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Relationship Between Ground Water and Surface Water in the Quilceda Creek Watershed

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Relationship Between Ground Water and Surface Water in the Quilceda Creek Watershed

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Abstract

The Quilceda Creek watershed in central Snohomish County is experiencing rapid growth and development. The physical and chemical character of Quilceda Creek, a Class A stream, will be impacted by this growth. This study investigates the relationship between Quilceda Creek and the surficial aquifer in a seven square mile study area in the Marysville Trough. We were primarily interested in whether ground water is an important component of streamflow and whether ground water influences the water quality of Quilceda Creek.

Eighteen wells and seven surface water stations were sampled in May, August, and December 1995. Samples were collected and analyzed for fecal coliform bacteria, nutrients (nitrogen and phosphorus), major cations (calcium, magnesium, sodium, and potassium) and anions (chloride, sulfate, and bicarbonate), TDS, TOC, metals, volatile organics, and pesticides. Field measurements of water temperature, pH, and specific conductance were also made. The depth to ground water is shallow, ranging from as little as one foot to 29 feet below ground surface.

Ground water within the study area is a major contributor to streamflow of Quilceda Creek, accounting for 46 to 60% of the streamflow during times when surface runoff is absent (not raining). Although ground water interacts with Quilceda Creek throughout its length, ground water recharge from precipitation is greatest in the northern portion of the study area and ground water discharge to Quilceda Creek is greatest in the southern portion. Fecal coliform bacteria appear to be primarily a surface water problem. Bacteria entering the creek are probably from non-point sources near the stream channel. Ground water is an important source of TDS, nitrate and chloride to Quilceda Creek as well as a minor source of TOC, ammonium, and phosphorus.

Acknowledgments

We thank the following people for their contributions to this study:

◊ Well owners for allowing us to sample and providing background information on their wells

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Introduction

The Quilceda Creek watershed is located in Snohomish County, Washington, a few miles northeast of the city of Everett. The main stream channel lies in the Marysville Trough between the cities of Arlington and Marysville.

Historically, the central portion of the watershed was covered with extensive wetlands. Most of these were drained, however, during the early part of the century when the lands were converted to agriculture. During the last few decades, residential and commercial growth has replaced many of the farms. Growth continues at a rapid pace with the construction of housing and support facilities for the Everett Naval Base, one of the recent developments. Significant industrial development is also occurring along the Interstate-5 corridor which passes through the center of the basin. Although most of the watershed is within the jurisdiction of Snohomish County, some land owners with whom we talked are interested in annexation by either Marysville or Arlington.

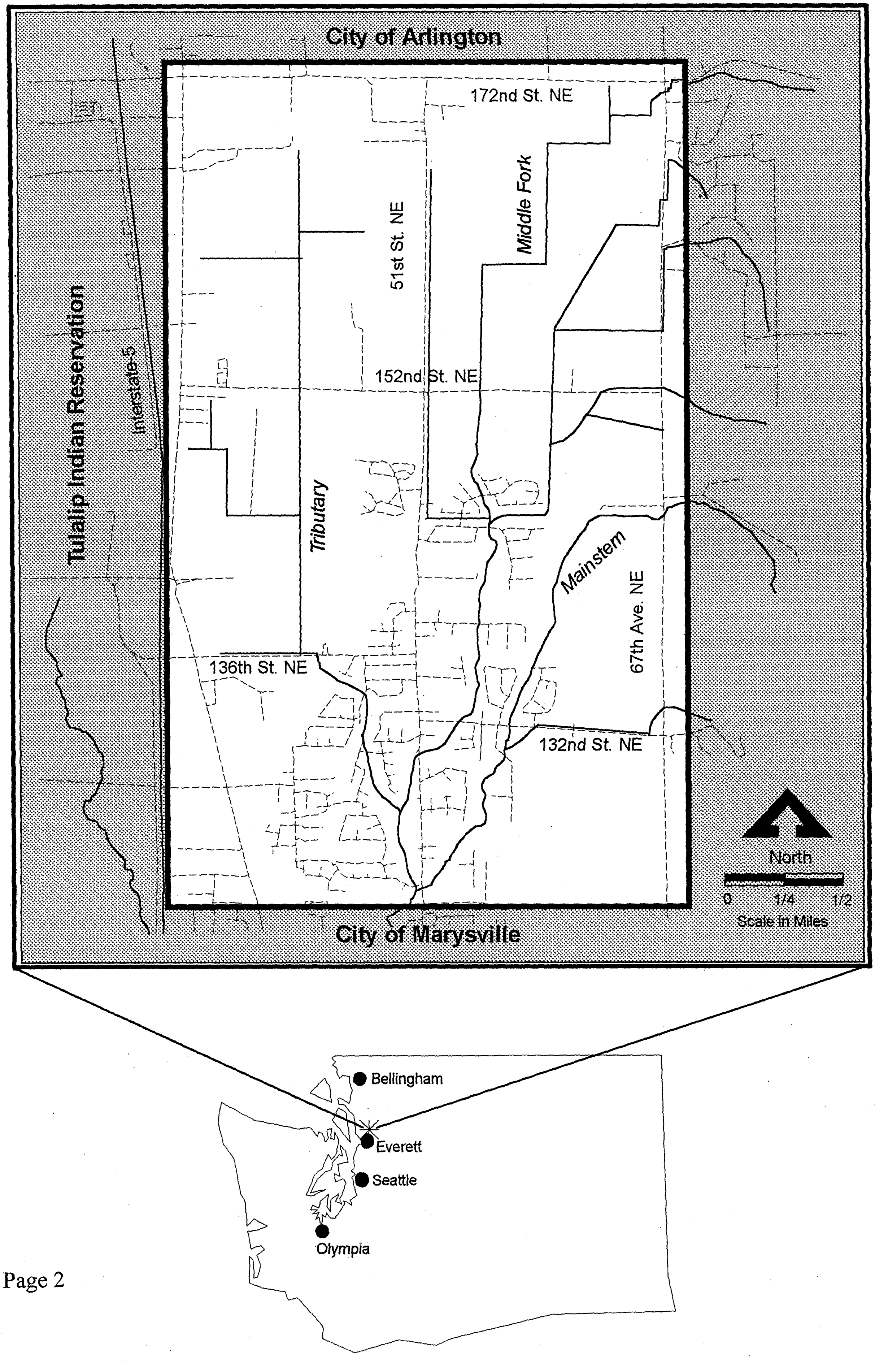
The rapid growth and change in land use have raised concerns over potential impacts on the quantity and quality of the watershed's surface and ground water. Quilceda Creek, a tributary of the Snohomish River, contains valuable habitat for salmon spawning and juvenile rearing and is classified as a Class A stream (173-201 WAC). Over the years the creek has been altered (rechanneled) by farming and construction activities.

Although it is recognized that ground water has a role in the streamflow of Quilceda Creek, the importance of ground water in the rapidly developing areas is not well understood (Carroll, 1994). Surface water quality problems already identified in the watershed include high levels of fecal coliform bacteria, nitrate, and phosphorus (Carroll and Thornburgh, 1994). Similar problems are suspected to occur in ground water, but have not been specifically identified. These water quality problems are associated with the large number of farms, particularly on the mainstem Quilceda, as well as failing septic systems. Since a portion of the streamflow in Quilceda Creek comes from ground water, protection of the creek requires knowledge of the role of ground water to both the flow and quality of the creek. If ground water is an important component of streamflow of Quilceda Creek, then it may be necessary to manage growth to protect ground water. Also, many people in the area rely on ground water for drinking water, although this number will likely decline as the cities extend their water and sewer services into the area.

Purpose

This study investigates the relationship between Quilceda Creek and the surficial aquifer that feeds the creek in the lowland portion of the watershed. We were primarily interested in quantifying how ground water affects flow and water quality in Quilceda Creek.

Figure 1: Quilceda Creek Study Area



Study Area

With a drainage area of about 50 square miles, Quilceda Creek is a minor tributary of the Snohomish River. The main stream drainage lies in the Marysville Trough, bordered on the east by the Getchell Hill plateau and on the west by the Tulalip plateau. The watershed has been characterized by Carroll and Thornburgh, 1994.

We chose approximately seven square miles of the central, lowland portion of the watershed, upgradient of the confluence of the Middle Fork and mainstem, for study (Figure 1). This relatively undeveloped area, lying between Marysville and Arlington, is experiencing rapid growth. Specifically, the study area is bounded on the west by Interstate-5, on the north by the Arlington city limits (172nd St NE), on the east by the 150-foot contour of the Getchell Hill plateau (roughly 67th Ave NE), and on the south by the city of Marysville (roughly 136th St NE). The study area is underlain by the Marysville Trough Aquifer, a large unconfined surficial aquifer that lies north to south in recessional outwash deposits (EES, 1991).

The northern portion of the study area, once mostly wetlands, has been artificially drained by ditches. The original stream channel has been rerouted along roads, around fields, and through developed areas. These ditches, designed to lower the water table, have enhanced the connection between surface and ground water.

The study area includes much of the remaining agricultural lands and is representative of other lowland farm areas within the watershed. It contains both commercial and noncommercial farms as well as rapidly developing residential and industrial areas. Although once very common, only one active dairy farm was found during reconnaissance of the study area. While horses are probably more common than in the past, the total number of farm animals, especially cows, is probably much lower. A few large farms remain, with strawberries a major crop. Although the Marysville sewer system serves the southern portion of the area, many homes rely on septic tanks, even within relatively high density residential areas (more than two homes per acre).

Methods

Study methods include the selection of sampling sites, water level and streamflow measurements, collection of water quality samples, and laboratory methods.

Sampling Sites

Eighteen wells and seven surface water stations were selected for monitoring (Figure 2). Although well logs from Ecology's Northwest Regional Office files were examined, most wells were selected during a door-to-door survey of the area. The majority of wells included in the study were 3-foot diameter, concrete-tile wells originally dug for domestic use. Well logs were never completed for most of these wells because of their age and shallow nature. Since Arlington and Marysville have expanded their water service into much of this area, these shallow wells were often not in use. Wells that were still in service were used mostly for landscape watering.

The seven stations on Quilceda Creek include two on the mainstem, two on a small western tributary, and three on the Middle Fork. The western tributary (of the Middle Fork) originates completely within the study area.

The Quilceda Creek mainstem, which cuts through the eastern corner of the study area, was sampled at an upper site (QCREF1) where it enters the study area (above the culvert on 67th Ave NE), and a lower site (QCREF2) where it exits the study area (above the culvert on 51st Ave NE). The mainstem branch between QCREF1 and QCREF2 drains an area of about 0.95 square miles.

The tributary was sampled above the culvert on 152nd St NE (QCRTR1), about half way between the tributary's origin and its confluence with the Middle Fork. The drainage area above QCRTR1 is about 1.30 square miles. A second tributary station (QCRTR2) is located below the bridge on 129th St NE about one quarter mile above the mouth. The contributing drainage area between QCRTR1 and QCRTR2 is about 1.15 square miles. The total drainage area of the tributary is about 2.5 square miles.

The three Middle Fork locations included one upstream of the study area, one near the center, and one where the stream exited the study area. The upstream site (QCRMF1) was located above the culvert on 172nd St NE at the intersection of 67th Ave NE (essentially the same site as Quilceda-1: Thornburgh et al. 1991; and QCLU: Carroll, 1994). The middle location (QCRMF2) was above the culvert at 142nd St NE. The drainage area (within the study area) between QCRMF1 and QCRMF2 was about 1.85 square miles. The lowest station (QCRMF3) was located below the box culvert at 122nd St NE. The area drained by Quilceda Creek between QCRMF2 and QCRMF3 is about 0.75 square miles, not including the tributary.

