Thurston County

Water Resources Monitoring Report
1997 - 1998 Water Year

Report Includes:

Water Quality
Stream Flows
Lake Levels
Precipitation
Groundwater Data

October 1999

Prepared by:

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In Cooperation With:

City of Olympia Public Works, Water Resources Program
City of Lacey Public Works, Water Resources Program
City of Tumwater Public Works Department
Washington State Department of Ecology

THURSTON COUNTY · LACEY · CITY OF TUMWATER · City of OLYMPIA · WASHINGTON STATE DEPARTMENT OF ECOLOGY

Ground Water Monitoring Report 1997-1998 Water Year

This section contains ground water quantity and quality data collected by the Thurston County Environmental Health Division during the 1997-1998 water year (October 1997 through September 1998). The County has a monitoring network in both the north and south parts of the County. This is the third year a summary of the ground water data has been included in the annual Water Resources Monitoring Report. Figure 1 shows the locations of all of the regularly monitored wells throughout the county.

The North County ground water data presented in this report was collected under the regional ground water program which was established and is funded by an agreement between Thurston County and the incorporated municipalities of Lacey, Olympia and Tumwater. This regional ground water program area has been designated as Ground water Management Area No. 10, North Thurston County by the State Department of Ecology. Ground water monitoring data and interpretation) are the focus of this report.

The South County monitoring was funded through a variety of funds, including the Thurston Conservation District, the Thurston County Environmental Health Department and the State Department of Health. The South County monitoring is focused on areas where ground water problems have already been identified.

The objectives of the ground water monitoring program are to:

- Collect baseline information about the quantity and quality of ground water in North Thurston County through an ambient monitoring network;
- Evaluate data to assess trends in flow and quality;
- Monitor existing drinking water wells at selected agricultural facilities in the southern part of the county;
- Identify and investigate problem areas and areas of concern.

Where possible and appropriate, data collected during the 1997-1998 water year are compared to data collected previously by the County, samples submitted by well owners, and the United States Geological Survey (USGS). In 1989 the USGS conducted a large ground water sampling effort to investigate the hydrology and quality of ground water in northern Thurston County (B.W.Drost, et al. 1998).

Monitoring Methods

Water Quantity

Ground water levels were measured from the top of the well casing to the nearest tenth or hundredth of a foot below ground surface using an electric tape well probe. Static water level conditions were measured when access was possible. A few wells are either buried underground or there are no available holes in which to slip the e-tape. A majority of the wells monitored are residential wells. Water levels were taken under static conditions at the well. In some cases the well pump was active upon arrival. After the pump shut down, the water level was monitored as it rose until it was static for at least five minutes. The last measurement was then recorded. The effects of long-term pumping at the well or near-by wells are possibly reflected in the water level measurements.

Water level data measured relative to depth below ground surface (BGS) were converted to equivalent elevations relative to mean sea level (MSL) to better understand relative conditions between aquifer levels.

Most well locations were not surveyed; locations by latitude and longitude and elevation were determined from topographic maps or from digitized aerial photographs. Elevation data was collected from digitized two-foot contour maps (reported to the tenth of a foot) or surveyed (reported with elevation to the hundredths of a foot).

Water Quality

Water quality data collected for the ambient monitoring network consist of parameters measured in the field at the time of sample collection, and chemical data analyzed in a laboratory after sample collection. Samples were collected as near the wellhead as possible; generally a faucet is available between the well and the pressure tank. If samples were collected after the holding tank, additional volume was purged. Water systems that included water treatment units (*e.g.*, water softeners) were either sampled before the treatment unit or the unit was turned off at the beginning of the purge process.

Parameters measured in the field at the time of sample collection included pH, specific conductance (μS/cm), temperature (°C) and dissolved oxygen (mg/L). A Hydrolab multi-parameter field instrument was used to measure these parameters while well water was actively being purged prior to sample collection. Well diameter, well depth and water level information were used to estimate the volume of water needed to be removed from the well casing to obtain a sample representative of formation (aquifer) water. Formation water was assumed to be actively recharging the well casing when, at a minimum, field parameters have stabilized. A sample was collected after field parameters had stabilized or when at least three casing volumes had been removed from the well.

Figure 1 - Thurston County Groundwater Monitoring Sites 1997-99

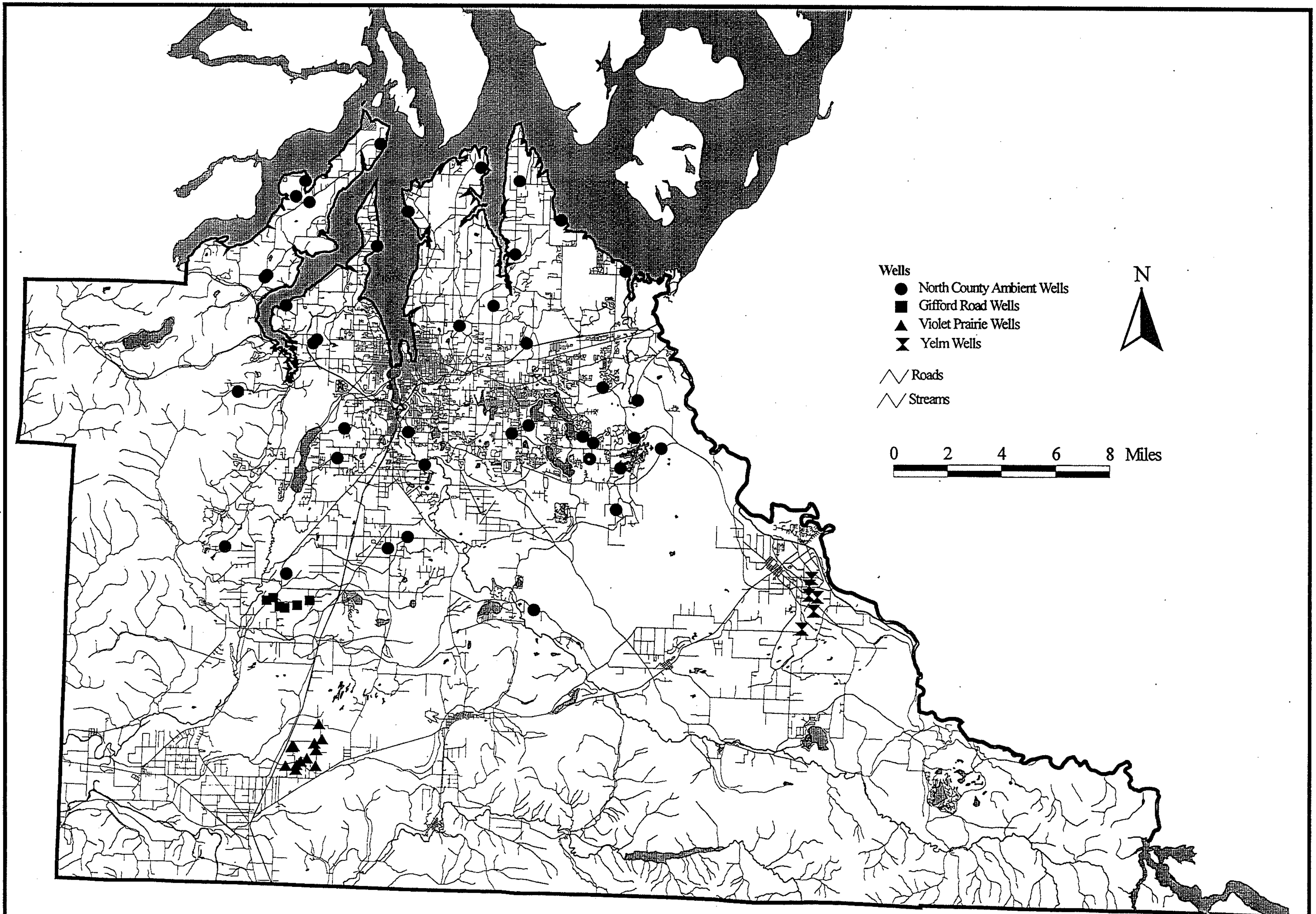
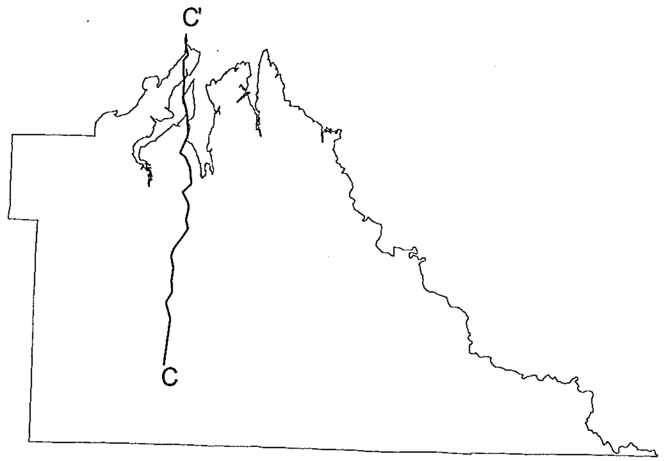
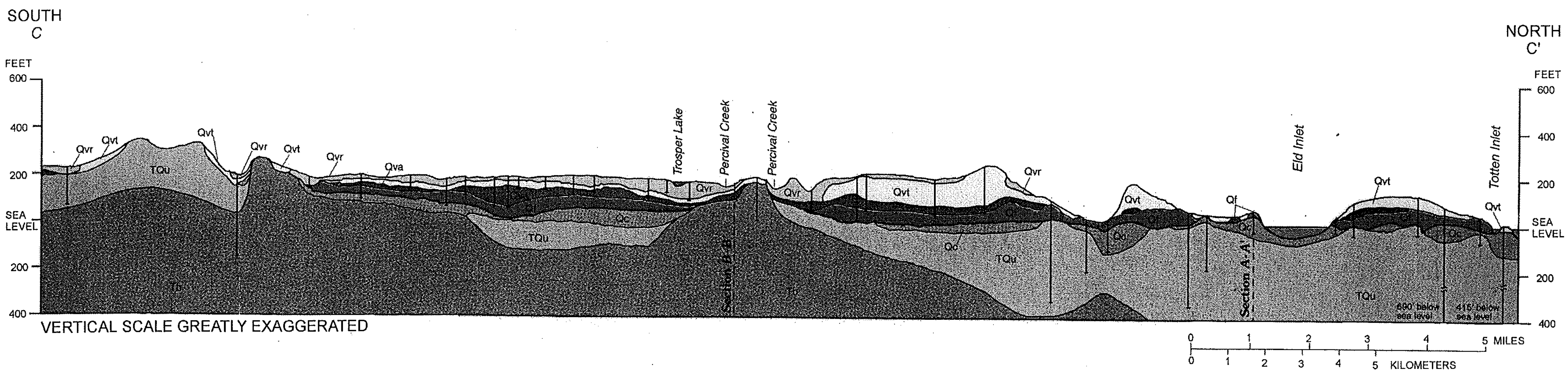


Figure 3 - USGS cross-section of Thurston County showing the hydrogeologic layers (Drost, *et al.*, 1998, Plate 1)





Qvr - Vashon recessional outwash
Qvt - Vashon till
Qva - Vashon advance outwash

Qf - Kitsap Formation
Qc - penultimate deposits
TQu - undifferentiated deposits

Tb - bedrock

Vertical lines represent the wells (and associated well-logs) used to create the cross-section.

Chemical parameters, including nitrate+nitrite, total iron and total manganese, were analyzed at a Washington Department of Ecology accredited analytical laboratory. Samples were collected directly into bottles provided by the lab, were capped, labeled, and stored in a cooled ice chest (4° C). Back in the office, the samples were transferred to a refrigerator until shipped to the lab for analysis. Chain of custody forms were submitted with each sample shipment.

Appropriate quality assurance/quality control measures were conducted by the laboratory. A replicate sample was taken for every 20 samples and submitted "blind" to the laboratory so that the combined field and laboratory variability could be assessed. None of the data were reported as unusable or "flagged" by the lab. More detailed quality control data is provided in the Results section (page 370).

Water Quality Standards

The Washington State drinking water standards are established in Chapter 246-290 WAC. The maximum contaminant levels (MCL's) for measured parameters are provided in Table 1. The primary standards are based upon health criteria; the secondary standards are based upon aesthetic considerations, such as taste and staining potential.

In addition to the drinking water standards, Washington State has Ground Water Quality Standards, Chapter 173-200 of the Washington Administrative Code (WAC). These standards were developed with the understanding that it is much more expensive to clean contaminated ground water than to prevent contamination in the first place. Depending upon the type and amount of contaminant and the location, it may be impossible or economically unfeasible to clean the water so that it could be used for drinking water. Under Chapter 173-200 degradation of ground water is acceptable only when: 1) it is in the overriding public interest and, 2) when all known, available, and reasonable methods of prevention, control, and treatment are used.

It is important to recognize that the drinking water standards, such as the nitrate standard at 10 mg N/L, are not the amount to which it is acceptable to pollute ground water; it is the level of contaminant that is considered unsafe to drink. Chapter 173-200 states that it is not acceptable to pollute ground water without taking the available steps to minimize or eliminate the impacts.

With the above in mind, Thurston County has adopted a resolution that acts as a warning system for areas with polluted ground water. Using an Early Warning Level of 2 mg N/L nitrate and a Contaminant Action Level of 4 mg N/L nitrate, the County monitors the situation or implements an appropriate response to prevent further contamination of the ground water.

Table 1 Drinking Water Standards		
Parameter	**Primary Maximum Contaminant Level**	**Secondary Maximum Contaminant Level**
Nitrate as N	10.0 mg/L	--
Total Iron	--	0.3 mg/L
Total Manganese	--	0.05 mg/L
Specific Conductivity	--	700 μmhos/cm

Monitoring Programs

There were two separate well monitoring programs conducted in Thurston County during the 1997-98 water year. The North County Ambient Monitoring Network consisted of 40 wells scattered throughout northern Thurston County which were selected to represent the ambient ground water condition.

There were also three impact studies in southern Thurston County. These studies were focused upon agricultural activities (dairies and poultry facilities) and were located at:

- **Gifford Road** - two wells upgradient and four wells downgradient from a dairy
- **Violet Prairie** - a total of 13 wells surrounding two dairies and a poultry operation
- **Yelm** - two wells upgradient and four wells downgradient from a poultry facility

These wells were selected to evaluate the impact the agricultural activities are having on the nitrate concentrations in drinking water aquifers. Static water levels and nitrate+nitrite, total iron and total manganese samples were taken twice a year. Location maps and the results from the South County study areas follow the North County section (page 372).

North County Ambient Monitoring Network

The North County monitoring effort was established in 1995; the area of study and wells monitored were based upon the 1989 US Geological Survey study of the northern Thurston County hydrogeology. The results of the USGS study were detailed in the 1998 report, *Hydrology and Quality of Ground Water in Northern Thurston County, Washington*, by B.W. Drost, G.L. Turney, N.P. Dion and M.A. Jones (Water-Resources Investigations Report 92-4109 [Revised]). Those who wish for a more detailed description of the hydrogeology of northern Thurston County can obtain a copy of the report from the Thurston County Environmental Health, Resource Protection Section.

Of the 40 North County ambient monitoring wells, 32 are residential wells, two are owned by businesses, three are owned by private water purveyors, and three are owned by local jurisdictions (Thurston County, City of Olympia and City of Lacey). Figure 2 shows the locations of the wells. Permission was obtained from all owners before including the wells in the monitoring network. Figure 2 shows the locations of wells used in the ambient monitoring network. All of the wells monitored by Thurston County are given a well ID number, such as 17N/01E-06C01; this represents a well in Township 17 North, Range 1 East, Section 6, quarter-quarter section area C (see box to right), well number 1. The Township, Range, and Section numbers in Figure 2 can be used to identify the well ID numbers.

