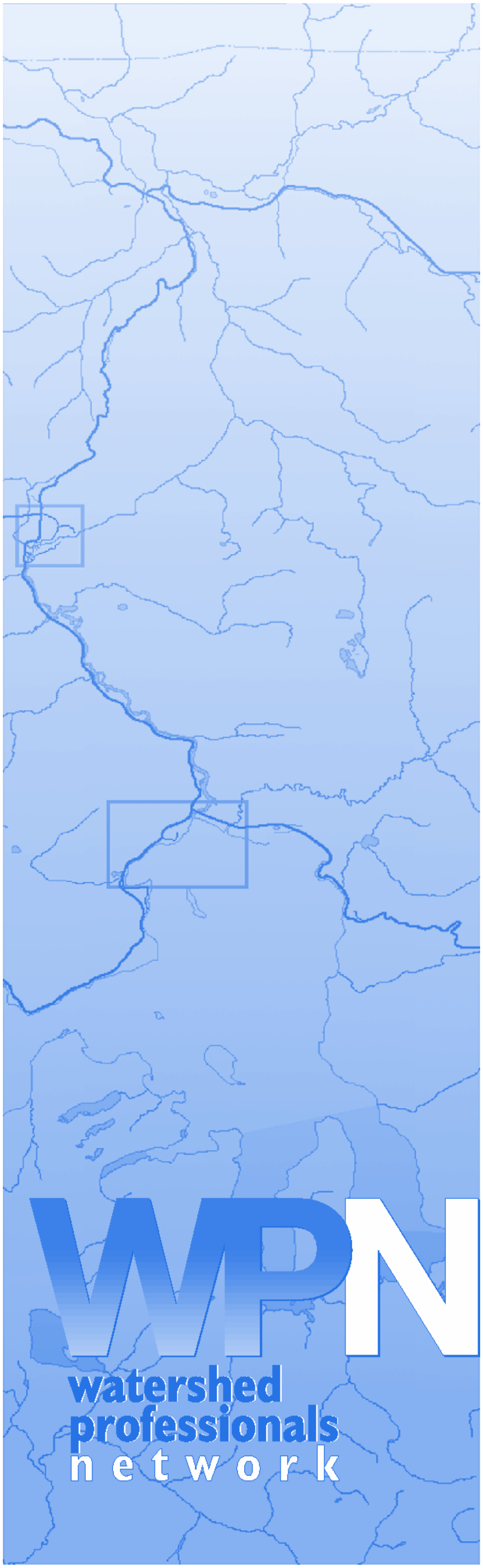

APPENDIX D

WRIA 30

PHASE II WATERSHED ASSESSMENT

NITRATE CONCENTRATION AND DISTRIBUTION STUDY

Prepared for:
Klickitat County Planning Unit

Prepared by:
Watershed Professionals Network

February 2004

Appendix D

WRIA 30

PHASE II WATERSHED ASSESSMENT

NITRATE CONCENTRATION AND DISTRIBUTION STUDY

February 20, 2004

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1 INTRODUCTION

This report presents the findings from a water quality assessment project, which was completed in the Water Resource Inventory Area 30 (WRIA 30), the Klickitat River watershed. The study encompassed three separate parts: 1) groundwater quality within the basin, 2) surface water quality (nitrates, *Escherichia coli*, fecal coliform), and 3) water temperature within Swale Creek subbasin.

Groundwater Quality: Concentrations of nitrate in wells within the Klickitat watershed have been documented to exceed the state drinking water standard of 10 mg/l. Nitrate concentrations above 20 mg/l have been documented in previous well water quality samples (Klickitat County Health Department unpublished data). There is some indication that concentrations above this limit can inhibit the oxygen-carrying capacity of blood and may cause methemoglobenemia (blue baby syndrome) in infants (EPA 2002; Francis, 1995).

Prior to this study, data regarding the spatial extent of the elevated nitrate levels and the frequency that high concentrations are found in wells were very limited. Upon review of the existing data, the Klickitat Watershed Planning Unit determined that additional study was warranted to better describe the situation. Therefore, the study was conducted to provide the needed information.

Surface Water Quality: Nitrate concentrations were also evaluated in surface waters of the Little Klickitat and Swale Creek subbasins to determine if concentrations were also elevated in these waters and to assist in the evaluation of potential sources of any elevated nitrates found in groundwater samples. Surface water samples were also evaluated for fecal coliform. The additional fecal coliform sampling was recommended in the Level I watershed assessment because existing data was sparse (Watershed Professionals Network, 2004). Concentrations of *Escherichia coli* (*E. Coli)* were also evaluated in anticipation of a change in water quality standards in the State of Washington; however, the *E. Coli* standard was not incorporated into the final rules adopted in July, 2003 (Ecology 2003).

This assessment was prepared by Watershed Professionals Network (WPN) and was funded through Washington Department of Ecology Grant No. G0300169 with Klickitat County as lead agency.

1.1 Purpose and Objectives

The purpose of the groundwater sampling portion of this project was to determine the distribution of elevated nitrate in the ground water within the populated areas of the Klickitat River watershed. The study is also intended to identify potential source areas of nitrate where present in the ground water. Specific objectives of the groundwater portion of the study were:

1. Identify areas of high nitrate concentration within the watershed based upon existing information, data collected through the planned Klickitat County Health Department study, and data collected in this study.
2. Identify probable source locations for nitrate inputs.
3. Identify probable land use effects on nitrate concentrations and a range of options for mitigating effects.
4. Determine if nitrate concentrations in ground water vary seasonally.

The purpose of the surface water portion of this project was to determine the distribution of elevated nitrate, if any, and the concentration of *E. Coli* and fecal coliform in the surface waters of the Swale and Little Klickitat Rivers and their major tributaries. The study is also intended to help identify potential source areas of nitrate where present in the ground water.

1.2 Hydrologic Overview

The study area lies within Klickitat County and includes forested, shrubland, and agricultural lands. The cities and towns of Centerville, Goldendale, and Glenwood are within the project area. Dryland and irrigated agriculture and pastureland are the dominant land uses in the study area. The sampling areas included the Swale Creek subbasin, the Little Klickitat River subbasin, and Glenwood area (Figure 1).

The Swale Creek subbasin includes aquifers in two geologic units which provide groundwater sources for domestic and irrigation supply. These geologic units include the Wanapum basalt and the alluvial deposits overlying the Wanapum. The Wanapum is well exposed at the surface across much of the southern watershed, and reaches a maximum thickness of greater than 1,000 feet beneath the eastern portion of the watershed. The Wanapum is comprised of multiple individual basalt flows and interbedded sedimentary units of variable thickness and composition. Groundwater is available at many depths within this unit.

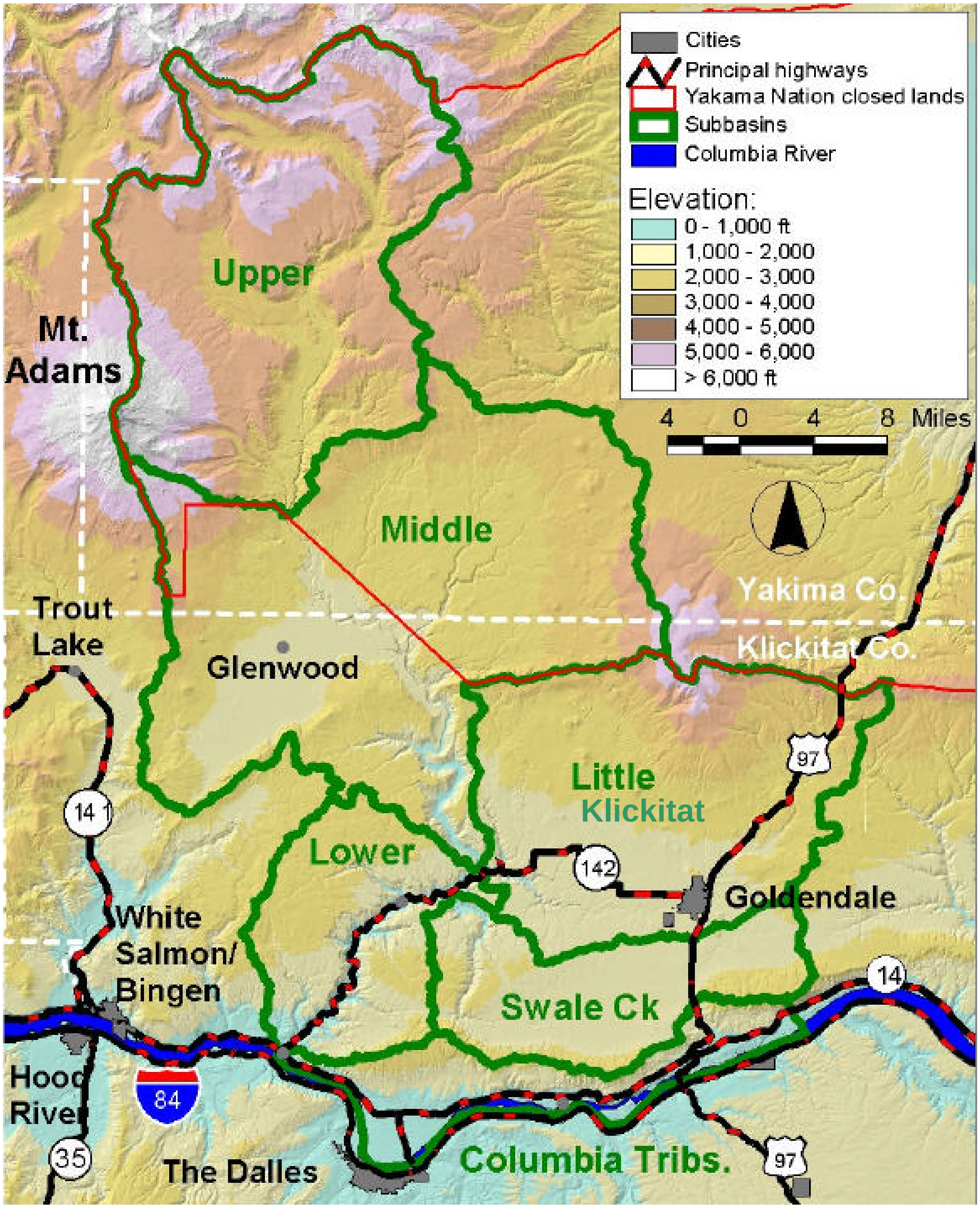

Figure 1. Map of WRIA 30 depicting major subbasins in the watershed.

East of Warwick, the Swale Valley is filled with alluvium extending roughly from Highway 97 to Warwick (Appendices B and C). This alluvium reaches depths greater than 200 feet near Centerville. Water within this aquifer is impounded by the Warwick Fault, which runs northwest to southeast through Warwick (Newcomb 1969). Recharge of this aquifer is primarily through spring runoff from the hills to the south and east of the valley (Appendices B and C). In late winter and early spring, localized flooding of low lying areas often occurs when water levels within the aquifer reach the surface. Groundwater levels in the alluvium then decrease throughout the balance of the year, suggesting there is little recharge from the Wanapum basalt underlying the alluvium. Groundwater levels rebound fully in late winter and early springs through runoff of the snowmelt and seasonal rains.

Both the Wanapum and alluvium formations extend a short distance into the southern portion of the Little Klickitat subbasin; however, the majority of the Little Klickitat subbasin overlies different geologic units. The Simcoe volcanics are present over most of the Little Klickitat subbasin. These volcanics originated in the Simcoe Mountains to the north and east of Goldendale. The Simcoe Volcanics are a highly variable unit that includes layers of solid basalt flows intermingled with deposits of ash, cinders, and mud flows. The majority of the wells in the Little Klickitat subbasin are constructed within this geologic formation.

Another geologic formation, known as the Ellensburg formation, is also present in the Little Klickitat basin. This formation was deposited by drainage systems during and between individual basalt flows and consists of compacted silt to gravel, which is easily eroded. Within the study area, these deposits are found primarily in the northern half of the Little Klickitat subbasin. A few wells are constructed entirely in this formation; however wells that draw from a combination of the Simcoe volcanics and the Ellensburg formation are more common.

1.3 State Water Quality Criteria

The State of Washington has developed water quality standards (WAC 173-200) to protect drinking water and ground water for existing and future beneficial uses. The state primary drinking water standard for nitrate is 10 mg/L; fecal coliform is 1 coliform colony per 100 ml. The secondary state drinking water standard for chloride is 250 mg/L. Concentrations of nitrate and fecal coliform above these limits are considered potentially harmful to public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational or other uses.

The State's current criteria for bacterial pollutants use fecal coliform as an indicator of contamination by humans and other warm-blooded animals. During the last review of the State water quality standards, *E. coli* was considered as a possible alternative to the current indicator. At the time this study was initiated, the *E. coli* standard was still under serious consideration. However, the new rule package as adopted on July 1, 2003, did not include an *E. coli* standard. The revised water quality standards retained fecal coliforms as the measure of bacteria contaminations. The revised bacteria criteria for surface waters are summarized in Table 1. All waters in the Little Klickitat River and Swale Creek are designated primary contact water.

Both *E. coli* and fecal coliforms were sampled in all well water samples. However, only *E. coli* was sampled in the surface waters during the spring sampling. Fecal coliform concentration was included in the fall surface water sampling program.

Table 1. Water Contact Recreation Bacteria Criteria in Fresh Water Category Bacteria Indicator (Chapter 173-201a WAC).

Primary Use of Water	Bacteria Criteria
Extraordinary Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.
Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies /100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200 colonies /100 mL.
Secondary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 200 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 400 colonies /100 mL.

1.4 Background Water Quality Information

1.4.1 Groundwater

The quality of groundwater in the Klickitat Basin was addressed in the Draft Level 1 Watershed Assessment (Appendix A) completed under RCW 90.82. This assessment reviewed available studies, databases and reports. The major sources of information regarding nitrate concentrations in groundwater that were reviewed during the level I assessment included the following:

- The Washington Department of Health database (Washington State Department of Health, 2000) contains 91 nitrate entries for Water Resource Inventory Area (WRIA) 30. Of the 91 entries, five were below the detection limit (<0.01 mg/L) of the study. The remaining 86 entries ranged in concentration from <0.1 mg/L to 9.4 mg/L. All but two of the entries had concentrations below 5.0 mg/L.
- The Geology and Water Resources of Klickitat County Report (Brown, 1979) contained nitrate data from 10 springs within the WRIA. Each of the springs was sampled once in 1973 or 1974. The nitrate concentrations ranged from 0.05 mg/L to 2.0 mg/L, well below the state drinking water standards.
- Water quality data is collected in conjunction with the Klickitat Horsethief Landfill. As part of their ground water quality monitoring, 108 samples were collected at four wells located in the landfill. The samples were analyzed for several parameters including nitrate. The samples ranged in concentration from <0.01 mg/L to 9.9 mg/L and therefore met the drinking water standard.

Since the release of the Draft Level I Watershed Assessment, additional information regarding nitrate concentrations in well water has been identified. The Klickitat County Health Department has required nitrate sampling in new wells since 1998, however, this data had not been published. Several of the well samples have nitrate levels in excess of the state water quality standard of 10 mg/L. Most of the reported water quality samples exceeding the nitrate standard were collected in the eastern half of the Klickitat River watershed.

1.4.2 Surface Water Quality (nitrate, fecal coliform, *E. coli*)

The quality of surface water in the Klickitat Basin was summarized in the Draft Level I Watershed Assessment (Appendix A). Data was collected in the mainstem Klickitat River at stations near Pitt and Lyle, Washington from 1966 to 1980 through Ecology's ambient monitoring program. Nitrate and *E. coli* were not collected at those sites. Fecal coliform concentrations collected at the Pitt site were less than the state criteria 100% of the time. At the Lyle site, fecal coliform concentrations did not meet the criteria 9 percent of the time. Exceedance of the bacteria criteria occurred only in summer.

Bacteria data collected by Ecology was also available for the Little Klickitat River near Wahkiacus. Peaks in bacteria concentration were frequently measured that exceeded the criteria. The criterion was exceeded roughly 25 percent of the time in summer and 9 percent of the time in winter over the entire period of record.

