GLADE-FOURMILE SUBBASIN WATER QUALITY REPORT

Water Resource Inventory Area 31

Prepared for: WRIA 31 Planning Unit

Project No. 030009-003-01 • June 21, 2005 Final

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Aspect Consulting, LLC

Steve Germiat, LHG, CGWP
Associate Hydrogeologist
sgermiat@aspectconsulting.com

Timothy J. Flynn, LHG, CGWP
Principal Hydrogeologist
tflynn@aspectconsulting.com

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Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

Water quality studies from the 1980s and 1990s document elevated concentrations of nitrate in surface waters and shallow groundwater of the Glade-Fourmile subbasin, which is the agricultural center of Water Resource Inventory Area 31 (WRIA 31). Shallow groundwater is a primary drinking water source in the subbasin. Since the time of those studies, the extent of irrigated agriculture in the subbasin has increased markedly. At the same time, agricultural methods have been improved to use less water and better manage chemical application. As part of the watershed planning process for WRIA 31, a water quality assessment was completed to evaluate current nitrate concentrations in subbasin groundwater and surface water, and thereby evaluate whether changes to irrigation practices are resulting in measurable water quality improvement (reduced nitrate concentrations).

The assessment included sampling those locations sampled in the mid-1990s to evaluate concentration trends over the past decade, sampling additional groundwater and surface water locations to expand the geographic area of data coverage relative to previous studies, and supplementing those field data with public water system data from Department of Health. The collective nitrate data set provides the most comprehensive assessment of subbasin water quality to date.

The conclusions and recommendation from this Glade-Fourmile subbasin water quality study are as follow:

- Groundwater nitrate concentrations above the 10 mg/L drinking water standard are limited to the shallow aquifer (Saddle Mountains Basalt). The deeper Wanapum Basalt Aquifer has considerably lower nitrate concentrations.
- Surface water nitrate concentrations in Glade Creek, and to a lesser extent Fourmile Canyon, are elevated. There is no surface water quality standard for nitrate based on protecting fish, and salmonids are not known to inhabit these surface water bodies.
- The elevated nitrate concentrations are limited to irrigated areas. Much lower concentrations occur in areas of dryland farming.
- Current nitrate concentrations in the Saddle Mountains Basalt Aquifer and Glade Creek surface water are generally similar or higher to those observed in 1995, but there are exceptions.
- Because the Saddle Mountains Basalt Aquifer is a drinking water source for many in the subbasin, groundwater nitrate concentrations above the drinking water standard could represent a public health risk. We recommend that the WRIA 31 Phase 3 Watershed Management Plan identify alternative source(s) of potable water for those wells that exceed drinking water standards (in cooperation with local Department of Health). An initial step would be to inventory and sample single family wells (non-public water system) for nitrate.

1 Introduction

This report details the water quality project for the Glade/Fourmile subbasin completed as part of watershed planning for Water Resource Inventory Area 31 (WRIA 31). This supplemental water quality project was funded under Grant number G0400370 obtained by the WRIA 31 Planning Unit from the Washington State Department of Ecology (Ecology) under the Watershed Management Act.

The following sections of this report are:

- Project Background;
- Methods;
- Results and Discussion; and
- Conclusions and Recommendations.

2 Project Background

This supplemental water quality project addresses water quality in one of the four WRIA 31 subbasins – the Glade/Fourmile subbasin (Figure 1). Background information pertinent to the Glade/Fourmile subbasin is summarized below (from the WRIA 31 Level 1 Assessment; Aspect Consulting and WPN 2004).

2.1 Topography and Climate

WRIA 31 occurs within the Columbia Plateau physiographic province. The Horse Heaven Hills, a broad east-west ridge, forms the Glade/Fourmile subbasin's northern boundary, and the Columbia River gorge forms the southern boundary. The watershed slopes gently from an elevation of approximately 3,000 feet to the north to approximately 300 feet in the Columbia Gorge.

The average annual precipitation in the Glade/Fourmile subbasin is typically around 8 to 10 inches. The greatest annual precipitation occurs in the northwest corner of the subbasin (12 inches or greater), while the least falls in the middle of the Glade Creek area (less than 8 inches per year). The mean annual precipitation calculated for the Glade/Fourmile subbasin is 9.4 inches (1961-1990).

2.2 Geologic Setting

Figure 1 is a surface geologic map of the Glade/Fourmile subbasin (from Washington Department of Natural Resources [DNR] 1:100,000 mapping). The WRIA 31 region is underlain by bedrock of the Columbia River Basalt Group (CRB) and interbedded sediments deposited during time periods between the individual lava flows. The CRB underlies the entire Glade/Fourmile subbasin and is the subbasin's principal source for groundwater. The CRB includes (from oldest to youngest; deepest to shallowest) the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt, separated by sedimentary interbed units (Figure 2).

Groundwater in the basalts occurs primarily at the tops and bottoms of the individual flows (interflow zones). The interflows are usually porous (vesicular) and permeable, and, therefore, transmit water more readily than the intervening massive portion of the basalt flow “interior.” Where sediments interbedded between basalt flows are coarse-grained, the interbeds may also transmit groundwater; however, the productivity of the interbeds is often low because of limited lateral extent and changes in composition.

The groundwater characteristics of the principal geologic units are discussed briefly below (from oldest to youngest).

Grande Ronde Basalt. The Grande Ronde Basalt forms the lower, basement geologic unit beneath the entire Glade/Fourmile subbasin; however, it is present at significant depth (typically 800 feet or more) and relatively few wells produce groundwater from it (Packard et al. 1996).

Wanapum Basalt. The Wanapum Basalt is present beneath the entire subbasin, and is the major source of groundwater supply for irrigation in the subbasin.

Saddle Mountains Basalt. The Saddle Mountains Basalt is present across the entire Glade/Fourmile subbasin, and represents the final outpouring of the CRB. Its thickness increases to greater than 600 feet in a broad synclinal (trough) feature - the Central Syncline - beneath the Glade Creek drainage. It is typically covered by a thin veneer of unconsolidated material (overburden) across the subbasin (Figure 1). The Saddle Mountains Basalt unit commonly supplies smaller quantities of groundwater for domestic and stock watering needs.

Sedimentary Interbeds within Basalt Units. Sediments between, within, and overlying the basalts occur as a result of deposition by drainage systems during time periods between individual basalt flows. The sediments are not considered part of the CRB, rather they are typically assigned to the Ellensburg Formation, a sedimentary deposit ranging in composition from silt to gravel and easily eroded. The sedimentary interbed separating the Grande Ronde from the overlying Wanapum is generally referred to as the Vantage member, and the interbed separating the Wanapum and Saddle Mountains Basalt is generally called the Mabton member, of the Ellensburg Formation. Because the interbeds’ composition, thickness, and extent are highly variable, groundwater production from these units is correspondingly variable.

Quaternary Flood Deposits and Alluvium (Overburden). Much of the Glade/Fourmile subbasin is covered with thin (generally less than 50 feet thick) deposits of Quaternary loess (wind blown silt), alluvium, and flood deposits of sands, gravels, and silts. In this subbasin, flood gravel deposits are constrained to the banks of the Columbia River between Whitcomb and Plymouth, whereas finer-grained flood deposits (silts and sands) extend up to 17 miles inland from the Columbia River in the Glade Creek drainage (Figure 1).

