Nitrate Trends in the Central Sumas-Blaine Surficial Aquifer

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For more information contact:

Author: Melanie Redding, L.G., L.HG.
Washington State Department of Ecology
Address: PO Box 47600, Olympia WA 98504-7600
E-mail: mkim461@ecy.wa.gov Phone: (360) 407-6524

Washington State Department of Ecology - www.ecy.wa.gov/

o Headquarters, Olympia	360-407-6000
o Northwest Regional Office, Bellevue	425-649-7000
o Southwest Regional Office, Olympia	360-407-6300
o Central Regional Office, Yakima	509-575-2490
o Eastern Regional Office, Spokane	509-329-3400

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Nitrate Trends in the Central Sumas-Blaine Surficial Aquifer

by
Melanie Redding, L.G., L.HG.

Environmental Assessment Program
Olympia, Washington 98504-7710

Waterbody No. WA-01-1010

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Abstract

The Sumas-Blaine aquifer has been identified as one of the most severely contaminated aquifers in Washington State (Erickson, 2000). The groundwater is contaminated with elevated concentrations of nitrate. Numerous studies have been conducted in this area to determine the extent of nitrate contamination and possible sources.

Whatcom County has many sources of nitrogen. These include (1) widespread agricultural activity such as dairy operations, raspberry and blueberry farms, poultry farms, and irrigation, (2) on-site sewage systems, and (3) residential fertilizer use.

This report characterizes groundwater quality in the Sumas-Blaine surficial aquifer. The study results will be used to:

- Determine statistically significant trends in nitrate concentrations.
- Determine seasonal variability of nitrate concentrations.
- Establish the framework for a long-term groundwater monitoring network.

The Washington State Department of Ecology conducted this study from March 2003 to March 2005. Thirty-five wells were sampled every other month for nitrate-nitrogen. Groundwater nitrate concentrations ranged from 0.01 to 43.1 mg/l with a mean of 11.43 mg/l. The overall trend for the study area indicates an increasing nitrate concentration at the rate of 0.46 mg/l per year.

Seventy-one percent of all the wells sampled had at least one concentration higher than the groundwater quality nitrate standard of 10 mg/l. Twenty-six percent of the wells had nitrate concentrations consistently above the 10 mg/l standard. Thirty-one percent of the wells sampled displayed an increasing nitrate trend over the two-year sampling period. The study also determined that seasonal fluctuations in nitrate influence 34% of the wells.

This study establishes a baseline for continued monitoring in the area to determine long-term nitrate trends in the Sumas-Blaine aquifer.

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Introduction

Purpose

The Washington State Department of Ecology (Ecology) conducted this study to describe groundwater quality trends in the central portions of the Sumas-Blaine surficial aquifer, which is located in northwest Washington State (Erickson, 2002).

The study was designed to monitor nitrate concentrations every other month for two years to provide the basis for determining trends and seasonal influences on groundwater quality. The frequent and extensive approach to sampling by this study provides the basis for developing a long-term monitoring program. The variability observed will be useful to define the frequency, timing, and sample locations for a long-term groundwater monitoring program that reflects groundwater quality trends in a surficial aquifer.

Nitrate concentrations in groundwater are the primary focus of this study. Nitrate is one of the most prevalent groundwater contaminants, and it is also a good overall indicator of general water quality conditions. Studies over the last 15 years have documented extensive nitrate contamination within the aquifer (Cox and Kahle, 1999; Erickson and Norton, 1990; Erickson, 1998; Erickson, 2000; Garland and Erickson, 1994; Mitchell et al., 2000; Cox and Liebscher, 1999; and Mitchell et al., 2005). These studies indicate that nitrate in the Sumas-Blaine aquifer has been a persistent problem for more than 15 years, with concentrations as high as 98.7 mg/l.

Sources of nitrate in the study area include the storage and application of dairy wastewater and manure, inorganic fertilizer application to irrigated agricultural fields (raspberries, strawberries, potatoes, corn, and grass), poultry operations, on-site sewage systems, and residential fertilizer use. Since the passage of the Dairy Nutrient Management Act, there has been a great effort on the part of dairy farmers to improve the handling and storage of dairy wastewater and manure. Additionally, two dairies where manure storage, handling, and land application practices have improved were targeted in this study to assess if these improvements translate into water quality improvements.

Background

The Sumas-Blaine surficial aquifer is the principal aquifer in the Nooksack Watershed (WRIA[1] 1; see Figure 1). The aquifer extends over 150 square miles and is the primary drinking water source for area residents. The aquifer is comprised mainly of permeable sand and gravel glacial outwash deposits as well as alluvial deposits from the Nooksack and Sumas Rivers. The aquifer is largely unconfined and shallow, with depths to water commonly less than 10 feet below land surface. These hydrogeologic characteristics create an aquifer which is highly susceptible to contamination from surface activities.

[1] Water Resource Inventory Area

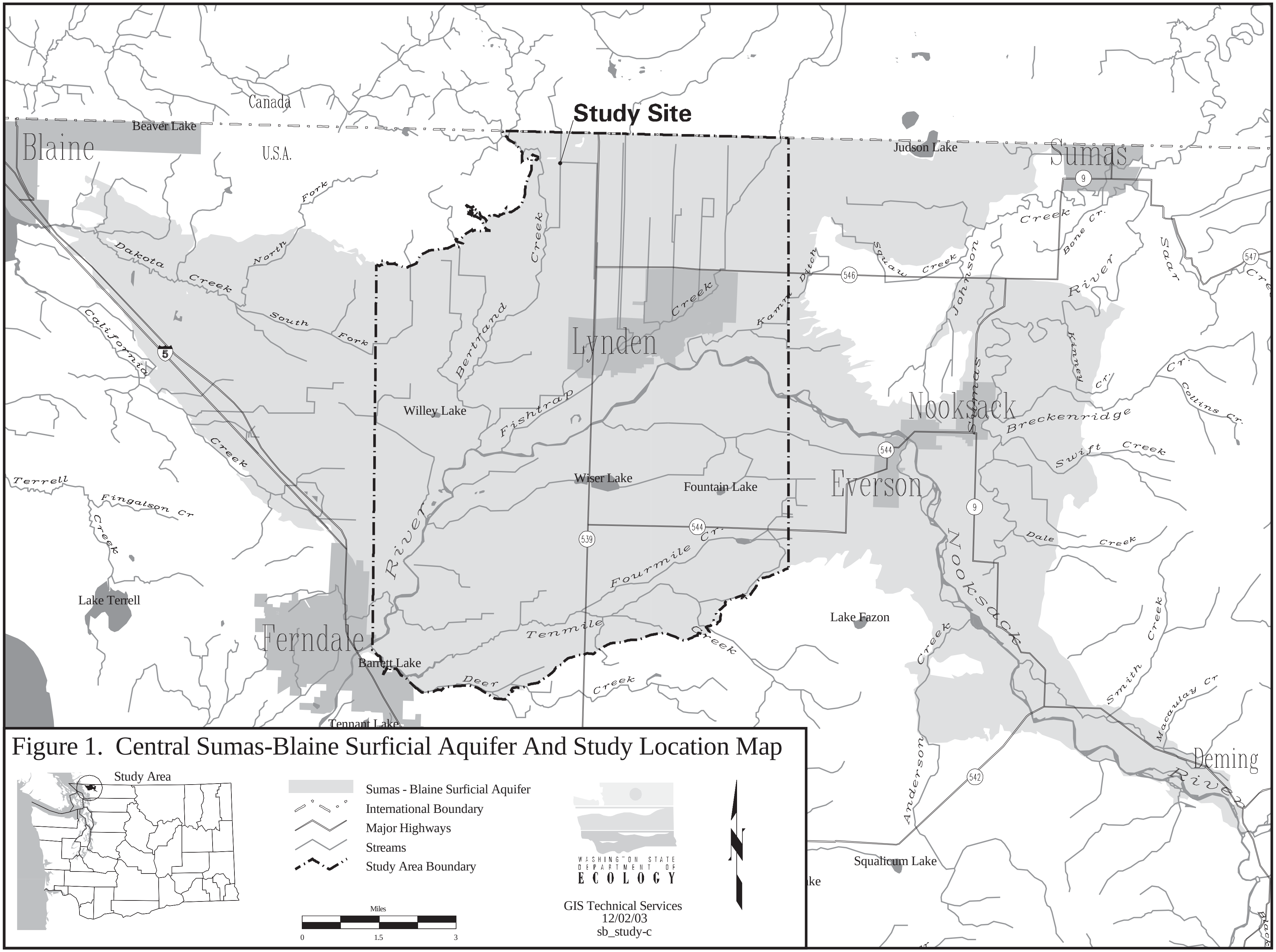

Figure 1. Central Sumas-Blaine Surficial Aquifer And Study Location Map

The Sumas-Blaine surficial aquifer was identified as one of the most severely contaminated aquifers in Washington State (Erickson, 2000). Agriculture is the predominant land use, and the density of dairies is among the highest in the state (Erickson, 2000). Whatcom County is also the nation's leading producer of raspberries. This aquifer is vulnerable to contamination due to permeable soils, a shallow water table, and historic and continued agricultural land use.

Study Area

The study area consists of the central portion of the Sumas-Blaine surficial aquifer, and is located northeast of Bellingham, Washington (Figure 1). It encompasses an area of approximately 80 square miles with the town of Lynden situated at the center of the study area. The study area is bounded by Tenmile Creek to the south, the Canadian border to the north, Bertrand Creek and South Fork Dakota Creek to the west and Northwood Road to the east.

The study area incorporates the main occurrences of nitrate contamination previously identified by Erickson (1998), with the exception of the Judson Lake area which was being investigated under a separate project conducted by Western Washington University (Mitchell, 2005).

The population of Lynden is 10,480 people. Agriculture, forestry, fishing, and hunting employ 3.7% of the Whatcom County population and produce 2.6% of the county's income. Farming uses approximately 11% of the county's land base (Washington State, Office of Financial Management, 2005).

The elevation of Lynden is 58 feet above mean sea level. The average annual temperature is 51.6 degrees Fahrenheit (°F), with a high of 90.9°F and a low of 12.7°F. The average annual precipitation at the weather station for the year 2004 was 33.89 inches per year (USDA, 2002).

Summary of Previous Studies

Previous studies have identified extensive nitrate groundwater contamination and scattered pesticide detections in groundwater in this area, resulting largely from agricultural activities. These studies are briefly summarized below:

Erickson and Norton (1990) sampled 27 wells in the Bertrand Creek area. They reported nitrate+nitrite-N concentrations ranging from less than 0.01 to 24 mg/l, with a mean of 6.7 mg/l. The nitrate standard of 10 mg/l was exceeded in 7 wells (26%).

Garland and Erickson (1994) reported nitrate+nitrite-N concentrations as high as 73 mg/l and a median concentration of 2.3 mg/l for 21 domestic and irrigation wells in a three-square-mile area north of Lynden. Several monitoring wells at a dairy operation were also monitored. The maximum nitrate concentration in the monitoring wells was 98.7 mg/l in January 1991. Ammonia nitrogen concentrations in dairy lagoon wastewater ranged from 275 to 600 mg/l.

Erickson (1998) defined the springtime distribution of nitrate+nitrite-N concentrations within the aquifer by sampling 248 wells and two springs. Nitrate+nitrite-N concentrations exceeded

10 mg/l at 53 wells (21%) located primarily in the central and north-central portions of the aquifer. Concentrations ranged from 0.01 to 53 mg/l, with a mean concentration of 5.8 mg/l.

Cox and Kahle (1999) defined the aquifer characteristics and water quality in the different hydrostratigraphic units. Sampling was conducted in wells from all units during 1990 to 1992. Twenty-one percent of the 230 wells sampled in the eastern portion of the Sumas aquifer showed concentrations exceeding 10 mg/l. The mean concentration was 5.6 mg/l, and the median concentration was 3.8 mg/l with a range of <0.05mg/l to 43 mg/l.

In the Everson-Vashon aquifer unit, the mean concentration was 0.68 mg/l with a range of <0.05 to 10 mg/l. In the Vashon unit, the mean concentration was 0.86 mg/l with a range of 0.08 to 6.2 mg/l. In the Bedrock unit, the mean concentration was 0.18 mg/l with a range of <0.05 to 1.6 mg/l.

Within the Sumas-Blaine surficial aquifer, approximately 70% of the wells sampled were determined to have been contaminated by land use activities based on the elevated concentrations of nitrate, chloride, iron, and manganese. Based on historical data, significant seasonal variations were identified. It was also determined that long-term groundwater nitrate concentrations indicate an increasing trend in the Sumas aquifer.

Cox and Liebscher (1999) sampled nine groundwater wells near the international border to assess the contamination originating in Canada and the United States. Seventy-eight percent of the wells exceeded the nitrogen standard of 10 mg/l. Nitrate concentrations ranged from <0.05 to 67 mg/l.

Erickson (2000) reported nitrate+nitrite-N concentrations for 53 wells in the north-central portion of the aquifer ranging from 0.012 to 22.1 mg/l with a mean concentration of 9.95 mg/l. Fifty-one percent of the wells exceeded the nitrate standard of 10 mg/l.

Mitchell et al., (2000) monitored 26 wells in 1997 and 1998 in the Judson Lake area. Nitrate concentrations ranged from 0.001 to 32.43 mg/l. The median concentration in 11 of the 26 wells (42%) exceeded the nitrate standard of 10 mg/l.

Mitchell et al., (2005) collected 466 groundwater quality samples from 26 wells in the Abbotsford-Sumas aquifer, south of Judson Lake. Eighty-seven percent of the samples and 81% of the wells had median nitrate concentrations greater than 3 mg/l. Anthropogenic effects are typically characterized by nitrate concentrations greater than 3 mg/l. Sixty-four percent of the samples and 54% of the wells had median nitrate concentrations greater than the nitrate standard of 10 mg/l. A predominantly increasing nitrate trend was noted in the wells over the study period.

Development of the 2003-05 Study Design

Agricultural activities are the predominant source of nitrogen loading in the area. These include dairy farms, land application of manure, irrigated agriculture, and poultry operations (Cox and Kahle, 1999). Other nitrogen sources present in the region include on-site sewage systems, residential lawn and garden fertilizer use, and municipal biosolids land application. All of these sources have a potential to contaminate groundwater. This aquifer's shallow water table, high hydraulic conductivity, thin soils, and a preponderance of nitrogen sources make the aquifer vulnerable to contamination from surface activities. Once an aquifer is contaminated, it is often expensive and sometimes impossible to clean up.

In 1998 the Dairy Nutrient Management Act (Chapter 90.46 RCW) required that all dairies prepare and implement a dairy nutrient management plan (DNMP) by the year 2003. The comprehensive improvements made by the dairy industry to implement water quality best management practices and implement their individual DNMPs were expected to result in improvements to area water quality. Based on these expectations, the Ecology Bellingham Field Office requested that the Environmental Assessment Program design and implement a monitoring program to define nitrate trends in groundwater.

Despite the numerous groundwater quality monitoring efforts in the Sumas-Blaine aquifer, previous studies have not provided data to be used to evaluate a long-term regional trend. This is because of the lack of continuity in locations and in the frequency and scope of sampling. Likewise, since wells were not consistently sampled throughout each study and wells were sampled at various times during the year, the influence of seasonality on groundwater contaminant concentrations has not been adequately assessed. Because previous studies were designed to primarily assess the spatial distribution of nitrate contamination in groundwater, it has been difficult to compare results between studies in order to gain an understanding of water quality trends.

These studies have been useful in determining the location of elevated nitrate areas, contaminant concentrations, and the extent of the groundwater nitrate contamination, which covers a large proportion of the Sumas-Blaine aquifer. Additionally, there has been significant progress in addressing the issues of contaminant sources and loading to the subsurface. The challenge remains to identify long-term groundwater quality trends, seasonality, delineate nitrogen sources, and quantify contaminant loading to the aquifer.

Erickson (2000; 2002) recommended long-term monitoring to determine seasonal variations in groundwater and identify long-term trends. Regular bi-monthly monitoring conducted over two years was recommended by Erickson (2002) to adequately determine the spatial and temporal variability between samples, and identify long-term trends. The variability observed in this study can be used to define the frequency and sample locations for a long-term groundwater monitoring program.

Based on the vulnerability of the aquifer, the agricultural history in the area, and the preponderance of nitrate contamination, this study was recommended to address unresolved groundwater issues. The goal of this study is to establish a baseline for determining nitrate trends and seasonal variations in nitrate concentrations for developing a future groundwater monitoring network.

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Geology

The study area lies within the Fraser-Whatcom Lowlands, which were formed within part of the Georgia basin. The Georgia basin is a large depression that extends from land into marine waters. The depression was created during the Mesozoic Era by tectonic activity. This tectonic activity also formed the Cascade Mountains and portions of the Pacific Coastline. Substantial sediments were deposited in the basin during the Tertiary Period and accumulated as a result of the rapid weathering of the new mountains. Lithification and consolidation of these sedimentary units formed the lower geologic bedrock units of the Chuckanut Formation and the Huntingdon Formation. During the Pleistocene Epoch, glaciers eroded and carved the bedrock eventually depositing unconsolidated glacial sediments over the Puget Sound Lowlands.

Within the Sumas-Blaine study area, the Fraser Glaciation had several advances and retreats. With each of these movements another series of glacial sediments was deposited. There were three main stages of glacial advances and retreats; the oldest was the Vashon Stade, then the Everson Interstade and then the youngest Sumas Stade. The combined glacial deposits range from 0 and 1500 feet thick over the study area. During the Holocene Epoch, the Nooksack River cut through and eroded the Sumas Formation creating the present day alluvial floodplain of the Nooksack River Valley (Easterbrook, 1971).

The Chuckanut Formation is comprised of sandstone, mudstone, and conglomerate with seams of coal interspersed around the area. The Huntingdon Formation is of similar composition but geologically distinct. These two sedimentary units comprise the area bedrock beneath the glacial and alluvial deposits (Easterbrook, 1971).

Peat deposits are present in the area and are typically marked by local depressions, such as Wiser Lake. Some of these deposits are up to 30 feet thick (Easterbrook, 1971). Peat deposits have the potential to be a location where denitrification can occur. The organic carbon levels are high, and typically the saturated fine-grained soils create a reducing environment which is essential for denitrification to occur.

Hydrogeology

The U.S. Geological Survey distinguishes four main hydrogeologic units within the project area: the uppermost Sumas aquifer, the Everson-Vashon semiconfining unit, the Vashon semiconfining unit, and the bedrock semiconfining unit (Cox and Kahle, 1999).

Sumas-Blaine Aquifer

The Sumas-Blaine aquifer is the surficial aquifer and the primary water source for the area. The Sumas-Blaine aquifer extends north into British Columbia, Canada, where the unit is also referred to as the Abbotsford aquifer. The Abbotsford aquifer is hydraulically connected across the international border, and the major groundwater flow direction is south from Canada (Cox and Kahle, 1999). The Sumas-Blaine aquifer continuously underlies a relatively flat glacial outwash plain between the towns of Sumas, Blaine, and Ferndale and the Nooksack River, comprising an area of approximately 150 square miles. The Sumas-Blaine aquifer is unconfined over the extent of the study area. Figure 2 illustrates the well locations and the surficial geology of the study area. The well numbers in Figure 2 correspond to the well ID described in Table 3.

The Sumas-Blaine aquifer is the primary water producing unit. It is comprised mainly of stratified sand and gravel outwash with minor clay lenses. Finer grained lenses are more predominant in the Lynden area. The Sumas-Blaine aquifer is a heterogeneous unit which includes glacial outwash sediments and alluvial deposits from the Nooksack and Sumas River systems. There are also isolated lenses of till, fine-grained lacustrine deposits, and peat deposits. It is a highly productive unconfined aquifer that includes the geologic units of Sumas Outwash, Sumas fine-grained ice-contact deposits, coarse-grained alluvium, fined-grained alluvium, and peat deposits (Cox and Kahle, 1999).

The glacial outwash plains are comprised of unconsolidated sand, silt, and gravel sediments deposited by glacial streams produced during the advancement and retreat of the glaciers. Overall the topography is fairly flat except for the glacial kettle depressions where lakes, marshes, and peat bogs formed. Localized peat deposits are scattered across the area in natural depressions. The area around Wiser Lake, and the area to the east of Fishtrap Creek and south of the international border, are the most significant peat deposits. Over time the Nooksack River has incised the glacial outwash plain 40 to 60 feet, forming the Lynden Terrace near the town of Lynden (Cox and Kahle, 1999).

The aquifer thickness ranges from 15 to 80 feet where the Nooksack River has eroded away much of the sand and gravel outwash unit. Depth to groundwater is typically less than 10 feet below land surface (Erickson, 2000). The median hydraulic conductivity was calculated to be 270 feet per day, with a range of 7 to 7,800 feet per day (Cox and Kahle, 1999). The extreme variation in hydraulic conductivities indicates substantial heterogeneity within the units, which is typical of a unit of glacial origin. Cox and Kahle (1999) estimate the hydraulic gradient in the Sumas-Blaine aquifer at about 15 feet per mile or 0.0028 foot per foot. Groundwater flow velocity of two feet per day was determined at a local dairy (Garland and Erickson, 1994).

Generally groundwater within the Sumas-Blaine aquifer flows toward the major river systems and tributaries in the area. The aquifer is in hydraulic connection with surface water and provides baseflows during the summer months (Erickson, 2000). Groundwater in the southern part of the study area flows north towards the Nooksack River. Groundwater in the northern part of the study area flows south towards the Nooksack River. The Nooksack River originates in the Cascade Mountain Range and traverses through the lowlands to the marine waters. The main tributaries are Bertrand, Fishtrap, and Tenmile Creeks. Groundwater naturally discharges to the Nooksack River. Secondary sources of groundwater discharge are groundwater wells and subsurface drains which can alter groundwater flow locally.

Groundwater has a slightly acidic pH with typical values between 5.7 to 6.8 standard units (S.U.) Groundwater is also well oxygenated, with dissolved oxygen values typically greater than 7 mg/l (Cox and Liebscher, 1999). Garland and Erickson (1994) determined that groundwater is a calcium sulfate ($CaSO_4$) type water.

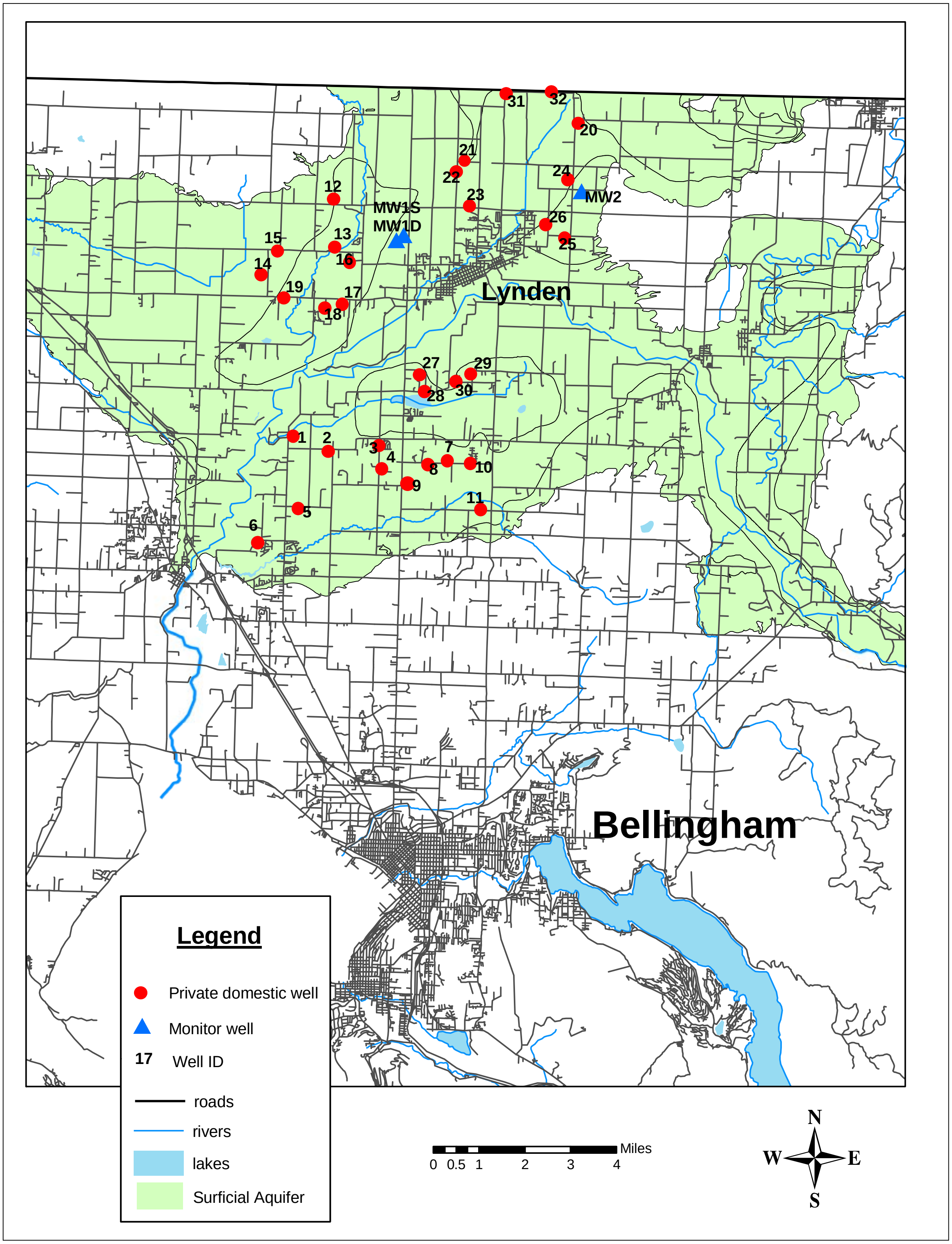

Figure 2. Well Locations.

The Sumas-Blaine aquifer is mainly recharged by precipitation and irrigation (Tooley and Erickson, 1996), although leachate from on-site sewage systems and manure storage lagoons also contribute to the recharge. Precipitation ranges from 60 inches per year near the international border to 32 inches per year in the southern part of the study area. Recharge rates are affected by precipitation rates, evapotranspiration rates, infiltration rates, and impervious surfaces. Within the study area, the recharge rates are estimated to range from 11 to 45 inches per year (Cox and Kahle, 1999).

Everson-Vashon Semiconfining Unit

The Everson-Vashon semiconfining unit lies beneath the Sumas-Blaine aquifer. It is predominantly glaciomarine drift comprised of unsorted gravelly clay and sandy silt. Some lenses of Vashon till have been noted by Cox and Kahle (1999). This unit generally acts as a confining unit, but areas of coarse-grained lenses can produce usable quantities of water. Chloride concentrations and total dissolved solids concentrations are elevated in the deeper wells compared to wells completed in the surficial aquifer. The median hydraulic conductivity value for this unit is calculated to be 81 feet per day. This value is high for fine-grained material and is likely to be biased high, since these values were calculated from specific capacity data from wells, which are normally found in the more productive portions of the aquifer (Cox and Kahle, 1999).

Vashon Unit

The Vashon semiconfining unit is located beneath the Everson-Vashon semiconfining unit. It is comprised primarily of poorly sorted Vashon glacial till and gravel. This unit is not extensive throughout the area. Water production is extremely variable. The median hydraulic conductivity is calculated to be 52 feet per day (Cox and Kahle, 1999).

Bedrock Unit

The Bedrock unit is located beneath the Vashon semiconfining unit. It is comprised of the Chuckanut and the Huntingdon Formations. They are sedimentary units of sandstone, mudstone, and conglomerate, with some coal-bearing strata. Water production is limited by fractures and secondary permeability within the fractured zones. The median hydraulic conductivity is calculated to be 0.55 feet per day (Cox and Kahle, 1999).

Nooksack River

The Nooksack River is the main surface waterbody which flows through the study area from east to west, draining the northwestern slopes of the Cascade Mountains. There is a Total Maximum Daily Load (TMDL; water cleanup plan) for fecal coliform bacteria being managed within the Nooksack River. There are three wastewater treatment plants and 151 commercial dairies in the Nooksack basin which discharge fecal coliform bacteria and have the potential to impact water quality. Seventy-eight percent of the dairy farms are located in the lower basin near the Lynden Terrace (Hood and Joy, 2000).

Traditionally it had been thought that since the Nooksack River is recharged by groundwater over most sections of the river (Cox, 2005), that elevated nitrate and fecal coliform bacteria in groundwater from agricultural activities were responsible for the surface water degradation. However, the hyporheic zone, which is the area beneath and adjacent to the river where groundwater and surface water mix, provides a reducing environment where denitrification occurs.

Water within the hyporheic zone does not contain fecal coliform or nitrate (Cox, 2005). This zone also contains low dissolved oxygen concentrations and elevated ferrous iron concentrations, which are indicative of a reducing environment. Therefore, the elevated nitrate and fecal coliform concentrations are coming from an alternate pathway other than groundwater. This hypothesis is further verified by the elevated levels of nitrogen gas in the hyporheic zone, which is the by-product of denitrification (Cox, 2005).

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Nitrogen

Nitrate is one of the most prevalent groundwater contaminants. Sources of nitrate contamination include irrigated agriculture, confined animal feeding operations, dairy operations, wastewater treatment facilities, land treatment sites, golf courses, lawn fertilizer, biosolids application sites, wastewater reuse sites, and on-site sewage systems. Nitrate also occurs naturally from mineral sources, vegetation, and atmospheric deposition.

Nitrate is an excellent indicator parameter of the vulnerability of groundwater since nitrate is soluble, mobile, and basically non-reactive. However, nitrate loss does occur during denitrification in anaerobic zones (Cohen et al., 1984). If elevated nitrate is present in groundwater, it likely originates from a source which contains other associated contaminants such as metals, pesticides, other organic chemicals or pathogens (Driscoll, 1986). The relationship between the presence of nitrate and other anthropogenic contaminants is well documented (Burkart and Kolpin, 1993; Baker et al., 1994; Cox and Kahle, 1999).

Nitrate Standards

Nitrate in amounts above the 10 mg/l standard can pose a public health threat. Nitrate in elevated concentrations can cause methemoglobinemia in infants. Methemoglobinemia affects infants by converting the nitrate to nitrite in their digestive system. The nitrite reacts with the oxyhemoglobin to bind to the available oxygen contained in the blood, depriving the infant of oxygen. Methemoglobinemia is also called blue baby syndrome since the child often turns a bluish color from a lack of oxygen.

Consuming water with elevated nitrates can also pose a health risk to pregnant women and those individuals with digestive problems, such as not having enough stomach acid, or the lack of an enzyme which converts red blood cells back to normal (Washington State Department of Health, 2004). There is also a concern that excessive ingestion of nitrate could cause cancer in adults (Plumb and Morrisett, 1988). Nitrate is often used as an indicator of general groundwater quality and to indicate anthropogenic (human-caused) impacts on water quality.

The Washington State drinking water standard, the federal drinking water maximum contaminant level (MCL), the Guidelines For Canadian Drinking Water Quality, and the Washington State Ground Water Quality Standard for nitrate are all 10 mg/l (Chapter 246-290 WAC; Title 40 CFR, Part 141 Subpart B; Health Canada, 1996; Chapter 173-200 WAC).

Nitrogen Cycle

Nitrogen is an essential element present in all living cells. The nitrogen cycle is the process where nitrogen gas (N_2) is transported out of the atmosphere to the earth's surface via precipitation. Nitrogen gas is converted into inorganic nitrogen through nitrogen fixation. Nitrogen is essential for plant growth and viability. Nitrogen is often the most limiting nutrient for plant growth since most plants can only take up nitrogen as ammonium (NH_4) or nitrate

(NO_3). Nitrogen is then passed through the food chain to animals and people, and then re-enters the environment through decomposition and discharge of waste products.