2 METHODS

Methods used in this study are described below. Groundwater was sampled in both spring (May 12-15) and fall (October 20-21) of 2003. The spring sampling included a wide range of parameters, including some that were collected to support another study. The fall sampling included only nitrate and chloride. Surface waters were sampled for nitrate and *E. coli* in spring (May 29) and for fecal coliform concentration in fall (October 22).

2.1 Overview

The spring sampling program was designed to sample wells that drew water from each of the major aquifers in each subbasin. The project included wells distributed across the spatial extent of each subbasin and through the depth range of each aquifer. A strict random sample design could not be employed since we could only sample wells with landowner permission. The fall sampling program included only sites that had been sampled in spring where permission to resample was provided by the landowners. The fall sites were also selected to focus on wells where higher concentrations of nitrate were found in spring.

Nitrate and several other parameters were sampled at each site in spring. Chloride was measured in both spring and fall to help determine the source of any nitrate identified in samples. Metals were sampled in spring to facilitate another study being conducted simultaneously in the same area (Appendices B and C).

The Level I Watershed Assessment identified a general lack of bacteria samples as a data gap. Hence, fecal coliform and *E. coli* were also sampled with the intent of starting to fill that gap. Both fecal coliform and *E. coli* were sampled since fecal coliform is the existing parameter used in the State water quality standards and *E. coli* was under consideration for inclusion as a new state criterion. No specific analysis of the bacteria data was proposed.

Sampling of surface waters was also conducted. This sampling was limited to nitrate and *E. coli* in spring. As was mentioned earlier, *E. coli* was expected to be adopted as the new state criteria. This did not come to pass. Hence, fecal coliform was analyzed in samples collected in the fall.

Stream flows were measured in conjunction with another groundwater study being conducted in the basin at the same time (Appendices B and C) and a temperature study conducted in Swale Creek in 2003 (Appendix E). Flow information was intended to help with interpretation of surface water results.

The original study design would have included isotope analysis of samples with high nitrate and/or bacteria concentrations. This isotope analysis would have been used to help identify sources of pollutants and differentiate between animal and human sources. Unfortunately, a laboratory could not be found that could run the samples prior to the end of the fiscal year (June 30, 2003), which was also the date that project funding ran out. Therefore, the isotope analysis was not completed.

2.2 Well Sample Site Selection

2.2.1 Spring Sampling

Well logs were reviewed to develop a list of wells that drew water primarily, if not entirely, from one aquifer. Within each aquifer, candidate wells for sampling were selected to represent the geographic area and a range of depths within the aquifer. The current owners of candidate wells were then identified where possible. Well logs are filed by the Washington Department of Ecology by the name of the person who had the well drilled and by township, range, and section. They are not cross referenced to parcel information or current owner and very few well logs list the actual address of the site. In cases where wells were still owned by the original owner, contact information could be found relatively easily in telephone books and County Assessor records. In cases where ownership had changed, finding the current owner was much more difficult, especially where more than one well was present with a section of land (more common than not). We are grateful to the Klickitat County Assessor's office who worked hard to look through old tax information to try to locate and track ownership. However, the current owner of a large percentage of the candidate wells could not be located.

A subset of the original candidate list was developed that included only those wells with known ownership. Landowners were then contacted to seek permission to sample their wells. The number of wells on the original candidate list within the Swale alluvium and in the Glenwood area was small. The subsample list was even smaller. Special effort was put towards attaining permission to sample these two subsets of wells. In some cases, shallow wells in the alluvium were identified and sampled while we were in the field based upon a neighbor's or family member's suggestion. In these cases, well logs needed to be found after the well was sampled and in two cases, no log was identified.

2.2.2 Fall Sampling

The fall data collection effort sampled wells that drew from the Swale alluvium and Wanapum basalt aquifers that were previously sampled in spring. Sample sites were identified by contacting well owners and attaining permission to conduct additional sampling. All owners of wells that had nitrate levels greater than 5 mg/l in spring, most of the owners that had nitrate concentrations greater than 1 mg/l were contacted, and a few of the owners that had no detectable nitrate levels in spring were also contacted. The list of sites sampled in fall included all owners that gave us permission to resample their wells.

2.3 Data Collection

2.3.1 Field

Ground water samples were collected in spring between May 12 and 15, 2003. Spring surface water samples were collected May 29, 2003. All data collection in the fall was conducted on October 20 and 21, 2003.

Domestic wells were purged prior to sample collection. Adequate purging was based on the stabilization of field parameters of pH, temperature, specific conductance and total dissolved solids. Field parameter measurements were considered stable when three successive measurements taken at intervals of five minutes or more differed by less than the following amounts:

specific conductance	5%
pH	0.1 unit
temperature	0.2° Celsius (C)
total dissolved solids	5%

Sampling was conducted from outdoor plumbing fixtures at each site. A flow through cell was used that allowed well water to pass over the probe of the field meter at a uniform flow rate.

Grab samples were collected after the well has been adequately purged. All samples were collected at the sampling port nearest the wellhead. Samples were collected on the wellhead side of any filters, softening devices, surge tanks, or chlorinating devices. Samples were sealed in the appropriate containers, labeled, and preserved.

Well condition, climatic conditions, time, date, and purging information were detailed on a ground water sampling form. Analytical information for each sample collected was entered on a chain-of-custody form. The chain-of-custody accompanied the sample to the laboratory and was used to trace possession and handling of the sample from the sample collection to the delivery to the laboratory. Samples were transported by courier to NCA Laboratory in Beaverton, Oregon each day.

All field meters were calibrated in accordance with the manufacturer's instructions at the start of each day. A field duplicate sample was collected at the site of each 10th sample (sample 10, 20, 30 etc.) collected by each field technician. A field duplicate is a second sample from the same well using identical sampling procedures. Duplicate sample results provided an estimate of overall sampling and analytical precision. One blind reference sample was also submitted with each sampling episode. This sample result was used to provide an estimate of the overall accuracy of the analytical results.

Surface water samples (grab samples) were collected directly from the flowing stretches of the Little Klickitat River and Swale Creek. No field parameter measurements were collected of surface water samples.

2.3.2 Laboratory

All ground water samples collected in spring were analyzed for common constituents found in water: calcium, magnesium, sodium, potassium, iron, manganese, arsenic, chloride, sulfate, alkalinity, ortho-phosphate phosphorus, ammonia, nitrite, nitrate, *E. coli* and fecal coliform. Fall ground water samples were analyzed for nitrate and chloride only. Surface water samples collected in spring were analyzed for nitrite, nitrate, ammonia, and *E. coli*. Fall surface water samples were analyzed for fecal coliform concentration.

All samples were analyzed using the laboratory methods listed on Table 2. Laboratory analyses, sample size, preservation, holding times, and methods. Laboratory analyses were conducted at North Creek Analytical (NCA) in Beaverton, Oregon. NCA and the analytical methods utilized are certified by the U.S. Environmental Protection Agency (EPA). NCA is also accredited by the Washington State Department of Ecology. The quality assurance objectives for the laboratory analysis are presented in Table 3.

2.4 Data Analysis

After receiving the data package from the laboratory, the QA/QC officer verified that the results met the measurement quality objectives for bias, precision, and accuracy for that sampling episode. Precision was estimated by calculating the relative percent difference (RPD) for field duplicate results. Analytical bias was assumed to be within acceptable limits if laboratory quality control limits are met for blanks, matrix spikes, and check standards. Overall accuracy was estimated by comparing the measured result with the true value of the blind reference sample.

Laboratory data was matched to well log information and field data to develop a database for analysis. Sample information attained from Klickitat County Health Department through its well testing program was also added to the database. Where possible, well logs were identified and matched to the County data to fill out the database. Not all samples could be matched to a well log. Hence, there are missing values in some fields in the master database. The County data included only nitrate, so all other parameters were missing for those records in the dataset.

Data analysis was conducted primarily through empirical evaluation of frequencies of occurrence. The ability to use standard statistical tests was limited by a) small sample sizes for some groups, and b) non-random sampling methods.

Nitrate concentrations were evaluated as a function of subbasin, aquifer, well depth, and depth of perforations in casings or linings within the aquifer. Correlations were developed between nitrate and chloride to determine if a significant relationship was present.

Data on other parameters was merely summarized with mean and range. No in depth analysis was conducted for these parameters.

Table 2. Laboratory analyses, sample size, preservation, holding times, and methods.

Analyses	Sample Size	Preservation	Holding Time	Method
Carbonate	Plastic 250 mL	None Required	14 Days	SM 2320B
Bicarbonate	Plastic 250 mL	None Required	14 Days	SM 2320B
Alkalinity	Plastic 250 mL	None Required	14 Days	SM 2320B
Calcium	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Iron	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Potassium	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Magnesium	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Manganese	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Sodium	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.7
Arsenic	Plastic 250 mL	Field Filter HNO_3 to pH < 2 Cool to 4°C	180 Days	EPA 200.8
Nitrate Nitrogen	Plastic 250 mL	Cool to 4^0 C	48 Hours	EPA 300.0
Nitrite Nitrogen	Plastic 250 mL	Cool to 4^0 C	48 Hours	EPA 300.0
Chloride	Plastic 250 mL	Cool to 4^0 C	28 Days	EPA 300.0
Sulfate	Plastic 250 mL	Cool to 4^0 C	28 Days	EPA 300.0
Ortho Phosphorus	250 mL	Cool to 4^0 C	48 Hours	EPA 365.2
Ammonia Nitrogen	50 mL	Acidify Cool to 4^0 C	28 Days	EPA 350.1
E. coli	50 mL	2.5 mL $Na_2S_2O_3$	6 Hours	SM 9223B
Fecal coliform	50 mL	2.5 mL $Na_2S_2O_3$	6 Hours	SM 9221

Table 3. Quality Assurance Objectives

Parameter	Matrix	Method	Detection Limit	Accuracy	Precision	Completeness
Calcium	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 10%	95%
Iron	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 15%	95%
Potassium	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 5%	95%
Magnesium	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 5%	95%
Manganese	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 10%	95%
Sodium	Water	EPA 200.7	0.01 mg/l	80 – 120 %	± 5%	95%
Arsenic	Water	EPA 200.8	0.01 mg/l	80 – 120 %	± 15%	95%
Ammonia	Water	EPA 350.1	0.005 mg/l	80 – 120 %	± 10%	95%
Ortho Phosphate	Water	EPA 365.2	0.01 mg/l	80 – 120 %	± 15%	95%
Chloride	Water	EPA 300.0	0.9 mg/l	80 – 120 %	± 15%	95%
Nitrate	Water	EPA 300.0	0.005 mg/l	80 – 120 %	± 10%	95%
Nitrite	Water	EPA 300.0	0.005 mg/l	80 – 120 %	± 10%	95%
Sulfate	Water	EPA 300.0	4.0 mg/l	80 – 120 %	± 15%	95%
Alkalinity	Water	SM 2320B	10 mg/l	80 – 120 %	± 5%	95%
Fecal Coliform	Water	SM 9221	1.0 CFU/100 ml	80 – 120 %	± 15%	95%
E. coli	Water	SM9223B	1.0 CFU/100 ml	80 – 120 %	± 15%	95%

NA* Not applicable

3 RESULTS

3.1 Quality Assurance

Field QA/QC protocols consisted of duplicate samples and blank samples. The field blanks consisted of distilled water, transported to the field, and poured off into properly prepared sample containers. The blank samples were used to determine the integrity of the field teams sampling handling, the cleanliness of the sample containers, and the accuracy of the laboratory methods. Arsenic was detected in the field blanks at concentrations ranging from 0.00253 to 0.00323 mg/l. It is likely the arsenic was not removed from the water in the commercial distilling process and not an indication of field sampling errors. There were no other constituents detected (above the method detection limits) for any of the blank samples submitted during this program. Field blank results are summarized in Table 4.

Duplicate samples consisted of two sets of sample containers filled (in the field) with the same composite water from the same sampling site. The duplicate samples were used to determine both field and laboratory precision. All of the QC samples were stored on ice and handled with the normal sample load for shipment to the laboratory. Table 5 summarizes analytical results for duplicate samples.

Table 4. Field Blank Results

Analyte	#584	#934	Field Blank Spring	Field Blank Fall
Arsenic	0.00253	0.00293	0.00323	
Calcium	ND	ND	ND	
Iron	ND	ND	ND	
Magnesium	ND	ND	ND	
Manganese	ND	ND	ND	
Potassium	ND	ND	ND	
Sodium	ND	ND	ND	
Ammonia	ND	ND	ND	
Ortho-phosphate	ND	ND	ND	
Chloride	ND	ND	ND	ND
Nitrate	ND	ND	ND	ND
Nitrite	ND	ND	ND	
Sulfate	ND	ND	ND	
Total Alkalinity	ND	ND	ND	
Fecal Coliform	ND	ND	ND	
E. Coli	ND	ND	ND	

Table 5. Duplicate Comparison, Mean and Standard Deviation

Parameters	Groundwater Mean	Duplicate Mean	Groundwater Standard Deviation	Duplicate Standard Deviation
Arsenic	0.00248	0.00276	0.0018	0.0020
Calcium	9.22	9.18	1.075	0.973
Iron	0.05	0.05	0.0	0.0
Magnesium	6.49	6.53	0.172	0.145
Manganese	0.005	0.005	0.0	0.0
Potassium	2.60	2.75	1.70	1.60
Sodium	8.61	8.81	4.21	4.47
Ortho-Phosphate	0.107	0.106	0.028	0.031
Ammonia	0.025	0.025	0.0	0.0
Nitrate	1.007	1.013	1.0	0.99
Nitrite	0.05	0.05	0.0	0.0
Chloride	1.336	1.323	0.33	0.37
Sulfate	0.76	0.76	0.46	0.46
Total Alkalinity	60.4	60.6	8.34	8.57

Precision is normally measured as relative percent difference (RPD) from duplicate samples. The calculation for RPD is as follows;

$$RPD = \frac{(C_1-C_2)*100\%}{(C_1+C_2)/2}$$

Where: RPD = Relative Percent Difference
C_1 = Larger of the two observed values
C_2 = Smaller of the two observed values

Two of the duplicate samples for arsenic and potassium and on of the duplicate samples of ortho-phosphate did not meet the precision goals established in Table 3. These are indicated in Table 6 in bold font.

Table 6. Relative Percent Differences (Duplicates).

Analyte	#36	#36 Duplicate	RPD	#114	#114 Duplicate	RPD	#80	#80 Duplicate	RPD
Arsenic	0.0005	0.0005	0	0.00394	0.0045	**13.0**	0.003	0.0033	**9.00**
Calcium	8.15	8.16	0.123	9.2	9.28	0.865	10.3	10.1	1.96
Iron	0.05	0.05	0	0.05	0.05	0	0.05	0.05	0
Magnesium	6.67	6.7	.45	6.33	6.44	1.72	6.46	6.46	0
Manganese	0.005	0.005	0	0.005	0.005	0	0.005	0.005	0
Potassium	4.51	4.51	0	2.03	2.37	**15.4**	1.27	1.38	**8.30**
Sodium	6.96	7.01	.716	13.4	13.9	3.66	5.48	5.53	0.908
Ammonia	0.0025	0.0025	0	0.0025	0.0025	0	0.0025	0.0025	0
Ortho-phosphate	0.119	0.12	.84	0.128	0.128	0	0.0748	0.0702	**6.34**
Chloride	1.44	1.41	2.18	1.6	1.64	2.5	0.97	0.92	5.3
Nitrate	2.15	2.15	0	0.32	0.32	0	0.55	0.57	3.6
Nitrite	0.05	0.05	0	0.05	0.05	0	0.05	0.05	0
Sulfate	1.29	1.3	.77	0.5	0.5	0	0.5	0.5	0
Alkalinity	54.9	55.0	.182	70.0	70.5	.712	56.3	56.4	0.177

3.2 Sample Size and Distribution

The Klickitat County Health Department (KCHD) database included 112 wells that had been tested for nitrate. Subbasins represented in the database included the Columbia River tributaries, the Glenwood area, the Little Klickitat River, the lower mainstem of the Klickitat River, the middle mainstem, and Swale Creek. The majority of the samples were collected from wells in the Little Klickitat and Swale subbasins (Figure 2). Forty-seven (47) wells were sampled in spring during this study, including 2 in the Glenwood area, 1 in the lower mainstem, and 19 and 25 samples in the Little Klickitat and Swale subbasins, respectively (Figure 2 and 3). The information that well logs provide include the depth of the well, the depth of well casing, the depth of perforations in the casing, and the geology from which water is drawn. The geologic information, in turn, was used to determine the aquifer that each well tapped. Hence, the tapped aquifer could not be determined for the samples missing well logs.