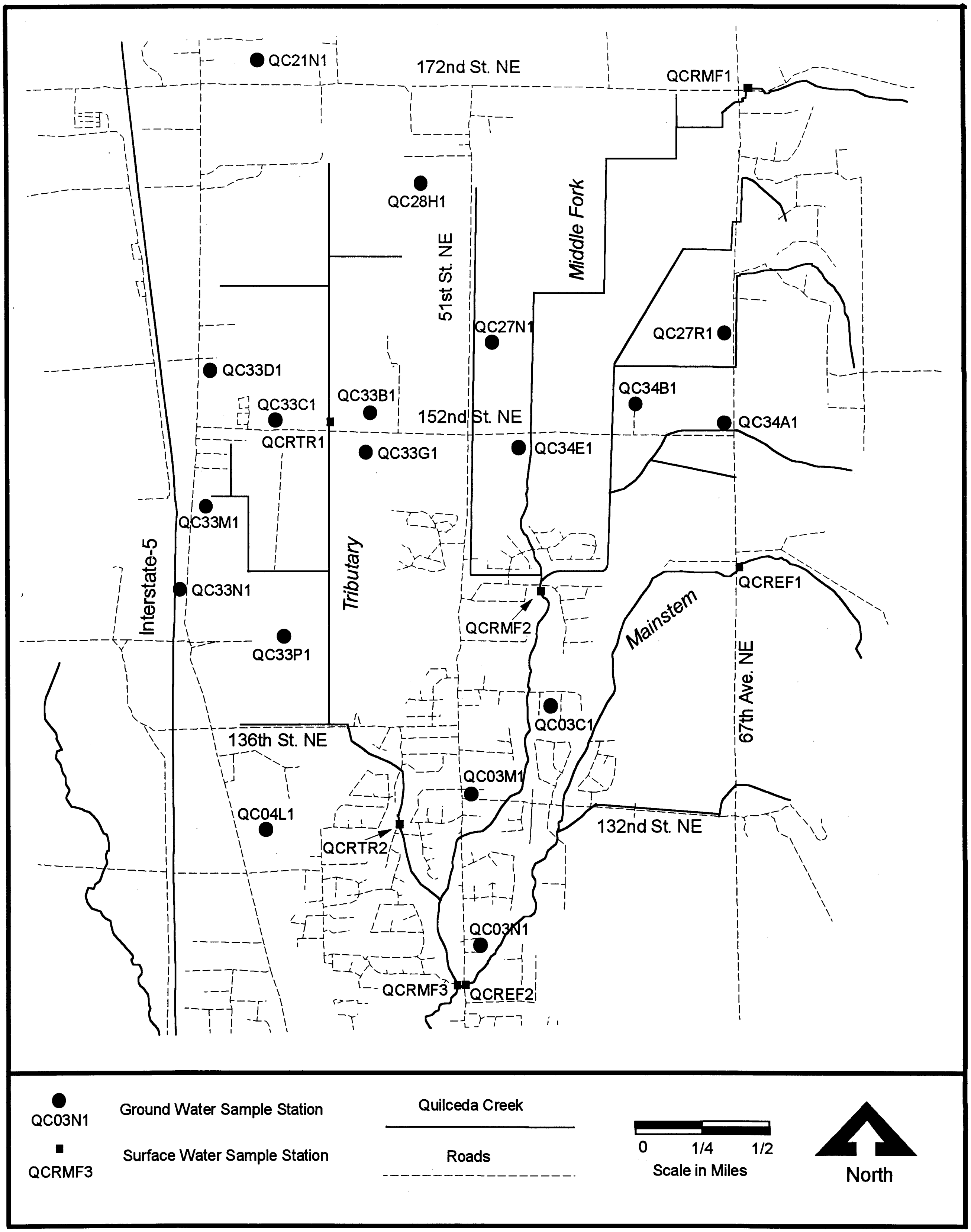


Figure 2: Quilceda Creek Sample Locations

The drainage area of the Middle Fork within the study area, including the tributary, is about 6.10 square miles, which is much larger than the 0.95 square miles drainage of the mainstem. The total study area drained by Quilceda Creek is approximately 7 square miles.

Water Level and Streamflow Measurements

Prior to sampling ground water, we measured the static water level using a commercial electric probe. The probe was rinsed with deionized water and wiped clean between measurements. Water level measurements (the depth below the ground surface) were recorded in March, May, August, and December 1995

The stage (water level) of Quilceda Creek was also recorded at each stream site during each event. Streamflow at all sampling sites and a few other stream locations was measured on May 24 and October 5, 1995, as well as January 11, 1996. The stage of the stream was also recorded. These measurements, combined with the stage recorded during each sampling event, allowed us to estimate the streamflow at the time of sampling. Streamflow was measured with a Swofford digital current meter using the standard USGS midsection method (Buchanan and Somers, 1969). Measured streamflow allowed the conversion of chemical concentrations into dissolved-solids loads. Also, the difference in streamflow between sites (no surface water inflow between sites) can be attributed to inflow of ground water.

Water Quality Sampling

We sampled both the ground water and Quilceda Creek in May, August, and December 1995. Water quality parameters were limited to constituents affected by land use which have the potential to adversely affect the beneficial uses of water. Based on a reconnaissance of predominant land uses, we selected several analytes for study. Nutrients (nitrogen and phosphorus) are the primary contaminants related to farming and residential development, and metals and volatile organics are associated with industrial and commercial activities. We also included dissolved iron and manganese which have been found above drinking water standards on the nearby Tulalip Indian Reservation (Drost 1983). For completeness, we included pH, electrical conductance, and the major cations (calcium, magnesium, sodium, potassium) and anions (chloride, sulfate, bicarbonate) as well as total organic carbon (TOC) and total dissolved solids (TDS). The list of analytes including the analytical methods and method detection limits used are presented in Appendix A.

We purged all wells for about one hour before sampling and until specific conductance, pH and temperature stabilized (changes of 10% or less between grab samples). No specific purge volume was selected, although the volume of water removed often exceeded 1,000 gallons. Residential wells with installed pumps were purged and sampled from a tap nearest the wellhead and before any water treatment system. Wells without installed pumps were purged with a Grundfos 4-inch submersible pump or a 1/3 HP centrifugal pump. We collected samples for metals and volatile organics with a decontaminated bottom-emptying teflon bailer and the remaining samples directly from the pump outflow. Bailers were pre-cleaned with sequential washes of Liquinox®, hot tap water, 10% nitric acid, distilled-deionized water and pesticide-grade acetone. Clean bailers were air-dried and wrapped in aluminum foil.

We sampled Quilceda Creek using simple grab sampling techniques. Samples were collected at mid-depth and as near the center of streamflow as could be reached from the bank.

Samples were collected in appropriately cleaned containers. Dissolved metal samples were filtered with a dedicated 0.45 micron polycarbonate in-line filter and preserved with 1 mL of nitric acid (HNO_3) to a pH < 2. Samples for volatile organics were collected free of headspace in three 40-mL glass vials with teflon-lined septa lids and preserved with 1:1 hydrochloric acid. Fecal coliform bacteria samples were collected in sterile glass bottles.

Labeled samples were stored in an ice-filled cooler. Those with a short holding time were sent to the laboratory by bus on the day of collection. Chain-of-custody procedures followed Manchester Laboratory protocol (Ecology, 1994).

Results

We have divided the results into three sections. The first deals with the physical characteristics of the study area, specifically ground water elevations and gradient as well as streamflow. The second discusses the chemical makeup of the ground water and Quilceda Creek. A third section discusses the dissolved solids load carried by the stream and the contribution of ground water to this load.

Physical Characteristics

Quilceda Creek, which drains the Marysville Trough, is underlain by an extensive surficial aquifer extending from Arlington and the Stillaguamish River on the north to Marysville and the Snohomish River on the south. The aquifer consists of the Marysville Sand formation and ranges from 10 to 150 feet thick (EES, 1991). This is a highly productive aquifer with a transmissivity and hydraulic conductivity of 10,000 to 50,000 gpd/ft and 50 to 200 ft/day, respectively. Individual wells in the aquifer may yield up to 300 gpm. The infiltration of precipitation over most of the undeveloped land is high. Recharge to the ground water from drainage of uplands via the overlying stream system probably occurs during wet months. Ground water inflow from other aquifers may also occur along the eastern and western boundaries of the aquifer where the advance outwash deposits of the surrounding plateaus rise in elevation above the plain of the Marysville Trough.

Ground Water

The 18 study wells ranged from 7.2 to 40 feet deep and averaged 20.3 feet (Table 1). Water levels in most wells were 1 to 10 feet below ground surface (bgs). Deeper water levels, about 10 to 30 feet bgs, occurred in the southern end of the study area (wells QC03C1, QC03M1, and QC03N1). To the south, Quilceda Creek flows through a ravine which is 30 to 50 feet below the surrounding land surface. The water table in this area occurs a like distance below the ground surface. The average depth to the water table, not including the above three wells, was 3.3 feet (March), 3.5 feet (May), 4.9 feet (August), and 2.2 feet (December). The water table fluctuated seasonally by as little as 1.0 foot (QC03N1) in the downstream portion of the study area, and as much as 4.3 feet (QC04L1) in areas distant from the stream.

In general, ground water flows in a south to southwest direction, perpendicular to the water table contours (Figure 3). In the northern portion of the study area, ground water flow parallels the stream channel, curving toward Quilceda Creek in the southern portion of the study area where the creek is incised into the landscape. Because the aquifer underlying Quilceda Creek is as much as 150 feet thick, not all ground water interacts with the creek. Deeper ground water probably continues southerly out of the study area discharging to the nearby Snohomish River.

Table 1. Study wells (measurements are in feet).

Site ID	Elevation[1]	Depth[2]	Use	Depth to Water during 1995.				Water table fluctuation[3]
				March	May	August	December	
QC03C1	85	16.7	I	10.7	10.7	12.4	10.2	2.2
QC03M1	88	30.3	U	18.9	18.3	20.1	19.1	1.8
QC03N1	75	38.8	I		27.7	28.7	28.7	1.0
QC04L1	82	23.9	I		2.5	5.2	0.9	4.3
QC21N1	121	16.5	D		6.7			
QC27N1	108	7.2	U	2.4	2.9	4.1	1.2	2.9
QC27R1	118	40	D	1.4	2.0		0.8	
QC28H1	115	17	D	3.4	3.7		2.6	
QC33B1	103	23.6	U		2.2	4.1	1.8	2.3
QC33C1	103	16.2	I		2.1	4.5	1.4	3.0
QC33D1	105	9.8	I	1.9	2.3	3.8	1.2	2.6
QC33G1	103	24.9	I	2.4	2.7	3.8	1.9	1.9
QC33M1	101	11	U	3.5	3.8	5.8	2.4	3.4
QC33N1	95	13	U	4.5	4.8	6.6	3.5	3.2
QC33P1	94	23.5	U	2.5	2.6	3.5	2.1	1.4
QC34A1	120	22.6	D	8.4	9.0	10.0	7.2	2.8
QC34B1	108	9.6	U	4.0	3.7		3.1	
QC34E1	102	20.5	D	1.8	2.4	2.3	0.9	1.4

[1] Ground surface from topo-map - contour interval 10 feet.
[2] Below ground surface.
[3] Difference between the lowest and highest water level measurements.
D,I,U - Well use, D=domestic, I=irrigation, U=unused.