Nitrification is the aerobic reaction which converts ammonium to nitrite (NO_2) and ultimately to nitrate, which is the most stable and mobile form of nitrogen. Denitrification is an anaerobic biological transformation of nitrate to nitrous oxide or nitrogen gas (N_2). Before denitrification can occur, nitrification is required. In anaerobic environments, positively charged ammonium ions will be attenuated in the subsurface by adsorbing to the negatively charged soil particles. As the adsorption capacity of the soils is reached, the ammonium ions must travel farther through the vadose zone to find adsorption sites. If there is excessive ammonium released into the environment, eventually the ammonium ions will reach groundwater. If there is sufficient dissolved oxygen in the vadose zone or groundwater, nitrification can occur, and ammonium will be converted to nitrate (Plumb and Morrisett, 1988).

The preponderance of nitrogen sources, and the ability of nitrogen to be readily converted into nitrate, make nitrate a very common and prevalent groundwater contaminant.

Correlation with Agriculture

In a review of national nitrate studies, Helsel (1994) found that nitrate water quality concentrations are related to the degree of agriculture in a watershed. Commercial fertilizer use increased 20 times between 1945 and 1981 in the US, and then since 1981 has leveled off and remained relatively constant (Alexander and Smith, 1990). It was also noted by Power and Schepers (1989) that typical current agricultural practices involve applying twice the amount of fertilizer to agricultural fields than is removed during the harvest. This, combined with the high mobility of nitrate, explains why elevated nitrate concentrations are correlated with irrigated agricultural land use.

Mueller et al., (1995) found that nitrate concentrations in groundwater were typically twice as high under agricultural areas than under other areas. Of the wells sampled in agricultural areas by Mueller, 21% exceeded the drinking water standard of 10 mg/l. This number decreases to 12% when considering only domestic supply wells, and further decreases to 1% when considering only public drinking water supply wells. Mueller concluded that the nitrate concentration in rural areas is much higher than in urban areas. Since private domestic wells do not have the same regulatory oversight and regular monitoring requirements, the well users could be at a higher risk and be unaware of the threat of contamination.

Nitrogen Occurrence in the Sumas-Blaine Aquifer

Numerous studies have indicated that agricultural activities including dairy farms and irrigated agriculture are the main nitrate source to the Sumas-Blaine aquifer. Mitchell et al., (2000) calculated ambient nitrate concentrations in groundwater at the Canadian border to be between 10 and 12 mg/l. Almasri and Kaluarachchi (2003) found that within the Sumas-Blaine aquifer area, manure and inorganic fertilizers contribute 87% of the nitrogen loading to the land surface

(Table 1). Based on the extensive agricultural activities and the degraded water quality over time, they determined that the nitrate concentration in the Sumas-Blaine aquifer is increasing.

Table 1. Nitrogen Loading to Land over the Sumas-Blaine Aquifer.

Source	N loading (lbs/acre/yr)	Area (acre)	% of Total
Manure	356.1	41,252	66%
Fertilizers	73.2	63,196	21%
Atmospheric deposition	7.3	236,196	8%
Legumes	5.0	85,604	2%
Dairy lagoons	1,900	190	2%
Irrigation	1.6	106,298	1%
On-site sewage systems	22.8	11,619	1%

(modified from Almasri and Kaluarachchi, 2003)

Almasri and Kaluarachchi (2003) determined that manure land application is the predominant source of nitrogen loading year-round except for the month of April when fertilizer application is at its peak. Manure loading is the greatest form of nitrogen application from April through September when dairy lagoons are being emptied.

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Land Use

Historically the Sumas-Blaine area was heavily forested. As the dense forests were logged and land was cleared, agriculture became the main economic source for the community. Fertile soils and relatively flat topography make this area a prime spot for agriculture. The transition between forestry and agriculture happened around 1950. Currently the main land uses are agriculture and residential (Cox and Kahle, 1999).

It was common in this area for subsurface tile drains and surface drains to be installed in the fine-grained sediment areas or in the peat deposits where drainage is poor. Irrigation return flow water typically has elevated concentrations of nitrate and other agricultural chemicals, such as pesticides and herbicides. Subsurface tile drains provide preferential flow pathways for irrigation return flow and transport water to other more permeable areas where water can infiltrate. The presence of subsurface tile drains can exacerbate water quality contamination and make it difficult to discern the source of contamination.

Agriculture is the predominant land use over the Sumas-Blaine aquifer. Grass, corn, raspberries, blueberries, strawberries, and seed potatoes are the main crops grown in this area. Whatcom County is one of the leading dairy producers in Washington State. Raspberries are also a big agricultural commodity. Both dairy farms and raspberry fields are potential sources of nitrogen in groundwater. Poultry farms are also a significant source of nitrogen in the area. Farmers typically store their manure and wastewater in lagoons during the non-growing season, and land apply during the warmer season when crops will utilize the nutrients. The majority of the rural residents use on-site sewage systems for their wastewater treatment and disposal. Larger wastewater treatment systems are present in the urban areas.

In 2002 the USDA reported that the number of farms in Whatcom County decreased by 12%, but the amount of land being farmed increased by 30%, and the average farm size increased by 47% (USDA, 2002). In 2002 there were 148,027 acres being farmed. Manure was applied to 40,907 of these acres (28%), with an additional 41,813 acres being fertilized (USDA, 2002).

Groundwater is the primary source of drinking water in this area. Over 100,000 people residing over this aquifer, both within the United States and Canada, rely on groundwater as their drinking water source (Mitchell et al., 2000).

Dairy Operations

Until recently Whatcom County was the top dairy producing county in Washington State. Currently Whatcom County ranks second in the state for milk and dairy production.

Estimates on the amount of nitrogen produced per cow and the number of cows varies slightly depending on the type of cow (milking, dry, heifers, or calves). There are between 53,000 and 60,000 dairy cows in Whatcom County. Each cow produces an average of 150 to 200 lbs of manure per day. This equates to approximately 3.3 to 3.9 billion pounds of manure produced each year (USDA, 2002; Almasri and Kaluarachchi, 2003).

Dairy manure averages between 5 to 9 pounds of nitrogen per ton (Bary et al., 2000). Garland and Erickson (1994) estimated the nitrogen content in dairy lagoon wastewater to be between 275 and 600 mg/l.

Raspberries

Washington State is ranked first in the nation in raspberry production and has steadily climbed to producing 90% of the nation's raspberries in 2004. Whatcom County produces 85% of Washington State's raspberries (WA State, Office of Financial Management, 2005). And in 1998 Washington was producing 10% of the raspberries grown worldwide (Menzies, 1998).

Raspberries were grown on 7,063 acres in 2002. This equates to 5% of the agricultural area in Whatcom County (USDA, 2002).

Raspberry fields are a source of nitrogen loading due to the heavy fertilization requirements. It is common to heavily fertilize raspberry fields at certain times during their growth cycle. Agronomists advocate that soil nitrogen amendments should begin a year before planting raspberries. A winter crop should be grown on the land and turned under, and an application of 8 to 12 tons of manure per acre should be applied in the fall. During the first year, nitrogen fertilizers should be limited to the rate of 10 to 20 pounds per acre and can be increased in the following years to the rate of 40 to 100 pounds per acre (Dickerson, 2000). The Whatcom County Conservation District recommends nitrogen application of 60 lbs nitrogen per acre per year for raspberries (Erickson and Norton, 1990).

Poultry Operations

Poultry production in Whatcom County has decreased from 10.3% of the state's total in 1997, to 5.3% in 2002 (USDA, 2002). Animal manure varies greatly in nutrient content depending on the type of animal, management practices, and manure storage. Poultry manure has an average of 73 pounds of nitrogen per ton, while dairy manure averages between 5 to 9 pounds of nitrogen per ton (Bary et al., 2000).

Canadian Agricultural Practices

Agriculture is also the predominant land use in British Columbia, Canada, which is north of the study area. British Columbia has a high concentration of poultry farms, raspberry fields, and dairies. All of these activities result in large inputs of nitrogen into the soils. In British Columbia, 60% of their poultry industry is near the border region (Cox and Kahle, 1999). The B.C. Ministry of Agriculture and Food acknowledges that the combination of agricultural activities is a significant contributor to the high nitrate concentrations in the Sumas-Blaine surficial aquifer (Hughes-Games and Zebarth, 1999).

The combination of the following factors makes it difficult to discern where the sources of nitrate originate:

- High nitrogen inputs into the environment in British Columbia and in Whatcom County.
- Complex geology.
- Southern groundwater flow across the international border into Whatcom County.
- Subsurface tile drains.
- Nitrogen transformations in the subsurface.

These compounding factors also make it difficult to observe whether improvements to farming practices translate into improvements in water quality. Mitchell et al., (2005) attempted to correlate land use with nitrate concentrations in groundwater but found that the Canadian contribution made it difficult to determine a cause-and-effect relationship.

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Methods

Well Selection Process

The groundwater monitoring network for this project consists of 35 wells; 3 of these are monitoring wells and 32 are private domestic water supply wells. Figure 2 illustrates the well locations. Wells were selected based on their spatial location within the Sumas-Blaine study area, and their proximity to areas which were previously identified as having elevated nitrate. Other factors affecting the well selection process include:

- The well owner must give permission to participate in the study for two years.
- The well construction must meet the well construction standards specified in Chapter 173-160 WAC.
- The well log should be available and the completed well depth known.
- The well must be completed only in the Sumas-Blaine surficial aquifer.
- The well is in an area known to have changes in manure or wastewater application.
- The well has a sampling history of elevated nitrate concentrations.
- The well must be accessible to sample.
- The water must be untreated prior to the sampling point.

Homeowners were contacted by phone and personal visits were made prior to sampling. This was done to assure (1) the homeowner's willingness to participate in the study and (2) the adequacy of the well in meeting the pre-determined standards (Erickson, 2002).

Wells were spatially located over the entire study area with an average of one well per 2.2 square miles. A data gap remains along the Nooksack River and in the town of Lynden, where few wells exist. Excluding these areas, the density of sampling points in the south part of the study area is an average of one well per 1.3 square miles. In the north part of the study area, the density of sampling points averages one well per 1.75 square miles.

Table B-1 in Appendix B describes the characteristics of the groundwater wells sampled, including location, construction, groundwater flow direction, and upgradient land use.

Monitoring Well Installation

Two monitoring wells were drilled in June 2003 at a dairy operation where water quality best management practices had been implemented and a current dairy nutrient management plan (DNMP) was approved and implemented. The wells were installed according to the well construction regulations specified in Chapter 173-160 WAC. The monitoring wells were located adjacent to, and downgradient of, one of the fields that receives manure applications.

- One well is shallow (MW1S), with a depth of 14.25 feet below land surface intercepting the uppermost surficial aquifer.

- The other well is screened deeper within the aquifer (MW1D), with a depth of 60.2 feet below land surface. This well was installed to determine the vertical extent of impacts by surface activities within the aquifer. This well is extremely limited in its potential to determine impacts, but was intended to provide information as to whether additional study is necessary.

Both wells were installed with a 2-inch diameter PVC casing drilled with a 4-inch diameter hollow stem auger, per Chapter 173-160 WAC. The wells have a 10-foot screened interval with silica sand filling the annulus. A bentonite surface seal was installed in both wells. A bentonite seal was inserted in the deep well directly above the screened interval.

The third monitoring well was previously installed at a second dairy operation. This well (MW2) is located within a sprayfield which receives manure applications. This well is from a previous Ecology groundwater study. It was drilled in May 1998 to a depth of 20 feet below land surface. This well also has a 2-inch diameter PVC casing with a 10-foot screened interval, which is also completed in the Sumas-Blaine aquifer. The annulus is filled with silica sand and has a bentonite surface seal.

Sampling and Analysis

Wells were sampled bi-monthly for two years from March 2003 through March 2005 as specified in the Quality Assurance (QA) Project Plan (Erickson, 2002).

All samples were analyzed for nitrite-nitrate as nitrogen. Field parameters included pH, temperature, electrical conductivity, and dissolved oxygen.

The presence or absence of ferrous iron in the sample was measured in the field using 2-2'dipyridyl (Heaney and Davison, 1977). This measurement was not described in the QA Project Plan, but was included to assess whether anaerobic conditions are present at some sites. The determination of anaerobic conditions is an indication that other nitrogen species might be present.

Total persulfate nitrogen (TPN) is a measure of all the nitrogen species combined (nitrate, nitrite, ammonium, and organic nitrogen). Nitrate is the most stable nitrogen species and is most commonly found in groundwater. Nitrogen is applied as fertilizer in the form of ammonium and organic nitrogen. Under aerobic conditions, the ammonium and organic nitrogen are oxidized and transformed into nitrate, which does not adsorb onto soil particles, and readily migrates through the vadose zone. Ammonium can also migrate to groundwater and be present in significant concentrations if the following conditions are present: (1) if the ammonium ion does not have the opportunity to be aerobically converted to nitrate at the land surface or in the vadose zone and (2) if the application of nitrogen is sufficient to saturate the adsorption sites in the vadose zone.

This phenomenon has been documented by Erikson (1994), and Garland and Erikson (1994) in groundwater near dairy operations.

By measuring TPN in the water samples, it provides assurance that the results capture the total nitrogen concentration in groundwater, and it verifies which nitrogen species are present. When nitrate concentrations are below detection limits, TPN can be used to clarify whether it is due to the absence of nitrogen, or because nitrogen is present but it is in the form of ammonium which has not been oxidized.

TPN was used as a measure of total nitrogen considering all of the nitrogen species. TPN was collected from all the wells on two occasions and bi-monthly during the last year (2004-05) from a small subset of wells. The 2-2'dipyridyl and the TPN measurements were used to determine (1) if reducing conditions are present in the aquifer and (2) which species of nitrogen are present in groundwater.

Standard sampling procedures were established and maintained to minimize sampling variability, (see Appendix A). Samples were collected as close to the wellhead as possible and were obtained prior to any type of water treatment. Sampling was conducted only on wells which were visually determined to have a good surface seal, and had no surface contamination resulting from preferential flow along the well casing. Samples were collected only while the pump was running in order to minimize contributions from storage water tanks.

Private domestic wells were sampled from a faucet as close to the wellhead as possible with a "Y" fitting. The "Y" adapter allowed the well to be purged while field parameters were constantly measured in a flow cell. This system is also advantageous for residences where a storage tank is in place prior to the closest tap. Variable flow controls allow large volumes of water to be purged from the tank which facilitates the pump cycling on, which then produces water directly from the borehole. One side of the "Y" was connected to a garden hose which was used to purge the well and discharge the water to a vegetated area. The other side of the "Y" was connected to a flow cell with a polyethylene hose.

The flow cell houses the pH, temperature, conductivity, and dissolved oxygen probes. The flow cell allows field measurements to be made prior to the water being exposed to the atmosphere. Purging was considered complete, and a sample was taken once two consecutive field measurements (which were taken at five-minute intervals) were made within the stability criteria previously defined by Erickson (2002) in the QA Project Plan. Samples were collected from the restricted side of the "Y" adapter after the polyethylene tubing was unhooked from the flow cell. This allowed a sample to be collected from as close to the wellhead as possible while minimizing the contact with field equipment and hoses.

Additionally, the monitoring wells were purged and sampled using low flow methods to assure (1) minimal stress to the formation and (2) that a representative groundwater sample was collected from the system.

The two adjacent monitoring wells (MW1S and MW1D) were sampled using dedicated silastic tubing and a small diameter submersible pump. Water was pumped from the submersible pump at a rate of 0.1 liter per minute. At this low volume, it is possible to directly pump water into the flow cell where field parameters were measured. Once the wells were adequately purged, the tubing was disconnected from the flow cell, and a sample was taken.

The third monitoring well (MW2) was located in the middle of a field, and was inaccessible by vehicle. This well was purged and sampled using dedicated silastic tubing and a peristaltic pump. Water was pumped at a rate of 0.l liter per minute. At this well, in-situ measurements were not possible, so grab samples were taken at five-minute intervals and field measurements were recorded. This method is less precise than using a flow cell, but still provides the necessary information to determine when stabilized conditions have been reached.

Each sample was placed in a 125-ml clear nalgene bottle preserved with sulfuric acid, obtained from Ecology's Manchester Laboratory. The sulfuric acid preserves the water sample to pH<2. Samples were refrigerated at 4 degrees Celsius and were transported while in the field in ice-filled coolers. The coolers were left at Ecology's Operation Center walk-in cooler, where a courier transported them to the Manchester Laboratory for analysis. Holding times were met for all samples.

Laboratory Methods

Nitrate+nitrite-N concentrations were determined using the cadmium reduction flow injection method, standard method 4500 NO3-I. Total persulfate nitrogen (TPN) concentrations were determined using standard methods 4500 NB, Standard Methods, 20^{th} Edition (Manchester Laboratory, 2005).

Field Methods

Field parameters are measurements which are made in the field. They are groundwater quality measurements and can also be used to verify when effective well purging has occurred based on when the parameters have stabilized. Groundwater stabilization assures that the groundwater sampled is representative of water in the aquifer formation and not stagnant water which has been residing in the borehole.

Field measurements were used to characterize groundwater conditions. Field parameters measured include pH, electrical conductivity, temperature, and dissolved oxygen. Electrical conductivity, temperature, and pH often stabilize within one casing volume while other chemical constituents often take longer. Puls and Powell (1992) recommend the use of dissolved oxygen as the best indicator of groundwater stabilization, since it typically takes longer to stabilize and it mimics the behavior of some inorganic constituents.

Field meters used to measure field parameters are listed in Table 2. All meters were calibrated twice daily against known standards to assure proper operation.

Table 2. Field Meters.

Parameter	Test Method
pH	Orion Meter 4500 H^+
Electrical Conductivity	Beckman Meter 2510
Temperature	Combination pH/Temperature Orion Meter
Dissolved Oxygen	Membrane Electrode 4500 O.G.

Redox potential is an important groundwater characteristic which indicates whether oxidizing or reducing conditions are present. A qualitative method for determining reducing conditions is the use of the 2-2'dipyridyl test, which indicates the presence of ferrous iron. Ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}) under anaerobic conditions by iron reducing bacteria (Faulkner et al., 1989). This is a reliable method of distinguishing between the presence of ferrous and ferric iron. A few drops of a 0.1% 2-2'dipyridyl (1,10 phenanthroline) solution added to a water sample will cause a slight-pink to bright-red reaction if ferrous iron is present. A positive test indicates that anaerobic conditions are present. (Heaney and Davison, 1977; Child, 1981).

The 2-2'dipyridyl test was conducted with a separate water sample after the well had been adequately purged. Determining redox conditions is important in assessing which nitrogen species to expect in groundwater. Nitrate is the most stable form of the nitrogen species. All the other forms readily convert to nitrate in an aerobic environment. Typically there is enough oxygen in the vadose zone to convert ammonia to nitrate. The uppermost portion of the aquifer naturally contains enough oxygen that nitrate will usually remain in solution and denitrification will not occur. However, in fine-grained sediments, oxygen is less abundant. Erickson (1994) documented that ammonia can be transported through the unsaturated zone to groundwater and continue to migrate downgradient through the aquifer when there is a large mass of manure or nitrogen fertilizer applied to the land surface.

Statistical Analysis

The QA Project Plan (Erickson, 2002) specifies that the study results be evaluated using the Seasonal Kendall statistical test at the 95% confidence level to identify trends. The Seasonal Mann-Kendall trend test is an appropriate method to evaluate trends when seasonal fluctuations may be present. This test compares the values for each year from the same month and, therefore, requires a minimum of three years of data. More data points result in stronger statistical analysis. This study was designed to conduct 13 sampling events over two years. Unfortunately, two sample points from each month, from two consecutive years, do not yield statistically significant results for this particular statistical test. Therefore, this statistical test is not adequate for the design of this study.

However, an alternate statistical method can be used to detect the presence of seasonality in the data and adjust for seasonal variations. The data are first evaluated using a seasonality test. If seasonality is present, the data are adjusted. The test for seasonality requires at least two years of data. The mean is calculated for all values collected in the same month during the different years. The universal mean is also calculated for all values in the data set. The seasonally adjusted value is calculated by subtracting the monthly mean from the original value and adding the universal mean. This allows the data to be analyzed without excessive variance due to natural seasonal influences (EPA, 1989; Fisher and Potter, 1989).

After this step, the non-parametric Mann-Kendall test for trends is applied to identify the presence of trends in the data for each well. This test is a monotonic trend analysis that evaluates trends in data where seasonal variations exist. A monotonic trend is one that is exclusively increasing or decreasing, but not both (EPA, 2000). The null hypothesis (*Ho*) is that the samples are independent and identically distributed variables that are random with respect to time, and therefore no distinguishable trend is present. The alternate hypothesis *(H_A)* is that a trend is present, either increasing or decreasing. The type of trend is determined by whether the calculated Mann-Kendall statistic *(S)* is positive or negative (Aroner, 1994). This nonparametric test can accommodate missing values, values less than the detection limit, and a non-normally distributed data set (Gilbert, 1987).

Values are compared to each other by their relative magnitude, and the signs of all of their differences are calculated. The signs are the relative difference indicated by a positive (+1) sign, negative (-1) sign, or a zero (0) if the values are equal. The sum of these signs *S*, which is called the Mann-Kendall statistic, is compared to a tabled value to determine the validity of the null hypothesis H_o. If *S* is a large positive number, values tend to get larger over time and indicate that the alternate hypothesis H_A is an increasing trend. If *S* is a large negative number, values tend to get smaller over time and suggest that the alternate hypothesis H_A is a decreasing trend.

Quality Assurance

Laboratory quality assurance (QA) samples for this project include duplicate samples, matrix spikes, control standards, and blanks. Accuracy is affected by both precision and bias. The targets for analytical precision are described in the QA Project Plan (Erickson, 2002). The QA results are discussed in Appendix D.

Duplicates

Field duplicate samples are used to measure the precision of the entire sampling and analytical process. Field duplicates are two samples collected from the same location at the same time. The duplicates are submitted as blind samples to the laboratory. Differences in the concentrations can be the result of natural heterogeneities in the aquifer, sample collection procedures, variances in the sample containers, preservation methods, or the analytical procedure. Duplicate samples were collected from 10% of the wells sampled during each event.

Laboratory duplicates are used to estimate analytical precision. This entails analysis of duplicate aliquots from a single sample container. Analytical duplicates run by the laboratory are typically used with one of the field duplicates to estimate total and analytical variability from the same sample. The relative percent difference (RPD) is a tool to measure the variability between samples. It is the ratio of the difference of the duplicate results and the mean of the duplicate results expressed as a percentage. The RPD is used to measure analytical precision. The lower the RPD, the more precise the results are (Lombard and Kirchmer, 2004).

Blanks

Method blanks were used to determine bias due to laboratory contamination. This is an analytical tool performed by the laboratory to measure the theoretical concentration of zero. Blanks are prepared using laboratory de-ionized water and analyzed along with the samples to measure any impacts to the samples from the analytical process.

Reference Sample

A reference sample is prepared specifically with a known concentration of nitrate. It is submitted blind to the laboratory and is used to estimate analytical accuracy. The reference sample is prepared by an inorganic chemist who is not involved in analyzing the samples.

Control Samples

Laboratory control samples, or check samples, are prepared with a known concentration of an analyte prepared independently of the calibration standards. This type of quality control is used to verify the analytical precision and to determine the level of bias due to calibration (Lombard and Kirchmer, 2004).

Matrix Spikes

Matrix spikes are a process of adding a known amount of an analyte to a portion of one of the submitted samples. Matrix spike recoveries indicate bias due to interference from elements in the sample matrix.

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Results

Nitrate

Nitrate+nitrite-N concentrations in the study area ranged from 0.01 to 43.1 mg/l. Mean nitrate+nitrite-N concentration for the study was 11.43 mg/l. Median nitrate concentration for the study was 12.2 mg/l. A compilation of the water quality data is located in Appendix C. The nitrate concentrations for each well collected over the course of the 2003-05 study are presented in Table C-1.

Figure 3 displays the mean nitrate+nitrite-N concentration of each well and categorizes them by concentrations: less than 5 mg/l, greater than or equal to 5 mg/l, and less than 10 mg/l, greater than or equal to 10 mg/l.

Seasonality

During the course of this 2003-05 study, there were sufficient data to determine seasonality for 31 wells (Table 3). The seasonality affected 13 wells, but it is not consistent throughout the aquifer in terms of when maximum and minimum concentrations occur.

TPN

Total persulfate nitrogen (TPN) was sampled at all wells on two occasions, January 2004 and July 2004. The minimum, maximum, and mean TPN concentrations were closely related to those for nitrate+nitrite-N concentrations. Additionally, a subset of eight wells was sampled for TPN during every sampling event during the last year. These wells were chosen based on their low dissolved oxygen concentrations in groundwater, the presence of ferrous iron, or whether other nitrogen species might be present in groundwater. There was no consistent pattern in the correlation between TPN and nitrate for any well throughout this last year. The relative percent difference between the two parameters varied dramatically for all eight locations.

Table C-2 summarizes the total persulfate nitrogen data and compares it to the nitrate data. Table C-3 summarizes the total persulfate nitrogen data collected from the small subset of wells during the last year of sampling.

Groundwater Quality at Dairy Operations

Three groundwater monitoring wells were installed at two dairy operations in the Sumas-Blaine area.

- The groundwater from the monitoring well in the northeast quadrant (well ID: MW2) exceeded the nitrate standard of 10 mg/l 92% of the time with a mean concentration of 16.5 mg/l. This well is located in a field that receives manure applications. The mean of 21 monthly samples collected from 1998 to 2000 was 12.6 mg/l from this well (Carey, 2002).

- The dairy in the northwest quadrant has two monitoring wells, one shallow (14.2 ft; well ID: MW1S) and one deep (60.2 ft; well ID: MW1D). Both wells are completed in the Sumas-Blaine aquifer. These wells are located adjacent to and downgradient of the dairy lagoon and adjacent to a field that receives manure applications. Both wells consistently contained nitrate+nitrite-N concentrations below the nitrate standard of 10 mg/l. The mean concentration for both wells was less than 1 mg/l. The presence of ferrous iron and low dissolved oxygen concentrations, indicate that reducing[2] conditions are present for both wells.

Quality Assurance

The quality of the data reported for his project is judged to be acceptable. The quality assurance results are discussed in Appendix D.

Static Water Level

Table B-2 presents the static water level elevations measured in the three monitoring wells sampled during this study. It was not possible to consistently measure the static water level in the private domestic wells, since the majority of the well owners requested that this measurement not be taken.

Static water levels were measured only at the three monitoring wells. Figure 4 illustrates how closely tied the water level elevations are in all three wells. This information indicates that there is some continuity across the region in how static water level is fluctuating across the area. Groundwater fluctuates seasonally approximately ten feet, with the highest elevations occurring in November, December, and January.

[2] A reducing environment is characterized by little or no free oxygen.

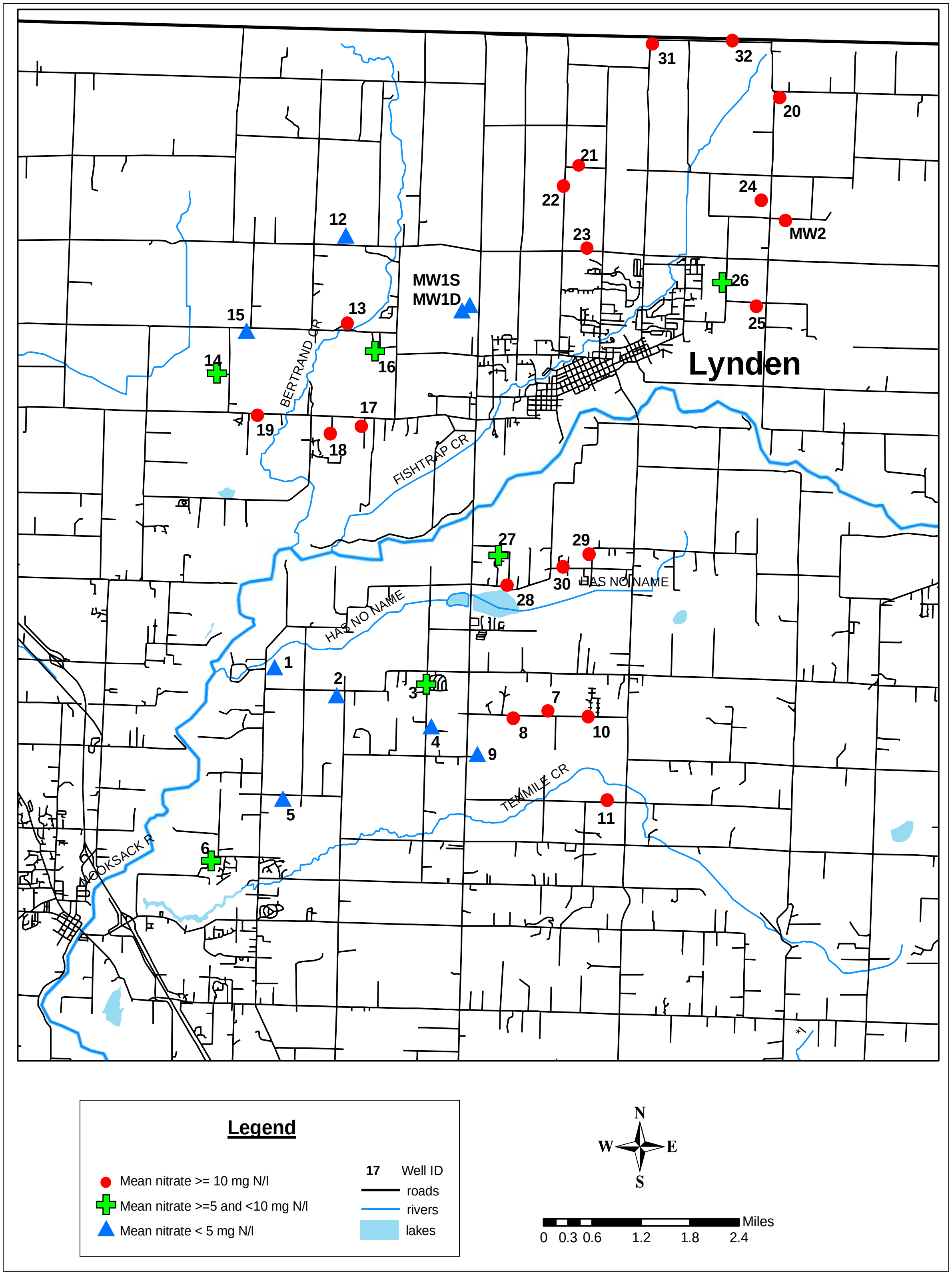

Figure 3. Mean Nitrate Concentrations in Groundwater.

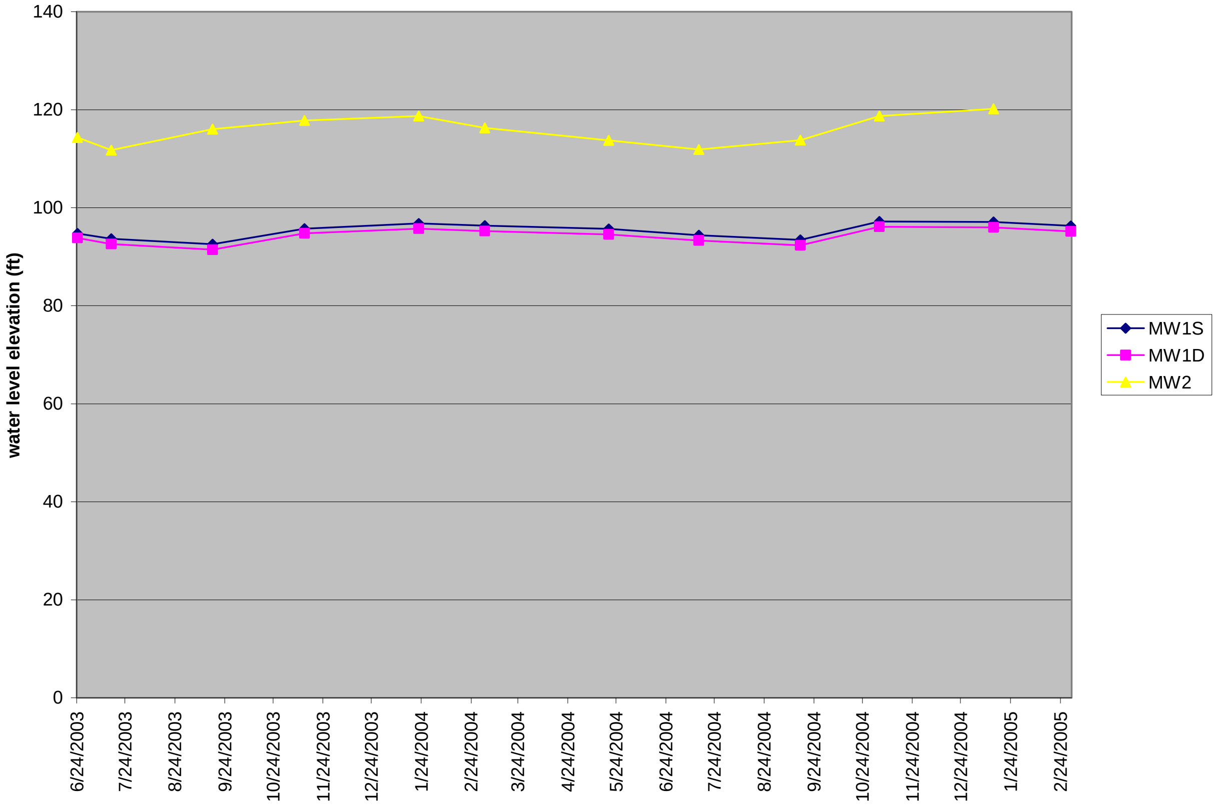

Figure 4. Static Water Level for the Monitoring Wells.