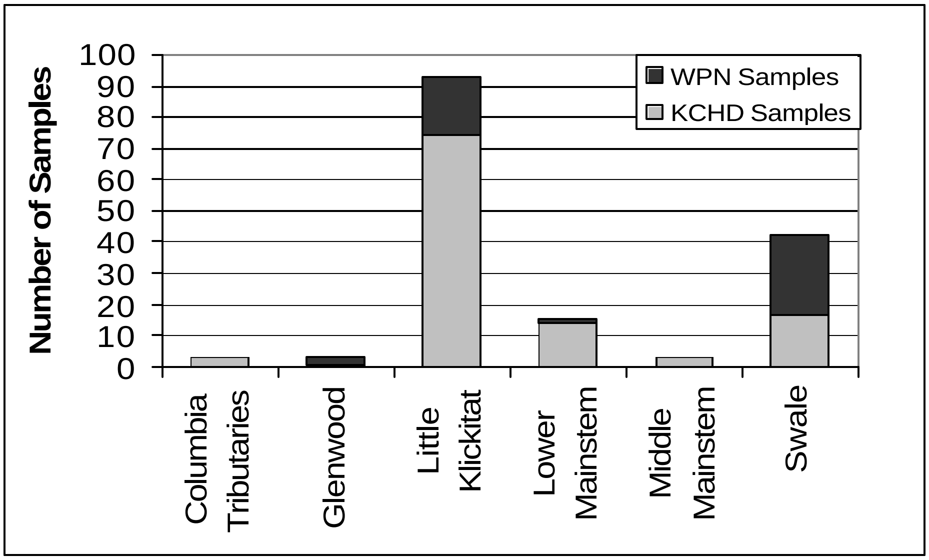

Figure 2. Number of wells sampled by KCHD and in this study by subbasin.

In some cases, two or more well logs were present for the location that was sampled. Where the exact well log that was associated with the sampled well could not be determined, the well logs were inspected to determine if there was similarity in the wells. For instance, if all the potential wells apparently drew from the same aquifer, then the aquifer that was associated with the sample could be determined although the well depth could not. The absence of well logs and other factors affected our ability to complete all fields of the database. Hence, the sample size available for various portions of the assessment is somewhat variable.

The 148 wells for which the tapped aquifer could be determined drew water from the Simcoe basalt, the Ellensburg basalt, the Wanapum basalt, the Swale Creek alluvium, alluvium in small tributaries of the Little Klickitat River, and other unknown basalts. The unknown basalts were all located in the Glenwood area and/or east of the Warwick fault that separates the Swale Creek and Wanapum basalt from the basalt in the eastern portion of the Klickitat River watershed. Most of the wells tapped the aquifers in the Simcoe and Wanapum basalts (Figure 4). Wells sampled again in fall primarily tapped the Swale alluvium, the Simcoe basalt, and the Wanapum basalt aquifers (Table 8)

The aquifers which the wells draw from in each subbasin reflect the geology of the subbasin. As expected, the majority of the wells sampled in the Swale subbasin were collected from wells that draw from the alluvium and/or the Wanapum basalt, reflecting the geologies present in that area (Figure 5). Wells sampled in the Little Klickitat subbasin draw primarily from the Simcoe and/or Ellensburg basalt, again reflecting the geology of the area. The Little Klickitat subbasin samples also included wells that draw from the alluvium and Wanapum basalt. The Wanapum basalt apparently extends a short distance into the Little Klickitat subbasin. Additionally, three of the alluvium samples in the Little Klickitat subbasin draw from aquifers in the northern portion of the subbasin rather than the Swale Creek alluvium.

Well logs could not be located for all of the wells that were sampled for nitrate. There are numerous reasons why logs may not be located. First, there are many wells throughout the state that do not have well logs on record. Second, well logs are recorded by the name of the owner at the time the well was drilled or deepened. Hence, locating well logs for wells where land ownership has changed is often difficult or impossible. Occasionally, the name on the well log is the builder rather than the first owner of the parcel. This, too, adds to the complexity of locating the correct well log for a site. The Klickitat County Assessors Office helped us locate several of the logs, however all logs could not been identified. Well logs were located for 96% of the samples collected in this study and 89% of the samples in the KCHD database (Table 7).

Table 7. Number of nitrate samples collected in each subbasin for which well logs could be located.

Subbasin	KCHD Samples	WPN Spring Samples
Columbia Tributaries	0	0
Glenwood	0	1
Little Klickitat	6	0
Lower Mainstem	2	0
Middle Mainstem	0	0
Swale	1	1
Total	**9**	**2**

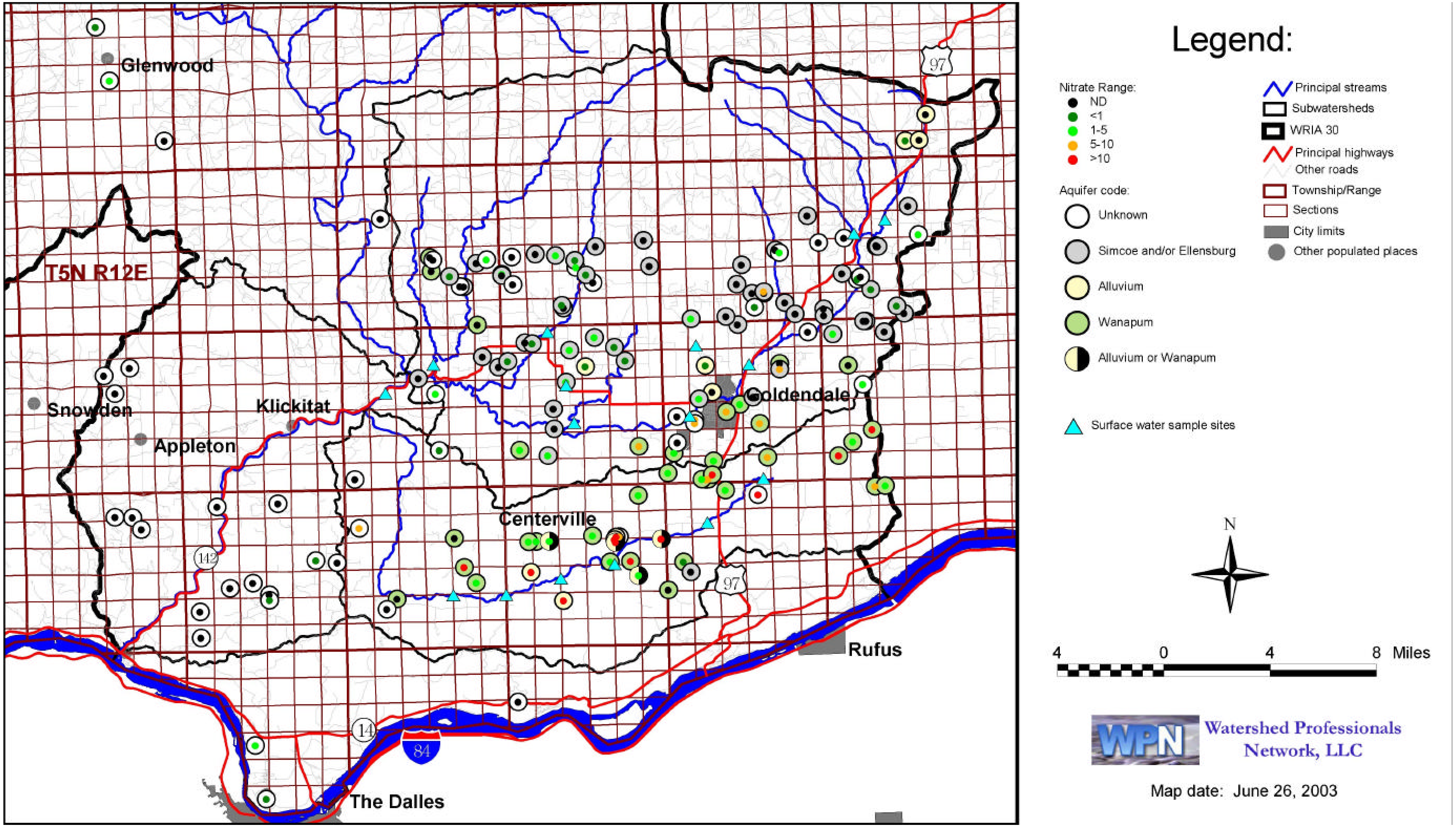

Figure 3. Map of sampling locations indicating aquifer of sample and nitrate concentrations.

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The information that well logs provide include the depth of the well, the depth of well casing, the depth of perforations in the casing, and the geology from which water is drawn. The geologic information, in turn, was used to determine the aquifer that each well tapped. Hence, the tapped aquifer could not be determined for the samples missing well logs.

In some cases, two or more well logs were present for the location that was sampled. Where the exact well log that was associated with the sampled well could not be determined, the well logs were inspected to determine if there was similarity in the wells. For instance, if all the potential wells apparently drew from the same aquifer, then the aquifer that was associated with the sample could be determined although the well depth could not. The absence of well logs and other factors affected our ability to complete all fields of the database. Hence, the sample size available for various portions of the assessment is somewhat variable.

The 148 wells for which the tapped aquifer could be determined drew water from the Simcoe basalt, the Ellensburg basalt, the Wanapum basalt, the Swale Creek alluvium, alluvium in small tributaries of the Little Klickitat River, and other unknown basalts. The unknown basalts were all located in the Glenwood area and/or east of the Warwick fault that separates the Swale Creek and Wanapum basalt from the basalt in the eastern portion of the Klickitat River watershed. Most of the wells tapped the aquifers in the Simcoe and Wanapum basalts (Figure 3). Wells sampled again in fall primarily tapped the Swale alluvium, the Simcoe basalt, and the Wanapum basalt aquifers (Table 8)

The aquifers which the wells draw from in each subbasin reflect the geology of the subbasin. As expected, the majority of the wells sampled in the Swale subbasin were collected from wells that draw from the alluvium and/or the Wanapum basalt, reflecting the geologies present in that area (Figure 4). Wells sampled in the Little Klickitat subbasin draw primarily from the Simcoe and/or Ellensburg basalt, again reflecting the geology of the area. The Little Klickitat subbasin samples also included wells that draw from the alluvium and Wanapum basalt. The Wanapum basalt apparently extends a short distance into the Little Klickitat subbasin. Additionally, three of the alluvium samples in the Little Klickitat subbasin draw from aquifers in the northern portion of the subbasin rather than the Swale Creek alluvium.

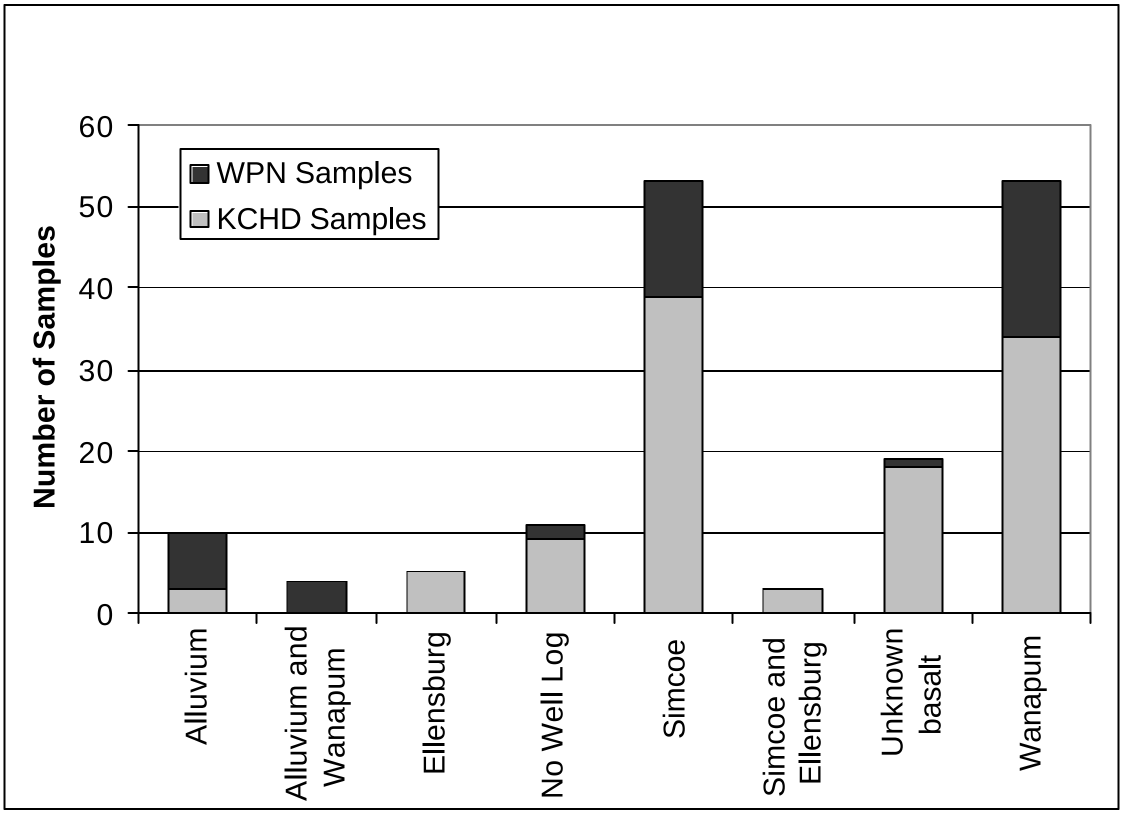

Figure 3. Distribution of samples within the various aquifers in the study area.

Table 8. Distribution of fall samples by Aquifer and Subbasin.

	SUBBASIN			
AQUIFER	**Little Klickitat**	**Lower Mainstem**	**Swale Alluvium**	**Grand Total**
Alluvium			5	5
Alluvium and Wanapum		1	2	3
Simcoe	5			5
Wanapum	1		2	3
Grand Total	**6**	**1**	**9**	**16**

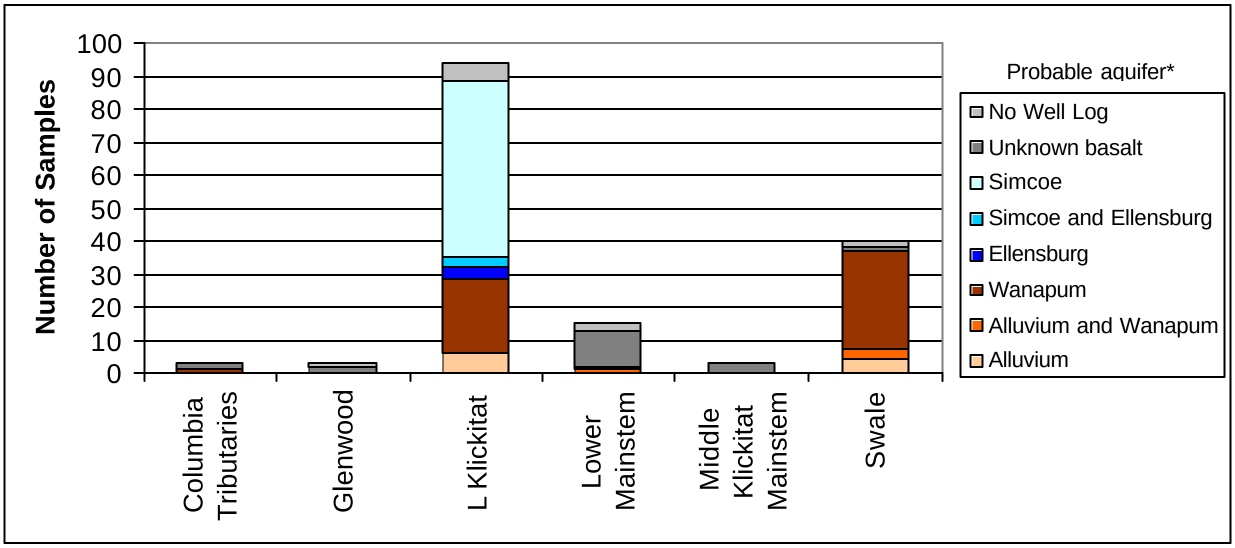

Figure 4. Number of nitrate samples in each aquifer by subbasin. *The listed aquifer is the best estimate based on geology reported on well logs.