Where present in sufficient thickness and volume along the Columbia River, the flood gravels can represent significant sources of groundwater (e.g., in Plymouth area). Inland from the Columbia River, the unconsolidated Quaternary deposits are generally unsaturated or in places partially saturated, and represent a marginal component of the groundwater occurrence within the WRIA.

2.3 Land Use

Agriculture dominates the Glade/Fourmile Creek subbasin, with cultivated land comprising approximately 60 percent of the total subbasin area in 2001 (IRZ Consulting 2004). Irrigated land dominates the low-elevation southern half of the subbasin, comprising 25 percent of the total subbasin in 2001. Dryland farming encompasses much of the northern half and far eastern portion of the subbasin, comprising 35 percent of the subbasin area in 2001. The distribution of dryland and irrigated lands in the subbasin is depicted on Figure 3. Non-cultivated shrubland is interspersed with the cultivated land, and comprises essentially the rest of the subbasin area. Developed land accounts for less than 1 percent of the subbasin area. A net reduction in total cultivated acreage has occurred in the subbasin between 1992 and 2001 (64 to 60 percent). This reduction is a result of the reduction in dryland farming acreage (48 to 35 percent of total subbasin area), since irrigated acreage has increased (16 to 25 percent of total area).

2.4 Existing Studies/Data

A series of water quality samplings/studies have been completed in the Glade/Fourmile subbasin as summarized below:

- In the early 1980s, the USGS completed spot sampling of seven wells in the Horse Heaven Hills which documented elevated nitrate concentrations (4 of 7 wells at or above the 10 mg/L drinking water standard) (Steinkampf et al. 1985; Turney 1986).
- In 1993, Ecology sampled surface water at the mouth of Glade Creek as part of the Washington State Pesticide Monitoring Program (WSPMP). Nitrate was detected in that sample at 34.5 mg/L and a suite of pesticides were detected at trace concentrations (less than 0.0004 mg/L) (Davis 1993).
- In 1993, the Benton-Franklin Health District sampled six wells in the Glade Creek drainage. Nitrate concentrations in the six wells ranged from 0.7 to 3.3 mg/L (all below the drinking water standard), with an average of 1.9 mg/L (Benton-Franklin Health District 1993).
- In 1995, Ecology completed a more in-depth groundwater and surface water quality characterization, focusing on nitrate, for the Glade Creek drainage. The study involved sampling one spring, three surface water locations in Glade Creek, and 11 wells tapping aquifers in the shallow overburden (Alluvial Aquifer), Saddle Mountains Basalt, and Wanapum Basalt. Samples were collected in May and September 1995, coinciding with the spring runoff/start of irrigation and the end of irrigation seasons, respectively. Four of the wells sampled were the same as those sampled by the USGS in the early 1980s allowing comparison of nitrate concentrations more than a decade later. Likewise, the Glade Creek sampling location was the same as sampled in 1993 during the WSPMP. This study concluded that nitrate impact is widespread in the two uppermost aquifers (Alluvium and Saddle Mountains Basalt) and in Glade Creek surface water, with higher concentrations

detected during the September sampling event. The nitrate impacts, and other water quality indicators, were generally correlated with the location of larger scale irrigation within the drainage. Nitrate was not detected in any of the four Wanapum Aquifer wells, indicating that the Mabton Interbed (separating Saddle Mountain and Wanapum Basalts) provides effective hydraulic isolation from the overlying aquifers. Comparison of the 1995 and 1980s data showed no appreciable water quality changes for the two Wanapum Basalt wells; one Saddle Mountain Basalt well showed no appreciable difference while the other had higher nitrate and other indicators of irrigation in the 1995 samples. The study also concluded that surface water flow in Glade Creek in May and September 1995 was water derived from irrigation return flow (Garrigues 1996).

2.5 Exceedence of State Water Quality Standards

The existing studies from the Glade/Fourmile subbasin document nitrate concentrations exceeding the 10 mg/L drinking water standard throughout the subbasin's shallow aquifers (Alluvium and Saddle Mountain Basalt) and surface waters. The existing studies indicate that groundwater in the deeper aquifer (Wanapum Basalt) meets drinking water standards. There are no state or federal aquatic life criteria for nitrate in surface water.

No water bodies in this subbasin are listed on Ecology's 2002/2004 water quality assessment list.

3 Methods

The sampling and analysis program was completed consistent with that outlined in the Quality Assurance Project Plan for this project (Aspect Consulting 2004), except as noted below.

3.1 Project Objective

The existing information available through the mid-1990s indicates that shallow groundwater and surface waters in the Glade Creek drainage have been impacted by nitrate as a result of extensive agricultural practices in the subbasin. However, discussions with local irrigators indicate that local irrigation practices have been refined over the past decades to use less water and better manage chemical application, which presumably reduces irrigation return flows responsible for the historical nitrate impact. Conversely, the total area of land being irrigated in the subbasin has increased markedly since the early 1990s (Section 2.3).

The primary objective of this project was to collect data to document current nitrate concentrations in groundwater and surface water in this subbasin, and thereby evaluate whether changes to irrigation practices are resulting in measurable water quality improvement (e.g., reduced nitrate concentrations).

3.2 Data Quality Objectives

The data from this project must be of sufficient technical quality to document the spatial distribution of nitrate in groundwater and surface water, as well as seasonal and longer-term changes in nitrate levels. This nitrate study makes use of field data collected in 2004-2005, as well as the existing data from previous studies (Section 2.4) and data collected from public water systems and reported to the Department of Health (DOH; Section 3.4). Field and laboratory QC procedures used for sampling and analysis in this project are described in Appendix A. The degree of documentation regarding data quality assurance for the previous studies is variable. The previous data relied upon the most in this study – from Garrigues (1996) – followed well documented industry standard quality control protocols. There is very little quality assurance information available for the data provided by public water systems and available through DOH's database. However, nitrate is a routine laboratory analysis for which comparable results are generally obtained whether using either of the two common analytical methods (EPA Methods 300.0 or 353.2). Consequently, the nitrate data from all sources are considered to be of sufficient quality and comparability for use in documenting general spatial and temporal trends as part of this study.

3.3 Field Sampling Plan

Aspect Consulting personnel completed two rounds of water quality sampling for nitrate and field parameters (temperature, conductance, pH, dissolved oxygen, redox potential, and turbidity at 12 groundwater and 4 surface water locations in the Glade/Fourmile subbasin (up to 16 water samples total). The groundwater samples were also analyzed for total dissolved solids (TDS) to assess degree of mineralization. We completed the two field sampling events to correspond to times near the end of the irrigation season and again prior to start of irrigation, for comparison with previous data. These sampling events took place September 28-30, 2004, and March 21-22, 2005, respectively. Existing data from public water systems were also obtained for use in the project, as outlined in Section 3.4. Figure 3 depicts locations of the wells and surface water locations sampled for this study, as well as PWS wells with data used in this study.

To the extent possible, samples were collected from wells and Glade Creek surface water locations sampled in the Garrigues (1996) study to document potential nitrate concentration changes over time. The groundwater sampling targeted wells tapping distinct aquifer zones to document potential water quality differences between aquifers. Ideally, to be considered for groundwater sampling, wells had to meet certain criteria, consistent with Garrigues (1996):

- The well must have an operational pump to allow purging and sample collection.
- Basalt Aquifer wells must have a well log so geology and well construction details can be determined. This criterion need not be met for Alluvial Aquifer wells (if obvious from well depth) since the information is not as critical and well logs might not be available.
- Basalt wells should be completed in a single aquifer unit. Wells completed in both the Saddle Mountains and Wanapum Basalts (both above and below the Mabton Interbed) were avoided.