Discussion

Within the central Sumas-Blaine surficial aquifer, 35 groundwater wells were sampled bi-monthly for two years. The combined mean nitrate+nitrite-N concentration for all 35 wells was 11.2 mg/l. Twenty-eight percent of the wells consistently had nitrate concentrations below the groundwater quality standard of 10 mg/l on every sampling event. Twenty-six percent of the wells consistently had nitrate concentrations above 10 mg/l on every sampling event. Seventy-one percent of the wells exceeded the nitrate standard of 10 mg/l at least once during the 2003-05 study period.

Seasonality

The original data set was evaluated to determine whether groundwater nitrate concentration variations are due to natural seasonal fluctuations. The Mann-Kendall test for trends was used to determine whether increasing, decreasing, or no trends were expressed in the data set. If it was determined that seasonality was present, the nitrate concentration data were adjusted to remove the effects of seasonality on the data. Seasonality was determined to affect the following wells:

NO39203Q1	NO39211F1
NO39212C1	NO39212K2
NO40211P1	NO40221J5
NO40303B1	NO40308P1
NO40310F1	NO40331L1
NO41333M1	NO41334E1
NO40332M2	

Seasonally adjusted nitrate values were used for wells where water quality was affected by natural seasonal fluctuations.

Figure 5 illustrates the location of wells with seasonality. Figure 6 is a graphical illustration of seasonal nitrate concentrations in a well.

Table 3 summarizes the water quality characteristics of each well, including trend, seasonality, percent exceedance of standard, range, and mean values.

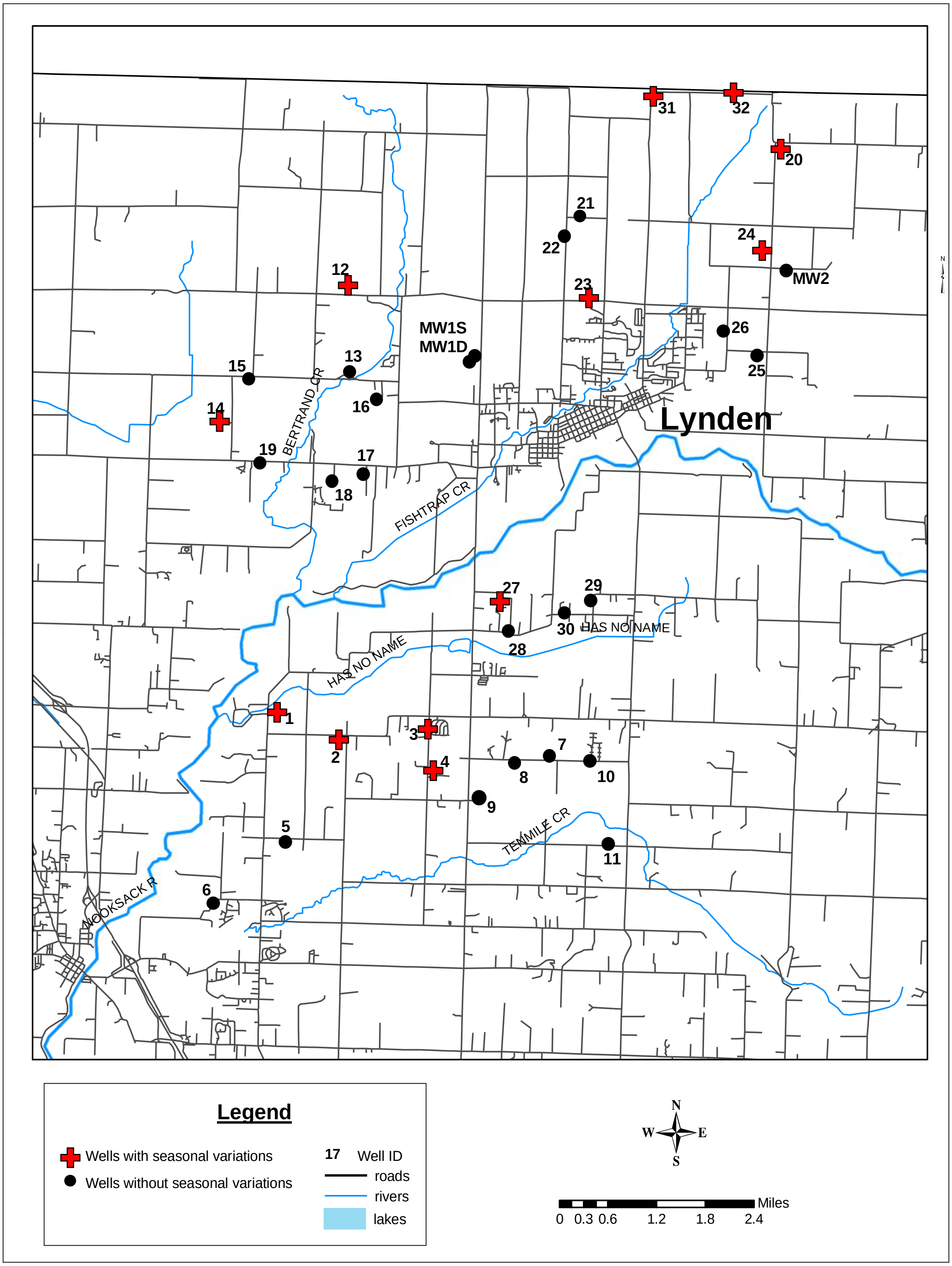

Figure 5. Seasonal Variations in Nitrate Groundwater Concentrations.

Table 3. Water Quality Characteristics (shaded cells = insufficient data to calculate trends).

Well No.	Site ID	Quadrant	Increasing Trend	No Trend	Decreasing Trend	Seasonality	High Month	Low Month	% Events NO_3 Exceeds Standard	Minimum Value	Maximum Value	Mean
1	NO39203Q1	SW	X			X	July	March	0%	0.19	4.51	2.08
2	NO39211F1	SW		X		X	Mar, May	Sept, Nov	0%	0.11	6.31	3.34
3	NO39212C1	SW		X		X	March	July, Sept	21%	6.75	10.6	8.47
4	NO39212K2	SW		X		X	May	Sept, Nov	0%	2	6.55	4.24
5	NO39215J1	SW		X					0%	1.6	3.67	2.52
6	NO39221H1	SW			X				7%	2.87	10.8	7.53
7	NO39307H1	SE		X					100%	31.8	37.4	33.76
8	NO39307K2	SE		X					100%	17.6	28.7	20.4
9	NO39307N1	SE							0%	0.01	2.77	0.89
10	NO39308F2	SE							100%	13.4	16.3	14.77
11	NO39317H1	SE	X						56%	0.28	22.1	13.01
12	NO40211P1	NW		X		X	Sept	May	0%	1.43	6.47	3.69
13	NO40214P1	NW			X				100%	15.9	19	17.37
14	NO40221J5	NW		X		X	Sept	Jan, Mar	29%	5.13	12.8	8.36
15	NO40222D1	NW	X						0%	1.6	9.77	4.78
16	NO40223A3	NW		X					21%	5.25	12.7	8.2
17	NO40226B1	NW		X					50%	8.54	15	10.56
18	NO40226D2	NW	X						93%	8.37	43.1	24.98
19	NO40227C1	NW		X					100%	15.8	36.5	22.44
20	NO40303B1	NE		X		X		Nov	75%	7.8	17.8	11.88
21	NO40305N3	NE	X						43%	5.52	20.4	11.4
22	NO40307H1	NE							100%	13.3	20.2	17.02
23	NO40308P1	NE		X		X	Nov	Jan	83%	5.83	17.5	12.96
24	NO40310F1	NE		X		X	Nov		100%	12.1	16.9	14.13
25	NO40315L1	NE	X	X					100%	12.4	15.6	13.79
26	NO40316H1	NE	X						27%	3.44	11.3	8.26
27	NO40331L1	SE		X		X		Nov	0%	2.69	9.92	7.21
28	NO40331P3	SE	X						64%	5.36	23.2	12.23
29	NO40332L1	SE	X						64%	2.69	13.6	10.67
30	NO40332M2	SE	X			X			100%	10	19.6	14.5
31	NO41333M1	NE		X		X	Mar	Sept, Nov	71%	7.82	33.9	14.47
32	NO41334E1	NE		X		X	Sept	Mar	86%	8.82	20.5	15.12
MW2	MW2	NE	X						92%	8.99	29	16.5
MW1S	MW1S	NW		X					0%	0.01	4.5	0.557
MW1D	MW1D	NW		X					0%	0.01	0.02	0.013

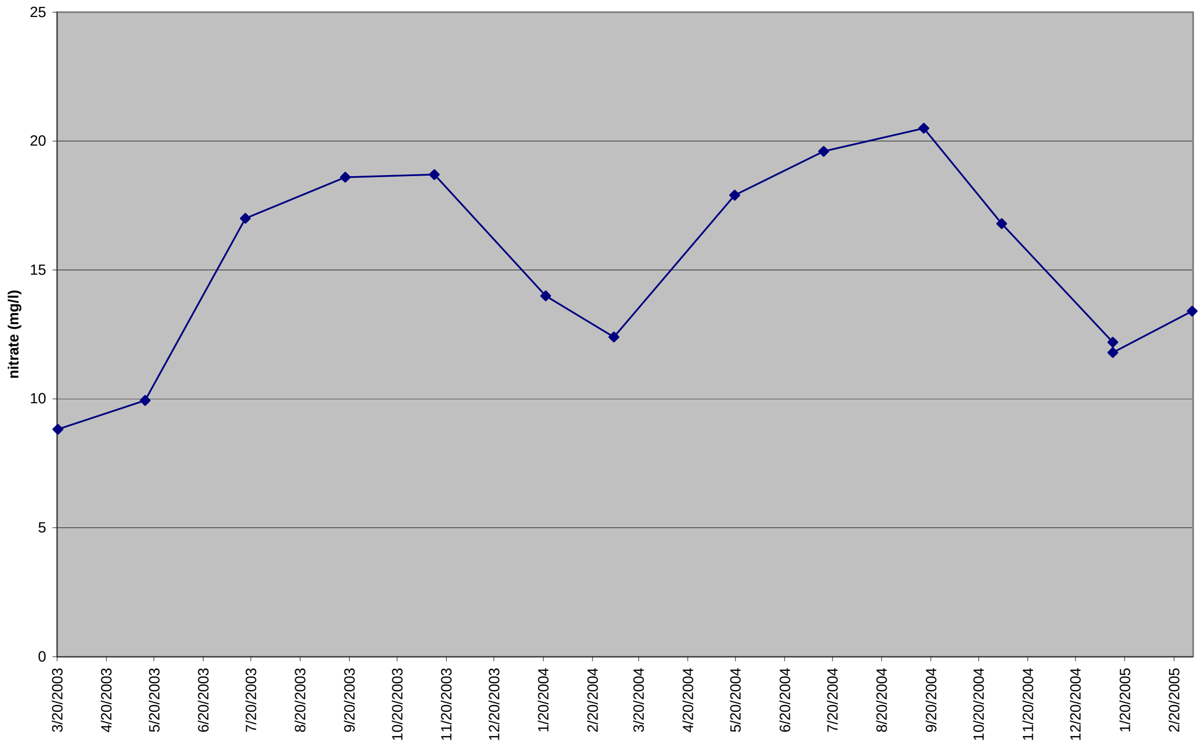

Figure 6. Example of Seasonal Influences (NO41334E1).

Groundwater Quality Trends

Trends were determined using the Mann-Kendall statistic with a 95% confidence level. Table 4 lists each well and its calculated trend. The wells were determined to either have an increasing trend, decreasing trend, or no distinguishable trend. Six percent of the wells displayed a decreasing trend. Fifty-four percent of the wells exhibited no distinguishable trend. Thirty-one percent of the wells displayed an increasing trend and 9% of the wells did not have sufficient data to determine trends or seasonality.

Table 4. Results of Trend Analysis for Individual Wells.

Increasing Trend	Decreasing Trend	No Distinguishable Trend	Insufficient Data to Determine Trend
NO39203Q1	NO39221H1	NO39211F1	NO39307N1
NO39317H1	NO40214P1	NO39212C1	NO39308F2
NO40222D1		NO39212K2	NO40307H1
NO40226D2		NO39215J1	
NO40305N3		NO39307H1	
NO40315L1		NO39307K2	
NO40316H1		NO40211P1	
NO40331P3		NO40221J5	
NO40332L1		NO40223A3	
NO40332M2		NO40226B1	
MW2		NO40227C1	
		NO40303B1	
		NO40308P1	
		NO40310F1	
		NO40331L1	
		NO41333M1	
		NO41334E1	
		MW1S	
		MW1D	

Figure 7 illustrates the trends in nitrate concentrations in the area over the duration of the study.

Figure 8 is an example of increasing nitrate concentrations in one of the wells. Figure 9 is an example of decreasing nitrate concentrations in one of the wells.

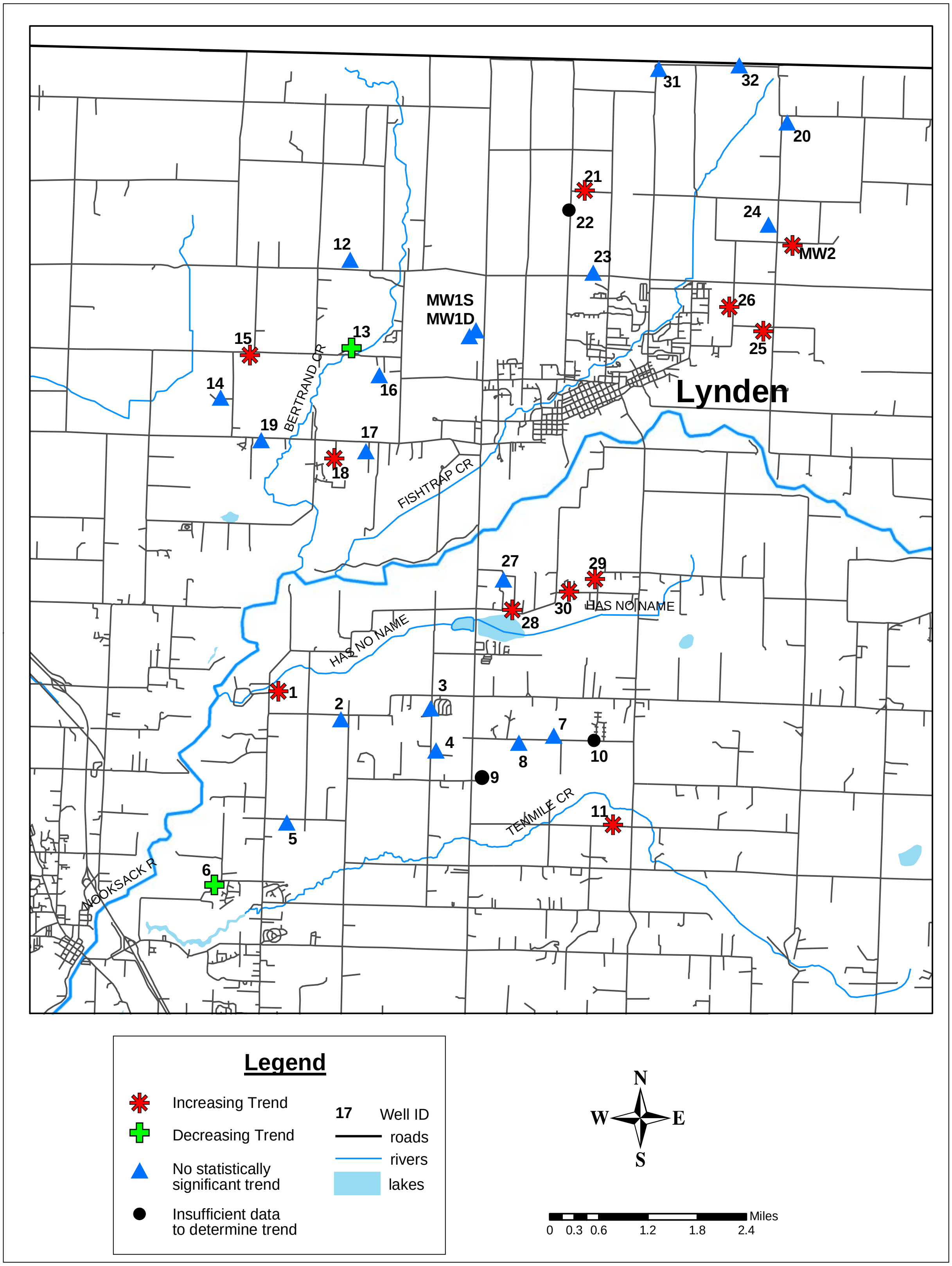

Figure 7. Nitrate Trends in Groundwater.

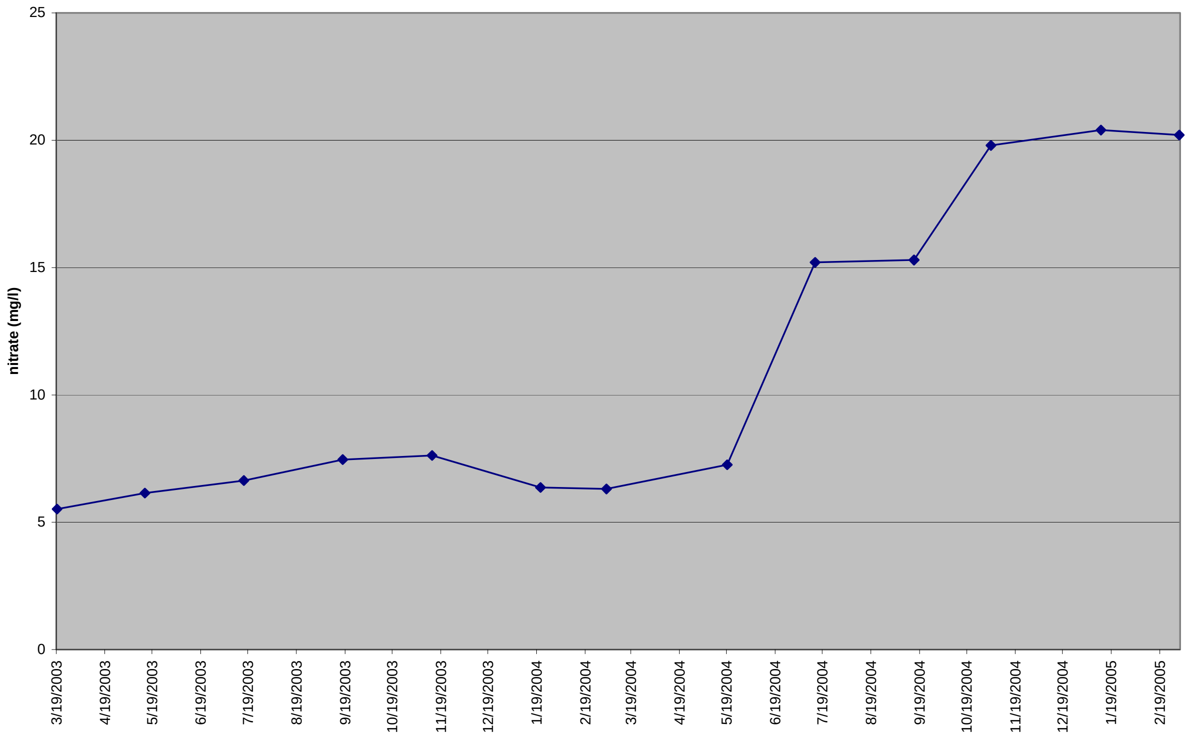

Figure 8. Example of Increasing Trend (Well NO40305N3).

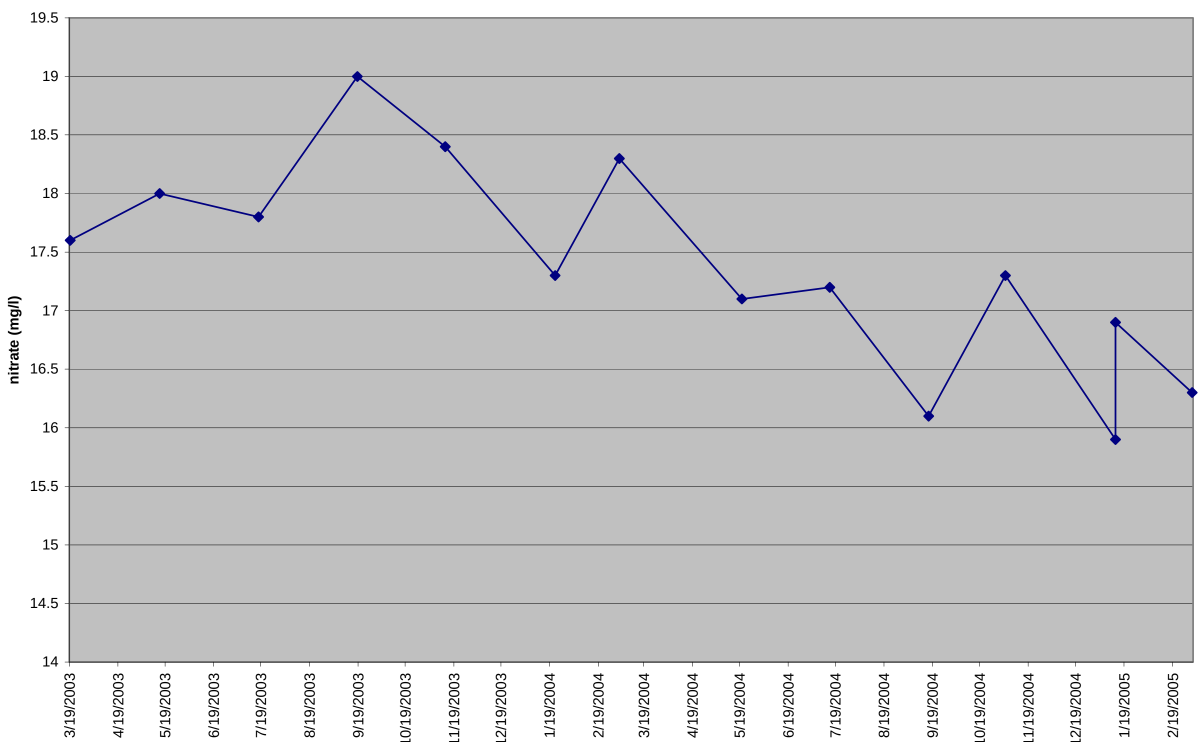

Figure 9. Example of Decreasing Trend (Well NO40214P1).

Correlations

Data were analyzed to determine if a correlation exists between groundwater nitrate concentrations, total persulfate nitrogen concentrations, dissolved oxygen, and well depth. There was no correlation with either well depth or dissolved oxygen content of the groundwater. The only correlation was between nitrate and total persulfate nitrogen. In January 2004 the R^2 coefficient was 0.9777, and in July 2004 the R^2 coefficient was 0.9352. This strong correlation is expected since nitrate is the predominant nitrogen species found in groundwater. This was also confirmed during this study. This indicates that organic nitrogen and ammonium nitrogen are converting to nitrate prior to reaching groundwater.

The lack of correlation between nitrate+nitrite-N concentration and well depth indicates that this contaminant (1) is pervasive throughout the aquifer and (2) has had the opportunity to disperse down to depths as great as 58 feet below land surface in concentrations above background water quality.

The lack of correlation between nitrate+nitrite-N or total persulfate nitrogen concentrations with dissolved oxygen is unanticipated. Cox (2005) describes an anoxic zone near streams which acts to denitrify groundwater. This is identified by low dissolved oxygen and low nitrate concentrations. Cox and Kahle (1999) also identify anoxic zones near naturally occurring peat deposits which also act to reduce nitrate concentrations.

During this study, this phenomenon was observed only at one dairy operation where dissolved oxygen levels were less than 1 mg/l and nitrate concentrations were close to analytical detection limits. The total persulfate nitrogen concentrations were close to the nitrate concentrations, indicating that the nitrogen is being converted to nitrate and denitrification is occurring.

Sub-Area Analysis

The Sumas-Blaine study area encompasses over 80 square miles. There are a variety of natural and anthropogenic factors impacting the area. The area is naturally divided by the Nooksack River and by the artificial boundary of Guide-Meridian Road. Dividing the area into quadrants is a tool to assist in identifying more localized factors affecting the nitrate concentrations in groundwater.

- The *southeast* quadrant is the area south of the Nooksack River and east of Guide-Meridian Road. This area is the most heavily impacted by nitrate in groundwater. Forty-four percent of the wells in this quadrant displayed an increasing nitrate trend after appropriately adjusting the values for seasonality. Forty-four percent of the wells consistently exceeded the nitrate standard of 10 mg/l for every sampling event. Seventy-eight percent of the wells have a mean nitrate concentration greater than the nitrate standard of 10 mg/l. This area also contains the well (NO39307H1) with the highest mean nitrate concentration of 33.76 mg/l.
- The *southwest* quadrant is the area south of the Nooksack River and west of Guide-Meridian Road. This area is where groundwater is the least impacted by nitrate. Sixty-seven percent of the wells were consistently below the nitrate standard of 10 mg/l for every sample taken.

One-hundred percent of the wells have a mean nitrate concentration below the nitrate standard of 10 mg/l.

- The *northeast* quadrant is the area north of the Nooksack River and east of Guide-Meridian Road. Forty percent of the wells display an increasing nitrate trend in groundwater. Fifty percent of the wells display a seasonal nitrate trend. Ninety percent of the wells have mean nitrate concentrations greater than the nitrate standard of 10 mg/l.
- The *northwest* quadrant is located north of the Nooksack River and west of Guide-Meridian Road. Ten percent of the wells display a decreasing nitrate trend. Forty percent of the wells have nitrate concentrations consistently below the nitrate standard of 10 mg/l for every sampling event. Sixty percent of the wells have a mean nitrate concentration below 10 mg/l. However, well NO40226D2 had the highest nitrate concentration recorded at (43.1 mg/l) during the project.

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Conclusions

Groundwater Quality Nitrate Trends

This study establishes a baseline for determining groundwater quality trends. Based on the combined average monthly values for the entire study area, nitrate concentrations are increasing in the Sumas-Blaine aquifer at a rate of 0.46 mg/l per year. Figure 10 illustrates the graphical trend of increasing nitrate concentrations in the aquifer. This rate increases to 0.825 mg/l per year if the trend line in Figure 10 is used.

Overall there is an increasing nitrate trend in groundwater which may be due to one or more of the following circumstances:

- A reservoir of excess organic nitrogen exists in the soil column which has developed over time and is still leaching into groundwater. This reservoir develops due to the lag time between the times when nitrogen is applied to the soil, nitrification occurs, and nitrate is transported to groundwater. This lag time is dependent on the application rate, the plant uptake, the nitrification rate, the redox potential, precipitation, the hydrostratigraphic conditions, and the depth to groundwater. This rate can vary temporally and spatially.

- Other sources of nitrogen are in the area. Many of these sources are not as heavily regulated as the dairy industry. These sources include irrigated agriculture of other crops, including raspberries and blueberries, on-site sewage systems, and home fertilizer use.

- Background nitrate concentrations in groundwater are already elevated as water flows south across the Canadian border. British Columbia (B.C.), Canada has a high concentration of poultry farms, raspberry fields, and dairies. All of these activities result in large inputs of nitrogen into the soils. The B.C. Ministry of Agriculture and Food acknowledges that the combination of agricultural activities is a significant contributor to the high nitrate concentrations in the surficial aquifer (Hughes-Games and Zebarth, 1999). This combination of high nitrogen inputs into the environment in B.C. and in Whatcom County makes it difficult to discern the sources of nitrate in groundwater.

An increasing nitrate trend in groundwater quality has been noted in other studies as well. In 1999, Cox and Kahle noted an increasing nitrate trend in groundwater. In 2000, Erickson noted that nitrate concentrations continue to remain elevated. In 2005, Mitchell et al., noted an increasing trend in nitrate concentrations in the northern portion of the aquifer. Historical springtime mean nitrate concentrations are plotted in Figure 11. Based on this combined data, plotted in Figure 11, nitrate is increasing in the aquifer at a rate of 0.30 mg/l per year.

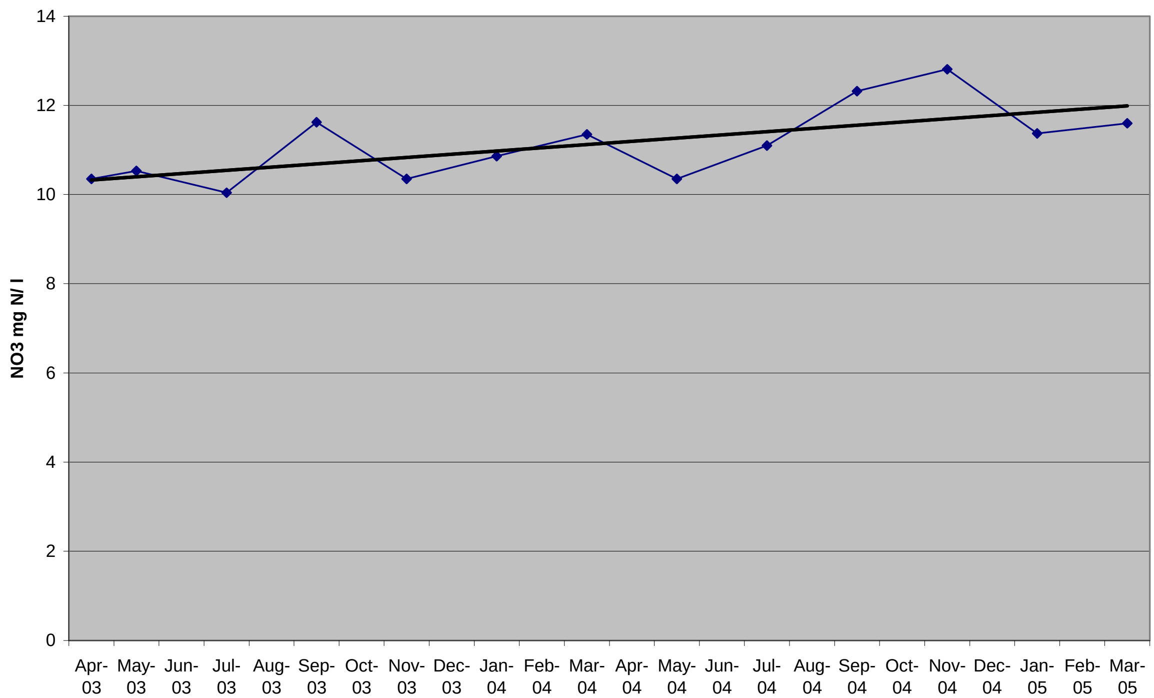

Figure 10. Mean Area Nitrate Trend in the Sumas-Blaine Surficial Aquifer.

