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Fecal Coliform and Nitrate transport in shallow groundwater discharging to Streams

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Fecal Coliform and Nitrate Transport in Shallow Groundwater Discharging to Streams

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in cooperation with the U.S. Geological Survey,
Washington Water District

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1 Introduction

Project Foundation and Staff

This project was conducted with funds provided by the Washington Department of Ecology (WaDOE) from their Centennial Clean Water Fund, and by the United States Geological Survey (USGS) under the provisions of a Cooperative Agreement. A grant application was submitted to the Department of Ecology by the Nooksack Indian Tribe in January 2002. Ecology notified the Nooksack Tribe in May 2002 of project eligibility for funding in the amount of and $187,461, with 25% ($62,403) to be provided by the grant recipient in matching funds. The Grant Agreement establishing the project scope of work and terms and schedule was signed in early 2003.

A cooperative agreement was signed by the Nooksack Indian Tribe and the USGS Water Science Center in Washington committing USGS funds to the project on August 15, 2002. This agreement dedicated $150,000 of the Ecology funds to the USGS, with an equal amount provided by the USGS to complete work on the project. The USGS funds provided the matching funds required in the Ecology Grant Agreement.

Soil sampling and data collection was conducted under agreement with Washington State University.

The project manager for the majority of the project was Llyn Doremus, the Nooksack Tribe hydrologist. During her leave of absence from the Nooksack Tribe from June 2004 through January 2005 Ryan Kopp, the water resources technician for the Nooksack Tribe managed the project. Steve Cox was the project scientist for the USGS. The WaDOE project manager for the most part of the project was Joanne Polayes. Early in 2005 Joan Nolan took over the management of the project for WaDOE. Tammy Riedell was the project financial manager for WaDOE. Clay Keown, with the Dept of Ecology Water Quality Program, coordinated the project data entry into the EIM database. Pat Check, was the Nooksack Tribe's Chief Financial Officer when the grant agreement was established. Brock Hochsprung replaced Pat in that position in early 2004.

Project Objectives and Justification

The project goal was to gather information with which to expand our understanding of the processes that affect nitrogen and bacteria distribution in the Nooksack Watershed, that derive from agricultural sources. The results are intended to assist water resource and agricultural production managers in determining best practices for protection and enhancement of the water quality in the Nooksack Watershed (in particular) and Western Washington in general. The explanation for the project was delineated in the grant application submitted, and is summarized as follows.

Water quality exceedences in the Nooksack watershed, while being well characterized, were not well understood with respect to their origin. The nitrate and fecal bacteria content in groundwater and surface water are known to derive from the large-scale agricultural dairy operations in the Nooksack watershed. Manure applied to agricultural fields to fertilize forage crops and to drain manure storage lagoons contains viable enteric bacteria populations and nutrients (including nitrogen). High rainfall rates during winter months causes water accumulation on the ground surface and migration as runoff to surface water. Runoff transports bacteria and nutrients in manure from agricultural fields to streams and rivers. While high fecal bacteria concentrations in surface water are measured after high rainfall events, high runoff and discharge conditions account for only 55% of elevated bacteria concentrations measured in the Nooksack watershed (Cox, et al. 2005). The remaining fraction of the bacteria detected in surface water is measured during periods of very low rainfall, suggesting there are alternative mechanisms for bacteria transport and loading to surface water besides the runoff from agricultural fields. The project examined the alternative mechanisms for transport of bacteria to surface water through groundwater discharge, field drains and through archiving of dormant bacteria in stream sediments for later re-entrainment in stream and river flows.

Nitrate in groundwater derives from the infiltration of nutrients in manure to the shallow groundwater aquifer. Elevated nitrate in groundwater has been documented throughout much of the Nooksack watershed, and in the adjacent, upgradient aquifer in Canada (Erickson, 2000; Cox and Kahle, 1999; Tesoriero et al. 2000). Discharge of nitrate from groundwater to surface water is indicated by increases in nitrate content in water along the length of the Nooksack River between river miles 27.4 (at North Cedarville) and 3.4 (at Brennan) as reported by Hallock (2002).

Nitrate degrades via a biologically mediated process termed denitrification. Denitrification is known to occur in oxygen-depleted conditions when sufficient carbon is available to support the biological respiration process that consumes the nitrate. The products of denitrification are nitrogen gas and carbon dioxide. When denitrification proceeds to completion, soil microorganisms continue the respiration process consuming sulfate, iron and manganese from the surrounding aquifer and aquifer materials.

Approach

To examine the processes affecting the fate and transport of nitrogen and fecal bacteria in groundwater and surface water of the Nooksack watershed, two overlapping approaches were employed. As previously described, fecal bacteria transport from agricultural fields to surface water via surface runoff is understood to be the dominant mechanism for bacteria transport to streams and rivers. Given the fact that a large amount of fecal bacteria detections in surface water occur during periods when surface runoff is not occurring (i.e. during low precipitation periods, typical of summer months), two alternate pathways for transport were considered. Both examined the outcome if bacteria infiltrates through agricultural fields to underlying groundwater. Bacteria content in subsurface field drain discharge and bacteria content in groundwater discharging to surface water was characterized.

To confirm that sampled groundwater accurately represented the constituents and conditions of discharging groundwater, discharge to surface water was monitored at locations adjacent to and under surface water bodies of the Nooksack Watershed for hydraulic gradient and geochemical conditions at four locations (the Everson Site along the Nooksack River, Fourmile Creek, an agricultural drainage ditch along Bertrand Creek, and the Assink Site on Fishtrap Creek) shown on Figure 1-1. Groundwater discharge via drains to surface water was examined by collecting effluent from drains discharging from fields to agricultural ditches at the Fourmile Creek site. The sampling and analyses results from the groundwater pathway characterization are included in Section 3.

Extensive nitrate detections in groundwater throughout the shallow aquifer of the Nooksack watershed have been linked to the application of manure and fertilizer for agricultural production purposes. The uneven distribution both spatially and temporally of nitrate in the shallow surficial aquifer of the lower Nooksack River watershed, and the relatively low concentrations of nitrate in surface water suggest that nitrate degradation is active in some portions of the aquifer. To characterize the nitrate fate and transport related processes, nitrate and associated denitrification geochemical parameters and byproducts were sampled at numerous locations along a groundwater flow path at the Everson Site. In addition, nitrate and denitrification products were sampled in discharging groundwater and the adjacent surface water body receiving the discharge at multiple locations.

Groundwater Discharge Locations

In order to collect data that was representative of discharging groundwater it was necessary to identify locations where groundwater was in fact discharging to surface water. These locations were considered also with respect to accessibility and logistical factors in determining sites to be suitable for more detailed characterization of groundwater discharge and the associated transport of bacteria and nitrate in groundwater. To refine our understanding of groundwater discharge patterns (both temporal and areal variations), existing data was evaluated and new data was collected. Existing data used to evaluate groundwater discharge was:

- Forward Looking Infrared (FLIR) flight water temperature in South Fork and Main Stem Nooksack River (collected August 28, 2001)
- Synoptic instream flows for South Fork (collected August 29 1998)
- DNR Geologic Map for Deming 7.5' Quadrangle (Dragovich, et al., 1997)
- Hydrographs from USGS stream gages at:
    - Nooksack River, located at: river mile 36.6 (gage no. 12210500)
    - South Fork, located at: river mile 14.8 (gage no. 12209000)
    - Fishtrap, located at: river mile 2.9 (gage no. 12212050)

New data collected over the course of this project characterizing groundwater discharge are:

- Temperature and total dissolved solids longitudinal measurement on South Fork Nooksack River (collected August 28, 2003)
- Groundwater/surface water hydraulic gradient measured in mini-piezometers accessing stream sediments below stream channels at four stream side locations and at nine points along the length of Fishtrap Creek. Locations are shown on Figure 1.1.

Nitrate Fate and Transport

Nitrate loading, transport and discharge were characterized along a groundwater flow path, and at groundwater discharge areas in sediments underlying stream and river channels. Nitrate fate and transport along a groundwater flow path was evaluated using data collected from groundwater beneath a field in agricultural production (of forage crops), from groundwater at locations between the field and the adjacent river (riparian zone), and at the river interface with underlying sediments (groundwater to surface water discharge area or hyporheic zone).

Nitrate degradation was evaluated at the groundwater discharge areas by measuring nitrate and its degradation products in samples collected from the groundwater in riparian and hyporheic zones, and in adjacent surface water. Data was collected simultaneously with hydraulic gradient measurements, to verify that groundwater hydraulic head was higher than adjacent stream elevation and groundwater discharge was actually underway at the time of sampling.

Fecal bacteria fate and transport pathways

To evaluate the mechanisms contributing to fecal bacteria detections in streams of the Nooksack Watershed, the transport pathways of: infiltration to and transport in groundwater that discharges through hyporheic zones to surface water; and bacteria movement through groundwater in agricultural drains discharging to surface water were characterized. Bacteria enumeration of E. coli in groundwater in the discharge zone sediments surrounding the stream channel and in agricultural field drain discharge was compared with surface water bacteria content to assess the relative magnitude of the mass of bacteria transported through a specific pathway.

In addition, a laboratory microcosm was used to study bacterial archiving and long-term survival in streambed sediments, as a source for bacteria detected during periods with prolonged lack of surface water runoff. Those results, while not documented further in this report, revealed that 90% of bacteria emplaced in streambed sediment conditions die-off within 48 days of deposition or emplacement. A description of the study and findings is presented in the U.S. Geological Survey report completed for this project (Cox, et al., 2005). These results are considered further in the discussion on bacteria transport pathways in Section 5.

Scope of Work

The project scope was defined in the grant agreement between the Department of Ecology and the Nooksack Natural Resources Department. Task 3 Monitoring and Analyses: defined the data to be collected and analyzed, which is as follows:

A. Delineate the surface water groundwater interface governing the discharge of contaminants to surface water, including:

- longitudinal temperature analysis
- hydrograph separation
- piezometers accessing streambed sediments in riparian zone

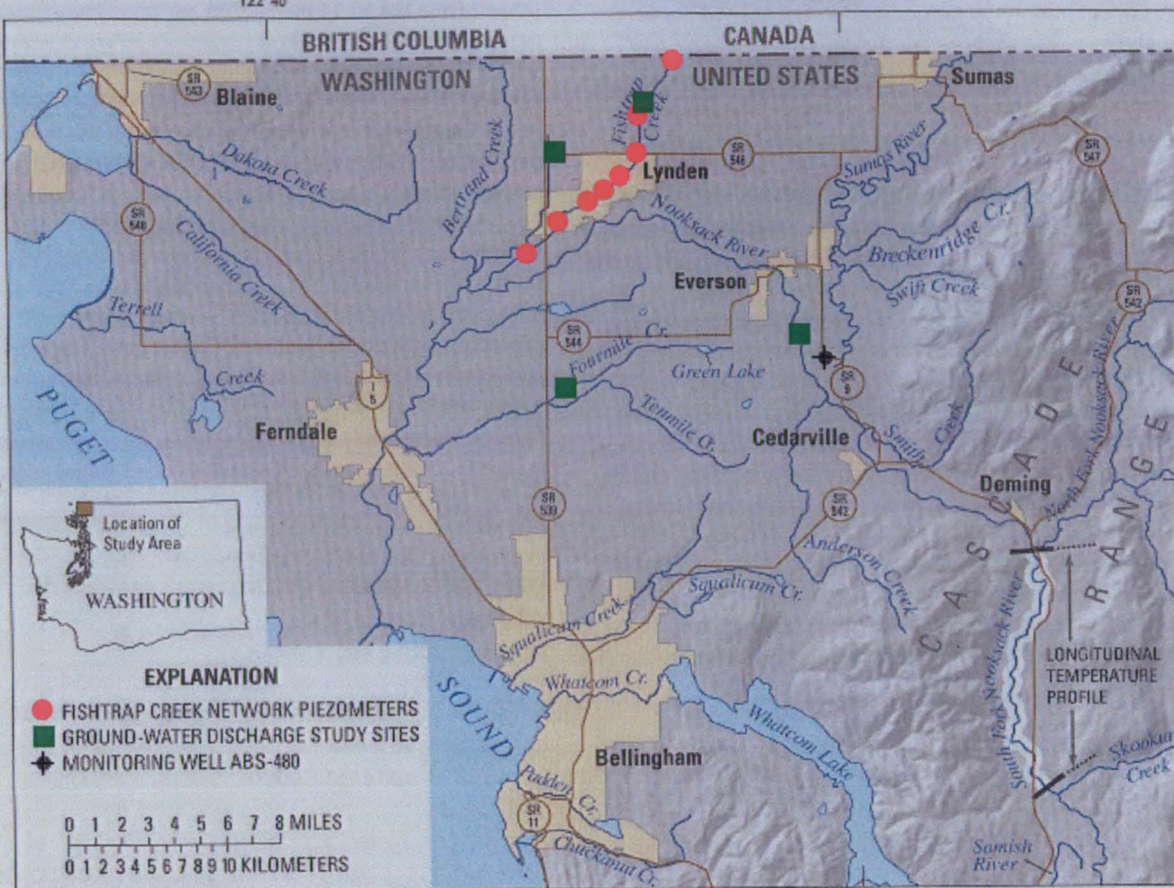


FIGURE 1.1 PROJECT VICINITY AND SAMPLE COLLECTION LOCATIONS

Green symbols illustrate sites sampled for groundwater-surface water characterization, includes sample site locations on:

Fourmile Creek (sites FMPZ-1 through FMPZ-6, FM 12212898 and agricultural drains)

Bertrand Watershed agricultural drainage ditch (sites BERT NE through BERT SW and BERT 12212248)

Main Stem Nooksack River, south of Everson, Everson site (sites VNDW 1-5, VNDW 1-6, VNDW 2-5 and Nooksack River, Multiple groundwater and soil chemistry measurements were also collected)

Fishtrap, near the Canadian border (Fishtrap Assink site) (sites FT Assink Lower RB through FT Assink upper RB and FT Assink surface)

Red dots illustrate longitudinal profile measurement sites along Fishtrap Creek at which multiple hydraulic gradient measurements between the Creek and underlying groundwater were collected during 2003 and 2004. (sites named: PZF-1 through PZF-9).

Black hatch marks on the South Fork Nooksack River indicate the river length for which groundwater discharge temperature and specific conductance was measured.

B. Monitor the flux of fecal bacteria from ground water discharging to surface water in selected stream reaches

- Monitor temperature, pH, dissolved oxygen, specific conductance and nitrate
- Water quality samples for analyses or parameters used to delineate denitrification

C. Monitor the fluxes of fecal bacteria and nitrate in discharging groundwater and in receiving surface waters during a significant rainfall event

Determine variations in ground water denitrification rates based on ground water compositions and ages of discharging ground water.

2 Sample Collection and Analyses

Project Objectives identified in Quality Assurance Project Plan

Data was collected to meet the following objectives:

1. Characterize groundwater discharge, confirm discharge conditions during water quality data collection, and characterize groundwater to surface water hydrologic transport
2. Evaluate stormwater runoff contribution to bacteria content in streams
3. Evaluate groundwater transport and discharge of bacteria to streams, and measure rate of transport (flux) of bacteria to streams
4. Measure bacteria content in Agricultural Field Drains (tile drains) discharge
5. Characterize denitrification in groundwater, and measure rate of transport (flux) of nitrate to streams

Sampling was conducted at four different environments in the lower Nooksack watershed. At each of the four environments data was collected that was used to analyze some subset of these project study objectives. The data collection methods are described in Section 3. Results are presented in Section 4. The sites are listed here, with the associated objectives.

South Fork Nooksack River:

- Groundwater discharge locations along river length from river mile 13 to 0 (confluence with Nooksack River)

Everson site:

- Groundwater discharge variations (as measured in hydraulic gradient, temperature, dissolved oxygen content)
- Nitrate fate and transport in groundwater
- Bacteria discharge from groundwater to surface water

Fishtrap Creek

- Groundwater discharge spatial and temporal variability along Creek length from river mile 9 to 0 (confluence with Nooksack River)
- Assink site (river mile 7): high spatial resolution characterization of groundwater discharge (as measured in hydraulic gradient, temperature, dissolved oxygen content)
- Stormwater characterization

Fourmile Creek

- high spatial resolution characterization of groundwater discharge (as measured in hydraulic gradient, temperature, dissolved oxygen content)
- agricultural drain discharge
- stormwater characterization

Bertrand watershed agricultural drainage ditch

- high spatial resolution characterization of groundwater discharge (as measured in hydraulic gradient, temperature, dissolved oxygen content)

Task A Groundwater Discharge Characterization

Data collected to characterize groundwater discharge provided confirmation of groundwater discharging conditions for characterization of flux rates of bacteria and nitrate to surface water. Temperature, hydraulic gradient and specific conductance were measured for characterization of discharging groundwater conditions. Specific data collected for are:

- Thermal profile and total dissolved solids measurements collected at high spatial resolution in the South Fork Nooksack River from river mile 13 to confluence with North Fork.
- Hydraulic gradient between shallow subsurface sediments and adjacent surface water flow 9 points along the length of Fishtrap Creek (in the U.S.)
- Temporal thermal and hydraulic gradient profile at Fourmile Creek
- Temporal thermal and hydraulic gradient profile at Nooksack River main stem
- Temporal thermal and hydraulic gradient profile at Fishtrap Creek
- Temporal thermal and hydraulic gradient profile at Bertrand Creek agricultural ditch
- Hydraulic gradient between shallow subsurface sediments and adjacent surface water flow in a grid configuration at one location along Nooksack River main stem,
- Hydraulic gradient between shallow subsurface sediments and adjacent surface water flow in a grid configuration (6 points) at one location along Fourmile Creek,
- Hydraulic gradient between shallow subsurface sediments and adjacent surface water flow in a grid configuration (9 points) at one on an agricultural ditch draining to Bertrand Creek.
- Hydraulic gradient between shallow subsurface sediments and adjacent surface water flow in a grid configuration (6 points) at one location along Fishtrap Creek

Measurement locations are shown in Figure 1-1. Results are presented in Section 4.