- Each well sampled must have an acceptable tap or other means of sample collection near the wellhead and prior to any water treatment facilities.

Note that Garrigues (1996) also sampled one spring in the uppermost reach of Glade Creek (station GC-96S; Figure 3) that discharges from the Alluvial Aquifer. This spring was sampled again for this study.

Groundwater and surface water samples collected by Garrigues (1996) that were targeted for sampling again in this project have "GC-" prefixes in their well identifiers, and are shown on Figure 3. Well GC-93, sampled by Garrigues (1996), could not be sampled during either sampling event because the pump was not operational. However, two additional wells were sampled during the September and March visits that were not previously sampled by Garrigues (1996). These wells were designated GC-01 and GC-02 (Figure 3). An additional surface water sample was also taken from Fourmile Canyon (FC-01).

Prior to sampling each groundwater well, the sample port through which samples were collected was purged using the existing pump at a rate of 10-30 liters per minute (Lpm) until field parameters stabilized, to ensure a representative sample of groundwater was obtained. During purging, purge water field parameters were measured every 2 to 4 minutes. Stabilization was defined as three consecutive measurements in which field parameter values vary by less than 10 percent, or 0.5 mg/L dissolved oxygen if those readings are below 1 mg/L. A single turbidity measurement was also recorded for each well. After the field parameters had stabilized, samples were collected in preserved, laboratory-supplied bottles, directly from the tap nearest to the wellhead. All samples were collected upstream of any storage or treatment of the water.

The only deviations from the above sampling methods were for Wanapum Basalt Aquifer wells GC-65 and GC-29, which were not running during either visit. Discussion with the well owners and visual observation indicated the wells were in operation, but they were not pumping during the actual times we were at each well. The sampling was conducted according to the above methods; however, since the pumps were not running, the samples were likely gravity fed from water stored in the distribution lines next to the wells. No water was obtained from well GC-29 during the September event. Based on measurements from the other Wanapum Aquifer wells, groundwater from these wells is expected to be anaerobic – having low dissolved oxygen and low redox potential. These field parameters were measured for the water sample collected from each well as described above. Low dissolved oxygen was measured during the September event at well GC-65 and the March sampling at GC-29. If the water sampled had any significant exposure to the atmosphere, thus potentially compromising sample quality, it would have quickly equilibrated with atmospheric oxygen and had dissolved oxygen readings on the order of 10 mg/L or greater (e.g., see dissolved oxygen readings for surface water samples in Table 3). The low dissolved oxygen readings indicate that the water sampled had come from the aquifer recently and thus the sample was judged to be of suitable quality for the purposes of this study. However, during the March 2005 event, the water from well GC-65 had elevated dissolved oxygen (about 9 mg/L) suggesting it had become oxygenated while residing in the pipe; therefore, this water was not submitted for analysis.

Discrete grab samples of surface water were collected, and field parameters measured, at each stream location (Figure 3). Water was flowing at each location so it was assumed that the surface water was fully mixed. Surface water samples were collected near mid-channel, upstream of the location where the sampler was standing, and at about one-half the stream depth. Samples were collected by immersing a lab-cleaned unpreserved bottle in the stream and transferring the contents into the preserved bottle provided by the laboratory. Field parameters were measured by immersing the probe directly in the stream at the location where the sample was collected. Stream discharge was also estimated visually at each sampling station.

Field sampling met the field quality control requirements outlined in the QAPP (Aspect Consulting 2004). One field duplicate sample was collected for each analysis during the September and March visits. The field duplicates were collected using identical sampling techniques as the sample it duplicated. The field parameter meter used was also calibrated daily in accordance with manufacturer's instructions as specified in the QAPP.

The groundwater and surface water samples were analyzed for nitrate by an Ecology-accredited laboratory using EPA Method 353.2; groundwater samples were also analyzed for total dissolved solids (TDS) using EPA Method 160.1. The analytical results were independently reviewed to ensure suitable data quality. The data quality review and copies of the laboratory reports are included in Appendix A.

3.4 Public Water System Data

In addition to the field sampling, we acquired nitrate data available from DOH for public water systems (PWS) within the subbasin. The data were requested from DOH in August 2004 and again in April 2005 to acquire the most recent data. These systems are required to test for nitrate regularly, with the frequency depending on type of water system (Group A or Group B) and whether DOH is aware of nitrate as a potential health concern in the area. Figure 3 shows the locations of PWS wells, with PWS identifier number assigned by DOH, within the Glade/Fourmile subbasin and having nitrate data.

Nitrate data collected from PWS wells were evaluated prior to inclusion in this report as follows:

- Only data from wells of a known depth were included; and
- Only data collected prior to water treatment that could potentially reduce nitrate concentrations were included.

The objective of this study is to document the groundwater quality in the watershed, which excludes samples that have been treated to reduce nitrate as a reliable source of data. In many cases, both untreated and treated water quality data for specific wells are included in DOH's PWS database; many samples are not designated as either (unknown). A review of PWS data from samples collected prior to water treatment and those collected after water treatment, however, indicates that there is usually no substantive change in nitrate concentrations (Table 2). Therefore, most PWS water treatment systems, which often may be only chlorine disinfection, are likely not targeting nitrate reduction. This is expected since, due to cost limitations, water treatment is typically not considered a viable long term solution to reduce elevated nitrate levels. One PWS well

(66475-01) has been treated to reduce nitrates for a period of time; these data are discussed further in Section 4.4.

4 Results and Discussion

4.1 Nitrate Concentrations in Groundwater

The current and historical groundwater quality data collected for wells sampled in this study are presented in Table 1. This table divides the wells by aquifer from which the well draws groundwater and provides well depth. Nitrate was detected at various concentrations in all of the wells from the Saddle Mountains Aquifer. Nitrate was also detected in the sample from the Alluvial Aquifer spring discharge. Nitrate was not detected above the detection limit of 0.005 mg/L in any of the three Wanapum wells sampled during September. Nitrates were detected at very low concentrations in the three Wanapum wells sampled during March. This is consistent with data from Garrigues (1996), where nitrate was not detected in the Wanapum wells tested and substantially higher levels occurred in the shallower aquifer unit.

The highest nitrate concentration (62.4 mg/L, greater than 6 times the drinking water standard of 10 mg/L) was detected in well GC-22 (Figure 4), which is 345 feet deep and completed in the Saddle Mountains Basalt Aquifer. Historically, very high nitrate values have been observed at well GC-22, dating back to 1982 (Steinkampf et al. 1985). Garrigues (1996) noted that the high nitrate values could be due to surface water entering the well through a poor surface seal around the well bore. The well log for well GC-22 indicates a surface seal of bentonite to 20 feet; however, “topsoil” is logged to a depth of 24 feet underlain by clay and broken basalt to a depth of 36 feet; “solid basalt” is logged starting at a depth of 36 feet. To effectively seal the well bore, the surface seal would ideally have been extended several feet into competent basalt. The well log indicates the well has perforated casing but does not indicate the depth interval of the perforations (i.e., the depth where water enters the well). Well GC-22 is reportedly used as a source of wash water for agricultural equipment and for mixing with fertilizers and pesticides; it is not used for potable supply (Garrigues 1996). The wash water is collected in a pit only 15 feet from the well. We assume that water containing elevated nitrate has infiltrated into the Saddle Mountains Aquifer via the outside of the well casing below the bottom of the 20-foot surface seal.