¼-¼ Section Numbers			
D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

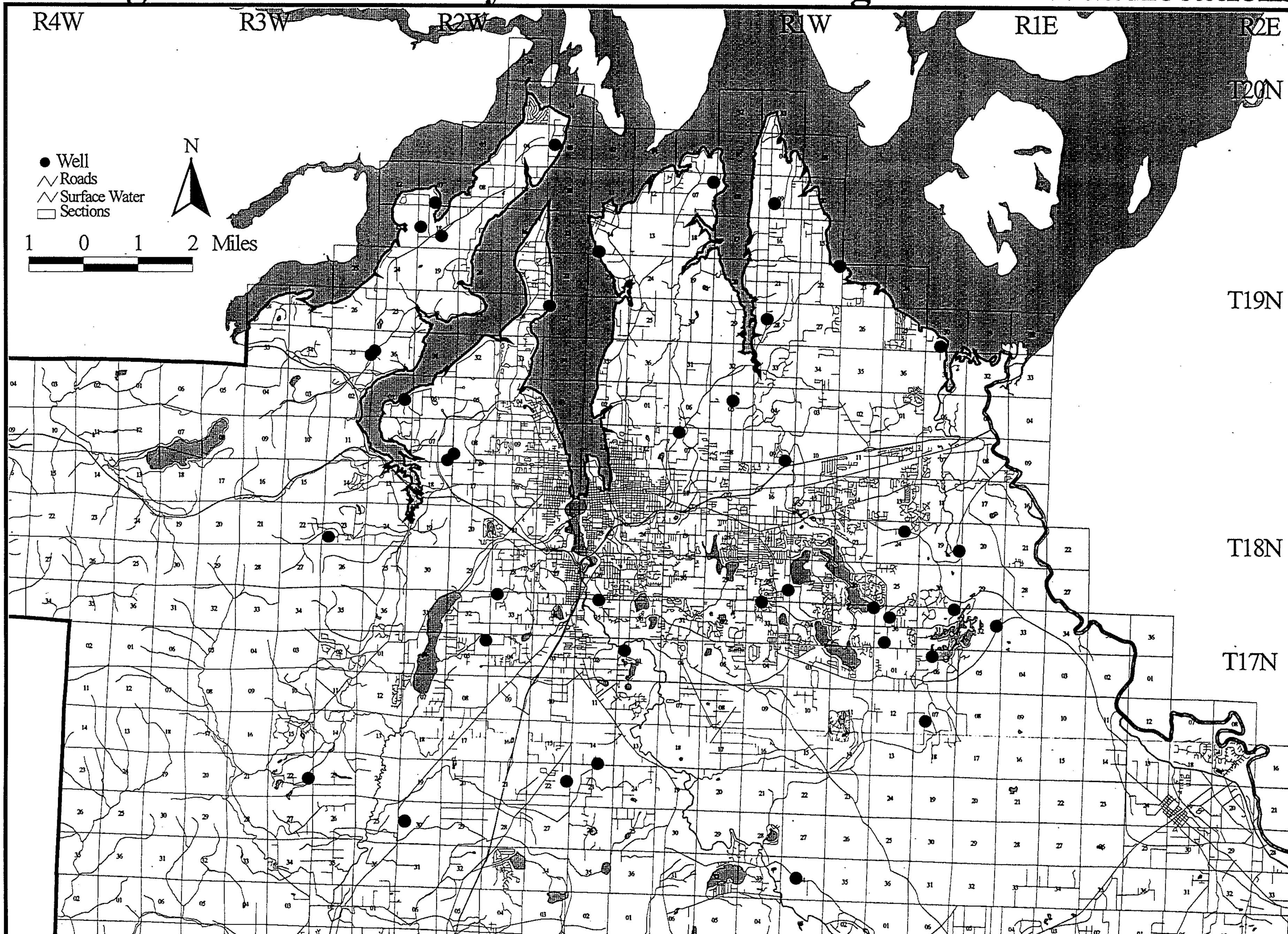
Geohydrologic Units

In general the geology of northern Thurston County consists of seven distinct layers. Some layers, like the recessional and advance outwashes are made up of sands and gravels that allow water to flow through and are used as aquifers. Other layers are aquitards; cemented materials (till) or clays that restrict the flow of water and provide some protection from pollutants to aquifers underneath. Such layers that restrict the vertical movement of water are also refered to as confining beds.

The following geologic framework was adapted from B.W. Drost, *et al.* (1998, p 7) and describes the seven major geologic layes underneath Thurston County from the top down (from youngest to oldest):

> Continental glaciers advanced into Thurston County at least twice during the Pleistocene Epoch. The most recent glaciation of the study area, referred to as the Vashon Stade of the Fraser Glaciation, began about 15,000 years ago when the climate cooled and a great continental ice mass formed in British Columbia, Canada. This glacier slowly moved southward, blanketing the entire Puget Sound basin. The southern part of Thurston County, near Tenino, is generally regarded as the southern-most extent of the continental glaciation in western Washington.
>
> The Vashon recessional outwash, formed when the climate warmed and the glacier retreated northward, consists of sands and gravels laid down by streams emanating from the melting and receding glacier. The receding glacier also left behind areas of hummocky terrain with depressions (kettles) north and southeast of Lake St. Clair and southwest of Black Lake. Numerous lakes in Thurston County are the result of kettles being below the water table, such as Lake St. Clair, Hewitt Lake and Ward Lake. The Vashon recessional outwash layer is labeled *Qvr*.
>
> Generally, Vashon recessional outwash is underlain by Vashon glacial till (hardpan). The till is made up of deposits of sand, gravel and boulders encased in

Figure 2 - North County Ambient Monitoring Network Well Locations



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a matrix of clay and silt. This layer is compact where it was formed under the weight of the glacier and less compact where it was formed during the glacial retreat. The Vashon till layer is labeled *Qvt*.

Ahead of the glacial advance, large amounts of stratified sand and gravel were deposited by meltwaters at the front and sides of the glacier. This Vashon advance outwash is typically made up of rounded gravels in a sand matrix, with some sand lenses. The Vashon advance outwash layer is labeled *Qva*.

Beneath the advance outwash is a generally fine-grained clay and silt layer described as the Kitsap Formation. This layer is thought to have been deposited by water in shallow lakes and swamps and is probably not a result of glaciation. Kitsap Formation can be seen at the surface along several stretches of the Puget Sound shoreline, typically occurring as high vertical bluffs. Kitsap Formation layer is labeled *Qf*.

Lying underneath the Kitsap Formation, the penultimate deposits are the leavings of the glacier before the Vashon glacier. The penultimate deposits are layered sands and gravels commonly stained with iron oxides. This layer is labeled *Qc*.

The sixth layer is a mish-mash of materials, believed to be of both glacial and nonglacial origins. The undifferentiated deposits overlay the bedrock and can be up to 1,800 feet thick. These deposits are labeled *TQu*.

The last layer is bedrock, or consolidated rocks in technical terms. Bedrock in Thurston County is a mix of claystone, siltstone, sandstone, and some beds of coal. In the Black Hills and near Tumwater, the bedrock is basalt. Bedrock is labeled *Tb*.

Figure 3 shows a cross-section of Thurston County along a line stretching from south of Littlerock north through the West Side (Cooper Point) and ends at Steamboat Island. The cross-section was generated by the USGS (B.W.Drost, *et al.*, 1998, Plate 1) using well logs to determine the depth and location of the various geohydrologic layers.

Table 2 summarizes the numbers of wells that withdraw water from each of the aquifers in Thurston County and the typical thickness of each layer. The Vashon till unit is generally not a water-bearing formation and is included in Table 2 for reference only. Geohydrologic units are listed on Table 2 in order from shallowest (Vashon recessional outwash) to deepest (Bedrock).

Table 2 Geohydrologic Units and Well Elevations North County Ambient Monitoring Network			
Geohydrologic Unit		**Number of wells**	**Typical thickness of unit[1] (feet)**
Vashon recessional outwash	Qvr	2	10-50
Vashon till	Qvt	0	20-60
Vashon advance outwash	Qva	17	15-35
Kitsap Formation	Qf	2	15-70
Penultimate deposits	Qc	12	15-50
Undifferentiated deposits	TQu	4	unknown
Bedrock	Tb	3	unknown

[1]Values taken from B.W. Drost, *et al.*, 1998, Table 1

The hydrogeologic characteristics of each of the seven units listed on Table 2 vary substantially. The units are listed in order from shallowest (youngest) to deepest (oldest). The three uppermost units were deposited by a single geological event, the Vashon glacial advance and retreat.

The Vashon recessional outwash (Qvr) is an unconfined sand-and-gravel aquifer that yields adequate volumes of water where saturated or where water is locally perched. In some areas it is an important aquifer, but in much of the county it is too thin to be a reliable aquifer. As the shallowest aquifer, it is also the most susceptible to pollution. It has a very high degree of interaction with surface water bodies. This unit is primarily of glacial origin but includes some recent stream deposits.

The Vashon till (Qt) is a confining unit of compact unsorted sand, gravel and boulders in a matrix of silt and clay. Although the till is not a reliable producer, thin lenses of clean sand and gravel do yield usable amounts of ground water; none of the network wells tap these lenses. In parts of northern Thurston County, late glacial period lake clay deposits are included within the till unit.

The till unit has an extremely important effect on the flow of shallow ground water in Thurston County. It can act as an important protective layer, partially shielding wells from surface pollution and diverting flows to surface water. It is also responsible for ground water flooding in parts of Thurston County by greatly reducing the rate at which shallow ground water can move downward during periods of high rainfall. Groundwater flooding due to high seasonal rainfalls has affected areas south of Tumwater and off Littlerock Road from 1996 through 1999. These areas had similar flooding in the 1970's due to above-average rainfall.

The Vashon advance outwash (Qva) is the uppermost major sand-and-gravel aquifer, which generally yields abundant ground water for public supplies mostly under confined conditions. In some areas, this unit may be relatively thin and often is more sand than gravel. This aquifer also has a significant amount of interaction with surface water, especially the larger streams such as the Deschutes and Nisqually Rivers.

The Kitsap Formation (Qf) is a clay-and-silt confining unit with lenses of sand and gravel that provide some limited yield of ground water. This nonglacial unit is older than the Vashon deposits and can best be seen along some of the marine shoreline bluffs of northern Thurston County.

The confined Penultimate deposits (Qc) also serves as a major aquifer in the county and supplies water to McAllister and Allison Springs and many major municipal wells. It represents sediments laid down during the next-to-last (penultimate) glaciation. It is sometimes referred to as the "sea-level aquifer" because its top is found near sea level in the northern part of Thurston County. The water from this aquifer generally discharges directly into Puget Sound without much interaction with other surface waters.

The Undifferentiated deposits (TQu) layer contains both aquifers and confining beds. This layer is tapped by only a few wells in the county because of its depth. The four monitored wells in this layer are between 112 and 336 feet deep. Not enough is known about the undifferentiated deposits to make it a completely predictable aquifer, and it commonly has water quality problems. Many wells tapping this unit produce water with high levels of iron and manganese, and in some cases hydrogen sulfide and iron bacteria. In northeastern Thurston County, this unit is up to 1,800 feet thick. In spite of its limitations, this unit is expected to be an increasingly important source of water in the future. The reasons for this are its thickness, and therefore the amount of available water and the general lack of hydraulic continuity with surface water.

With the federal government listing of several native species of salmon as threatened, surface water uses, as well as new water withdraws from the shallow aquifers that feed the steams and rivers, will be under much tighter regulation and review. Deeper aquifers, not connected with surface waters, will be of increasing importance as population growth demands increased ground water quantity.

The Bedrock unit (Tb) is generally unreliable as an aquifer, but locally does provide limited volumes of water that are contained in fractures and joints. The bedrock unit consists of dark volcanic rocks (basalt and andesite) in the Bald and Black Hills and sandstone and claystone in the Maytown uplands and Michigan Hill areas.

Table 3 provides elevation data, the formation tapped, and identification number for each well in the North County network. Most wells consist of six-inch diameter steel casing and are open at the bottom.

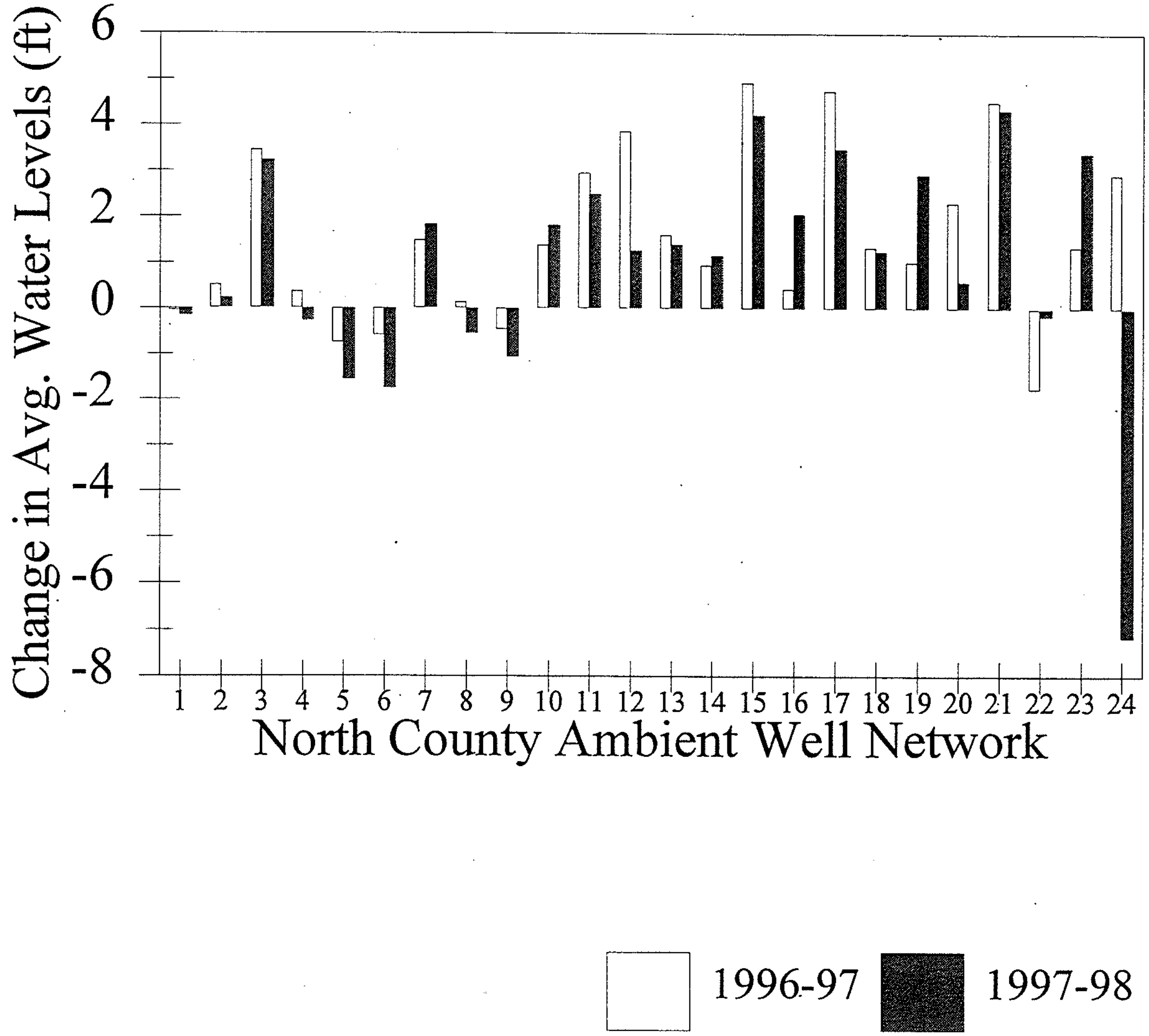
Table 3
Well ID's and Elevations
North County Ambient Monitoring Network

Aquifer	Well ID	Elevation* (feet above MSL**)	Well Depth (feet BGS**)	Elevation of Bottom of Well (feet above MSL)
Qvr	17N/02W-05A02	157.9	32	125.9
	18N/01W-35A04	160.4	32	128.4
Qva	17N/01E-06C01	104.8	52.1	52.7
	17N/01E-07L01	214	72	142
	17N/02W-01E02	176.7	92	84.7
	17N/02W-14Q02	192.6	40	152.6
	17N/02W-22H02	199.2	66.7	132.5
	17N/03W-22J01	185.7	98	87.7
	18N/01W-05G02	114.8	56	58.8
	18N/01W-07C01	172.2	62.5	109.7
	18N/01W-24B02	224.9	103	121.9
	18N/01W-28J01	183.4	127	56.4
	18N/01W-33C01	206.9	73	133.9
	18N/01W-36N01	219.2	180	39.2
	18N/02W-07R01	164.8	125	39.8
	18N/03W-23N01	332.4	41	291.4
	19N/01W-09L02	185.1	90	95.1
	19N/03W-35J02	161	113	48
	19N/03W-36E03	144.5	94	50.5
Qf	18N/02W-08N03	161.0	120	41.0
	19N/02W-18M01	60.2	71	-10.8
Qc	18N/01E-31A01	85.4	92	-6.6
	18N/01E-32H02	251.3	216	35.3
	18N/01W-09J01	109.4	195	-85.6
	18N/02W-35B02	185	157	28
	18N/03W-01J02	68.8	75	-6.2
	19N/01E-30P06	161.4	186	-24.6
	19N/01W-07A01	91.0	79	12.0
	19N/01W-28F02	117.7	98.6	19.1
	19N/02W-03E02	70	90	-20
	19N/02W-07P02	78.1	99	-20.9
	19N/02W-14P02	154.7	222	-67.3
	19N/02W-27D04	50.0	115	-65.0
TQu	18N/01E-19J02	40.6	92.5	-51.9
	18N/01W-36C02	201.5	336	-134.5
	19N/01W-22A01	63.4	143	-79.6
	19N/02W-18K02	131.8	166	-34.2
Tb	17N/01W-34L02	280.8	125	155.8
	17N/02W-30E03	186.7	146	40.7
	18N/02W-33C01	217	304	-87

* Elevation was determined to the nearest foot using digital aerial photographs and digitized two-foot contours and represents ground surface. Elevations reported to the tenth-of-a-foot include the well stick-up and are the measuring point for water levels.
**MSL - mean sea level (NGVD of 1929) - BGS - below ground surface

Figure 4 - Change in Well Water Levels

Baseline is 1995-96 Avg. Water Level



Well Label	Aquifer	Well ID#
1	Qvr	17N/02W-05A02
2		18N/01W-35A04
3	Qva	17N/01E-06C01
4		17N/02W-01E02
5		17N/02W-14Q02
6		17N/02W-22H02
7		18N/01W-05G02
8		18N/01W-07C01
9		18N/01W-24B02
10		18N/01W-28J01
11		18N/01W-33C01
12		18N/01W-36N01
13		18N/02W-07R01
14		18N/03W-23N01
15	Qf	18N/02W-08N03
16		19N/02W-18M01
17	Qc	18N/01E-31A01
18		18N/01W-09J01
19		19N/01W-28F02
20	TQu	18N/01E-19J02
21		18N/01W-36C02
22		19N/01W-22A01
23		19N/02W-18K02
24	Tb	18N/02W-33C01

Water Levels

Water levels were measured quarterly in October of 1997 and February, May and August of 1998. Due to inaccessibility, water levels were not measured at all wells during all four quarters.