Task B Bacteria transport to surface water

To monitor the flux of fecal bacteria from ground water discharging to surface water in project stream reaches, water quality measurements were collected from ground water discharging to surface water, and in surface water adjacent to groundwater discharge sample locations. At locations monitored for groundwater discharge mini-piezometers were installed in a grid configuration accessing the groundwater below the stream bottom and in the adjacent stream shoreline areas. Mini-piezometers are described in detail in the Groundwater Discharge Characterization part of Section 3, Data Collection. Surface water was collected from the stream directly above the locations where mini-piezometers accessed the stream bottom.

The sites monitored for bacteria discharge in groundwater are: Assink Site (Fishtrap Creek), Agricultural Drainage Ditch (tributary to Bertrand Creek), and Fourmile Creek.

Bacteria content was also enumerated in groundwater samples collected from the various sampling sites along the Nooksack River (at the Everson site). The locations where samples were collected for enumeration of bacteria content are listed Table 2-1, and specified by the sample objective of bacteria & nitrate flux, and are shown on Figure 1.1. Samples were analyzed for Escherichia coli (*E.coli*) content reported as colony forming units/ 100 milliliters of water (col/100 ml).

Task C Bacteria transport to surface water during a storm event

Samples of surface water and discharging groundwater collected before during and after a storm event were used to characterize stormwater contribution to instream bacteria content. Samples for E coli enumeration were collected during and following the storm event of May 27 and 28, 2004 from the Fourmile Creek.

Stormwater runoff contribution to surface water discharge was originally planned for measurement at all four of the project watersheds. However, the stormwater sample collection equipment was flooded out and lost during the major storm event on October 17, 2003. Data collected during the subsequent May 27-28 sample event in Fourmile Creek documented the affects of stormwater runoff transport to surface water.

Task D Denitrification investigation

Denitrification was assessed using measurements of nitrate degradation byproducts in discharging groundwater at three of the project watersheds, and along a groundwater transport pathway discharging to the Nooksack River. Parameters used to characterize denitrification are:

- nitrate, nitrite
- ferrous iron concentration,
- dissolved oxygen content.

Sample collection locations are listed in Table 2.1 and are identified as having sample objectives of bacteria & nitrate flux, and denitrification.

Nitrate loading, transport and discharge were characterized along a groundwater pathway underlying an agricultural field that discharged to the Nooksack River (at the Everson site). Samples were collected of groundwater discharge areas in sediments underlying and adjacent to the Nooksack River and anlalyzed for nitrate and dissolved oxygen content. The sites sampled accessing up-gradient groundwater, and within one mile of the Nooksack River, EVW-1 port 3 (7 feet below ground surface), port 4 (24 ft bgs), port 5 (41 ft bgs), EVW-2 port 1 (12 ft bgs), port 6 (27 ft bgs) and port 5 (42 ft bgs), VNDW 3-1, VNDW 3-2, VNDW 3-3, VNDW 3-4. The VNDW 2-5 samples were collected from groundwater directly beneath the Nooksack River within five feet of the shoreline.

In addition, to assess nitrogen loading along the groundwater pathway, soil samples were collected for analyses of nitrate content, temperature, and soil moisture content at four locations in the Everson site agricultural fields, overlying the locations of the groundwater pathway piezometers.

To estimate nitrate flux to surface water nitrate and denitrification products were measured in all of the "grid-configured", higher spatial resolution sample locations. At these groundwater discharge zones nitrate degradation was evaluated in samples collected from the groundwater in riparian and hyporheic zones and in surface water. The sampled sites are as follows:

- Fishtrap Assink site (FT assink Lower CTR, FT assink Lower LB, FT assink Lower RB, FT assink Upper RB, FT assink upper CTR, FT assink upper LB, FT assink SW),
- Fourmile Creek site (PZF–1, PZF-02, PZF-03, PZF-04, PZF-05, PZF-06, FM 12212898)
- Bertrand watershed agricultural ditch (BERT NC, BERT NE, BERT NW, BERT CW, BERT CC, BERT CE, BERT, CE, BERT SE, BERT SC, BERT 12212248).

Data was collected simultaneously with hydraulic gradient measurements, to verify that groundwater hydraulic head was higher than adjacent stream elevation and groundwater discharge was ongoing at the time of sampling.

Table 2.1 Water Sample Collection Sites

sample site name	location of sample access	depth (ft)	Ecology well no.	sample objectives
Everson Site / Nooksack River				
VNDW 1-5	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
VNDW 1-6	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
VNDW 2-5	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
Nooksack River	surface grab sample	surface		gw/sw interface, bacteria & nitrate flux
VNDW-3-4	piezometer / riparian	15	AFK-179	denitrification
VNDW-3-3	piezometer / riparian	40	AFK-178	denitrification
VNDW-3-2	piezometer / riparian	15	AFK-177	denitrification
VNDW-3-1	piezometer / riparian	25	AFK-176	denitrification
VNDW-2-4	piezometer / riparian	15	AFK-175	denitrification
VNDW-2-3	piezometer / riparian	40	AFK-174	denitrification
VNDW-2-2	piezometer / riparian	15	AFK-173	denitrification
VNDW-2-1	piezometer / riparian	25	AFK-172	denitrification
VNDW-1-4	piezometer / riparian	10	AFK-171	denitrification
VNDW-1-3	piezometer / riparian	40	AFK-170	denitrification
VNDW-1-2	piezometer / riparian	10	AFK-169	denitrification
VNDW-1-1	piezometer / riparian	25	AFK-168	denitrification
EVW 1 port 3	multiport piezometer / recharge	7	AKS-028	denitrification
EVW 1 port 5	multiport piezometer / recharge	41	AKS-028	denitrification
EVW 1 port 4	multiport piezometer / recharge	24	AKS-028	denitrification
EVW 2 port 5	multiport piezometer / recharge	12	AKS-461	denitrification
EVW 2 port 5	multiport piezometer / recharge	27	AKS-461	denitrification
EVW 2 port 5	multiport piezometer / recharge	42	AKS-461	denitrification
Fishtrap Creek				

sample site name	location of sample access	depth (ft)	Ecology well no.	sample objectives
FT assink Lower RB	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink Lower CTR	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink Lower LB	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink upper RB	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink upper CTR	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink upper LB	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, dentrification
FT assink SW	surface grab sample	surface		gw/sw interface, bacteria & nitrate flux
PZF-01	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-02	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-03	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-04	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-05	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-06	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-07	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-08	mini piezometer / hyporheic	< 3		gw/sw interface
PZF-09	mini piezometer / hyporheic	< 3		gw/sw interface
Fourmile Creek				
FMPZ-1	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FMPZ-2	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FMPZ-3	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FMPZ-4	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FMPZ-5	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FMPZ-6	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
FM 12212898	surface grab sample	surface		gw/sw interface, bacteria & nitrate flux, denitrification
4-mile downstream tile drain	agricultural drain	surface		bacteria & nitrate flux
4-mile upstream tile drain	agricultural drain	surface		bacteria & nitrate flux
Agricultural Drainage Ditch / Bertrand Creek				

sample site name	location of sample access	depth (ft)	Ecology well no.	sample objectives
BERT NC	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT NE	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT NW	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT CC	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT CW	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT CE	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT SE	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT SC	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT SW	mini piezometer / hyporheic	< 3		gw/sw interface, bacteria & nitrate flux, denitrification
BERT 12212248	surface grab sample	surface		gw/sw interface, bacteria & nitrate flux

Modifications to Quality Assurance Project Plan

Data collection methods were modified from those originally documented in the project Quality assurance project plan (QAPP). The following analyses were originally identified, and subsequently changed when the actual data was collected for this project.

1. Nitrate concentration in groundwater was not measured consistently during early months of 2004 at the groundwater flow path investigation site (Everson site piezometers, and multi-port monitoring wells), nor at the other groundwater discharge characterization sites (Fourmile, Bertrand Agricultural Drainage and Assink Ste). The groundwater discharge characterization sites samples analyses consistently yielded non-detect measurements of nitrate (with a few exceptions). The lack of nitrate detections in groundwater were useless in the evaluation of the progress and factors contributing to denitrification. As a consequence analyses for groundwater nitrate content were discontinued. Instead, measurement of gas concentrations of nitrogen and argon in groundwater were initiated to assess the comparative saturation of nitrogen and argon to assess whether denitrification had proceeded to completion and produced over-saturated groundwater nitrogen (gas) concentrations.

2. Nitrate measurement in groundwater was restricted to the period when soil nitrate was hypothesized to contribute to groundwater nitrate content, after crops were harvested during the late summer and through the early winter months. Soil nitrate concentrations were measured at various locations in the vicinity up-gradient of the riparian area instrumented for groundwater measurements, locations are shown in Figure 2-3. Groundwater nitrate content was measured

along a flow path through the monitored crop fields, and at the downgradient riparian and hyporheic zone sites adjacent to the Nooksack River.

3. Characterization of soil nitrate content was completed under contract with Washington State University. Soil samples were collected bi-weekly for six months from August through December 2004, and analyzed for nitrate and moisture content at the WSU laboratory in Pullman. The results were used to help in the assessment of sources of nitrate loading to groundwater.

4. Water samples collected from mini-piezometers for characterization of general chemistry bi-monthly using a Spectrophotometer were not completed. Instead water chemistry was analyzed using National Water Quality Laboratory methods (listed in Table 3-1) for the following parameters:

    - calcium
    - chloride
    - iron
    - magnesium
    - manganese
    - pH
    - silica
    - sodium
    - specific conductance
    - potassium
    - nitrogen, ammonia,
    - nitrogen, ammonia plus organic nitrogen
    - nitrogen, nitrite
    - nitrogen, nitrite plus nitrate
    - phosphorous
    - phosphorous, ortho-phosphate

    During the course of the project, there was a change in staff committed to project completion. New staff were not familiar with the Spectrophotometer analyses techniques. As a consequence, an alternate analyses technique using USGS measurement methods replaced the method initially identified in the QAPP.

5. Stormwater runoff characterization was completed at one of the four initially proposed project watershed sites, with samples collected only once during a precipitation event.

6. A hydrograph separation was not completed for any sites. The project data revealed that groundwater discharge was not transporting bacteria to surface water. As a consequence, The analyses of hydrograph components, intended to assist in the delineation of bacterial flux proportions in groundwater and surface water, was irrelevant. The proportion of bacteria transported in groundwater was zero. A hydrograph separation analysis was not necessary to make that determination. With the proportion of bacteria transport in groundwater established as zero, analyses of hydrograph components to further delineate flux pathways and rates in groundwater was pointless.

7. Agricultural tile drain samples were not analyzed for Total Kjeldahl nitrogen and total suspended solids, contrary to the analyses listed in the QAPP for agricultural field drains. Agricultural drains were difficult to locate and access, which also reduced the number of samples collected from the drains. During wet, high runoff periods the tile drain discharge locations planned for sampling were submerged in water accumulating in the ditches receiving the runoff. Conversely, during drier periods drains were not transmitting water.

3 Data Collection

Groundwater Discharge Characterization

The various methods used to interpret groundwater discharge locations and variability are listed above in *Task A Groundwater Discharge Characterization* of Section 2. Parameters of hydraulic head and gradient, water temperature and total dissolved solids (and specific conductance) were used for interpretation of discharging conditions. The specific procedures for each method of data collection follow.

Instream Water Temperature Profile

Data was collected along two stream lengths to characterize longitudinal variation in groundwater discharge for this project. Along the lower 13-mi reach of the South Fork Nooksack River a reconnaissance longitudinal streambed water-temperature survey was conducted. The survey was done during base-flow conditions on August 28, 2003 (flow was 85 ft^3/s, Kimbrough and others, 2004) at a time when the difference between the ground-water temperatures and surface-water temperatures exceeded 4°C. The longitudinal thermal profile survey was conducted between 9:00 AM and 4:00 PM during the increasing limb of the diurnal temperature cycle. The survey was conducted by towing a recording sensor along the bed of the river to collect data at two-second intervals on water temperature, depth, and specific conductivity along the bed of the river. A simultaneously recording Global Positioning System (GPS) was used to generate geo-referenced data. However, most of the GPS data was corrupted, so field notes and travel time were used to interpolate between known points. Locations of discharging ground water were identified by changes in slope of the longitudinal temperature profile. This method is described by Lee and others (1997) and has been successfully applied in the Yakima River (John Vaccaro U.S. Geological Survey, written communication, 2002). Results of the survey are presented in Section 4.

Hydraulic Gradient and Water Temperature Profile

To assess groundwater discharge conditions and variability along the length of Fishtrap Creek measurements of groundwater and surface water elevation were collected at nine points (shown in Figure 3-1) and repeated eleven times over the period from September 2002 and July 2004. Ground water levels were calculated using temporary piezometers installed in sediments below the stream bed and measuring water levels with either a manometer board or steel measuring tape. The vertical hydraulic gradient was computed by dividing the head difference between the surface water and ground water levels by the distance between the streambed surface and the midpoint of the screened interval (Winter and others, 1988). Ground-water discharge is indicated when the groundwater level measured in the temporary piezometers is greater than the water level of the stream. This condition suggests that the stream is gaining flow, and by convention the vertical hydraulic gradient is assigned a positive value. In losing stream reaches, the water level in the piezometer is lower than the water level of the stream and the vertical hydraulic gradient is assigned a negative value. The use of the manometer board is shown in figure 3-2, and additional details on measurement of vertical hydraulic gradients are described in Simonds and others (2004). The data collected is reported in Section 4 and shown on Figure 4-2.

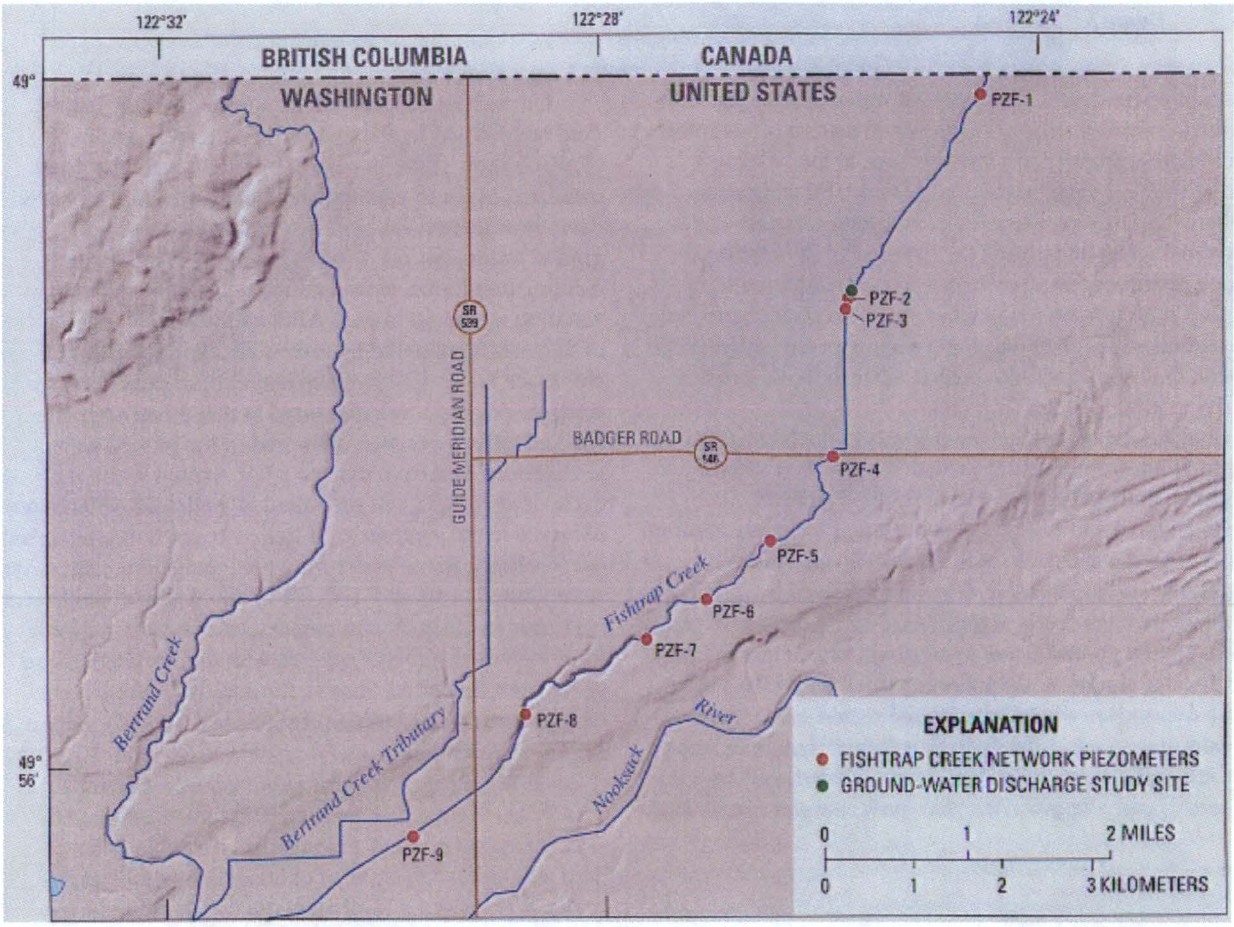


FIGURE 3-1 HYDRAULIC GRADIENT PROFILE MEASUREMENT LOCATIONS ALONG FISHTRAP CREEK

The temporary in-stream piezometers used to measure ground-water levels (and to collect water-quality samples of discharging ground water) were installed beneath the streambed in areas of calm water away from riffles to avoid measurement of surface flow induced variations of hydraulic head. They were constructed from a 7-foot length of 0.5-inch-diameter steel pipe in which the end was crimped and perforated with numerous holes roughly 0.063 in. in diameter. The piezometer was driven into the streambed until the perforations were positioned about 3.0 to 3.5 ft below the sediment-water interface to reduce the possibility of sampling surface water from within the hyporheic zone. A peristaltic pump was used to flush sediment and turbid water from the screen area and develop communication between the piezometer and the shallow aquifer. Isolation of the ground water and surface water was confirmed by comparison of water-quality parameters including water temperature, specific conductance, and dissolved oxygen (measurement techniques described in the water quality subsection that follows).