The nitrate data from the DOH PWS database is compiled in Table 2. Detectable nitrate concentrations are common in all but two PWS wells (26214-01 and 26214-02; Figure 3) that are completed in the Saddle Mountains Aquifer. Detectable nitrate concentrations are less common in wells that draw water from the Wanapum Aquifer. Only two PWS wells in the Wanapum Aquifer consistently have detectable nitrate concentrations (PWS 30816-01 and 06559-01 wells).

Additional discussion of spatial and temporal trends in groundwater nitrate is provided in Sections 4.3 and 4.4.

4.2 Nitrate Concentrations in Surface Water

The current and historical surface water quality data collected at locations sampled in this study are presented in Table 3 (sample locations shown on Figure 3). Nitrate concentrations in surface waters of the Glade/Fourmile subbasin are elevated above expected background concentrations. Nitrate concentrations at the mouth of Glade Creek (GC-97SW) were 39.0 mg/L in September 2004 and 44.6 mg/L in March 2005. These values are similar to measurements recorded in the 1990s that were some of the highest recorded nitrate concentrations in state surface waters according to Garrigues (1996). Similar concentrations were also found upstream in upper Glade Creek (GC-99SW) and East Branch Glade Creek (GC-98SW) in September 2004 (42.7 mg/L and 37.7 mg/L, respectively). Nitrate concentrations increased slightly to 44.2 mg/L and 42.0 mg/L (GC-99SW and GC-98SW, respectively) in March 2005.

Fourmile Creek (FC-01SW, located at Plymouth Road crossing in SW ¼, SW ¼, Sec. 29, T6N, R28E) was sampled for the first time in September 2004. The concentration of nitrate was considerably lower (5.4 mg/L in September, 9.5 mg/L in March) than measured in Glade Creek.

4.3 Spatial Distribution of Nitrate

Figure 4 presents the spatial distribution of nitrate concentrations in the Saddle Mountains Aquifer, overlain on the 2001 agricultural cropland distribution (from IRZ Consulting 2004). Values displayed represent the most recent nitrate concentration measured at each location, including wells sampled in this study and PWS wells. The data presented range in date from August 1994 through March 2005. The Alluvial Aquifer spring location in the northwest corner of the subbasin (GC-96S) is also presented on this figure.

Wells located in areas of dryland farming (e.g., the northern half of the subbasin) have significantly lower concentrations of nitrate than in southern areas dominated by irrigated agriculture. The highest concentration of nitrate in the dryland farming area was from the PWS 15545-01 well (2.80 mg/L) which is still well below the 10 mg/L drinking water standard.

With few exceptions, the wells in the Saddle Mountains Aquifer located in the irrigated cropland area are near or above the drinking water standard. The exceptions are either on the edge of the irrigated area (PWS 03392-01 and 02689-01 wells), shallow wells along the Columbia River (PWS AA341-01, 02380-01, and 02431-01 wells) or along the subbasin divide (PWS 26214-01 and 26214-02 wells) (Figure 4). Although some of the wells along the Columbia River are located within areas mantled by Columbia River flood gravels, the well logs indicate that they are drawing water from the Saddle Mountains Aquifer, rather than the gravels. However, the lower nitrate concentrations in these wells (e.g., 0.9 to 1.4 mg/L), in close proximity to higher concentration wells immediately to the north, suggests that the Saddle Mountains Aquifer is locally being recharged by the river. Alternatively, the Columbia Hills anticline may be locally controlling groundwater flow directions that contribute to the observed water quality differences.

The extent of elevated nitrate in the Saddle Mountains Aquifer extends farther east than documented by Garrigues (1996), into the Bing Canyon area (well GC-02). The lone well with data in the Fourmile Canyon area (PWS 02689 well), east of Bing Canyon, had a relatively lower concentration (2 mg/L) (Figure 4).

The distribution of elevated nitrate concentrations supports the correlation between the presence of irrigated cropland and nitrate levels in the Saddle Mountains Aquifer, as identified by Garrigues (1996).

The presence and observed concentrations of nitrate in Glade Creek surface water also support the correlation. In September and March, both Glade Creek and East Branch Glade Creek were dry upstream of irrigated cropland. Streamflow increased to approximately 1-2 cfs in both Glade Creek and East Branch Glade Creek at their confluence. Streamflow increased to an estimated 20 cfs at the Highway 14 bridge. This increase in streamflow is attributed to discharge of irrigation return flow in the lower half of the Glade Creek drainage. Nitrate concentrations in this surface water were on the order of 40 mg/L in September 2004 and March 2005 as discussed above.

Relative to the Saddle Mountains Aquifer, nitrate concentrations are uniformly lower in the deeper Wanapum Aquifer. Three of the four wells with detectable nitrate (above 0.1 mg/L) based on the most recent data are clustered in the south-central area of the subbasin (T5N R26E), with concentrations ranging from 0.3 to 4.5 mg/L (Figure 5). Of these wells, the most recent result from PWS 63913-01 well (4.5 mg/L in June 2004) is anomalously higher than eight previous samples from this well (non-detect in 6 of 8 samples; Table 2). The reason for this anomalous reading is uncertain. Reviewing the historical data from the Wanapum wells in this immediate area, the PWS 30816-01 well has had the highest concentrations (1.2 to 4.8 mg/L), but the concentrations have sequentially declined between 2001 and 2004 (Table 2). Notably, the well located closest to the river in this area has had non-detectable nitrate (PWS 19060-02 well).

The highest nitrate values observed in the Wanapum Aquifer in the Glade/Fourmile subbasin are from the PWS 06559-01 well, located in the Switzler Canyon area to the east (Figure 5). This well is deep, cased to a depth of 814 feet and perforated between depths of 714 and 814 feet. Since 1998, nitrate concentrations have been detected at concentrations between 3.5 and 8.6 mg/L in 11 of 11 samples. The concentrations appear to have gradually increased over the 7-year period of monitoring (Table 2). Although these values meet the 10 mg/L drinking water standard, they are a cause for concern because the Wanapum Aquifer throughout the subbasin has been observed to have low concentrations of nitrates. The well log for the PWS 06559-01 well, local geologic maps, and a model of the basalt stratigraphy in the area indicate that the well is likely drilled through overburden from 0-40 feet, through the Saddle Mountains Basalt from about 40-200 feet, and into the Wanapum Basalt to a depth of 800+ feet. The well does not reach the Grande Ronde Basalt. The well log indicates that a surface seal of cement was installed from 75 -105 feet below ground surface (bgs) followed by a bentonite and drill cuttings seal from 0-75 ft bgs, likely sealing off the aquifer from the surface. However, since the Saddle Mountains Basalt exists to a depth of approximately 200 feet (bgs), the bottom of the Saddle Mountains Aquifer could be in hydraulic communication with the deeper Wanapum Aquifer and thus acting as a conduit for downward migration of nitrate-impacted groundwater via the unsealed well bore below 105 feet in the well. Given the information from all other Wanapum Aquifer wells in the subbasin, it is difficult to explain the nitrate consistently detected in this deep well in other ways.