Figure 4 compares the average static water levels of the 24 wells that were measured in 1995-96, 1996-97 and 1997-98. The 1995-96 average static water level was used as a baseline for comparison purposes. Two-thirds of the wells had higher average water levels in 1996-97 and 1997-98 than the baseline. The remaining wells were less than two feet lower than the baseline. The exception to this is the 24th well, ID# 18N/02W-33C01.

Well ID# 18N/02W-33C01 is a 304 foot deep well that withdraws water from the Tb (bedrock) aquifer. Normally, the water level in this well is around 40 feet below the ground. However, in September 1995 and July 1998, the water level dropped to 85 and 94 feet below the ground, respectively. There was little information on the amount of water the well produced at the time it was drilled or on the amount of drawdown (the lowering of the water level in the well after water is pumped out). Generally, water in bedrock formations lies in fractured areas and is of limited quantity. It is not uncommon to have large drawdowns due to the slow movement of water back into the well casing after pumping.

Figure 5 shows a summary of forty years of water level data available for well 18N/02W-07R01. Water levels at this well appear to have been stable over the past forty years. Long-term data are not available for other wells in the ambient monitoring network. This well draws water from the Vashon advance unit at an elevation of 45 feet MSL (or a depth of about 125 below ground surface). The Vashon advance is the shallower of the two most frequently tapped aquifers in the county.

A comparison of the 1997-98 water year annual low and high water levels with historical data indicate that water levels at this locale have remained relatively stable. However, the gradual rise in static water level since water year 1994-95 matches the gradual increase in yearly rainfall for the county (Figure 6). In the decade preceding the 1994-95 water year, eight years had below-average rainfall, compared to three consecutive years of above-average rainfall (1994-95 through 1996-97). Additional, continuous monitoring of water levels at this well will help determine the Qva aquifer's sensitivity to long-term rainfall patterns.

It is important to monitor water levels over time in order to assess the rate of water withdraws compared to recharge (via rainfall). A steady decrease of water levels over a few years would suggest that water withdraws are occurring at a greater rate than recharge. This could be the result of increasing development pressure, or long-term changes in rainfall patterns. Such information will be crucial in assessing the aquifers' ability to provide an adequate supply of high quality water for a growing population while maintaining necessary base flows to surface water bodies.

Figure 5 - Long Term Water Levels

Well ID# 18N/02W-07R01

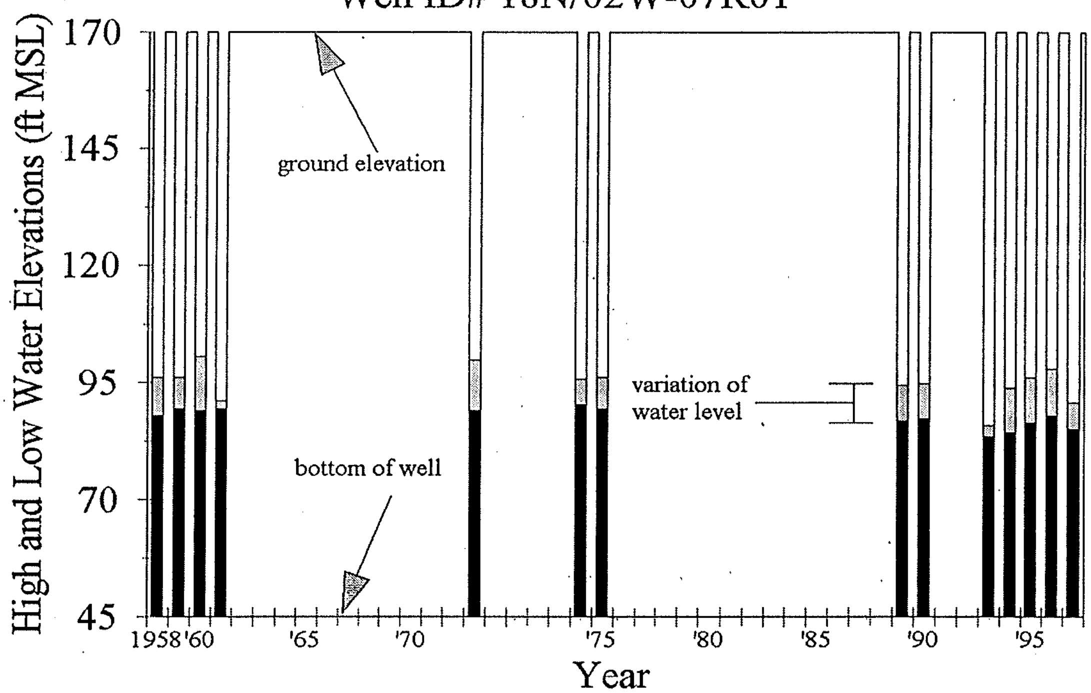
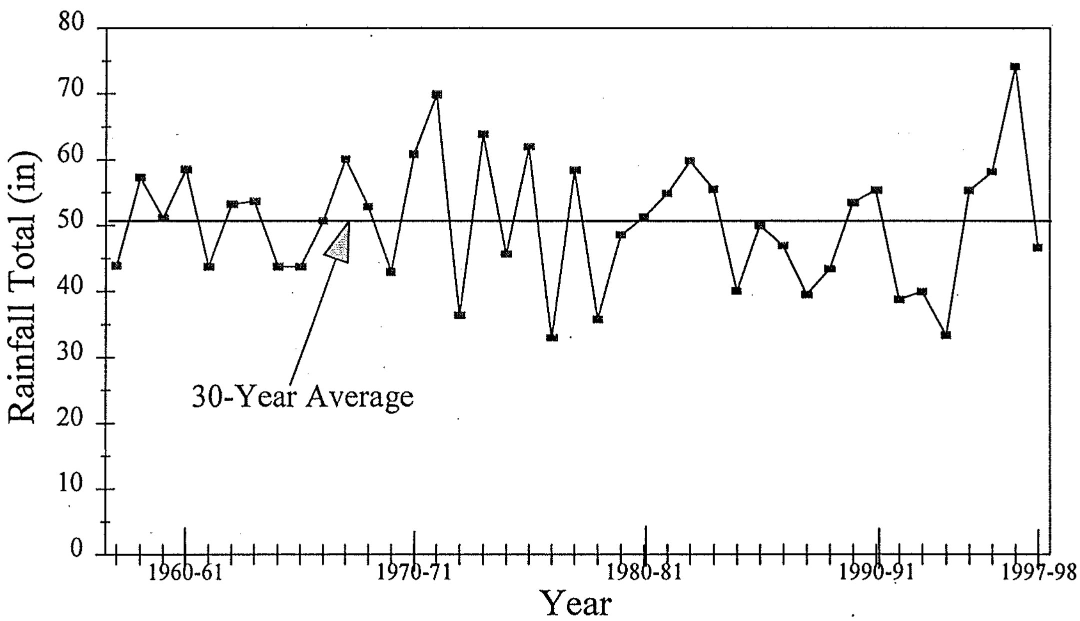


Figure 6 - Yearly Rainfall Totals*

By Water Year (October - September)



*Rainfall data provided by NOAA at the Olympia Airport

Water Quality. The following discussion on the North County ambient monitoring network presents water quality data for both field and analytical constituents. Field parameters were collected at 37 wells; the remaining three wells were used to collect water level data only.

Field Parameters

Table 4 provides basic statistics of field parameter data for wells in the ambient monitoring network, including minimum, maximum, and average values. The 1996-97 and 1997-98 values are presented. Nitrate values are discussed separately on page 368. Appendix A provides detailed field parameter and nitrate data for all wells in the North County ambient network. Of the six hydrogeologic units tapped by the ambient monitoring network, most data were collected from the Vashon advance outwash (n=16) and the Penultimate deposits (n=12).

In general, there was little change in the field parameters between 1996-97 and 1997-98. pH, conductivity, temperature and dissolved oxygen values in 1997-98 were very similar to the previous year's values, as well as to data collected in 1995-96.

Specific conductance is the only field parameter for which a (secondary) maximum contaminant level (MCL) has been established - 700 µmhos/cm @ 25 °C. All conductivity values were below the standard; the highest value was 600, at well 17N/01W-34L02. This well had exceeded the standard the previous year, with a conductivity of 822 µmhos/cm @ 25 °C in April 1997. Data was not collected on this well in 1995-96. This well had a conductivity of 700 µmhos/cm @ 25 °C in June 1989 (Drost and others, 1998). This well draws its water from bedrock in an area where groundwater commonly contains high levels of chloride. The chloride is thought to have originated as connate seawater; in other words sea water that was trapped in the bedrock at the time it was deposited (Noble and Wallace, 1966).

Specific conductance and pH tend to increase with depth. This results from the water in the deeper aquifers generally having spent more time in contact with the rocks that make up the aquifer framework. This has allowed the water to dissolve more minerals from the rocks. The pH levels also increase with depth for the same reason. The pH is highest in the bedrock because as the local volcanic bedrock weathers and breaks down it produces calcite. The easily-dissolved calcite (calcium carbonate) acts as a chemical base, increasing the pH.

The deeper aquifers also tend to have lower levels of dissolved oxygen and nitrate because both constituents originate from above. Dissolved oxygen comes from natural contact with the atmosphere and nitrate originates primarily as a contaminant from human activities (both residential and agricultural) at the surface.

Water from the Vashon advance outwash (Qva) is slightly acidic to neutral as indicated by the pH values. The low specific conductance values indicate the water is relatively soft and does not contain substantial amounts of inorganic salts, organic matter or dissolved gases. It is well oxygenated and, with an average dissolved oxygen content of 6.2 mg/L, is oxidizing. A high value of 15.6 mg/L indicates relatively recent recharge events and that the water may be slightly corrosive.

Field parameters for the shallow Vashon recessional outwash (Qvr) are few in number (n=2); available data indicate that field conditions are similar to those for the Vashon advance outwash.

The field parameter data appear to show that wells in the Kitsap Formation and the shallower aquifers are chemically similar in most parameters and the three deeper aquifers appear to form another chemically similar group. This pattern is generally similar to the patterns found in the 355 wells in northern Thurston County sampled in 1989 by Drost and others (1998).

Field parameters measured for the Penultimate deposit (Qc) show minor but consistent differences from the Vashon advance outwash. The median pH for the Vashon advance outwash was slightly acidic at 6.8, while the median pH for the Penultimate deposit was slightly higher at 6.9. Lower concentrations of dissolved oxygen (average = 1.8 mg/L) in the Penultimate deposit are consistent with what is generally expected for water in deeper aquifers with a longer residence time and a slower rate of recharge. Specific conductance is slightly higher while nitrate is significantly lower.

Too few data points are available for the undifferentiated deposits (TQu) (n=2) and Tertiary bedrock (Tb) (n=3) to make significant conclusions about the aquifers. However, field parameter values do indicate alkaline conditions (higher pH) and much lower oxygen levels than for the units above the Penultimate deposits. Alkaline conditions are typically associated with waters quite low in dissolved oxygen. This combination of high pH and low oxygen levels is consistent with that identified by the USGS investigation (Drost and others, 1998) for these deeper deposits, and likely reflects the effect of slower recharge rates and longer contact time between ground water and aquifer materials. The longer contact time also allows more minerals to be dissolved into the water, increasing the conductivity, alkalinity, and buffering capacity of the water.

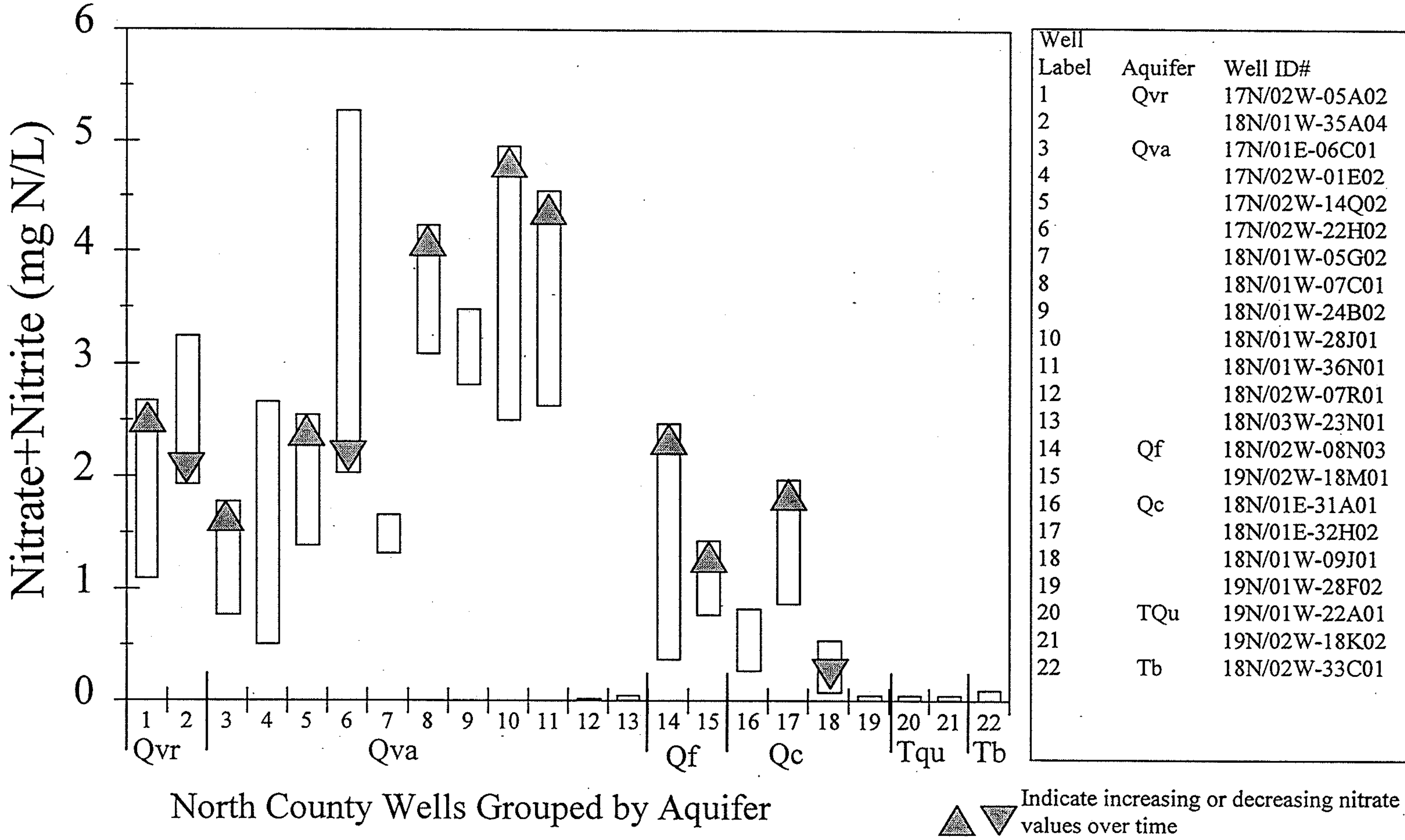
Table 4
Monitoring Parameter Data Summary
1996-97 (*in italics*) and 1997-98 Minimum, Maximum and Average Values
North County Ambient Monitoring Network

Aquifer		Number of Wells Sampled	pH*	Specific Conductance (µmhos/cm @ 25 °C)	Temperature (°C)	Dissolved Oxygen (mg/L)	Nitrate+Nitrite (mg N/L)	Total Iron† (mg/L)	Total Manganese† (mg/L)
Vashon recessional outwash **Qvr**	Min	*2* / 2	*6.1* / 5.9	*125* / 122	*10.5* / 10.5	*2.9* / 3.1	*2.44* / 1.87	<0.1	0.005
	Max		*7.0* / 6.8	*142* / 138	*10.6* / 11.0	*6.9* / 5.5	*2.52* / 3.00	<0.1	0.088
	Avg		*6.6* / 6.7	*134* / 130	*10.5* / 10.8	*4.9* / 4.1	*2.48* / 2.25	<0.1	0.058
Vashon advance outwash **Qva**	Min	*13* / 16	*6.0* / 5.8	*91* / 81	*9.5* / 9.4	*0.1* / 0.1	*0.02* / <0.01	<0.1	<0.01
	Max		*7.6* / 7.6	*341* / 305	*11.6* / 12.0	*10.5* / 15.6	*4.95* / 4.21	0.990	0.130
	Avg		*6.8* / 6.5	*163* / 145	*10.7* / 10.7	*5.4* / 6.2	*2.31* / 1.79	0.225	0.024
Kitsap Formation **Qf**	Min	*2* / 2	*6.4* / 6.2	*127* / 113	*9.9* / 9.7	*6.8* / 5.4	*1.43* / 1.09	<0.1	<0.01
	Max		*6.9* / 6.7	*178* / 170	*10.8* / 10.7	*8.9* / 8.2	*2.47* / 1.47	0.340	<0.01
	Avg		*6.7* / 6.6	*152* / 142	*10.3* / 10.2	*7.8* / 7.2	*1.95* / 1.29	0.152	<0.01
Penultimate deposits **Qc**	Min	*7* / 12	*6.5* / 6.2	*130* / 123	*9.6* / 9.3	*0.1* / 0.1	*0.02* / <0.01	<0.1	<0.01
	Max		*8.0* / 8.0	*327* / 359	*11.3* / 11.7	*7.8* / 10.8	*1.97* / 1.65	3.900	0.870
	Avg		*7.1* / 6.9	*189* / 209	*10.3* / 10.4	*1.8* / 1.8	*0.4* / 0.27	0.487	0.162
Undiff. deposits **TQu**	Min	*2* / 2	*7.9* / 7.6	*158* / 140	*10.2* / 10.0	*0.1* / 0.1	*0.02* / <0.01	0.100	0.029
	Max		*8.2* / 8.0	*214* / 206	*11.4* / 11.2	*0.1* / 0.2	*0.02* / 0.17	0.330	0.160
	Avg		*8.0* / 7.8	*186* / 172	*10.8* / 10.6	*0.1* / 0.1	*0.02* / 0.05	0.200	0.095
Bedrock **Tb**	Min	*3* / 3	*6.8* / 5.8	*154* / 140	*8.2* / 8.5	*0.1* / 0.1	0.02 / <0.01	<0.1	<0.01
	Max		*9.2* / 9.1	*822* / 600	*10.5* / 10.6	*3.0* / 4.4	0.16 / 0.64	<0.1	0.024
	Avg		*8.9* / 8.8	*383* / 243	*9.5* / 9.7	*1.1* / 1.0	0.06 / 0.16	<0.1	0.092

* pH average values were calculated as medians.
† Iron and manganese samples were not taken in 1996-97.