The sample strategy strived to sample wells that were roughly evenly distributed between shallow wells (<100 feet), wells of moderate depth (100-300 ft), and deep wells (>300 feet). There are relatively few shallow wells recorded in the study area. Special focus was put on identifying and attaining permission to sample wells in this depth range. Nevertheless, our sample size within the shallow well depth range was substantially smaller than the number of samples in the moderate and deep depth ranges. Depths of sampled wells ranged from 68 to 925 feet deep. Most of the wells were less than 600 feet deep (Figure 6).

Wells drawing from the Swale Creek alluvium tended to be shallower, reflecting the depth of the alluvial deposits (Figure 7). Samples drawn from the Ellensburg formation tended to be deep, reflecting the location of that formation under the Simcoe basalt. The range of depths was reasonably well represented in samples from the other aquifers.

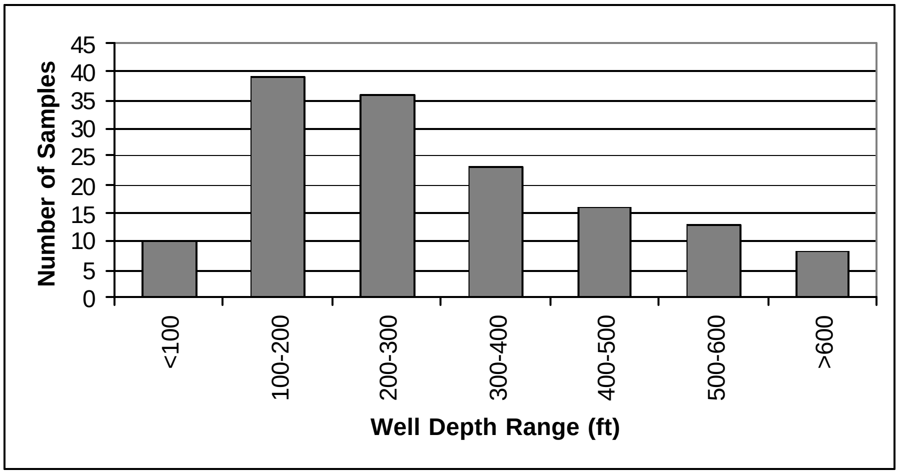

Figure 5. Distribution of depths of sampled wells.

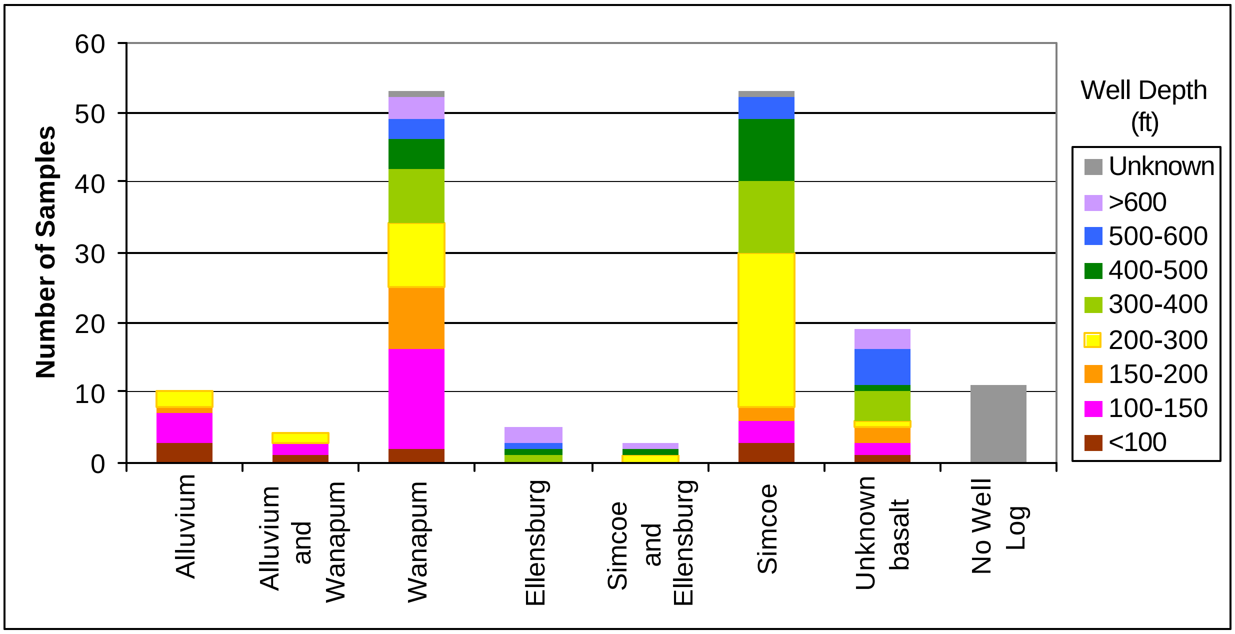

Figure 6. Depths of sampled wells in each aquifer.

Well depth is not necessarily reflective of the depth at which water is drawn. Most wells have some casing, but the casing depths are highly variable. Additionally, many of the wells have perforated casings or linings, which allow the well to draw water from depths that are shallower than both the well depth and the casing or lining depth (Figure 8). The majority of the sampled wells draw water from shallow (<100 feet) depths (Figure 9). Once the minimum depth of water withdrawal is factored in, the functional depth of the wells changes (Figure 10).

The aquifers labeled as "Alluvium and Wanapum" and "Simcoe and Ellensburg" in the charts and graphs within this report are indicative of wells that were constructed such that they draw water from 2 aquifers. For the purposes of data analysis, an estimate of the portion of water present in these wells from each aquifer and/or drawn from various depths would have been helpful. These proportions, however, cannot be estimated because the relative flow of water at the various depths is unknown.

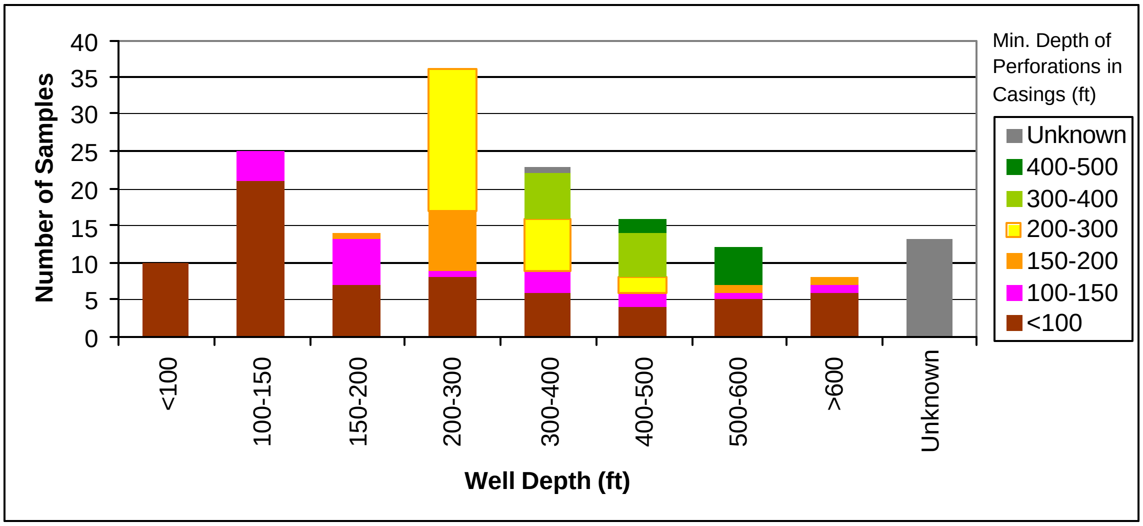

Figure 7. Minimum depth of perforations in casings or linings relative to well depth.

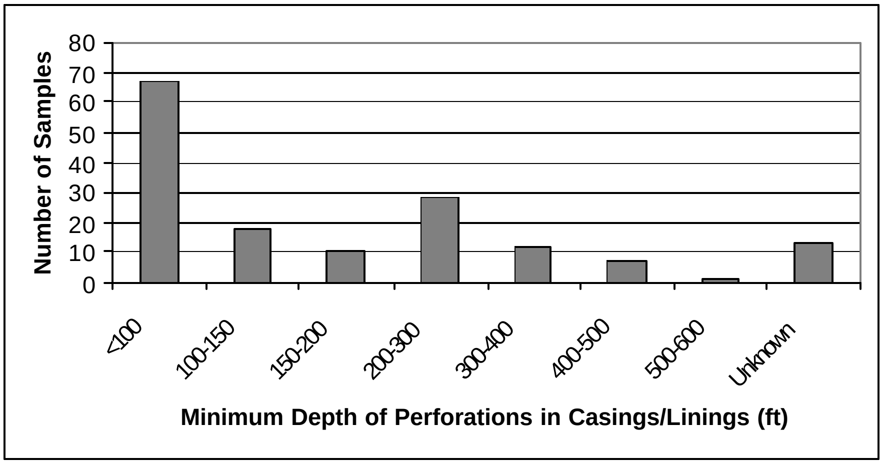

Figure 8. Distribution of sampled wells across minimum depth at which water is drawn.

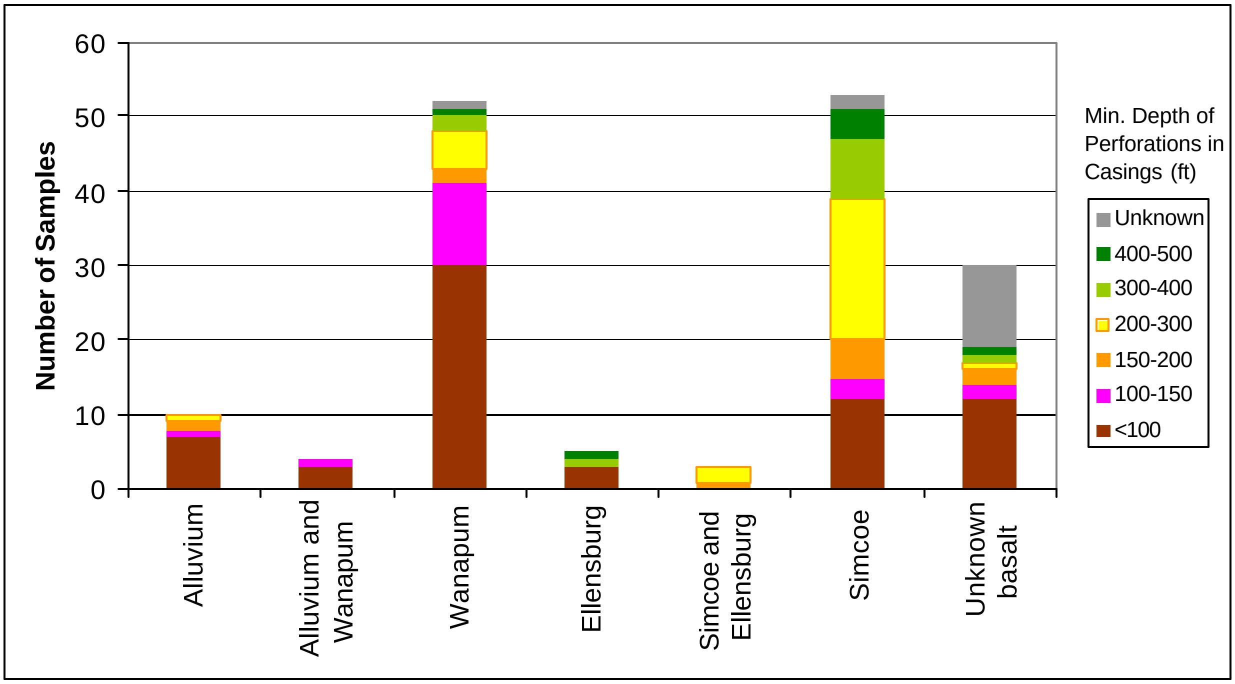

Figure 9. Minimum depth of perforations in casings/linings in sampled wells within each aquifer.

3.3 Nitrate

The following discussion is broken into three sections. Section 3.3.1 covers nitrate concentrations found in samples collected by this study in spring and by the Klickitat County Health Department. Results of the duplicated sampling conducted in fall and comparison of differences between spring and fall are covered in Section 3.3.2. Nitrate concentrations measured in surface waters in spring are discussed in Section 3.3.3.

3.3.1 Nitrate in Spring and Klickitat County Samples

Nitrate concentrations from samples collected in spring and samples collected by Klickitat County fell below the laboratory detection limit (ND) in 49% of the samples (Figure 11). Measured nitrate values ranged from <0.1 to 53.2 mg/l. Nitrate concentrations exceeded the state standard of 10 mg/l in 8 percent of the samples (n=12).

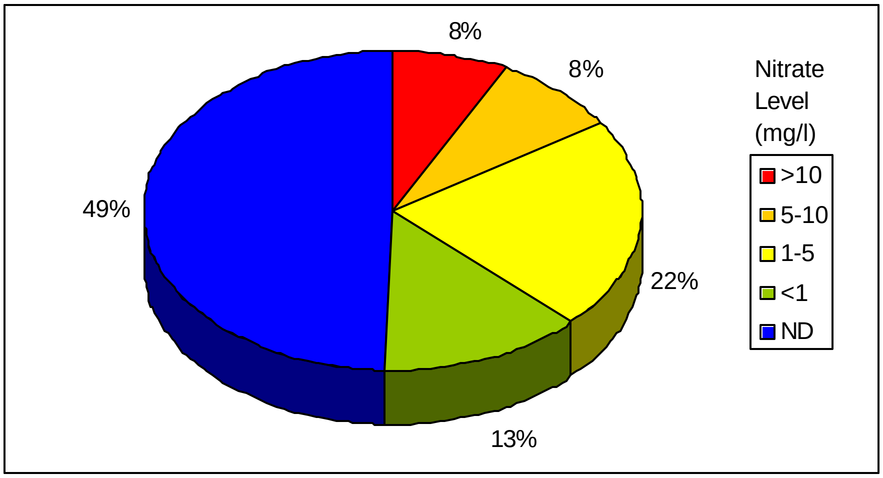

Figure 10. Distribution of nitrate concentrations in samples.

SUBBASIN AND AQUIFER DISTRIBUTION

All but two of the samples that exceeded the state standard for nitrate were found in the Swale subbasin (Figure 12). The one exception came from a well in the Little Klickitat subbasin. This location lies within the area in the Little Klickitat subbasin that is underlain by the Wanapum basalt (which is predominately found in the Swale subbasin). The site is also the historical location of a farm chemical distribution plant. One additional sample located near the Columbia River exceeded the standard. Most of the samples with nitrate concentrations greater than 5 mg/l were also found in the Little Klickitat and Swale subbasins.

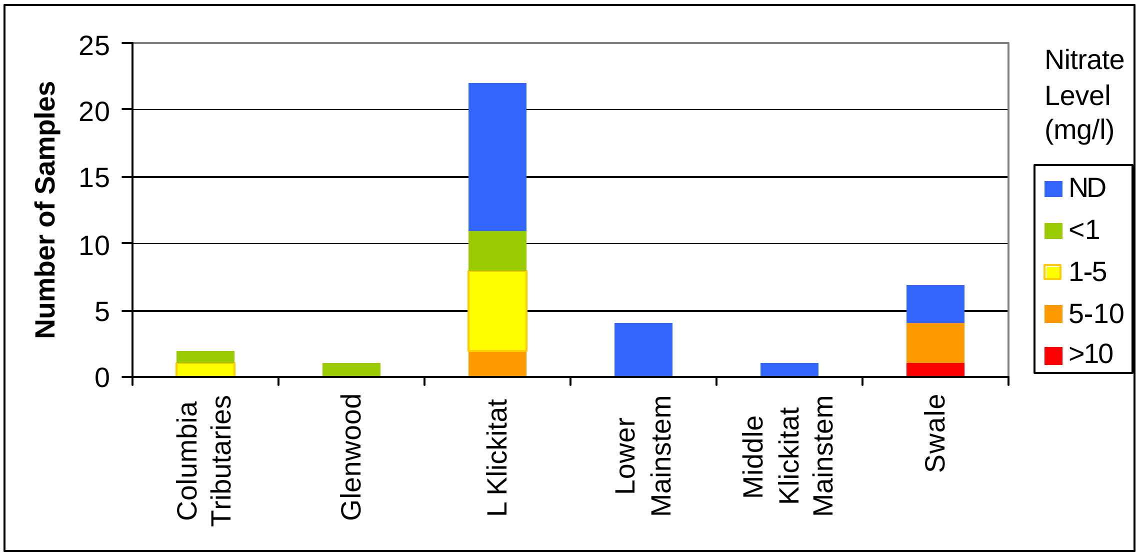

Figure 11. Depiction of nitrate concentrations by subbasin (spring and Klickitat County samples).