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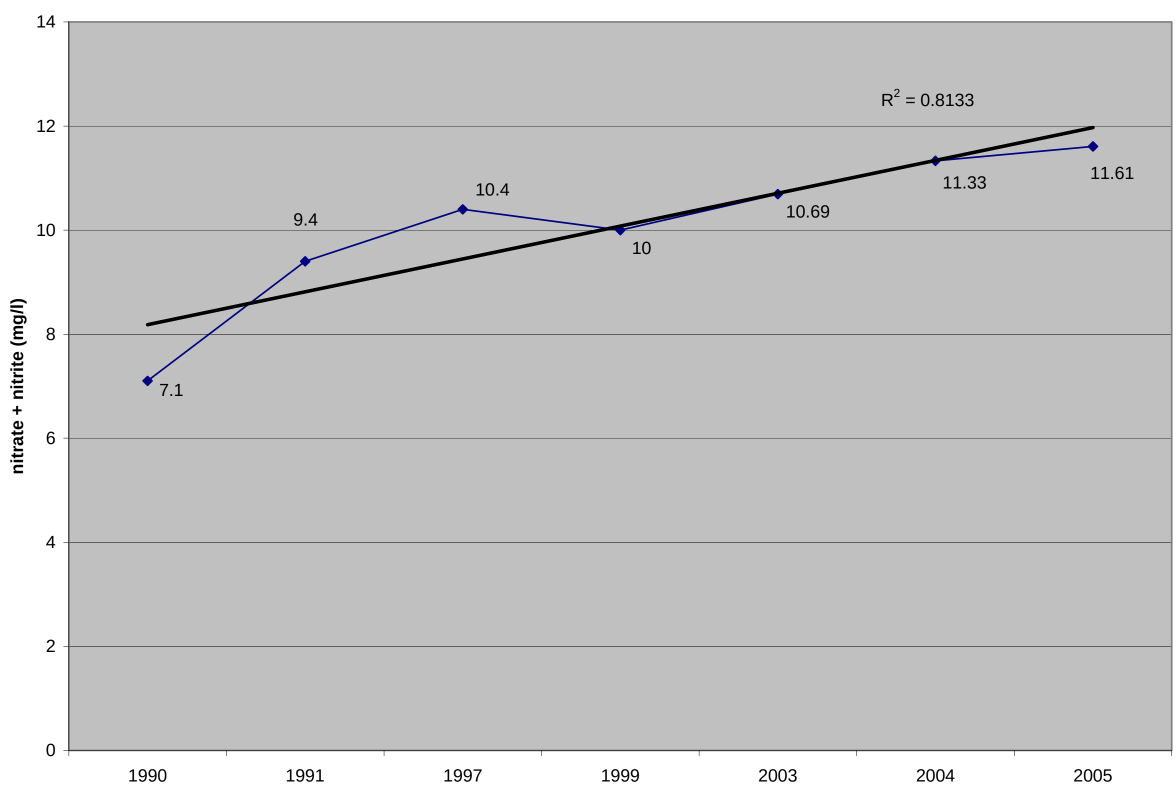

Figure 11. Historical Mean Nitrate Concentrations in Groundwater in the Spring. (Erickson and Norton, 1990; Garland and Erickson, 1994; Erickson, 1998, 2000).

Figure 12 compares the nitrate concentrations with those measured in March 1997 to the mean study results for individual wells. Thirty-one of the wells sampled during this 2003-05 study were sampled during Erickson's 1997 study (Erickson, 1998). Fifty-eight percent of the wells have greater nitrate concentrations in 2005 than in 1997. This is not sufficient information alone to determine trends; however, it supports the conclusions from this 2003-05 study, that nitrate concentrations appear to be increasing in groundwater.

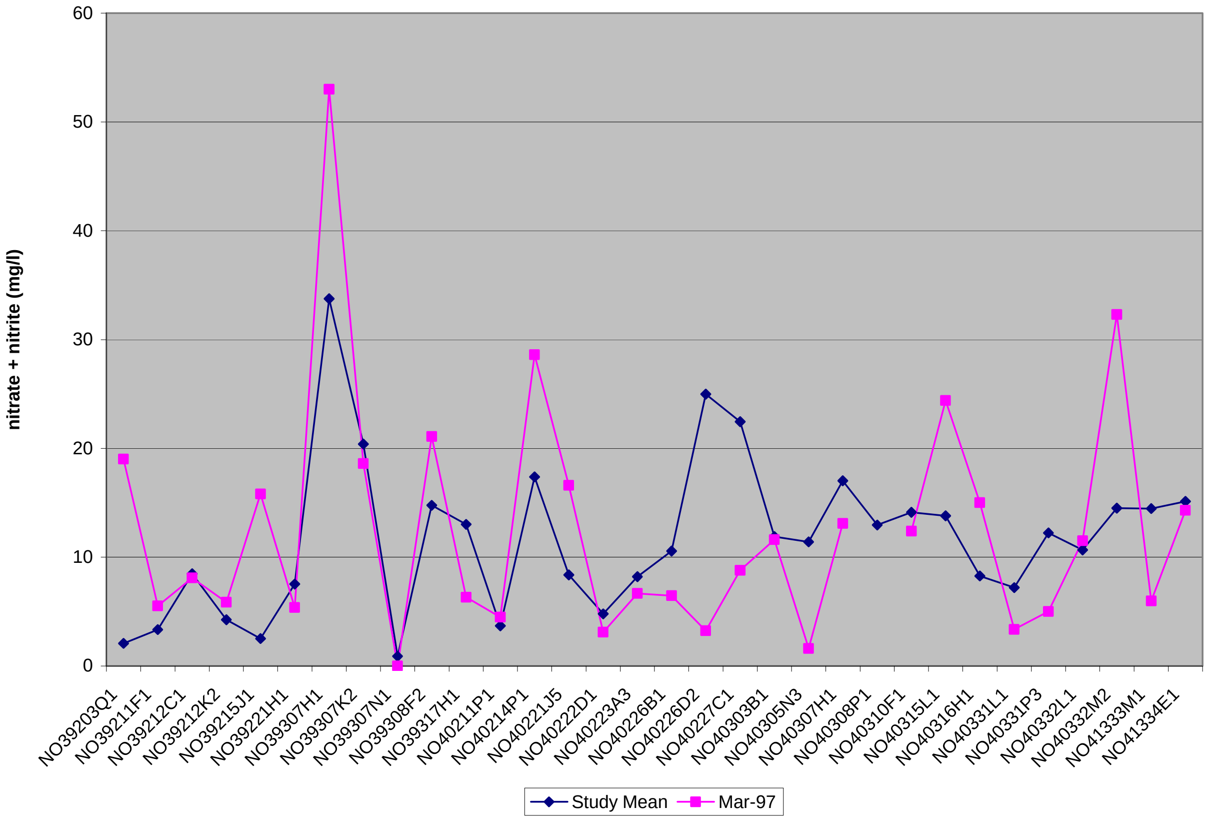

Figure 12. Comparison of 1997 Nitrate Values with 2003-05 Study Nitrate Mean Values. (Erickson, 1998).

Seasonal Groundwater Variations

Seasonality for nitrate was observed in wells in many areas within the Sumas-Blaine aquifer. Thirty-four percent of the wells displayed a seasonal influence. Determining seasonal variations is essential when establishing a groundwater monitoring network, since monitoring on an annual basis does not reflect the natural fluctuations that occur within each well.

Influence of Dairy Practices on Groundwater Quality

Elevated nitrate concentrations in groundwater have traditionally been attributed to the strong agricultural influence over the central Sumas-Blaine aquifer. It was theorized that with the implementation of the Dairy Nutrient Management Act that groundwater nitrate concentrations would decline. Unfortunately, this 2003-05 study was not designed to specifically address this issue; and therefore, conclusions about the effectiveness of the dairy program cannot be correlated to the results of this study.

Conclusions about agricultural influences cannot be drawn from this study for several reasons:

- Only three monitoring wells were included in this study, and these were not strategically located upgradient and downgradient of dairy operations. These wells were not adequate to assess improvements in water quality from a specific source.
- The remaining 32 wells were private domestic wells, which are typically screened deeper within the aquifer, so they are not well suited to monitoring changes to water quality from a specific source. Domestic wells for monitoring during this study were not selected based on their proximity to dairy or raspberry operations.
- There are multiple sources of nitrogen in this area. Raspberries have become a predominant crop in Whatcom County, yet nutrient management plans are not required for this land use. The effect of raspberries on groundwater quality is unknown.
- Land use has changed over time. Trying to correlate existing groundwater quality with existing land use or historic land use is difficult without an extensive inventory. This was beyond the scope of this study; therefore, no conclusions can be drawn about specific sources of nitrate contamination.

These compounding factors make it difficult to observe whether improvements in farming practices translate to improvements in groundwater quality. Unfortunately improvements in the diary industry’s nutrient management alone have not resulted in improvements to groundwater quality, based on the broad-scale monitoring network used in this study. Better management of all nutrient sources may be necessary to achieve improved groundwater quality.

Recommendations

Nitrate concentrations in groundwater are continuing to increase in the Sumas-Blaine aquifer, the most contaminated aquifer in Washington State.

To improve groundwater quality, the challenge remains to identify long-term groundwater quality trends, delineate sources, quantify contaminant loading to the aquifer, and ultimately to better manage nitrogen holistically over the aquifer.

As a result of this study, the following recommendations are made:

- Ideally, the full suite of 35 wells monitored in this study should be continually monitored on a yearly basis.

- If this is not possible, a subset of the wells in this study should be monitored annually or every other year to assess long-term trends. Wells should be sampled every year during the same months. Assuming the well owner would be willing to participate, Table 5 lists the rationale for the recommended wells.

  Table 5. Proposed Long-term Groundwater Monitoring Network.

Well ID	Quadrant	Trend	Nitrate Condition
NO39307H1	SE	No trend	> 10 mg/l mean nitrate, highest mean concentration
NO40305N3	NE	Increasing trend	> 10 mg/l mean nitrate
NO40214P1	NW	Decreasing trend	> 10 mg/l mean nitrate
NO40226D2	NW	Increasing trend	Highest single nitrate concentration
NO40211P1	NW	No trend	< 5 mg/l mean nitrate concentration
NO39203Q1	SW	Increasing trend	< 5 mg/l mean nitrate concentration
NO39221H1	SW	Decreasing trend	5 - 10 mg/l mean nitrate concentration

  March and November are the recommended months for continued biannual sampling. March is after the growing season and at the end of the rainy season, so much of the nitrate in the soils should have migrated to groundwater. November appears to be when groundwater is the most vulnerable to nitrate contamination. It is after the growing season and at the beginning of the rainy season. Excess nitrogen which has been stored in the soil column will percolate to groundwater as the rainfall increases. Cox and Kahle (1999) also identify winter and early spring as the time of peak nitrate concentrations. This was confirmed by the data collected in this study.

- Work cooperatively with Environment Canada and other counterparts in governments and research agencies to coordinate data collection and analysis as well as future groundwater monitoring efforts and to develop long-term management goals.

- Correlate land use with agronomic loading and the spatial distribution of manure and fertilizers. This information can be used to more definitively determine the sources of nitrogen in groundwater. The premise of this study was that nitrate concentrations in groundwater would show evidence of improvements based on the recent improvements to the dairy operations in Whatcom County. However, there are nitrogen sources other than dairies that complicate a broad-scale analysis which should also be addressed in this area to make sure that holistically there is less nitrogen loading to the aquifer.

- Monitor soils to determine if excessive nitrogen is present.

- Other nitrogen sources should be assessed to determine the load to the aquifer. A basin wide nitrogen mass balance study should be conducted to evaluate all nitrogen sources which need to be better managed.

- The contribution of nitrogen to groundwater from raspberry and blueberry production should be assessed.

- Use the aquifer as a natural chronological documentation of historic water quality. Groundwater that has entered the aquifer over time is stratified at different depths. By using a combination of age-dating and contaminant concentration measurements, a history of concentrations can be established over time.

- Adopt a long-term view of groundwater remediation and protection. Groundwater moves slowly; therefore, documented improvements may take many years.

- Implement watershed improvements including:
  - Reducing the amount of fertilizers/manure applied to the land surface.
  - Evaluating the timing of the fertilizer application and irrigation.
  - Reusing groundwater with elevated nitrate concentrations as a fertilizer source.
  - Adopting fertilizer management plans for all agricultural activities.

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Appendices

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Appendix A: Individual Well Information

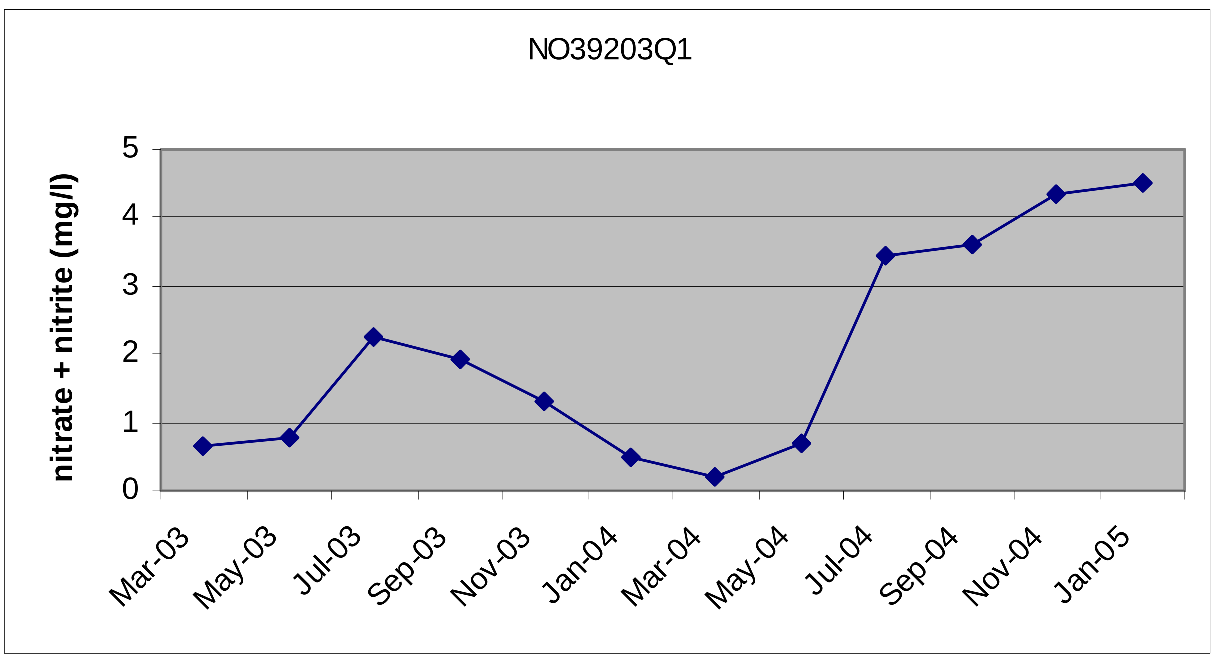
NO39203Q1

Well NO39203Q1 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows northwest towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as pasture land.

The well is a private domestic well which has a 6-inch diameter casing and is 31 feet deep. Nitrate concentrations in the well range from 0.19 and 4.51 mg/l, with a mean of 2.08 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of anoxic conditions is probably based on the low dissolved oxygen values and the presence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



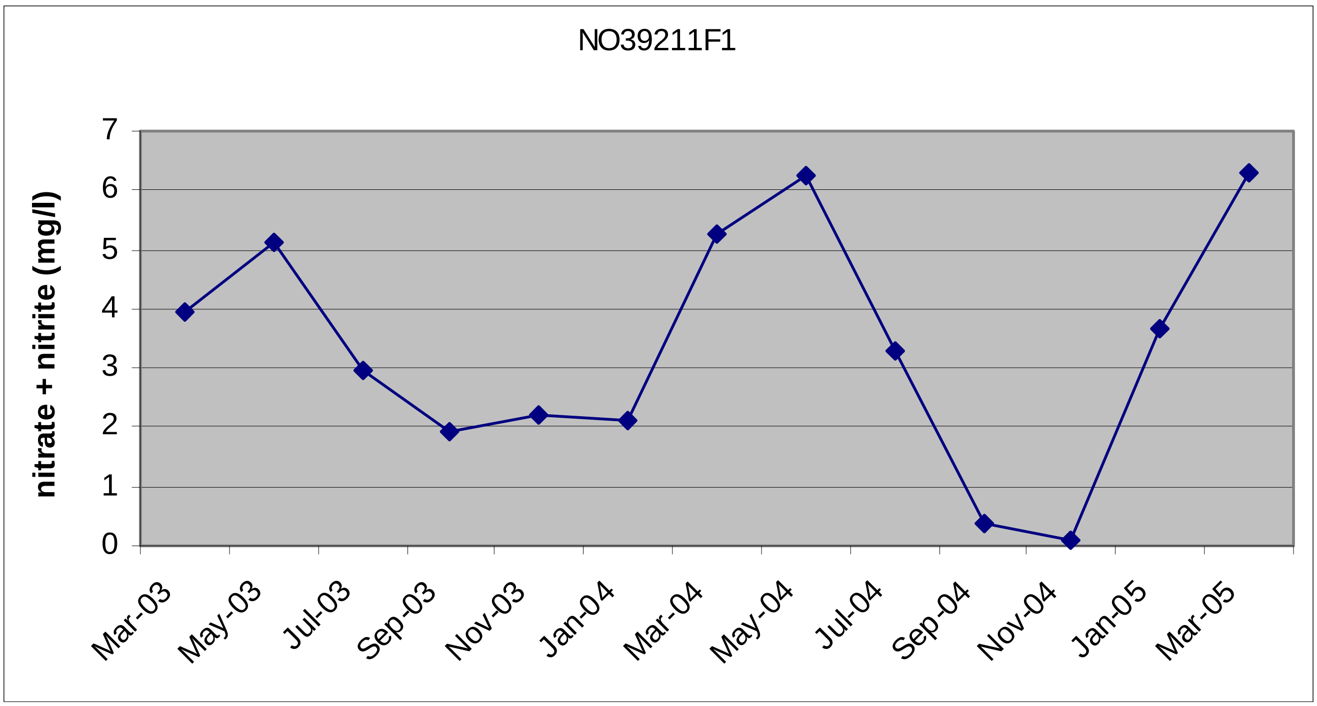
NO39211F1

Well NO39211F1 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows north-northwest towards the Nooksack River. The well has raspberry fields located upgradient of the well. In 1997 the upgradient land use included a tree farm and strawberries. The wellhead is located adjacent to a gravel driveway where trucks are typically washed.

The well is an irrigation well which has a 36-inch diameter casing and is 30 feet deep. Nitrate concentrations in the well range from 0.11 and 6.31 mg/l with a mean of 3.34 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trend.

The presence of anoxic conditions may be present on a seasonal basis. Low dissolved oxygen values, less than 1 mg/l, were detected between May and November, 2004. The presence of ferrous iron was also detected. Total nitrogen tests were conducted on water samples from this well on six occasions. These tests indicate the majority of nitrogen is present in groundwater in the form of nitrate.



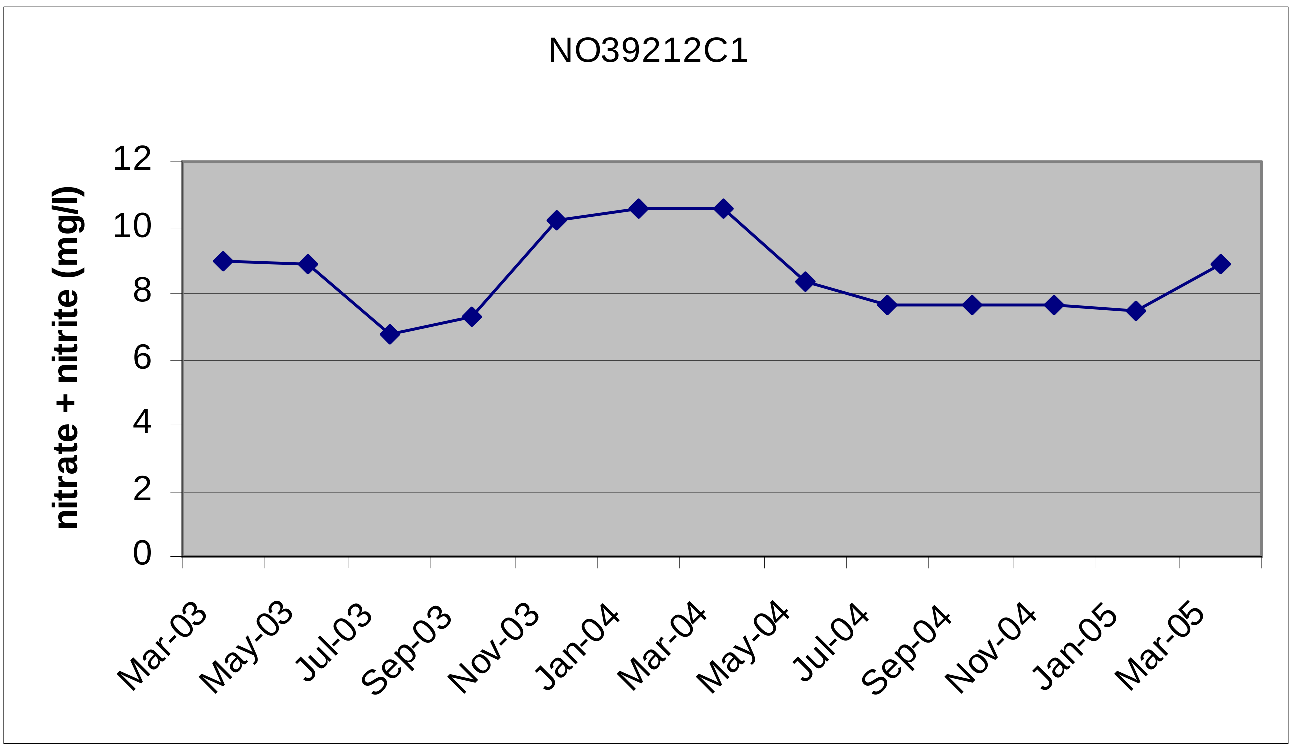
NO39212C1

Well NO39212C1 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows northwest towards the Nooksack River. The well is located in a rural residential area, although the wellhouse is located in a small horse pasture.

The well is a private well which is used for domestic and commercial purposes. The well has a 36-inch diameter casing and is 32 feet deep. Nitrate concentrations in the well range from 6.75 and 10.6 mg/l with a mean of 8.47 mg/l. The nitrate standard of 10 mg/l was exceeded 21% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trend.

The groundwater conditions appear to be oxic based on the lack of ferrous iron and the elevated dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



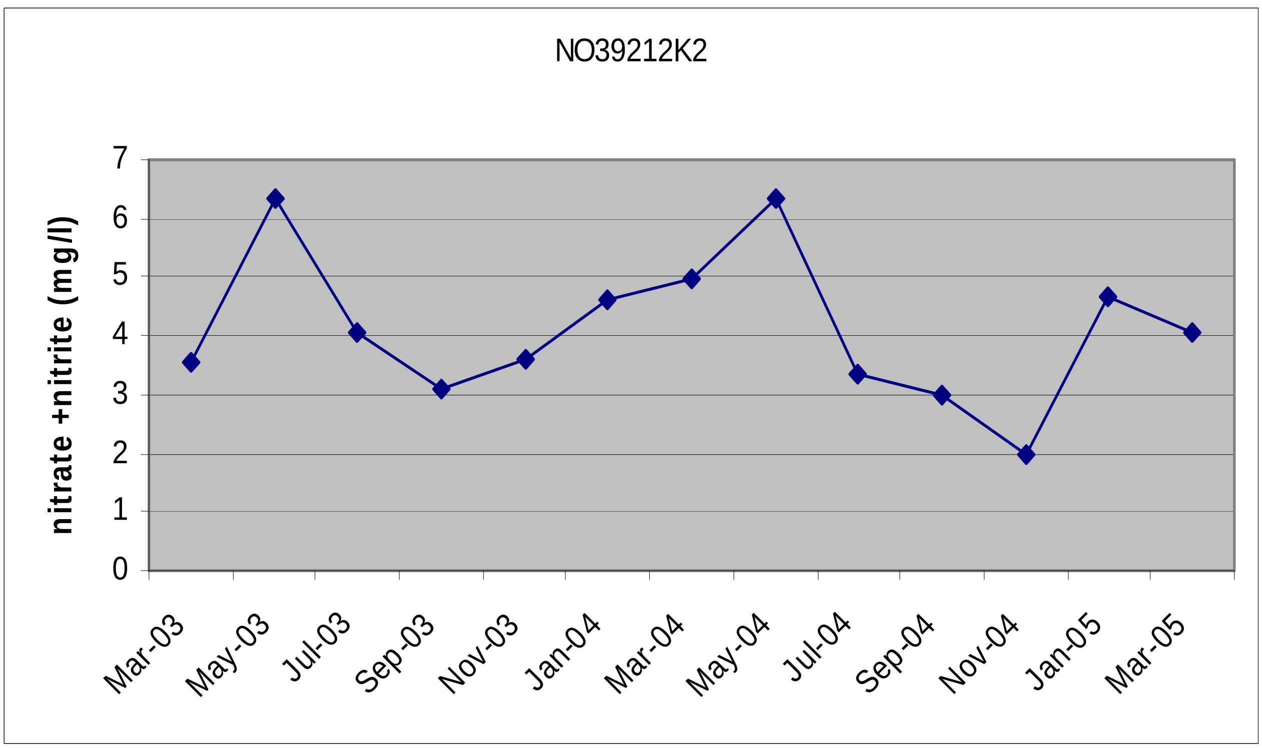
NO39212K2

Well NO39212K2 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows to the west and south towards the Nooksack River. The well is located in a rural residential area with nearby pastures.

The well is a private domestic well, which has a 12-inch diameter casing and is 20 feet deep. Nitrate concentrations in the well range from 2 and 6.55 mg/l with a mean of 4.24 mg/l. There were no exceedances of the nitrate standard during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trend.

The groundwater conditions appear to be oxic based on the lack of ferrous iron and the elevated dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



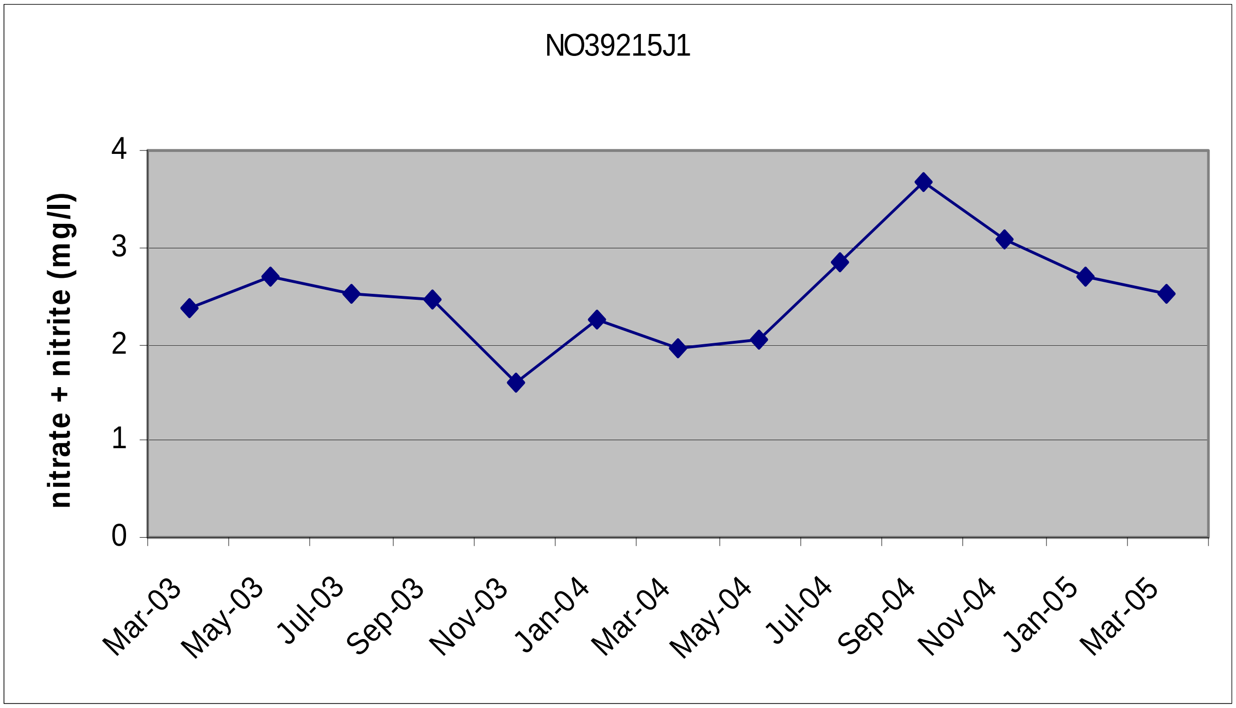
NO39215J1

Well NO39215J1 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows southwest towards the Nooksack River. The well is located adjacent to a pasture, and raspberry fields are located upgradient of the well. The land use today is similar to the land use in 1997.

The well is a private domestic well, which has an 18-inch diameter casing tapering down to a 12-inch diameter opening and is 21 feet deep. Nitrate concentrations in the well range from 1.6 and 3.67 mg/l with a mean of 2.52 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trend.

The groundwater conditions appear to be oxic based on the lack of ferrous iron and the elevated dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



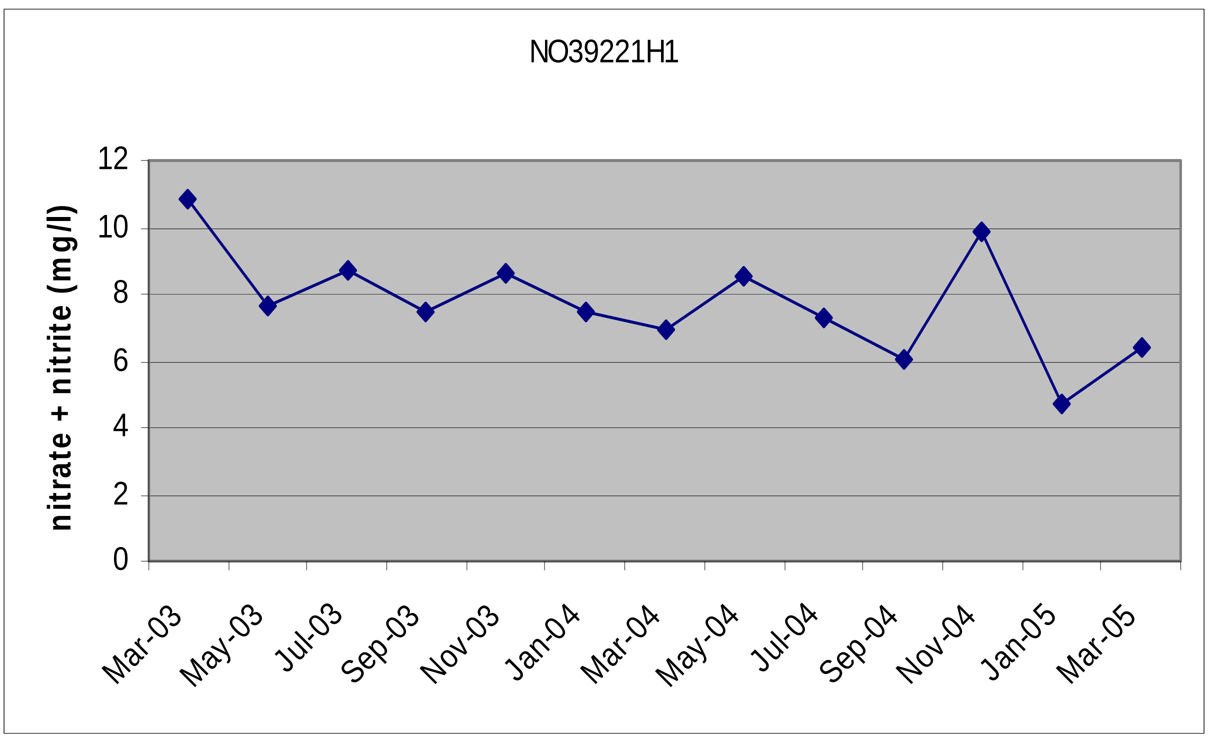
NO39221H1

Well NO392221H1 is located in the southwest quadrant of the study area. Groundwater in the immediate area flows west towards the Nooksack River. The well is located in a rural residential wooded area. The current land use is similar to the land use described in 1997. A large load of manure was received by a neighbor during November 2003 and was stored upgradient of the well.