Figure 7 - Range of Nitrate Values

Data from Spring 1989, 1995-98



Well Label	Aquifer	Well ID#
1	Qvr	17N/02W-05A02
2		18N/01W-35A04
3	Qva	17N/01E-06C01
4		17N/02W-01E02
5		17N/02W-14Q02
6		17N/02W-22H02
7		18N/01W-05G02
8		18N/01W-07C01
9		18N/01W-24B02
10		18N/01W-28J01
11		18N/01W-36N01
12		18N/02W-07R01
13		18N/03W-23N01
14	Qf	18N/02W-08N03
15		19N/02W-18M01
16	Qc	18N/01E-31A01
17		18N/01E-32H02
18		18N/01W-09J01
19		19N/01W-28F02
20	TQu	19N/01W-22A01
21		19N/02W-18K02
22	Tb	18N/02W-33C01

Nitrate

Samples were collected from 37 wells for nitrate+nitrite (NO_3+NO_2 as N) analysis in the Fall of 1997 and Spring of 1998. Table 4 shows summary nitrate results for each aquifer for the 1996-97 and 1997-98 water years. There was little change in either the range or average of nitrate concentrations when grouped by aquifer.

A full listing of all the 1997-98 data is located in Appendix A. No well in the ambient monitoring network exceeded the nitrate maximum contaminant level of 10 mg N/L. However, 8 wells exceeded the Early Warning Level of 2 mg N/L and two wells exceeded the Contaminant Action Level of 4 mg N/L.

Figure 7 and Table 5 compare the 1997-98 nitrate+nitrite concentrations in 22 wells with data from 1989 (Drost and others, 1998) and 1995-97. Wells without comparison data were not included. Data is taken from the spring samples to avoid seasonal fluctuations. Nitrate concentrations in nine of the 22 wells compared increased over time, three wells had decreases, and ten remained at about the same concentrations. Nitrate levels have increased in all but the two deepest aquifers, the undifferentiated deposits (TQu) and bedrock (Tb).

Table 5
Nitrate Data Collected During the Spring Quarter *
North County Ambient Monitoring Network

Well Label	Aquifer	Well ID#	Nitrate+Nitrite (mg N/L) 4-6/89	3/95	3/96	4/97	4-5/98	Change in nitrate levels
1	Qvr	17N/02W-05A02	1.10		2.67	2.52	1.88	Increase
2		18N/01W-35A04		3.24	1.93	2.44	3.00	Decrease
3	Qva	17N/01E-06C01		0.78	1.30	1.78	0.83	Increase
4		17N/02W-01E02	0.67	0.50	1.08	2.66	0.77	Mixed
5		17N/02W-14Q02	1.40	1.51	2.07	2.54	2.01	Increase
6		17N/02W-22H02	5.10	5.27	4.03	3.07	2.04	Decrease
7		18N/01W-05G02	1.40	1.47	1.57	1.66	1.33	Mixed
8		18N/01W-07C01	3.10	4.21	4.05	4.23	3.38	Increase
9		18N/01W-24B02	3.40	2.82		3.48	2.87	Mixed
10		18N/01W-28J01	2.50	2.66	3.41	4.95	4.21	Increase
11		18N/01W-36N01		2.63		4.54	3.42	Increase
12		18N/02W-07R01		<0.01	<0.01	0.02	0.02	No Change
13		18N/03W-23N01	0.05			0.02	<0.01	No Change
14	Qf	18N/02W-08N03	0.38	1.70	1.11	2.47	1.09	Increase
15		19N/02W-18M01	0.99	1.06	0.77	1.43	1.32	Increase
16	Qc	18N/01E-31A01	0.51	0.71	0.82	0.45	0.28	Mixed
17		18N/01E-32H02	0.88		1.31	1.97	1.60	Increase
18		18N/01W-09J01	0.44	0.54	0.47	0.26	0.09	Decrease
19		19N/01W-28F02	0.05	<0.01	<0.01	0.04	<0.01	No Change
20	TQu	19N/01W-22A01	0.05	0.03	<0.01	0.02	<0.01	No Change
21		19N/02W-18K02	0.05	0.03	0.00	0.02	0.02	No Change
22	Tb	18N/02W-33C01		<0.01		<.01	0.10	No Change

*see previous text for details

Figure 8 - Nitrate Levels
Well 17N/02W-05A02

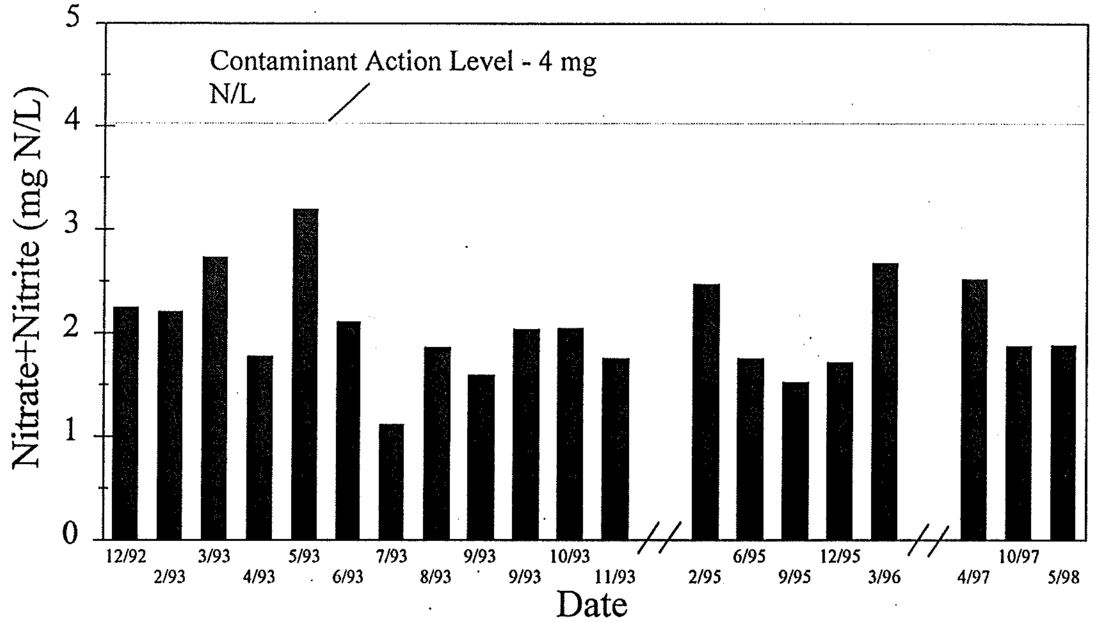


Figure 8 displays the nitrate concentrations in one well, ID# 17N/02W-05A02, over several years. This well is 33 feet deep and withdraws water from the Qvr aquifer. The nitrate values show a fair amount of variability from month to month, with seasonal peaks in the spring. This pattern is common among those wells in Thurston County that exhibit seasonal variation patterns. This well exceeded the Early Warning Level for nitrate several times but is below the Contaminant Action Level.

Iron and Manganese. 37 wells were sampled for total iron and total manganese in 1997-98. Iron and manganese samples were also taken by the US Geological Society in 1989 and additional samples were taken in 1995-96. Iron and manganese samples were not taken in 1996-97.

Table 6 compares metals concentrations between aquifers. Underlined values exceed the secondary maximum contaminant levels; 0.3 and 0.05 mg/L, for iron and manganese respectively. These values were set for aesthetic reasons, such as taste, and to reduce the staining of plumbing fixtures and laundry.

The highest iron concentration in this sampling round was at well ID# 19N/02W-03E02, a 90 foot well completed in the Qc (penultimate) aquifer. Iron concentrations were 3.9 and 3.8 mg/L for the October, 1997 and May, 1998 samples. US Geological Survey samples taken from this well in June, 1989 had similar levels of iron.

Paraphrasing from Drost (1998, p. 38), the distribution of iron and manganese in groundwater throughout Thurston County is highly variable and largely dependent upon low levels of dissolved oxygen to encourage dissolution of the metals from the local geology.

The low oxygen levels that mobilize iron and manganese are commonly caused by naturally-occurring bacteria consuming various types of organic matter, a process that also consumes oxygen. For this reason, iron and manganese levels can be a useful goechemical indicator of the presence of introduced contaminants, such as petroleum products, sewage, food wastes, manure, or other organic matter. Iron and manganese can also indicate the presence of natural organic matter, such as peat or wetland organic matter.

Table 6
1997-98 Iron and Manganese Concentrations
North County Ambient Monitoring Network
Grouped by Aquifer

Aquifer (number of wells sampled)	Iron (mg/L)			Manganese (mg/L)		
	Min	Max	Avg	Min	Max	Avg
Qvr (2)	<0.1	<0.1	<0.1	<0.01	0.088*	0.058
Qva (17)	<0.1	0.990	0.225	<0.01	0.130	0.024
Qf (2)	<0.1	0.340	0.152	<0.01	<0.01	<0.01
Qc (12)	<0.1	3.90	0.487	<0.01	0.870	0.162
TQu (2)	0.1	0.330	0.200	0.029	0.160	0.095
Tb (3)	<0.1	<0.1	<0.1	<0.01	0.024	0.012

*underlined values exceed secondary maximum contaminant levels

Data from the 1989 USGS investigation and other smaller county projects indicate an inverse relationship between nitrate and iron and manganese concentrations. Elevated iron and manganese concentrations (above the MCL) generally occur with relatively low nitrate concentrations (below about 2 mg/L). Elevated nitrate levels also tend to occur with low iron and manganese concentrations. This apparent trend is most pronounced at very high levels of either iron and manganese or nitrate and is less noticeable at relatively low concentrations. There is a more detailed discussion of the relationship between nitrate and metals concentrations in the Violet Prairie section (page 377).

Quality Assurance/Quality Control Results

Several analysis were conducted to ensure and verify the accuracy of the sampling effort and the associated laboratory analysis. Lab blanks, lab splits, lab duplicative analysis, lab spikes and field replicates were all performed. All laboratory quality tests were conducted with each batch of samples submitted and all were within acceptable limits (non-detect for the blanks and within 10% of the expected values for the other tests).

Four sets of field replicates were taken during the water year for nitrate+nitrite, iron and manganese analysis. Relative percent differences (RPD) were calculated for each pair of samples using the equation at left, where X_s and X_d are the sample and replicate values. RPD are a common way to evaluate replicate values, although the difference between values near detection limits is exaggerated. The average nitrate RPD was 7.9%, the iron average RPD was 0% (all sample pairs were non-detect) and the manganese RPD average was 4.8%. Values less than 20% relative percent difference were considered to be acceptable.

$$RPD = \frac{|X_s - X_d|}{(X_s + X_d)/2}$$

North County Ground Water Quality Summary

After three years of above-average rainfall, including 1996-97, in which the rainfall total was 150% of the average, rainfall in 1997-98 was around 10% below average (Figure 6). The 1994-95 water year was preceded by almost a decade of below-average rainfall. The 1988-89 sampling by the U.S. Geological Society was at the end of a three-year dry period. Periods of increased rainfall increase the probability that nitrogen compounds would be "pushed" through the soil and into aquifers rather than be processed by chemical and biological activities into organic nitrogen compounds that would be used by plants or converted into nitrogen gas.

For most wells, nitrate values increased between 1989 and 1998 (Table 5 and Figure 7)). The averages were calculated from a set of 22 wells that had at least two spring samples (taken between March and June). Most wells were sampled four out of the five years. The overall average of the 22 wells is displayed in Table 7.

The maximum nitrate value in 1997-98 was 4.20 mg N/L at well ID# 18N/01W-28J01. This is a 127 foot well in the Qva (Vashon advance) aquifer. This well also had the previous year's high nitrate value at 4.95 mg N/L. Wells with nitrate levels below the detection limit (<0.10 mg/L) in 1989 have nitrate levels in 1997-98 that have generally remained the same. It is not known what specifically caused nitrate levels to increase at individual wells. Possible nitrogen sources include: increased development, with more sewage effluent discharged into the ground through on-site sewage systems; agricultural activities; and excess fertilizing of lawns. Increased rainfall may have also played a role.

Table 7
Average Nitrate+Nitrite Concentrations by Year
North County Ambient Monitoring Network

Year	1989-90	1994-95	1995-96	1996-97	1997-98
Average	1.3 mg N/L	1.5 mg N/L	1.5 mg N/L	1.8 mg N/L	1.4 mg N/L
Number of samples	17	19	18	22	22

1998-1999 North County Ambient Monitoring Program

The 40 well network currently monitored will remain the same. Water levels will be taken quarterly and nitrate, iron and manganese samples will be taken twice annually. Some additional wells will be monitored in the Lacey and Tumwater areas on a limited basis as part of a long-term screening process in areas lacking groundwater data.

South County Study Areas

There were three impact studies conducted in southern Thurston County. These studies were focused on agricultural activities (dairies and poultry facilities) and were located at (Figures 9, 13 and 15, respectively):

Gifford Road - two wells upgradient and four wells downgradient from a dairy
Violet Prairie - a total of 13 wells around two dairies and a poultry operation
Yelm - two wells upgradient and four wells downgradient from a poultry facility

These wells were selected to quantify the nitrate impact the livestock activities are having on the drinking water aquifers. Static water levels, temperature, pH, conductivity, and dissolved oxygen measurements, and nitrate+nitrite, iron and manganese samples were taken.

Gifford Road

This rural area is located off Littlerock Road, just south of 113th Ave and north of the town of Littlerock (Figure 9). Six wells were selected to monitor the impact of a dairy on ground water. The dairy spreads manure on-site year-round, putting significant amounts of nitrogen into surface and ground water during the winter when rain causes runoff and the cover crop is dormant and not using the nitrogen in the manure.

Monitoring was started in March 1995 and is expected to continue through 2000. Table 8 shows the sampling results of the wells. Well 17N/02W-31JA is located in the middle of the pasture and in the past has been surrounded by liquid manure during applications. The nitrate level in this well is the second highest recorded in the County at 52 mg N/L in 1996, 44 in 1997 and 46 in 1998.

A shallow well (depth unknown) just west of the dairy had the highest nitrate level the County's database of 63 mg N/L in 1996. This well has since been replaced by a deeper well (120 feet deep), 17N/03W-36JB. Well 17N/03W-36JB has had low nitrate levels since installation; the last sample taken in 1998 had a nitrate concentration of 0.919 mg N/L.