4.4 Temporal Distribution of Nitrate

The design of this project allows for the analysis of both seasonal trends and long-term trends in nitrate concentrations in the Glade/Fourmile subbasin. Seasonal trends can be identified by examining the nitrate concentrations from the end (September) and at the beginning (March) of the irrigation season. Long-term trends can be identified for longer data sets, particularly those from the PWS wells.

Seasonal Trends in Nitrate Concentrations

Garrigues (1996) found that nitrate concentrations were consistently higher in September than in March 1995. The results from this study (Table 1, Figure 4) are less consistent. Only four of the nine Saddle Mountains Aquifer wells sampled showed lower concentrations in March than in September. The two Wanapum wells that were sampled in September and March both had higher concentrations in March (albeit still very low). The wells that did show a decrease from September 2004 to March 2005 are located out of the primary irrigation areas. For the Saddle Mountains wells that showed an increase from September 2004 to March 2005, the average nitrate concentration increase was 19 percent from March to September. One explanation for the seasonal effect observed in 1995 is the lag time in return flow and precipitation recharge. By the end of the irrigation season, irrigation return flows may have had sufficient time to recharge the local Saddle Mountains Aquifer. By the following spring, winter precipitation has begun to recharge the aquifer, lowering concentrations again somewhat. However, the winter of 2004-2005 was extremely dry, and this seasonal trend may not have occurred due to the lack of precipitation.

In general, nitrate concentrations in surface water have shown little seasonal fluctuation. Garrigues found a slight decrease in concentrations in Glade Creek from September to March. The latest data from this study show that nitrate concentrations increased from September 2004 to March 2005 by 4 to 15 percent. Nitrate concentrations increased 75 percent from September to March in the Fourmile Creek sampling location (Table 3; Figure 4)

Long-Term Trends in Nitrate Concentrations

An objective of this study was to assess whether nitrate concentrations are increasing or decreasing over time (temporal trends). This is of particular interest for groundwater in the Saddle Mountains Aquifer, which is a primary source of domestic drinking water in the subbasin. Nitrate concentrations in Saddle Mountains wells, having data spanning several years, were plotted as a time series to evaluate the presence or absence of long-term trends in nitrate concentrations.

Those Saddle Mountains Aquifer wells located outside the main irrigated agricultural area (i.e., in dryland agricultural areas) typically have nitrate concentrations below the 10 mg/L drinking water standard, and those concentrations have been generally decreasing slightly since the mid-1990s (upper plot on Figure 6). Notably, dryland area well GC-27, which was first sampled in 1982, shows essentially constant concentrations (0.9-1.2 mg/L) over the 23-year period of measurement (Table 1).

Consistent trends in the nitrate concentrations in Saddle Mountains wells located in the areas of irrigated cropland are difficult to recognize (lower plot on Figure 6). In general, the trend seems to be stable (66475-01 and GC-16) or slightly increasing (06152-01), with the exception of the PWS 02091-01 well which has decreased from the 20-25 mg/L range ten years ago to approximately 10 mg/L over the past few years. The PWS 63913-01 well (GC-69) had a relatively stable trend until the two samples collected during this study, which were higher.

Well GC-22, which has the highest nitrate measured in this study (up to 62 mg/L; see Section 4.1) also has a very long period of measurement (since 1982). Over this 23-year period, nitrates started around 30 mg/L in 1982, peaked at up to 70 mg/L in the mid-1990s, and have declined somewhat to about 60 mg/L currently (upper plot on Figure 7).

One PWS of interest was contacted regarding very sharp reductions observed in nitrate concentrations from a Saddle Mountains well over time (PWS 66475). Nitrate concentrations were relatively stable between 20 and 32 mg/L from 1994 through 2002 (lower plot on Figure 7). The concentrations dropped dramatically below the 10 mg/L standard in early 2003. Conversations with the PWS personnel indicated that the difference was the result of implementing a reverse-osmosis treatment system designed to reduce nitrate levels. (The DOH database did not indicate pre- vs. post-treatment for samples from this PWS.) The PWS used the treatment system for approximately 16 months until a new deeper well was drilled (into the Wanapum Basalt Aquifer). These data demonstrate clearly the differences in nitrate concentrations between aquifers. Also note the apparent seasonal fluctuation in nitrate concentrations in data from the original Saddle Mountains well. The lowest concentrations were typically measured in the Winter and Spring, and the highest concentrations occurred in the Summer and Fall (lower plot on Figure 7; Table 2).

Alluvial Aquifer spring discharge in the northwestern corner of the subbasin (GC-96S; Figure 4) has shown little change in nitrate concentrations over the past decade (0.8 to 1.2 mg/L).

Surface water nitrate data from the mouth of Glade Creek (GC-97SW) indicate that nitrate concentrations have shown a gradual increase from 1992 to present (35 to 45 mg/L; Table 3). However, nitrate concentrations measured at the two upstream locations GC-98SW and GC-99SW increased more than three-fold between 1995 and present (from roughly 12 to 42 mg/L). This is consistent with a northward expansion of irrigated agriculture in the subbasin over the past decade.

4.5 Conventional Water Quality Parameters

Total Dissolved Solids and Specific Conductance

Total dissolved solids (TDS) was also analyzed by the lab for all groundwater samples in this study to assess general water quality in each well. TDS is comparable to specific electrical conductance (EC) in that both generally measure degree of groundwater mineralization (total ionic strength). Secondary drinking water standards for TDS and

EC are 500 mg/L and 700 umhos/cm, respectively (WAC 246-290-310). Measured values typically exceed these secondary standards from Saddle Mountains wells located in the irrigated agricultural land.

TDS concentrations (in mg/L) were plotted against EC measured in the field (in µmhos/cm) to develop a correlation between the two measurements (upper plot on Figure 8). The strong correlation between the two values allows TDS values to be estimated based on EC (which is easy and inexpensive to collect in the field). Based on this relationship, at relatively low EC values (e.g., 200 µmhos/cm) the TDS is approximately 50 percent of the corresponding EC measurement; at high EC values (e.g., 2,000 µmhos/cm) TDS is almost 75 percent of the EC value.

Often, groundwater in deeper basalt aquifers (e.g., Wanapum) has a greater degree of mineralization, and thus higher TDS and EC, than typically observed in shallow aquifers (e.g., Saddle Mountains). Therefore, EC can often be used as a simple way to help differentiate groundwaters from different aquifers. However, review of the TDS and EC data from the set of wells in this study indicates that this general relationship does not necessarily hold in this subbasin. The higher TDS groundwaters generally occur in the Saddle Mountains Aquifer instead of the Wanapum Aquifer (Table 1). Because TDS and EC are a measure of total dissolved ions in the water, the nitrate ion concentration will be reflected in these measurements. Plotting both TDS and EC against nitrate concentration shows strong correlations (lower plot on Figure 8), indicating that nitrate is a factor in the measured TDS and EC measurements for wells in this subbasin.

Dissolved Oxygen

Dissolved oxygen (DO), and associated oxidation/reduction potential (Eh), values in groundwaters from the Saddle Mountains and Wanapum Aquifers were notably different (Table 1). DO in the Saddle Mountains Aquifer was relatively high (3.1 to 13.4 mg/L; aerobic conditions), suggesting the more immediate source of infiltration recharge from ground surface. DO in the Wanapum Aquifer was very low (0.2 to 0.7 mg/L; anaerobic conditions), suggesting longer groundwater residence times and greater travel distances from surface recharge sources. Based on these data, it is likely that reliable DO measurements can be used to differentiate groundwaters between the two aquifers.