The well is a private domestic well which has a 12-inch diameter casing and is 27 feet deep. Nitrate concentrations in the well range from 2.87 and 10.8 mg/l with a mean of 7.53 mg/l. The nitrate standard of 10 mg/l was exceeded 7% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit a decreasing trend.

The groundwater conditions appear to be oxic based on the lack of ferrous iron and the elevated dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



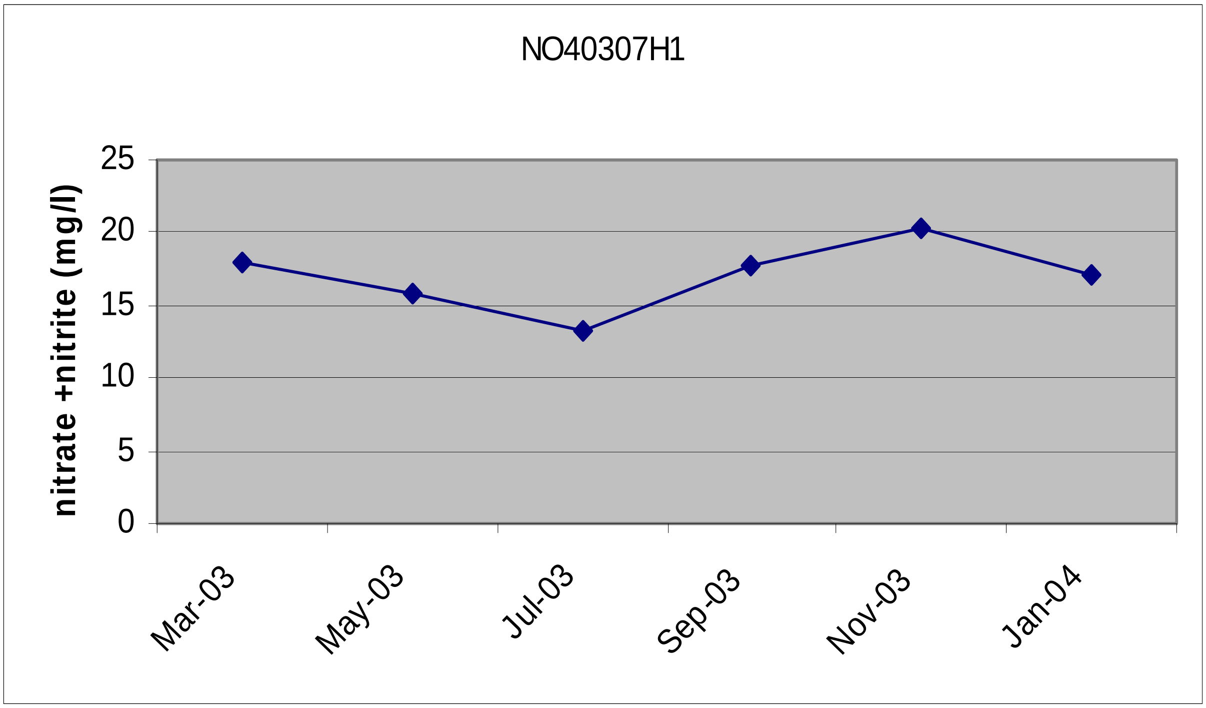
NO39307H1

Well NO39307H1 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows west-southwest towards the Nooksack River. The well is 100 feet downgradient of raspberry fields, which have been there since at least 1997. There is an old abandoned dairy barn directly east of the well.

The well is a private domestic well which has a 6-inch diameter casing and is 29 feet deep. Nitrate concentrations in the well range from 31.8 and 37.4 mg/l. This well had the highest mean of 33.76 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trend.

The groundwater conditions appear to be oxic based on the lack of ferrous iron and the elevated dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



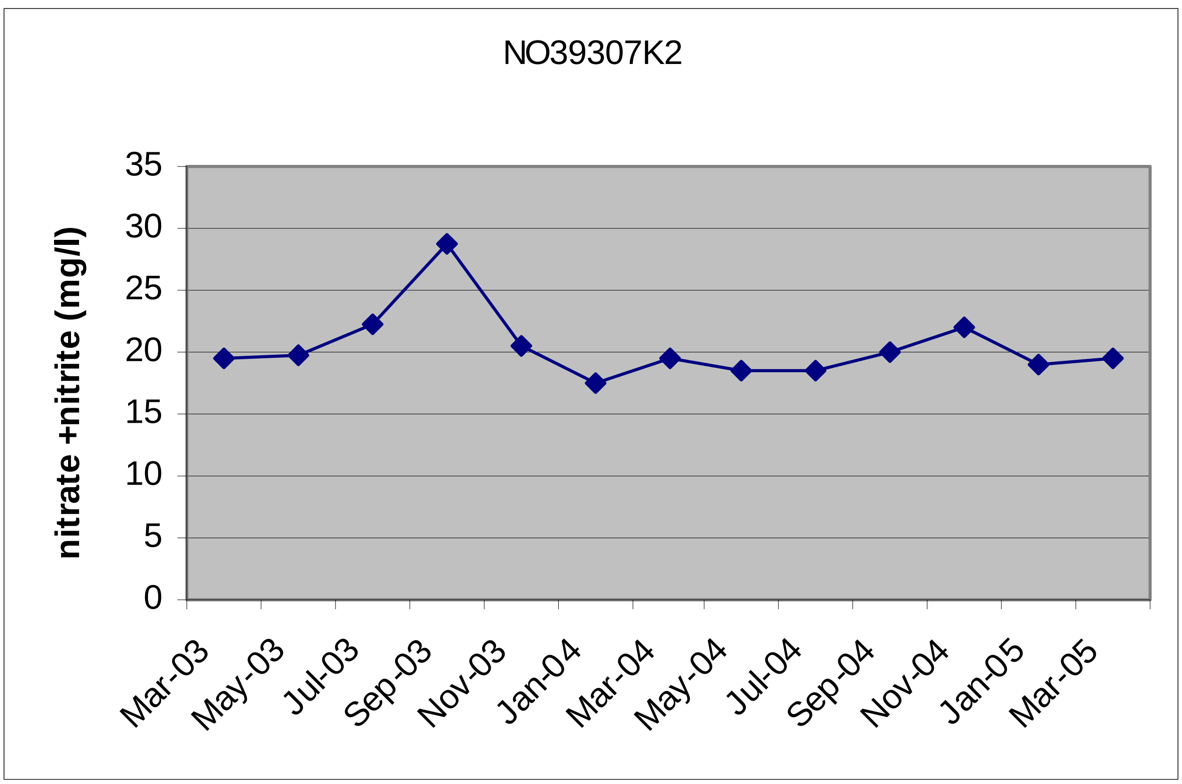
NO39307K2

Well NO39307K2 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows west and south. The well has raspberry fields located upgradient of the well, and there is a corn field to the east. In 1997 there was a dairy and raspberry fields upgradient of the well.

The well is a private domestic well which has a 36-inch diameter casing and is 24 feet deep. Nitrate concentrations in the well range from 17.6 and 28.7 mg/l, with a mean of 20.4 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trends.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.

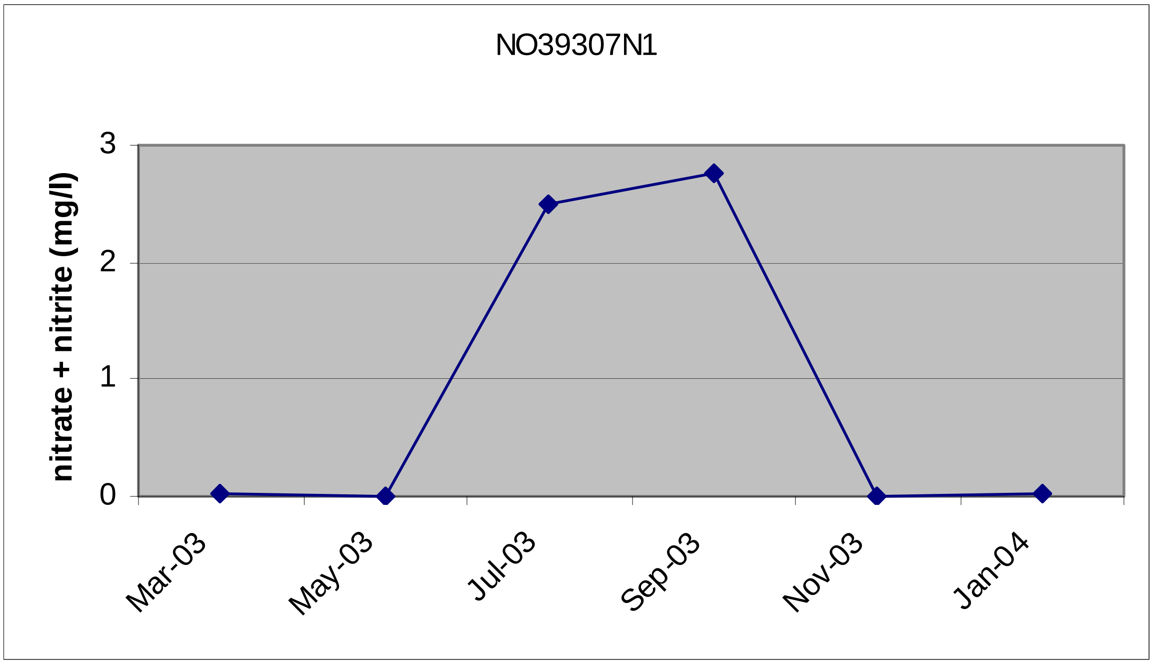


NO39307N1

Well NO39307N1 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows south. The well has pasture lands located adjacent to the well. In 1997 there was a dairy located upgradient of the well.

The well is a private domestic well which is 30 feet deep. The well has a treatment system which was manually turned off prior to collecting the sample. Nitrate concentrations in the well range from 0.01 and 2.77 mg/l, with a mean of 0.89 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

Data were only collected for one year, which is an insufficient amount of time to determine if seasonal variations or trends exist.

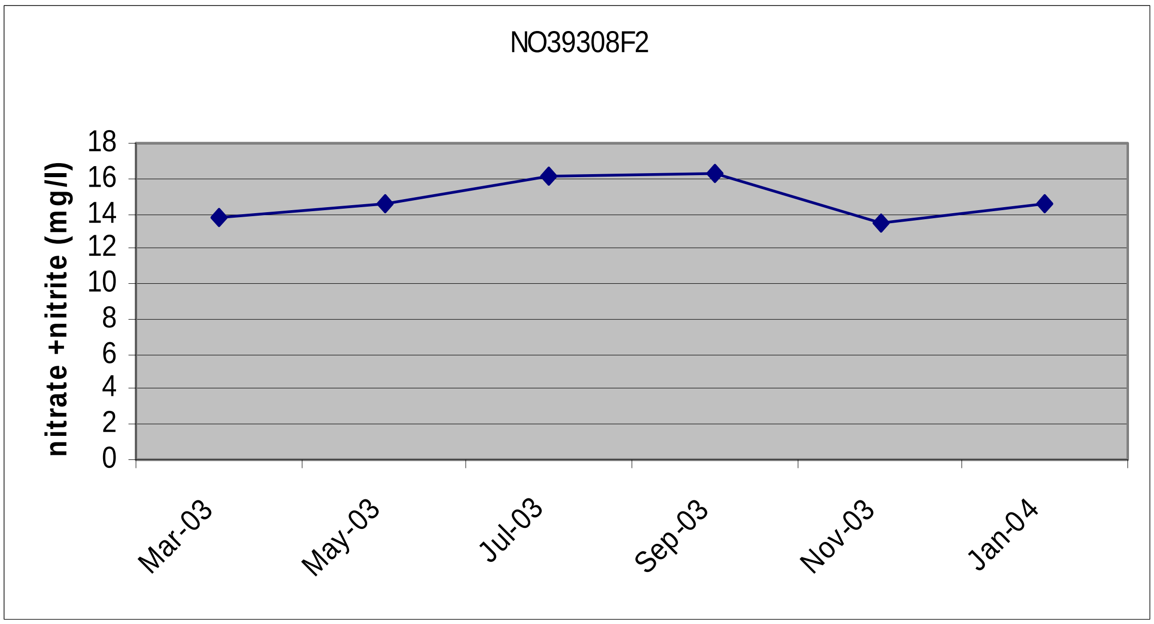


NO39308F2

Well NO39308F2 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows west. The well is located in a residential area near a golf course, and there are raspberry fields to the west of the well. In 1997 the upgradient land use included raspberry fields and a dairy operation.

The well is a private domestic well which has a 12-inch diameter casing and is 20 feet deep. Nitrate concentrations in the well range from 13.4 and 16.3 mg/l, with a mean of 14.77 mg/l. There nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

Data were collected for only one year, which is an insufficient amount of time to determine if seasonal variations or trends exist.



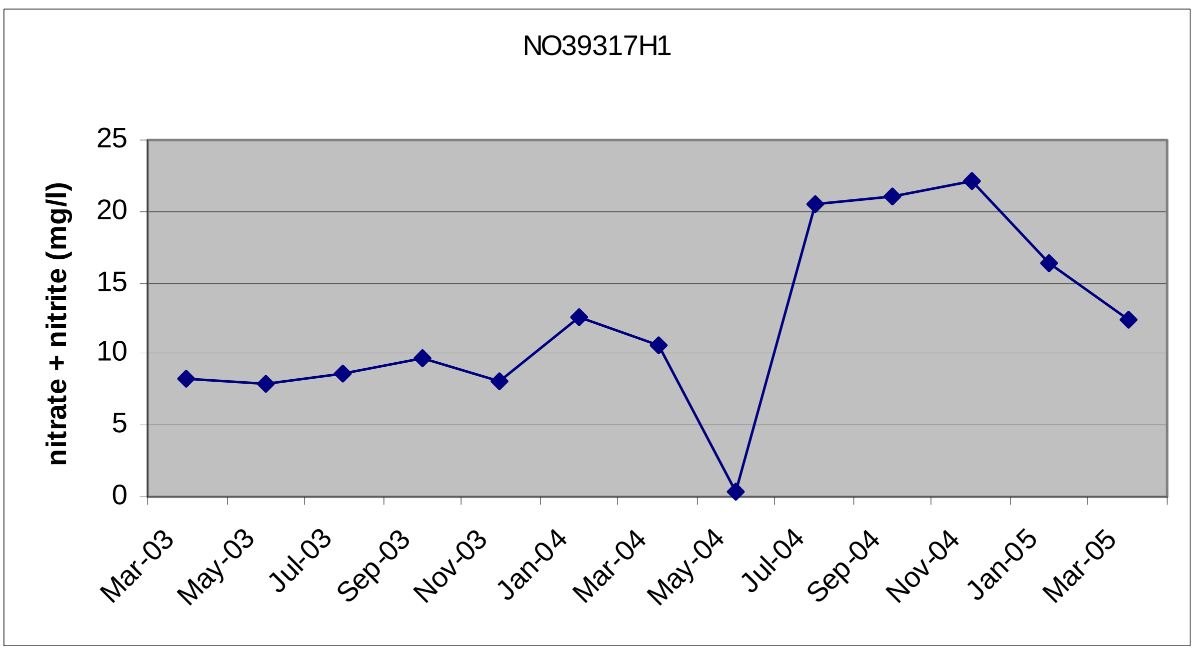
NO39317H1

Well NO39317H1 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows north-northeast. The well has a school and dairy pasture land located adjacent and upgradient of the well. In 1997 the upgradient land use was similar to today's land use.

The well is a private domestic well which has an 18-inch diameter casing. Nitrate concentrations in the well range from 0.28 and 22.1 mg/l, with a mean of 13.01 mg/l. The nitrate standard of 10 mg/l was exceeded 56% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of anoxic conditions is probably based on the low dissolved oxygen values and the presence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



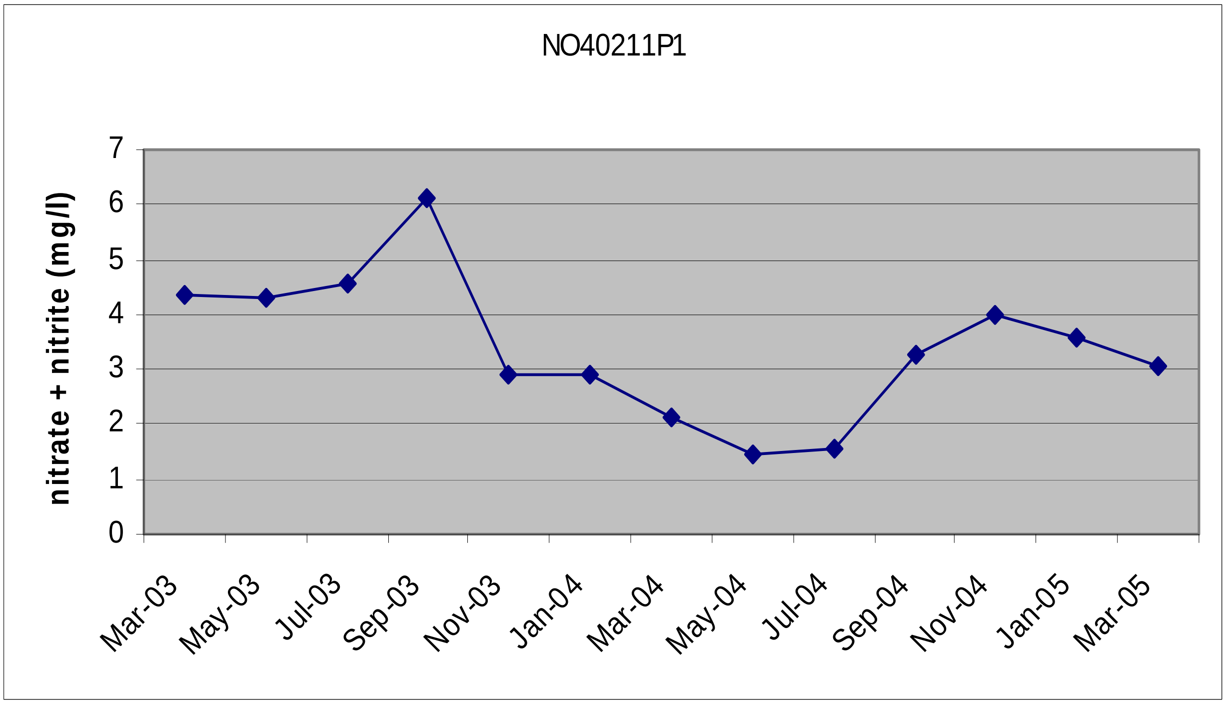
NO40211P1

Well NO40211P1 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south-southeast towards Bertrand Creek. The well is located on a dairy adjacent to a lagoon and pasture land. The land use was similar in 1997. In March 2003 the fields were injected with dairy manure.

The well is a private stock watering well which has a 36-inch diameter casing and is 31 feet deep. Nitrate concentrations in the well range from 1.43 and 6.47 mg/l, with a mean of 3.69 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.

The presence of anoxic conditions is probably based on the low dissolved oxygen values and the presence of ferrous iron in groundwater. The water is typically reddish brown and would not clear prior to sampling. Total nitrogen tests conducted on two occasions indicate approximately 50% of the nitrogen is present in groundwater in the form of nitrate.



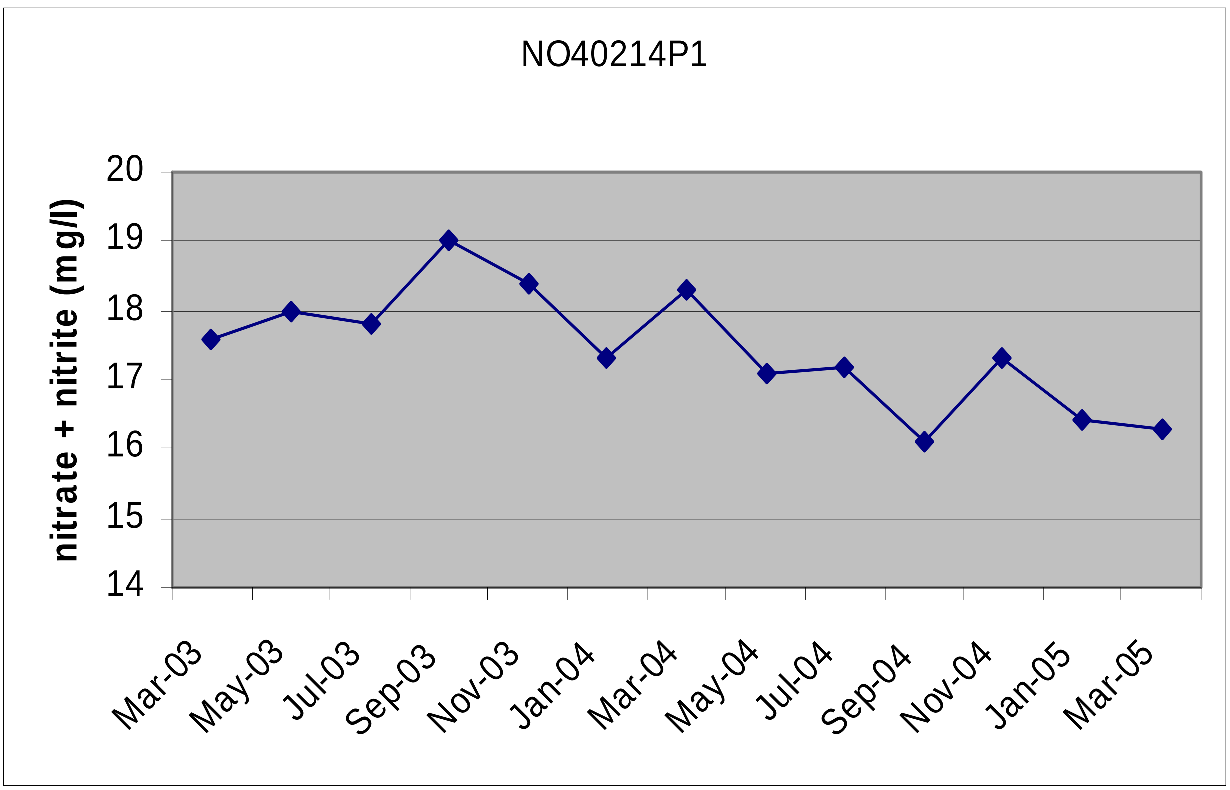
NO40214P1

Well NO40214P1 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south towards Bertrand Creek. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the land use was similar to current land uses.

The well is a private domestic well which has a 36-inch diameter casing and is 43.1 feet deep. Nitrate concentrations in the well range from 15.9 and 19 mg/l, with a mean of 17.37 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit a decreasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



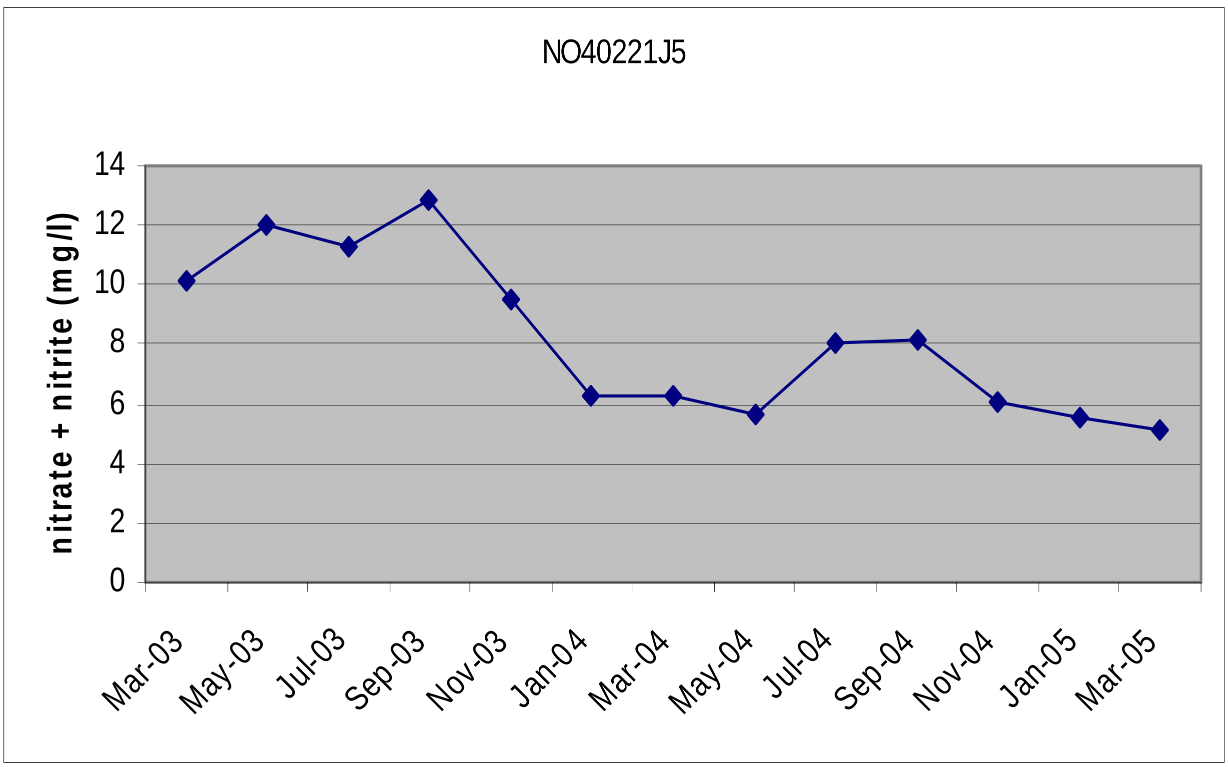
NO40221J5

Well NO40221J5 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was also documented as raspberry fields.

The well is a private domestic well which has an 18-inch diameter casing and is 17 feet deep. Nitrate concentrations in the well range from 5.13 and 12.8 mg/l, with a mean of 8.36 mg/l. The nitrate standard of 10 mg/l was exceeded 29% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



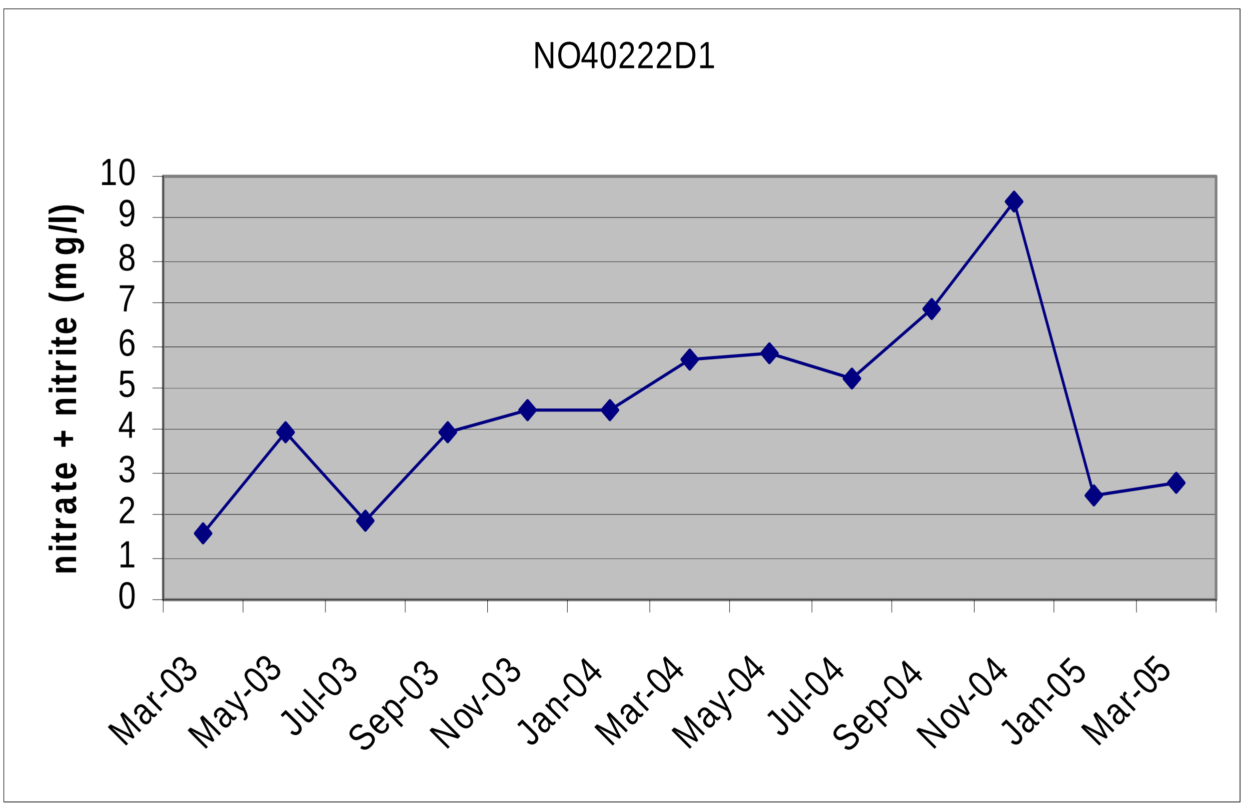
NO40222D1

Well NO40222D1 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south towards the Nooksack River. The well has corn fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as pasture land.

The well is a community water supply well which has an 18-inch diameter casing. Nitrate concentrations in the well range from 1.6 and 9.77 mg/l, with a mean of 4.78 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



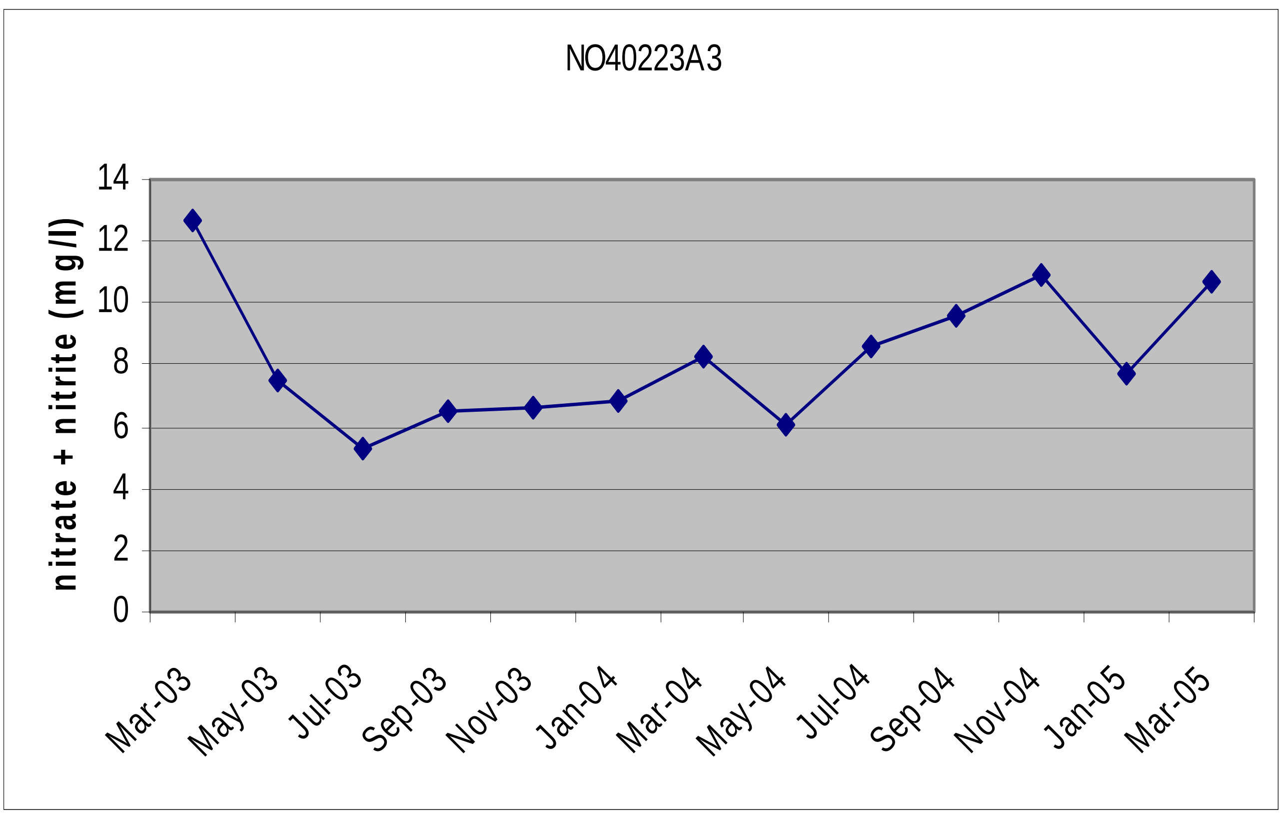
NO40223A3

Well NO40223A3 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south-southwest towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as strawberry fields.