Figure 9 - Gifford Road Study Area Well Locations

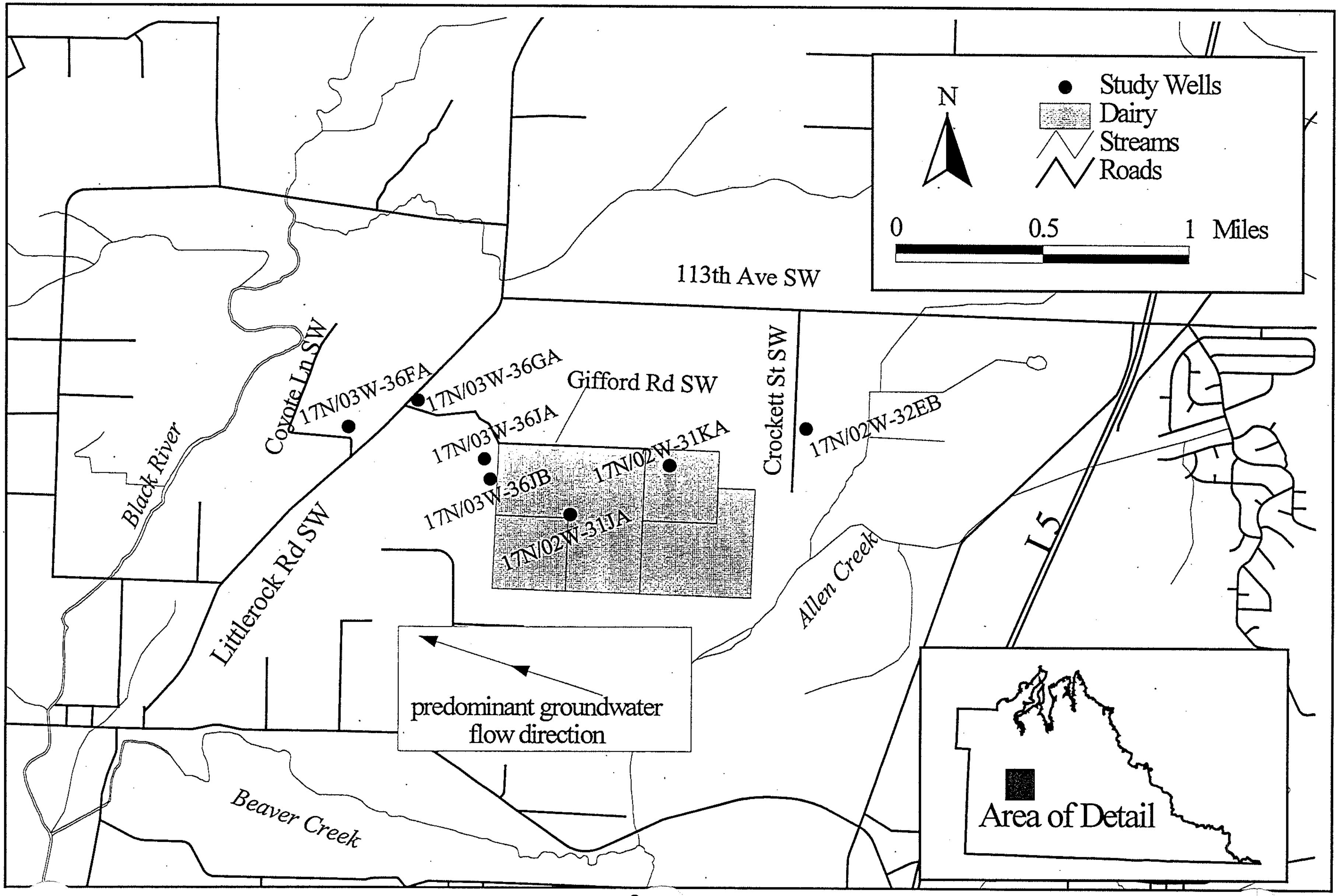


Table 8
Gifford Road Study Area Monitoring Results
1995-98 (In order from up- to downgradient)

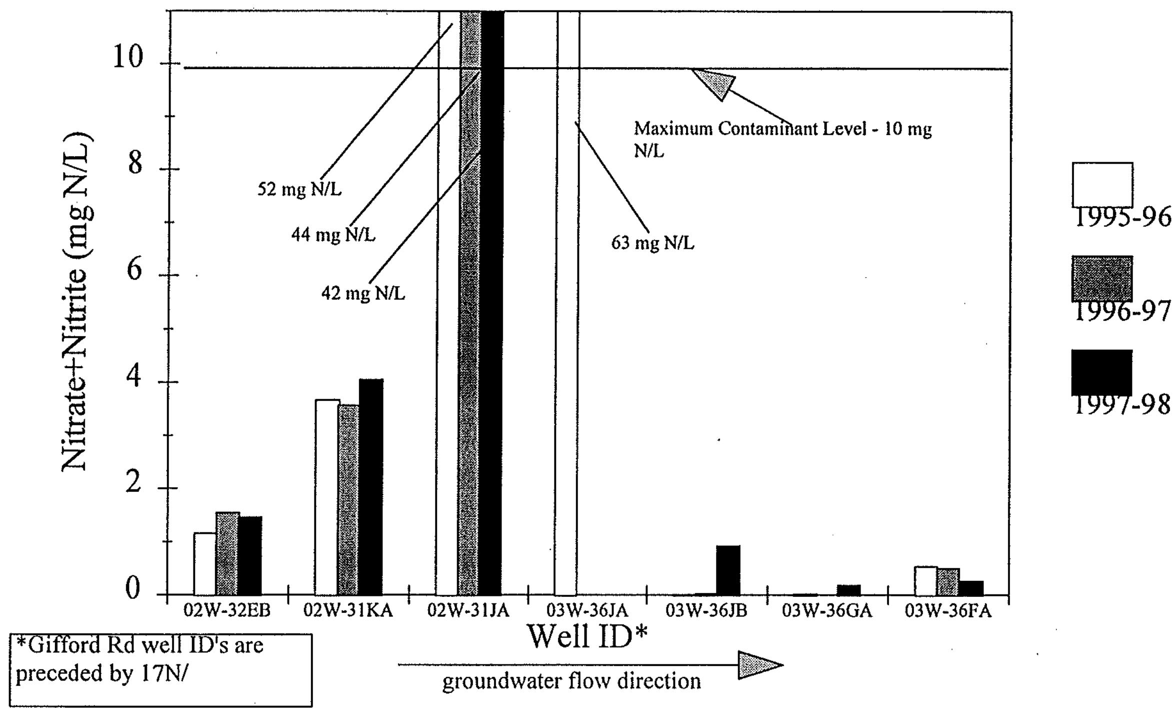
Local ID#	Date	Static Water Level (ft)	Bottom Elevation (MSL)	Nitrate+Nitrite (mg N/L)	Total Iron (mg/L)	Total Manganese (mg/L)
17N/02W-32EB (up-gradient)	04/15/96	N/A	168	1.150		
	06/04/97			1.550	0.015	0.003
	10/15/97			1.550	0.080	0.001
	4/16/98			1.470	0.025	0.001
17N/02W-31KA (up-gradient)	10/24/95	22.38	188			
	04/15/96	13.50		3.670		
	06/04/97	15.79		3.570	0.062	0.002
	10/13/97	19.60		3.470	0.120	0.003
	4/16/98	14.85		4.050	0.093	0.003
17N/02W-31JA (dairy)	04/15/96	N/A	135	52.0		
	06/04/97			44.3	0.038	0.007
	10/13/97			42.4	0.025	0.007
	4/16/98			46.1	0.025	0.008
17N/03W-36JA (shallow down-gradient)	4/15/96	N/A	140	63.3		
17N/03W-36JB (down-gradient)	04/15/96	11.00	60	0.005		
	06/04/97	N/A		0.021	0.240	0.280
	10/13/97	N/A		< 0.010	0.320	0.310
	4/16/98	N/A		0.919	0.360	0.330
17N/03W-36GA (down-gradient)	10/24/95	11.70	75			
	04/15/96	10.10		0.014		
	10/17/96	11.85		0.005		
	10/13/97	10.61		0.011	4.200	0.290
	4/16/98	10.05		0.185	3.600	0.270
17N/03W-36FA (down-gradient)	04/15/96	N/A	120	0.534		
	06/04/97			0.496	1.190	0.046
	10/17/97			0.369	21.0	0.100
	4/16/98			0.261	12.0	0.081

Table 8 shows the disparity in nitrate levels between the dairy well, 17N/02W-31JA, and the other wells around it. The County keeps a database of the all nitrate samples analyzed at the Environmental Health lab (usually submitted by property owners and water supply managers). A review of the available data shows that neighboring wells had nitrate concentrations ranging from non-detection to 5.3 mg N/L, with no discernable pattern between them or the study wells. The lab data dates back to 1994.

Figure 10 compares the Gifford Road nitrate levels between 1995-96 and 1996-97. Well 17N/02W-31JA exceeded the drinking water standard for nitrate by 4 times in 1998. Well 17N/03W-36JA was replaced by -36JB for domestic use in 1996. Subsequent samples from the contaminated well were not taken as the pump was disconnected by the owner when the new well was placed on-line.

Figure 10 - Spring Nitrate Levels

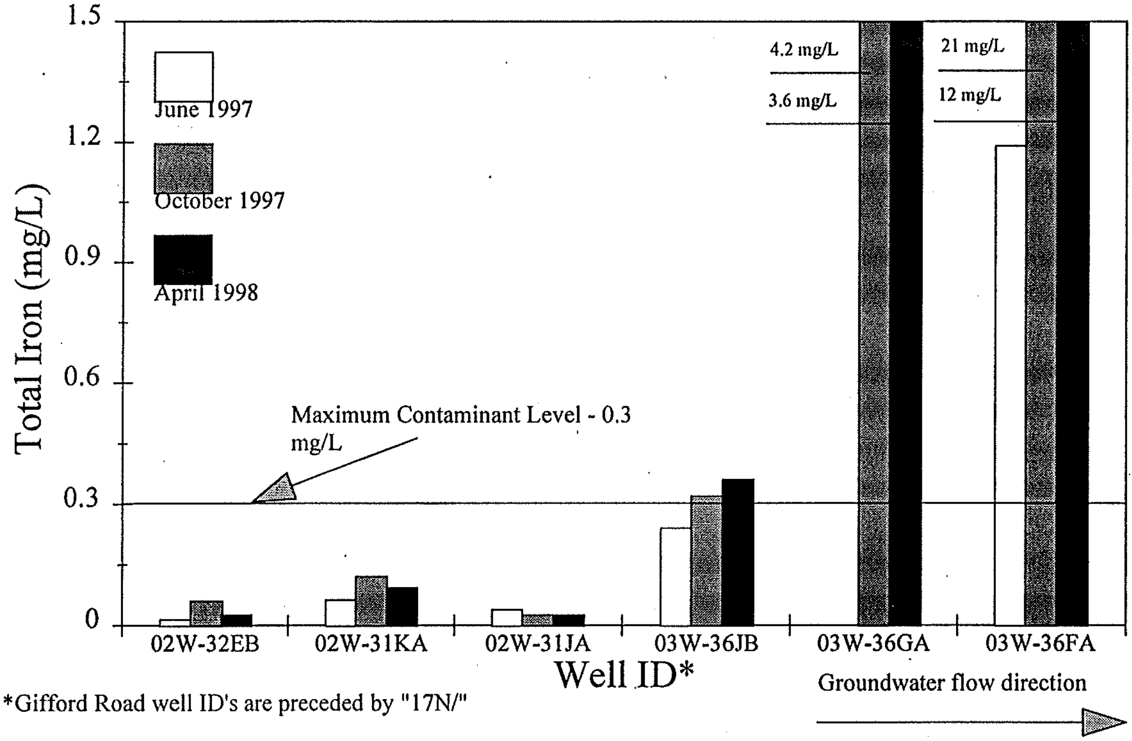
Gifford Road



Well 17N/03W-36FA had extremely high iron levels at 12 and 21 mg/L in 1997 and 1998 (Figure 11). Wells -36JB, -36GA and -36FA also had high manganese levels (Figure 12). All three wells have low amounts of dissolved oxygen, which results in higher amounts of metals in the ground water.

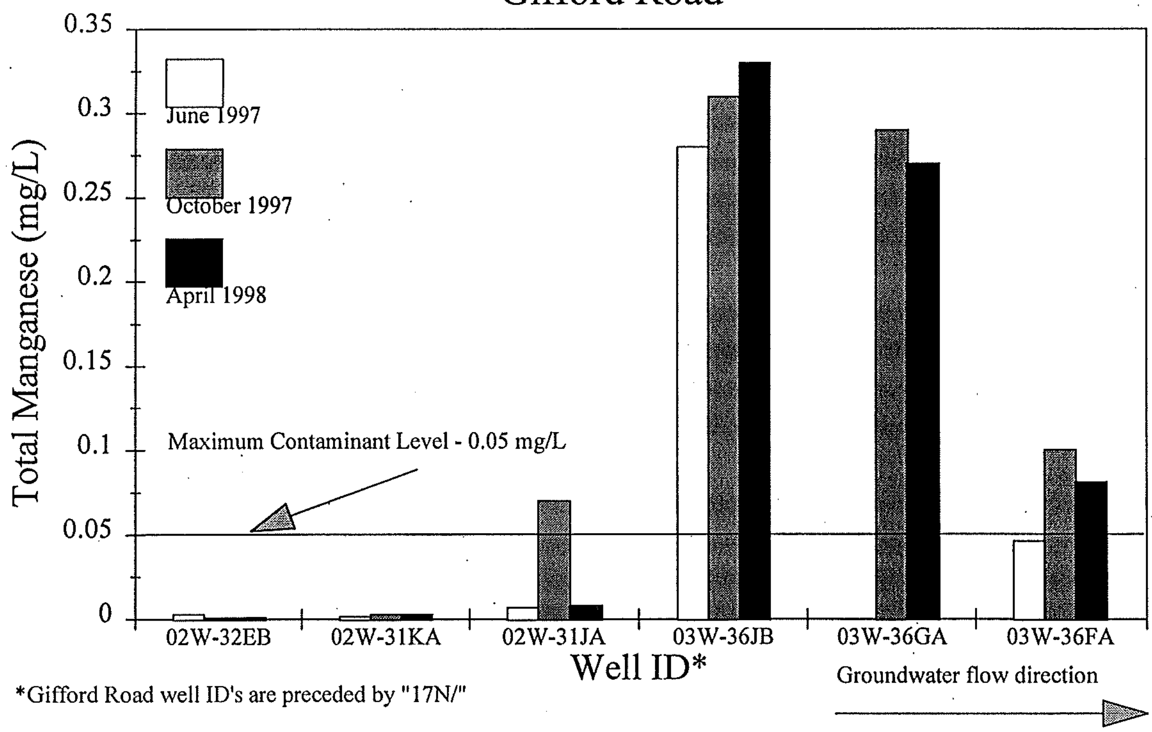
At this time, the impact of the dairy seems to be localized around the dairy and the neighboring property's abandoned shallow well, 17N/02W-31JA. The dairy operator is currently examining the possibility of vacating the site and developing it. If approved, the land use change is expected to significantly reduce the nitrogen loading to the ground water. The County will continue to monitor the area through 2000. Monitoring beyond that point will be re-examined based upon the proposed land-use change and budget priorities.

Figure 11 - Iron Levels
Gifford Road



*Gifford Road well ID's are preceded by "17N/"

Figure 12 - Manganese Levels
Gifford Road



*Gifford Road well ID's are preceded by "17N/"

Violet Prairie

Violet Prairie is just east of Interstate 5 off the Grand Mound exit. This area is mainly agricultural in nature, although in the past decade large amounts of land have been converted into residential. There have been many different livestock operations in the study area (Figure 13), including a fish farm, a rabbit farm, several poultry operations, and dairies. During the 1996-97 monitoring two dairies were active in the study area. A poultry operation off Gibson and 169th was shut down for a few years but was reactivated in 1998.

Violet Prairie is part of the Scatter Creek/Black River aquifer, which drains to the south-west from Tenino to Oakville, Grays Harbor County (Sinclair and Hirschey, 1992).

> The Scatter Creek/Black River aquifer is contained within highly transmissive sand and gravel drift deposits of Penultimate and Vashon Age [*the last two glacial periods*]. The aquifer is unconfined and is recharged principally from local precipitation and seasonal seepage from area streams and rivers. ...

In general terms, Violet Prairie could be described as a gravel-filled trough, tilted slightly to the south-west. Due to the gravelly nature of the soils and the lack of any confining layers, such as hardpan or clay layers, rainwater and anything it picks up quickly reaches the aquifer. Groundwater is generally 20-30 feet below the ground.

As a result of the above, any contaminants such as nitrates are washed down with rainwater and are not removed before entering the aquifer. A major source of nitrates in the area is manure applications by livestock operations. Manure, if applied during the growing season at appropriate rates, can be used by cover crops. This greatly reduces the amount of nitrogen compounds that are available to be carried by rainwater into the aquifer. If manure is applied during the winter, little nitrogen is used by the dormant plants while heavy rainfall washes the manure downward.

The recent installation of large manure lagoons at the two dairies on Gibson Road has allowed the dairies to store manure during the winter and apply it in the spring and summer. Past practice had been to apply manure year-round, resulting in large amounts of nutrients, namely nitrates, to be mobilized by rainfall and leached into the aquifer.

The ground water under Violet Prairie is generally slightly acidic, low in conductivity and well oxygenated (Table 9). For the 1997-98 water year, the median pH was 6.4, the average conductivity was 191 µmhos/cm at 25 °C and the average dissolved oxygen was 7.4 mg/L. These values are very similar to the previous years'.

The average Violet Prairie nitrate level decreased slightly in 1997-98 from 1996-97, a decrease to 5.9 mg N/L from 6.2 mg N/L. This lower 1997-98 nitrate average also includes two new wells with high nitrates, wells not included in the 1996-97 average. The 1997-98 nitrate average without the new wells is 5.0 mg N/L, a drop of 1.2 mg N/L from 1996-97. This is the second year in a row nitrate values have decreased in the Violet Prairie aquifer (Figure 14).