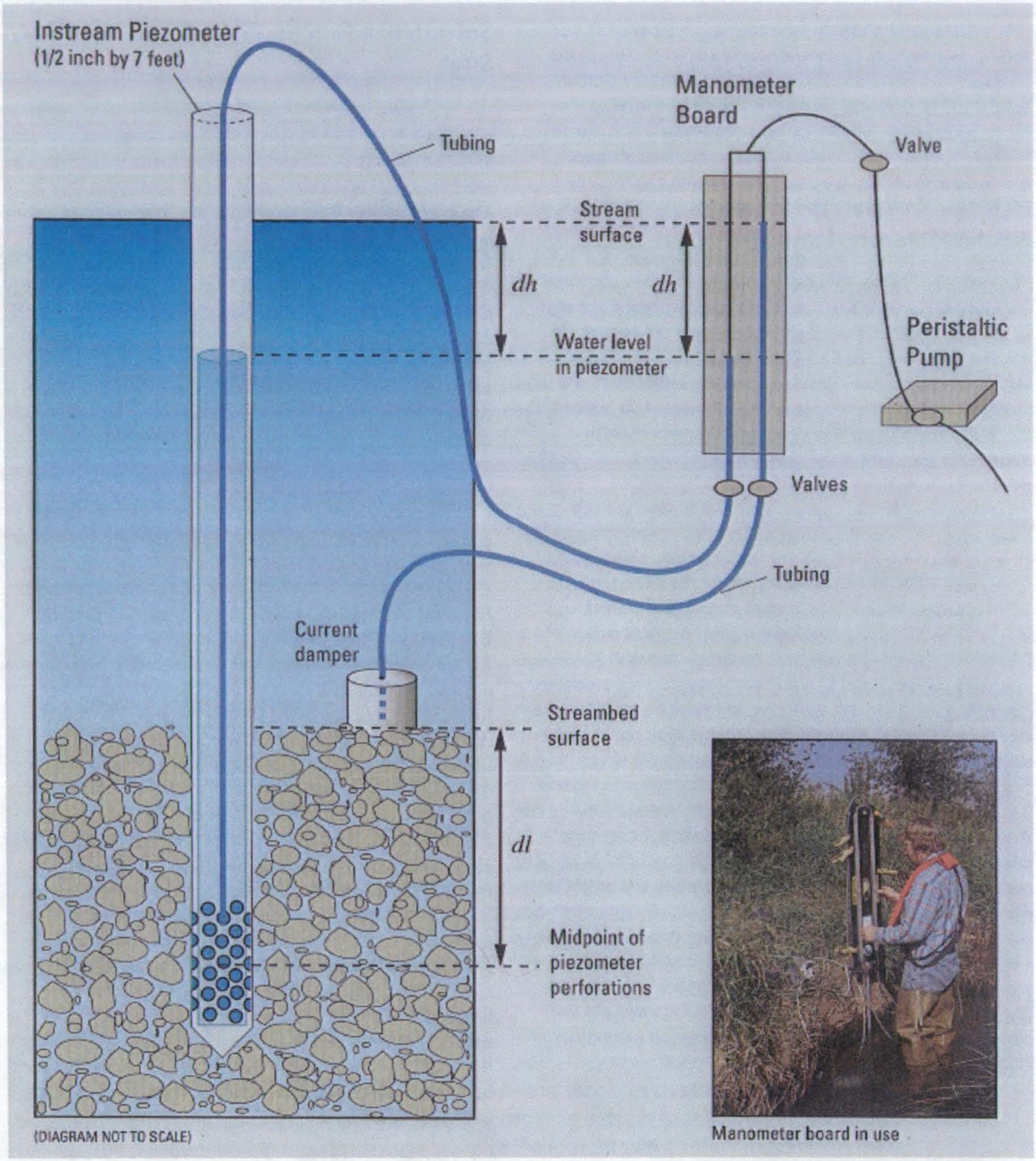


FIGURE 3-2_ MANOMETER BOARD DIAGRAM

Illustrates the principle of direct measurement of hydraulic head differences throughout a streambed and the computation of vertical hydraulic gradients.

Temporal Ground Water Vertical Gradient and Temperature Characterization

Temporary water level gaging stations were established at sites in and along Fishtrap Creek, Fourmile Creek and in Bertrand Watershed agricultural drainage ditch at locations illustrated in Figure 1-1 by the green dots. A permanent monitoring well was used for measuring groundwater levels in the Nooksack watershed; its location is indicated in Figure 1-1 by a black circle and cross-hatch. The temporary gaging stations provided continuously monitored data on surface water stage and groundwater levels in the adjacent shallow aquifer. At each site a staff plate was installed so that surface and ground water level measurements could be referenced to a common arbitrary datum that was established for the individual site. To monitor surface-water levels, a 1.25- to 1.5-inch diameter pipe was installed to house a data logger just above the streambed. To monitor ground-water levels, a similar 1.25- to 1.5-inch pipe, fitted with a 6-inch well screen, was driven into the streambed such that the screened interval was 3.0 to 3.5 ft below the streambed. This piezometer was also instrumented with a data logger placed within the screened section. Data loggers consisted of a self-contained pressure transducer and temperature thermister and recorded readings at one hour intervals. Piezometers were vented to the atmosphere and all data were compensated barometric pressure as recorded by a separate data logger placed at the land surface and exposed to the atmosphere. Periodic staff gage readings and physical measurement of groundwater levels were used to confirm the continuous data and make adjustments as necessary. Data collected at these Temporal Gradient Sites is reported in Section 4 (in subsection titled Temporal Groundwater and Surface Water Levels Profile), and shown in Figures 4-4 through 4-7.

Ground Water Pathway Characterization

The fate and transport of nitrate in ground water was assessed with data collected from piezometers, multip-port piezometers and mini-piezometers at the Everson site, located in an approximate upgradient alignment from the Nooksack River. Groundwater samples were analyzed in the field for nitrate, pH, specific conductance, and dissolved oxygen (DO) using a Hydrolab minisonde-4a multipprobe sensor calibrated with known standards on the day of measurement according to procedures described in the Quality Assurance Project Plan (Doremus, 2004). Ferrous iron was measured using CHEMets colorimietric ampoules (manufactured by CHEMetrics, Inc., Calverton, VA).

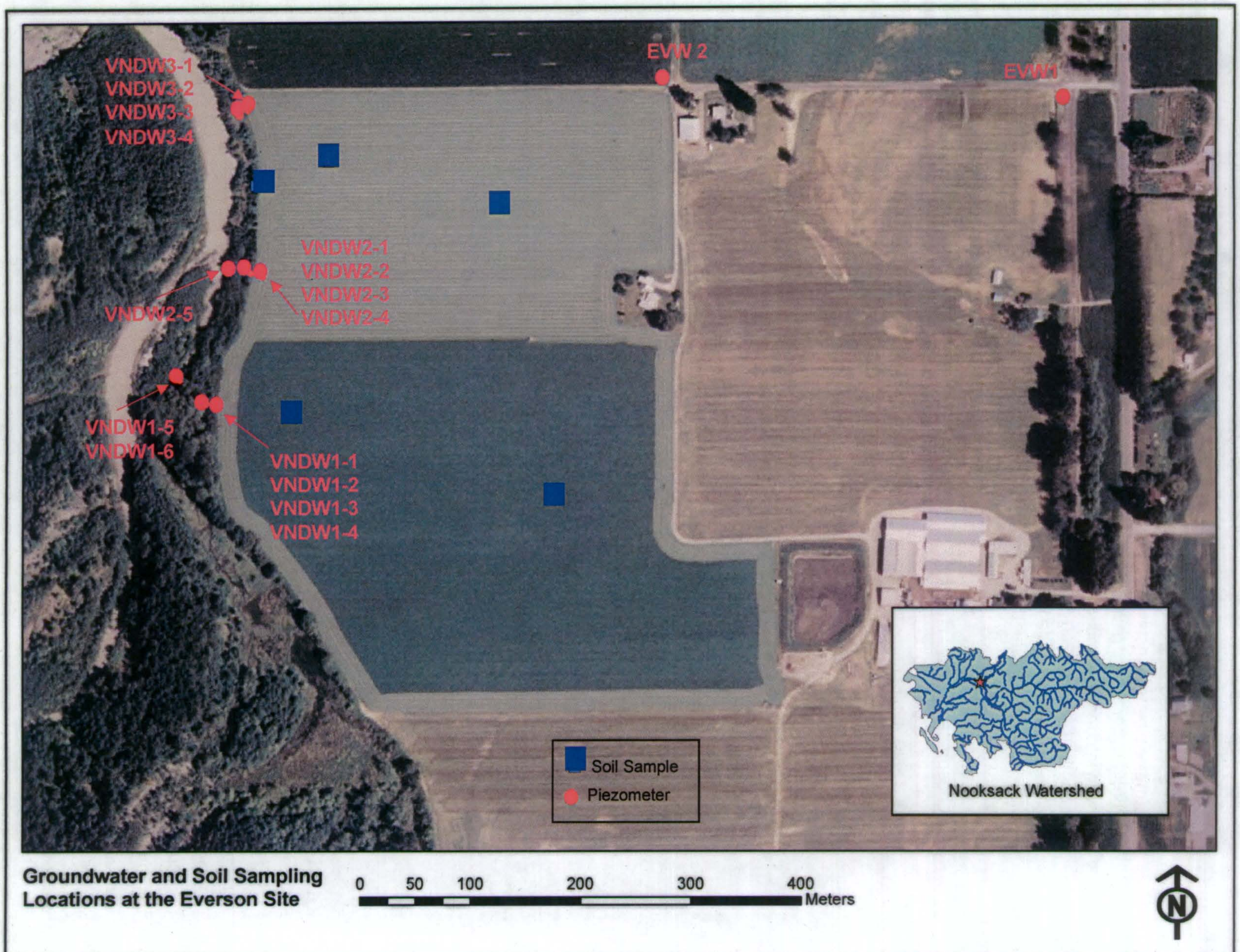
Soil samples collected from overlying agricultural fields were analyzed for nitrate, in coordination with the August through December 2004 ground water measurements. Soil data collection methods are described in the Sediment Quality Data Collection section that follows. Sample collection locations for ground water and soil are shown in Figure 3-3 (shown on the following page).

FIGURE 3-3 EVERSON SITE SAMPLE COLLECTIONS LOCATIONS, INCLUDING SOIL SAMPLES, SHALLOW GROUNDWATER SAMPLES, RIPARIAN AREA SAMPLES, AND HYPORHEIC ZONE SAMPLES (FROM MINI-PIEZOMETERS)

Piezometers accessing riparian area groundwater are in groups of four (i.e. VNDW3-1, VNDW3-2, VNDW3-3, VNDW3-4), configured in groups of two, with a shallow and deep piezometer in each group. For clarity each group of two is shown as one piezometer in the figure.

VNDW1-5, VNDW1-6, VNDW2-5 are mini-piezometers accessing groundwater discharging from shallow sediments underneath the Nooksack River bottom. For clarity the two mini-piezometers VNDW1-5 and VNDW1-6 are shown as one in the figure.

EVW1and EVW2 are mulit-port piezometers, with three screened intervals in each



Groundwater and Soil Sampling Locations at the Everson Site

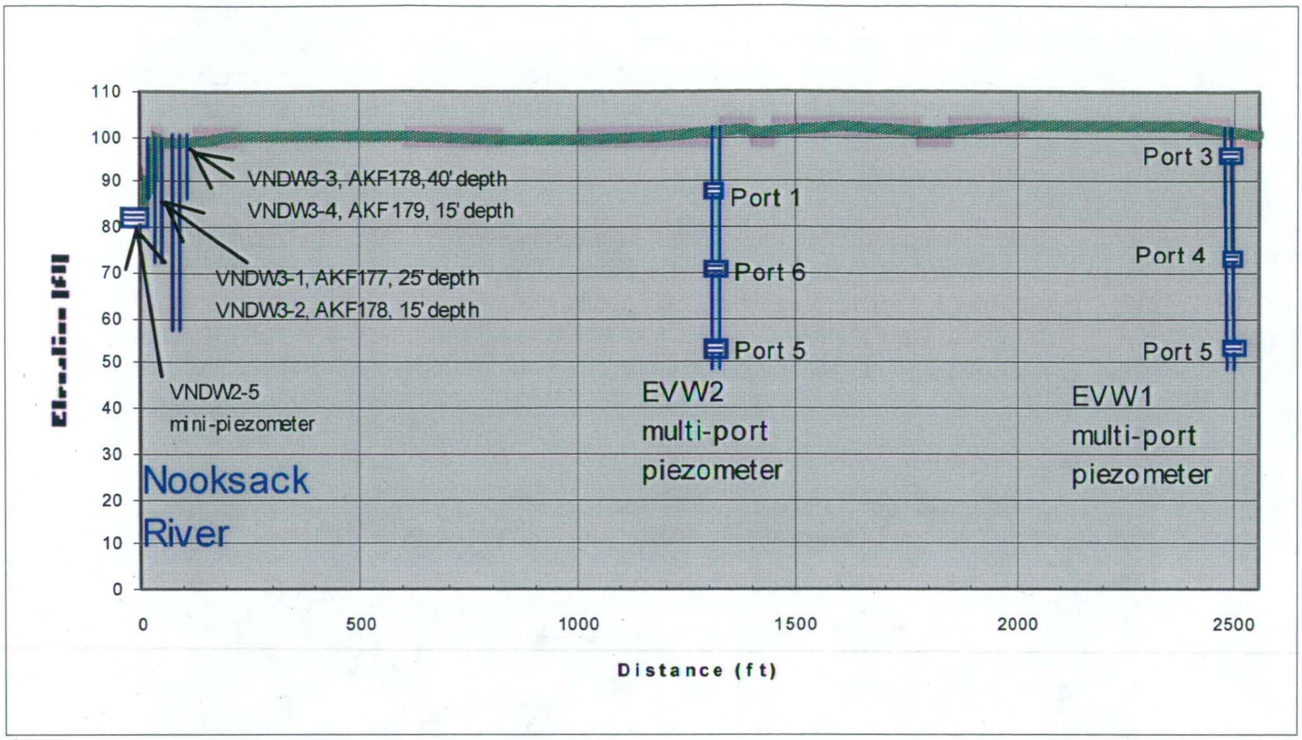


FIGURE 3-4 CROSS SECTION OF EVERSON SITE GROUND WATER FLOW PATH SAMPLE LOCATIONS

Detailed Spatial Delineation of Ground Water Discharge

To assess the temporal and small-scale spatial variability in ground water discharge mini-piezometers were installed at three detailed study sites located: on Fishtrap Creek (Assink Site); Fourmile Creek; and the agricultural drainage ditch tributary to Bertrand Creek. Mini-piezometers were constructed by driving a 0.5-in. pipe with a loosely fitting plug about 3.5 ft below the surface. A 6-in. long stainless-steel screen was attached to a section of 0.375-in. polyethylene tubing and inserted to the bottom of the pipe. The pipe was then withdrawn in a manner that detached the plug allowing the screen to remain in place as the pipe was removed. Saturated sediment around the polyethylene tubing typically collapsed against the tubing. Bentonite pellets were used to fill the annular space and seal void areas in the unsaturated sediments near the surface. To flush sediment and turbid water from the screen area and develop communication between the piezometer and the shallow aquifer, piezometer tubing connecting the well screen to the ground surface access point was evacuated using a peristaltic pump. Isolation of the ground water and surface water was confirmed by comparison of water-quality parameters measured in adjacent surface and groundwater. To measure the hydraulic gradient between groundwater and surface water, a manometer board was used. Water drawn from the mini-piezometer through the access tube, and water drawn from the adjacent creek were both pumped through separate tubing in the manometer board, and then allowed to equilibrate with the atmosphere. The water level difference between the tube containing the groundwater and the tube containing the surface water was read from the calibration scale on the manometer board, providing a hydraulic head measurement. The difference in water level between the creek level elevation and the manometer access screen depth was divided into the hydraulic head difference to calculate the hydraulic gradient.