DO values measured in the surface water sampling locations indicate that the surface water is essentially saturated with oxygen (Table 3).

5 Conclusions and Recommendations

Conclusions and recommendations from this water quality study for the Glade/Fourmile subbasin are as follows:

- Groundwater nitrate concentrations above the drinking water standard are limited to the Saddle Mountains Aquifer; the deeper Wanapum Aquifer shows considerably less effect.

- Based on the expanded well coverage in this study, the extent of elevated nitrate in the Saddle Mountains Aquifer extends farther east than documented by Garrigues (1996), into the Bing Canyon area. The lone well with data in the Fourmile Canyon area, east of Bing Canyon, had a relatively lower concentration.
- Surface water nitrate concentrations in Glade Creek, and to a lesser extent Fourmile Canyon, are elevated; however, there is no surface water quality standard for nitrate based on protecting fish. Furthermore, salmonids are not known to inhabit these surface water bodies (see Section 5 of Aspect Consulting and WPN 2004).
- The current nitrate concentrations in the Saddle Mountains Aquifer and Glade Creek are generally higher than observed in 1995, but there are individual exceptions.
- The elevated nitrate concentrations are a consequence of irrigation return flows and thus coincident to areas of irrigated agriculture.
- More efficient application of irrigation water has been increasingly accomplished over the past couple decades, presumably decreasing return flow quantities from a given area of irrigated land. However, the extent of irrigated land has increased substantially in the subbasin over the past couple decades. The net result is that nitrate concentrations in surface water and shallow groundwater (Saddle Mountains Aquifer) generally appear to be stable or increasing over the past 10 years across much of the subbasin. The one well in the heart of the irrigated agricultural area with the longest period of data (23 years) indicates nitrate is now about double what it was in the early 1980s. It appears that refinements in irrigation practices to reduce return flow quantities are not reducing or have not yet significantly reduced nitrate concentrations, likely being offset by the expansion of irrigated acreage in the subbasin.
- Economic growth within the Glade/Fourmile subbasin is tied directly to increasing use of water for irrigation. We expect that the economic incentives for irrigators to continue to conserve water and irrigate efficiently will reduce return flows to the extent practical, and this represents the best means to limit further degradation of shallow groundwater and surface water quality in the subbasin.
- Because the Saddle Mountains Aquifer is a drinking water source for many in the subbasin, we recommend that the Phase 3 Watershed Management Plan for WRIA 31 address finding alternative source(s) of potable water for those wells that exceed drinking water standards. An initial step in this effort should include an inventory of non-public water system wells (i.e., single family domestic wells) with nitrate above the drinking water standard. This effort should be conducted in cooperation with local Departments of Health

6 References

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Table 1 - Current and Historical Nitrate Data for Wells Sampled for this Study

			Water Quality Parameters		Field Parameters					
Sample	Well Depth	Sample Date	Nitrate + Nitrite as N in mg/L	TDS	Dissolved Oxygen in mg/L	Specific Conduct. in µmhos/cm	pH	Eh in millivolts	Turbidity in NTU	Temp. in °C
Wells in Saddle Mountains Aquifer										
GC-01	164	9/28/04	4.75	449	7.8	655	7.4	57	1.7	16.2
		3/21/05	5.57	455	6.3	653	7.6	81	1.8	15.9
GC-02	NA	9/30/04	55.1	1910	10.4	2377	7.5	62	0.6	16.6
		3/22/05	45.1	1930	12.1	2437	7.4	105	7.7	9.4
GC-16	208	5/9/95	5.34	516	na	782	7.3	na	na	17.7
		9/27/95	6.42	545	na	818	7.1	na	na	17.9
		9/28/04	8.43	576	6.9	851	7.1	109	0.5	17.0
		3/21/05	7.24	541	5.63	798	7.4	111	6.4	16.8
GC-22	345	3/31/82	33	na	na	1010	7.7	na	na	17.9
		8/26/82	45	na	na	1020	7.6	na	na	19.0
		3/2/83	47	na	na	1330	7.5	na	na	17.5
		7/20/83	54	na	na	1460	7.6	na	na	18.5
		5/10/95	67	1150	na	1632	7.6	na	na	17.6
		9/26/95	70	1170	na	1646	7.5	na	na	18.0
		9/29/04	56.9	1270	11.1	1724	7.6	31	1.2	17.8
		3/22/05	62.4	1260	10.1	1727	7.1	143	2.4	17.5
GC-27	532	3/31/82	0.89	na	na	290	7.8	na	na	19.5
		5/8/95	0.992	213	na	300	7.9	na	na	18.8
		9/26/95	1.23	na	na	305	7.6	na	na	19.9
		9/28/04	0.71	236	3.1	305	7.8	51	1.3	23.9
		3/22/05	1.11	236	2.2	310	7.7	89	2.8	21.1
GC-69	290	5/10/95	28.1	568	na	838	7.6	na	na	15.8
		5/10/95	28.3	559	na	838	7.6	na	na	15.8
		9/26/95	30.4	574	na	838	7.7	na	na	16.6
		9/28/04	42.6	796	13.4	1139	7.5	21	0.2	17.7
		3/22/05	44.4	797	11.6	1164	7.4	97	1.3	17.2
GC-93	220	5/9/95	1.79	292	na	398	7.8	na	na	16.8
		9/27/95	1.87	na	na	437	7.7	na	na	18.0
GC-94	213	5/9/95	1.68	223	na	300	7.5	na	na	15.5
		5/9/95	1.63	216	na	300	7.5	na	na	15.5
		9/27/95	1.74	na	na	300	7.7	na	na	15.2
		9/30/04	1.36	226	5.3	298	7.2	162	0.9	15.7
		3/21/05	1.48	229	7.8	298	7.1	165	1.7	14.2
GC-95	90	5/9/95	0.853	341	na	515	7.4	na	na	14.6
		9/27/95	2.92	na	na	524	7.5	na	na	15.0
		9/29/04	1.1	351	7.4	498	7.3	149	0.3	15.0
		3/21/05	1.01	335	6.2	473	7.3	163	1.0	14.5
GC-96S	0	5/9/95	0.795	158	na	218	7.2	na	na	7.9
	(spring)	9/27/95	1.25	na	na	215	7.3	na	na	9.5
		9/29/04	1.15	170	10.6	213	6.6	179	0.6	11.6
		3/21/05	0.809	173	8.5	214	6.9	161	1.4	9.7