Figure 13 - Violet Prairie Study Area Well Locations

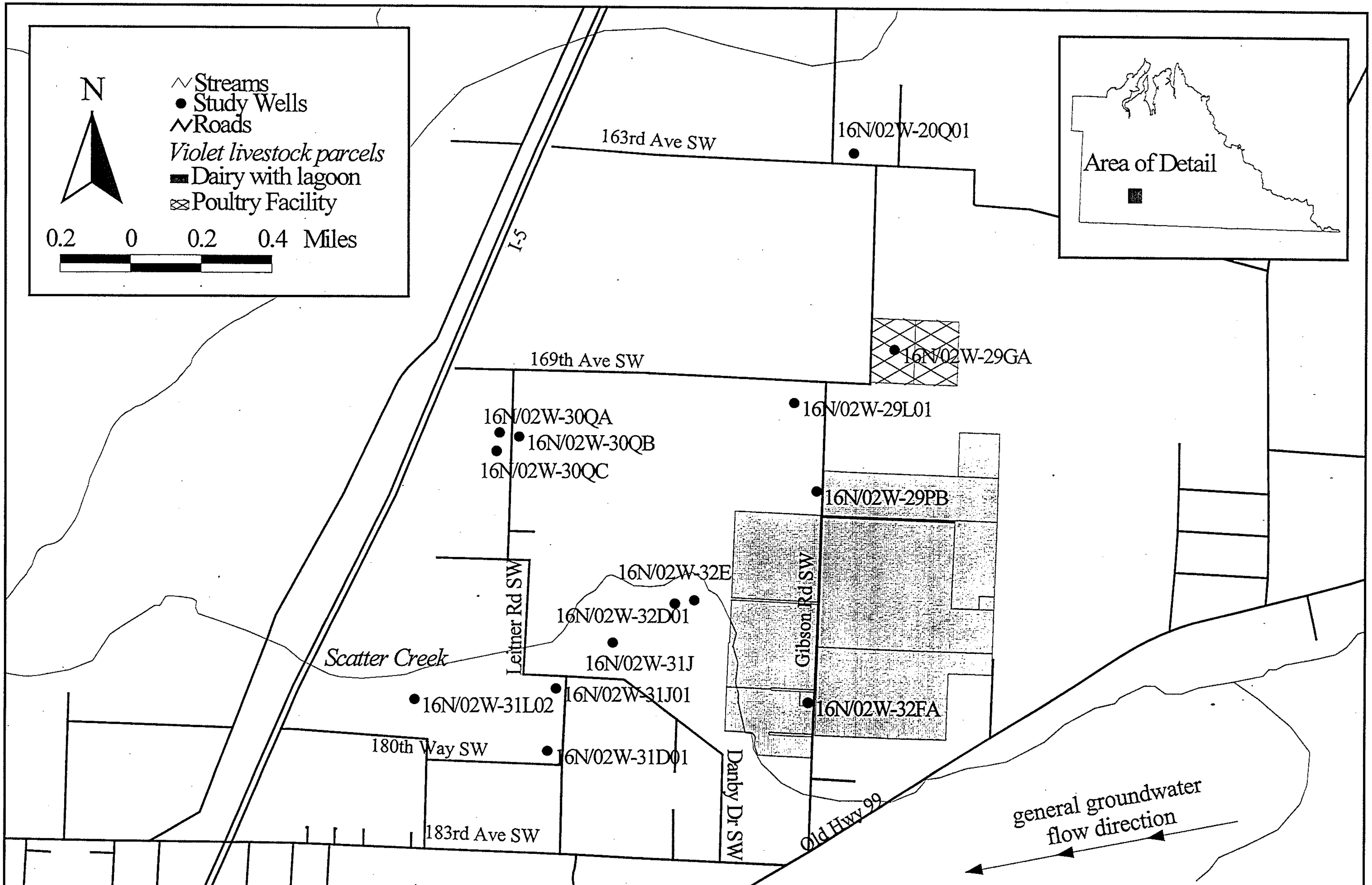
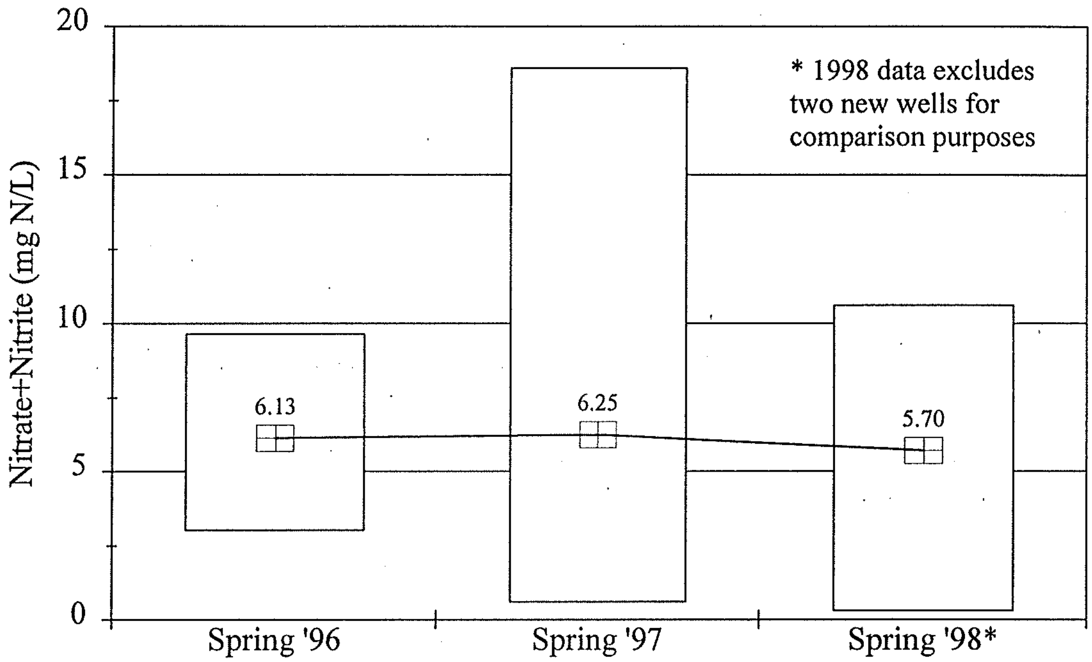


Figure 14 - Nitrate Averages and Range

Violet Prairie data grouped by year



Two wells new to this study, 16N/02W-32D01 and -32E, tied for the highest nitrate level this year at 21.6 mg N/L. Well -32D01 is a residential well that is located across Scatter Creek from a recently installed dairy manure lagoon. -32E is located on the same property, although closer to the creek. It is a 26.8 feet deep monitoring well installed by the Washington State Department of Ecology (State unique ID - ABG726) to look at groundwater impacts of the lagoon.

Previously, well -32FA had higher levels of nitrate, including a maximum of 45 mg N/L in March 1995 (Figure 14). Well -32FA is situated in a depression in one of the dairy pastures. During heavy manure applications or rainfall, run-off collects around the well house. Until late 1997, there was also no sanitary seal on the well casing (essentially a cover on the top of the well casing to prevent mice and other undesirable objects from falling down the well). Nitrate levels at this well have dropped significantly from 18.6 in May 1997 to 3.3 in April 1998.

Out of the 22 samples taken in Violet Prairie between 1996 and 1997, 4 were greater than 2 mg N/L, 15 were greater than 4 mg N/L, and 1 was greater than 10 mg N/L. These results are similar to other Violet Prairie well samples analyzed by the County's laboratory. 19 nitrate samples were taken by well owners in the vicinity (from the study area west to Interstate 5) between 1994 and 1998. Of these samples, 4 were greater than 2 mg N/L, 8 were greater than 4 mg N/L, and 2 exceeded the drinking water standard. 26 samples were taken in 1997-98, with a similar spread of values; 5 samples over 2, 14 over 4 mg N/L, and 5 samples exceeded the maximum contaminant level of 10 mg N/L.

Table 9
Violet Prairie Study Area
Water Years 1995-96 through 1997-98

Local Well ID	Elevation (ft - MSL)	Well Depth (ft - BGS)	Well Bottom Elev. (ft -MSL)	Date	Static Water Level (ft)	pH	Cond (µmhos/cm @ 25 C)	Temp (deg. C)	Dissolved Oxygen (mg/L)	Nitrate+ Nitrite (mg N/L)	Iron (mg/L)	Manganese (mg/L)
16N/02W-20Q01	203.93	N/A	N/A	05/22/96	N/A	6.2	112	11.02	9.92	4.37		
				05/28/97		6.3	102	11.06	10.03	3.19	0.163	0.002
				10/15/97		6.4	114	10.59	10.87	3.42	0.060	0.001
				04/13/98		6.3	95	10.41	9.94	3.36	0.730	0.004
16N/02W-29GA	209.17	77	132.17	05/22/96	24.25	5.9	151	11.31	0.12	6.97		
				05/28/97	25.78	6.0	156	11.00	0.12	0.604	1.860	0.277
				04/13/98	23.80	6.3	186	11.64	0.07	4.64	0.025	0.530
16N/02W-29L01	224.5	80	144.5	05/22/96	23.25	6.7	146	10.48	8.50	3.80		
				10/14/97	36.10	6.7	149	10.82	9.56	4.03	0.025	0.001
				04/13/98	23.10	6.7	145	10.64	8.41	4.10	0.110	0.001
16N/02W-29PB	219.3	105	114.3	05/22/96		6.6	137	10.67	6.12	3.02		
				05/28/97		6.7	143	10.80	6.74	2.77	0.034	0.002
				10/14/97		6.8	136	10.77	6.65	2.77	0.025	0.001
				04/13/98		6.7	129	10.38	6.74	2.94	0.050	0.003
16N/02W-30QA	218	88	130	05/23/96		6.7	184	10.20	9.41	7.36		
				05/29/97		6.7	191	10.51	9.54	6.87	0.045	0.002
				04/15/98	26.23	6.7	170	10.39	10.80	6.89	0.050	0.001
16N/02W-30QB	212	70	142	05/23/96	19.10	6.6	198	10.38	11.53	9.55		
				05/29/97	20.65	6.6	187	10.46	10.01	6.31	0.050	0.002
				10/15/97	35.00	6.7	173	11.58	13.22	6.05	0.025	0.005
				04/13/98	20.60	6.6	156	11.24	10.61	6.52	0.070	0.004
16N/02W-30QC	212	60	152	05/23/96	21.20	6.7	203	10.45	10.17	9.16		
				05/29/97	22.15	6.8	201	10.84	10.21	7.67	0.075	0.002
				10/15/97		5.4	216	10.98	10.63	0.330	0.025	0.002
				04/13/98	20.90	6.7	166	10.54	10.53	7.13	0.074	0.001

Table 9
Violet Prairie Study Area
Water Years 1995-96 through 1997-98

Local Well ID	Elevation (ft - MSL)	Well Depth (ft - BGS)	Well Bottom Elev. (ft -MSL)	Date	Static Water Level (ft)	pH	Cond (µmhos/cm @ 25 C)	Temp (deg. C)	Dissolved Oxygen (mg/L)	Nitrate+ Nitrite (mg N/L)	Iron (mg/L)	Manganese (mg/L)
16N/02W-31D01	209	65	144	05/23/96	6.36	6.3	169	10.30	6.96	7.68		
				05/29/97	16.21	6.3	199	10.52	3.73	8.44	0.475	0.012
				12/08/97	16.05	6.2	200	10.54	5.05	8.28		
				04/15/98	15.18	6.3	172	10.65	5.39	8.08	0.740	0.007
16N/02W-31J	207	N/A	N/A	05/22/96	9.60	6.1	254	10.12	8.00	4.55		
				05/28/97	10.13	6.3	240	10.60	6.62	4.58	0.020	0.002
				10/15/97	20.75	6.3	249	10.93	6.20	11.90	0.025	0.001
				04/15/98	9.60	6.2	195	11.16	5.38	10.60	0.110	0.003
16N/02W-31J01	199	40	159	05/23/96	21.20	6.8	191	10.45	7.33	6.38		
				05/29/97	22.00	6.8	193	10.77	6.77	4.81	0.027	0.002
				10/14/97	33.25	6.8	178	10.78	12.98	4.58	0.190	0.004
				04/15/98	19.50	6.7	186	10.82	7.17	5.91	0.025	0.001
16N/02W-31L02	204	77	127	05/23/96		6.6	146	10.02	6.51	4.55		
				05/29/97		6.5	166	10.16	6.10	4.88	0.102	0.002
				12/08/97		6.4	144	10.48	4.29	3.18		
				04/15/98		6.5	154	10.56	5.92	4.94	0.025	0.001
16N/02W-32D01	203			04/16/98	10.80	6.2	347	10.79	5.60	21.60	0.130	0.001
16N/02W-32E	197	26.8	170.2	06/18/98	8.23	6.1	350	11.40		21.60		
16N/02W-32FA	212	35	177	05/28/97	15.05	6.3	348	11.50	9.03	18.60	0.122	0.002
				10/15/97	24.78	6.4	248	11.42	9.53	12.00	0.080	0.002
				04/13/98	14.10	6.2	339	11.14	8.29	3.29	0.070	0.001

MSL - mean sea level
BGS - below ground surface

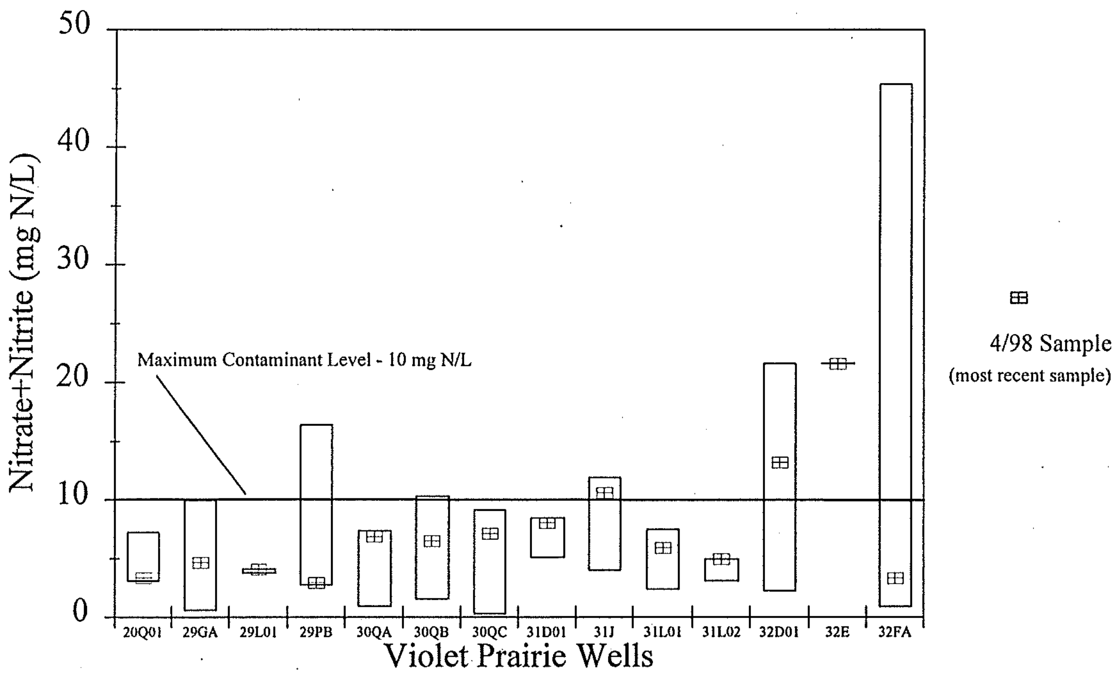
There is not enough data to determine if the reduction in nitrate levels in 1996-97 and 1997-98 is part of a trend due to the implementation of better manure handling practices and the installation of a manure lagoon or if it is caused by other factors, such as climate. Monitoring of Violet Prairie is funded to continue through 2000. Additional monitoring into the 21st century will depend upon available funds and department priorities.

One well that stood out from the others is 16N/02W-29GA. This well is one of the production wells used at the poultry operation. Compared to the other wells, -29GA has lower pH and almost no dissolved oxygen (0.12 mg/L in May 1997). It also has substantially higher metals levels concentrations than the other wells; at least 10 times for iron and over 100 times for manganese.

The nitrate levels at the well are highly variable, dropping from 9.96 mg N/L in March 1995 to 6.97 in May 96 to 0.604 in May 1997. Recent data from the 1997-98 water year (April 1998) showed the nitrate level had increased to 4.64 mg N/L. At the same time the iron level dropped from 1.86 mg/L to 0.025. These reductions in contaminant levels may be due to the period when the poultry operation was out of operation and no manure was being generated or spread on the site. Since restarting operations in mid-1998, the well has not been available for monitoring.

Figure 15 - Range of Nitrate Values

Data from 1982 through 1998



Violet Prairie well ID's preceded by '16N/02W'

Based upon limited data, it appears that the well's water quality is being influenced by biological processes in the vicinity. The combination of low pH, low dissolved oxygen, elevated temperature, and elevated iron and manganese suggests that bacteria are consuming organic matter from some source. The bacterial activity generates heat and consumes oxygen. The low levels of dissolved oxygen causes iron and manganese to changes from insoluble to soluble forms. This process is very common in Thurston County ground water and is generally responsible for elevated levels of iron and manganese (Drost and others, 1998).