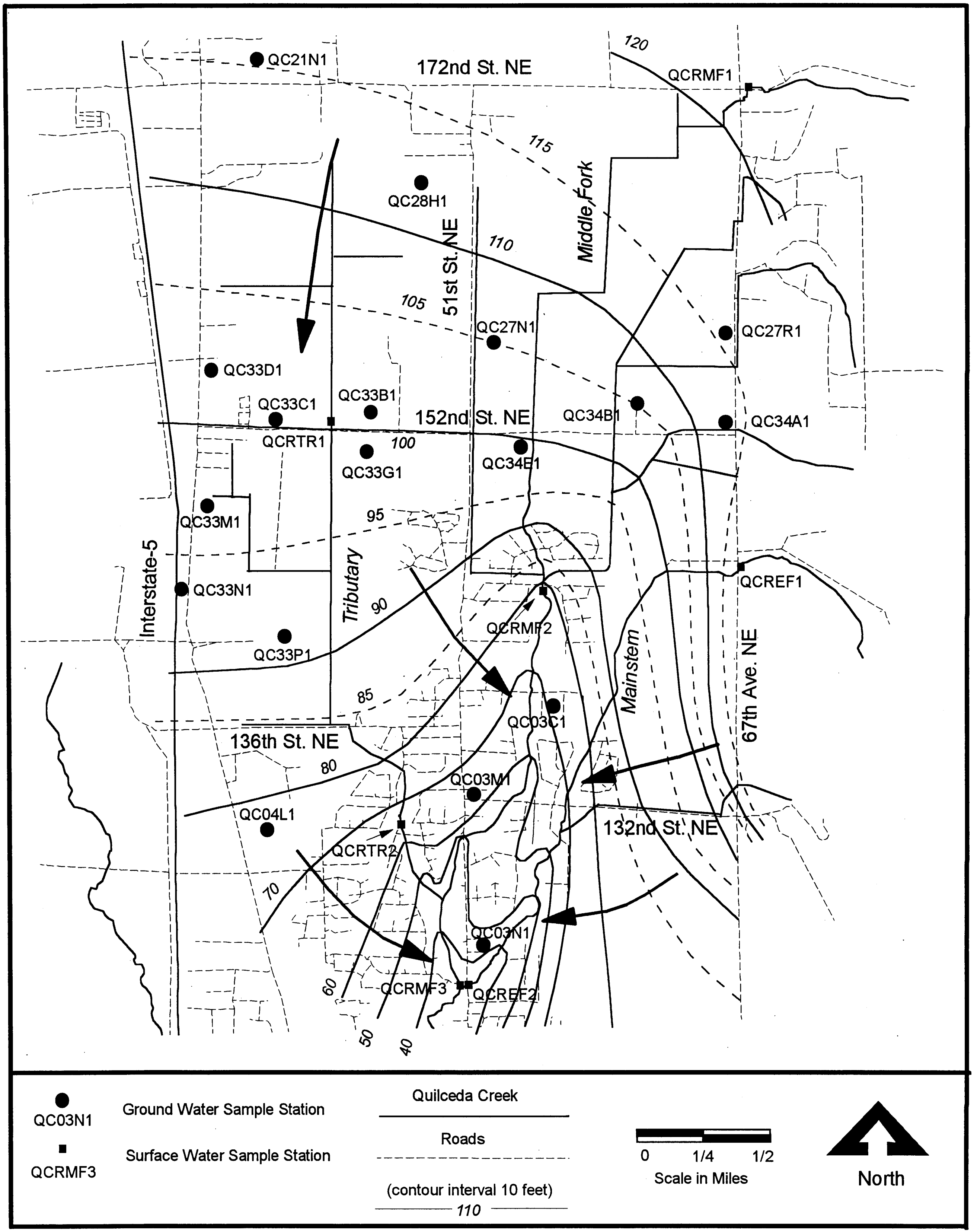


Figure 3: Average Ground Water Elevation Contour Map for the Surficial Aquifer (March through December 1995), elevation based on mean sea level datum

Streamflow

Streamflow for selected dates is presented in Table 2. Streamflow of minor tributaries entering the study area was also measured or estimated, and these values are summarized in the table as miscellaneous inflow.

Table 2. Measured and estimated streamflow at selected locations on specified dates (in cubic feet per second - cfs).

Location	May 4, 1995[e]	May 24, 1995[m]	August 14, 1995[e]	October 5, 1995[m]	December 5, 1995[e]	January 11, 1996[m]
Tributary to Middle Fork of Quilceda Creek						
QCRTR1	0.65	0.45	0.05	0.16	2.4	2.4
QCRTR2	1.35	0.90	0.10	0.31	4.4	4.4
Main Stem Quilceda Creek						
Misc Inflow	0.1	0.1	0.1	0.1	1.5	1.7
QCREF1 (Inflow)	3.6	2.3	2.0	2.3	8.6	10.7
QCREF2 (Outflow)	4.0	2.9	2.5	2.7	15.0	14.4
Outflow-Inflow	0.3	0.5	0.4	0.3	4.9	2.0
Middle Fork of Quilceda Creek						
Misc Inflow	0.5	0.48	0.4	0.44	5.0	5.8
QCRMF1 (Inflow)	0.55	0.50	0.50	0.52	1.7	1.8
QCRMF2	1.9	1.6	1.5	1.6	15.0	14.8
QCRMF3 (Outflow)	6.0	5.7	4.0	4.2	22.0	22.8
Outflow-Inflow	5.0	4.7	3.1	3.2	15.3	15.2
Total Quilceda Creek Inflow to and Outflow from the study area.						
Total Inflow	4.8	3.4	3.0	3.4	16.8	20.0
Total Outflow	10.0	8.6	6.5	6.9	37.0	37.2
Difference Outflow-Inflow	5.2	5.2	3.5	3.5	20.2	17.2

[e] = estimated from water level (stage) of stream.
[m] = measured.
Misc Inflow = summation of all other surface water contributions to the study area.
Outflow-Inflow = difference between the streamflow into the study area and out of the study area, equals the contribution of ground water to streamflow.

Ground Water Contribution to Streamflow

Streamflow was measured and sampled only when surface runoff was not evident: the pavement was dry and roadside ditches were not flowing. Under these conditions, we assumed that differences in streamflow between upper and lower stations were caused by ground water discharging to the stream. The contribution of ground water to streamflow as a percentage of streamflow out of the study area is presented in Table 3.

The tributary stream, while not explicitly shown in Table 3, is included in the results of the Middle Fork, of which it is a tributary. Because it originates within the study area, it is 100% ground water drainage whenever surface runoff is absent.

Table 3. Ground water contribution to streamflow of Quilceda Creek (Percent).

May 4, 1995	May 24, 1995	August 14, 1995	October 5, 1995	December 5, 1995	January 11, 1996
Mainstem Quilceda Creek					
8	17	16	11	33	14
Middle Fork of Quilceda Creek					
83	82	78	76	70	67
Quilceda Creek as it leaves the study area.					
52	60	54	51	55	46

This table is based on Table 2.

The ground water contribution to streamflow in the mainstem ranged from 8 to 33%. The mainstem has a relatively short length of channel within the study area, explaining the relatively small ground water contribution. In contrast, the Middle Fork, with a long stream segment in the study area (including the tributary), had a much greater contribution of ground water to streamflow. Ground water comprised between 67 and 83% of streamflow. The combined flow of both the mainstem and the Middle Fork consisted of between 46 and 60% contribution from ground water.

It is clear that ground water is an important source of streamflow in Quilceda Creek during non-storm periods. Ground water continues to contribute to streamflow during storm events, but is of less importance as streamflow into the study area rises and surface runoff from roads and other paved surfaces increase.

To further refine the watershed areas that are most responsible for ground water contributions, we calculated the ground water contribution to streamflow in cubic-feet/sec per square mile of drainage (Table 4). Table 4 was constructed by dividing the increase in streamflow between stations, by the watershed area between stations. If we assume that rainfall is evenly distributed over this relatively small basin, then the contribution of ground water per unit area should be equal if ground water recharge and ground water discharge are similar throughout the area.

Table 4. Contribution of ground water to streamflow in cubic feet/second per square mile (cfs/sq.mi.).									
Contribution Area	Watershed area (sq. mi.)[1]	Ground Water gradient (%)	Stream gradient (%)	May 4, 1995	May 24, 1995	Aug 14, 1995	Oct 5, 1995	Dec 5, 1995	Jan 11, 1996
Above QCRTR1	1.30	0.25	0.35	0.50	0.54	0.07	0.12	1.9	1.9
From QCRTR1 to QCRTR2	1.15	0.50	0.50	0.61	0.39	0.04	0.13	1.7	1.7
From QCREF1 to QCREF2	0.95	.85	0.75	0.32	0.53	0.42	0.32	5.2	2.1
From QCRMF1 to QCRMF2	1.85	0.45	0.40	0.46	0.34	0.32	0.35	4.5	3.9
From QCRMF2 to QCRMF3[2]	0.75	0.60	0.65	3.7	4.3	3.2	3.1	3.5	4.8
TOTAL	7.05			0.74	0.74	0.50	0.50	2.9	2.4

1 Within study area.
2 Does not include streamflow from the Tributary.

Table 4, however, indicates that ground water recharge and ground water discharge are not similar throughout the study area. Ground water recharge from precipitation is greater in the northern portion of the study area, while ground water discharge to Quilceda Creek is greater in the southern portion.

During the drier times of the year, the greatest contribution of ground water to surface water occurs along the channel of the lower Middle Fork, between QCRMF2 and QCRMF3. Along this segment, both the ground water gradient and the stream gradient increase, and as shown in Figure 3, the direction of ground water flow bends in toward the stream. The source of this ground water, however, is not necessarily local. Much of it probably flows from the upper part of the study area, only surfacing in this segment.

Thus, although most of the ground water contribution to the Middle Fork appears to come from the 0.75 sq.mi. watershed between QCRMF2 and QCRMF3, this is not necessarily true. The source of much of this water is probably the larger 1.85 sq. mi. watershed above QCRMF2 where ground water recharge is greater than the ground water discharge to the stream. During December, the wettest time of the year, the contribution from the northern portions of the watershed exceeded that of the southern, possibly due to the efficiency of artificial drainage ditches.

Any reduction in ground water recharge occurring in the northern portion of the study area will probably reduce ground water discharge to the stream channel in the southern or lower portion of the study area. Likewise, contamination of ground water in the northern area may not show up in the stream for a considerable distance downstream.

Water Quality

For discussion we have divided the water quality parameters into seven groups: (1) field parameters measured during field sampling, (2) fecal coliform bacteria, (3) major cations and anions, (4) nutrients, (5) metals, (6) volatile organic compounds, and (7) pesticides. All samples met appropriate laboratory quality assurance. A discussion of the quality assurance results is included as Appendix B.

Field Parameters

Field parameters include water temperature, pH, and electrical conductance. The results for both ground water and surface water are summarized in Table 5.

Table 5. Temperature (°C), pH, and electrical conductance (umhos/cm) of ground water and Quilceda Creek (sampled May, August, and December 1995).

Site ID	Temperature		pH		Electrical Conductance	
	Range	Max-Min	Range	Average	Range	Average
Ground Water						
QC03C1	10.9-13.3	2.4	6.1-6.4	6.3	110-149	125
QC03M1	12.0-12.7	0.7	6.2-6.5	6.3	145-225	185
QC03N1	10.1-11.0	0.9	6.8-7.2	7.0	110-165	145
QC04L1	10.0-12.0	2.0	6.8-6.9	6.8	120-170	140
QC21N1	9.9-11.3	1.4	6.1-6.5	6.2	120-145	135
QC27N1	9.3-13.8	4.5	6.6-6.8	6.7	208-300	259
QC27R1	10.0-10.7	0.7	7.4-7.7	7.5	128-190	166
QC28H1	9.8-13.0	3.2	6.1-6.3	6.2	145-210	185
QC33B1	10.2-12.2	2.0	7.3-7.5	7.4	190-285	228
QC33C1	9.9-12.8	2.9	6.5-6.8	6.7	150-210	170
QC33D1	9.0-12.4	3.4	6.5-6.6	6.5	110-165	142
QC33G1	10.8-11.7	0.9	7.5-7.5	7.5	220-340	287
QC33M1	9.2-11.7	2.5	6.3-6.4	6.4	90-165	138
QC33N1	10.4-12.5	2.1	6.2-6.4	6.3	62-105	90
QC33P1	9.7-13.2	3.5	6.6-7.0	6.8	165-260	225
QC34A1	10.2-11.2	1.0	6.9-7.2	7.1	110-175	149
QC34B1	10.5-12.5	2.0	6.4-6.5	6.5	180-190	185
QC34E1	11.0-12.5	1.5	7.0-7.1	7.0	240-350	305
Median	**10.0-12.5**	**2.0**	**6.5-6.8**	**6.7**	**136-190**	**168**
Quilceda Creek						
QCRTR1	6.4-12.5	6.1	6.8-7.1	7.0	115-240	161
QCRTR2	6.5-13.0	6.5	7.1-7.2	7.1	140-210	175
QCREF1	5.2-11.4	6.2	7.0-7.4	7.2	65-148	94
QCREF2	4.8-12.1	7.3	7.0-7.5	7.2	78-165	109
QCRMF1	6.0-10.9	3.9	7.1-7.3	7.2	88-165	115
QCRMF2	6.3-12.4	6.1	7.0-7.3	7.2	110-235	160
QCRMF3	5.8-12.4	6.6	7.0-7.5	7.3	125-235	170

Temperature

Ground water temperature ranged from a low of 9.0°C to a high of 13.8°C. It averaged 10.4°C (51°F) in May, rising to an average 12.2°C (54°F) in August, and cooling to an average 10.7°C (52°F) in December. The seasonal fluctuation of ground water temperature in any well ranged from as little as 0.7°C to a high of 4.5°C. For the most part, fluctuations in temperature were least in deep wells and greatest in shallow wells. The deeper ground water ranged between 10 and 12°C, while shallower ground water reached a low of 9°C and a high near 14°C.