All samples collected in the Glenwood area, the Middle Mainstem subbasin, and the Columbia tributaries contained nitrate levels of less than 1 mg/l. Sample sizes in these subbasins were small; hence these results should be interpreted with care. A larger sample size may reveal different patterns in the distribution of elevated nitrate concentrations.

All of the nitrate concentrations that exceeded 5 mg/l were collected from wells that draw from the alluvium, the Wanapum basalts, and/or the Simcoe basalts and all of the samples that exceeded the state standard were collected from wells in the alluvium and/or Wanapum basalt (Figure 13). Nineteen percent of the samples collected from wells in the Wanapum basalts and/or Swale Creek alluvium exceeded the state standard (10 mg/l) and another 13% had nitrate concentrations between 5 and 10 mg/l (Table 9 and Figure 14).

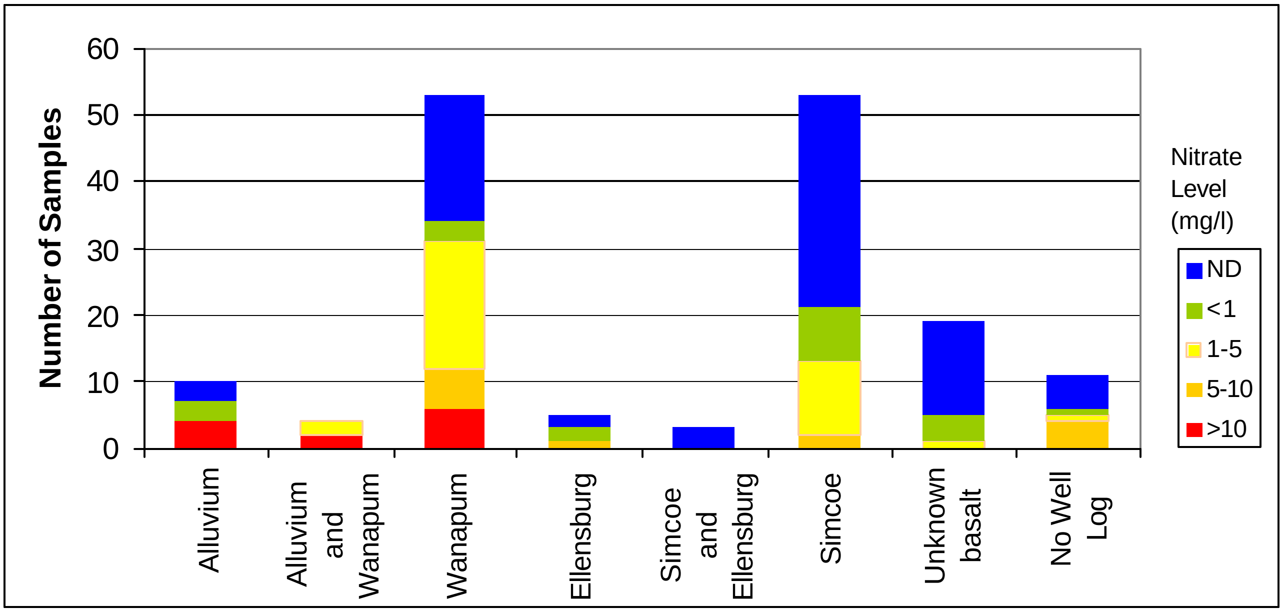

Figure 12. Depiction of nitrate concentrations by aquifer.

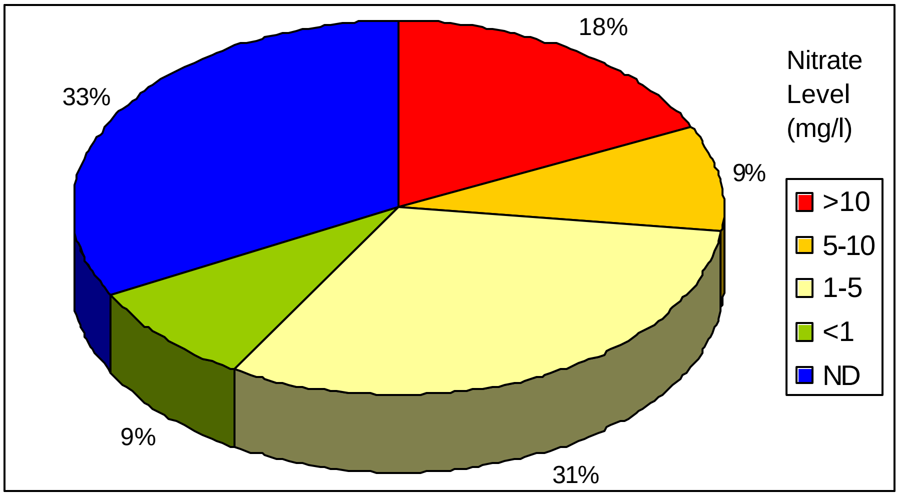

Figure 13. Percent of samples within each nitrate range (mg/l) within the combined samples collected in the Swale Creek alluvium, the Wanapum basalt, and combinations of both aquifers.

Table 9. Number and percent of samples collected from wells in the Swale Creek alluvium and Wanapum volcanics by range of nitrate concentrations (mg/l) (spring and Klickitat County samples only).

Aquifer	ND	<1	1-5	5-10	>10
Alluvium	3 30%	3 30%	0 0%	0 0%	4 40%
Alluvium and Wanapum	0 0%	0 0%	2 50%	0 0%	2 50%
Wanapum	19 36%	3 6%	19 36%	6 11%	6 11%

Several samples that had no well log also had elevated nitrate concentrations. All of the elevated measurements in the samples with no well logs came from the Swale and Little Klickitat subbasins (Figure 15).

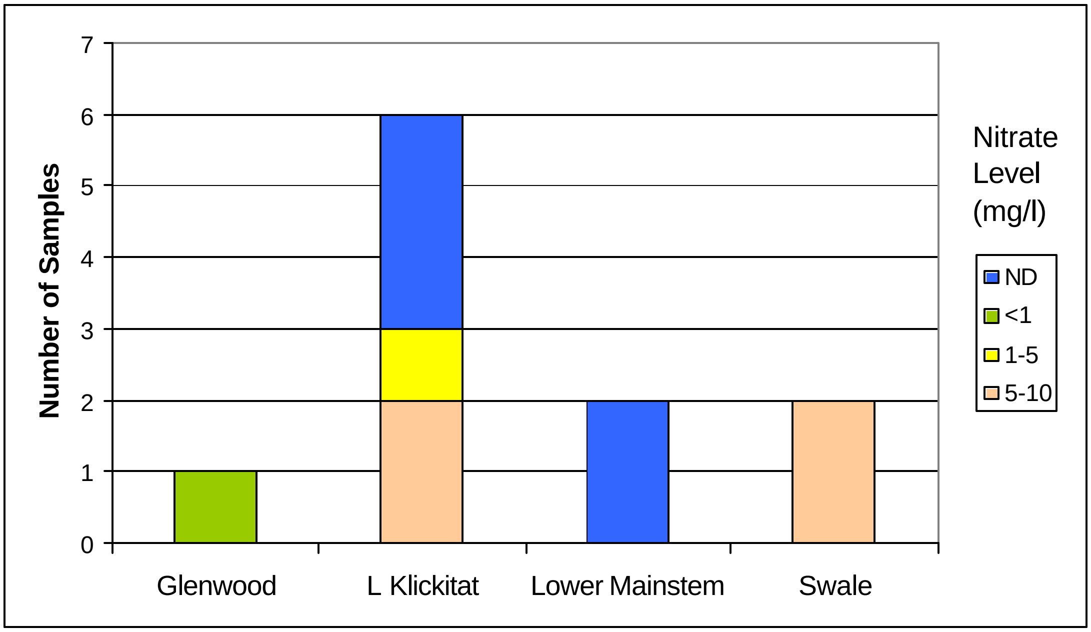

Figure 14. Nitrate concentrations by subbasin for the samples for which no well log was located.

DEPTH DISTRIBUTION

The analysis of the concentration of nitrate with depth was limited to the Wanapum basalt, the Swale alluvium, and the Simcoe basalt. No indication of elevated nitrate in the other areas was indicated in the data.

Swale Alluvium

There were only 14 samples taken from the Swale alluvium or a combination of Swale alluvium and Wanapum basalt for which well logs were available. Hence, the power of the data analysis is somewhat limited. Six of the samples exceeded the state standard for nitrate (10 mg/l).

Sampled wells drawing from the alluvium ranged in depth from 80 to 260 feet (Figure 16). One of the deeper wells had a casing with no perforations that ran most the length of the well hole. The other deep well had perforations starting at less than 50 feet (Figure 17); hence, it draws water from shallower waters in the aquifer. Most of the other wells in this group also draw water from shallower waters. All of the wells with elevated nitrate concentrations drew water from less than 100 feet (Figure 18). No increasing or decreasing trend with depth was apparent in the data.

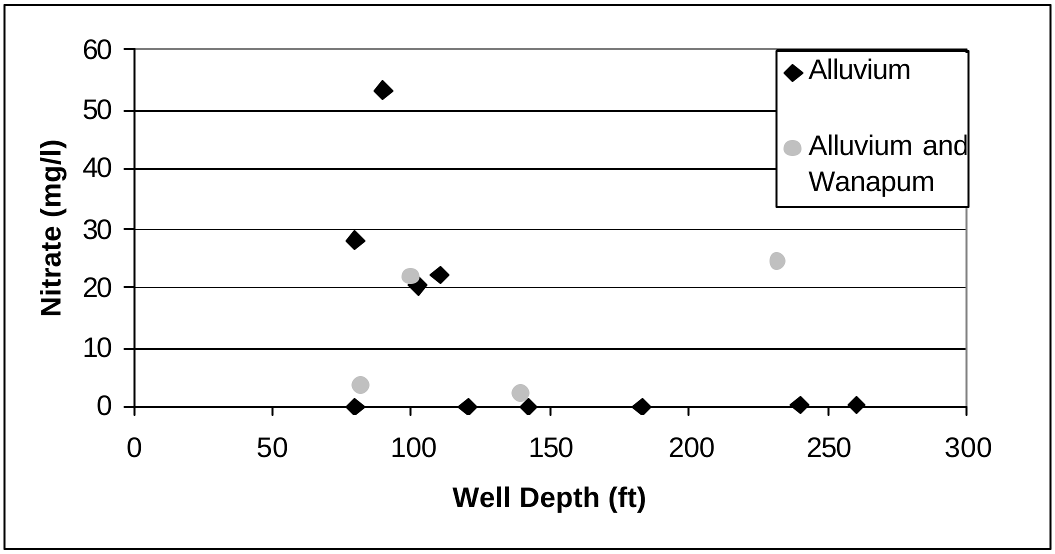

Figure 15. Nitrate concentration versus well depth in the Swale subbasin alluvium.

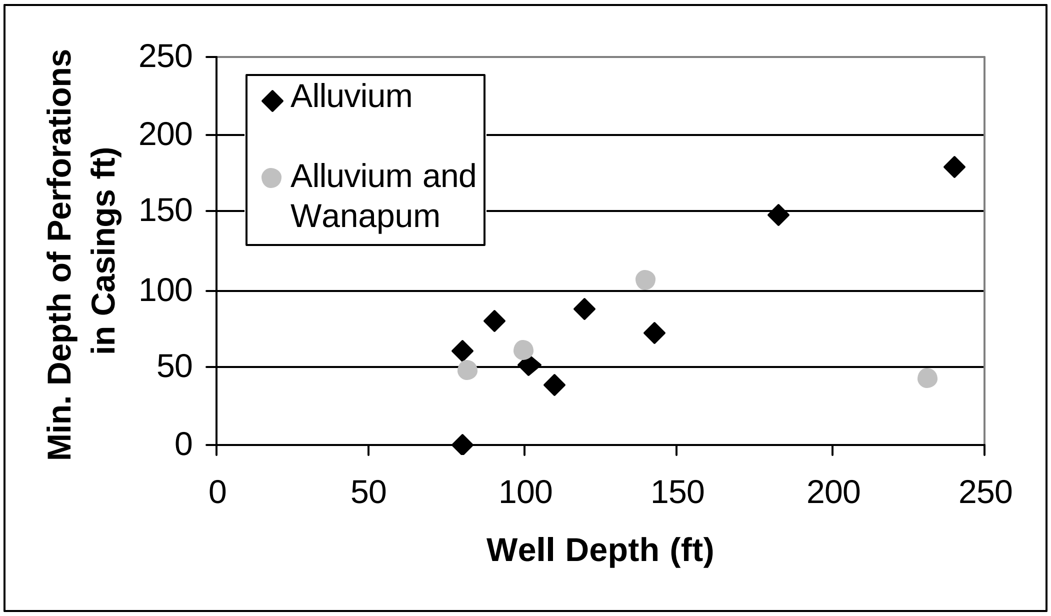

Figure 16. Well depth versus minimum depth of perforations in the casings/linings of wells within the Swale alluvium or a combination of alluvium and Wanapum basalt.

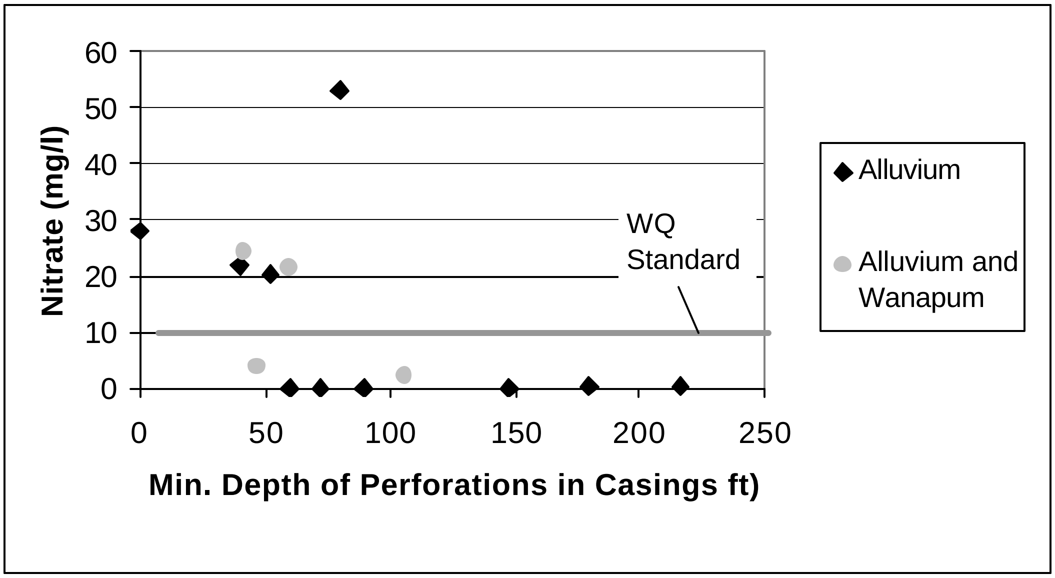

Figure 17. Nitrate concentration in water from wells in the Swale subbasin alluvium and a combination of alluvium and Wanapum basalt as a function of the minimum depth of perforations in well casings/linings.

Wanapum Basalt

Fifty-three (53) samples that had well logs available were taken from Wanapum basalt. Six of these (11%) exceeded the state standard and another 6 samples (11%) had nitrate concentrations between 5 and 10 mg/l. The highest concentrations tended to be found in shallower wells (Figure 19); however, concentrations at or greater than the state standard were found in wells up to 500 feet deep.