Well 16N/02W-29L01, just one-third mile southwest of -29GA shows none of the characteristics of it's neighbor. Dissolved oxygen levels are above 8 mg/L and the nitrate and metal concentrations are stable. The bottoms of both wells are at similar elevations; -29L01 is at 144 feet-mean sea level, while -29GA is at 132 ft. The deepest of the study wells, 16N/02W-29PB is only one-half mile away, with a bottom elevation of 114 ft. -29PB shares similar dissolved oxygen and nitrate levels with -29L01.

It is not known for sure why nearby wells, at depths above and below well -29GA do not share the same characteristics. Sometimes bacterial action can produce very localized changes in water chemistry that change back to the dominant regional chemical conditions outside the area of bacterial effects.

Generally, iron and manganese levels in Violet Prairie have been low. Of the 14 wells monitored in 1997-98, only three had metal levels that exceeded the secondary (aesthetic) maximum contaminant levels of 0.3 mg/L for iron and 0.05 mg/L for manganese (Table 9). One of the three was the poultry well, -29GA. The other two wells, -20Q01 and -31D01 had elevated iron levels compared to the rest of the wells monitored but the specific cause(s) for the higher iron levels at these two wells are unknown.

Yelm Study Area

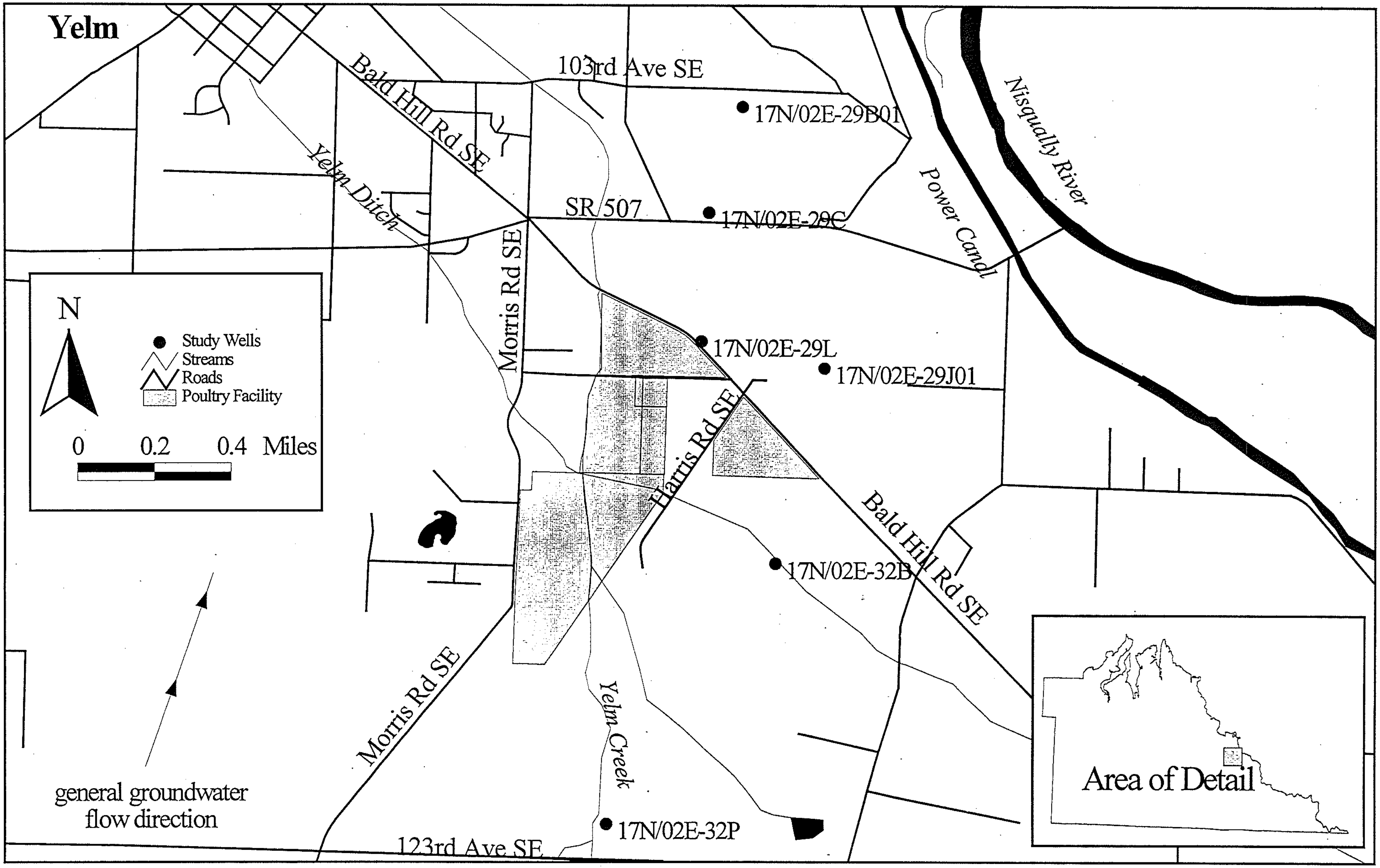
The Yelm study area is one mile southeast of the City of Yelm. In 1994 six wells were selected to monitor the effects of a large poultry facility on ground water. Generally, there are three aquifers in the study area, separated by two aquitards (cemented till and compacted silty layers) (Erickson, 1998). Most wells in the area use the middle aquifer, the Vashon advance outwash aquifer.

Five of the study wells use the Vashon advance outwash aquifer, ranging in depth from 50 to 107 feet deep. Well 17N/02E-29L is more shallow at 35 feet and uses the Vashon recessional outwash aquifer. Figure 16 shows the location of the poultry facility and the study wells.

The poultry facility has historically spread manure year-round, and was doing so during the 1997-98 sampling. They are working with the Thurston Conservation District to develop a farm plan and a building for winter-time manure storage has been constructed.

Table 8 shows the available data from the study wells. The two up-gradient wells, 17N/02E-32P and -32B are of similar depth, 100 and 103 feet deep, respectively. They also share a slightly

Figure 16 - Yelm Study Area Well Locations



basic pH, similar conductivity, temperature, and low dissolved oxygen levels. Well -29L is typical of shallow wells in that it has acidic pH (closer to the pH of rainwater), moderate conductivity and is well oxygenated.

Nitrate levels have been variable over time in this study area (Figure 17). Nitrate levels peaked between 1993 and 1994 and then declined sharply. The last three sampling results have shown a gradual increase at 17N/02E-29L, -29C and -29B01. Possible causes for the increase include high rainfall levels in 1995 and 1996 washing nitrogen compounds out of sediments or changes in manure handling practices. It will take several years of consistent sampling in order to develop more substantial trend patterns and possibly identify the factors behind the trends.

The shallow well, -29L, had nitrate levels that ranged from 2.53 mg N/L in November, 1993, up to 10.3 in both May and August, 1994, then dropped down to 2.92 in May 1996 and 0.82 mg N/L in June, 1997. Well -29J01 also had a drastic reduction in nitrate levels from 13.3 mg N/L in April, 1994 to 0.854 in May, 1996 and 0.86 in June, 1997. Note that well -29J01 is over 70 feet deeper than -29L and in a lower aquifer.

The two wells further down gradient had smaller peaks in nitrate levels in the following years. Well -29C's nitrate levels increased from 1.36 mg N/L in April, 1994 to 4.07 in May, 1996 and then decreased to 1.98 in May, 1997. Well -29C is of similar depth as -29J01 and about 0.3 miles north of the poultry facility.

The northen-most study well, 17N/02E-29B01, is 0.6 miles north of the poultry facility. The well depth is 50 feet below ground surface . The nitrate levels increased from 1.08 mg N/L in April, 1994 to 3.65 in April, 1997, continued to rise in October, 1997 and as of April, 1998 was at 8.07 mg N/L.

Table 8 - Yelm Study Area - Water Years 1993-94 through 1997-98

Local ID	Sur. Elev. (ft- MSL)	Well Depth (ft)	Well Bottom Elev. (Ft-MSL)	Date	SWL (ft - BGS)	pH	Cond (µmhos/cm @ 25 °C)	Temp (deg C)	DO (mg/L)	Nitrate+ Nitrite (mg N/L)	Iron (mg/L)	Manganese (mg/L)
17N/02E-32P (up-gradient)	375	100	275	4/25/94	33.18	7.5	186	11.99	1.60	1.91		
				5/21/96		7.4	211	11.26	1.49	1.65		
				6/03/97		7.4	230	11.69	1.94	2.57	0.027	< 0.003
				10/17/97		7.3	216	11.47	3.85	2.96	< 0.050	< 0.002
				4/20/98		7.3	207	11.94	1.69	2.13	< 0.050	< 0.002
17N/02E-32B (up-gradient)	345	103	242	4/26/94		7.5	179	11.16	2.03	0.005		
				5/21/96		7.5	203	11.16	0.42	0.19		
				6/03/97		7.4	216	11.49	0.50	0.02	0.071	0.009
				10/17/97		7.4	201	11.35	1.46	< 0.010	< 0.050	< 0.020
				4/20/98		7.4	196	10.98	0.78	0.015	0.120	< 0.020
17N/02E-29L (shallow down-gradient)	346	35	311	11/15/93		7.0	155	10.45	3.04	2.53	0.039	< 0.003
				2/22/94	20.49	6.8	172	10.45	6.50	8.13	0.116	< 0.003
				5/23/94	17.8	6.8	193	10.87	6.96	10.3	0.113	0.004
				8/22/94	23.6	6.4	186	10.91	9.26	10.3	0.102	0.004
				5/21/96	7.35	6.3	128	9.60	6.70	2.92		
				6/03/97	9.80	6.4	103	9.40	6.70	0.82	0.237	0.008
				10/17/97	19.82	6.3	120	10.02	11.90	1.96	< 0.050	0.004
				4/20/98	9.50	6.3	125	9.90	11.46	3.06	< 0.050	0.009
17N/02E-29J01 (down-gradient)	350	107	243	4/26/94	26.4	7.7	69	11.62	5.41	13.3		
				5/21/96	3.1	7.7	74	11.54	4.88	0.854		
				6/03/97		7.7	80	11.89	4.30	0.86	< 0.010	< 0.003
				10/17/97		7.6	75	11.82	2.34	0.84	< 0.050	< 0.003
				4/20/98		7.7	73	11.63	5.02	1.05	< 0.050	< 0.003
17N/02E-29C (down-gradient)	355	100	255	4/25/94	24.28	6.2	431	11.47	9.89	1.36		
				5/21/96	17.6	6.3	139	10.13	6.56	4.07		
				5/30/97	21.08	6.3	116	9.52	5.43	1.98	0.014	< 0.003
				10/17/97	27.90	6.2	158	10.50	10.96	4.21	0.025	< 0.003
				4/20/98	19.30	6.2	137	10.43	10.31	5.69	0.025	< 0.003
17N/02E-29B01 (down-gradient)	350	50	300	4/25/94	10.2	6.4	287	11.07	6.76	1.08		
				5/30/97	8.30	6.4	146	11.93	4.94	3.65	0.039	0.003
				10/17/97	27.28	6.2	165	11.60	6.96	5.38	0.120	0.018
				4/20/98	7.11	6.3	165	10.98	7.87	8.07	0.700	0.100

Erickson (pg 15, 1998) suggested using a groundwater velocity rate of between one and two feet/day for the advance outwash aquifer as a best estimate. Calculations of ground water velocity were based upon the following assumptions:

1. the poultry facility is the source of the nitrate increase in wells -29C and -29B01,
2. a nitrate plume started flowing northward in early 1994 (based on nitrate results from well -29L, the shallow well across the street from the facility),
3. the generalized ground water flow direction is north-northeast.

The average ground water velocity would need to be 2.2 feet/day to reach well -29C by May 1996 and 2.9 feet/day to reach well -29B01 by April, 1997. These velocities do not take into account the vertical distance the theoretical nitrate plume would have to cover in order to reach the bottoms of the wells (at 100 and 50 feet deep for wells -29C and -29B01, respectively). It would appear that the increases in these wells are the result of a single nitrate plume. As stated previously, it will take additional sampling over time to more definitively determine if this theory is correct.

The iron and manganese levels in the Yelm study area were low in general. Well -29L had high levels of iron that peaked in June 1997 at 0.237 mg/L. Well -29B01 had a sharp increase in both iron and manganese levels; as of the April, 1998 sampling both metals were at levels above the maximum contaminant levels (Figure 18). The cause of the increase is unknown.

Monitoring of the six Yelm wells will continue through the 1999-2000 water year. Monitoring after that is uncertain, depending upon budget priorities.

Figure 17 - Nitrate Levels

Yelm Nitrate Levels - 1986-1998

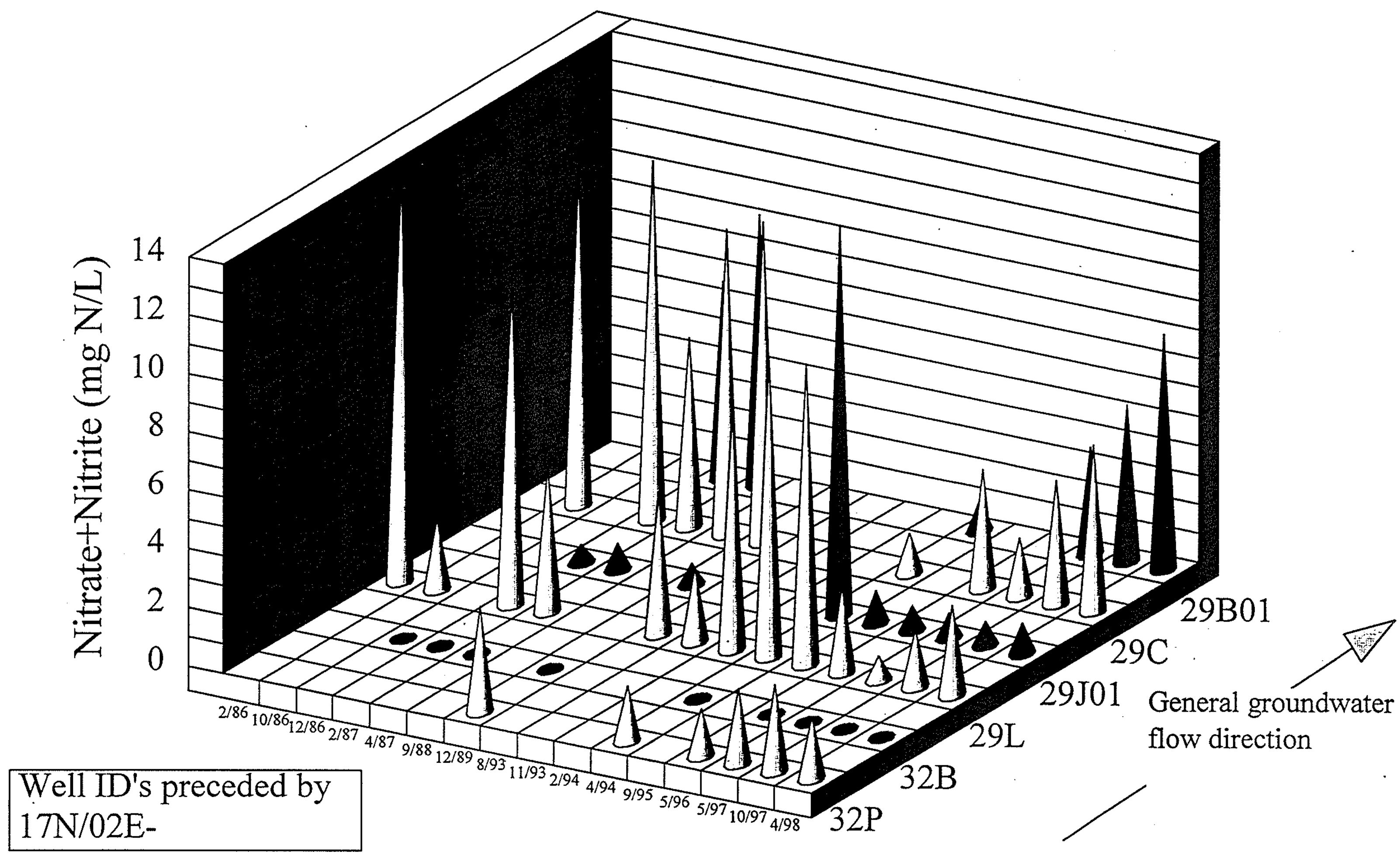
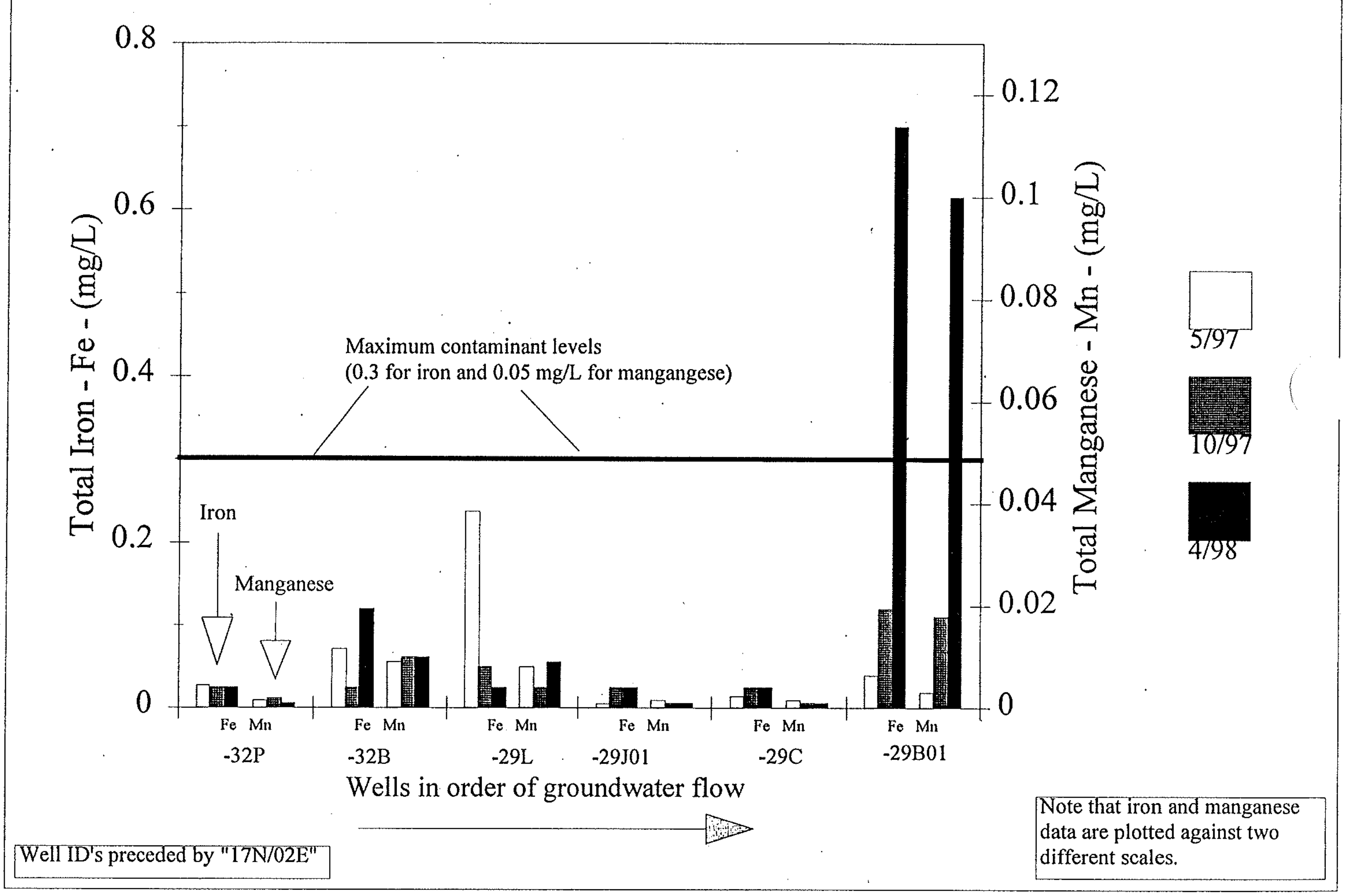