Stream temperatures varied more than ground water temperatures. The average stream temperature in May was 9.3°C (49°F), rising to 12.0°C (54°F) in August, and declining to 5.9° C (43°F) in December. In May and August, water entering the study area from the uplands was cooler than the stream water leaving the study area. In August, the stream temperature increased as much as 1.5°C as the stream crossed the study area. This trend was reversed in December, with the water cooling slightly as it crossed the study area. These results are similar to data reported by Snohomish County (Carroll, 1994).

Although a relationship between ground water and stream temperatures is not obtainable from our data, ground water probably moderates the extremes of surface water temperature. Ground water warms Quilceda Creek during the winter and helps cool it during the summer. Presently, the temperature of Quilceda Creek within the study area meets Class A water quality requirements (<18.0°C) and is suitable for salmonid fish.

pH

The pH of ground water averaged 6.7 and ranged from 6.1 to 7.7. Although there were seasonal differences in pH at individual wells, the average pH of all ground water samples remained at 6.7 in May, August, and December. There is a weak relationship between pH and ground water depth, with pH increasing with depth. The average pH in the nine wells less than 20 feet deep ranged from 6.2 to 6.7 while the average pH in the nine wells greater than 20 feet deep ranged from 6.8 to 7.5 (with one exception of 6.3 at a depth of 30.3 ft).

The pH of Quilceda Creek ranged from 6.8 to 7.5 with only small and inconsistent differences between seasons. The average pH of waters entering the study area was 7.2 while the average of waters leaving the study area was 7.3. In general, there was a slight downstream increase in pH. The pH of Quilceda Creek is similar to that of deeper ground water and is within the 6.5 to 8.5 range for Class A waters.

Electrical conductance

The conductance of ground water ranged from 62 to 350 µmhos/cm; all measurements were below the 700 µmhos/cm secondary drinking water standard (DOH, 1992). The average ground water conductance in May was 146 µmhos/cm, rising to 212 µmhos/cm in August and declining to 187 µmhos/cm in December. Unlike temperature and pH, there was no apparent relationship between conductance and well depth.

The conductance of Quilceda Creek ranged from a low of 65 to a high of 240 µmhos/cm. Like ground water, the stream conductance was lowest in spring (May) and winter (December), and highest in summer (August). Conductance increased as the stream passed through the study area. Stream water leaving the study area (QCMF3) averaged about 50 µmhos/cm higher than water entering at the upper end of the study area (QCMF1). Since the conductance of water entering the study area (about 100 µmhos/cm) was 50 to 100% less than the average conductance of ground water, the downstream increase in conductance is probably caused by the influx of ground water. The highest surface water conductance, most like those of ground water, were found in the small tributary to Quilceda Creek (QCRTR1 and QCRTR2). This tributary originates from ground water sources entirely within the study area.

Fecal Coliform Bacteria

Bacteria were tested for in both ground water and Quilceda Creek.

In general, ground water was clean of fecal coliform bacteria. High counts of bacteria were detected in only one of the 18 sampled wells. Initial concentrations of bacteria in well QC33B1 were 80 colony forming units (cfu)/100mL, and 250 cfu/100mL in a follow-up sample. These bacteria detections were discussed with the owner of this presently unused well. Local contamination is suspected.

Fecal coliform bacteria were found in Quilceda Creek (Table 6). In general, bacteria concentrations increased as Quilceda Creek crossed the study area. The increase in bacteria was not caused by a general contamination of ground water but must be related to surface runoff or near channel activities.

Table 6. Fecal coliform bacteria in Quilceda Creek (cfu/100mL).			
Site	May	August	December
QCRTR1	68	21	22
QCRTR2	360	330	14
QCREF1	170	120	40
QCREF2	1500J	1000	170
QCRMF1	88	110	17
QCRMF2	520	220	46
QCRMF3	400/540	220/220	53/26
J = positively identified, but the value is an estimate. /=duplicate samples.			

Because ground water input could not account for increases in fecal coliform bacteria, six additional sites were sampled along Quilceda Creek in August and December (Figure 4). The additional sites were intended to pinpoint where the bacteria increases were occurring. Four intermediate sites (FEC1 - FEC4) were sampled upgradient of station QCRMF2: one on the Middle Fork channel and three on smaller tributaries. Station FEC1 was sampled to provide additional inflow data along 67th Ave NE. Stations FEC2 through FEC4 were selected to provide information on the agricultural areas in the north half of the study area. Another station, FEC6, was located in a residential area between QCRMF2 and QCRMF3. A final station, FEC5, was selected as an intermediate site on the mainstem between QCREF1 and QCREF2 at the 132nd Street crossing.

In general results from the additional sampling were not useful. However, we found some consistency in bacteria results from the Middle Fork sites. Bacteria concentrations were relatively low entering the study area, and most of the increase in concentration occurred in the upper half of the study area, north of QCRMF2. The bacteria concentrations remained essentially unchanged between QCRMF2 and the outflow from the study area at QCRMF3. Land use north of QCRMF2 is more agriculture and less residential than land to the south.

Two channels join the Middle Fork just upstream of QCRMF2, a west and an east tributary. The west tributary drains along 51st Street, and the east tributary drains lands toward the eastern boundary of the study area. In an effort to determine if one of these channels was the major contributor of bacteria, we sampled the two tributaries and the Middle Fork just above the residential development surrounding QCRMF2. Although residential development is occurring throughout the study area, especially along the major roads, the land use north of the three intermediate sites remains largely agriculture, primarily pasture for horses and cattle. Results of this sampling were inconclusive, probably due to the seasonal differences between sampling. In August the major contributor of bacteria was the west tributary (FEC2=1300 cfu/100mL), with minor

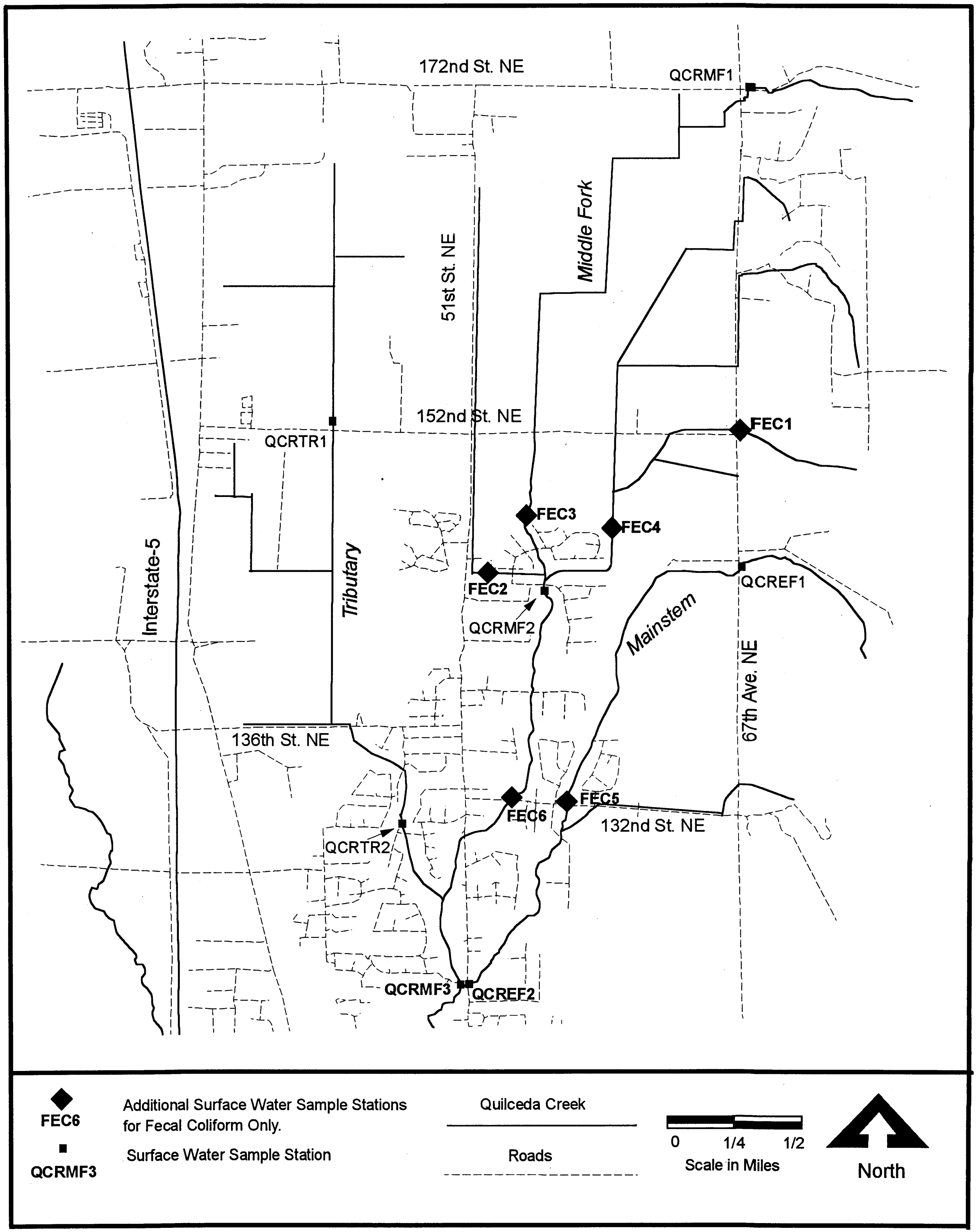


Figure 4: Quilceda Creek Fecal Coliform Sample Locations

contributions from the Middle Fork (FEC3=260 cfu/100mL) and the east tributary (FEC4=170 cfu/100mL). In December the major contributor of bacteria was the main Middle Fork channel (FEC3=110 cfu/100mL), followed by the west tributary (FEC2=40 cfu/100mL); and, as in August, very little contribution was from the east tributary (FEC4=9 cfu/100mL).

In August the mainstem bacteria count increased from 120 cfu/100mL at QCREF1 where the stream enters the study area, to 1000 cfu/100mL at QCREF2 just above the confluence of the Middle Fork. Most of this increase occurred south of the FEC5 intermediate site which had a concentration of 400 cfu/100mL. However, the reverse was noted in December. The December count at QCREF1 was 40 cfu/100mL and at QCREF2 was 170 cfu/100mL. The bacteria count at FEC5 was 160 cfu/100mL, indicating the increase occurred north or upgradient of this station.

The tributary stream, originating in the upper northwest portion of the study area, had relatively low coliform bacteria concentrations at its upper sampling site (QCRTR1) at 152nd St NE. Bacteria counts increased substantially between the upstream (QCRTR1) and downstream sites (QCRTR2).

The fecal coliform bacteria results are similar to the more extensive results collected by Snohomish County (Carroll, 1994), indicating that by the time water passes through the study area it no longer meets Class A water-quality standards. However, the source of the bacteria remains obscure, although it appears to be a non-point source.

Major Cations/Anions and Total Dissolved Solids

The major cations and anions are presented in Table 7. With the exception of chloride and total dissolved solids (TDS), only one sample was collected for these parameters from each site. Since we collected some samples in May and the remainder in August, a seasonal variation is imbedded in the results. We assumed that these chemical parameters are relatively stable with time. However, any trends apparent in the data may be spurious because of the lag time between samples. Samples for chloride and TDS were collected during each sampling event; however, only the average of the results is shown. The complete set of chloride and TDS results are shown in Appendix C.