The well is a private domestic well which is only used for irrigation. The well has a 6-inch diameter casing and is 23 feet deep. Nitrate concentrations in the well range from 5.25 and 12.7 mg/l, with a mean of 8.2 mg/l. The nitrate standard of 10 mg/l was exceeded 21% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trends.

The presence of anoxic conditions is possibly based on the presence of ferrous iron in groundwater. Orange water was purged from the well on several occasions. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



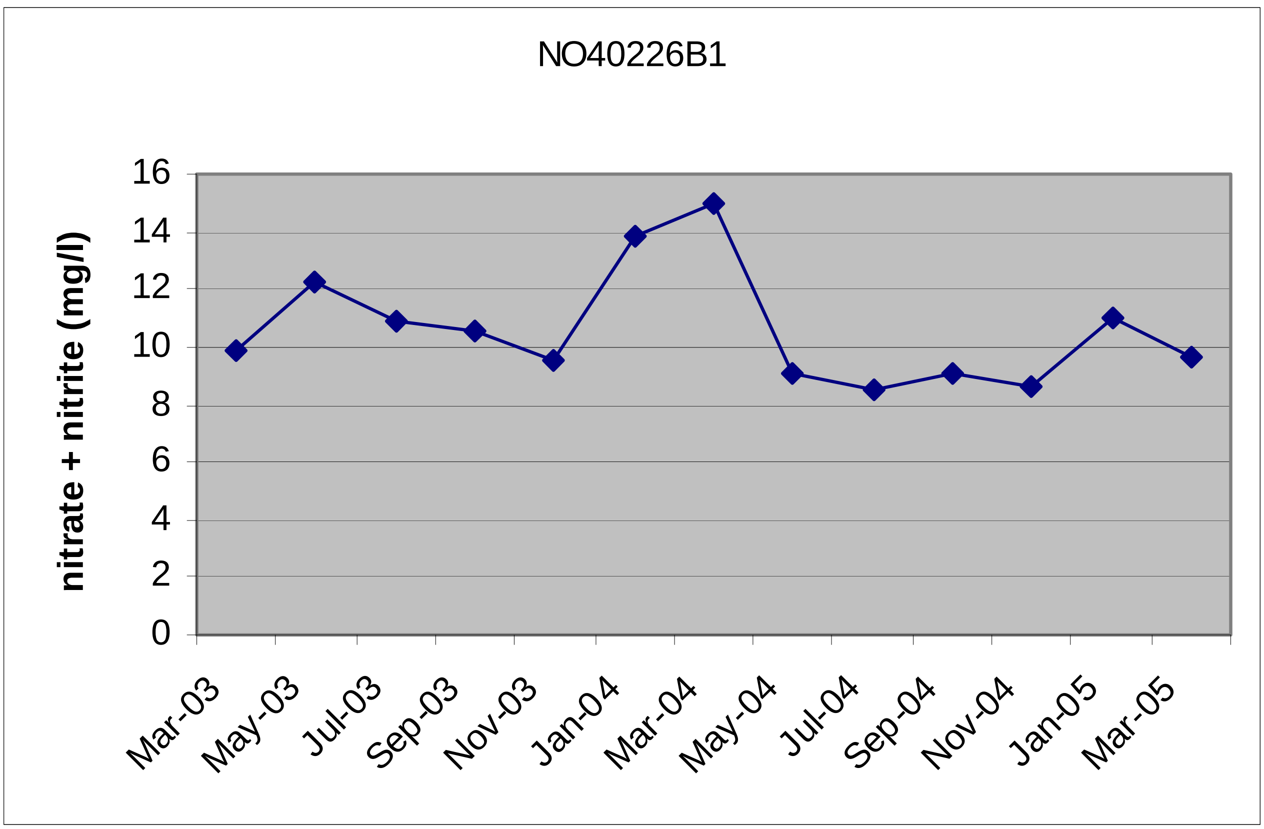
NO40226B1

Well NO40226B1 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows southeast towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as raspberry fields and pasture land. In July 2003 new raspberries were planted in the fields south of the well, and eight inches of manure was applied. During the first year of growth, manure was applied three times.

The well is a private domestic well which has a 6-inch diameter casing and is 23 feet deep. Nitrate concentrations in the well range from 8.54 and 15 mg/l, with a mean of 10.56 mg/l. The nitrate standard of 10 mg/l was exceeded 50% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trends.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



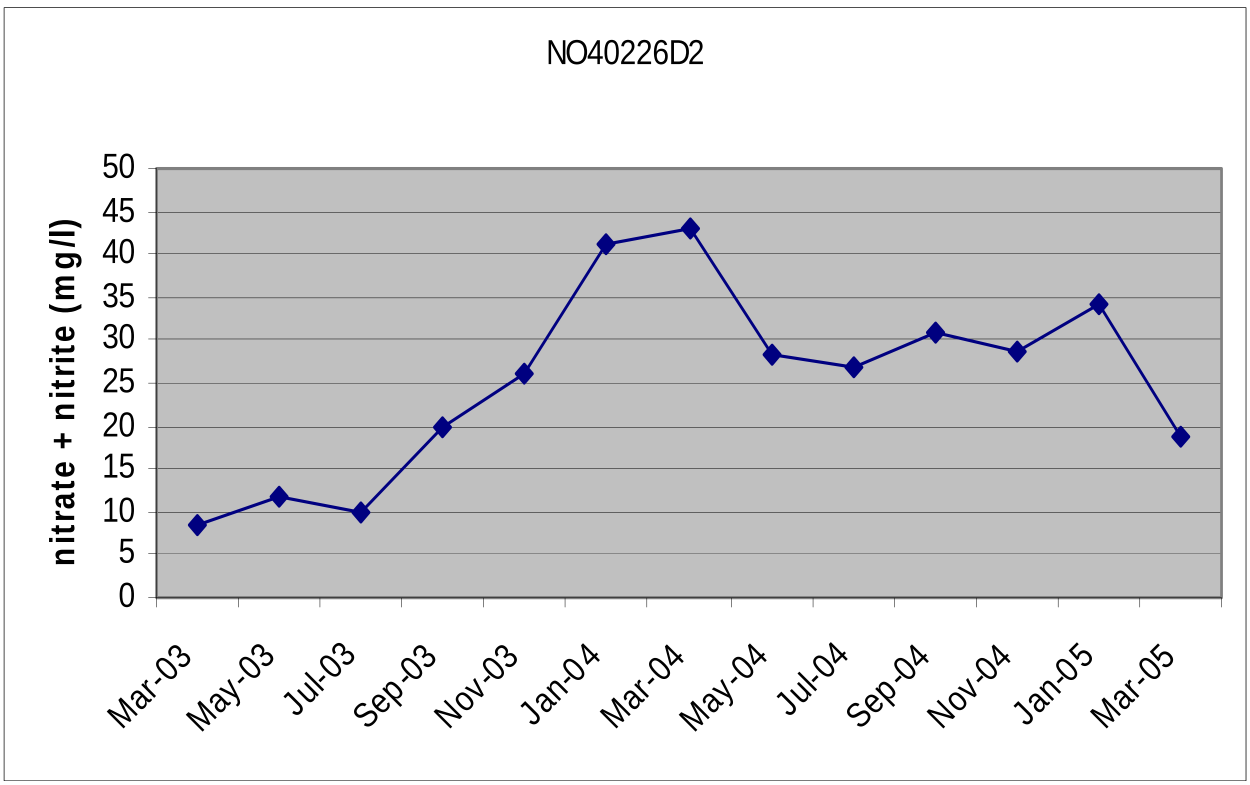
NO40226D2

Well NO40226D2 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows south towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as raspberry fields and pasture land.

The well is a private domestic well which is 15 feet deep. This well had the highest nitrate concentration of all the wells during the study period. Nitrate concentrations in the well range from 8.37 and 43.1 mg/l, with a mean of 24.98 mg/l. The nitrate standard of 10 mg/l was exceeded 93% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



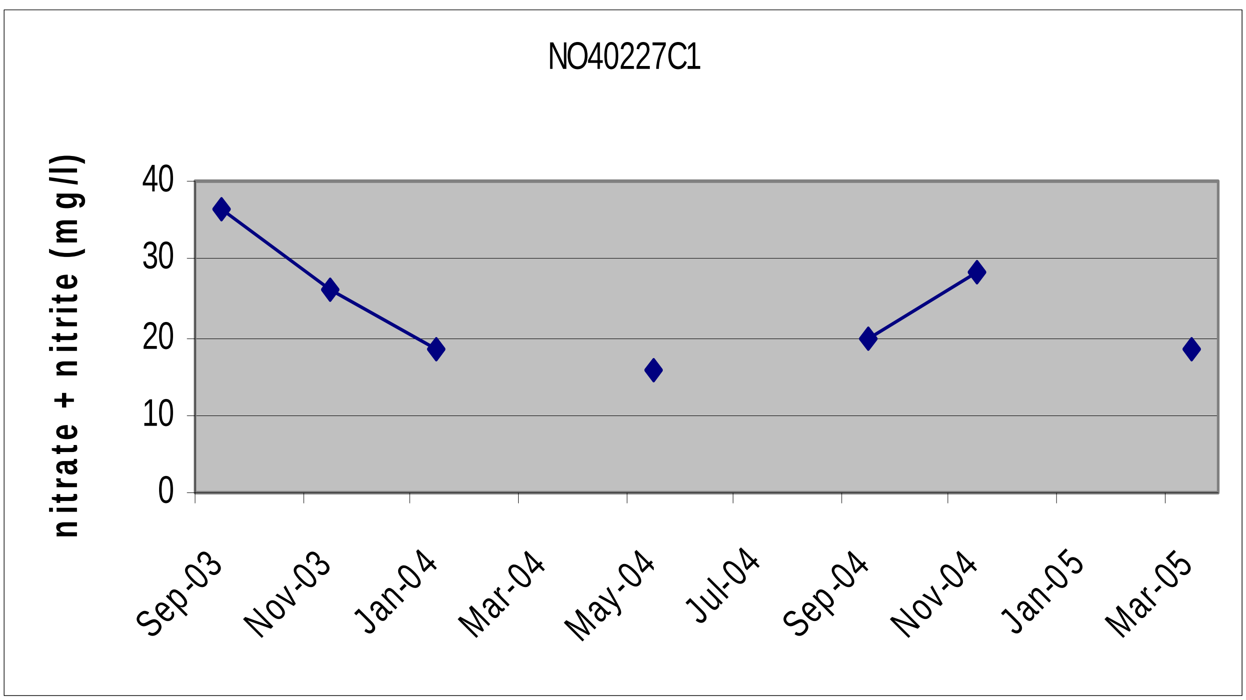
NO40227C1

Well NO40227C1 is located in the northwest quadrant of the study area. Groundwater in the immediate area flows southeast towards the Nooksack River. The well has raspberry fields located adjacent and upgradient of the well. There is also an industrial manufacturer to the north which emits strong solvent-smelling vapors. In 1997 the upgradient land use was documented as raspberry fields.

The well is a private domestic well which is used solely for irrigation. It has an 18-inch diameter casing and is 32 feet deep. Nitrate concentrations in the well range from 15.8 and 36.5 mg/l, with a mean of 22.44 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

This well was not always accessible or operational, so the data set is not complete enough to determine seasonality or trends in the data.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



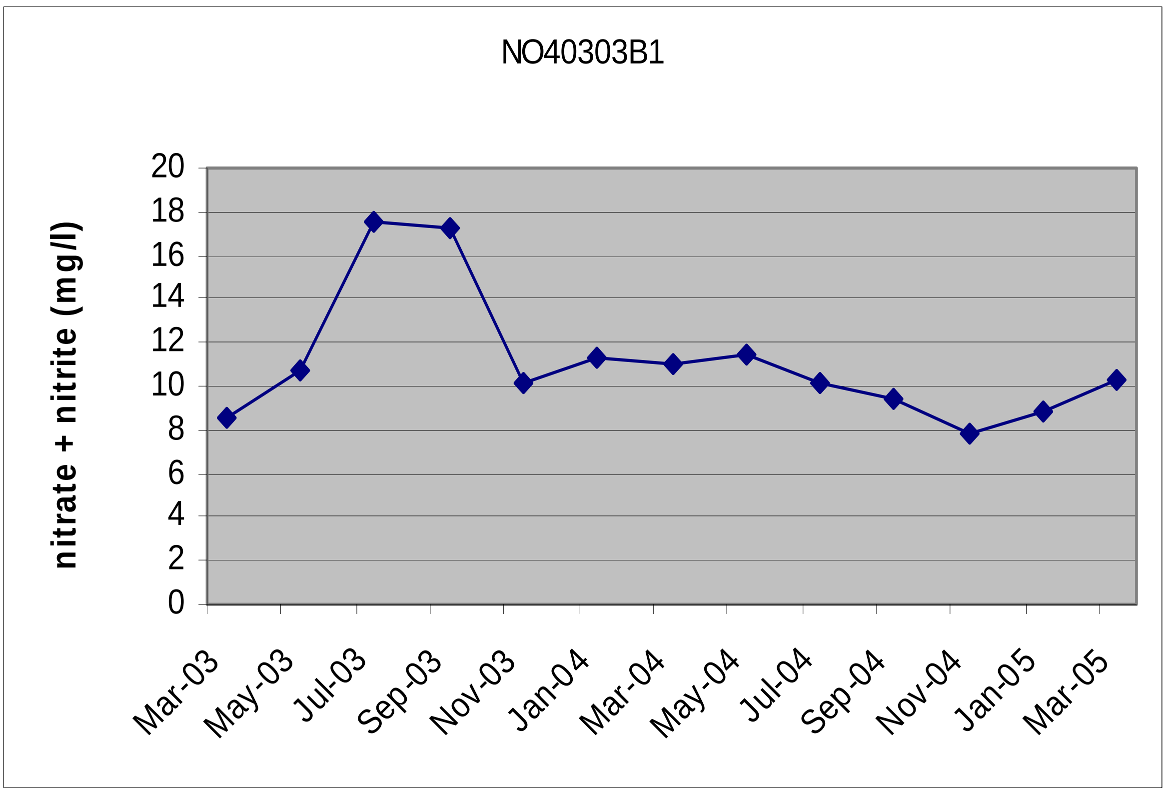
NO40303B1

Well NO40303B1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows southwest towards Fishtrap Creek. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use included a dairy operation and a wooded area.

The well is a private domestic well which has a 6-inch diameter casing and is 29 feet deep. Nitrate concentrations in the well range from 7.8 and 17.8 mg/l, with a mean of 11.88 mg/l. The nitrate standard of 10 mg/l was exceeded 75% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.

The presence of oxic conditions is probably based on the low dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



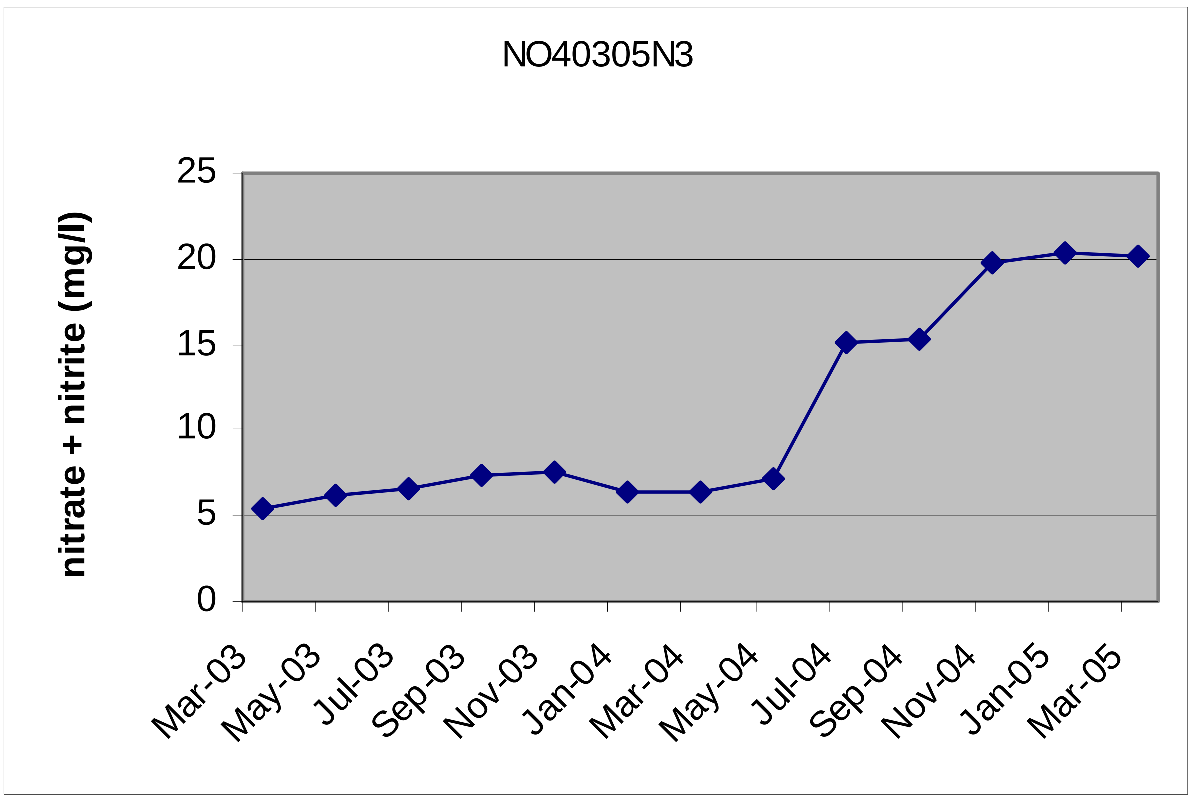
NO40305N3

Well NO40305N3 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south-southeast towards Fishtrap Creek. The well has raspberry fields and a dairy operation located adjacent and upgradient of the well. In 1997 the upgradient land use included a dairy operation with fields of corn and potatoes.

The well is a private domestic well which has a 36-inch diameter casing and is 26 feet deep. Nitrate concentrations in the well range from 5.52 and 20.4 mg/l, with a mean of 11.4 mg/l. The nitrate standard of 10 mg/l was exceeded 43% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.

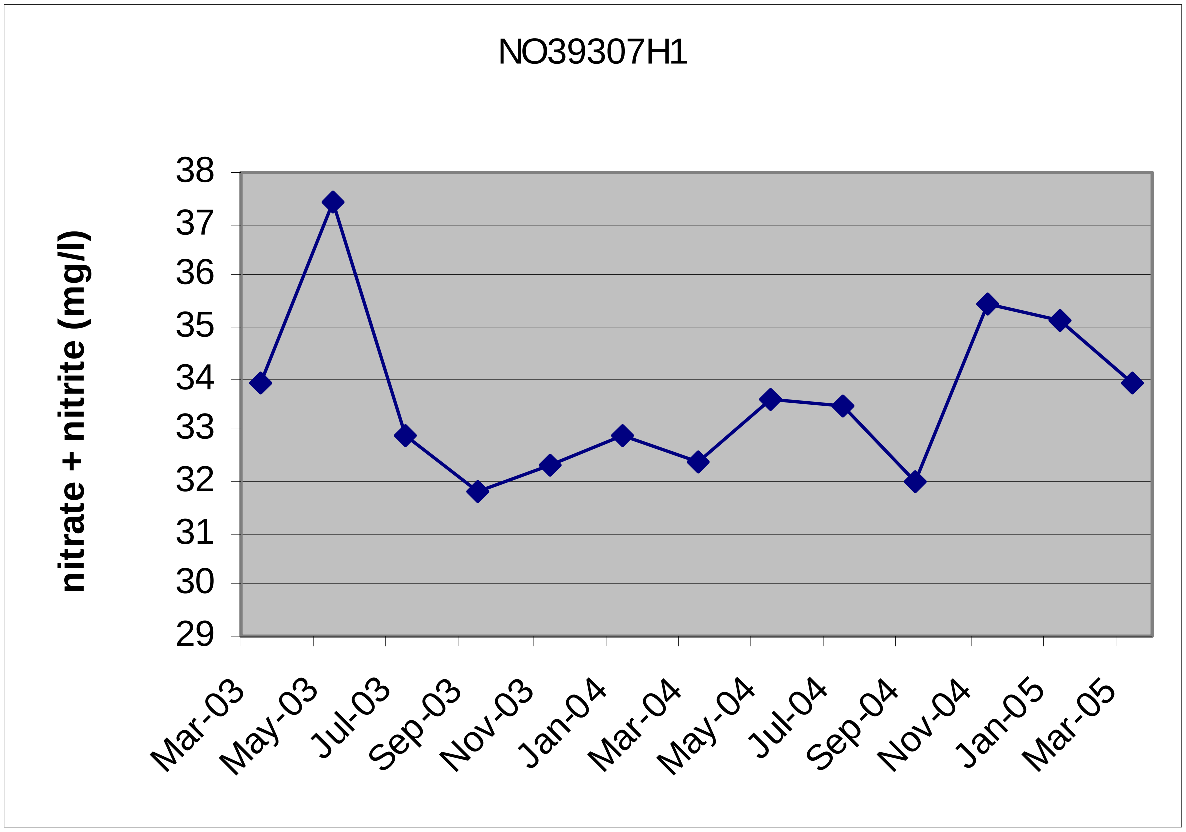


NO40307H1

Well NO40307H1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south towards Fishtrap Creek. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use included a dairy operation and raspberry fields.

The well is a private domestic well which has a 24-inch diameter casing and is 21 feet deep. Nitrate concentrations in the well range from 13.3 and 20.2 mg/l, with a mean of 17.02 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

The well owner decided not to continue participating in the study after one year. Consequently there is not enough information to determine seasonality or trends in groundwater data.



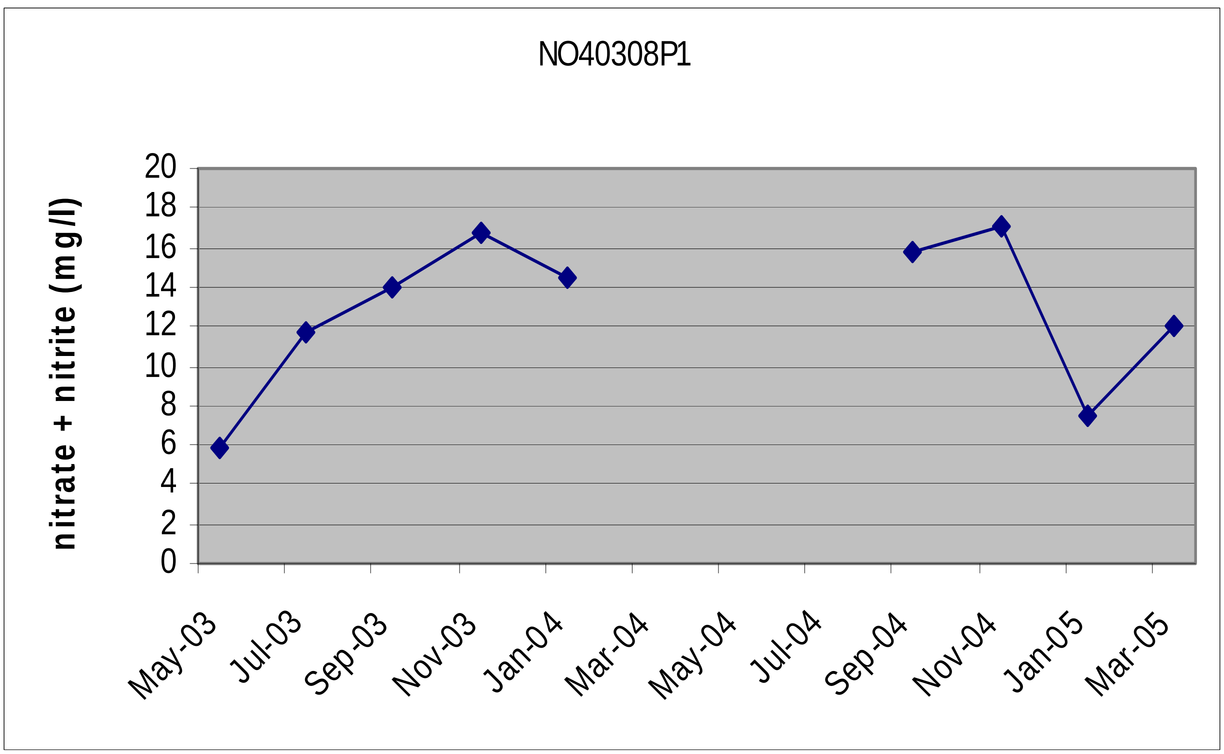
NO40308P1

Well NO40308P1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south-southwest towards Fishtrap Creek. The well has a dairy operation and pasture lands located adjacent and upgradient of the well.

The well is a private domestic well which has a 36-inch diameter casing and is 15 feet deep. Nitrate concentrations in the well range from 5.83 and 17.5 mg/l, with a mean of 12.96 mg/l. The nitrate standard of 10 mg/l was exceeded 83% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.

The well was out of commission for six months due to construction, which resulted in a large data gap.



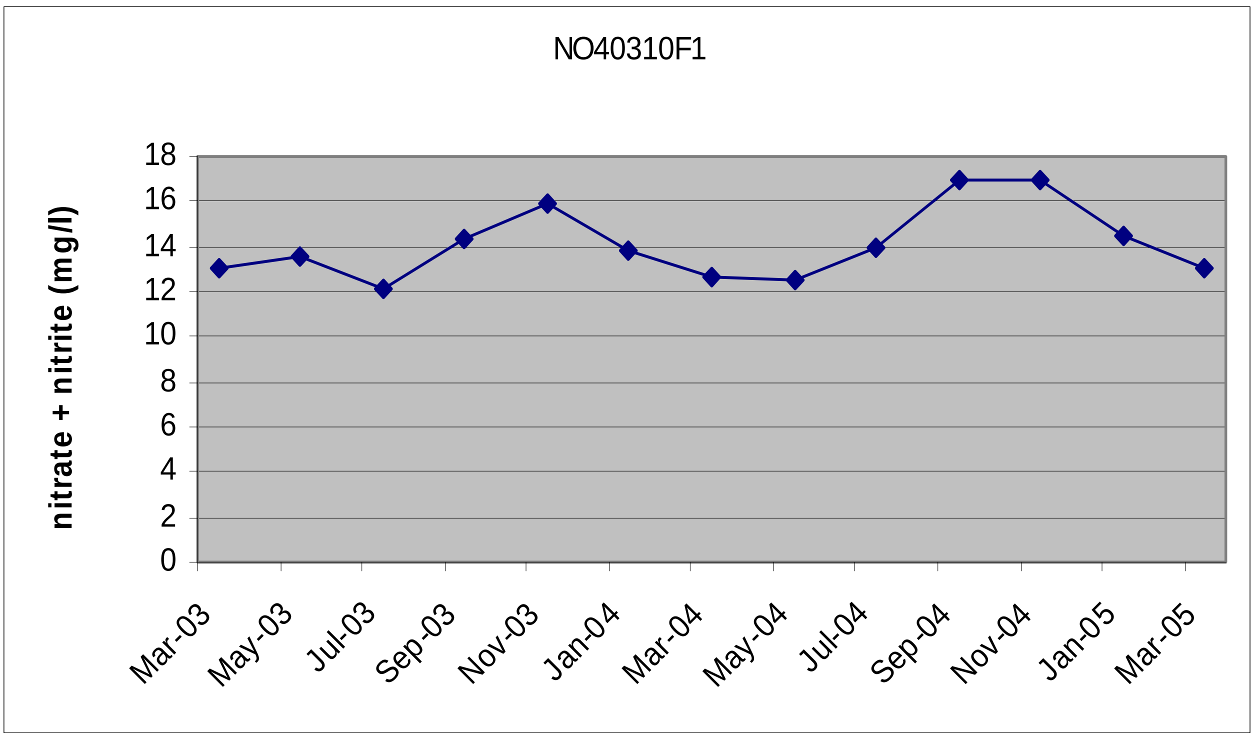
NO40310F1

Well NO40310F1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows southwest towards Fishtrap Creek. The well has raspberry fields located adjacent and upgradient of the well. In 1997 the upgradient land use was also documented as raspberry fields.

The well is a private domestic well which has a 36-inch diameter casing and is 21 feet deep. Nitrate concentrations in the well range from 12.1 and 16.9 mg/l, with a mean of 14.13 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.

The presence of oxic conditions is probably based on the high dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



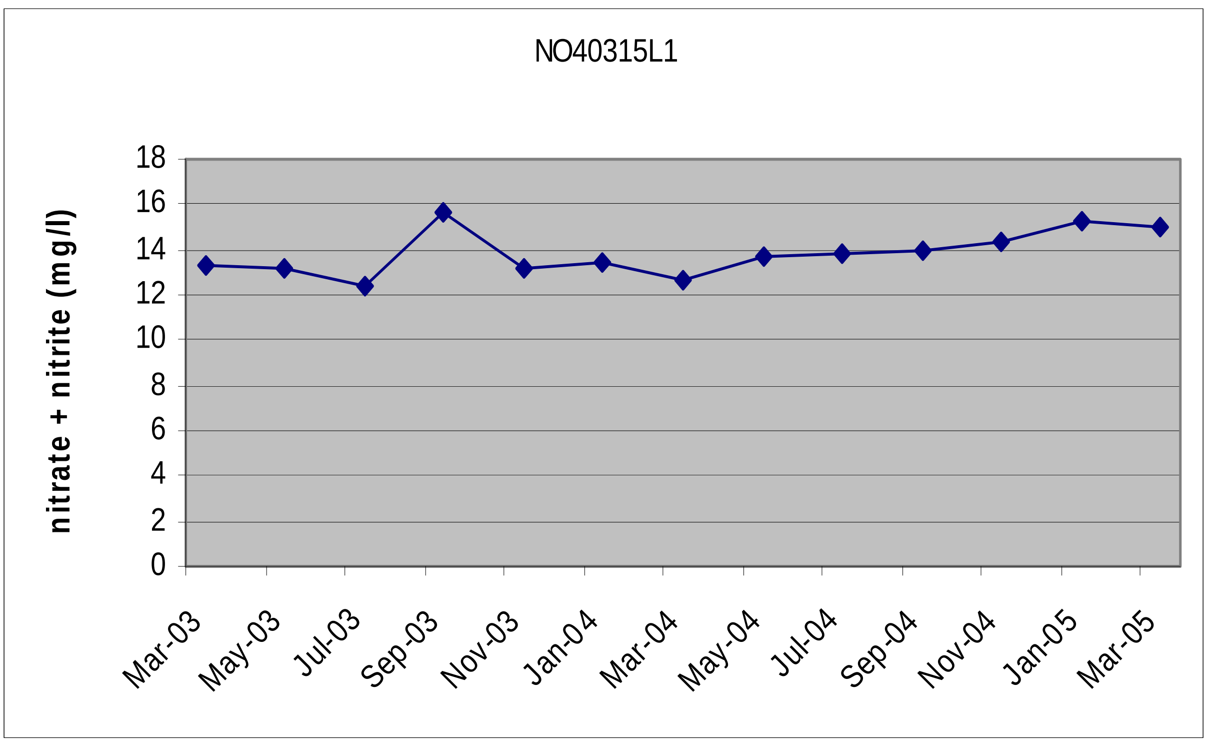
NO40315L1

Well NO40315L1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows southeast towards the Nooksack River. The well is located in a residential area.