Fourmile Creek Site

Two transects of three mini-piezometers each were installed perpendicular to the Creek at the detailed study site on Fourmile Creek. The site was located approximately one mile upstream of the Fourmile Creek confluence with Tenmile Creek. Vertical hydraulic gradients were measured in each piezometer with a manometer board four times from February through May 2004. Fourmile Creek sample locations are shown in Figure 3-4.

FIGURE 3-5 APPROXIMATE LOCATIONS OF THE SIX MINI-PIEZOMETERS SAMPLED ALONG FOURMILE CREEK.

The two tile drains sampled at the Fourmile site were located approximately 100 feet upstream and 100 feet downstream of the downstream mini-piezometer on the north side of the Creek.

Agricultural Drainage Ditch Site, Bertrand Creek Watershed

Three transects of three mini-piezometers each were installed perpendicular to the agricultural drainage ditch at intervals of approximately 50 feet, across a transverse length from shore to shore of approximately 20 feet. The surface water gaging station (at which the hydraulic gradient profile data was collected) was located at the center transect. Vertical hydraulic gradients were measured throughout the autumn and winter of 2003 and into the spring and summer of 2004 in each of the nine mini-piezometers. The Bertrand site was located along an agricultural ditch that drained to road side drainage ditch along Badger Road, about 1.3 miles east of Bertrand Creek. The locations of the mini-piezometers sampled at this site are shown in Figure 3-5.

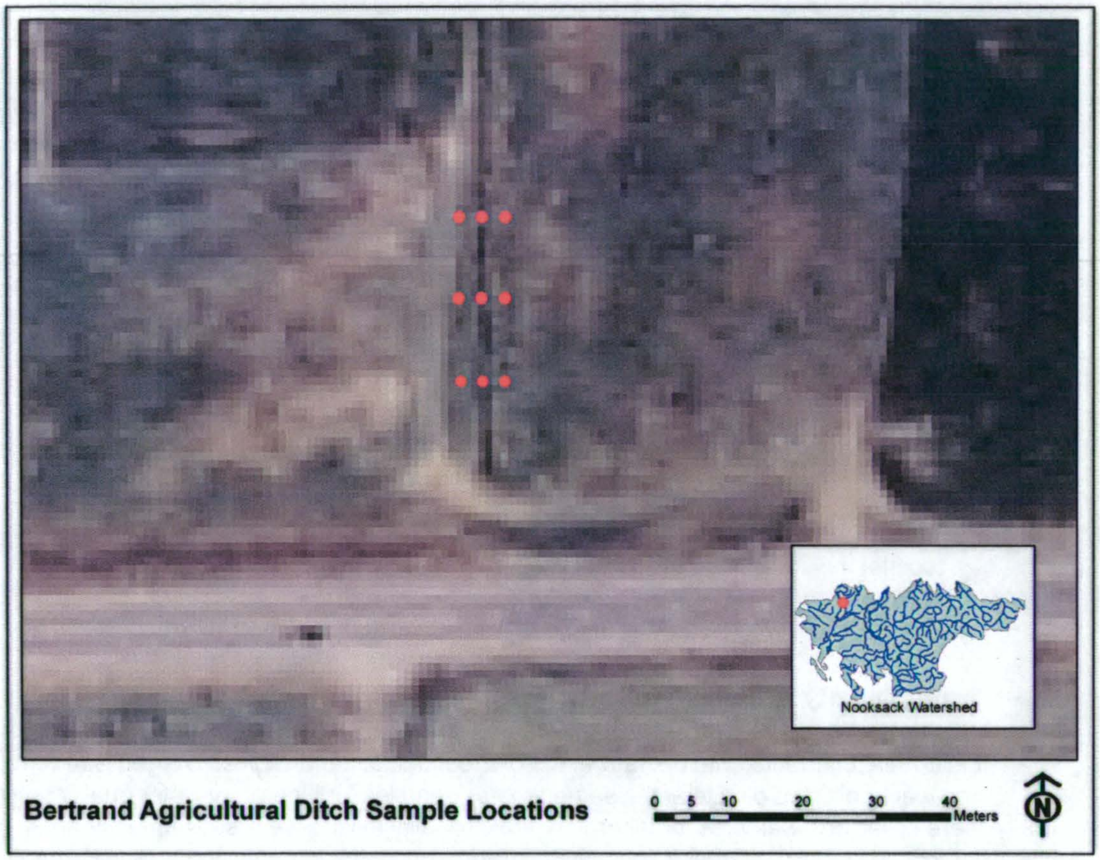


FIGURE 3-6 MINI-PIEZOMETER LOCATIONS ACCESSING THE BERTRAND AGRICULTURAL DITCH GROUNDWATER DISCHARGE ZONE

Assink Site, Fishtrap Creek

Vertical hydraulic gradients were measured periodically in two perpendicular transects of mini-piezometers installed near PZF-2 (Figure 3-1). Each transect consisted of a mini-piezometer installed on each creek shoreline, and one in the creek bottom (total of 3 mini-piezometers per transect). Manometer board measurements were taken intermittently from October 1, 2003 to May 6, 2004. The grid configuration of mini-piezometers sampled at the Assink site is similar to the grid configuration shown in the Fourmile Creek in Figure 3-6.

Water Quality Characterization

Water quality data was collected to support the project objectives of: confirming discharging groundwater conditions, assessing bacteria transport pathway via groundwater discharge to surface water, assessing nitrate transport via groundwater discharge to surface water and estimation of rate of nitrate degradation in groundwater.

Groundwater Discharge Conditions Evaluation

Water quality data collected from mini-piezometers (installed using methods described in the previous subsection on Detailed Spatial Delineation of Groundwater Discharge) was used to confirm groundwater discharge conditions. The water quality parameters used to assess groundwater discharge were: dissolved oxygen, specific conductance and temperature. These data were collected in mini-piezometers at:

- Nooksack River, Everson site (three sample points)
- Along the length of Fishtrap Creek (nine sample points)
- Assink detailed sampling site along Fishtrap Creek (six sample points),
- Fourmile Creek detailed sampling site (six sample points)
- Bertrand watershed agricultural drainage ditch detailed sampling site (nine sample points)

Specific locations where samples and data were collected are listed in Table 2.1.

Water Quality Measurements

Field measurements of temperature, specific conductance, dissolved oxygen and ferrous iron were collected on-site at the same time as samples for laboratory water quality testing were collected. Samples for laboratory water quality testing were subsequently analyzed for concentrations of major ions and nitrate using National Water Quality Laboratory methods (listed in Table 3.1). On-site temperature and specific conductance measurements used a temperature compensated probe and specific conductance meter. Dissolved oxygen and ferrous iron measurements were made using CHEMettes colorimetric ampoules (manufactured by CHEMetrics, Inc., Calverton, Va.). Instruments used for field measurement temperature and specific conductance were calibrated daily with known standards, and temperature recording instrument readings were compared with standard thermometer measurements during site visits.

Bacteria Flux Characterization

Water-quality samples collected from the mini-piezometers at all four detailed spatial delineation sites were analyzed for *E. coli* bacteria. Sterile techniques were used during collection, storage, and analysis of stream and groundwater samples for bacterial analysis. Stream samples were collected by hand from the mid point of the stream. For mini-piezometers, samples were obtained by use of a peristaltic pump with autoclavable silicon tubing. Samples for bacteria analysis were collected into a sterile 500-ml polyethylene bottle and transported on ice to a field laboratory of the USGS Washington Water Science Center, Tacoma, Washington for processing and incubation within 24 hours of collection.

Bacteria samples analyzed for concentrations of *E. coli.* were enumerated using the enzyme-substrate most-probable number (MPN) enumeration technique (American Public Health Association and others, 1998). This technique was used because it requires less field processing and produces results that are comparable to the membrane filter technique outlined in the USGS National Field Manual for the collection of water-quality data (Myers and Sylvester, 1997).

Quality-assurance measures used throughout the study included blanks, replicates and positive control samples containing less than 50 cells each of *E. coli*, *Klebsella Pneumoniae*, and *Pseudomonas aeruginosa*. The positive control samples were provided by IDEXX Laboratories (Westbrook, Maine). All positive samples gave the proper enzymatic color change response and resulted in most-probable number concentrations of from 7 to 15 CFU/ 100 mL E. coli was not detected in any of the field of laboratory blank samples. The relative percentage of difference of duplicate samples ranged from 87 to 315 per cent.

Nitrate Flux and Denitrification Characterization

Everson Site Groundwater Pathway Characterization

Samples for analysis of nitrate and major ions were passed through a 0.45-um membrane filter into polyethylene bottles, chilled and sent to the USGS National Water Quality Laboratory (NWQL). At the NWQL, samples were analyzed for concentrations of nitrate by colorimetry as described by Fishman (1993). Major ions were analyzed by ion chromatography described by Fishman and Friedman (1989). Table 3-1 lists the methods used for ion analyses.

Quality assurance measures used throughout the study include submitting approximately 15 percent of samples to the laboratory as quality assurance samples, which are a combination of replicate and blank samples.

Table 3-1 National Water Quality Laboratory Analytical Methods

PARAMETER CODE AND NAME	METHOD	CITATION
# P00915 Calcium, water, filtered, milligrams per liter	Metals in filtered water by ICP-AES,	USGS I-1472-87 OF 93-125, p.101
# P00925 Magnesium, water, filtered, milligrams per liter	Metals in filtered water by ICP-AES	USGS I-1472-87 OF 93-125, p.101
# P00930 Sodium, water, filtered, milligrams per liter	Metals in filtered water by ICP-AES	USGS I-1472-87 OF 93-125, p.101
# P90410 Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH	Alkalinity by automated electrometric titration to pH 4.5	USGS I-2030-85 TWRI 5-A1/1989, p. 57

PARAMETER CODE AND NAME	METHOD	CITATION
4.5) titration, laboratory, milligrams per liter as calcium carbonate		
# P00940 Chloride, water, filtered, milligrams per liter	Anions in filtered water, by automated IC	USGS I-2057-90 OF 93-125, p. 9
# P00955 Silica, water, filtered, milligrams per liter	Silica in filtered water by ASF molybdate blue formation and colorimetry	USGS I-2700-85 TWRI 5-A1/1989, p. 417
# P00945 Sulfate, water, filtered, milligrams per liter	Anions in filtered water by automated IC	USGS I-2057-90 OF 93-125, p.19
# P00608 Ammonia, water, filtered, milligrams per liter as nitrogen	Ammonia in filtered water, by ASF salicylate-hypochlorite colorimetry	USGS I-2522-90 OF 93-125, p. 125
# P00631 Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen	Nitrite plus nitrate in filtered water, by ASF cadmium reduction -diaxotiztion colorimetry	USGS I-2545-90 OF 93-125, p. 157
# P00613 Nitrite, water, filtered, milligrams per liter as nitrogen	Nitrite in filtered water, by ASF diazotization colorimetry	USGS I-2540-90 OF 93-125, p. 143
# P62854 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered, analytically determined, milligrams per liter	Total nutrients in filtered water by alkaline persulfate digestion	USGS I-2650-03 WRI 03-417
# P00671 Orthophosphate, water, filtered, milligrams per liter as phosphorus	Orthophosphate in low ionic-strength water, by ASF phosphomolybdate colorimetry	USGS I-206-89 OF 93-125, p. 191
# P00666 Phosphorus, water, filtered, milligrams per liter	PHOSPHORUS-P, DIS, LL	USEPA 365.1
# P50468 Escherichia coli, Defined Substrate Technology, water, most probable number per 100 milliliters	Colisure, Coliler (24-48 hrs)	IDEXX Laboratories
# P99114 Iron(II), water, filtered, field, milligrams per liter		
# P01046 Iron, water, filtered, micrograms per liter	Metals in filtered water, by ICP-AES	USGS I-1472-87 OF 93-125, p. 101
# P01056 Manganese, water, filtered, micrograms per liter	Metals in filtered water, by ICP-AES	USGS I-1472-87 OF 93-125, p. 101

Sediment Quality Data Collection

Soil samples collected from one foot below the ground surface were obtained weekly from August 3, 2004 through November 27, 2004 at five locations in the Everson site vicinity upgradient of the discharge and riparian areas characterized for this project. One soil sample was obtained on December 16, 2004. The five sampling locations were located as follows: 2 in a grass field, 2 in a cornfield, and 1 sampling in native vegetation along the riverbank.

Soil for analyses was collected using a 6" dia hand held soil core borer. Soil samples were placed in bottles, sealed and refrigerated during transport to Soil Farm Consultant Laboratories in Moses Lake, Washington. Soil temperature was recorded at each site at 6 inches below the ground each time soil samples were obtained. Weather data was monitored and recorded through 2004 at the Everson site.

Soil nitrate concentration and moisture content were measured for each soil sample. Analyses were completed at the Soil Test Farm Consultant Labs in Moses Lake, Washington. Nitrate was analyzed using a calcium sulfate extraction, and nitrate was determined by chromotrophic acid method S3.30 (WCC, 2003). Soil moisture content was measured using a gravimetric method.

Ground water measurements were obtained in adjacent upgradient areas within one half mile of the Nooksack River shoreline during the period that soil data was collected, using procedures described in the previous section on Groundwater Pathway Characterization.

Groundwater Discharge

Stream Length Longitudinal profile data

Water temperature, specific conductance and hydraulic head data collected along longitudinal profiles was used to interpret groundwater discharge locations on the South Fork Nooksack River (shown in Figure 4-1) and for Fishtrap Creek (shown in Figure 4-2).

The South Fork August 28, 2003 longitudinal thermal profile indicates five locations where groundwater is discharging to the River, based on the difference in water temperatures at the stream bottom and in the water of the surrounding stream flow. The longest reach of groundwater discharge is between river mile 6 and 9, an almost three mile long stream reach. Three additional locations of groundwater discharge extending less than 0.5 mile of the river length, are located around river mile(s) 1, 2 and 4. Groundwater discharge was indicated at river mile 13, the uppermost stream reach surveyed, where longitudinal profile measurements were initiated. The length of the reach that groundwater discharge extends upstream beyond this point cannot be determined from this data.

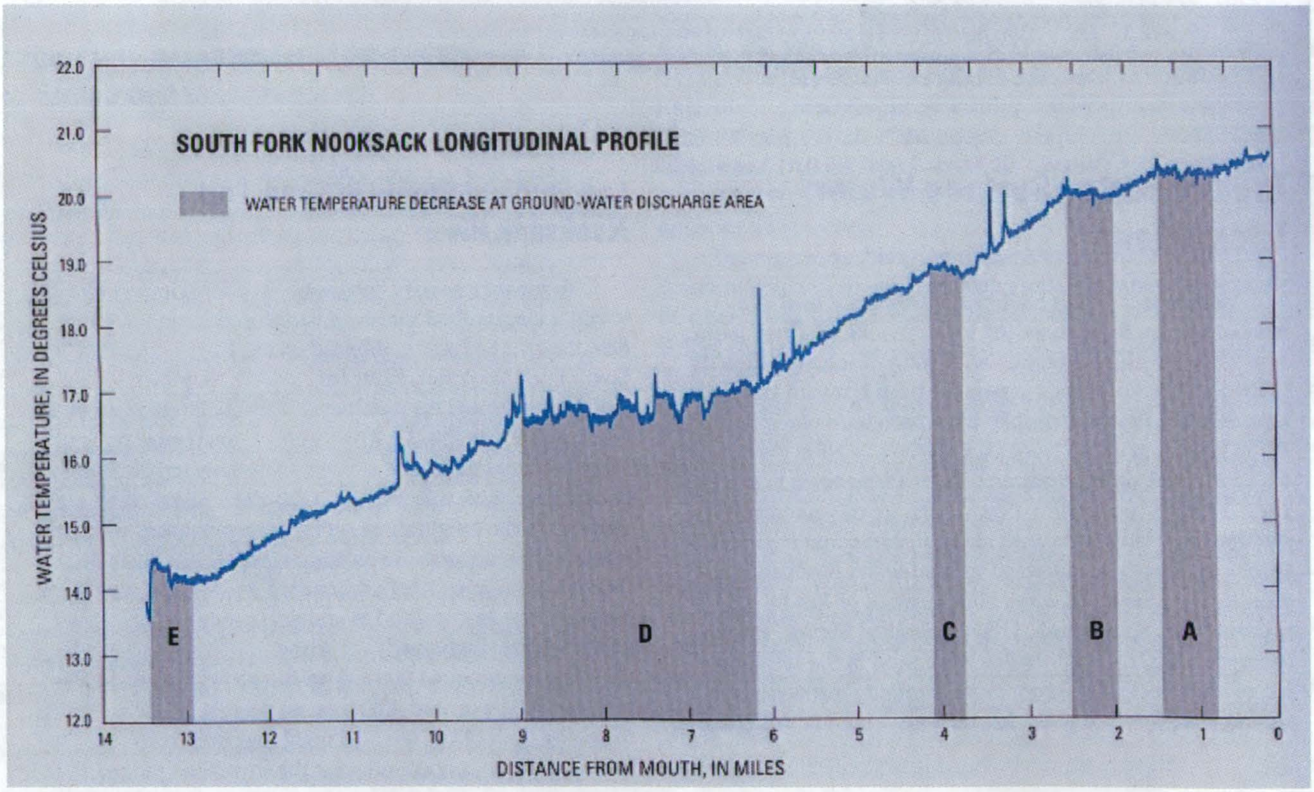


FIGURE 4-1 SOUTH FORK NOOKSACK RIVER LONGITUDINAL WATER TEMPERATURE PROFILE AT RIVER BOTTOM, FROM RIVER MILE 13.5 TO CONFLUENCE WITH NORTH FORK, AUGUST 28, 2003

The Fishtrap Creek longitudinal profile consisted of repeated hydraulic gradient measurements at nine points along the Creek length from September 2002 through July 2004. The measured hydraulic gradients indicate a relatively consistent positive hydraulic gradient pattern throughout the data collection period, with some notable exceptions. PZF-6, located in the Lynden Municipal Park showed a consistent negative gradient, whereas the remainder of Fishtrap Creek showed a predominant positive gradient. The PZF-6 mini-piezometer used for measurement of groundwater elevation and water quality data collection was installed each time that a measurement was made, because the park location was used for recreation purposes. If the mini-piezometer was left in place between measurements it would have interfered with recreational activities at the park. The repeated installation, and potential for poor seal between sediments and piezometer pipe may have contributed to the negative gradients measured.