Almost half of the wells in the Wanapum basalt had casings without perforations that reached nearly the full depth of the well (points running diagonally in Figure 20). The rest of the wells draw water over a wider range of depths. All the samples with nitrate levels in excess of the state standard draw water from less than 120 feet deep in the Wanapum basalt (Figure 21).

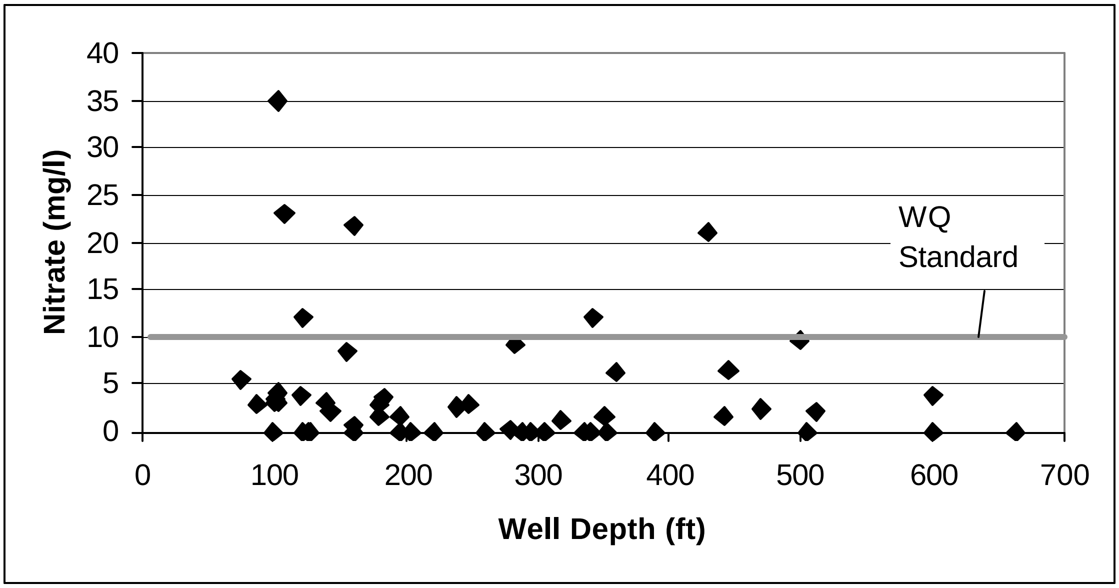

Figure 18. Nitrate concentration in samples from Wanapum basalt as a function of well depth.

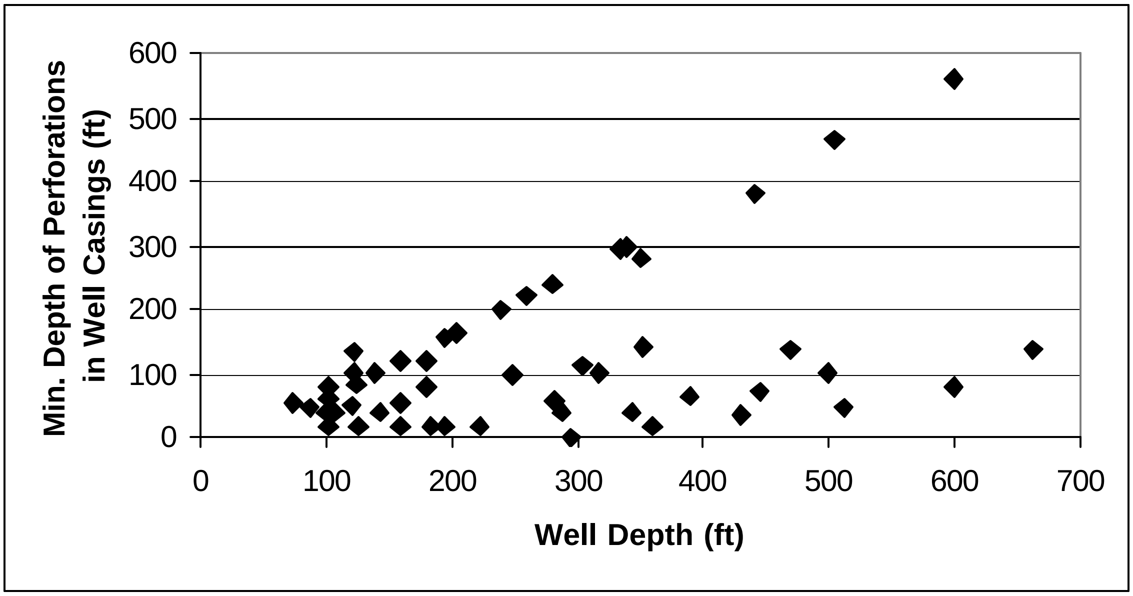

Figure 19. Minimum depth of perforations in well casings or linings as a function of well depth for wells drawing from Wanapum basalt.

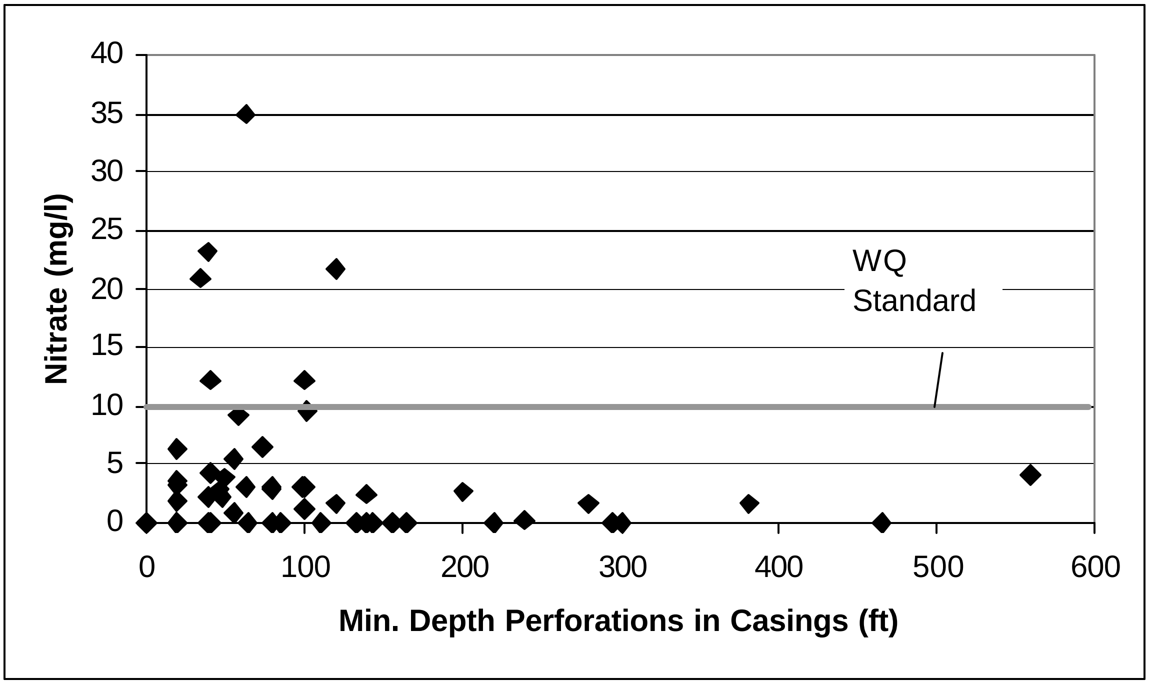

Figure 20. Nitrate concentrations in wells drawing from Wanapum basalt as a function of the minimum depth of perforations in well casings or linings.

Simcoe Basalt

None of the 56 samples taken from Simcoe basalt exceeded the state standard; however, a few of the samples were elevated, one sample approached the standard, and several had measurable concentrations of nitrate (Figure 22). Measurable nitrate was found in wells as deep as 440 feet. No trend in nitrate concentration with well depth was apparent in the data.

Unlike the wells in the Swale alluvium and Wanapum basalt, the majority of the wells in Simcoe basalt were cased without perforations to nearly their full depth (Figure 23). No trend in nitrate concentration with minimum depth of perforations was apparent in the data (Figure 24).

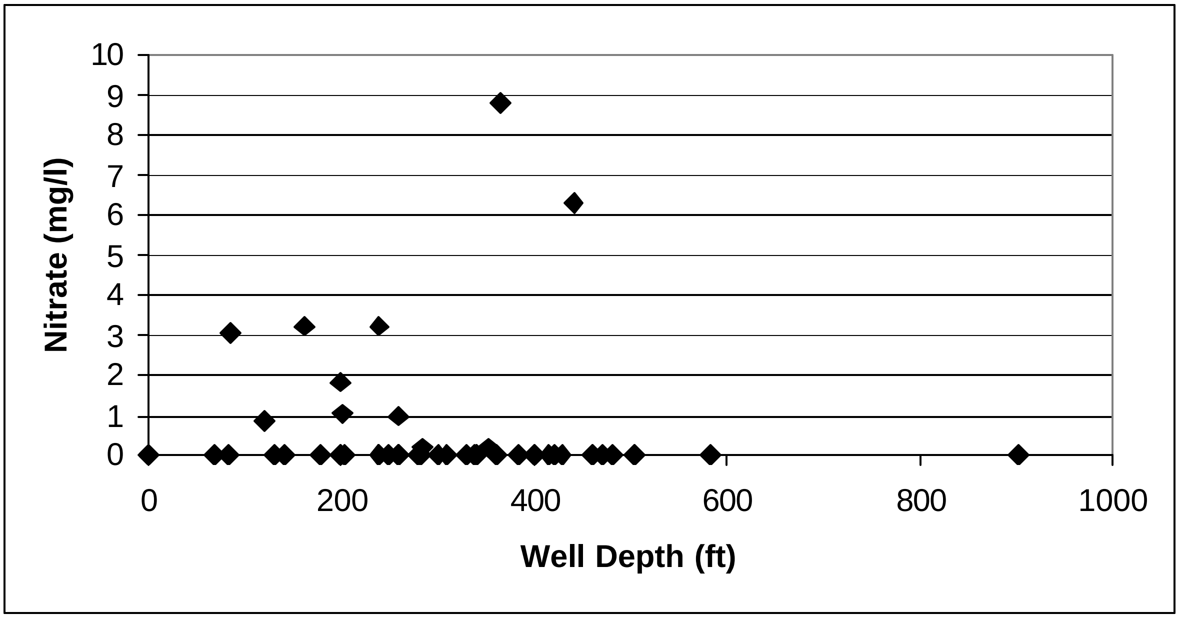

Figure 21. Nitrate concentrations in Simcoe basalt samples as a function of well depth.

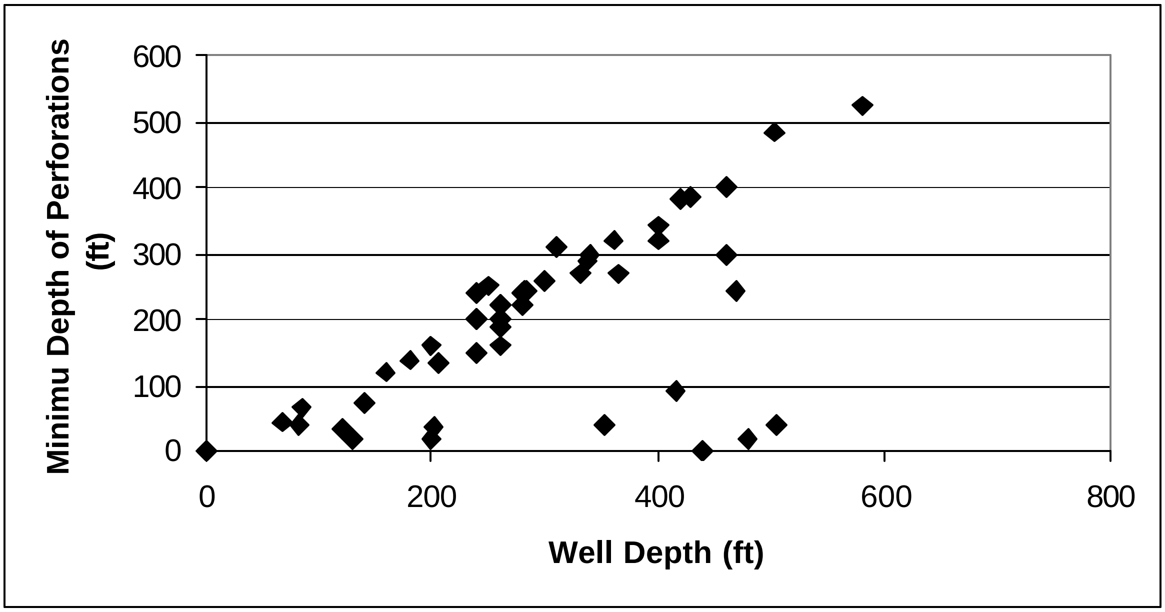

Figure 22. Minimum depth of perforations in well casings/linings as a function of well depth in Simcoe basalt.

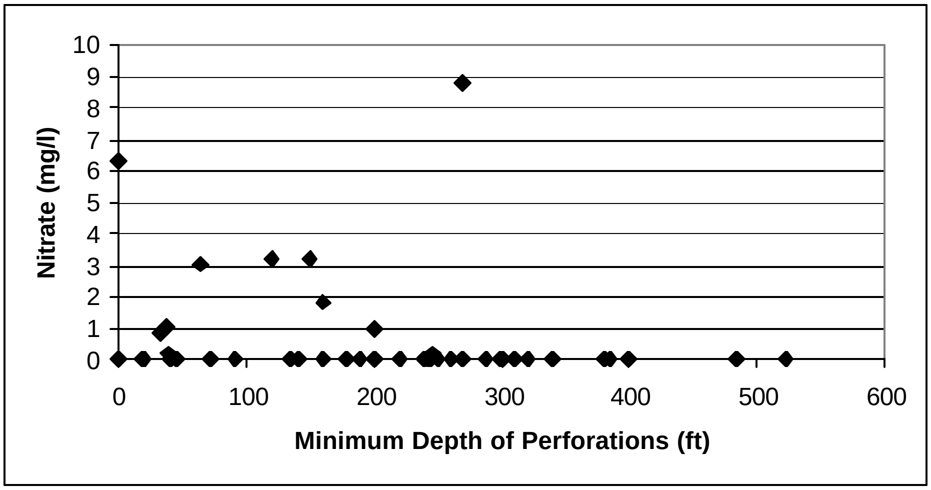

Figure 23. Nitrate concentration in Simcoe basalt wells as a function of the minimum depth of perforations in well casings/linings.

CORRELATION WITH CHLORIDE

Chloride in water samples is often indicative of a household source. Chloride is introduced into the water column primarily through the disposal of various cleaning products. Chloride was sampled in this study to determine if a correlation existed between nitrate concentration and chloride. Such a correlation would suggest that septic systems are likely a primary source of the contaminants.

Chloride samples were not available for the data points collected by KCDH. Therefore, the sample size for this analysis was reduced. Nitrate concentrations in Simcoe basalt samples collected in this study were all below detection limits. Chloride concentrations were likewise very low (<5 mg/l). Hence, the Simcoe basalt samples collected in this study were not included in this analysis. There are 27 samples available from the Wanapum basalt and Swale alluvium that have measures of both nitrate and chloride concentration.

Nitrate in this subset of data ranged from 0 to 24.5 mg/l and chloride ranged from 0 to 57.3 mg/l. There is a strong correlation between nitrate concentration and chloride concentration in the samples (Figure 25). A linear regression of the data was performed (Schaeffer et al, 1996). The analysis produced a significant ($p<.01$) relationship with a correlation coefficient of 0.82, which means the regression equation explained 82% of the variation in the data. The predictive equation is:

Nitrate (mg/l) = 0.6494 * Chloride (mg/l) +1.7062.

As Figure 26 depicts, all samples with nitrate values in excess of the state standard also have high chloride concentrations. The one sample with high nitrate concentrations and lower chloride concentrations is the site where the historical fertilizer plant was located. It is possible that residual nitrogen in the soils is having a local effect on nitrate levels at that location. All samples with elevated nitrates had perforations at of less than 100 feet deep and most draw water from less than 50 feet deep.