Table 7. Major Cation and Anion concentrations in ground water and Quilceda Creek (mg/L) - Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Sulfate (SO_4), Chloride (Cl), Bicarbonate (HCO_3), and Total Dissolved Solids (TDS).								
Site	Ca	Mg	Na	K	SO_4	Cl	HCO_3	TDS
Ground Water								
QC03C1	9.5	5.1	8.6	1.1	14.7	7.4	31	82
QC03M1	15.9	5.2	12.4	1.3	19.0	10.3	122	137
QC03N1	9.1	6.3	13.5	1.2	5.4	4.3	59	111
QC04L1	14.3	7.8	5.3	1.8	20.1	4.6	76	102
QC21N1	7.7	3.9	10.9	1.6	10.5	10.1	22	96
QC27N1	32.5	8.4	8.9	4.2	26.2	9.2	121	183
QC27R1	18.5	8.6	5.6	2.3	0.5	1.8	111	135
QC28H1	17.5	9.0	5.4	2.1	6.4	9.8	34	141
QC33B1	27.7	6.1	5.9	6.4	11.0	10.1	86	158
QC33C1	20.4	5.6	5.6	5.0	17.5	5.8	62	122
QC33D1	10.1	10.0	3.7	2.5	8.3/8.3	2.1	81	110
QC33G1	42.4	11.7	5.6	3.3	23.2	12.4	156/157	222
QC33M1	7.7	3.5	9.2	13.3	11.1	4.5	42	94
QC33N1	6.7	3.1	7.6	1.5	9.1	2.5	37	85
QC33P1	25.6	7.4	7.2	5.9	27.9	5.4	110	158
QC34A1	14.5	8.2	5.5	2.0	0.8	2.8	99	119
QC34B1	ns	ns	ns	ns	ns	3.7	ns	206
QC34E1	24.8	13.0	7.8	3.5	7.0	6.2	177	228
Median	**15.9**	**7.4**	**7.2**	**2.3**	**11.0**	**5.6**	**81**	**127**
Quilceda Creek								
QCRTR1	22.1	8.6	4.6	4.0	24.6	5.2	73.9	124
QCRTR2	17.3	7.1	8.7	2.5	18.2	6.3	60.4	132
QCREF1	10.8	8.3	4.8	1.4	6.1	3.0	61.3/61.9	82
QCREF2	8.1	5.5	4.6	1.7	4.6	3.9	40.4	85
QCRMF1	9.5	6.5	4.8	1.5	4.5	3.4	151.0	94
QCRMF2	19.6	10.9	7.9	2.6	11.1	5.2	91.0	129
QCRMF3	16.5	7.8	7.5	2.4	11.0	6.3	67.3	135
ns = Not Sampled / = Duplicate Sample								

Ground water

Calcium (Ca) is the primary cation in ground water, with a median concentration of 15.9 mg/L. Ground water Ca concentrations ranged from 6.7 to 42.4 mg/L. The remaining cations are mostly accounted for by magnesium (Mg) and sodium (Na), with median concentrations of 7.4 mg/L and 7.2 mg/L, respectively. The median concentration of potassium (K) is 2.3 mg/L.

The major anion in ground water is bicarbonate (HCO_3). The bicarbonate values presented in Table 7 were not directly measured but are estimated from the alkalinity results. Alkalinity is primarily a measure of the carbon dioxide dissolved in the water. Between a pH of 6.4 and 8.3, the dissolved carbon dioxide species is predominantly bicarbonate. Samples from most of the wells had a pH greater than 6.4 (median pH was 6.7), indicating that bicarbonate is predominant. However, several wells had an average pH of 6.2-6.3. In these wells, H_2CO_3 is also important. Unlike ground water, however, the dominant dissolved carbon dioxide species in Quilceda Creek was always bicarbonate as testified by average stream pH's of greater than 7.0. For simplicity, all results are reported as bicarbonate.

Ground water bicarbonate concentrations ranged from 22 to 177 mg/L, with a median concentration of 81 mg/L. Concentrations of other anions were much lower than bicarbonate; median concentrations were 11 mg/L for sulfate (SO_4) and 5.6 mg/L for chloride (Cl). The total of the median anion and cation concentrations in ground water was about 120 mg/L, similar to the median ground water value for TDS (127 mg/L).

A slight relationship is noted between well depth and Ca, Mg, and bicarbonate concentrations, with concentrations being greater in deeper ground water. The average Ca concentration in wells less than 20 feet deep was 14.0 mg/l while the average of wells greater than 20 feet was 22.5 mg/l. Similarly the average Mg concentration in the shallower wells was 6.1 mg/L and in deeper wells was 8.2 mg/L. However, several of the higher concentrations of both Ca and Mg were in the shallower wells. The average bicarbonate of wells less than 20 feet was 54 mg/L while that in the deeper wells was 110 mg/L. TDS also increased slightly with well depth, with the average TDS for the nine wells less than 20 feet in depth between 5 and 30% lower than the average TDS for the nine deeper wells. This would be expected since Ca, Mg, and bicarbonate are major contributors to TDS.

There was no apparent difference in the concentration of Na, K, Cl or SO_4 with well depth.

Quilceda Creek

As with ground water, only one sample was collected from each stream station to represent most parameters. Based on our limited data, it appears that concentrations of most cations and anions increase as the Middle Fork of Quilceda Creek crosses the study area. Bicarbonate was an exception: concentrations were greater than those of ground water as the Middle Fork enters the study area, but declined to near ground water concentrations before exiting the study area. TDS, which represents the sum of all dissolved ions, consistently increased in the tributary, mainstem, and Middle Fork.

Chloride, which was sampled in May, August, and December, is the best example of this downstream increase. The chloride concentration in both the Middle Fork and mainstem of Quilceda Creek increased downstream (ground water contribution) exiting the study area with an average concentration similar to that of ground water. Water entering the study area at QCREF1 had an average chloride concentration of about 3 mg/L, and water entering at QCRMF1 had an average concentration of about 3.4 mg/L, both lower than the median ground water concentration of chloride (5.6 mg/L). In comparison, the chloride concentration of the tributary stream, which originates completely within the study area, was nearer the ground water concentration, ranging from 4.5 to 7.8 mg/ L.

No samples of ground water or surface water exceeded the secondary drinking water standard for chloride of 250 mg/L (DOH, 1992).

Nutrients

The nutrients investigated include nitrogen, phosphorus, and carbon.

Nitrogen

Water samples were analyzed for two forms of nitrogen, nitrate+nitrite (NO_3+NO_2 as N) and ammonium (NH_4^+ as N). Because the concentration of nitrite is usually negligible in comparison to nitrate, nitrate + nitrite was assumed to be equivalent to nitrate alone and is referred to simply as nitrate in the remainder of this report. Nitrate and ammonium results are summarized in Table 8.

Table 8. Nitrate+Nitrite (NO_3+NO_2 as N) and Ammonium (NH_4^+ as N) concentrations in ground water and Quilceda Creek (mg/L).						
	NO_3+NO_2	NH_4^+	NO_3+NO_2	NH_4^+	NO_3+NO_2	NH_4^+
Site	May		August		December	
Ground Water						
QC03C1	4.86/4.90	0.011/0.011	4.52	0.012	3.59	0.01U
QC03M1	7.02	0.025	8.97	0.014	4.7	0.01U
QC03N1	5.04	0.01U	5.06	0.01U	5.32	0.01U
QC04L1	0.50	0.034	0.21	0.010	0.68	0.03
QC21N1	9.77	0.015	5.22	0.01U	5.38	0.010
QC27N1	0.03	0.221	0.03	0.353	0.03	0.195
QC27R1	0.01U	0.247	0.01U	0.343	0.01U	0.245
QC28H1	13.7	0.010	12.3	0.016	11.8	0.01U
QC33B1	0.08	0.05	1.97	0.08	0.07	0.025
QC33C1	4.05	0.021	1.84	0.025	1.99	0.013
QC33D1	0.03	0.018	0.01U	0.005	0.03	0.01U
QC33G1	0.01U	0.084	0.01U	0.137	0.01U	0.086
QC33M1	3.29	0.01U	4.99	0.035	5.41	0.01U
QC33N1	1.00	0.01U	1.35	0.01U	0.56	0.01U
QC33P1	1.83	0.017	1.46/1.47	0.012/0.01U	0.89/0.89	0.060/0.066
QC34A1	0.01U	0.070	0.01	0.402	0.04	0.035
QC34B1	0.01U	0.069	ns	ns	1.19	0.01U
QC34E1	0.05	0.504	0.09	0.560	0.03	0.476
Median	**0.75**	**0.023**	**1.46**	**0.016**	**0.78**	**0.011**
Quilceda Creek						
QCRTR1	1.49	0.021	0.16	0.10	1.46	0.081
QCRTR2	1.07	0.022	1.42	0.027	1.11	0.091
QCREF1	0.34	0.017	0.39	0.079	0.73	0.026
QCREF2	0.57	0.030	0.60	0.028	0.94	0.041
QRMF1	0.75	0.013	0.61	0.018	1.37	0.021
QCRMF2	0.01U	0.064	0.31	0.013	1.08	0.091
QCRMF3	0.92/0.92	0.043/0.044	1.13/1.16	0.030/0.038	1.27/1.26	0.095/0.095

U=not detected above the value shown.
ns = not sampled.
/=duplicate samples.

Nitrate+nitrite concentrations in ground water ranged from <0.01 to 13.7 mg/L. Median concentrations were 0.75, 1.46, and 0.78 mg/L in May, August, and December, respectively. Ammonium concentrations ranged from <0.01 to 0.56 mg/L. Median concentrations were 0.023, 0.016, and 0.011 mg/L in May, August, and December, respectively. Greatest concentrations of both nitrate and ammonium occurred during August.

Nitrate concentrations in half of the wells consistently exceeded 1.0 mg/L, a value often used as the transition point between natural concentrations and man-caused contamination

(Dion, et al., 1994, Turney, et al., 1995). The maximum nitrate concentrations were detected in well QC28H1 located immediately down gradient from a poultry farm. Nitrate concentrations in this well exceeded the 10 mg/L drinking water standard (DOH, 1992). With that exception, there is no apparent relationship between nitrate concentrations and (1) well locations within the study area or (2) well depth.

Nitrate concentrations in Quilceda Creek were similar to median concentrations in ground water, ranging from <0.01 mg/L at QCRMF2 to 1.49 mg/L at QCRTR1. Concentrations generally increased in a downstream direction, although changes were not large and increases were not consistent. Greatest concentrations were found in the tributary stream draining agricultural lands in the northern half of the study area. Five of the six samples collected from the tributary had concentrations greater than 1.0 mg/L (range 0.16 to 1.49 mg/L).

Ammonium in stream water ranged over an order of magnitude, from about 0.01 to 0.10 mg/L. Nitrate is the more prevalent form of nitrogen in both ground and surface water. In the presence of oxygen, ammonium is rapidly transformed to nitrate by nitrifying bacteria. Unless contaminated by human activities, the ammonium concentration in natural waters is generally low.

Phosphorus

Water samples were analyzed for total phosphorus and dissolved ortho-phosphate (Table 9). Although total phosphorus was sampled in May, August, and December, ortho-phosphate was sampled only in May to determine its contribution to the total.

Table 9. Dissolved ortho-phosphate as P and total phosphorus as P concentrations in ground water and Quilceda Creek (mg/L).				
	Ortho-Phosphate	Total Phosphorus		
Site	May	May	August	December
Ground Water				
QC03C1	0.01U	0.01U/0.01U	0.061	0.046
QC03M1	0.01U	0.04	0.071	0.054
QC03N1	0.014	0.017	0.03	0.03
QC04L1	0.01U	0.01U	0.01U	0.039
QC21N1	0.01U	0.01U	0.01U	0.01U
QC27N1	0.17	0.107	0.051	0.114
QC27R1	0.462	0.512	0.676	0.5
QC28H1	0.01U	0.01U	0.01U	0.01U
QC33B1	0.052	0.06	0.573/0.567	0.173
QC33C1	0.01U	0.01U	0.01U	0.044
QC33D1	0.01U	0.014	0.01U	0.017
QC33G1	0.11	0.139	0.162	0.144
QC33M1	0.01U	0.01U	0.01U	0.012
QC33N1	0.01U	0.01U	0.01U	0.01U
QC33P1	0.017	0.02	0.01U/0.01U	0.051/0.062
QC34A1	0.099	0.114	0.38	0.058
QC34B1	0.019	0.031	ns	0.036
QC34E1	0.254	0.205	0.174	0.174
Median	**0.01**	**0.018**	**0.030**	**0.045**
Quilceda Creek				
QCRTR1	0.01U	0.019	0.196	0.049
QCRTR2	0.01U	0.033	0.011	0.047
QCREF1	0.031	0.054	0.173	0.062
QCREF2	0.033	0.082	0.125	0.066
QRMF1	0.123	0.155	0.370/0.371	0.081
QCRMF2	0.037	0.076	0.104	0.091
QCRMF3	0.037	0.105/0.108	0.188/0.194	0.098/0.095
U = not detected above the value shown. ns = not sampled. /=duplicate samples.				