The hydraulic gradient measurements on Fishtrap Creek reveal a general pattern of groundwater discharging along the length of the Creek. The noticeable exception is the decrease or reversal in gradient at most of the monitored sites for the September 2002, July 2003 and July 2004 dates, likely associated with low groundwater elevation from the minimal rainfall typical received during the summer and early fall.

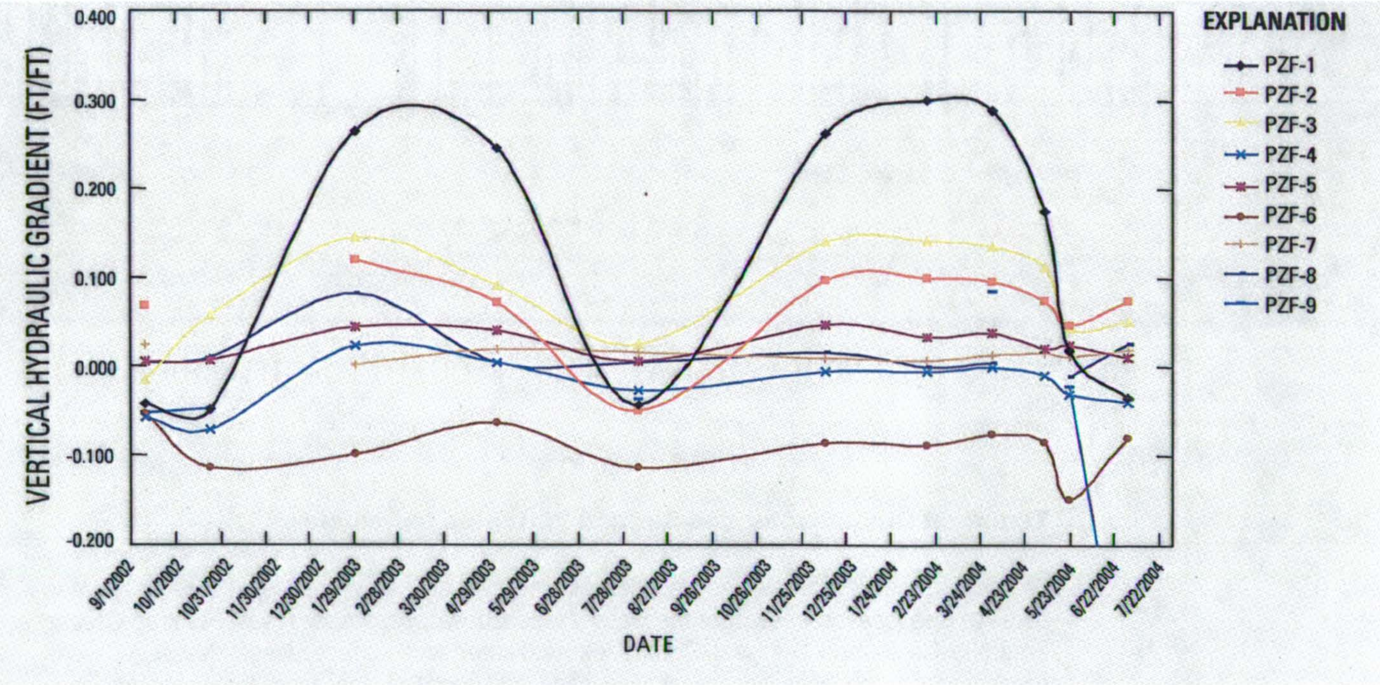


FIGURE 4-2 LONGITUDINAL HYDRAULIC GRADIENT PROFILE OF FISHTRAP CREEK COLLECTED AT NINE POINTS ALONG THE CREEK LENGTH BETWEEN SEPT 2002 AND JULY 2004

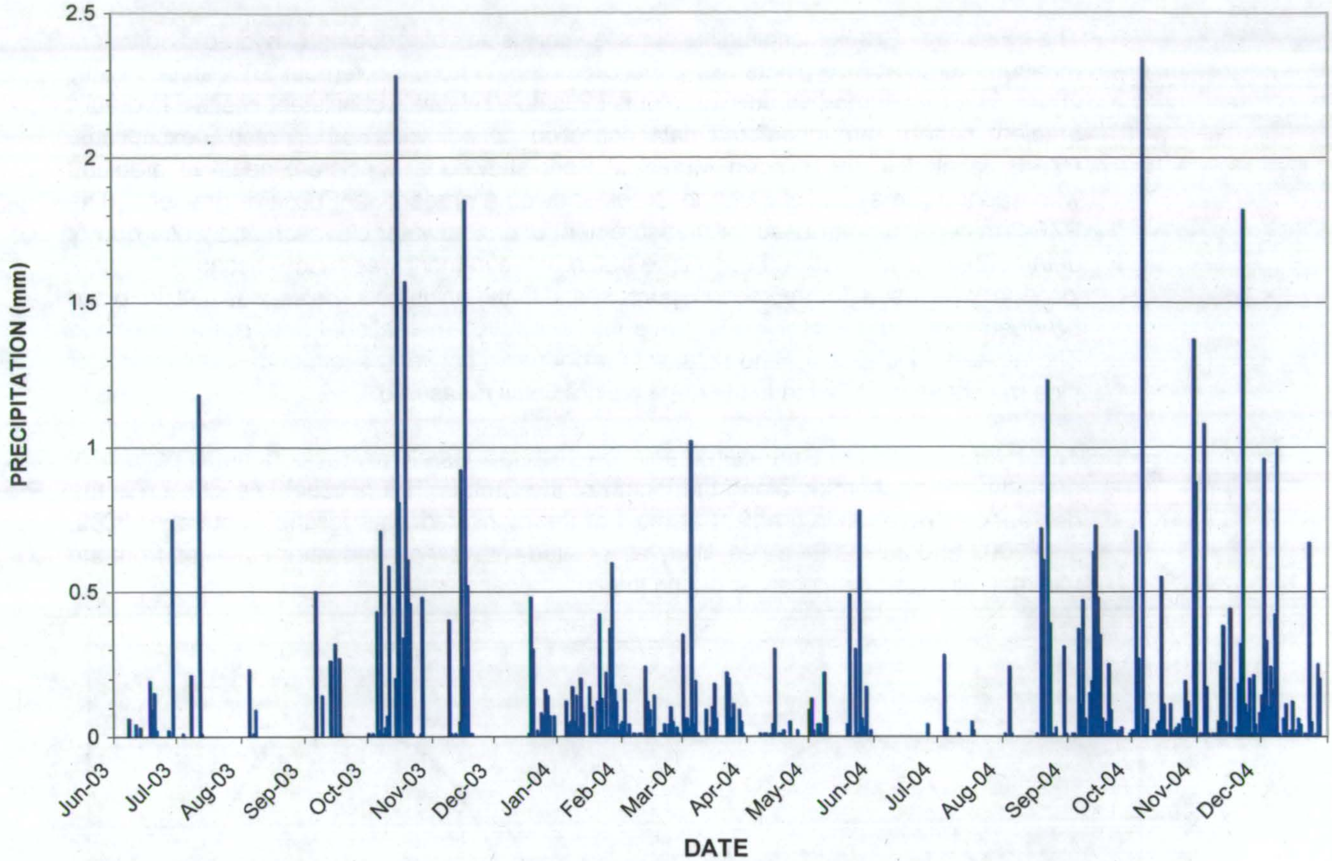


FIGURE 4-3 PRECIPITATION MEASURED AT THE EVERSON SITE FOR THE PROJECT DURATION

Temporal Groundwater and Surface Water Measurements

Temporal profiles illustrate the variations in groundwater elevations over time in greater detail at one location in each of the watersheds studied: Nooksack River, Fishtrap Creek, Fourmile Creek and Bertrand Creek. Groundwater and surface water elevations were measured at the detailed monitoring sites at each of the four rivers or streams characterized. Elevations were measured in relation to a datum established at each site. The hydraulic gradient was calculated by subtracting the measured surface water elevation from the measured groundwater elevation and dividing by the difference between the elevation of the piezometer screen mid-point and the streambed elevation. The period of measurement varies between sites, although measurements were collected at all sites from March through November 2004. The main stem Nooksack River was monitored starting in September 2002 (Figure 4-4); Fourmile Creek from November 2003 through October 2004 (Figure 4-5); the Bertrand Agricultural Ditch was monitored from March through October 2004 (Figure 4-6); and Fishtrap Creek from March 2003 through November 2004 (Figure 4-8).

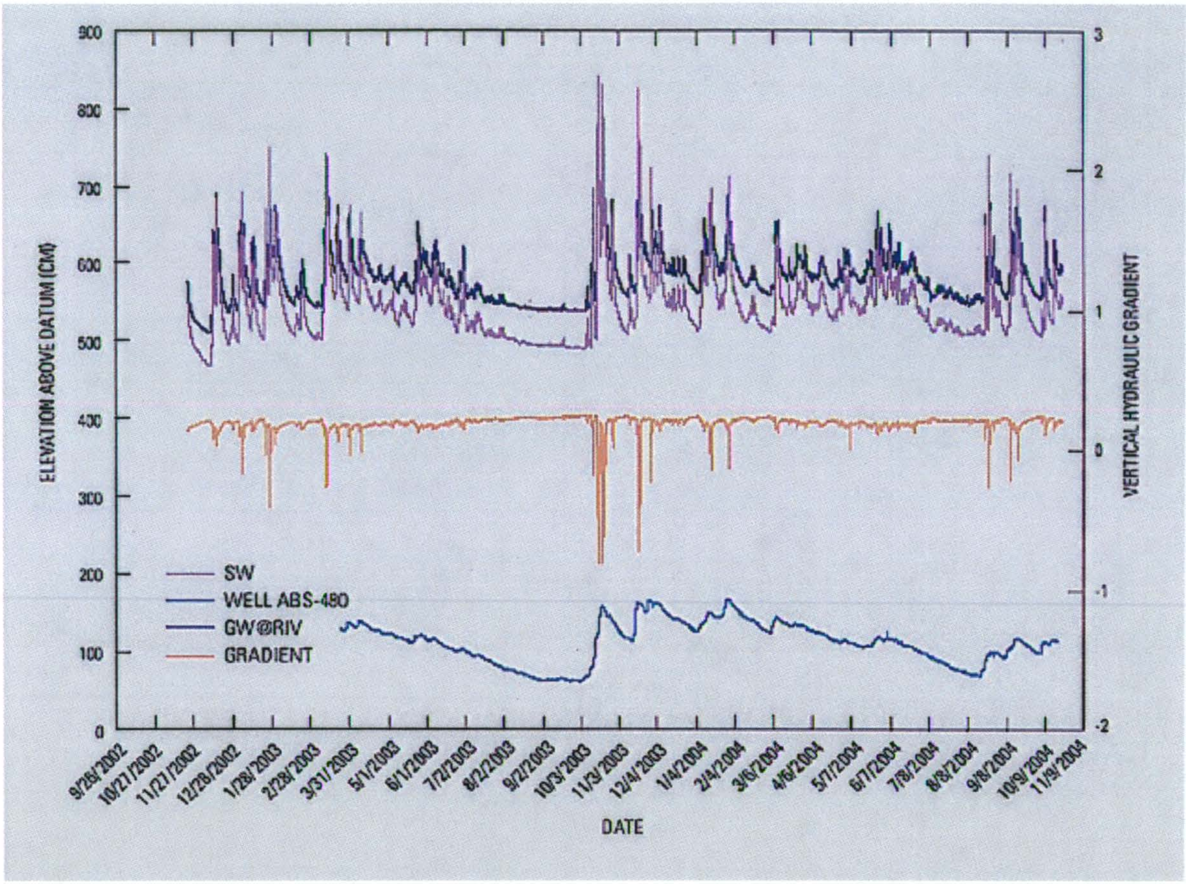


FIGURE 4-4 NOOKSACK RIVER GROUNDWATER AND SURFACE WATER ELEVATIONS MEASURED BETWEEN AUGUST 2002 AND NOVEMBER 2004 NEAR RIVER MILE 26, AND GROUNDWATER ELEVATION AT AN UPGRADIENT WELL LOCATED APPROXIMATELY ONE HALF MILE EAST OF THE NOOKSACK RIVER, AT RIVER MILE 27.

Everson Site, Nooksack River

Groundwater elevation measured in the Nooksack River hyporheic zone varied between 500 and 850 cm above the datum, a range of almost 3.5 meters, with a similar range in the adjacent surface water elevation of approximately 4 meters. The hydraulic connection between shallow groundwater and surface water is evidenced in the measurements presented in Figure 4-4, with a close correlation also evident in the groundwater elevations measured at the ABS-480 well (about 2,500 feet from the river). For most of the monitored period the groundwater gradient is positive, indicating that water in the Nooksack River vicinity generally migrates from groundwater to surface water. The reversal of this pattern occurred during period of high river elevation (associated with higher discharge from precipitation events) during the high rainfall months of fall (October and November) and winter (January, February). Precipitation record for the same period is shown in Figure 4-3.

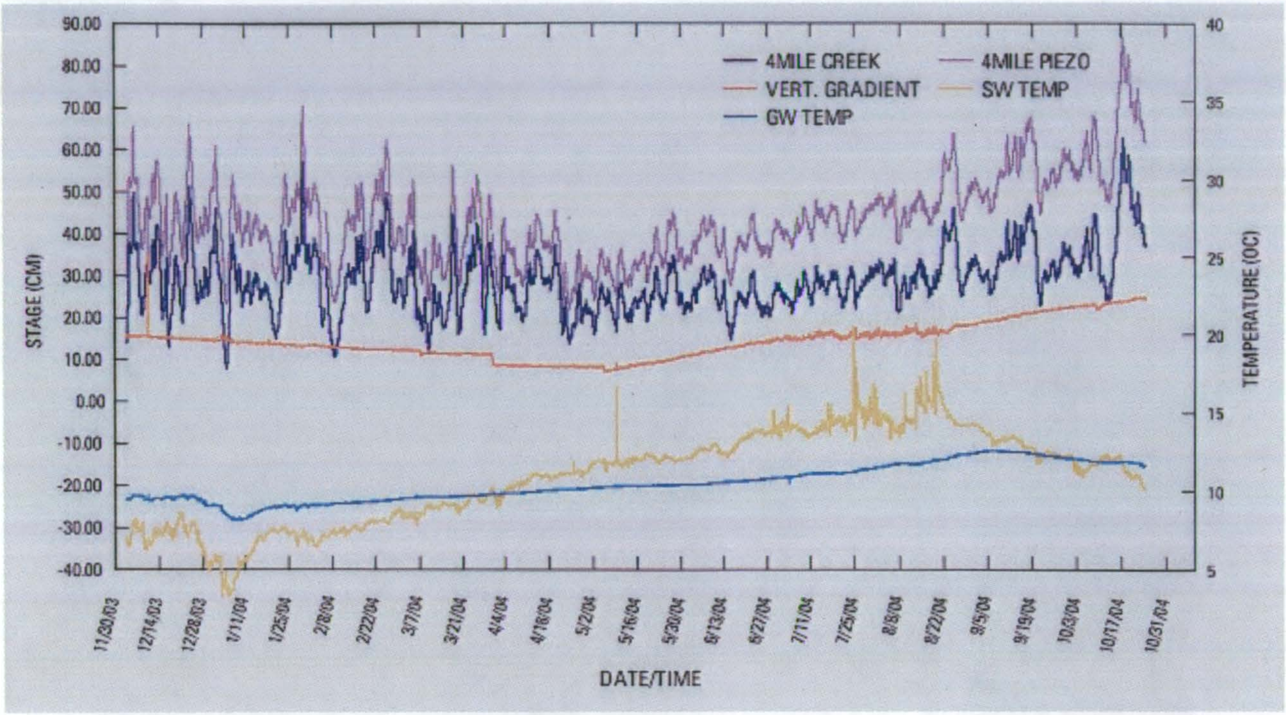


FIGURE 4-5 FOURMILE CREEK GROUNDWATER, SURFACE WATER ELEVATIONS AND TEMPERATURES, AND THE HYDRAULIC GRADIENT MEASURED FROM NOVEMBER 2003 THROUGH OCTOBER 2004

Fourmile Creek

Water levels in the Fourmile Creek about one mile upstream of the Creek mouth were measured from November 2003 through October 2004 (as shown in Figure 4-5). Water levels shown in Figure 4-5 are in relation to a site datum, and do not represent the actual elevations of Fourmile Creek. The surface water level varied over a range of 55 centimeters, and the groundwater level measured in the hyporheic zone adjacent to Fourmile Creek varied between over a range of 70 centimeters. The hydraulic gradient remained positive over the entire monitored period, indicating consistent and constant groundwater discharge to Fourmile Creek. The groundwater temperatures show a smooth variation and small range, supporting the interpretation that groundwater maintained a discharging flow direction throughout the monitored period. The higher variability in surface water temperatures is not reflected in the groundwater temperatures measured.

