3000 rpm for 35 minutes. The supernatant was decanted and the sediment was sonicated to disperse it. An aliquot was placed on a clean microscope slide with 50/50 glycerol –water and covered with a cover slip for microscopic examination.

A variety of particulate matter (PM) was observed in the filter sample, 99438114. These included fine mineral grains, rust particles, and man-made fibers from the filter cartridge along with a variety of biological materials including diatoms and algae. Although the filter cake was two weeks old at the time it was examined microscopically, microorganisms including pigmented diatoms and chlorophyll containing flagellates were relatively numerous and viable (Figure1).



A B

Figure 1. Smith Prairie 99438114 Bright Field 250X sequential photographs showing diatom motility.

Although a variety of microorganisms were present in the filter sediment, the predominant micro-organism was a diatom, Figure 1, A comparison of diatoms in Standard Methods showed a good correlation to the polluted water algae Nitzschia, Figure 2.

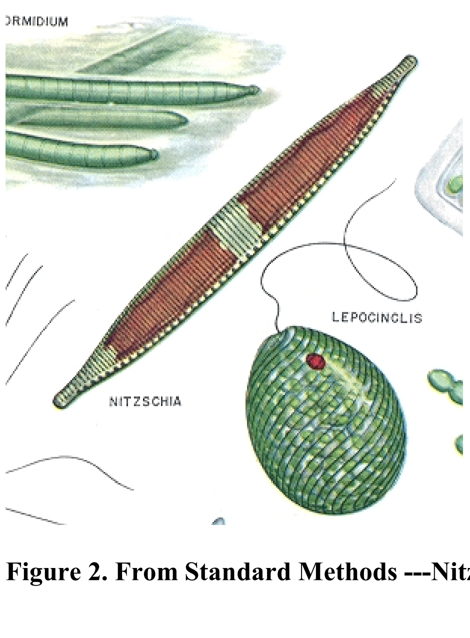


Figure 2. From Standard Methods ---Nitzschia center

The water sample 99488085, from the Nuclepore filter and the centrifuged precipitate showed a number of iron "rust" particles along with very numerous fine mineral grains. Surface water diatoms and algae were not observed but the sample volumes examined were limited, less than 100 milliliters, for the filtered sample and only 10 milliliters from the bottom of the sample jar. A few particles of biological origin were observed. These included two possible diatom frustules shaped like Nitzschia but generally biological particulate matter was relatively scarce

A wide variety of microorganisms were present in the ditch sample, 99488088 SPDITCH#1. These included filamentous algae, spores, flagellate algae and diatoms including those similar to those found on the well filter, 99438114. Figure 3.