Total phosphorus concentrations in ground water ranged from <0.01 to 0.676 mg/L. Median concentrations were 0.018, 0.03, and 0.045 mg/L in May, August, and December, respectively. Ortho-phosphate concentrations ranged from <0.01 to 0.46 mg/L. The median concentration was about 0.01 mg/L. Phosphorus concentrations in ground water are relatively low when compared to stream concentrations.

With the exception of the tributary stream, total phosphorus concentrations in Quilceda Creek were two to ten times greater than those in ground water. Concentrations in the mainstem ranged from 0.081 to 0.098 mg/L, and concentrations in the Middle Fork ranged from 0.104 to 0.371 mg/L. Concentrations in the small tributary were generally lower than in the remainder of the stream, most closely resembling the concentrations in ground water.

Higher concentrations of ortho-phosphate and total phosphorus in the stream, than in ground water, indicate that factors other than a contribution from ground water are controlling phosphorus. This is especially noticeable for ortho-phosphate which is barely detectable in ground water. During May and August, the total phosphorus concentration decreases downstream. Although this may be partially caused by ground water dilution, phosphorus is an important plant nutrient and is rapidly removed from the water column, especially by algae. This is a more likely explanation for the downstream decline in total phosphorus, especially for the large decrease that occurred in the Middle Fork during May and August (growing season).

TOC

Total organic carbon (TOC) results are shown in Table 10.

Table 10. Total organic carbon concentrations in ground water and Quilceda Creek (mg/L).

Site	May	August	December
Ground Water			
QC03C1	1U/1U	1U	1U
QC03M1	1U	1.1	1U
QC03N1	1U	1U	1U
QC04L1	1.8	1.6	2.3
QC21N1	1U	1U	1U
QC27N1	11.4	9.2	20.1
QC27R1	1.8	2.0/1.9	2.0
QC28H1	1U	1U	1U
QC33B1	2.1	8.6	3.9
QC33C1	3.3	2.2	5.3
QC33D1	2.1	1.2	2.2
QC33G1	2.3	2.0	2.2
QC33M1	1.3	1.2	1.9
QC33N1	1U	1U	1U
QC33P1	1.6	1.4/1.5	2.0/2.0
QC34A1	2.6	2.4	3.9
QC34B1	13.4	ns	4.7
QC34E1	8.7	8.0	9.4
Median	**1.8**	**1.5**	**2.1**
Quilceda Creek			
QCRTR1	3.5	3.9	5.6
QCRTR2	3.6	2.2	4.4
QCREF1	9.1	3.8	10.1
QCREF2	9.0	4.2	9.7
QRMF1	3.2	1.7/1.7	4.7
QCRMF2	7.9	5.5	9.1
QCRMF3	6.2/6.2	3.5/3.5	7.1/7.3

U = not detected above the value shown.
ns = not sampled.
/=duplicate samples.

Ground water TOC concentrations ranged from <1.0 to 20.1 mg/L. Although median concentrations were low (1.8, 1.5, and 2.1 mg/L in May, August, and December, respectively) the variation between wells was large. A significant seasonal variation is not apparent. TOC concentrations were generally greater in Quilceda Creek than in ground water; however, they remained within the range found for ground water. There was either no change (mainstem) or a slight increase in concentrations (Middle Fork) as the stream water flowed through the study area. Since concentrations were generally higher in the stream than in ground water, and increased downstream, the ground water contribution had little impact on TOC.

Metals

Metal concentrations for cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc are presented in Table 11. Cadmium, chromium, and lead were not detected at any site above their respective detection limits. Copper and nickel were not detected above their respective detection limits at any Quilceda Creek site, and only detected in a few wells. Only iron, manganese, and zinc were detected with any frequency. Iron and manganese are natural derivatives of rock weathering and are often found in association.

Table 11. Metals concentrations in ground water and Quilceda Creek (ug/L).

Site	Cadmium	Chromium	Copper	Lead	Iron	Manganese	Nickel	Zinc
Ground Water								
QC03C1	3.0U	5.0U	4.0U	20U	1810/1260	59.4/40.5	10U	6P/5.8P
QC03M1	3.0U	5.0U	4.0U	20U	1430	38.1	10U	17
QC03N1	3.0U	5.8P	4.0U	20U	128	7.7P	10U	21
QC04L1	3.0U	5.0U	4.0U	20U	1650	128	14P	223
QC21N1	3.0U	5.0U	31P	20U	11P	1U	10U	14P
QC27N1	3.0U	5.0U	4.0P	20U	22700	498	10U	104
QC27R1	3.0U	5.0U	4.0U	20U	733	174	10U	36P
QC28H1	3.0U	5.0U	4.0U	20U	12P	154	10U	6.5P
QC33B1	3.0U	5.0U	4.0U	20U	570	405	10U	14P
QC33C1	3.0U	5.0U	4.0U	20U	280	32.3	10U	28P
QC33D1	3.0U	5.0U	4.0U	20U	427	62	10U	54.9
QC33G1	3.0U	5.0U	4.0U	20U	3250	397	10U	4.3P
QC33M1	3.0U	5.0U	4.0U	20U	32P	5.7	10U	7P
QC33N1	3.0U	5.0U	4.0U	20U	957	994	10U	60.7
QC33P1	3.0U	5.0U	4.0U	20U	18P	55.7	10U	20P
QC34A1	3.0U	5.0U	4.0U	20U	198	122	10U	15P
QC34B1	3.0U	5.0U	7.4P	20U	883	190	42P	16P
QC34E1	3.0U	5.0U	4.0U	20U	6900	570	10U	11P
Median					**650**	**125**		**16**
Quilceda Creek								
QCRTR1	3.0U	5.0U	4.0U	20U	467	172	10U	4U
QCRTR2	3.0U	5.0U	4.0U	20U	684	141	10U	6.1P
QCREF1	3.0U	5.0U	4.0U	20U	342	35.5	10U	8.5P
QCREF2	3.0U	5.0U	4.0U	20U	963	83.7	10U	5.9P
QCRMF1	3.0U	5.0U	4.0U	20U	99P	14.2	10U	4U
QCRMF2	3.0U	5.0U	4.0U	20U	1190	124	10U	4.6P
QCRMF3	3.0U	5.0U	4.0U	20U	1220/1250	147/148	10U	4.3P/6.6P

U = Not detected at or above the value shown.
P = Above the instrument detection limit but below the minimum quantitation limit.
/ = Duplicate Sample

Iron concentration in ground water ranged from 11 to 22,700 ug/L, with a median concentration of about 650 ug/L. Eleven of the wells (61%) had iron concentrations that exceeded the 300 ug/L secondary drinking water standard (DOH, 1992). Iron concentration in the tributary stream, which originates completely within the study area, was similar to the median concentration in ground water. However, the median ground water concentration was two to six times greater than the concentration of surface water entering the study area at QCREF1 or QCRMF1. Iron concentration of the mainstem increased three-fold as it crossed the study area. Likewise, iron concentration in the Middle Fork increased ten-fold as it crossed the study area. Ground water is responsible for increased iron in Quilceda Creek.

Manganese concentration in ground water ranged from the detection limit (1 ug/L) to 994 ug/L with a median concentration of about 125 ug/L. Thirteen wells (72%) had manganese concentrations greater than the 540 ug/L secondary drinking water standard (DOH, 1992). Like iron, manganese concentration in the tributary stream was similar to the median concentration in ground water; and concentrations in surface water entering the site were significantly less than the median for ground water. Also like iron concentrations, manganese increased two to ten fold as Quilceda Creek crossed the study area.

Zinc in ground water ranged from a concentration of 4.3 to 223 ug/L, with a median concentration of 16 ug/L. Although many of the wells had galvanized pipe leading into the well, none of the high concentration zinc samples were collected through these pipes. In most cases, we used our stainless steel submersible pump for purging and sampling. The drinking water standard for zinc is 5,000 ug/L (DOH, 1992). Zinc concentration in Quilceda Creek was only one-quarter to one-half the median concentration in ground water and did not appreciably increase as it crossed the study area.

There was no apparent relationship between well depth and concentration of iron, manganese, or zinc; a few of the highest concentrations were in the shallower wells.

Volatile Organics

We tested for volatile organic compounds in seven wells. A list of compounds tested is included as Appendix D. No volatile organic compounds were detected in five of the seven wells. Benzene and toluene were detected in well QC33G1 at estimated concentrations of 0.23 and 0.52 ug/L, respectively. The detection limit for both compounds was 1.0 ug/L, thus the validity of the results is questionable. Acetone and chloroform were detected in well QC03M1. Acetone was detected at an estimated concentration of 9.8 ug/L with a quantification limit of 10.0 ug/L. Chloroform was 1.1 ug/L with a quantification limit of 1.0 ug/L. Acetone used for cleaning bailers is probably responsible for the single acetone detection.

Pesticides

We tested for pesticides in five wells. A list of 131 pesticides tested for is included as Appendix E. Pesticides were detected in two wells. Atrazine was detected at an estimated concentration of 0.065 ug/L in well QC28H1. It was also detected in a follow-up sample at a concentration of 0.088 ug/L. Atrazine is a common herbicide used to control weeds on a wide variety of food and non-food crops. The maximum contaminant limit for atrazine in drinking water is 3.0 ug/L. (248-54 WAC)

Terbacil was detected at an estimated concentration of 0.039 ug/L in well QC33P1. It was detected in a follow-up sample at an estimated concentration of 0.037 ug/L. Atrazine was also detected in this follow-up sample at an estimated concentration of 0.006 ug/L. Terbacil is a herbicide used for the selective control of annual and perennial weeds in crops, including strawberries. It is persistent and mobile in soil and has the potential to get into ground water. The Lifetime Health Advisory set by the Environmental Protection Agency (EPA) for Terbacil is 90 ug/L, much greater than the level detected in this well (EPA 1987).

Dissolved-Solids Loads

We calculated the dissolved load of nitrogen, phosphorus, TDS, TOC, and chloride carried by the stream (kg/day) at the time of each sampling event. The load for each parameter was determined by multiplying its concentration by the streamflow at the time of sampling (and an appropriate conversion factor). The dissolved loads for each chemical parameter are presented in Appendix F. We did not estimate the dissolved load of parameters analyzed from only one sampling event.

The change in the dissolved load (hereafter referred to as the DELTA Load) as the stream crosses the study area is represented by the difference between the load entering (surface water inflow) and the load exiting the study area (surface water outflow). This difference is a combination of changes resulting from instream processes and the contribution from ground water.

We estimated the contribution of ground water to the total dissolved load of Quilceda Creek by multiplying the median ground water concentration by the increase in streamflow across the study area. The estimate of ground water loading, expressed as a percentage of the DELTA Load, indicates the relative significance of ground water input to the total change in dissolved load (Table 12). Where ground water is the primary control over the dissolved load, the magnitude of the DELTA Load and the estimated ground water load will be similar, and this percentage will be large.

Although the numbers are rough, we believe that ground water exerts a primary control over changes in stream load when the percentage is greater than 50% (estimate of ground water loading is greater than one-half the DELTA Load). On the other hand, where the percentage is less than 50% (estimate of ground water loading makes up less than one-half the DELTA Load) then changes in the dissolved load are not controlled by ground water but rather by instream processes.

Table 12. Relative importance of ground water in controlling changes in the dissolved load of selected parameters.

	TDS	TOC	Nitrate	Ammonium	Phosphorus	Chloride
% G W	90%	22%	75%	32%	31%	86%

Table 12 indicates that ground water is an important contributor to the dissolved load of TDS, nitrate, and chloride, but only a minor contributor to the load of TOC, ammonium, and phosphorus. Thus, an increase in the concentration of either nitrate or chloride in ground water will likely lead to a similar increase in their respective concentrations in stream water. Although the same can be said for TDS, the meaning is not as clear because total dissolved solids is a compilation of all dissolved substances in the water and not a single parameter.

Conclusions

- The depth to ground water is shallow, ranging from as little as one foot below the ground surface in the northern part of the study area, to 29 feet below ground in the southern part. This shallow water table supports the few remaining wetlands and is the reason for the many ditches constructed to drain the agricultural areas. Future development must contend with this high water table. For instance, the shallow ground water will make it difficult (costly) to construct retention ponds. Deep ponds will fill with ground water, losing their capacity to store surface runoff. Shallow ponds will need to cover extensive areas to store the necessary runoff volumes above the water table.