Figure 18 - Iron and Manganese Levels

Yelm Study Area



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Appendix A
North Thurston County Ambient Monitoring Network Data
1997-1998

Local ID Elevation (ft MSL)* Well Depth (ft)	Aquifer	Date	Time	Static Water Level (ft)	Static Water Elevation (ft - MSL)	pH	Conductivity @25c (umhos/cm)	Temp (deg C)	Dissolved Oxygen (mg/L)	Nitrate (mg N/L)	Iron (mg N/L)	Manganese (mg N/L)
17N/02W-05A02	Qvr	10/23/97	1615	3.50	154.40	6.7	131	10.47	3.60	1.87	<0.10	0.088
		02/17/98	1100	2.60	155.30							
157.9		05/06/98	0900	3.84	154.06	6.8	138	10.74	3.11	1.88	<0.10	0.080
32		07/14/98	1030	3.90	154.00							
18N/01W-35A04	Qvr	10/28/97	1410	9.60	150.80							
		02/13/98	1340	8.70	151.70							
160.4		04/23/98	1340	9.40	151.00	5.9	122	11.03	5.50	3.00	<0.10	<0.01
32		07/15/98	1305	10.02	150.38							
17N/01E-06C01	Qva	10/28/97	1330	38.20	66.60	6.1	151	10.34	6.65	2.12	<0.10	<0.01
		02/12/98	1400	36.00	68.80							
104.8		04/22/98	1530	36.22	68.58	6.4	145	10.56	2.94	0.83	<0.10	<0.01
52.1		07/14/98	1330	38.01	66.79							
17N/01E-07L01	Qva	10/24/97	1545	23.10	190.90	6.0	92	10.79	15.56	1.27	<0.10	<0.01
		02/12/98	1415	20.90	193.10							
214		04/23/98	1445	20.23	193.77	6.1	83	10.71	11.00	0.42	<0.10	<0.01
72		07/14/98	1315	22.50	191.50							
17N/02W-01E02	Qva	10/23/97	1430	66.20	110.50	6.0	161	11.36	2.93	3.40	0.650	0.058
		02/17/98	0930	64.00	112.70							
176.7		05/04/98	1115	65.36	111.34	6.1	180	11.60	2.06	0.77	0.980	0.080
90		07/14/98	1510	66.45	110.25							
17N/02W-14Q02	Qva	10/29/97	1340	13.30	179.30	5.8	105	10.45	6.68	1.99	<0.10	<0.01
		02/13/98	1100	6.10	186.50							
192.6		05/06/98	0815	9.25	183.35	6.0	107	11.01	6.04	2.01	<0.10	<0.01
40		07/14/98	1145	12.31	180.29							
17N/02W-22H02	Qva	10/29/97	1245	14.30	184.90	6.3	149	11.56	4.42	4.16	<0.10	<0.01
		02/13/98	1110	9.40	189.80							
199.2		05/04/98	1430	12.63	186.57	6.5	130	11.96	3.05	2.04	<0.10	<0.01
66.7		07/20/98	1120	15.62	183.58							
17N/03W-22J01	Qva	10/30/97	1240	35.10	150.60	6.1	85	9.39	8.66	0.88	0.140	<0.01
		02/17/98	1030	24.50	161.20							
185.7		05/08/98	1530	27.26	158.44	6.2	81	9.69	7.75	0.86	0.170	<0.01
98		07/14/98	1115	32.62	153.08							
18N/01W-05G02	Qva	10/22/97	1400	21.20	93.60	6.5	157	10.22	11.23	1.22	<0.10	<0.01
		02/12/98	1120	19.20	95.60							
114.8		04/21/98	6.6	19.30	95.50	6.6	152	10.37	11.90	1.33	<0.10	<0.01
56		07/13/98	1055	20.74	94.06							
18N/01W-07C01	Qva	10/23/97	1045	41.70	130.50	6.0	147	11.00	9.37	3.81	<0.10	<0.01
		02/12/98	1015	41.50	130.70							
172.2		04/21/98	1000	40.40	131.80	6.4	11	139.00	8.96	3.38	0.100	<0.01
62.5		07/13/98	0930	41.50	130.70							
18N/01W-24B02	Qva	10/24/97	1255	53.00	171.90	7.0	305	11.25	4.79	2.91	0.160	<0.01
		02/13/98	0945	48.10	176.80							
224.9		04/23/98	1045	48.75	176.15	7.3	290	11.42	5.60	2.87	0.160	<0.01
103		07/14/98	1430	52.90	172.00							
18N/01W-28J01	Qva	10/23/97	1300	25.70	157.70	6.6	182	10.74	10.19	4.14	<0.10	<0.01
		02/13/98	1405	24.70	158.70							
183.4		04/23/98	1300	25.00	158.40	6.8	177	11.02	8.90	4.21	0.260	<0.01
127		07/15/98	1350	25.33	158.07							
18N/01W-33C01	Qva	10/23/97	1330	36.40	170.50							
		02/13/98	1320	34.60	172.30							
206.9		07/15/98	1335	35.12	171.78							
73		04/23/98	1145	37.08	169.82							
18N/01W-36N01	Qva	10/24/97	1315									
		02/19/98	1100	143.10	76.10							
219.2		04/23/98	0930	140.55	78.65	6.7	177	10.05	6.63	3.42	<0.10	<0.01
180		07/20/98	0930	143.29	75.91							
18N/02W-07R01	Qva	10/30/97	1345	79.60	85.20	7.1	141	9.74	0.09	<0.01	0.990	0.130
164.8		05/06/98	1100	74.07	90.73	7.2	138	9.97	0.08	0.02	0.930	0.130
125		07/10/98	0532	76.50	88.30							
18N/03W-23N01	Qva	10/27/97	1600	1.90	330.50	7.4	131	10.71	0.16	0.01	0.140	0.071
		02/17/98	1201	0.10	332.30							
332.4		05/05/98	0930	1.33	331.07	7.6	129	11.03	0.15	<0.01	<0.10	0.070
41		07/13/98	1500	2.42	329.98							
19N/01W-09L02	Qva	10/21/97	1115			6.8	98	10.56	4.92	0.05	0.200	<0.01
185.1		04/21/98	1400			7.2	90	10.69	5.81	0.07	0.490	0.017
90												
19N/03W-35J02	Qva	10/27/97	1145	74.85	86.15	6.4	139	10.06	11.78	1.94	<0.10	0.005
		02/19/98	1320	72.80	88.20							
161		05/05/98	1030	70.40	90.60	6.6	141	10.49	11.10	1.76	<0.10	<0.01
113		07/21/98	1045	72.88	88.12							

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Local ID Elevation (ft MSL)* Well Depth (ft)	Aquifer	Date	Time	Static Water Level (ft)	Static Water Elevation (ft - MSL)	pH	Conductivity @25c (umhos/cm)	Temp (deg C)	Dissolved Oxygen (mg/L)	Nitrate (mg N/L)	Iron (mg N/L)	Manganese (mg N/L)
19N/03W-36E03	Qva	10/27/97	1500	56.30	88.20	6.4	124	9.85	11.72	1.56	<0.10	<0.01
		02/19/98	1525	55.20	89.30							
144.5		05/05/98	1115	53.61	90.89	6.6	121	10.18	9.50	2.02	0.130	<0.01
94		07/21/98	1100	55.34	89.16							
18N/02W-08N03	Qf	10/30/97	1445	83.50	77.50	6.2	119	9.73	7.60	1.47	<0.10	<0.01
		02/19/98	1200	80.00	81.00							
161.0		05/06/98	1200	78.54	82.46	6.4	113	9.89	5.40	1.09	<0.10	<0.01
120		07/14/98	0945	81.15	79.85							
19N/02W-18M01	Qf	10/31/97	1250	37.70	22.50	6.7	170	10.45	7.69	1.26	0.170	<0.01
		02/19/98	1345	36.90	23.30							
60.2		05/05/98	1315	36.31	23.89	6.7	167	10.73	8.20	1.32	0.340	<0.01
71		07/16/98	1300	37.06	23.14							
18N/01E-31A01	Qc	10/23/97	1200	57.90	27.50	6.3	136	10.25	4.97	0.20	<0.10	<0.01
		02/12/98	1320	52.60	32.80							
85.4		04/22/98	1315	53.70	31.70	6.5	140	10.80	4.07	0.28	<0.10	<0.01
92		07/14/98	1345	57.38	28.02							
18N/01E-32H02	Qc	10/24/97	1345			6.6	137	9.80	10.80	1.65	<0.10	<0.01
251.2		04/23/98	0950			6.9	132	10.05	8.61	1.60	0.120	<0.01
216												
18N/01W-09J01	Qc	10/22/97	1430	36.10	73.30	6.8	190	9.44	0.12	0.12	0.150	0.023
		02/12/98	1130	34.60	74.80							
109.4		04/21/98	1130	34.80	74.60	6.8	180	9.72	0.30	0.09	0.320	0.024
195		07/13/98	1320	36.38	73.02							
18N/02W-35B02	Qc	10/29/97	1000	100.54	84.46	6.7	190	10.09	0.16	0.03	0.640	0.870
		02/17/98	0900	98.70	86.30							
185		05/04/98	1015	99.55	85.45	7.4	202	10.44	0.08	<0.01	0.460	0.820
157		07/20/98	1335	101.00	84.00							
18N/03W-01J02	Qc	10/30/97	1545	34.90	33.90	7.7	123	9.27	0.07	0.01	0.150	0.079
68.8		02/19/98	1210	34.20	34.60							
75		07/13/98	1440	35.27	33.53							
19N/01E-30P06	Qc	10/21/97	1530	154.25	7.15	6.9	205	10.61	0.06	0.04	0.280	<0.01
		02/12/98	1145	154.70	6.70							
161.4		04/22/98	1145	154.70	6.70	6.9	211	10.82	0.05	<0.01	0.150	<0.01
186		07/13/98	1215	151.07	10.33							
19N/01W-07A01	Qc	10/22/97	1100	44.80	46.20	6.3	288	10.58	1.49	0.61	<0.10	0.054
91.0		04/22/98	0930	41.70	49.30	6.7	286	10.87	1.54	0.86	<0.10	0.049
79		07/14/98	1200	42.12	48.88							
19N/01W-28F02	Qc	10/21/97	1400	63.10	54.60	7.7	148	10.69	0.07	0.06	0.110	0.220
117.7		04/21/98	1300	62.10	55.60	8.0	145	11.35	0.07	<0.01	0.120	0.290
98.6		07/13/98	1115	62.38	55.32							
19N/02W-03E02	Qc	10/27/97	1000	64.00	6.00	6.7	355	10.32	0.10	0.01	3.900	0.540
		02/19/98	1455	63.50	6.50							
70		05/08/98	1315	63.67	6.33	7.1	359	10.58	0.06	<0.01	3.800	0.530
90		07/21/98	1000	64.12	5.88							
19N/02W-07P02	Qc	10/31/97	1200			6.9	188	10.41	4.11	0.25	<0.10	<0.01
		02/19/98	1405	64.20	13.90							
78.1		05/05/98	1400	64.25	13.85	7.0	185	10.65	4.59	0.31	<0.10	<0.01
99		07/16/98	1315	64.58	13.52							
19N/02W-14P02	Qc	10/22/97	1300	152.70	2.00	7.6	201	9.95	0.28	0.07	0.120	0.088
		02/12/98	1050	152.50	2.20							
154.7		04/22/98	1030	153.90	0.80	7.9	204	10.27	0.18	0.04	0.430	0.086
222		07/13/98	1020	153.36	1.34							
19N/02W-27D04	Qc	10/31/97	1445	34.20	15.80	6.4	299	11.07	0.06	0.01	<0.10	<0.01
		02/19/98	1240	33.20	16.80							
50.0		05/05/98	1500	32.21	17.79	6.2	306	11.69	0.06	<0.01	<0.10	<0.01
115		07/13/98	1400	33.53	16.47							
18N/01E-19J02	TQu	10/24/97	1100	27.97	12.63							
		02/13/98	0920	27.70	12.90							
40.6		04/22/98	1420	27.05	13.55							
92.5		07/20/98	1015	28.10	12.50							
18N/01W-36C02	TQu	10/28/97	1345	123.50	78.00							
		02/12/98	1345	122.70	78.80							
201.5		04/22/98	1500	121.90	79.60							
336		07/14/98	1400	123.53	77.97							
19N/01W-22A01	TQu	10/21/97	1300	57.10	6.30	7.9	206	9.95	0.07	<0.01	0.120	0.160
		02/13/98	1235	58.10	5.30							
63.4		04/21/98	1440	58.60	4.80	8.0	199	10.26	0.06	<0.01	0.100	0.160
143		07/13/98	1145	58.05	5.35							

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Local ID Elevation (ft MSL)* Well Depth (ft)	Aquifer	Date	Time	Static Water Level (ft)	Static Water Elevation (ft - MSL)	pH	Conductivity @25c (umhos/cm)	Temp (deg C)	Dissolved Oxygen (mg/L)	Nitrate (mg N/L)	Iron (mg N/L)	Manganese (mg N/L)
19N/02W-18K02	TQu	10/31/97	1100	103.30	28.50	7.6	143	10.99	0.07	0.03	0.250	0.029
		02/19/98	1430	102.10	29.70							
131.8		05/05/98	1215	103.18	28.62	7.7	140	11.24	0.16	0.17	0.330	0.030
166		07/21/98	1020	102.41	29.39							
17N/01W-34L02	Tb	10/29/97	1445	40.00	240.80	5.8	600	8.49	4.40	0.64	< 0 10	0.024
280.8		02/13/98	1030	34.50	246.30							
125		07/14/98	1215	42.21	238.59							
17N/02W-30E03	Tb	10/30/97	1115	22.10	164.60	8.8	164	9.54	0.08	0.01	< 0 10	0.013
		02/17/98	1015	20.50	166.20							
186.7		05/04/98	1340	22.36	164.34	8.8	164	9.90	0.12	< 0.01	< 0 10	0.011
146		07/14/98	1520	28.31	158.39							
18N/02W-33C01	Tb	10/29/97	1110	42.40	174.60	8.9	145	10.22	0.18	0.02	< 0 10	< 0.01
		02/17/98	1130	37.40	179.60							
217.0		05/06/98	1000	45.53	171.47	9.1	140	10.56	0.11	0.10	< 0 10	< 0.01
304		07/14/98	1005	94.33	122.67							

* Elevation was determined to the nearest foot using digital aerial photographs and digitizied two-foot contours and represents ground surface. Elevations reported to the tenth-of-a-foot include the well stickup and are the measuring point for water levels.