Table 1 - Current and Historical Nitrate Data for Wells Sampled for this Study

Wells in Wanapum Aquifer										
GC-19	870	3/29/82	0.1 U	na	na	333	8.3	na	na	20.5
		8/25/82	0.1 U	na	na	358	8.3	na	na	21.0
		3/7/83	0.28	na	na	358	8.2	na	na	19.5
		7/9/83	0.1 U	na	na	343	8.4	na	na	24.5
		5/9/95	0.01 U	237	na	352	8.4	na	na	24.1
		9/28/04	0.005 U	264	0.2	350	8.3	-142	0.3	24.1
		3/21/05	0.014	266	0.4	352	8.3	1	1.4	24.0
GC-29	730	8/3/72	na	na	na	454	8.2	na	na	22.0
		8/4/72	na	na	na	454	8.2	na	na	22.0
		10/5/72	na	na	na	430	8.2	na	na	21.5
		5/8/95	0.01 U	310	na	456	8.3	na	na	22.0
		5/8/95	0.01 U	297	na	456	8.3	na	na	22.0
		3/22/05	0.00602	372	1.0	511	7.2	-172	1.3	8.4
GC-62	1093	5/9/95	0.01 U	273	na	398	8.8	na	na	25.3
		9/28/04	0.005 U	300	0.3	387	8.7	-139	0.3	20.2
		3/21/05	0.00913	290	0.4	388	8.7	7	1.5	24.9
GC-65	1095	5/9/95	0.01 U	254	na	356	8.4	na	na	23.3
		9/30/04	0.005 U	285	0.7	498	6.8	-141	4.0	18.0

1) Well depth in feet below ground surface. NA = Not Available

2) Data Qualifier: U = Not detected at or above the associated detection limit. na= Not analyzed.

Table 2 - Nitrate Data from Public Water System Wells in Subbasin

PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment	PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment
Wells in Saddle Mountains Aquifer							
26214-01	4/13/94	0.5 U	Pre-Treatment	66475-01	3/31/94	30.30	Pre-Treatment
	12/10/96	0.58	Pre-Treatment		10/11/94	32.10	Pre-Treatment
	9/28/98	0.2 U	Pre-Treatment		12/15/94	30.00	Pre-Treatment
	6/3/99	0.47	Unknown		1/26/95	28.70	Pre-Treatment
	12/17/02	0.04	Pre-Treatment		12/27/95	27.30	Pre-Treatment
	7/22/03	0.5 U	Pre-Treatment		9/26/96	30.40	Pre-Treatment
26214-02	12/13/01	0.19	Pre-Treatment		1/29/97	30.10	Unknown
	12/17/02	0.05	Pre-Treatment		5/27/97	27.60	Pre-Treatment
	7/8/03	0.5 U	Pre-Treatment		8/17/97	26.90	Pre-Treatment
30816-02	2/26/99	10.20	Pre-Treatment		12/30/97	20.60	Pre-Treatment
	4/17/00	13.80	Pre-Treatment		3/24/98	25.70	Unknown
	1/30/01	13.30	Unknown		5/28/98	26.90	Pre-Treatment
	4/18/01	3.35	Pre-Treatment		7/28/98	29.00	Pre-Treatment
	2/4/03	14.20	Pre-Treatment		12/8/98	23.80	Unknown
	2/26/03	0.20	Pre-Treatment		3/23/99	22.70	Unknown
03392-01	4/21/94	3.80	Pre-Treatment		4/27/99	25.20	Unknown
	1/31/97	4.93	Pre-Treatment		8/12/99	27.50	Unknown
	9/12/02	3.10	Unknown		12/1/99	24.30	Unknown
04236-01	11/29/94	22.40	Pre-Treatment		1/31/00	22.90	Unknown
	12/13/99	21.00	Pre-Treatment		5/29/00	27.40	Unknown
17641-01	3/31/94	20.10	Post-Treatment		8/29/00	25.80	Unknown
	6/16/94	22.70	Post-Treatment		12/14/00	24.50	Unknown
	9/19/94	20.90	Post-Treatment		2/28/01	24.50	Unknown
	11/17/94	20.00	Post-Treatment		4/24/01	27.90	Unknown
	12/21/94	23.10	Post-Treatment		9/17/01	27.10	Unknown
	3/30/95	21.70	Post-Treatment		10/25/01	24.20	Unknown
	6/6/95	21.70	Post-Treatment		2/21/02	24.40	Unknown
	12/19/95	15.50	Post-Treatment		9/9/02	32.50	Pre-Treatment
	3/26/96	22.70	Post-Treatment		1/6/03	4.60	Post-Treatment *
	9/19/96	18.80	Post-Treatment		2/6/03	6.00	Post-Treatment *
	12/3/96	20.80	Post-Treatment		3/3/03	3.80	Post-Treatment *
	3/27/97	18.70	Post-Treatment		5/22/03	8.00	Post-Treatment *
	7/25/97	14.80	Post-Treatment		6/5/03	7.40	Post-Treatment *
	9/18/97	14.90	Post-Treatment		7/8/03	7.50	Post-Treatment *
	12/19/97	17.60	Post-Treatment		8/7/03	6.10	Post-Treatment *
	3/20/98	16.10	Post-Treatment		9/7/03	5.60	Post-Treatment *
	6/24/98	14.80	Post-Treatment		10/30/03	8.70	Post-Treatment *
	9/18/98	1.40	Post-Treatment		11/17/03	4.30	Post-Treatment *
	12/2/98	15.00	Post-Treatment		12/1/03	5.00	Post-Treatment *
	12/4/98	5.60	Post-Treatment		1/29/04	4.20	Post-Treatment *
	3/17/99	14.40	Post-Treatment		2/2/04	8.90	Post-Treatment *
	7/28/99	14.10	Post-Treatment		3/1/04	3.00	Post-Treatment *