- Ground water within the study area is a major contributor to streamflow of Quilceda Creek, accounting for 46 to 60% of the streamflow during times when surface runoff is absent (not raining). Any development that decreases ground water recharge or storage capacity of the aquifer will decrease the flow in Quilceda Creek, especially during periods of no rainfall and lowest flows.

- Although ground water interacts with Quilceda Creek throughout its length, infiltration of precipitation and aquifer recharge is greater than aquifer discharge to the stream in the northern portion of the study area, and discharge to the stream is greater than aquifer recharge in the southern portion. Rainfall is stored in the northern portion, moves via ground water to the south, and discharges to the stream where it is incised in narrow canyons. Activities in the northern agricultural portion, such as additional ditching or paving (without adequate storage), will decrease aquifer recharge, increase winter stormflow, and decrease summer low flows.

- While surface water fails to meet Class A water quality for fecal coliform bacteria, ground water, in general, is free of coliform bacteria. Bacteria are probably from non-point sources near the stream channel. If ground water is contaminated, the contamination is occurring very near the stream channel.

- Dissolved iron and manganese in ground water exceed the secondary drinking water standards. Ground water is the source of relatively high concentrations of these metals found in Quilceda Creek. Iron and magnesium occur naturally in the glacial deposits underlying the area.

- Ground water is an important source of TDS, nitrate, and chloride, but only a minor source of TOC, ammonium, and phosphorus. Thus, an increase in either nitrate or chloride in ground water will likely lead to a similar increase in stream water.

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Appendices

Appendix A. Target Analytes, Test Methods, and Detection Limits.

Analytes	Method	Reference	Detection Limit
Field Parameters			
Water Level	Slope Indicator Well Probe	NA	0.01 feet
Specific Conductance	Beckman Conductivity Bridge	NA	10 umhos/cm
pH	Orion pH Meter	NA	0.1 Std. Units
Temperature C	Orion pH Meter	NA	0.1 C
Conventionals			
Ammonium	#350.1	EPA, 1983	0.01 mg/L
Chloride	#429	APHA, 1985	0.1 mg/L
Nitrate/Nitrite	#353.2	EPA, 1983	0.01 mg/L
Total Phosphorus	#365.3	EPA, 1983	0.01 mg/L
Orthophosphate	#365.3	EPA, 1983	0.01 mg/L
Total Dissolved Solids	#160.1	EPA, 1983	1.0 mg/L
Total Organic Carbon	#505	APHA, 1985	0.1 mg/L
Bacteriology			
Fecal Coliform	#909C	APHA,1985	1#/100 mL
Major Cations and Anions			
Calcium	#200.7	EPA, 1983	0.01 mg/L
Magnesium	#200.7	EPA, 1983	0.03 mg/L
Sodium	#200.7	EPA, 1983	0.03 mg/L
Bicarbonate	#406C	APHA, 1985	1 mg/L
Carbonate	#406C	APHA, 1985	1 mg/L
Sulfide	#429	APHA, 1985	1.05 mg/L
Potassium	#ICAP	EPA, 1983	0.4 mg/L
Metals			
Cadmium	#ICAP	EPA, 1983	0.002 mg/L
Chromium	#ICAP	EPA, 1983	0.005 mg/L
Copper	#ICAP	EPA, 1983	0.003 mg/L
Lead	#ICAP	EPA, 1983	0.02 mg/L
Iron	#ICAP	EPA, 1983	0.01 mg/L
Manganese	#ICAP	EPA, 1983	0.001 mg/L
Nickel	#ICAP	EPA, 1983	0.01 mg/L
Zinc	#ICAP	EPA, 1983	0.004 mg/L
Volatile Organics	#524	EPA, 1984	1-5 ug/L
Pesticides	See Appendix E.		

Appendix B. Quality Assurance Review

Analyses were conducted at the Ecology/EPA Manchester Laboratory. The qualitative and quantitative accuracy, validity, and usefulness of data were reviewed by Manchester Laboratory staff. Laboratory quality control (QC) followed standard Manchester guidelines and included laboratory blanks and duplicates, and spiked samples. All data are considered usable with the following qualifications. In August and December, some of the TDS samples were analyzed one day over the holding time. The holding times for TDS analyses are set to prevent minimal biodegradation from becoming a significant factor affecting the results. All samples were relatively clear. Therefore it's considered unlikely that the extra day affected the results.

In addition to laboratory QC samples, field quality assurance (QA) samples consisted of duplicate samples for both ground water and surface water during each sample event. A duplicate sample consisted of an identical sample submitted to the laboratory with different sample identification. Duplicate samples were used to calculate the relative percent difference. The relative percent difference (RPD) was used to estimate analytical precision. The RPD is the ratio of the difference and the mean of duplicate (or replicate) samples expressed as a percentage. Quality assurance results are shown in Table B1.

In general, the quality of the results are good. Relative percent differences were generally less than 15%. Duplicate samples for fecal coliform were the exception, consistently exceeding the 15%. This may be due to field procedures. Some of the fecal coliform sample bottles were overfilled. This can interfere with the analytical procedure and result in lower bacteria counts. This could explain the high RPD% for some of the duplicate samples.

Appendix C1. Chloride concentrations in ground water and Quilceda Creek (mg/L).			
Site	May	August	December
Ground Water			
QC03C1	9.8/8.7	8.7	4.5
QC03M1	10.7	12.0	8.3
QC03N1	3.9	4.6	4.5
QC04L1	3.9	3.5	6.5
QC21N1	13.1	9.2	8.2
QC27N1	9.7	9.3	8.7
QC27R1	1.9	1.8	1.8
QC28H1	10.3	9.9	9.2
QC33B1	9.8	13.5	7.1
QC33C1	6.3	6.6	4.5
QC33D1	1.9	2.1	2.3
QC33G1	12.0	12.8	12.4
QC33M1	4.3	4.6	4.6
QC33N1	2.1	3.2	2.3
QC33P1	6.0	5.5/5.5	4.8/4.8
QC34A1	2.1	2.0	4.2
QC34B1	4.8	ns	2.7
QC34E1	6.4	6.0	6.2
Median	**6.1**	**6.0**	**4.7**
Quilceda Creek			
QCRTR1	4.9	6.3	4.5
QCRTR2	5.6	7.8	5.4
QCREF1	2.9	2.6	3.4
QCREF2	3.5	4.2	3.9
QRMF1	3.5	3.0	3.8
QCRMF2	4.5	5.9	5.2
QCRMF3	5.6/5.6	7.7/7.8	5.8/5.7
ns = not sampled. /=duplicate samples.			

Appendix C2. Total dissolved solids concentrations in ground water and Quilceda Creek (mg/L).

Site	May	August	December
Ground Water			
QC03C1	97/98	101	49
QC03M1	148	154	108
QC03N1	111	122	100
QC04L1	96	130	81
QC21N1	124	95	68
QC27N1	209	180	160
QC27R1	145	142	119
QC28H1	151	152	120
QC33B1	194	152	128
QC33C1	138	136	92
QC33D1	131	109	89
QC33G1	230	234	203
QC33M1	97	114	71
QC33N1	119	81	56
QC33P1	169	159/160	141/148
QC34A1	127	124	105
QC34B1	312	ns	101
QC34E1	246	233	205
Median	**142**	**136**	**103**
Quilceda Creek			
QCRTR1	110	143	118
QCRTR2	131	120	146
QCREF1	71	96	80
QCREF2	84	104	66
QRMF1	88	109	86
QCRMF2	115	146	127
QCRMF3	129/131	144/146	130/132

ns = not sampled.
/=duplicate samples.

Appendix D. Volatile Organic Analysis.

Volatile Organics	Method	Quantification Limit (µg/L)
Dichlorodifluoromethane	SW8260	1.0
Chloromethane	SW8260	1.0
Vinyl Chloride	SW8260	1.0
Bromomethane	SW8260	1.0
Chloroethane	SW8260	1.0
Trichlorofluoromethane	SW8260	1.0
Acetone	SW8260	10.0
1,1-Dichloroethene	SW8260	1.0
Carbon Disulfide	SW8260	1.0
Methylene Chloride	SW8260	1.0
Trans-1,2-Dichloroethene	SW8260	1.0
1,1-Dichloroethane	SW8260	1.0
2-Butanone	SW8260	2.0
Cis-1,2-Dichloroethene	SW8260	1.0
2,2-Dichloropropane	SW8260	1.0
Bromochloromethane	SW8260	1.0
Chloroform	SW8260	1.0
1,1,1-Trichloroethane	SW8260	1.0
1,1-Dichloropropene	SW8260	1.0
Carbon Tetrachloride	SW8260	1.0
1,2-Dichloroethane	SW8260	1.0
Benzene	SW8260	1.0
Trichloroethene	SW8260	1.0
1,2-Dichloropropane	SW8260	1.0
Dibromomethane	SW8260	1.0
Bromodichloromethane	SW8260	1.0
Cis-1,3-Dichloropropene	SW8260	1.1
4-Methyl-2-Pentanone	SW8260	1.0
Toluene	SW8260	1.0
Trans-1,3-Dichloropropene	SW8260	0.94
1,1,2-Trichloroethane	SW8260	1.0
1,3-Dichloropropane	SW8260	1.0
2-Hexanone	SW8260	1.0
Tetrachloroethene	SW8260	1.0
Dibromochloromethane	SW8260	1.0
1,2-Dibromoethane (EDB)	SW8260	1.0
Chlorobenzene	SW8260	1.0
Ethane, 1,1,1,2-Tetrachloro-	SW8260	1.0
Ethylbenzene	SW8260	1.0
m & p-Xylene	SW8260	2.0
o-Xylene	SW8260	1.0
Total Xylenes	SW8260	3.0
Benzene, Ethenyl-(Styrene)	SW8260	1.0
Bromoform	SW8260	1.0
Isopropylbenzene (Cumene)	SW8260	1.0
Ethane, 1,1,2,2-Tetrachloro-	SW8260	1.0
1,2,3-Trichloropropane	SW8260	1.0
Bromobenzene	SW8260	1.0
n-Propylbenzene	SW8260	1.0
2-Chlorotoluene	SW8260	1.0
1,3,5-Trimethylbenzene	SW8260	1.0
4-Chlorotoluene	SW8260	1.0
Tert-Butylbenzene	SW8260	1.0
1,2,4-Trimethylbenzene	SW8260	1.0
Sec-Butylbenzene	SW8260	1.0

Appendix D. Continued.

Volatile Organics	Method	Quantification Limit (µg/L)
p-Isopropyltoluene	SW8260	1.0
1,3-Dichlorobenzene	SW8260	1.0
1,4-Dichlorobenzene	SW8260	1.0
Butylbenzene	SW8260	1.0
1,2-Dichlorobenzene	SW8260	1.0
1,2-Dibromo-3-Chloropropane	SW8260	5.0
1,2,4-Trichlorobenzene	SW8260	5.0
Hexachlorobutadiene	SW8260	1.0
Naphthalene	SW8260	10.0
1,2,3-Trichlorobenzene	SW8260	5.0

Appendix E. Target pesticides.