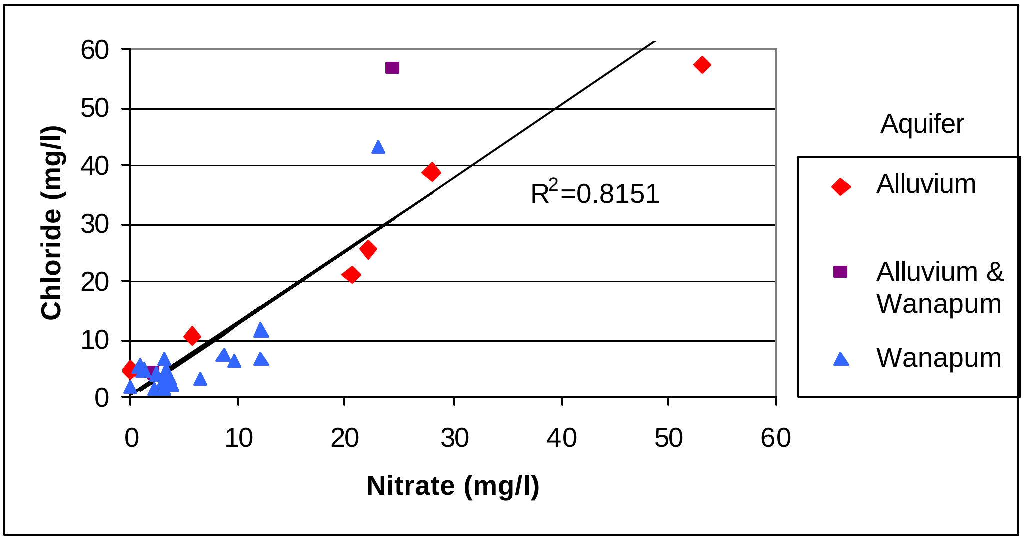

Figure 24. Nitrate versus chloride concentrations in samples from the Swale subbasin alluvium and Wanapum basalt.

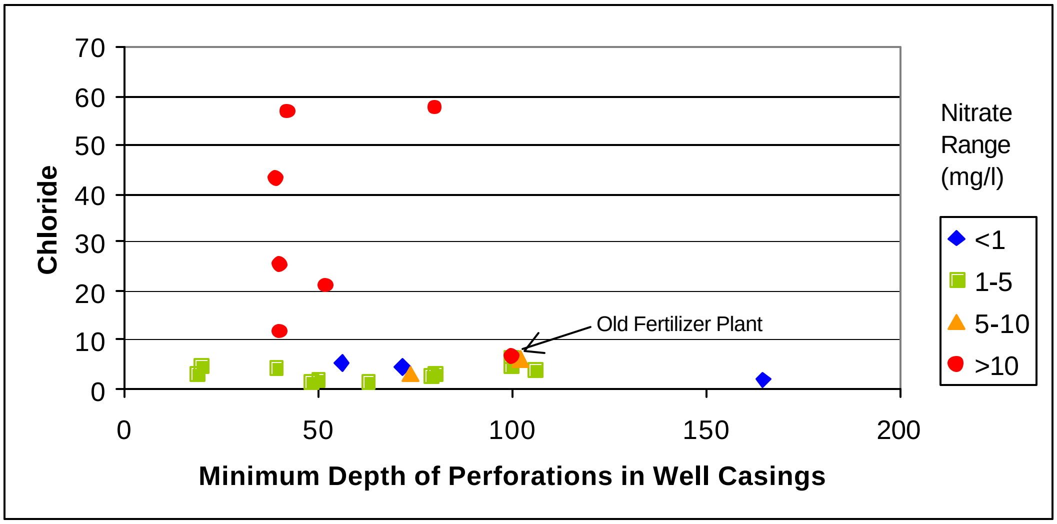

Figure 25. Minimum depth of perforations versus chloride and nitrate concentrations.

3.3.2 Variability Between Seasons

Nitrate and chloride concentrations at most of the duplicated sites changed little between spring and fall (Figures 27 and 28). Substantial changes in nitrate were, however, found at two sites. Substantial changes in chloride were also found at these two sites and at an additional site.

Sample location 11 was a site where major modifications had been made to the well between the samples. The modifications appear to have reduced nitrate levels substantially. At this location, a water filtration system was also installed that was intended to further reduce nitrate levels. Samples were collected at the well head at this location and also after the filtration system to determine the effectiveness of the system. Nitrate was further reduced substantially by the filtration system (Table 10), however chloride increased substantially. Specifics regarding the filtration system are unknown, but it may include treatment with chlorine which could increase the chloride content of water.

Nitrate and chloride concentrations also increased between spring and fall at site number 10 and chloride increased between spring and fall at site 9. No explanation for these changes is available.

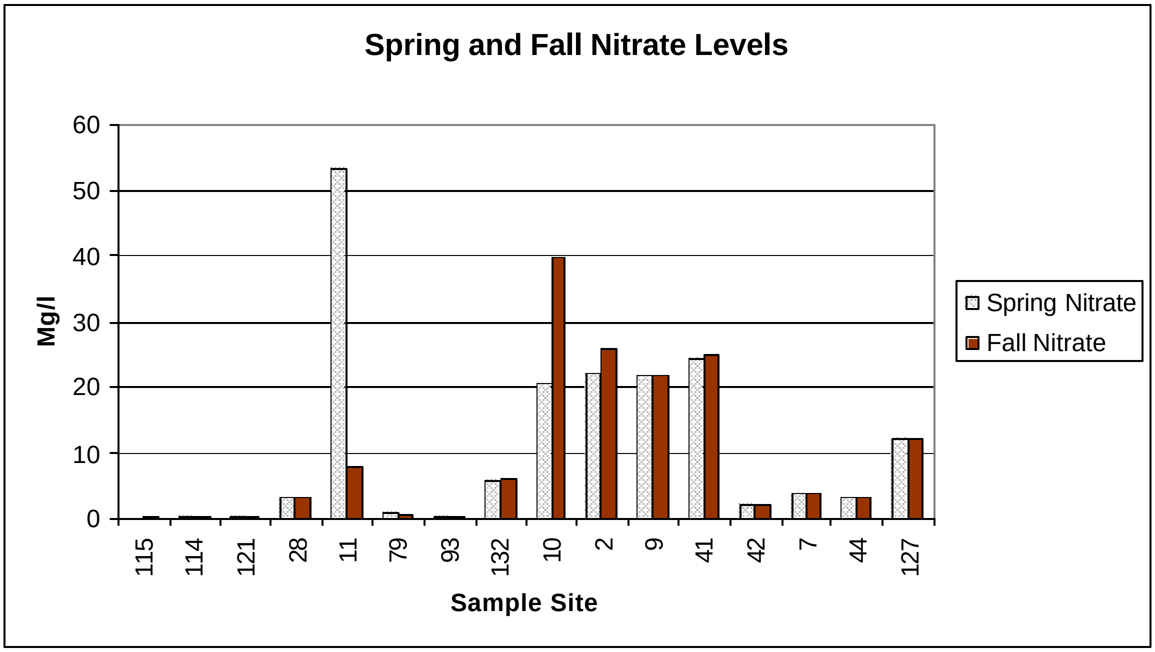

Figure 26. Comparison of nitrate concentrations found at each site sampled in spring and fall.

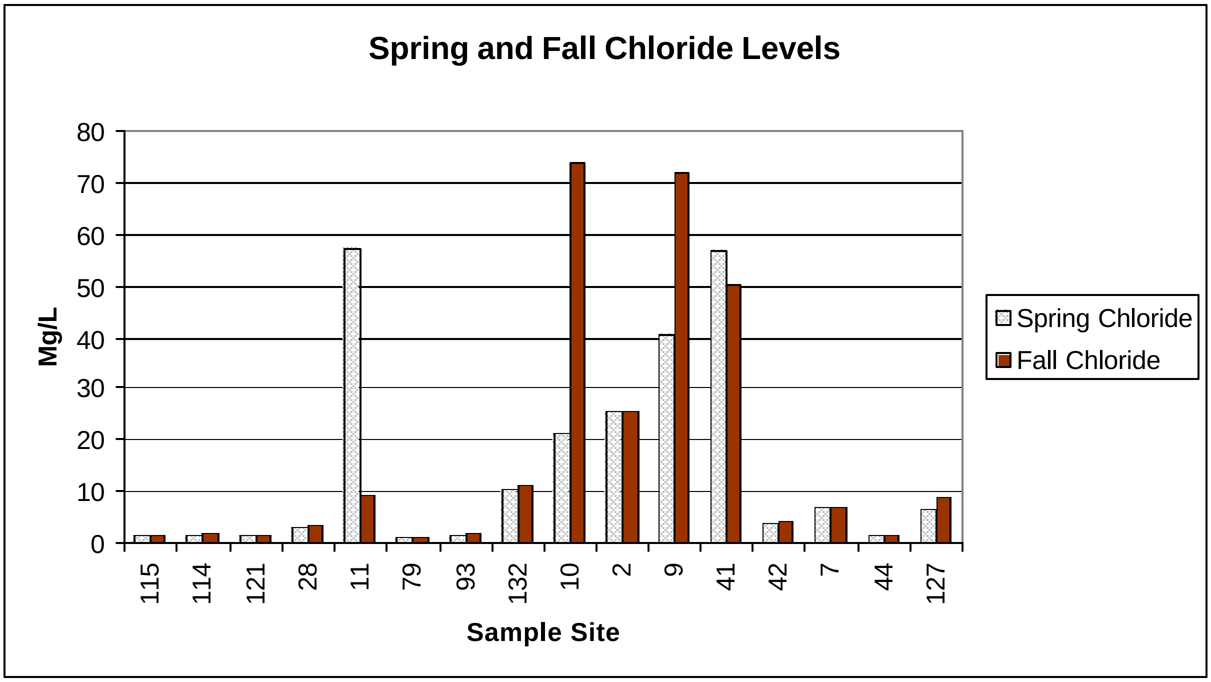

Figure 27. Comparison of chloride concentrations found at each site sampled in spring and fall.

Table 10. Comparison of nitrate and chloride levels at sample location 11 before and after passing through a treatment system.

Compound	**At Well Head**	**After Filtration**
Nitrate	7.73 mg/L	0.210 mg/L
Chloride	9.28 mg/L	73.7 mg/L

As would be expected, the correlation between nitrate and chloride concentrations seen in the spring samples also is present in the fall samples (Figure 29). Note that the correlation between the two parameters is strongest at chloride concentrations below 30 mg/l. At concentrations higher than that value, both chloride and nitrate tend to be elevated, but the linear relation between the two is less evident.

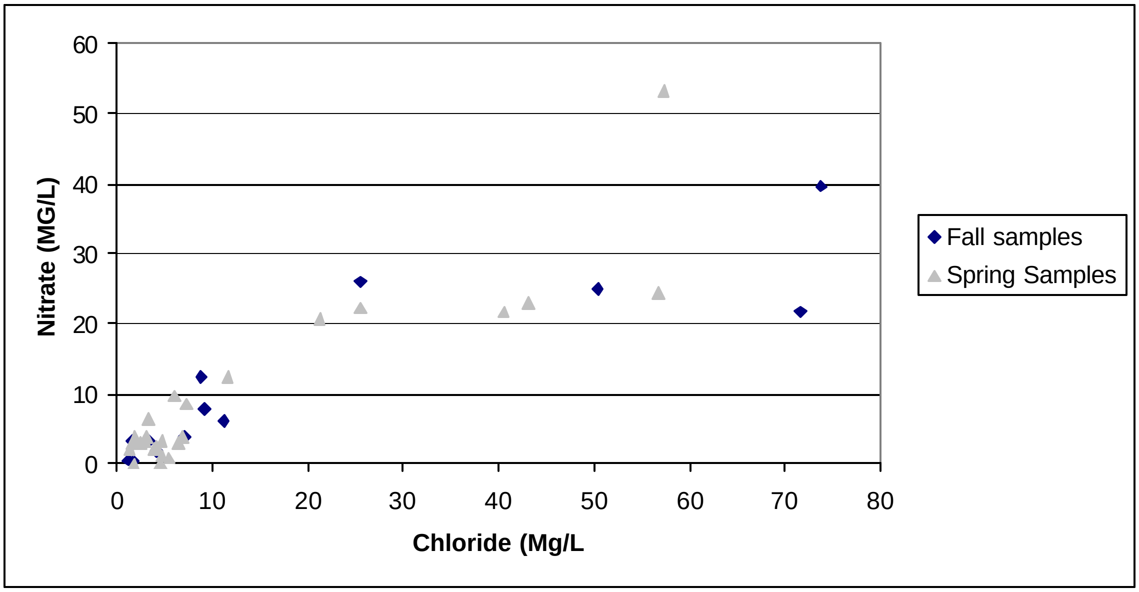

Figure 28. Relationship between nitrate concentration and chloride concentration in spring and fall samples.

3.3.3 Nitrate in Surface Water

All surface water samples had nitrate concentrations that were well below the state standard (Table 11). The highest concentration (3.07 mg/l) detected was found in Blockhouse Creek near the confluence with the Little Klickitat River.

3.4 Bacteria

Water quality samples collected from wells by this study in spring were analyzed for fecal coliform and *Escherichia coli* (*E. Coli)* bacteria. No bacteria detections were found in any groundwater wells sampled in this project.

Sixteen surface water locations were sampled in the Little Klickitat and Swale Creek subbasins (Table 12). Measurable *E. coli* were found in spring in all but one of the surface water samples. The highest concentrations were found in Spring Creek, Blockhouse Creek, Mill Creek, and Swale Creek near highway 97 (sample 12b in Table 12). Fecal coliform concentrations were present at all sites in fall (Table 12). The state standard for fecal coliform concentration was exceeded at the mouth of Bloodgood Creek, the mouth of Blockhouse Creek, and all of the Swale Creek sample sites.

Table 11. Nitrate concentrations in surface water samples.

Sample Number	Sample Location	Township, Section, Range	Nitrate Concentration (mg/l)
1	East Prong near crossing of Box Canyon Road	T5N, R17E, 16	ND
2	West Prong near confluence with Little Klickitat	T5N, R17E, 17	0.12
3	Little Klickitat at ;intersection of Hwy 97 and Tallman Rd	T4N, R16E, 10	ND
4	Little Klickitat just west of Goldendale (at Miller Road)	T4N, R16E, 20	ND
5	Bloodgood Creek near confluence with Little Klickitat (at Pine Forest Rd)	T4N, R16E, 5	0.20
6	Spring Creek near confluence with Little Klickitat (at Olson Rd)	T4N, R15E, 5	0.88
7	Blockhouse Creek near confluence with Little Klickitat (at Hwy 42)	T4N, R15E, 16	3.07
8	Mill Creek near confluence with Little Klickitat (at Garrison Rd)	T4N, R15E, 21	ND
9	Bowman Creek near confluence with Little Klickitat	T4N, R14E, 10	0.23
10	Little Klickitat at confluence with mainstem	T4N, R14E, 17	0.28
11	Swale Creek about 1.5 mile east of Hwy 97 (at Clyde Story Rd)	T4N, R16E ,28	0.1
12	Swale Creek about 0.5 miles west of Hwy 97 (at Centerville Hwy)	T3N, R16E, 8	0.49
12b	Swale Creek near Centerville (at Eshelman Rd)	T3N, R16E, 18	ND
13	Swale Creek west of Centerville (near X-section of Dalles Mt and Basse Rd)	T3N, R15E, 13	ND
14	Swale Creek between Centerville and Warwick (at Woods Rd)	T3N, R15E, 21	ND
14b	Swale Creek between Centerville and Warwick (at Erickson Rd)	T3N, R15E, 20	ND
15	Swale Creek between Centerville and Warwick (at Uecker Rd)	T3N, R14E, 25	ND
16	Swale Creek near Warwick (at Harms Rd)	T3N, R14E, 27	ND

Table 12. *E. coli* and fecal coliform concentrations in surface water samples. The standard for fecal coliform is 100 colonies per 100 ml. Numbers in bold indicate measurements in excess of the standard.