Table 2 - Nitrate Data from Public Water System Wells in Subbasin

PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment	PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment
Wells in Saddle Mountains Aquifer (continued)							
17641-01	9/15/99	12.20	Post-Treatment	02380-01	2/23/95	2.70	Post-Treatment
(continued)	10/27/99	19.00	Post-Treatment		8/16/00	1.30	Post-Treatment
	12/1/99	12.70	Post-Treatment		1/30/02	0.60	Pre-Treatment
	3/8/00	12.60	Post-Treatment		2/27/02	1.80	Pre-Treatment
	6/14/00	5.10	Post-Treatment		2/27/02	0.50	Pre-Treatment
	9/13/00	9.80	Post-Treatment		2/27/02	1.40	Pre-Treatment
	12/20/00	11.70	Post-Treatment		4/3/02	0.60	Pre-Treatment
	3/14/01	8.50	Post-Treatment		4/24/02	0.50	Pre-Treatment
	6/12/01	8.10	Post-Treatment		2/24/03	1.20	Pre-Treatment
	9/19/01	7.50	Post-Treatment		8/19/03	1.10	Pre-Treatment
	12/18/01	10.00	Post-Treatment		12/8/03	1.00	Pre-Treatment
	3/27/02	8.90	Post-Treatment		3/25/04	1.30	Pre-Treatment
	5/29/02	9.60	Post-Treatment		10/20/04	1.00	Unknown
	6/12/02	9.70	Post-Treatment		3/16/04	1.80	Unknown
	9/25/02	9.10	Pre-Treatment	06152-01	5/19/98	8.70	Pre-Treatment
	12/19/02	10.50	Pre-Treatment		5/4/99	0.70	Post-Treatment
	2/19/03	10.10	Pre-Treatment		5/4/99	11.60	Post-Treatment
	5/21/03	9.60	Pre-Treatment		5/4/99	9.26	Post-Treatment
	6/17/03	9.10	Pre-Treatment		2/21/00	11.40	Unknown
	8/19/03	9.40	Pre-Treatment		4/18/00	12.70	Unknown
	11/12/03	9.10	Pre-Treatment		2/2/01	12.10	Unknown
	2/18/04	8.90	Pre-Treatment		4/19/01	11.10	Unknown
	3/25/04	9.40	Pre-Treatment		6/14/01	11.50	Unknown
	5/12/04	8.90	Pre-Treatment		9/21/01	9.50	Unknown
	5/20/04	9.50	Pre-Treatment		12/7/01	10.90	Unknown
	6/30/04	8.80	Post-Treatment		3/19/02	12.40	Pre-Treatment
	8/23/04	9.50	Pre-Treatment		3/19/02	12.80	Pre-Treatment
	11/17/04	9.60	Pre-Treatment		5/22/02	7.47	Pre-Treatment
	3/16/05	9.80	Unknown		3/11/03	13.40	Pre-Treatment
15545-01	12/13/01	0.20	Unknown		5/7/03	12.30	Post-Treatment
	8/29/02	2.60	Unknown		5/7/03	10.50	Post-Treatment
	5/19/03	2.80	Unknown		9/30/03	17.80	Post-Treatment
AA341-01	7/22/03	0.5 U	Post-Treatment		11/12/03	8.02	Post-Treatment
	10/2/03	0.95	Post-Treatment		3/15/04	16.00	Pre-Treatment
	8/12/04	0.90	Pre-Treatment		6/30/04	16.00	Post-Treatment
	3/1/05	0.70	Unknown		10/5/04	18.7	Unknown
02431-01	3/21/95	1.10	Pre-Treatment		12/22/04	21.0	Unknown
	11/30/99	1.00	Pre-Treatment	63913-01	2/22/95	23.90	Pre-Treatment
	12/18/01	1.50	Pre-Treatment	(GC-69)	5/10/95	28.1	Pre-Treatment
	12/31/02	1.50	Unknown		9/26/95	30.4	Pre-Treatment
	12/29/03	1.40	Unknown		1/12/00	30.90	Unknown
	12/28/04	1.40	Unknown		4/17/00	26.60	Unknown
19060-01	1/5/94	8.00	Pre-Treatment		7/14/00	27.20	Unknown
	11/8/98	3.50	Unknown		10/25/00	28.90	Unknown
	2/17/99	5.10	Unknown		1/17/01	28.90	Unknown
	5/19/99	3.80	Unknown		4/19/01	28.80	Unknown
	8/23/99	4.20	Unknown		7/25/01	29.40	Unknown
	6/19/01	9.70	Unknown		10/18/01	27.50	Unknown
03843-01	8/9/94	9.10	Pre-Treatment		2/21/02	26.20	Unknown
AA140-01	8/21/00	12.60	Post-Treatment		4/15/02	25.80	Pre-Treatment
	8/28/00	19.50	Post-Treatment		9/26/02	21.90	Unknown
75883-01	12/27/95	7.30	Pre-Treatment		10/10/02	19.10	Unknown
	10/8/02	9.30	Unknown		2/25/03	25.80	Unknown
02689-01	3/1/96	3.30	Pre-Treatment		2/27/03	26.00	Unknown
	3/6/00	3.00	Unknown		9/28/04	42.6	Pre-Treatment
	2/15/05	2.00	Unknown		3/22/05	44.40	Pre-Treatment

Table 2 - Nitrate Data from Public Water System Wells in Subbasin

PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment	PWS Number	Sample Date	Nitrate + Nitrite as N in mg/L	Treatment
Wells in Wanapum Aquifer							
63913-02	1/17/03	0.31	Pre-Treatment	06559-01	4/29/98	4.40	Pre-Treatment
	2/3/03	1.42	Pre-Treatment		7/16/98	4.00	Unknown
	5/6/03	0.5 U	Post-Treatment		2/24/99	3.90	Pre-Treatment
	8/4/03	0.5 U	Pre-Treatment		7/19/01	3.50	Pre-Treatment
	9/15/03	0.5 U	Unknown		4/17/03	5.20	Unknown
	10/1/03	0.5 U	Unknown		9/25/03	5.20	Pre-Treatment
	11/5/03	0.5 U	Unknown		3/30/04	7.10	Unknown
	3/18/04	0.5 U	Post-Treatment		6/3/04	7.50	Unknown
	6/30/04	4.50	Post-Treatment		9/29/04	7.80	Unknown
30816-01	10/15/01	4.81	Pre-Treatment		12/20/04	7.60	Unknown
	2/18/02	1.69	Pre-Treatment		3/28/05	8.60	Post-Treatment
	3/8/04	1.15	Pre-Treatment	19060-02	9/25/01	0.03 U	Unknown
66475-02	4/13/04	0.2 U	Unknown		8/27/02	0.20	Unknown
	5/3/04	0.40	Unknown		3/18/03	0.2 U	Unknown
	9/30/04	0.30	Unknown		5/25/04	0.2 U	Pre-Treatment
66479-01	2/22/94	0.20	Pre-Treatment	AA389-01	3/25/03	1.89	Pre-Treatment
	1/31/00	0.5 U	Unknown		4/10/03	0.5 U	
	8/20/02	0.40	Post-Treatment				
	1/14/04	0.80	Pre-Treatment				
	1/3/05	0.2 U	Unknown				
68045-01	4/2/01	0.5 U	Post-Treatment				
	6/11/01	1.49	Pre-Treatment				
	7/11/01	2.43	Pre-Treatment				
	7/11/01	2.32	Pre-Treatment				
	1/19/04	0.5 U	Pre-Treatment				

*Based on communications with PWS administratior

Data Qualifier: U = Not detected at or above the associated detection limit.

Data obtained from Washington State Department of Health database (September 2004 and April 2005).

Table 3 - Current and Historical Nitrate Data for Surface Water Locations Sampled for this Study

		Water Quality Parameters		Field Parameters					
Sample	Sample Date	Nitrate + Nitrite as N in mg/L	Total Dissolved Solids in mg/L [1]	Dissolved Oxygen in mg/L [1]	Specific Conduct. in µmhos/cm	pH	Eh in mV [1]	Turbidity in NTU [1]	Temp. in °C
Glade Creek									
GC-97SW (near mouth)	5/31/92	34.5	na	na	1280	7.6	na	na	15.6
	5/10/95	37.0	908	na	1283	8.3	na	na	18.5
	5/10/95	36.0	893	na	1283	8.3	na	na	18.5
	9/26/95	40.0	na	na	1369	8.1	na	na	17.6
	9/29/04	39.0	na	10.4	1289	8.1	122	1.0	14.7
	3/22/05	44.6	na	14.3	1355	8.1	119	2.4	8.4
GC-98SW (East Branch Glade Creek)	5/10/95	11.6	593	na	882	8.8	na	na	19.0
	9/29/04	37.7	na	8.3	1376	7.7	69	0.3	14.4
	3/22/05	42.0	na	15.0	1511	7.9	122	2.7	7.3
GC-99SW (Upper Glade Creek)	5/10/95	13.3	797	na	1133	8.4	na	na	18.2
	9/29/04	42.7	na	10.4	1555	7.8	112	0.3	14.3
	3/22/05	44.2	na	15.2	1511	8.0	124	1.6	7.8
Fourmile Canyon									
FC-01SW	9/30/04	5.41	na	12.9	1381	8.6	78	0.7	15.4
	3/22/05	9.46	na	17.8	1533	8.2	103	1.2	5.8

1) Data Qualifier: na = Not analyzed.