Pesticide	Method	Quantification Limit (µg/L)
1,2-Dibromo-3-Chloropropane (DBCP)	EPA 504	0.02
1,2-Dibromoethane (EDB)	EPA 504	0.02
1,2-Dichloropropane	EPA 846	1.0
1-Naphthol	EPA 531.1	1.0
2,3,4,5-Tetrachlorophenol	EPA 615	0.02
2,4,5-T	EPA 615	0.01
2,4,5-TB	EPA 615	0.01
2,4,5-TP (Silvex)	EPA 615	0.01
2,4,5-Trichlorophenol	EPA 615	0.02
2,4,6-Trichlorophenol	EPA 615	0.02
2,4-D	EPA 615	0.03
2,4-DB	EPA 615	0.06
3,5-Dichlorobenzoic Acid	EPA 615	0.03
3-Hydroxycarbofuran	EPA 531.1	0.50
4-Nitrophenol	EPA 615	0.07
5-Hydroxydicamba	EPA 615	0.02
Abate (Temephos)	EPA 1618	0.75
Acifluorfen (Blazer)	EPA 615	0.03
Alachlor	EPA 1618-N	0.20
Aldicarb	EPA 531.1	1.0
Aldicarb Sulfone	EPA 531.1	1.0
Aldicarb Sulfoxide	EPA 531.1	2.0
Ametryn	EPA 1618-N	0.08
Atraton	EPA 1618-N	0.25
Atrazine	EPA 1618-N	0.08
Azinphos Ethyl	EPA 1618	0.13
Azinphos Methyl (Guthion)	EPA 1618	0.15
Baygon (Propoxur)	EPA 531.1	1.0
Benefin	EPA 1618-N	0.13
Bentazon	EPA 615	0.11
Bolstar (Sulprofos)	EPA 1618	0.06
Bromacil	EPA 1618-N	0.50
Bromoxynil	EPA 615	0.01
Butachlor	EPA 1618-N	0.29
Butifos (DEF)	EPA 1618	0.12
Butylate	EPA 1618-N	0.13
Carbaryl	EPA 531.1	2.0
Carbofuran	EPA 531.1	2.0
Carbophenothion	EPA 1618	0.08
Carboxin	EPA 1618-N	0.92
Chloramben	EPA 615	0.02
Chlorothalonil (Daconil)	EPA 1618-N	0.20
Chlorpropham	EPA 1618-N	0.42
Chlorpyrifos	EPA 1618	0.06
Cis-1,3-Dichloropropene	EPA 846	1.0
Coumaphos	EPA 1618	0.10
Cyanazine	EPA 1618	0.10
Cycloate	EPA 1618-N	0.13
Dacthal (DCPA)	EPA 615	0.01
Dalapon (DPA)	EPA 615	0.05
Demeton-O	EPA 1618	0.05
Demeton-S	EPA 1618	0.06
Di-allate (Avadex)	EPA 1618	0.30
Diazinon	EPA 1618	0.07
Dicamba	EPA 615	0.01

Appendix E. Continued.

Pesticide	Method	Quantification Limit (µg/L)
Dichlobenil	EPA 1618-N	0.10
Dichlorprop	EPA 615	0.03
Dichlorvos (DDVP)	EPA 1618	0.07
Diclofop Methyl	EPA 615	0.06
Dimethoate	EPA 1618	0.06
Dioxathion	EPA 1618	0.13
Diphenamid	EPA 1618-N	0.25
Disulfoton (Di-Syston)	EPA 1618	0.05
Diuron	EPA 1618	0.10
EPN	EPA 1618	0.08
Eptam	EPA 1618-N	0.13
Ethalfluralin (Sonalan)	EPA 1618-N	0.13
Ethion	EPA 1618	0.06
Ethoprop	EPA 1618	0.07
Fenamiphos	EPA 1618	0.12
Fenarimol	EPA 1618-N	0.25
Fenitrothion	EPA 1618	0.06
Fensulfothion	EPA 1618	0.08
Fenthion	EPA 1618	0.06
Fenvalerate	EPA 1618	0.31
Fluridone	EPA 1618-N	0.67
Fonofos	EPA 1618	0.05
Hexazinone	EPA 1618-N	0.13
Imidan	EPA 1618	0.09
Ioxynil	EPA 615	0.01
MCPA	EPA 615	1.7
MCPP	EPA 615	1.7
MGK264	EPA 1618-N	0.59
Malathion	EPA 1618	0.07
Metalaxyl	EPA1618	0.50
Methiocarb	EPA 531.1	1.0
Methomyl	EPA 531.1	1.0
Methyl Chlorpyrifos	EPA 1618	0.06
Methyl Paraoxon	EPA 1618	0.15
Methyl Parathion	EPA 1618	0.06
Metolachlor	EPA 1618-N	0.25
Metribuzin	EPA 1618-N	0.08
Mevinphos	EPA 1618	0.08
Molinate	EPA 1618-N	0.22
Napropamide	EPA 1618-N	0.25
Norflurazon	EPA 1618-N	0.13
Oxamyl (Vydate)	EPA 531.1	2.0
Oxyfluorfen	EPA 1618-N	0.22
Parathion	EPA 1618	0.07
Pebulate	EPA 1618-N	0.20
Pendimethalin	EPA 1618-N	0.13
Pentachlorophenol	EPA 615	0.004
Permethrin	EPA 1618	0.16
Phenothrin	EPA1618	0.16
Phorate	EPA 1618	0.06
Phosphamidan	EPA 1618	0.20
Picloram	EPA 615	0.02
Profluralin	EPA 1618	0.20
Prometon (Pramitol 5p)	EPA 1618-N	0.08

Appendix E. Continued.

Pesticide	Method	Quantification Limit (µg/L)
Prometryn	EPA 1618-N	0.08
Pronamide (Kerb)	EPA 1618-N	0.25
Propachlor (Ramrod)	EPA 1618-N	0.17
Propargite	EPA 1618	0.16
Propazine	EPA 1618-N	0.08
Propetamphos	EPA 1618	0.17
Resmethrin	EPA 1618	0.16
Ronnel	EPA 1618	0.06
Simazine	EPA 1618-N	0.08
Sulfotepp	EPA 1618	0.05
Tebuthiuron	EPA 1618-N	0.08
Terbacil	EPA 1618-N	0.42
Terbutryn (Igran)	EPA 1618-N	0.08
Tetrachlorvinphos (Gardona)	EPA 1618	0.17
Trans-1,3-Dichloropropene	EPA 846	1.0
Treflan (Trifluralin)	EPA 1618-N	0.13
Triadimefon	EPA 1618-N	0.22
Triallate	EPA 1618-N	0.22
Tributylphosphorotrithioite(Folex),(Merphos)	EPA 1618	0.13
Trichlopyr (Garlon)	EPA 615	0.03
Vernolate	EPA 1618-N	0.13
Xylene, Total	EPA 846	1.0

Appendix F1. The nitrate as N load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.			
	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	1,997	2,004	18,042
Outflow	4,045	3,671	34,503
DELTA Load = Outflow-Inflow.	2,048	1,667	16,461
Direct estimate of ground water contribution [1]	918	1,429	9,352
Direct estimate/DELTA Load.	45%	86%	57%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	1,799	1,343	22,461
Outflow	12,832	11,060	67,831
DELTA Load = Outflow-Inflow.	11,033	9,717	45,370
Direct estimate of ground water contribution [1]	8,626	11,076	29,202
Direct estimate/DELTA Load.	88%	86%	64%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	3,796	3,347	40,503
Outflow	16,877	14,731	102,334
DELTA Load = Outflow-Inflow.	13,081	11,384	61,831
Direct estimate of ground water contribution [1]	9,544	12,505	38,554
Direct estimate/DELTA Load.	73%	90%	62%
Inflow= streamflow into study area times nitrate-N concentration of inflow sample. Outflow = streamflow out of study area times nitrate-N concentration of outflow sample. [1] estimated ground water flow times the median nitrate-N concentration of ground water samples.			

Appendix F2. The ammonium as N load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.			
	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	100	406	643
Outflow	213	171	1505
DELTA Load = Outflow-Inflow.	113	-235	862
Direct estimate of ground water contribution [1]	28	16	132
Direct estimate/DELTA Load.	25%	0%	15%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	31	40	344
Outflow	600	333	5114
DELTA Load = Outflow-Inflow.	569	293	4770
Direct estimate of ground water contribution [1]	265	121	412
Direct estimate/DELTA Load.	47%	41%	9%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	131	446	987
Outflow	813	504	6619
DELTA Load = Outflow-Inflow.	682	58	5632
Direct estimate of ground water contribution [1]	293	137	544
Direct estimate/DELTA Load.	43%	42%	10%
Inflow= streamflow into study area times ammonium-N concentration of inflow sample. Outflow = streamflow out of study area times ammonium-N concentration of outflow sample. [1] estimated ground water flow times the median ammonium-N concentration of ground water samples.			

Appendix F3. The chloride load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.

	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	17,031	13,361	84,030
Outflow	24,837	25,694	143,150
DELTA Load = Outflow-Inflow.	7,806	12,333	59,119
Direct estimate of ground water contribution [1]	8,075	6,656	68,345
Direct estimate/DELTA Load.	97%	54%	84%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	8,381	6,606	62,300
Outflow	78,106	75,366	306,854
DELTA Load = Outflow-Inflow.	69,725	68,760	244,554
Direct estimate of ground water contribution [1]	76,034	51,489	213,403
Direct estimate/DELTA Load.	91%	75%	87%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	25,412	19,967	146,330
Outflow	102,943	101,060	450,004
DELTA Load = Outflow-Inflow.	77,531	81,093	303,674
Direct estimate of ground water contribution [1]	83,981	58,239	281,748
Direct estimate/DELTA Load.	92%	72%	93%

Inflow= streamflow into study area times chloride concentration of inflow sample.
Outflow = streamflow out of study area times chloride concentration of outflow sample.
[1] estimated ground water flow times the average chloride concentration of ground water samples.

Appendix F4. The total dissolved phosphorous as P load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.			
	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	317	889	1,532
Outflow	582	765	2,423
DELTA Load = Outflow-Inflow.	265	-124	891
Direct estimate of ground water contribution [1]	22	29	540
Direct estimate/DELTA Load.	8%	0%	61%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	372	815	1328
Outflow	1423	1860	5114
DELTA Load = Outflow-Inflow.	1051	1045	3786
Direct estimate of ground water contribution [1]	207	228	1685
Direct estimate/DELTA Load.	20%	22%	45%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	689	1704	2860
Outflow	2005	2625	7537
DELTA Load = Outflow-Inflow.	1316	921	4677
Direct estimate of ground water contribution [1]	229	257	2225
Direct estimate/DELTA Load.	18%	28%	48%

Inflow= streamflow into study area times phosphorus-P concentration of inflow sample.
Outflow = streamflow out of study area times phosphorus-P concentration of outflow sample.
[1] estimated ground water flow times the median phosphorus-P concentration of ground water samples.

Appendix F5. The total dissolved solids load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.

	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	416,983	493,344	1,977,200
Outflow	596,064	636,272	2,422,530
DELTA Load = Outflow-Inflow.	179,081	142,928	445,330
Direct estimate of ground water contribution [1]	173,808	133,144	1,234,970
Direct estimate/DELTA Load.	97%	93%	277%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	211,024	240,018	1,409,970
Outflow	1,813,240	1,419,260	7,052,254
DELTA Load = Outflow-Inflow.	1,602,216	1,179,242	5,642,284
Direct estimate of ground water contribution [1]	1,633,142	1,031,696	3,856,217
Direct estimate/DELTA Load.	98%	87%	68%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	628,007	733,362	3,387,170
Outflow	2,409,304	2,055,532	9,474,784
DELTA Load = Outflow-Inflow.	1,781,297	1,322,170	6,087,614
Direct estimate of ground water contribution [1]	1,806,950	1,164,840	5,091,187
Direct estimate/DELTA Load.	99%	88%	84%

Inflow= streamflow into study area times TDS concentration of inflow sample.

Outflow = streamflow out of study area times TDS concentration of outflow sample.

[1] estimated ground water flow times the median TDS concentration of ground water samples.

Apppendix F6. The Total Organic Carbon (TOC) load (kg/day) carried by Quilceda Creek and the percentage of the load contributed by ground water.			
	May	August	December
East Fork Quilceda Creek mainstem - Inflow at QCREF1 and misc. inflows, Outflow at QCREF2.			
Inflow	53,444	19,528	249,622
Outflow	63,864	25,696	356,039
DELTA Load = Outflow-Inflow.	10,420	6,168	106,417
Direct estimate of ground water contribution [1]	2,203	1,469	25,179
Direct estimate/DELTA Load.	21%	24%	24%
Middle Fork Quilcdeda Creek - Inflow at QCRMF1 and misc inflows, Outflow at QCRMF3.			
Inflow	7,674	3,743	77,057
Outflow	86,478	34,258	387,605
DELTA Load = Outflow-Inflow.	78,804	30,515	310,548
Direct estimate of ground water contribution [1]	2,070	11,379	78,622
Direct estimate/DELTA Load.	3%	37%	25%
Total streamflow - Inflow at QCREF1, QCRMF1, and misc inflows, Outflow at QCREF2 and QCRMF3			
Inflow	61,118	23,271	326,679
Outflow	150,342	59,954	743,644
DELTA Load = Outflow-Inflow.	89,224	36,683	416,965
Direct estimate of ground water contribution [1]	4,273	12,848	103,801
Direct estimate/DELTA Load.	5%	35%	25%
Inflow= streamflow into study area times TOC concentration of inflow sample. Outflow = streamflow out of study area times TOC concentration of outflow sample. [1] estimated ground water flow times the median TOC concentration of ground water samples.			