The well is a private domestic well which is 20 feet deep. Nitrate concentrations in the well range from 12.4 and 15.6 mg/l, with a mean of 13.79 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



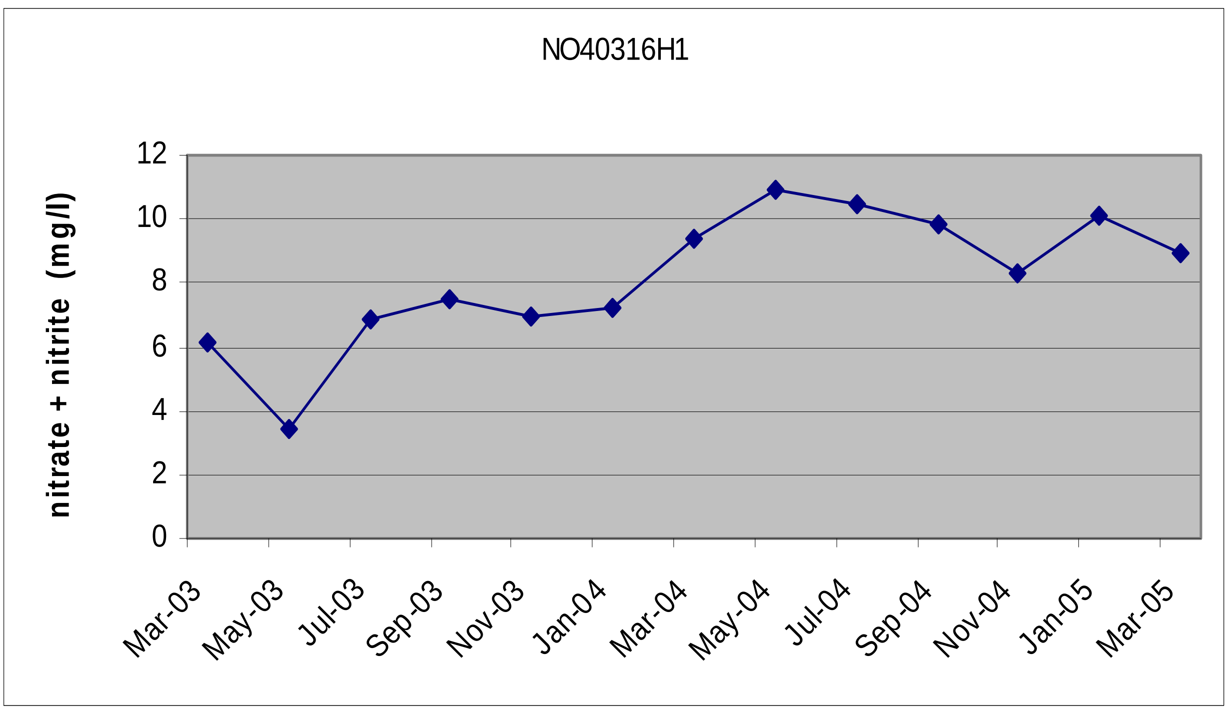
NO40316H1

Well NO40316H1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south towards Fishtrap Creek. The well has corn fields located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as raspberry and corn fields.

The well is a private domestic well which has a 6-inch diameter casing and is 58 feet deep. Nitrate concentrations in the well range from 3.44 and 11.3 mg/l, with a mean of 8.26 mg/l. The nitrate standard of 10 mg/l was exceeded 27% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

Total nitrogen tests conducted on five occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



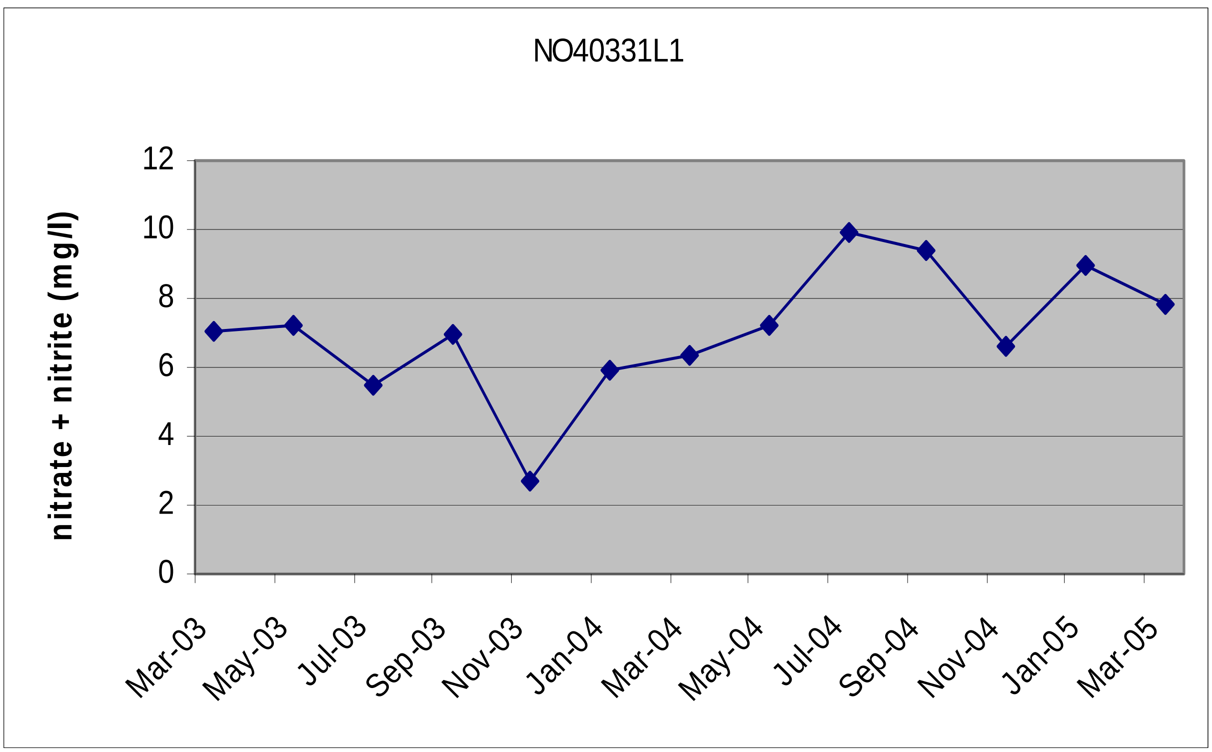
NO40331L1

Well NO40331L1 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows north-northwest towards the Nooksack River. The well has a dairy operation located adjacent to the well and a wooded area upgradient of the well. In 1997 the upgradient land use was similar to current land uses.

The well is a private domestic well which has an 18-inch diameter casing and is 30 feet deep. Nitrate concentrations in the well range from 2.69 and 9.92 mg/l, with a mean of 7.21 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



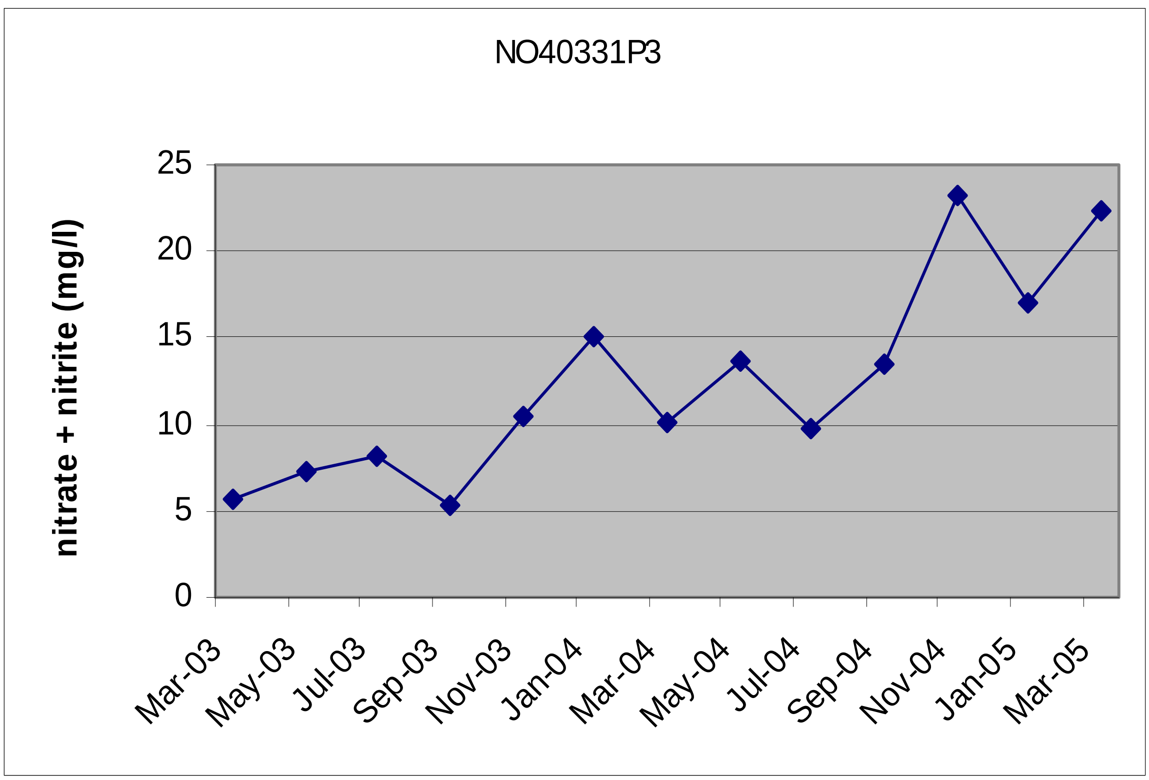
NO40331P3

Well NO40331P3 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows south-southwest towards Wiser Lake. The well is located in a residential area with a dairy operation located upgradient of the well. In 1997 the upgradient land use was similar to current land uses.

The well is a private domestic well which has an 18-inch diameter casing and is 30 feet deep. Nitrate concentrations in the well range from 5.36 and 23.2 mg/l, with a mean of 12.23 mg/l. The nitrate standard of 10 mg/l was exceeded 64% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



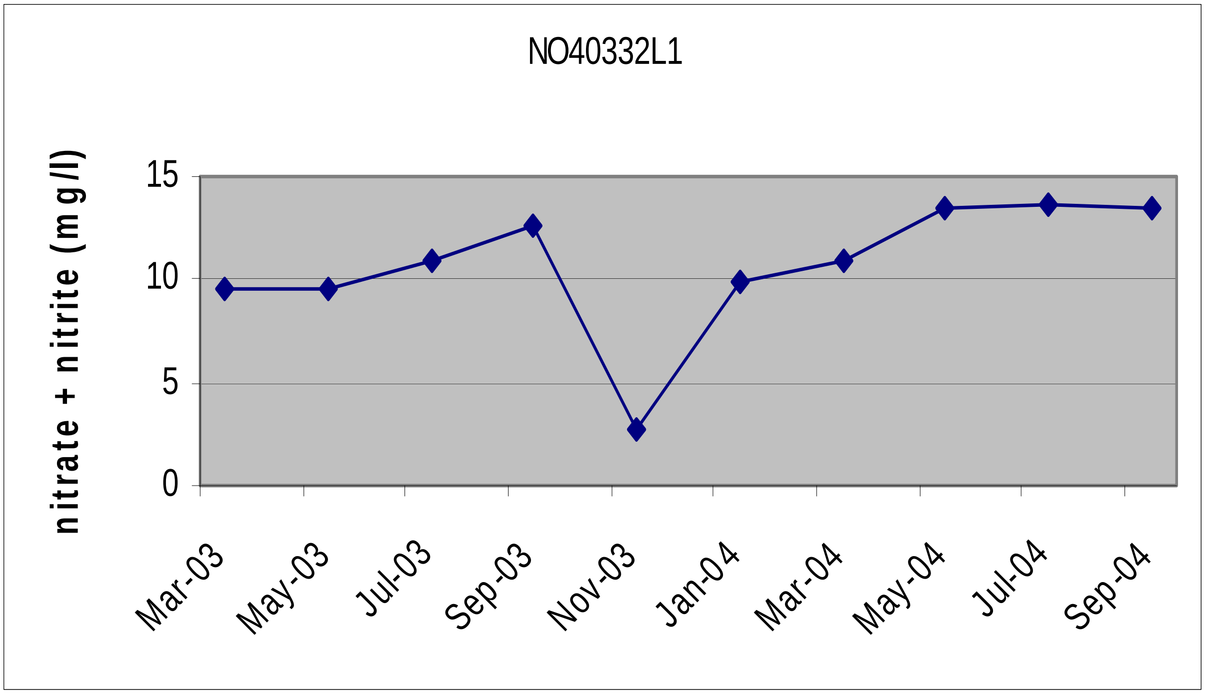
NO40332L1

Well NO40332L1 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows north-northwest towards the Nooksack River. The well is located in a residential area. In 1997 the area was residential but there were also wooded areas and pasture land upgradient of the well.

The well is a private domestic well which has a 36-inch diameter casing and is 50 feet deep. Nitrate concentrations in the well range from 2.69 and 13.6 mg/l, with a mean of 10.67 mg/l. The nitrate standard of 10 mg/l was exceeded 64% of the time during the study period.

The well owner decided not to continue to participate in this study after September 2004. Consequently, seasonal variations could not be determined. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



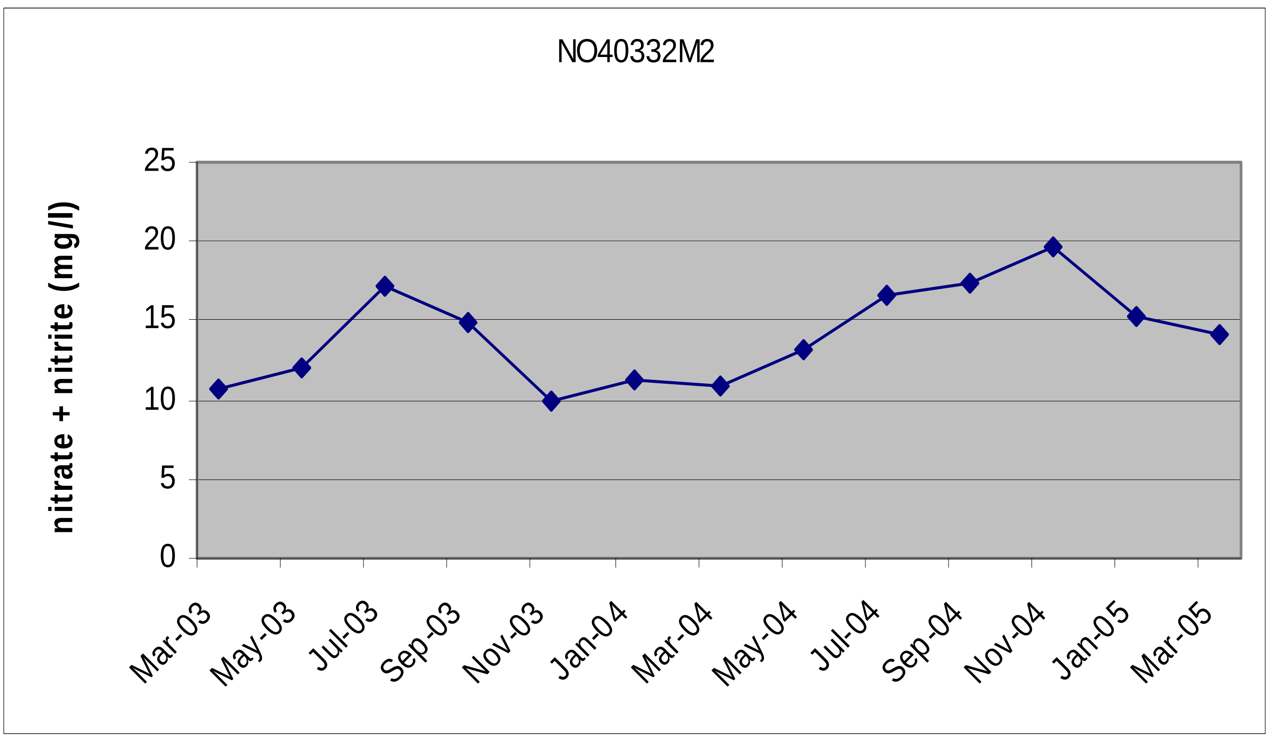
NO40332M2

Well NO40332M2 is located in the southeast quadrant of the study area. Groundwater in the immediate area flows north towards the Nooksack River. The well has a cemetery located upgradient of the well. In 1997 the upgradient land use was documented as pasture land.

The well is a private domestic well which has a 6-inch diameter casing and is 20 feet deep. Nitrate concentrations in the well range from 10 and 19.6 mg/l, with a mean of 14.5 mg/l. The nitrate standard of 10 mg/l was exceeded 100% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of oxic conditions is probably based on the high dissolved oxygen values and the absence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.

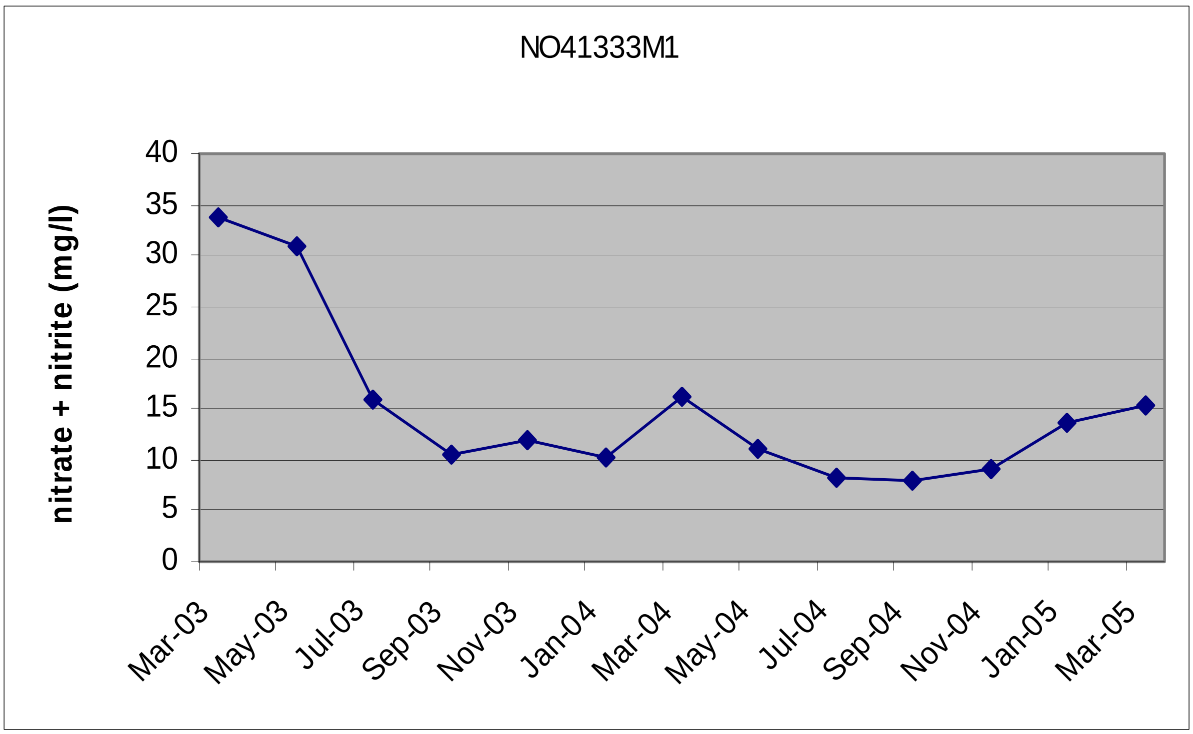


NO41333M1

Well NO41333M1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south-southeast towards Fishtrap Creek. The well has raspberry fields and pasture lands located adjacent and upgradient of the well. In 1997 the upgradient land use was documented as pasture land.

This well is located just south of the Canadian border and supplies water to a dairy operation. The well is a private domestic well which has a 6-inch diameter casing and is 38 feet deep. Nitrate concentrations in the well range from 7.82 and 33.9 mg/l, with a mean of 14.47 mg/l. The nitrate standard of 10 mg/l was exceeded 71% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.



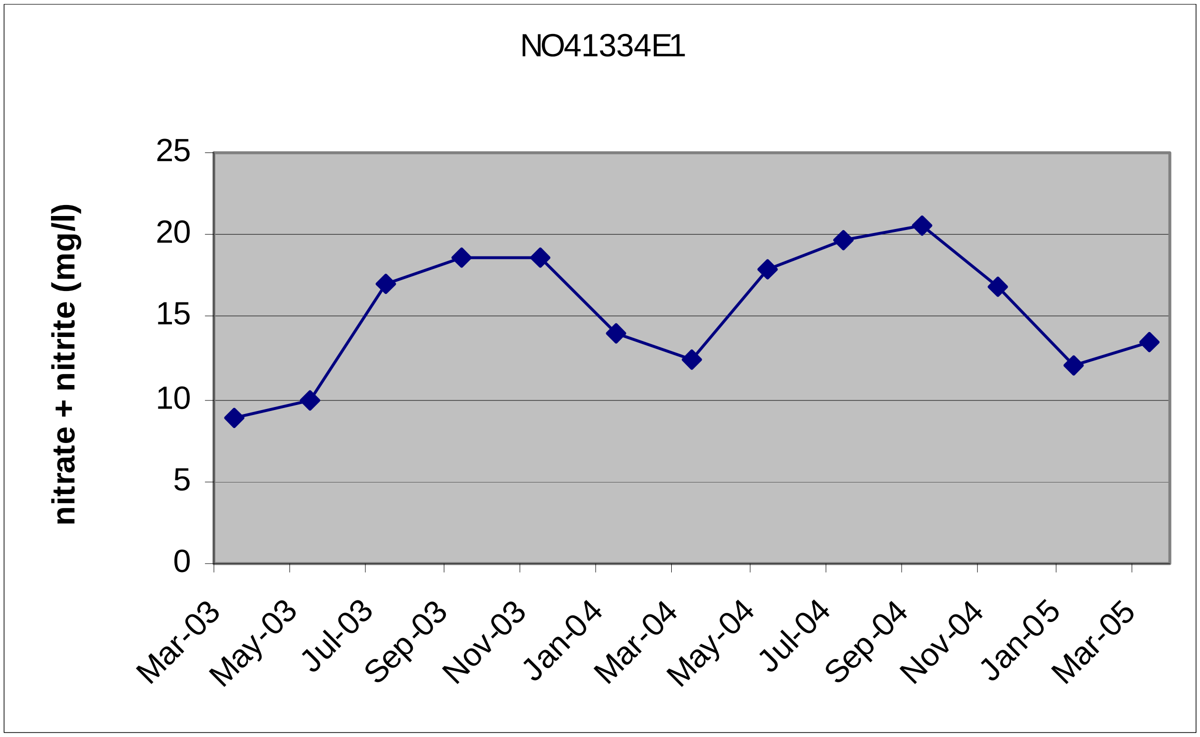
NO41334E1

Well NO41334E1 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows south towards Fishtrap Creek. Raspberry fields are located directly north across the Canadian border and upgradient of the well. In 1997 raspberry fields and poultry operations were documented upgradient of the well. In March 2005 a rabbit hutch was observed in the barn next to the wellhead.

This well is located just south of the Canadian border. The well is a private domestic well which has an 18-inch diameter casing and is 12 feet deep. Nitrate concentrations in the well range from 8.82 and 20.5 mg/l, with a mean of 15.12 mg/l. The nitrate standard of 10 mg/l was exceeded 86% of the time during the study period.

The nitrate concentrations from this well exhibit seasonal variations. Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable increasing or decreasing trends.

The presence of oxic conditions is probably based on the high dissolved oxygen values. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



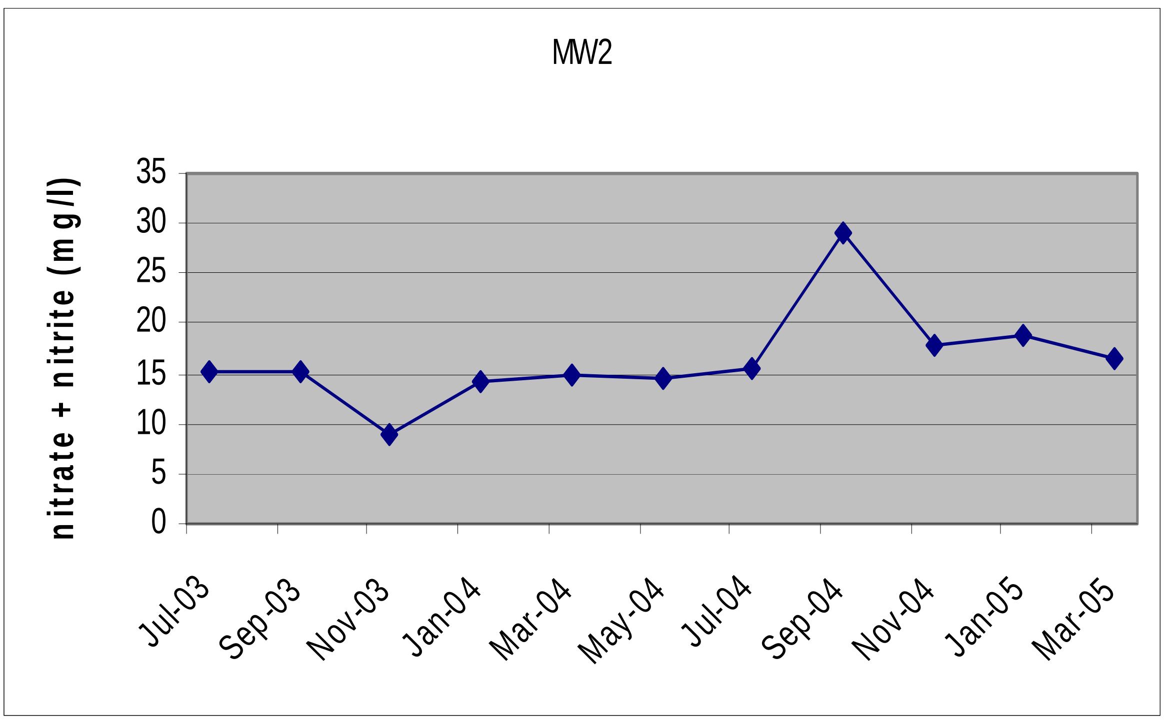
MW2

Well MW2 is located in the northeast quadrant of the study area. Groundwater in the immediate area flows southwest towards Fishtrap Creek. The well has a dairy operation located adjacent and upgradient of the well. The well is located in the middle of a field which receives manure applications.

The well is a monitoring well which has a 2-inch diameter casing and is 20 feet deep. Nitrate concentrations in the well range from 8.99 mg/l and 29 mg/l, with a mean of 16.5 mg/l. The nitrate standard of 10 mg/l was exceeded 92% of the time during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit an increasing trend.

The presence of anoxic conditions is possible based on the presence of ferrous iron in groundwater. Total nitrogen tests conducted on two occasions indicate the majority of nitrogen is present in groundwater in the form of nitrate.



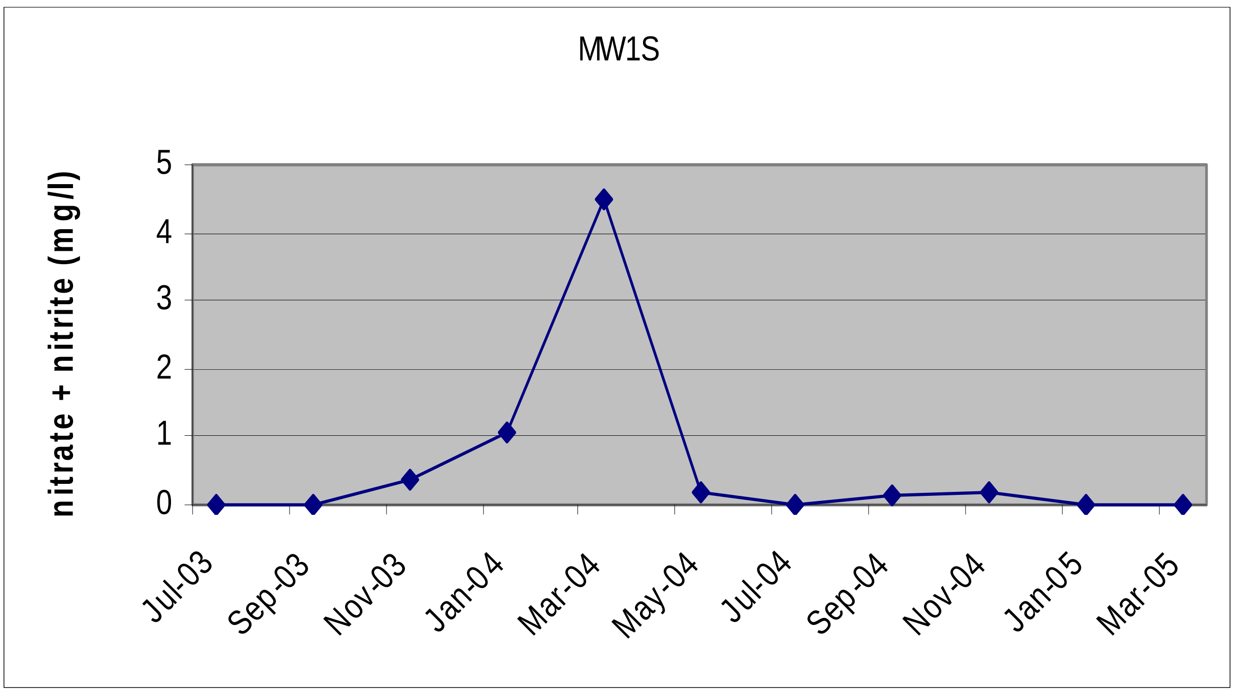
MW1S

Well MW1S is located in the northwest quadrant of the study area. Groundwater in the immediate area flows southwest. The well has corn fields located upgradient of the well. This well is located at a dairy operation adjacent to a manure lagoon and fields which receive manure applications.

The well is a monitoring well which has a 2-inch diameter casing and is 14.25 feet deep. Nitrate concentrations in the well range from 0.01 and 4.5 mg/l, with a mean of 0.56 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trends.

The presence of anoxic conditions is probably based on the low dissolved oxygen values and the presence of ferrous iron in groundwater.



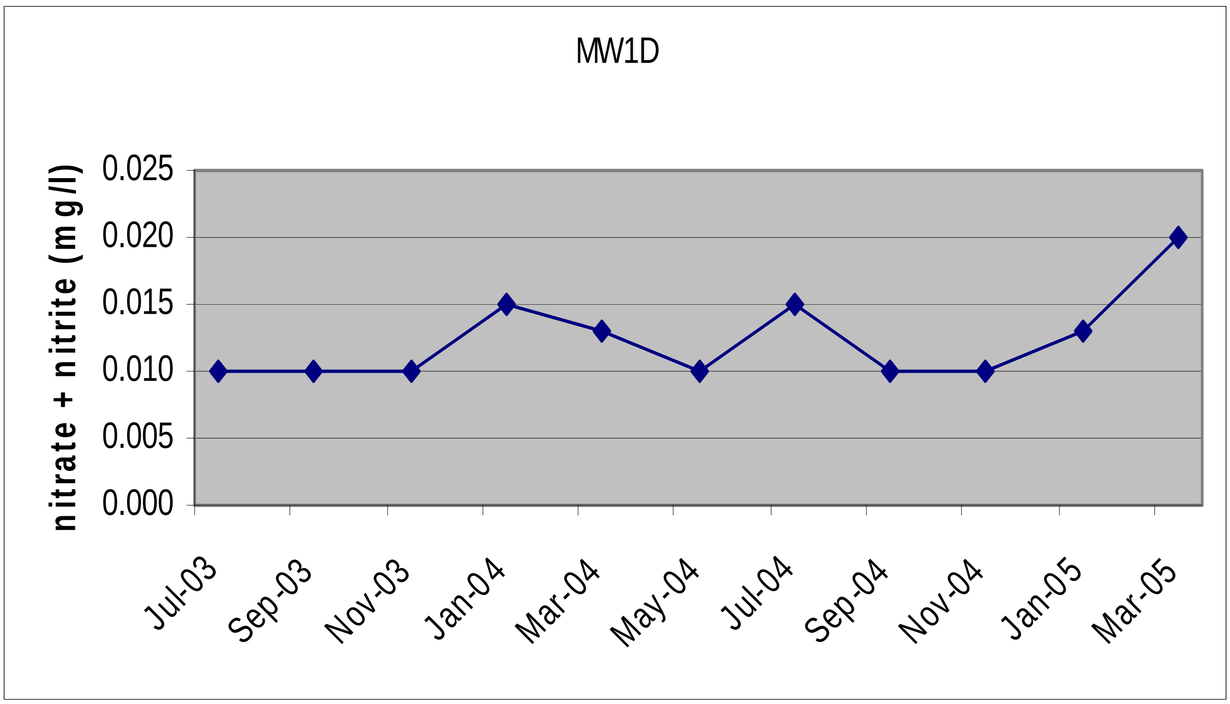
MW1D

Well MW1D is located in the northwest quadrant of the study area. Groundwater in the immediate area flows southwest. The well has corn fields located upgradient of the well. This well is located at a dairy operation adjacent to a manure lagoon and fields which receive manure applications.