Sample Number	Sample Location	Township, Range, Section	*E. Coli* (Colonies per 100 ml)	Fecal Coliform (Colonies per 100 ml)
1	East Prong near crossing of Box Canyon Road	T5N, R17E, 16	2.0	11
2	West Prong near confluence with Little Klickitat	T5N, R17E, 17	3.1	2
3	Little Klickitat at intersection of Hwy 97 and Tallman Rd	T4N, R16E, 10	23.1	1.3
4	Little Klickitat just west of Goldendale (at Miller Road)	T4N, R16E, 20	55.2	50
5	Bloodgood Creek (at Pine Forest Rd)	T4N, R16E, 5	61.3	**900**
6	Spring Creek near confluence with Little Klickitat (at Olson Rd)	T4N, R15E, 5	178	23.0
7	Blockhouse Creek (at Hwy 42)	T4N, R15E, 16	111	**130**
8	Mill Creek near confluence with Little Klickitat (at Garrison Rd)	T4N, R15E, 21	125	80
9	Bowman Creek near confluence with Little Klickitat	T4N, R14E, 10	54.6	9.0
10	Little Klickitat at confluence with mainstem	T4N, R14E, 17	26.9	30.0
11	Swale Creek about 1.5 mile east of Hwy 97 (at Clyde Story Rd)	T4N, R16E ,28	55.6	**1600**
12	Swale Creek about 0.5 miles west of Hwy 97 (at Centerville Hwy)	T3N, R16E, 8	123	**220**
12b	Swale Creek near Centerville (at Eshelman Rd)	T3N, R16E, 18	ND	
13	Swale Creek west of Centerville (near X-section of Dalles Mt and Basse Rd)	T3N, R15E, 13	95.9	**1600**
14	Swale Creek between Centerville and Warwick (at Woods Rd)	T3N, R15E, 21	67.6	
14b	Swale Creek between Centerville and Warwick (at Erickson Rd)	T3N, R15E, 20	57.3	
15	Swale Creek between Centerville and Warwick (at Uecker Rd)	T3N, R14E, 25	73.3	**900**
16	Swale Creek near Warwick (at Harms Rd)	T3N, R14E, 27	326	**240**

All the sample sites in Swale Creek were taken from standing water with negligible flow. Hence, there is little or no upstream or downstream movement of pollutants through surface water. The highest concentrations (1600 MPN/100 ml) were found in Swale Creek near Clyde Story Road and near the intersection of Dalles Mountain Road and Basse Road. No fecal coliform concentrations were found in groundwater in the Swale Creek area, indicating that the pollutants are not percolating into the groundwater at a measurable rate. Fecal coliform concentrations in the sample areas within Swale Creek are likely reflective inputs within the vicinity of the sample site which cumulate over the summer period of no flow.

It should be noted that the measurements taken in each stream reach represent only one sample at each location. The Washington State standard for fecal coliform organisms is measured against a geometric mean value. For the waters in the Swale and Little Klickitat subbasins, the geometric mean is not to exceed 100 colonies per 100 ml with not more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies per 100 mL. The use of the geometric mean recognizes that numerous events could occur that temporarily raise the fecal coliform levels in a stream reach. Additional samples (9 or more per site) should be taken in the areas where elevated concentrations were found in 2003 to allow for the calculation of a geometric mean and to determine if the standards are truly exceeded and to ensure that the concentrations found in October were not anomalous.

The most likely sources of bacteria in the Little Klickitat and Swale subbasin are domestic animal waste sources, agricultural animal waste sources, septic systems, and wildlife near surface waters.

3.5 Minerals and Other Nutrients

Nitrite, calcium, ammonia, sodium, potassium, phosphorus, alkalinity, magnesium, iron, manganese, chloride, sulfate, arsenic, water temperature, total dissolved solids, and specific conductance were evaluated for all well water samples collected during the spring sample period. Most of these parameters do not have water quality standards established in the state of Washington. This means that, currently, there are no health concerns associated with drinking water that contains any of these parameters. Iron, manganese, chloride, sulfate, and arsenic all have established water quality criteria. One of the samples exceeded the standard for iron (Table 13). All other samples met all applicable standards. Ammonia-nitrate was the only other water quality parameter that was sampled in surface waters. Ammonia-nitrate was not detected in any of the surface water samples.

Table 13. Summary of results of parameters other than nitrate and bacteria evaluated in water samples

Constituent	Applicable Standard	Minimum	Maximum	Median[1]
Nitrite (mg/l)	None	ND	ND	ND
Calcium (mg/l)	None	6.58	85.9	18.4
Ammonia (mg/l)	None	ND	ND	ND
Sodium (mg/l)	None	3.46	31.6	11.2
Potassium (mg/l)	None	ND	6.82	1.71
Phosphorus (mg/l)	None	ND	0.654	0.06
Alkalinity (mg/l)	None	27.3	348	79.5
Magnesium (mg/l)	None	2.43	53.6	10.3
Iron (mg/l)	0.30 mg/l	ND	0.36[2]	0
Manganese (mg/l)	0.05	ND	0.185[3]	0
Chloride (mg/l)	250	0.97	57.3	3.85
Sulfate (mg/l)	250	ND	34.6	3.05
Arsenic (mg/l)	10	ND	0.00441	.0032
Water Temperature ($^?$F)	None	49.5	59.2	54.7
pH	None	6.5	8.3	7..4
Specific Conductance	None	89	764	243
Total Dissolved Solids (mg/l)	None	.035	.810	0.144

1/ Median rather than the mean is reported here because the results are not normally distributed. Non-detects were treated as 0 for the purposes of calculating the median.

2/ One sample exceeded the state standard for iron. The concentration in this sample was 0.36 mg/l.

3/ Two samples exceeded the state standard for manganese. Measure concentrations of these samples were 0.185 and 0.103 mg/l.

3.6 Stream Flow

Stream flows were measured by Aspect Consulting (Aspect Consulting, 2003) in spring and by WPN in support of the Swale Creek Temperature Study (WPN 2004) in October 20 and 21. Flows in Swale Creek in spring were 0.6 cfs at Highway 97, 1.0 cfs at Harms Road, and 5.1 cfs at the confluence with the mainstem Klickitat River. In fall, attempts were made to measure flow at numerous locations in Swale Creek from Highway 97 to the mouth. No measurable or perceptible flow was found upstream of RM 3.5. No flow was found at the mouth of Swale Creek either; however the segment ranging from just above the mouth to approximately RM 3.5 had a perceptible flow of roughly 0.4 cfs. This flow was not measurable with standard instruments and was estimated visually.

Measured stream flows in the Little Klickitat subbasin are summarized in Table 14.

Table 14. Spring stream flow measurements in the Little Klickitat subbasin (Appendix B).

Location	Flow (cfs)	Location	Flow (cfs)
Idlewild 2	2.4	Mill 1	3.9
Dry 1	1.9	Mill 2	6.3
Dry 2	4.7	Mill 3	15.4
Dry 3	6.4	Mill 4	24.5
Dry 4	4.6	Devil 1	7.1
Butler 1	21.2	Bowman 1	35
Butler 2	19	Bowman 2	22.7
West Prong 1	1.1	Bowman 3	20.6
West Prong 2	12.9	Bowman 4	16.3
Bloodgood 2	8.5	Canyon 1	3.9
Blockhouse 1	9.35	Canyon 2	1.5
Blockhouse 2	4.56		

4 DISCUSSION AND CONCLUSIONS

4.1 Nitrate

4.1.1 Distribution of Elevated Nitrate Concentrations

The sampling effort that was conducted in this study indicates that nitrate concentrations in wells that draw from the Simcoe volcanics and the Ellensburg formation are very low and are not an area of concern within the watershed. None of the samples exceeded that state standard for nitrate and only 2 (4%) exceeded 5 mg/l. Areas underlain by these geologic units are distributed throughout most of the Little Klickitat subbasin.

Nitrate levels in the Glenwood area and in areas in the subbasin referred to as the Columbia tributaries were below the state standard of 10 mg/l. Sample size in these areas was small (n=3 in each case). Different results could potentially be found in a more comprehensive well testing program. It should be noted, however, that most of the residences in the Glenwood area do not use wells as their source of water. The Glenwood area only has 11 recorded wells. The sample of 3 wells represents roughly a third of the entire set. Therefore, the likelihood that a significant public nuisance is present in the area is low. Conversely, there appear to be a number of wells in and around the Dallesport area. The Dallesport area was not included in the sampling effort conducted under this study. Well nitrate concentration for that area is represented by the

Klickitat County Health Department's data. Expanded sampling in this area may reveal a pattern that was not evident in the existing data.

The majority of the higher concentrations of nitrate were found in wells drawing from the Wanapum volcanics and the Swale Creek alluvium. These aquifers are located primarily within the Swale Creek subbasin, but extend a short distance into the Little Klickitat subbasin near Centerville.

Within this area, 18% of the well samples had nitrate concentrations greater than the state criteria (10 mg/l) and an additional 9% had concentrations in the range of 5 to 10 mg/l. All of the wells with elevated nitrate concentrations in these aquifers drew water from less than 150 feet deep. Note that the minimum depth of the perforations in the well casings or linings is a better indicator of the minimum depth of water that is drawn than is well depth. Hence, the wells where nitrate concentrations may be elevated are limited to those that draw from the Wanapum basalts and Swale Creek alluvium that have a total well depth or a minimum depth of perforations less than 150 feet deep. There was no significant difference in the nitrate concentrations found in repeated samples in spring and fall.

4.1.2 Nitrate Source Evaluation

Within the Swale Creek alluvium and Wanapum basalt, nitrate concentrations were highly and significantly correlated with chloride concentrations. This correlation strongly suggests the source of nitrate is associated with septic systems. No elevated concentrations of nitrate were found in the surface waters sampled in this study, suggesting that nitrate problems in wells are a problem that is local to the site and not manifested across the entire aquifer. The presence of many shallow wells within the aquifers that have non-detectable or very low nitrate concentrations further supports the conclusion that nitrate inputs have a localized effect.

BIOLOGICAL EFFECTS OF EXPOSURE

The significant of the elevated nitrate concentrations remains somewhat controversial because study results have been inconsistent. The primary avenue through which nitrates affect humans is the oxidation of iron in hemoglobin forming methemoglobin. Infants less than 6 months old are the most sensitive to the effects (Hartman, 1982; Bouchard et al., 1992). Baby formula made with drinking water with nitrate levels <10 mg/l have not been documented to result in toxic effects (Francis, 1995).

One study indicated a correlation between the number of congenital malformations and the amount of inorganic nitrate in the mother's drinking water (Dorsch et al., 1984). Other studies have supported this correlation. Rates, guinea pigs, mice, hamsters, and rabbits showed no malformations with exposure, however fetal toxicity was observed at doses of 4000 mg/l (Francis, 1995). This concentration is two orders of magnitude higher than any measured in the Klickitat watershed. Hence, residents of the watershed should not be concerned about this possible toxic effect.

EPA has established a reference dose for nitrates of 10 mg/l in drinking water based on the signs of methemoglobenemia in 0 to 3 month old infants (Bosch et al., 1950, Walton, 1951). This dose was based on the most sensitive populations.

Given the clinical evidence that supports some risk for the development of methemoglobenemia (Blue Baby Syndrome) in babies up to 6 months old, use of drinking water with nitrate concentrations <10 mg/l should be avoided in the preparation of formula for infants. There is no evidence to suggest potential effects to unborn or nursing infants resulting from the intake of nitrates by the mother. Future clinical studies may further clarify the connection between nitrates and methemoglobenemia and provide information that can better guide residents with high nitrate concentrations in their drinking water.

POTENTIAL MITIGATION OPTIONS

Potential mitigation options include removing the source of the pollutant, avoiding contaminated water, and water treatment. Specific options include the following:

- **Location of well relative to drain field.** Locate or move either the septic system or the well to locations that are far apart to minimize local contamination of groundwater.

- **Upgrade septic system.** Many drain fields have been installed deep in the ground. Shallow drain fields may provide a greater opportunity for filtration of nitrates prior to reaching the aquifer. Water discharged from pipes in the drain field will also filter more quickly if the water is dispersed over a larger area. Where the current drain field system discharges to a relatively small area, improvements in the effectiveness of the drain field may be achieved by installing an upgraded system that disperses effluent over a wider area. Where shallow groundwater cannot be avoided, septic systems incorporating mounds can be constructed to facilitate filtration of effluent. Hence, modification of drain field systems may reduce the resultant nitrate concentrations in drinking water.

- **Maintain septic system.** We have no data regarding the maintenance history of septic systems at sites where elevated nitrate concentrations were found. Maintenance of the system to avoid leaks through cracks in septic tanks and pipes and pumping at regular intervals to avoid overflowing the system are highly recommended to help avoid introduction of nitrates into groundwater.

- **Withdraw water from deeper depths**. As was indicated above, all wells with high nitrate concentrations drew water from less than 150 feet deep. Where wells with high nitrate concentrations are shallower than 150 feet, the well could be deepened and cased with no perforations to at least 150 feet. Where the well is already deep but the casing runs less than 150 feet deep or perforations are less than 150 feet deep, the well may be modified by installing new casing without perforations to a depth of at least 150 feet.

- **Treat water.** Filtration devices are available that will reduce the quantity of nitrates in drinking water. These devices can be installed between the well head and the first tap used for drinking water. The systems are expensive, but are relatively effective if properly designed.

- **Avoid feeding water with high nitrate concentrations to infants under 6 months old.** As was discussed above, the documented human effects of nitrate concentrations >10mg/l are limited to infants under 6 months old. The potential effects can be avoided by using bottled water to feed young infants.

4.2 Other Water Quality Parameters

No widespread patterns in contaminants other than nitrates were found in well samples. One well had concentrations of iron in excess of state water quality standards and two had high manganese levels. Since these were isolated incidents, the measured concentrations are likely a reflection of the construction of the well pump and pipes and/or a reflection of unusual highly isolated local geology. All owners have received copies of the well sample results. Those owners with high iron or manganese are encouraged to inspect their systems for possible sources of these metals and upgrade the systems as appropriate.

Surface waters in the Swale and Little Klickitat subbasins all have concentrations of *E. coli.* Since *E. Coli* was not incorporated into the state standards, these measures do not constitute a violation of regulated water quality parameters. Fecal coliform in Blockhouse and Bloodgood

Creeks exceeded the Washington State criteria, as did all the sampled sites in Swale Creek. The lack of water flow at sampled sites in Swale Creek most likely contributes to the high fecal coliform concentrations at those sites. The most likely sources for bacteria are septic systems, livestock, or wildlife.

5 RECOMMENDATIONS

We would like to forward the recommendations listed below. Some of the recommendations are forwarded as suggestions for consideration and are not necessarily needed to address the situations identified in this report.

- **Mitigate areas with elevated nitrate**. Landowners with wells where nitrate levels >10 mg/l have been documented are encouraged to evaluate the possible mitigation approaches described in the previous section to determine which option best suits their needs. Implementation of one or more of the options is highly recommended.

- **Design future wells and/or septic systems to avoid nitrate problems**. The potential interaction between well casing depth and septic system design referred to in the previous section should be considered when new well are constructed within the Swale Creek subbasin. Prior planning may help to avoid high nitrate concentrations in drinking water.

- **Additional sampling of bacteria and source investigation**. The study results indicate bacteria are present in concentrations exceeding the state standards in Swale Creek, Bloodgood Creek, and Blockhouse Creek. Additional sampling to determine whether the state standard as measured by a geometric mean is exceeded. If the concentrations found in October 2003 are found to be persistent, an evaluation of sources of fecal coliform is recommended. In stream measurements coupled with stream flow measurements would allow for development of a mass balance approach to identifying specific locations where inputs are high. This would help identify sources. In identified locations where both septic and animal sources are potentially contributing to measured concentrations, consideration should be given to using isotope analysis to help determine whether pollutants originate from human or animal related sources.

6 ACKNOWLEDGEMENTS

We would like to thank the Klickitat County Planning Department, the Klickitat County Health Department, the Klickitat County Assessor's Office, the WRIA 30 Planning Unit, and all the landowners and several other citizens of the County for their help and cooperation in this study.

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APPENDIX A

Laboratory Certificates of Analysis

North Creek Analytical Inc.

(Note, in some cases the samples that were submitted to the laboratory were labeled with the owner's name. The names of individuals have been blacked out in the attached to preserve their privacy)