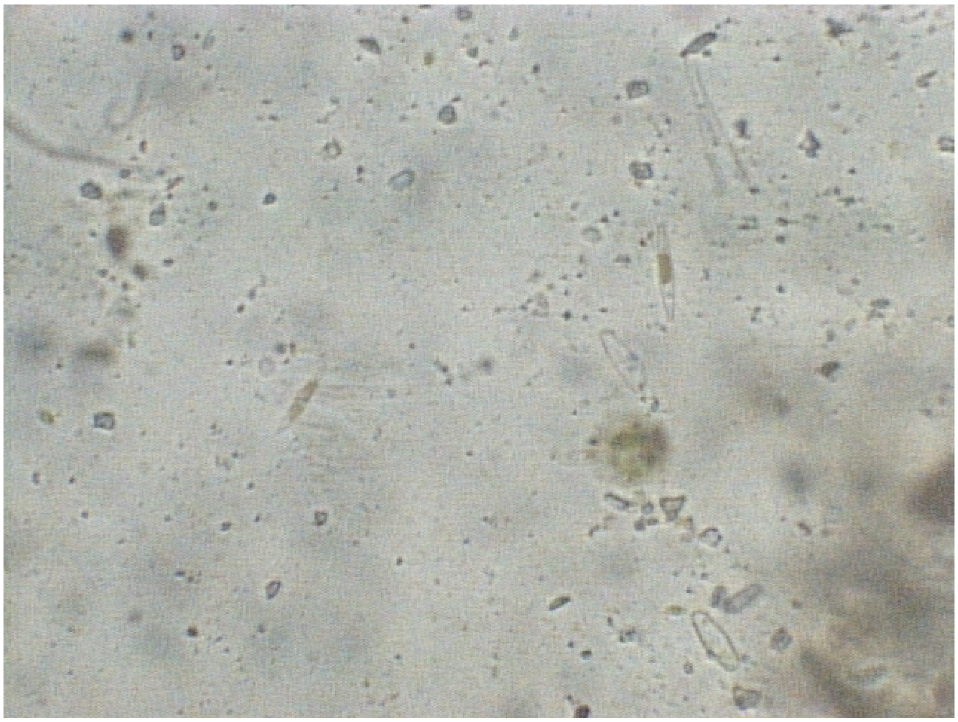


Figure 3. Smith Prairie 99488088 SPDITCH#1, 630X

Sample 99488089 SPDITCH#2 had microorganisms similar to that from the well's filter, Figure 4. but the relative numbers were less than those found in 99488088, SPDITCH#1

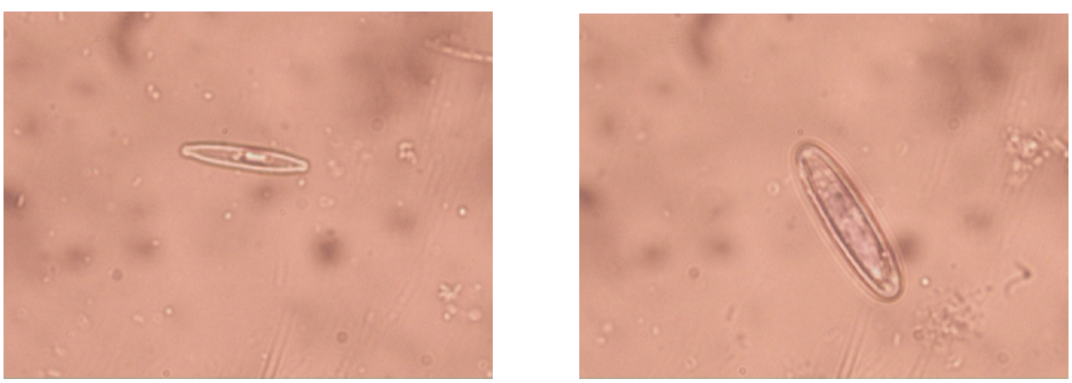


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Figure 4. Sample 99488089 diatoms. 500X

Conclusions

Initial results concerning the possibility of surface water contamination were reported verbally to the project officer. The well depth is around 76 feet with no obvious surface contamination sources.

According to the EPA manual (EPA 910/9-92-029) for determining ground waters under the influence of surface waters, "The repeated occurrence of a significant number of pigment bearing diatoms (not diatomal frustules) and other chlorophyll containing algae should be considered strong evidence of GWDI." (Ground Waters under the Direct Influence).

The presence of viable diatoms and flagellate algae in the filter sample indicates a probable surface water connection. Determining the exact source of the surface water to the well is a more difficult problem. The most common source would be an improperly sealed well casing, which is permitting surface water to enter along the well casing. A second possibility is subsurface flow of ground water through a "porous" aquifer. This would require relatively large pores since the diatoms observed in the wells filter were generally 20-30 micrometers long by 3-6 micrometers wide.

Based on the microscopical observations of sample 99488088, SPDITCH#1 and the presence of diatoms and algae similar to those observed in the filter sample, 99438114, it could be a viable source area. Although similar microorganisms were present in 99438089, SPDITCH#2 the abundance was much less. Confirmation would require application of chemical or fluorescent tracers to the surface water and monitoring of the well.

References

"Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (MPA)", EPA 910/9-92-029, October 1992. Manchester Environmental Laboratory, 7411 Beach Drive E, Port Orchard, WA. 98366.

Standard Methods for the Examination of Water and Wastewater Including Bottom Sediments and Sludges, Twelfth Edition, American Public Health Association, Inc, 1969.