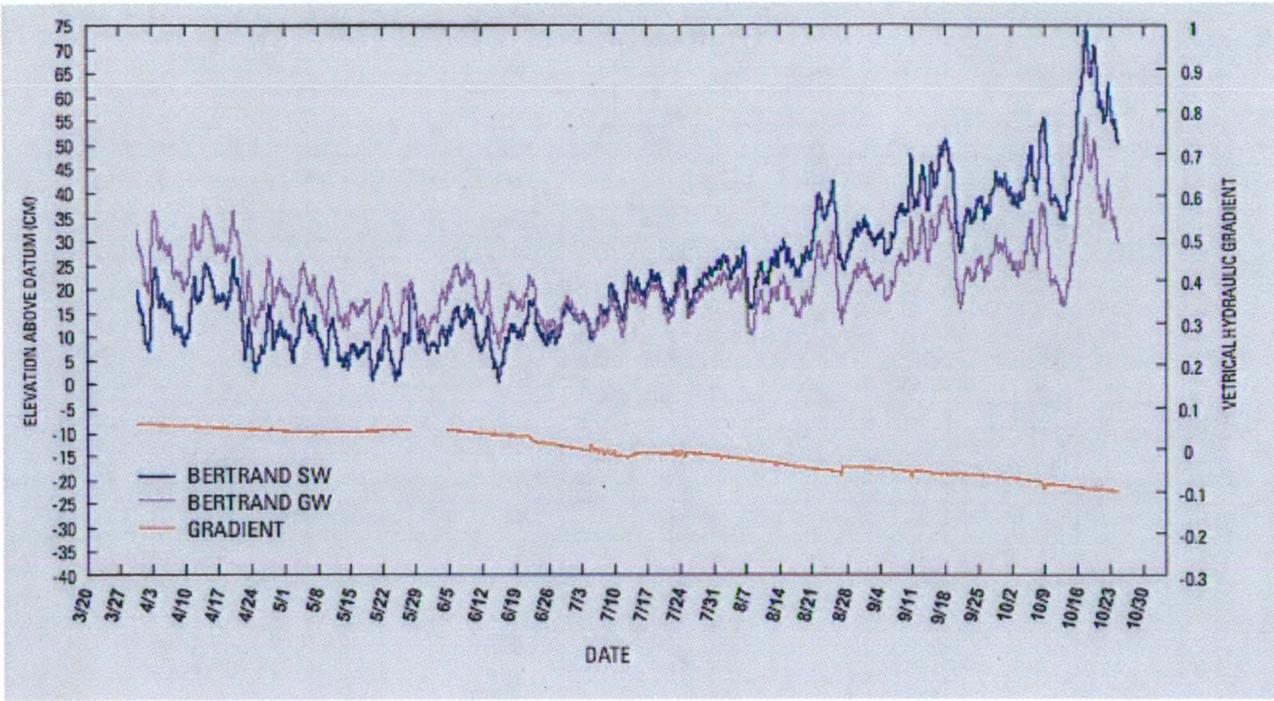


FIGURE 4-6 BERTRAND AGRICULTURAL DRAINAGE DITCH WATER LEVELS, SHALLOW GROUNDWATER LEVELS, AND HYDRAULIC GRADIENT, MEASURED FROM MARCH TO OCTOBER 2004.

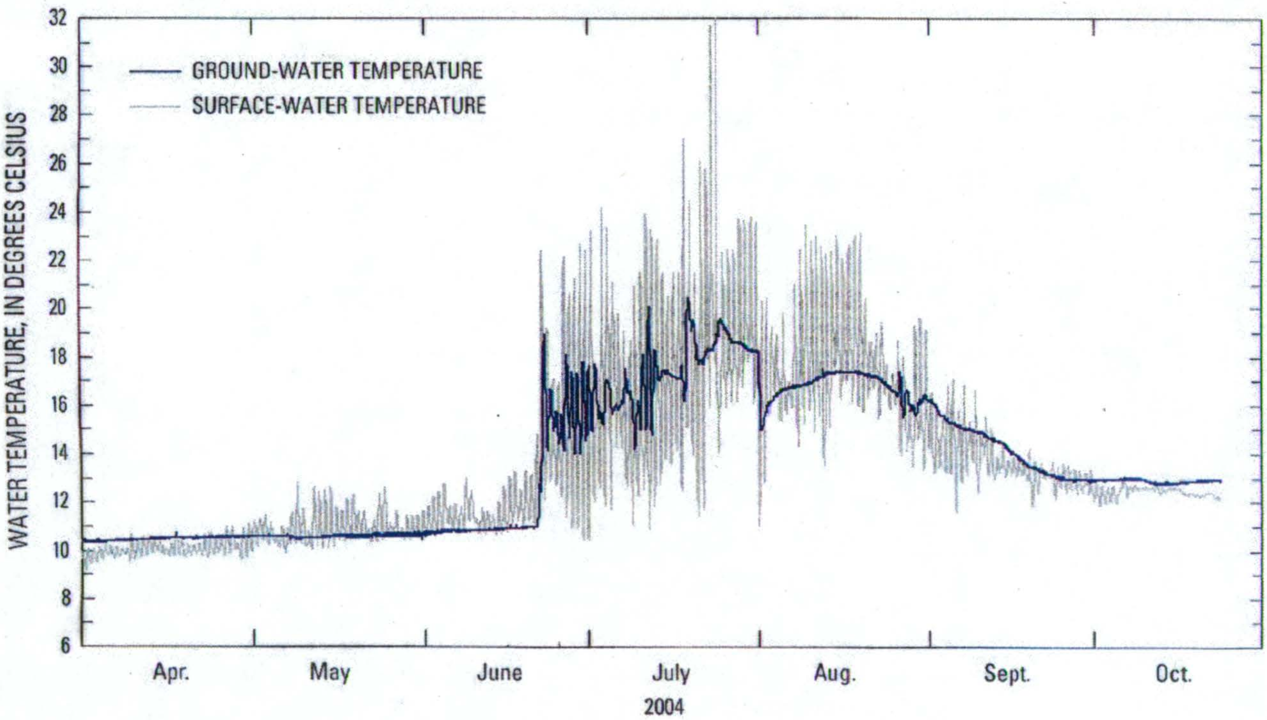
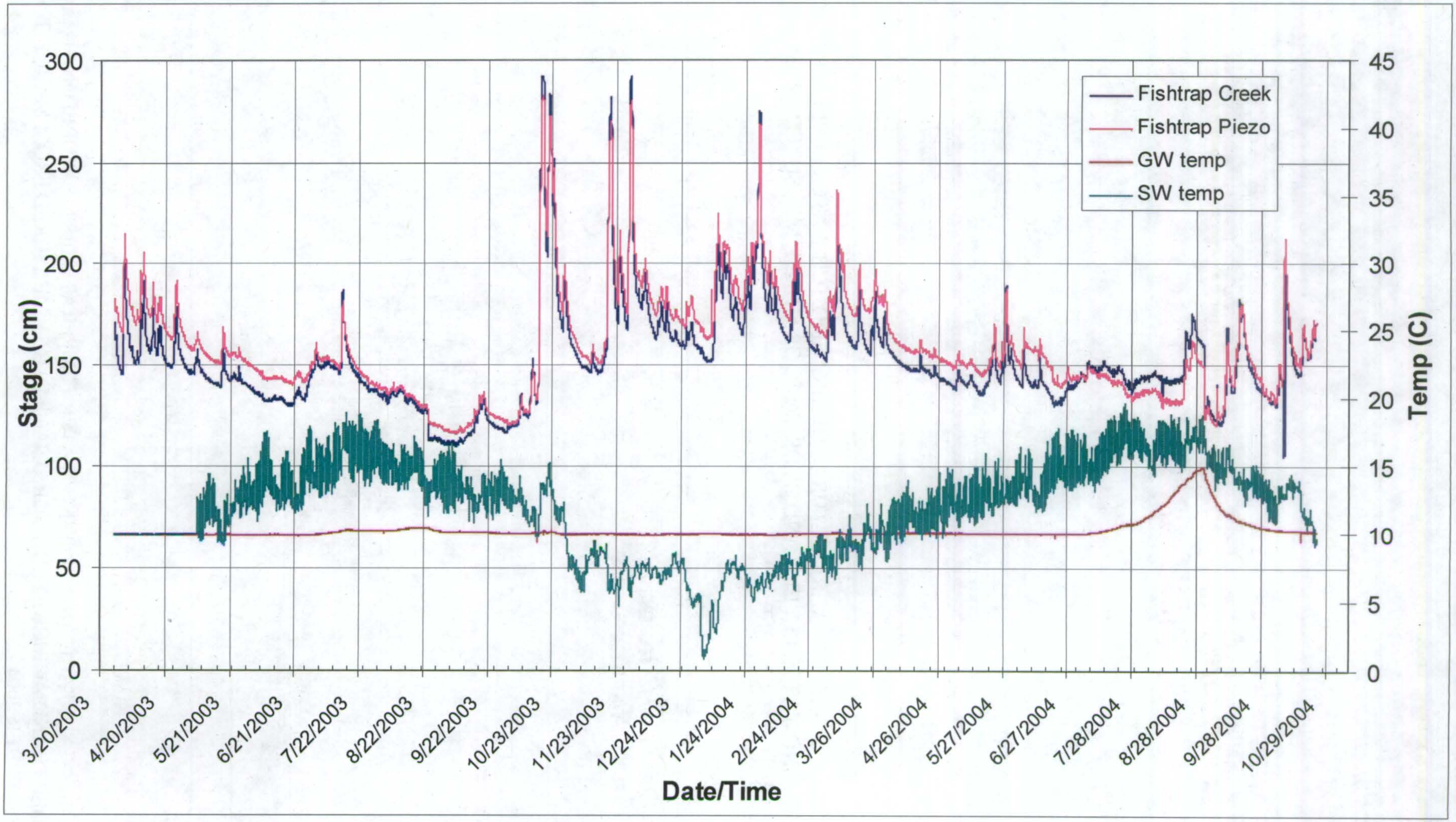


FIGURE 4-7 SURFACE AND GROUND WATER TEMPERATURES MEASURED IN BERTRAND AGRICULTURAL DRAINAGE DITCH, MEASURED FROM MARCH TO OCTOBER 2004.

FIGURE 4-8 FISHTRAP CREEK HYDRAULIC GRADIENT AND WATER TEMPERATURES MEASURED AT PANGBORN ROAD BRIDGE, MARCH 2003 TO OCTOBER 2004



Bertrand Creek agricultural drainage ditch

The water levels measured in the agricultural drainage ditch in the Bertrand Creek watershed are shown in Figure 4-6. Water levels measured in the drainage ditch varied over a range of about 50 cm, and the groundwater level varied over a 0.75 meter range. Over the March to October period monitored, the hydraulic gradient declined, with the transition to a negative gradient (surface water discharging to groundwater) around June 20. Because the monitoring equipment drifted over the monitored period, the magnitude of the gradient presented in Figure 4-6 may be considered as an indicator, and not an absolute value. The hydraulic gradient remained negative through October. The water temperature for the surface water and groundwater (shown in Figure 4-7) indicates that hydraulic communication from surface water to ground water continued through to the end of the monitored period (October 2003).

Fishtrap Creek

The groundwater and surface water levels in Fishtrap Creek illustrated on Figure 4-8 were measured from March 2003 through October 2004. They show a positive groundwater gradient for the most part. The gradient reverses during high flow events, where high surface water runoff induces groundwater infiltration for short periods (October through December 2003, and February 2004). In addition, the groundwater gradient reversed during low stream flow conditions briefly in July 2003 and from July through early September 2004. The reversal in gradients appears to be of either short enough duration or small enough magnitude that the groundwater temperatures monitored for the most part do not reflect the influence of surface water. However, the gradual increase in groundwater temperature during the summer of 2004 suggests that surface water consistently infiltrated to groundwater throughout late July, August and September 2004.

Near the Assink monitored site debris accumulation was observed in August 2004 that dammed stream flow, causing a pond to form and the water level to rise. The increased water level may have caused the reversal in the hydraulic gradient observed. The pond formation may have increased surface water infiltration to groundwater and the increase in groundwater temperature observed during late summer 2004. The unique nature of the groundwater temperature change, where the temperature gradually increases over an extended period, suggests a different mechanism for ground water–surface water communication than that observed at other sites monitored for this project. Formation of a pond might be unique in its affect on the movement of water between groundwater and surface water.

Groundwater Quality Data

Water quality data was collected from groundwater discharging to surface water and the receiving surface water body at all locations characterized. One location was characterized for nitrate fate and transport along a groundwater flow pathway: the Everson site. Three locations were sampled to delineate spatial variations in groundwater discharge to surface water and the associated groundwater chemistry and bacteria content: the Assink site on Fishtrap Creek; the agricultural drainage ditch draining to Bertrand Creek; and the Fourmile Creek site. Groundwater and surface water quality were characterized at the nine sample locations along the length of Fishtrap Creek.

Everson Site Groundwater Pathway Characterization

Data collected along a groundwater pathway originating in an agricultural field and discharging to the Nooksack River at the Everson Site is presented in Table 4-3. Field measurements of dissolved oxygen, temperature, pH, specific conductance, nitrate and ferrous iron content in groundwater and surface water were collected from August through December 2004. Soil nitrate content and temperature data were collected in adjacent fields over the same period (as described in the section that follows). Nitrate concentrations in groundwater ranged from 0.05 to 4.1 mg/l, and in surface water from 0.55 to 2.1 mg/l, with an average groundwater nitrate concentration of 1.23 mg/l, and a surface water average of 1.65 mg/l. Total Kjeldahl Nitrogen in groundwater ranged from .05 to 0.56 mg/l, with an average content of 0.16. TKN measured in surface water ranged from 0.05 to 0.31 mg/l, with an average value of 0.136. Comparison of groundwater and surface water nitrate and TKN concentrations shows a similar range in concentrations

Surface water dissolved oxygen ranged from 4.1 to 8.0 mg/l, with an average value of 5.4. Groundwater dissolved oxygen content was measured between 0.1 and 4.1 mg/l, with an average measured value of 0.73 mg/l.