The well is a monitoring well which has a 2-inch diameter casing and is 60.2 feet deep. Nitrate concentrations in the well range from 0.01 and 0.02 mg/l, with a mean of 0.013 mg/l. There were no exceedances of the nitrate standard of 10 mg/l during the study period.

Based on the Mann-Kendall test of trends, nitrate concentrations from this well exhibit no distinguishable trends.

The presence of anoxic conditions is probably based on the low dissolved oxygen values and the presence of ferrous iron in groundwater.



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Appendix B: Well Construction, Location, and Land Use

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Table B-1. Well Construction, Location, and Land Use.

Site ID	State Plane X	State Plane Y	Land Surface Datum (MSL)	Diameter (inches)	Depth (feet)	GW Flow (Regional)	1997 Upgradient Land Use	2003 Upgradient Land Use
NO39203Q1	1509695	1304532	55	6	31	NW	Pasture	Raspberries
NO39211F1	1513875	1302767	71	36	30	N and NE	Tree Farm, Strawberries	Raspberries 200'
NO39212C1	1519363	1303459	81	36	32	NW	Rural Residential	Residential
NO39212K2	1519796	1300723	80	12	20	W and S? (CD)	Rural Residential, Pasture	Rural Residential, Pasture
NO39215J1	1510263	1296171	58	12-18	21	S	Pasture, Berries	Raspberries, Pasture
NO39221H1	1505531	1292181	55	12	27	NW(CD)	Residential, Wooded	Residential, Wooded
NO39307H1	1526850	1301685	84	6	29	W and SW? (CD)	Raspberries	Raspberries 100'
NO39307K2	1525187	1301212	82	36	24	W and S (CD)	Dairy, Raspberries	Raspberries, some Corn
NO39307N1	1523220	1298923	80		30	S	Dairy	Pasture
NO39308F2	1530007	1301359	85	12	20	W	Raspberries, Dairy	Residential, Golf Course
NO39317H1	1531787	1295980	90	18		N and NE	Dairy, Pasture	School, Dairy Pasture
NO40211P1	1514356	1331834	105	36	31	S and SE	Dairy	Dairy
NO40214P1	1514449	1326156	90	36	43.1	S	Raspberries	Raspberries
NO40221J5	1505644	1323128	83	18	17	S	Raspberries	Raspberries
NO40222D1	1507832	1325661	91	18		S	Pasture	Corn
NO40223A3	1516133	1324386	90	6	23	SW and W	Strawberries	Raspberries
NO40226B1	1515304	1319692	75	36	30	SE	Pasture, Raspberries	Raspberries
NO40226D2	1513207	1319296	70		15	S	Pasture, Raspberries	Raspberries
NO40227C1	1509123	1320311	70	18	32	SE	Raspberries	Raspberries
NO40303B1	1542223	1340297	142	6	29	SW	Wooded, Dairy	Raspberries
NO40305N3	1529381	1336084	123	36	26	SE and S	Corn, potatoes, Dairy	Raspberries, Dairy
NO40307H1	1528113	1333932	114	24	21	S	Dairy, Raspberries	Raspberries
NO40308P1	1530141	1330845	111	36	15	S and SW	- -	Pasture, Dairy
NO40310F1	1540909	1333950	131	36	21	SW	Raspberries	Raspberries xgrad 50'
NO40315L1	1541039	1327333	95		20-24R	SE	Not recorded	Residential
NO40316H1	1538682	1328690	115	6	58	S,SW, SE	Strawberries, Raspberries	Corn
NO40331L1	1524120	1311570	64	18	30	N and NW	Wooded, Dairy	Wooded, Dairy
NO40331P3	1524440	1309664	76	18	30-36	S and SW	Residential, Dairy	Residential, Dairy
NO40332L1	1530138	1311373	87	36	50	N and NW (CD)	Pasture, Residential, Wooded	Residential,
NO40332M2	1527878	1310744	72	6	20-25	N (CD)	Pasture	Cemetery
NO41333M1	1534163	1343694	145	6	38-43	S and SE	Pasture	Pasture, Raspberries
NO41334E1	1539465	1343956	145	18	12-20	S and SW	Raspberries, chickens	Raspberries
MW2	1542905	1332598	130	2	10-20	SW	Unknown	Dairy
MW1S	1522354	1327299	99	2	4.0-13.7	SW	Unknown	Corn
MW1D	1522360	1327299	99	2	49.9-59.6	SW	Unknown	Corn

CD= Close to groundwater divide   GWD= Groundwater divide   xgrad= Cross-gradient

Table B-2. Static Water Level Elevations.

Well ID	Depth to Water (feet)	Date	Water Level Elevation (feet)
MW1S	4.25	6/24/03	94.75
	5.33	7/15/03	93.67
	6.44	9/16/03	92.56
	3.28	11/12/03	95.72
	2.2	1/22/04	96.80
	2.65	3/3/04	96.35
	3.31	5/19/04	95.69
	4.6	7/14/04	94.40
	5.55	9/15/04	93.45
	1.79	11/3/04	97.21
	1.9	1/13/05	97.10
	2.71	3/2/05	96.29
MW1D	4.14	6/24/03	93.86
	5.41	7/15/03	92.59
	6.54	9/16/03	91.46
	3.23	11/12/03	94.77
	2.29	1/22/04	95.71
	2.76	3/3/04	95.24
	3.41	5/19/04	94.59
	4.7	7/14/04	93.30
	5.67	9/15/04	92.33
	1.87	11/3/04	96.13
	2.02	1/13/05	95.98
	2.82	3/2/05	95.18
MW2	14.76	7/18/03	114.34
	17.33	9/18/03	111.77
	13.07	11/12/03	116.03
	11.26	1/22/04	117.84
	10.41	3/3/04	118.69
	12.81	5/19/04	116.29
	15.36	7/14/04	113.74
	17.22	9/15/04	111.88
	15.29	11/3/04	113.81
	10.38	1/12/05	118.72
	8.91	3/2/05	120.19

Appendix C: Groundwater Quality Data

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Table C-1. Nitrate Concentrations in mg/l.

Site ID	quadrant	Mar-03	May-03	Jul-03	Sep-03	Nov-03	Jan-04	Mar-04	May-04	Jul-04	Sep-04	Nov-04	Jan-05	Mar-05	*Mean*
NO39203Q1	SW	0.661	0.771	2.25	1.92	1.33	0.49	0.19	0.70	3.44	3.62	4.35	4.51	NS	*2.02*
NO39211F1	SW	3.95	5.12	2.97	1.94	2.19	2.11	5.27	6.26	3.29	0.37	0.106	3.65	6.29	*3.35*
NO39212C1	SW	9.00	8.9	6.75	7.29	10.20	10.60	10.60	8.38	7.62	7.68	7.66	7.5	8.93	*8.55*
NO39212K2	SW	3.56	6.36	4.08	3.10	3.60	4.60	4.95	6.33	3.34	2.97	2.00	4.68	4.06	*4.13*
NO39215J1	SW	2.36	2.7	2.51	2.47	1.60	2.26	1.96	2.05	2.85	3.67	3.07	2.71	2.52	*2.52*
NO39221H1	SW	10.8	7.62	8.71	7.46	8.62	7.49	6.96	8.55	7.31	6.06	9.89	4.7	6.43	*7.74*
NO39307H1	SE	33.9	37.4	32.90	31.8	32.30	32.90	32.40	33.60	33.50	32.00	35.45	35.10	33.90	*33.63*
NO39307K2	SE	19.6	19.7	22.30	28.7	20.50	17.60	19.40	18.60	18.50	19.90	22.00	19.25	19.40	*20.42*
NO39307N1	SE	0.014	0.005	2.50	2.77	0.005	0.01	NS	NS	NS	NS	NS	NS	NS	*0.88*
NO39308F2	SE	13.8	14.5	16.10	16.3	13.40	14.50	NS	NS	NS	NS	NS	NS	NS	*14.77*
NO39317H1	SE	8.26	7.87	8.59	9.76	8.08	12.60	10.70	0.28	20.45	21.1	22.10	16.30	12.50	*12.20*
NO40211P1	NW	4.35	4.3	4.56	6.12	2.89	2.90	2.12	1.43	1.54	3.25	3.97	3.57	3.05	*3.39*
NO40214P1	NW	17.6	18.0	17.80	19.0	18.40	17.30	18.30	17.10	17.20	16.10	17.30	16.4	16.30	*17.45*
NO40221J5	NW	10.17	12.0	11.30	12.8	9.47	6.26	6.22	5.65	8.09	8.10	6.07	5.55	5.13	*8.22*
NO40222D1	NW	1.6	3.93	1.83	3.93	4.49	4.47	5.67	5.79	5.25	6.87	9.43	2.46	2.77	*4.50*
NO40223A3	NW	12.7	7.47	5.25	6.46	6.62	6.81	8.23	6.01	8.59	9.62	10.90	7.7	10.70	*8.24*
NO40226B1	NW	9.82	12.3	10.90	10.6	9.48	13.80	15.00	9.12	8.54	9.08	8.67	11.00	9.68	*10.61*
NO40226D2	NW	8.37	11.8	10.10	19.9	26.20	41.10	43.10	28.3	26.90	30.70	28.50	34.10	18.7	*25.21*
NO40227C1	NW	NS	NS	NS	36.5	26.20	18.50	NS	15.80	NS	19.85	28.20	NS	18.55	*23.37*
NO40303B1	NE	8.58	10.75	17.5	17.30	10.20	11.30	11.00	11.50	10.10	9.38	7.80	8.78	10.30	*11.11*
NO40305N3	NE	5.52	6.15	6.64	7.46	7.62	6.37	6.31	7.26	15.20	15.3	19.80	20.40	20.20	*11.09*
NO40307H1	NE	17.9	15.9	13.30	17.7	20.20	17.10	NS	NS	NS	NS	NS	NS	NS	*17.02*
NO40308P1	NE	NS	5.83	11.70	14.0	16.70	12.8	NS	NS	NS	15.80	17.15	7.44	12.05	*12.61*
NO40310F1	NE	13.0	13.6	12.10	14.3	15.90	13.80	12.70	12.50	14.00	16.90	16.90	14.5	13.10	*14.10*
NO40315L1	NE	13.3	13.2	12.40	15.6	13.20	13.50	12.60	13.70	13.80	14.7	14.30	15.20	15.00	*13.88*
NO40316H1	NE	6.15	3.44	6.85	7.49	6.92	7.19	9.39	10.9	10.50	9.84	8.28	10.10	8.97	*8.16*
NO40331L1	SE	7.06	7.21	5.52	6.96	2.69	5.93	6.35	7.21	9.92	9.38	6.60	8.96	7.79	*7.04*
NO40331P3	SE	5.66	7.29	8.11	5.36	10.40	15.00	9.88	13.60	9.81	13.50	23.20	17.00	22.40	*12.40*
NO40332L1	SE	9.53	9.59	10.9	12.6	2.69	9.89	10.90	13.40	13.60	13.40	NS	NS	NS	*10.65*
NO40332M2	SE	10.7	12.1	17.20	14.90	10.00	11.30	10.90	13.20	16.55	17.4	19.60	15.30	14.10	*14.10*
NO41333M1	NE	33.9	30.8	15.80	10.5	12.00	10.30	16	11.00	8.11	8	9.12	13.50	15.40	*14.96*
NO41334E1	NE	8.82	9.94	17.00	18.6	18.70	14.00	12.40	17.90	19.60	20.50	16.80	12	13.40	*15.36*
MW2	NE	NS	NS	15.10	15.2	8.99	14.30	14.80	14.40	15.40	29.00	17.8	18.70	16.50	*16.38*
MW1S	NW	NS	NS	0.005	0.005	0.373	1.070	4.500	0.170	0.013	0.158	0.188	0.014	0.010	*0.59*
MW1D	NW	NS	NS	0.005	0.005	0.005	0.015	0.013	0.005	0.015	0.005	0.005	0.013	0.020	*0.01*
Monthly Mean		*10.69*	*10.86*	*10.28*	*11.91*	*10.61*	*11.17*	*11.33*	*10.67*	*11.37*	*12.60*	*13.10*	*11.61*	*11.61*	*11.43*

Table C-2. Dissolved Oxygen, Nitrate, and Total Persulfate Nitrogen Concentrations.

Site ID	January 2004				July 2004			
	DO (mg/l)	NO3 (as N) (mg/l)	TPN (mg/l)	RPD (%)	DO (mg/l)	NO3 (as N) (mg/l)	TPN (mg/l)	RPD (%)
NO39203Q1	0.85	0.49	0.59	19.53	2.50	3.44	3.45	0.29
NO39211F1	8.48	2.21	2.44	9.89	0.26	3.29	3.34	1.51
NO39212C1	5.29	10.60	10.90	2.79	3.05	7.62	8.45	10.33
NO39212K2		4.60	5.37	15.45	5.16	3.34	3.71	10.50
NO39215J1		2.26	2.30	1.75	3.97	2.85	2.85	0.00
NO39221H1		7.49	8.80	16.08	4.22	7.31	6.92	5.48
NO39307H1		32.90	33.0	0.3	4.77	33.50	32.3	3.6
NO39307K2		17.60	18.2	3.4	4.15	18.50	17.8	3.9
NO39307N1	0.18	0.01	0.09	146.94				
NO39308F2		14.50	14.5	0.0				
NO39317H1		12.60	11.80	6.56		19.90	20.35	2.24
NO40211P1	4.78	2.90	4.87	50.71	2.80	1.54	2.49	47.15
NO40214P1		17.30	19.9	14.0	6.75	17.20	17.4	1.2
NO40221J5		6.26	7.2	14.5	5.92	8.09	8.4	3.9
NO40222D1		4.47	4.62	3.30	3.41	5.25	5.16	1.73
NO40223A3		6.81	6.81	0.00	4.94	8.59	8.15	5.26
NO40226B1	6.41	13.80	14.3	3.6	2.21	8.54	8.5	0.9
NO40226D2		41.10	37.8	8.4	3.89	26.90	26.9	0.0
NO40227C1	9.38	18.50	17.8	3.9				
NO40303B1		11.30	10.5	7.3	4.70	10.10	10.8	6.7
NO40305N3	5.82	6.37	6.69	4.90	3.51	15.20	14.20	6.80
NO40307H1	2.94	17.10	18.4	7.3				
NO40308P1	1.96	11.20	14.8	27.7				
NO40310F1		13.80	13.3	3.7	5.23	14.00	13.8	1.4
NO40315L1		13.50	15.0	10.5	6.37	13.80	15.7	12.9
NO40316H1		7.19	7.24	0.69	3.71	10.50	12.90	20.51
NO40331L1	5.38	5.93	7.32	20.98	3.54	9.92	9.61	3.17
NO40331P3		15.00	15.30	1.98	5.02	9.31	11.45	20.62
NO40332L1		9.89	13.3	29.4	6.72	13.60	15.0	9.8
NO40332M2	4.28	11.30	11.9	5.2	3.48	17.40	17.0	2.3
NO41333M1		10.30	13.2	24.7	2.68	8.11	7.9	2.6
NO41334E1		14.00	13.0	7.4	6.24	19.60	19.0	3.1
MW2		14.30	14.8	3.4	4.25	15.40	14.8	4.0
MW1S	0.71	1.07	1.86	53.92	0.28	0.013	10.10	199.49
MW1D	0.17	0.014	0.31	182.72	0.13	0.011	0.21	179.63

DO = dissolved oxygen
NO_3 = nitrate
TPN = total persulfate nitrogen (nitrate, nitrite, ammonium, and organic nitrogen)
RPD = relative percent difference

Table C-3. Total Persulfate Nitrogen and Nitrate Concentrations.

Site ID	January 2004			March 2004			May 2004		
	NO_3	TPN	RPD	NO_3	TPN	RPD	NO_3	TPN	RPD
NO39211F1	2.11	2.44	14.51						
NO40316H1	7.19	7.24	0.69						
NO40331L1	5.93	7.32	20.98	6.35	7.18	12.27	7.21	7.45	3.27
NO40332L1	9.89	13.3	29.4	10.9	12.2	11.3	13.4	14.0	4.4
NO41333M1	10.3	13.2	24.7	16.0	16.4	2.5	11.0	11.7	6.2
MW2	14.3	14.8	3.4						
MW1S	1.070	1.860	53.925	4.500	6.480	36.066	0.170	8.390	192.056
MW1D	0.015	0.310	181.538						

Site ID	July 2004			September 2004			November 2004		
	NO_3	TPN	RPD	NO_3	TPN	RPD	NO_3	TPN	RPD
NO39211F1	3.29	3.34	1.51				0.106	0.21	65.82
NO40316H1	10.5	12.90	20.51				8.3	8.03	3.07
NO40331L1	9.92	9.61	3.17	9.38	12.05	24.92	6.60	6.41	2.92
NO40332L1	13.6	15.0	9.8	13.4	13.60	1.48			
NO41333M1	8.1	7.9	2.6	8.0	7.7	3.8	9.1	9.9	8.5
MW2	15.4	14.8	4.0						
MW1S	0.013	10.100	199.486	0.158	7.320	191.549	0.188	7.490	190.206
MW1D	0.015	0.205	172.727						

Site ID	January 2005			March 2005		
	NO_3	TPN	RPD	NO_3	TPN	RPD
NO39211F1	3.65	3.93	7.39	6.29	6.68	6.01388
NO40316H1	10.10	8.97	11.85	8.97	9.49	5.63
NO40331L1	8.96	9.05	1.00	7.79	7.58	2.73
NO40332L1						
NO41333M1	13.5	12.70	6.11	15.40	16.10	4.44
MW2						
MW1S	0.014	0.669	191.801	0.010	0.845	195.322
MW1D		0.277	100.000	0.020	0.279	173.244

NO_3 = nitrate
TPN = total persulfate nitrogen (nitrate, nitrite, ammonium, and organic nitrogen)
RPD = relative percent difference

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Appendix D: Quality Assurance Results

Data quality assurance performance requirements are described in Erickson, 2002. Data that do not meet the specified data quality objectives are highlighted in the data tables. The quality of the data reported for this project is judged to be acceptable.

Field duplicates

Table D-1 summarizes the quality assurance data for the field duplicate results for nitrate. Ninety four-percent of the field duplicate samples met the pre-specified 15% relative percent difference. The four samples which did not meet this criterion are highlighted in Table D-1. The mean relative percent difference (RPD) for all the field duplicates is 6.7%, with a range of 0.5% to 48.3%.

In January 2004 the duplicates taken at NO40308P1 were 11.2 and 14.4 mg/l with a 25.0% RPD. On this date all other quality assurance goals were met.

In July 2004 the duplicates taken at MW1D were 0.11 and 0.18 mg/l with a 48.3% RPD. Using RPD as a statistical tool to measure quality assurance is less precise when the results are so close to the detection limit.

In September 2004 the duplicates taken at NO40331L1 were 13.1 and 11.0 mg/l with a 17.4% RPD. On this date all other quality assurance goals were met.

In March 2005 the duplicates taken at NO40308P1 were 13.2 and 10.9 mg/l with a 19.1% RPD. On this date all other quality assurance goals were met.

Laboratory duplicates

Table D-2 summarizes the quality assurance data for the laboratory results for nitrate. Table D-3 summarizes the quality assurance data for the laboratory results for total persulfate nitrogen. All of the laboratory duplicate samples are within the acceptable limits of 20% RPD. The mean RPD for all the laboratory duplicates is 4.1%, with a range of 0.0% to 16.2%.

Blanks

No analytically significant levels of analytes were detected in the method blanks associated with these samples.

Reference sample

All of the reference samples are within the recommended acceptance limits of 3 standard deviations. Reference samples were submitted to the lab for analysis for only 30% of the sampling events. This information provides only limited assurance of the data quality since reference samples were not used consistently throughout the study.

Control samples

All laboratory control samples are within the acceptable +/- 20% range.

Matrix spikes

On three occasions - 7/03, 3/04, and 7/04 - the percent matrix spike recoveries were outside of the acceptable +/- 25% range. The laboratory judged the data from these sampling dates to still be considered acceptable for use since all the other quality assurance parameters were within the acceptable limits.

Table D-1. Quality Assurance Summary for Field Duplicate Results of Nitrate (as N).

Date	Site ID	Sample ID	Sample ID	Parameter	Duplicate results (mg/l)	Duplicate results (mg/l)	RPD (+/- 15%)
Mar-03	39212K2	3128281	3128282	NO_3	3.53	3.58	1.4
Mar-03	40226B1	3128296	3128297	NO_3	10.2	9.43	7.8
Mar-03	40221J5	3128299	3128300	NO_3	10.8	9.54	12.4
Mar-03	40315L1	3128310	3128311	NO_3	13.9	12.7	9.0
May-03	40303B1	3204252	3204253	NO_3	10.2	11.3	10.2
May-03	40211P1	3204258	3204259	NO_3	4.48	4.12	8.4
May-03	39212K2	3204231	3204232	NO_3	6.17	6.55	6.0
May-03	39221H1	3204238	3204239	NO_3	7.96	7.27	9.1
Jul-03	40303B1	3294253	3294254	NO_3	17.2	17.8	3.4
Jul-03	40211P1	3294259	3294260	NO_3	4.48	4.63	3.3
Jul-03	39211F1	3294232	3294233	NO_3	3	2.93	2.4
Jul-03	40332L1	3294242	3294243	NO_3	11.5	10.3	11.0
Sep-03	39211F1	3384232	3384233	NO_3	1.93	1.95	1.0
Sep-03	40332M2	3384243	3384244	NO_3	14.5	15.2	4.7
Sep-03	40303B1	3384253	3384254	NO_3	17.2	17.4	1.2
Sep-03	40211P1	3384260	3384261	NO_3	6.47	5.77	11.4
Nov-03	40316H1	3464296	3464297	NO_3	6.88	6.96	1.2
Nov-03	39317H1	3474312	3474313	NO_3	8.12	8.04	1.0
Nov-03	39203Q1	3464282	3464291	NO_3	1.25	1.4	11.3
Jan-04	39211F1	4044257	4044258	TPN	2.44	2.48	1.6
Jan-04	40308P1	4044230	4044231	TPN	14.8	14.4	2.7
Jan-04	MW1D	4044240	4044241	TPN	0.31	0.314	1.3
Jan-04	39211F1	4044257	4044258	NO_3	2.21	2.01	9.5
Jan-04	40308P1	4044230	4044231	NO_3	11.2	14.4	**25.0**
Jan-04	MW1D	4044240	4044241	NO_3	0.014	0.016	13.3
Mar-04	41333M1	4104232	4104233	NO_3	16.1	15.9	1.3
Mar-04	40331P3	4104251	4104252	NO_3	10.1	9.66	4.5
Mar-04	40227C1	4104262	4104264	NO_3	23.7	22.2	6.5
May-04	MW1S	4214282	4214283	NO_3	0.17	0.174	2.3
May-04	40226D2	4214294	4214295	NO_3	29.6	27	9.2
May-04	40222D1	4214315	4214316	NO_3	5.98	5.59	6.7
May-04	MW1S	4214282	4214283	TPN	8.28	8.5	2.6
Jul-04	39317H1	4294230	4294231	NO_3	19.9	21	5.4
Jul-04	MW1D	4294233	4294234	NO_3	0.011	0.018	**48.3**
Jul-04	40332M2	4294256	4294257	NO_3	17.1	15.7	8.5
Jul-04	40331P3	4294260	4294261	NO_3	9.31	10.3	10.1
Jul-04	39317H1	4294230	4294231	TPN	20.4	20.3	0.5
Jul-04	MW1D	4294233	4294234	TPN	0.2	0.21	4.9
Jul-04	40332M2	4294256	4294257	TPN	17.1	16.9	1.2
Jul-04	40331P3	4294260	4294261	TPN	11.3	11.6	2.6

Date	Site ID	Sample ID	Sample ID	Parameter	Duplicate results (mg/l)	Duplicate results (mg/l)	RPD (+/- 15%)
Sep-04	40331L1	4384986	4384987	TPN	13.1	11	**17.4**
Sep-04	39317H1	4384950	4384951	NO_3	21	21.2	0.9
Sep-04	40315L1	4384961	4384962	NO_3	15.4	14	9.5
Sep-04	41333M1	4384967	4384968	NO_3	8.17	7.82	4.4
Sep-04	40227C1	4384971	4384972	NO_3	19.9	19.8	0.5
Sep-04	40332M2	4384983	4384984	NO_3	17.6	17.2	2.3
Sep-04	40331L1	4384986	4384987	NO_3	8.88	9.88	10.7
Nov-04	39307H1	4454231	4454232	NO_3	37.4	33.5	11.0
Nov-04	MW2	4454239	4454240	NO_3	17	18.6	9.0
Nov-04	40308P1	4454241	4454242	NO_3	17.5	16.8	4.1
Nov-04	40222D1	4454249	4454250	NO_3	9.08	9.77	7.3
Jan-05	40310F1	5024284	5024285	NO_3	14.6	14.4	1.4
Jan-05	41334 E1	5024288	5024289	NO_3	12.2	11.8	3.3
Jan-05	40223A3	5024294	5024295	NO_3	7.85	7.54	4.0
Jan-05	39212C1	5024302	5024303	NO_3	7.63	7.36	3.6
Jan-05	40214P1	5024308	5024309	NO_3	15.9	16.9	6.1
Jan-05	39307K2	5024316	5024317	NO_3	19	19.5	2.6
Mar-05	39211F1	5094230	5094231	NO_3	6.26	6.31	0.8
Mar-05	40308P1	5094247	5094248	NO_3	13.2	10.9	**19.1**
Mar-05	40226D2	5094257	5094258	NO_3	18.6	18.8	1.1
Mar-05	40227C1	5094264	5094265	NO_3	19.4	17.7	9.2
Mar-05	39211F1	5094230	5094231	TPN	6.63	6.72	1.3
						mean	6.7
						min	0.5
						max	48.3

RPD = relative percent difference
Results outside of acceptable limits are highlighted

Table D-2. Quality Assurance Summary for Laboratory Results of Nitrate (as N).

Date	Sample ID	Duplicate results (mg/l)	Duplicate results (mg/l)	RPD	Control (+/- 20%)	Matrix Spikes ('+/- 25%)
Mar-03	3128289	0.014	0.014	0.0		81.9
Mar-03	3128301	1.6	1.64	2.5		105
Mar-03					106	
Mar-03					102	
Mar-03					106	
May-03	3204237	0.01	0.01	0.0		82.1
May-03					99.7	
May-03					105	
May-03					102	
May-03					93.5	
Jul-03	3294248	0.01	0.01	0.0		**72.1**
Jul-03	3294247	0.01	0.01	0.0		**47.5**
Jul-03	3294231	4.08	3.47	16.2		83.3
Jul-03					99.3	
Jul-03					100	
Jul-03					100	
Sep-03	3384232	1.93	1.68	13.9		NC
Sep-03	3384250	7.49	7.97	6.2		NC
Sep-03					96.6	
Sep-03					96	
Sep-03					99.2	
Nov-03	3464285	8.99	9.94	10.0		
Nov-03	3464282	1.25	1.26	0.8		
Nov-03	3464300	6.62	5.84	12.5		
Nov-03	3464280					81.7
Nov-03	3464281					90.5
Nov-03	3464299					96.7
Nov-03					97.4	
Nov-03					99.4	
Nov-03					103	
Nov-03					101	
Jan-04	4044258	2.01	2.24	10.8		
Jan-04	4044230	11.2	10.3	8.4		
Jan-04	4044257					106
Jan-04	4044233					102
Jan-04					106	
Jan-04					104	
Jan-04					101	
Jan-04					105	
Mar-04	4104241	0.013	0.013	0.0		
Mar-04	4104240					**66.7**
Mar-04					101	
Mar-04					100	
Mar-04					98.8	
May-04	4214283	0.174	0.178	2.3		
May-04	4214300	18.6	17.2	7.8		

Date	Sample ID	Duplicate results		RPD	Control (+/- 20%)	Matrix Spikes ('+/- 25%)
		(mg/l)	(mg/l)			
May-04	4214282					82.5
May-04	4214307					83.9
May-04					104	
May-04					106	
Jul-04	4294233	0.011	0.012	8.7		
Jul-04	4294254	2.85	2.93	2.8		
Jul-04	4294232					**74.2**
Jul-04	4294253					89.2
Jul-04					102	
Jul-04					103	
Sep-04	4384953	3.34	3.31	0.9		83.5
Sep-04	4384971	19.9	20	0.5		
Sep-04	4384990	0.366	0.371	1.4		101
Sep-04	4384970					95.1
Sep-04					100	
Sep-04					100	
Sep-04					101	
Nov-04	4454238	0.01	0.01	0.0		
Nov-04	4454254	0.106	0.102	3.8		103
Nov-04	4454237					85.3
Nov-04					107	
Nov-04					110	
Jan-05	5024298	2.71	2.76	1.8		
Jan-05	5024314	15.3	15.3	0.0		76.5
Jan-05	5024296					79.5
Jan-05					87.9	
Jan-05					91.1	
Jan-05					102	
Mar-05	5094254	15.4	15.4	0.0		88.9
Mar-05	5094260	2.65	2.66	0.4		93
Mar-05					103	
Mar-05					101	
Mar-05					101	

RPD = relative percent difference.
Results outside of acceptable limits are highlighted.

Sep-03 NC = not calculated. Matrix spike recoveries were not calculated since the native source concentrations were considerably greater than the spike; therefore, the recoveries were insignificant.
Jul-03 Matrix interference
Mar-04 Outside limits
Jul-04 294232 estimated

Table D-3. Quality Assurance Summary for Laboratory Results of Total Persulfate Nitrogen.

Date	Sample ID	Duplicate results (mg/l)	(mg/l)	RPD	Control (+/- 20%)	Spikes (+/- 25%)
Jan-04	4044234	13.2	13.9	5.2		
Jan-04	4044241	0.314	0.313	0.3		
Jan-04	4044233					75.8
Jan-04	4044240					96.2
Jan-04					106	
Jan-04					108	
Jan-04					105	
Jan-04					117	
Mar-04	4104249	12.2	11	10.3		
Mar-04	4104240					105
Mar-04					113	
May-04	4214308	7.45	7.57	1.6		
May-04	4214291					103
May-04					103	
May-04					102	
Jul-04	4294234	0.21	0.21	0.0		
Jul-04	4294253	3.71	3.72	0.3		99.5
Jul-04	4294233					97
Jul-04					103	
Jul-04					104	
Sep-04					89.2	
Nov-04					104	
Jan-05	5024311	0.277	0.278	0.4		
Jan-05	5024310					97.7
Jan-05					96.2	
Mar-05	5094239	0.279	0.279	0.0		
Mar-05	5094238					78.2
Mar-05					101	

RPD = relative percent difference.
Results outside of acceptable limits are highlighted.