Table 4-1 Field measurements of groundwater and surface water quality at the Everson Site, February 2003 through December 2004

SiteID	Date	Water Level (ft)	Temp (C)	DO (mg/L)	Spec C uS/cm	pH	NO_3 (mg/L)	Fe^{+2} (mg/ L)
AFK176	12/28/04	92.2	10.65	0.1	442	6.82	0.05	–
AFK177	12/28/04	93.0	11.01	0.3	584	6.73	2.2	–
AFK178	12/28/04	92.5	10.15	0.25	584	6.73	0.05	–
AFK179	12/28/04	92.8	10.15	0.25	383	6.50	0.05	–
VNDW2-5	12/28/04	87.0	10.40	0.20	434	6.86	1.00	–
EVW2Port1	12/28/04	92.6	11.25	0.25	607	6.35	7.00	–
EVW2Port5	12/28/04	62	10.54	0.45	414	6.74	0.05	–
EVW2Port6	12/28/04	79	10.70	0.50	415	6.86	0.05	–
SW	12/28/04		9.00	3.15	212	6.93	1.30	–
AFK176	12/16/04	94.1	10.62	0.3	370	6.7	1.30	–
AFK177	12/16/04	94.0	10.97	0.4	452	6.7	0.05	–
AFK178	12/16/04	94.1	10.33	0.4	309	6.66	2.4	–
AFK179	12/16/04	94.3	10.73	0.4	418	6.58	0.05	–
VNDW2-5	12/16/04	87	9.96	0.2	368	6.71	1.2	–
EVW2Port1	12/16/04	92.6	11.61	0.2	515	6.47	7.9	–
EVW2Port5	12/16/04	62	10.38	0.2	344	6.81	0.05	–
EVW2Port6	12/16/04	79	10.64	0.2	355	6.72	0.05	–
SW	12/16/04		8.83	5.02	172	6.86	1.8	–
AFK176	11/30/04	93.3	10.4	0.1	400	6.72	1.4	–
AFK177	11/30/04	93.2	10.84	0.2	498	6.74	0.05	–
AFK178	11/30/04	93.3	10.14	0.6	314	6.76	2.4	–
AFK179	11/30/04	93.5	10.7	0.1	440	6.44	0.05	–
VNDW2-5	11/30/04	87	9.81	0.1	427	6.78	1.5	–

SiteID	Date	Water Level (ft)	Temp (C)	DO (mg/L)	Spec C uS/cm	pH	NO_3 (mg/L)	Fe^{+2} (mg/ L)
EVW2Port1	11/30/04	92.6	11.68	0.3	620	6.4	7.2	–
EVW2Port5	11/30/04	62	10.34	0.2	380	6.89	0.05	–
EVW2Port6	11/30/04	79	10.7	0.2	392	6.8	0.05	–
SW	11/30/04		9.19	4.51	209	6.75	2.1	–
AFK176	11/15/04	92.4	10.57	<1.0	360	6.79	1.6	–
AFK177	11/15/04	92.30	11.04	<1.0	403	6.83	0.05	–
AFK178	11/15/04	92.5	10.35	<1.0	276	6.76	2.5	–
AFK179	11/15/04	92.61	11.03	<1.0	435	6.61		–
VNDW2-5	11/15/04	87	10.28	<1.0	355	6.95	1.6	–
EVW2Port1	11/15/04	92.6	12.15	<1.0	621	6.65	4.1	–
EVW2Port5	11/15/04	62	10.53	<1.0	348	6.93	0.05	–
EVW2Port6	11/15/04	79	10.73	<1.0	359	6.86	0.05	–
SW	11/15/04		9.73	5.35	195	6.99	2.2	–
AFK176	11/3/04	94.34	10.63	0.51	343	6.77	1.7	–
AFK177	11/3/04	94.15	11.14	0.63	385	6.78	0.05	–
AFK178	11/3/04	94.44	10.42	0.98	291	6.76	2.6	–
AFK179	11/3/04	94.46	11.08	0.71	402	6.78	0.05	–
VNDW2-5	11/3/04	87	9.92	0.65	346	6.79	1.7	–
EVW2Port1	11/3/04	92.6	12.28	0.62	389	6.73	0.05	–
EVW2Port5	11/3/04	62	10.69	0.43	350	6.84	0.05	–
EVW2Port6	11/3/04	79	10.54	0.44	349	6.89	0.05	–
SW	11/3/04		9.37	4.12	160	6.82	1.3	–
AFK176	10/20/04	92.04	10.88	0.54	347	6.7	1.8	–
AFK177	10/20/04	91.90	11.36	0.34	408	6.76	0.05	–
AFK178	10/20/04	92.04	10.65	0.8	273	6.74	2.6	–
AFK179	10/20/04	92.21	11.83	0.8	413	6.82	0.05	–
EVW2Port1	10/20/04	92.6	12.5	0.6	391	6.74	0.05	–
EVW2Port5	10/20/04	62	10.92	0.62	350	6.86	0.05	–
EVW2Port6	10/20/04	79						–
SW	10/20/04		10.26	7.97	198	7.15	2.1	–
AFK168	8/25/04	92.81	10.64	1.86	231	6.61	3.1	–
AFK169	8/25/04	93.36	13.26	2.55	437	6.62	0.092	–
AFK170	8/25/04	94.30						–
AFK171	8/25/04	94.24	10.73	2.00	214	6.44	3.1	–
AFK172	8/25/04	93.94	11.59	2.35	510	6.65	3.2	–
AFK173	8/25/04	93.96	11.54	1.59	493	6.68	0.77	–
AFK174	8/25/04	93.92	10.69	4.07	482	6.61	3.8	–
AFK175	8/25/04	94.77	11.23	1.43	229	6.58	2.9	–
AFK176	8/25/04	93.89	11.13	0.4	338	6.81	1.9	–
AFK177	8/25/04	93.75	11.34	0.5	397	6.80	0.05	–
AFK178	8/25/04	93.99	11.34	0.4	282	6.71	2.6	–
AFK179	8/25/04	93.98	12.16	0.6	418	6.69	0.05	–

SiteID	Date	Water Level (ft)	Temp (C)	DO (mg/L)	Spec C uS/cm	pH	NO_3 (mg/L)	Fe^{+2} (mg/ L)
EVW2Port1	8/25/04	92.6	12.22	0.64	410	6.67	0.05	–
EVW2Port5	8/25/04	62	11.45	0.6	351	6.95	0.05	–
EVW2Port6	8/25/04	79	10.93	0.68	355	6.78	0.05	–
SW	8/25/04						0.55	–
AFK-168	5/6/04	–	10.5	<0.1	252	–	–	<0.10
AKF-169	5/6/04	–	–	–	–	–	–	–
AFK-170	5/6/04	–	10.4	>1.0	249	–	–	<0.10
AFK-172	5/6/04	–	10.5	1	267	–	–	<0.10
AFK-173	5/6/04	–	10.3	1	327	–	–	0.96
AFK-174	5/6/04	–	10.6	1	266	–	–	<0.10
AFK-175	5/6/04	–	10.4	1	258	–	–	<0.10
AFK-176	5/6/04	–	10.3	0.05	406	–	–	<0.10
AFK-177	5/6/04	–	9.9	0.2	507	–	–	<0.10
AFK-178	5/6/04	–	10.9	0.2	348	–	–	<0.10
AFK-179	5/6/04	–	10.1	<0.10	473	–	–	1.7
EVW1Port3	5/6/04	–	10.5	0.10	355	–	–	<0.10
EVW1Port4	5/6/04	–	10.4	0	340	–	–	0.05
EVW1Port5	5/6/04	–	10.4	0.1	341	–	–	<0.10
EVW2Port1	5/6/04	–	10.1	0.1	488	–	–	0.01
EVW2Port5	5/6/04	–	10.8	0.1	363	–	–	0.02
EVW2Port6	5/6/04	–	10.6	0	371	–	–	0.01
VNDW1-5	5/6/04	–	10.5	–	399	–	–	0.02
VNDW2-5	5/6/04	–	11.1	0.8	270	–	–	0.01
AFK-168	4/1/04	–	10.0	>1.0	249	–	–	–
AFK-170	4/1/04	–	10.1	>1.0	246	–	–	–
AFK-172	4/1/04	–	10.1	0.8	264	–	–	< 1.00
AFK-173	4/1/04	–	9.6	0.2	349	–	–	1
AFK-174	4/1/04	–	10.2	0.9	254	–	–	0
AFK-175	4/1/04	–	10.5	>1.0	259	–	–	0
AFK-176	4/1/04	–	10.3	0.1	400	–	–	0
AFK-177	4/1/04	–	9.6	0.2	503	–	–	0
AFK-178	4/1/04	–	10	0.04	347	–	–	0
AFK-179	4/1/04	–	9.6	0.2	470	–	–	6
EVW1Port3	4/1/04	–	10.1	0.1	354	–	–	0
EVW1Port4	4/1/04	–	9.9	0	338	–	–	0.1
EVW1Port5	4/1/04	–	9.1	0.05	338	–	–	0
EVW2Port1	4/1/04	–	9.4	0.1	666	–	–	0
EVW2Port5	4/1/04	–	10.1	0.3	328	–	–	0.2
EVW2Port6	4/1/04	–	10.3	0.1	367	–	–	0.1
VNDW1-5	4/1/04	–	–	0.2	–	–	–	0
VNDW2-5	4/1/04	–	–	0.6	–	–	–	0
AFK-168	12/4/03	–	10	>1.0	250	–	–	0

SiteID	Date	Water Level (ft)	Temp (C)	DO (mg/L)	Spec C uS/cm	pH	NO_3 (mg/L)	Fe^{+2} (mg/ L)
AFK-169	12/4/03	–	9.6	–	442	–	–	–
AFK-170	12/4/03	–	10.1	1	250	–	–	0.1
AFK-172	12/4/03	–	10.2	1	259	–	–	0
AFK-173	12/4/03	–	10.7	0.2	333	–	–	0.8
AFK-174	12/4/03	–	10	>1.0	258	–	–	< 0.10
AFK-175	12/4/03	–	10.2	1	254	–	–	< 0.10
AFK-176	12/4/03	–	10.3	<0.1	382	–	–	0
AFK-177	12/4/03	–	9.4	0.2	465	–	–	< 0.10
AFK-178	12/4/03	–	10	0.2	310	–	–	< 0.10
AFK-179	12/4/03	–	10.7	0	480	–	–	3
VNDW2-5	12/4/03	–	9.5	1	260	–	–	–
AFK-169	2/24/03	–	10.4	0.04	293	–	–	–
AFK-176	2/24/03	–	10.5	0.05	296	–	–	–
AFK-177	2/24/03	–	10.1	0.03	334	–	–	–
AFK-178	2/24/03	–	9.9	0.1	249	–	–	–

Results of analyses for anions and cations for the Everson site sample access points are shown in Table 4-2. The concentrations of both the anions and cations are fairly uniform across this site, with concentrations generally ranging between 5 and 55 mg/L. Potassium concentrations were consistently measured between 1 and 2 mg/L. Sulfate content varied more than other constituents measured, ranging from 16 to 72 mg/L. Nutrient content for this site was the highest of any sites measured, nitrate was detected at concentrations up to 7.9 mg/L in shallow groundwater (screen depth at 12 feet below ground surface) monitored in the agricultural field (EVW2 Port1).

Analyses for bacteria for the most part found not detections, with two exceptions. Of 46 groundwater analyses, bacteria was detected only on December 4, 2004 in the VNDW2-5 mini-piezometer accessing the aquifer directly underlying the shoreline of the Nooksack River, and on the same date in the monitoring well AFK-169 (VNDW1-2). Both samples were collected on the same day, and are relatively close to each other (although not likely to be in the same groundwater flow path), suggesting the potential for contamination of sampling equipment at the time the samples were collected.

Measurements of Spatial Variation in Groundwater Discharge

Fourmile Site

The grid of six mini-piezometers accessing the shallow groundwater surrounding Fourmile Creek was sampled over the period from March through October 2004. The grid was located approximately one mile upstream of the Fourmile Creek confluence with Tenmile Creek. It was configured in two lines of three mini-piezometers crossing Fourmile Creek, similar to the grid installed at the Assink Site. The two lines were located approximately 100 feet apart. Hydraulic gradient measurements are shown in Table 4-3 and water quality data is shown in Table 4-4.

Groundwater has slightly different constituent concentrations than those measured at the Assink, Everson and Bertrand Sites. The specific conductance is generally higher than the other sites monitored, which is expressed in the higher calcium, sodium and chloride concentrations measured. Also unique to this site are higher carbonate and pH values. Nutrient concentrations are consistently low, with the exception of nitrate in the discharge from the downstream tile drain May and June 2004. Ferrous iron content measured in the field ranges from 0 to over 10 mg/L, with one laboratory determination exceeding 22 mg/L. Dissolved oxygen concentrations in groundwater are consistently low, measured between 0 and 0.3 mg/L.

Table 4-2 Everson Site laboratory analyzed ground water and surface water quality data

Site Name	DATES	pH	Calcium	Magnesium	Potassium	Sodium	Chloride	Silica	Sulfate	Ammonia	NO2+ NO3	Orthophosphate	Phosphorus	Total nitrogen	organic carbon	E. coli, Coliler	Iron	Manganese
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	mg/L	MPN/ 100mL	ug/L	ug/L
AFK-179	2/24/03	7.4	17.8	11.1	1.16	5.28	5.94	19.7	16.7	<.04	2.61	<.02	<.04	–	0.4	–	18	6.8
AFK-178	2/24/03	7.2	21.9	21.1	1.68	8.11	9.81	28.3	29.8	<.04	2.64	E .01	<.04	–	0.6	–	<10	<2.0
AFK-177	2/24/03	7.3	13.3	40.7	1.91	10.3	11.4	29.1	62.3	<.04	<.06	<.02	<.04	–	1.3	–	24	122
AFK-176	2/24/03	7.2	25.1	26.7	1.82	9.35	12.3	31.4	41.2	<.04	1.61	0.02	E .03	–	1.1	–	<10	94.2
AFK-169	2/24/03	7.2	25.2	26.2	1.86	9.24	12	31.5	40.9	<.04	1.62	E .02	E .02	–	1	–	E 8	63.9
AFK-168	2/24/03	7.2	25.6	26.3	1.86	9.24	12	31.9	41.2	<.04	1.6	E .02	E .03	–	1	–	E 5	74.8
AFK-168	12/4/03	–	–	–	–	–	–	–	–	<.04	3.15	0.008	0.012	3.34	–	<1	–	–
AFK-169	12/4/03	–	–	–	–	–	–	–	–	<.04	0.2	E .004	0.009	0.38	–	25	–	–
AFK-170	12/4/03	–	–	–	–	–	–	–	–	<.04	3.17	E .036	0.047	3.19	–	<1	–	–
AFK-172	12/4/03	–	–	–	–	–	–	–	–	<.04	2.85	0.01	0.012	2.88	–	<1	–	–
AFK-173	12/4/03	–	–	–	–	–	–	–	–	<.04	0.23	<.006	<.004	0.31	–	<1	–	–
AFK-174	12/4/03	–	–	–	–	–	–	–	–	<.04	3.14	0.022	0.042	3.17	–	<1	–	–
AFK-175	12/4/03	–	–	–	–	–	–	–	–	<.04	2.73	0.007	0.015	2.79	–	<1	–	–
AFK-176	12/4/03	–	–	–	–	–	–	–	–	<.04	1.43	0.016	0.021	1.58	–	<1	–	–
AFK-177	12/4/03	–	–	–	–	–	–	–	–	<.04	<.06	<.006	E .003	0.1	–	<1	–	–
AFK-178	12/4/03	–	–	–	–	–	–	–	–	<.04	2.49	0.015	0.026	2.6	–	<1	–	–
VNDW2-5	12/4/03	–	–	–	–	–	–	–	–	<.04	2.93	0.012	0.012	3	–	34	–	–
VNDW2-5	9/28/04	–	–	–	–	–	–	–	–	<.04	1.82	–	–	1.93	–	–	–	–
VNDW2-5	10/25/04	–	–	–	–	–	–	–	–	–	1.80	–	–	–	–	–	–	–
VNDW2-6	9/28/04	–	–	–	–	–	–	–	–	<.04	1.81	–	–	1.93	–	–	–	–
VNDW2-6	10/25/04	–	–	–	–	–	–	–	–	–	1.82	–	–	–	–	–	–	–
EVW1 PORT3	4/1/04	7.3	29.6	21.9	–	8.34	11.5	27.9	36.4	<.04	2.96	0.012	0.015	3.06	–	<1	30	41.5
EVW1 PORT4	4/1/04	7.1	26.6	22.2	–	8.15	11	24.7	30.9	0.07	<.06	0.065	0.075	0.23	–	–	61	72.1
EVW1	4/1/04	7.4	26.9	22.4	–	8.28	10.8	25	31.1	<.04	0.64	<.006	< .004	0.65	–	–	13	78.4

Site Name	DATES	pH	Calcium	Magnesium	Potassium	Sodium	Chloride	Silica	Sulfate	Ammonia	NO2+ NO3	Orthophosphate	Phosphorus	Total nitrogen	organic carbon	E. coli, Coliler	Iron	Manganese
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	mg/L	MPN/ 100mL	ug/L	ug/L
PORT5																		
EVW2 PORT1	4/1/04	7	33.2	30.7	--	53.2	20.1	32.4	72	0.17	0.86	0.006	0.01	1.05	--	<1	11	922
EVW2 PORT1	9/28/04	--	--	--	--	--	--	--	--	0.14	0.34	--	--	0.62	--	--	--	--
EVW2 PORT1	10/25/04	--	--	--	--	--	--	--	--	--	0.16	--	--	--	--	--	--	--
EVW2 PORT5	4/1/04	7.1	26	26.5	--	9.45	10.8	31.5	38.2	0.05	<.06	0.027	0.035	0.12	--	<1	50	1050
EVW2 PORT5	9/28/04	--	--	--	--	--	--	--	--	0.07	<.06	--	--	0.21	--	--	--	--
EVW2 PORT5	10/25/04	--	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--
EVW2 PORT6	4/1/04	7.3	23.8	26.6	--	9.68	11.4	31.7	41.6	<.04	0.49	<.006	E.002	0.55	--	--	42	1110
EVW2 PORT6	9/28/04	--	--	--	--	--	--	--	--	E 0.03	<.06	--	--	0.14	--	--	--	--

Table 4-3 Fourmile Creek site hydraulic gradient measured between groundwater and Creek

Site name	Date	Average head difference (cm)	Average gradient	Temp (C)
FMPZ-1	Feb 6, 04	6.70	.04	8.7
	Mar 30, 04	5.44	.03	9.8
	May 5, 04	4.38	.02	13.3
	May 28, 04	3.53	.02	11
FMPZ-2	Feb 6, 04	3.15	.02	9.5
	Mar 30, 04	2.46	.02	9.8
	May 5, 04	2.38	.02	13.2
	May 28, 04	2.73	.02	12.5
FMPZ-3	Feb 6, 04	3.93	.03	9.5
	Mar 30, 04	3.05	.02	10.1
	May 5, 04	2.52	.02	12.5
	May 28, 04	2.83	.02	12.5
FMPZ-4	Feb 6, 04	3.65	.02	9.4
	Mar 30, 04	3.65	.02	9.5
	May 5, 04	3.30	.02	12.8
	May 28, 04	5.78	.04	11.8
FMPZ-5	Feb 6, 04	3.92	.03	8.5
	Mar 30, 04	2.73	.02	11.0
	May 5, 04	2.65	.02	13.4
	May 28, 04	5.57	.04	13.9
FMPZ-6	Feb 6, 04	2.27	.01	9.0
	Mar 30, 04	2.40	.01	11.0
	May 5, 04	2.10	.01	12.0
	May 28, 04	2.03	.01	12.6

Table 4-4 Fourmile Creek ground water and agricultural (tile) drain water quality data

SITE NAME	DATES	Dissolved O_2	pH	Spec Cond lab	Spec cond, fld	Temp water	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2+ NO3	Nitrite	Total Nitrogen	Orthophosphate	Phosphorus	E. coli, Coliler	Iron (II), fld	Iron lab	Manganese
		mg/L		uS/cm	uS/cm	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	MPN/ 100mL	mg/L	ug/L	ug/L
FMPZ-1 Left Bank down stream	3/30/04	0																		<1	>10.0		
	5/6/04																			<1	–		
	5/28/04		7.1	742			75.3	40.4	27.1	183	71.8	17.5	111	0.15	<.06	<.008	0.72	<.006	0.061	--	9.9	22700	942
	6/4/04													0.15	<.06	<.008	0.76	<.006	0.006	<1	–		
	10/25/04	<.1			1360	10.5									<.06					–	>10.0		
FMPZ-2 Right Bank Down Stream	3/30/04	0.2																		<1	0.1		
	5/6/04	0.2																		<1	–		
	5/28/04		E8.3	696			4.31	5.11	150	94	129	15.8	68.4	0.23	<.06	<.008	0.27	0.225	0.21	--	--	40	9.1
	6/4/04													0.2	<.06	<.008	0.29	0.267	0.23	<1	–		
	10/25/04	0.2													<.06					–	2		
FMPZ-3 Center Down stream	3/30/04	0.2																		<1	5		
	5/6/04	0.1																		<1	–		
	5/28/04		7.1	1300			198	54.7	36.9	387	97	37.4	64	0.42	<.06	<.008	1.44	E.005	0.012	–	4.98	5770	3350
	6/4/04													0.37	<.06	<.008	1.38	<.006	0.01	<1	–		
	10/25/04	0.1			2070	10.8									<.06					–	0.2		
4-MILE DOWNSTREAM TILE DRAIN	3/30/04																			<1			
	5/28/04													0.05	8.54	<.008	8.21	<.006	E.003	--	––		
	6/4/04													E.04	8.95	<.008	8.38	<.006	<.004	1	–		
FMPZ-4 Right Bank Up Stream	3/30/04	0.3																		<1	0.2		
	5/6/04																			<1			
	5/28/04		7.8	330			45.6	12	6.35	65	21.4	22.1	67.8	<.04	<.06	<.008	<.03	0.025	0.032		0	56	176
	6/4/04													<.04	<.06	<.008	0.05	0.034	0.043	<1			
	10/25/04	0.1			474	11.7									<.06						0.3		
FMPZ-5 Center Up	3/30/04	0.2																		<1	0.1		
	5/6/04	–																		<1			
	5/28/04	–	8	300	–	–	38.9	10.3	8.43	66	21.9	22.9	49.9	E.03	<.06	<.008	0.07	0.038	0.047	–	0.03	<6	74.9

SITE NAME	DATES	Dissolved O_2	pH	Spec Cond lab	Spec cond, fld	Temp water	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2+ NO3	Nitrite	Total Nitrogen	Orthophosphate	Phosphorus	E. coli, Coliler	Iron (II), fld	Iron lab	Manganese
		mg/L		uS/cm	uS/cm	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	MPN/ 100mL	mg/L	ug/L	ug/L
Stream	6/4/04	–	–	–	–	–	–	–	–	–	–	–	–	0.06	<.06	<.008	0.07	0.082	0.091	<1	–	–	–
	10/25/04	0.1	–	–	309	10.7	–	–	–	–	–	–	–	–	<.06	–	–	–	–		0.2	–	–
FMPZ-6	3/30/04	0.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	0.1	–	–
Left	5/6/04	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–
Bank	5/28/04	–	8.1	237	–	–	20.5	5.71	19.7	61	18.7	21.9	26.7	0.06	<.06	<.008	0.09	0.072	0.08	–	0	32	65.9
Up	6/4/04	–			–	–	–	–	–	–	–	–	–	0.04	<.06	<.008	0.06	0.076	0.086	<1	–	–	–
Stream	10/25/04	0.2			324	10.1	–	–	–	–	–	–	–	–	<.06	–	–	–	–	–	0.2	–	–
4-MILE	3/30/04	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–
UPSTREAM	5/28/04	–	–	–	–	–	–	–	–	–	–	–	–	0.25	<.06	<.008	0.58	<.006	E.003	–	–	–	–
TILE DRAIN	6/4/04	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Dry	–	–	–
4-MILE	3/30/04	–	–	–	274	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–
CREEK	5/6/04	–	–	–	330	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	–	–	–
Surface	5/28/04	–	–	–	332	–	–	–	–	–	–	–	–	0.17	2.41	–	3.48	–	–	34	–	–	–
water	10/25/04	–	–	–	398	–	–	–	–	–	–	–	–	–	1.83	–	–	–	–	–	–	–	–

Bertrand agricultural drainage ditch

Groundwater quality measurements collected in the nine mini-piezometers accessing the groundwater underlying the drainage ditch, the receiving water in the ditch and from a temporary field well are shown in Table 4-6. Hydraulic gradients measured in the nine mini-piezometers are shown in Table 4-5. Anions and cations showed relatively similar concentrations to those measured at the Everson site, ranging from 5 to 51 mg/L for most analyzed, with higher variation in sulfate (ranging from 5 to 90 mg/L).

Field measurements showed low concentrations of dissolved oxygen (maximum value measured of 0.5 mg/L), and average pH values. Relatively high groundwater temperatures (up to 17 C measured June 4, 2004) suggest a thermal conductance between groundwater and surface water, although the positive hydraulic gradient indicates groundwater was discharging to the surface ditch on that date. Nutrient concentrations are low, nitrate was not detected, and phosphorus and orthophosphate concentrations had a maximum measured value of 0.09 mg/L. Manganese content was less than 1mg/L in all samples analyzed. Iron content was high, with values of 5 mg/L or more in all samples tested in the field.

Bacteria were detected in two of the 38 samples analyzed from this site, at a concentration of 1 unit per 100 milliliters. Both detections were measured in samples collected on October 6, 2003.

The temporary well (named Bertrand Field well in data presented in Table 4-6) was installed in the adjacent field approximately 100 feet south of the agricultural ditch. Total nitrogen was measured at 3.35 mg/L in water collected here, and nitrite (a byproduct of denitrification) present at an estimated concentration of 0.04 mg/L. Phosphorous and orthophosphate concentrations were relatively low (0.09 mg/L maximum value).

Table 4-5 Bertrand agricultural ditch hydraulic gradient measurements at nine grid sites; site names correspond to relative location of measurement point

measurement date	**north west**	**north center**	**north east**
Oct 21, 03	0.018	0.026	0.025
Nov 19, 03	0.028	0.029	0.022
Feb 19, 04	0.126	no data	0.124
Mar 31, 04	0.092	0.091	0.095
May 07, 04	0.064	0.060	0.065
May 27, 04	0.063	0.059	0.064
June 04, 04	0.060	0.058	0.063
	Center west	**Center center**	**Center east**
Oct 21, 03	0.018	0.020	0.017

Nov 19, 03	0.028	0.028	0.025
Feb 19, 04	0.091	0.096	0.095
Mar 31, 04	0.067	0.070	0.068
May 07, 04	0.044	0.045	0.040
May 27, 04	0.045	0.047	0.044
June 04, 04	0.043	0.045	0.044
	South west	**South center**	**South east**
Oct 21, 03	0.019	0.022	0.008
Nov 19, 03	0.027	0.029	0.017
Feb 19, 04	0.091	0.089	0.093
Mar 31, 04	0.062	0.062	0.064
May 07, 04	0.037	0.037	0.038
May 27, 04	0.039	0.039	0.041
June 04, 04	0.038	0.038	0.039

Table 4-6 Bertrand agricultural drainage ditch water quality

Site Name	DATES	Dissolved oxygen	pH	Spec Cond uS/cm @ 25C		temp	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2 + NO3	Nitrite	Orthophosphate	Phosphorus, wf	Total nitrogen	E. coli, Coliler	Iron (II)	Iron	Manganese
		mg/L	lab	lab	field	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	MPN/ 100mL	field mg/L	mg/L	ug/L
BERT NC	9/30/03	0	--	--	330	15.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	10/21/03	<.1	--	--	304	13.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	441	9.3	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	3/31/04	0	--	--	386	9.8	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/7/04	0	--	--	435	10.6	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	6.2	315	426	10.6	36.4	11.5	8.21	51	19.2	27.8	64.7	0.34	<.06	<.008	<.006	0.041	0.66	<1	12.5	39.1	505
	6/4/04	0	--	--	424	15.3	--	--	--	--	--	--	--	0.35	<.06	E.005	E.003	0.004	0.72	<1	>10	--	--
	10/25/04	0	--	--	342	12.0	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	>10	--	--
BERT NE	9/30/03	0.4	--	--	272	15.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	10/21/03	0.2	--	--	138	13.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	418	10.1	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	3/31/04	0	--	--	436	9.7	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/7/04	0	--	--	483	10.5	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	7	375	471	12.4	50.6	12.6	13.6	103	18.8	30.1	63.3	0.34	<.06	<.008	<.006	0.049	0.62	<1	4.68	25.5	673
	6/4/04	0	--	--	475	12.2	--	--	--	--	--	--	--	0.35	<.06	<.008	<.006	<.0064	0.63	<1	>10	--	--
	10/25/04	0	--	--	333	12.9	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	>10	--	--
BERT NW	9/30/03	0.2	--	--	233	13.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--
	10/21/03	0.1	--	--	244	13.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	384	9.1	--	--	--	--	--	--	--	--	--	--	--	--	--	< 100	>10	--	--
	3/31/04	0	--	--	410	9.3	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/7/04	0.3	--	--	390	10.7	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	6.2	341	614	11.8	30.1	8.35	21.4	22	23.2	26.4	88.9	0.3	<.06	<.008	E .014	0.014	0.56	<1	9.5	15.3	313
	6/4/04	--	--	--	614	11.8	--	--	--	--	--	--	--	0.38	<.06	E .004	<.006	0.007	0.8	<1	>10	--	--

Site Name	DATES	Dissolved oxygen	pH	Spec Cond uS/cm @ 25C		temp	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2 + NO3	Nitrite	Orthophosphate	Phosphorus, wf	Total nitrogen	E. coli, Coliler	Iron (II)	Iron	Manganese
		mg/L	lab	lab	field	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	MPN/ 100mL	field mg/L	mg/L	ug/L
	10/25/04	--	--	--	446	12.5	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--	--
BERT CC	9/30/03	0	--	--	244	14.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	10/21/03	<.1	--	--	199	13.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	383	9.1	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	10	--	--
	3/31/04	--	--	--	445	10.1	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	5/7/04	0.1	--	--	373	10.7	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	7	311	686	11.2	45.3	7.48	12.8	133	13.6	34.7	15.6	0.22	<.06	E.005	E .087	0.082	0.4	<1	8	11.5	600
	6/4/04	0	--	--	357	15.8	--	--	--	--	--	--	--	0.2	<.06	<.008	0.009	0.019	0.51	<1	--	--	--
	10/25/04	0	--	--	401	12.3	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--	--
BERT CW	9/30/03	0	--	--	254	15.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	10/21/03	<.1	--	--	214	13.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	411	9.3	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	3/31/04	0	--	--	433	9.3	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/7/04	0.1	--	--	425	10.6	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	6.1	385	--	10.9	33.4	10.1	21.6	21	22.9	25.4	105	0.38	<.06	0.008	E .019	0.021	0.63	<1	13	22.9	409
	6/4/04	0	--	--	428	14.1	--	--	--	--	--	--	--	0.4	<.06	E.005	<.006	<.0064	0.72	<1	>10	--	--
	10/25/04	0	--	--	403	12.2	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--	--
BERT CE	9/30/03	0	--	--	254	13.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--
	10/21/03	<.1	--	--	392	14.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12/4/04	--	--	--	375	10.2	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	3/31/04	0	--	--	>10	10.2	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/7/04	0	--	--	393	10.8	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	>10	--	--
	5/27/04	0	6.8	284	327	12.8	50.5	7.45	9.25	112	15.8	32	32.3	0.21	<.06	<.008	E .040	0.076	0.43	<1	8	17.8	712
	6/4/04	0	--	--	402	14.5	--	--	--	--	--	--	--	0.21	<.06	<.008	<.006	<.0064	0.48	<1	>10	--	--
	10/25/04	--	--	--	430	12.6	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--	--
BERT SE	9/30/03	1	--	--	334	13.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	10/6/03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	--

Site Name	DATES	Dissolved oxygen	pH	Spec Cond uS/cm @ 25C		temp	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2 + NO3	Nitrite	Orthophosphate	Phosphorus, wf	Total nitrogen	E. coli, Coliler	Iron (II)	Iron	Manganese
		mg/L	lab	lab	field	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	MPN/ 100mL	field mg/L	mg/L	ug/L
	10/21/03	0.5	–	–	360	13.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	12/4/04	–	–	–	425	11.1	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	3/31/04	0	–	–	451	9.2	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	5/7/04	0.1	–	–	402	10.9	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	5/27/04	0	6	295	755	11.4	34.1	7.12	14.1	44	13.1	27.6	70.9	0.71	<.06	<.008	E .040	0.048	1.26	<1	10.5	22.9	484
	6/4/04	0	–	–	365	17.4	–	–	–	–	–	–	–	0.77	<.06	0.015	E .003	0.156	1.41	<1	>10	–	–
BERT SC	9/30/03	0	–	–	290	13.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	10/6/03	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
	10/21/03	<.1	–	–	101	13.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	12/4/04	–	–	–	395	9.6	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	10	–	–
	3/31/04	0.3	–	–	334	11.8	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	5/7/04	0.3	–	–	334	11.8	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	10	–	–
	5/27/04	0	6.2	363	661	11.9	41.9	5.68	15.8	136	11.3	33.6	5.7	0.22	<.06	E .004	E .087	0.09	0.37	<1	5.2	7.56	613
	6/4/04	0	–	–	326	15.2	–	–	–	–	–	–	–	0.26	<.06	<.008	0.007	0.02	1	<1	9	–	–
BERT SW	9/30/03	0	–	–	236	13.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	10/6/03	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–
	10/21/03	0	–	–	114	13.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	12/4/04	–	–	–	436	11	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	3/31/04	0	–	–	411	9.5	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	5/7/04	0	–	–	410	10.3	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	>10	–	–
	5/27/04	0.5	6.2	300	730	12.2	30	9.46	27	25	27.8	25.2	91.4	0.85	<.06	0.01	E .021	0.025	1.15	<1	9.5	19.5	349
	6/4/04	0	–	–	422	13	–	–	–	–	–	–	–	0.91	<.06	<.008	0.006	0.007	1.95	<1	>10	–	–
FIELD WELL	6/4/04	–	–	–	–	–	–	–	–	–	–	–	–	2.09	<.06	0.021	0.043	0.059	3.35	<1	–	–	–
BERT ditch	6/4/04	–	–	–	–	–	–	–	–	–	–	–	–	0.92	E 0.04	E 0.004	<.006	0.005	1.47	–	–	–	–

Site Name	DATES	Dissolved oxygen	pH	Spec Cond uS/cm @ 25C		temp	Calcium	Magnesium	Sodium	ANC, lab	Chloride	Silica	Sulfate	Ammonia	NO2 + NO3	Nitrite	Orthophosphate	Phosphorus, wf	Total nitrogen	E. coli, Coliler	Iron (II)	Iron	Manganese
		mg/L	lab	lab	field	degree C	mg/L	mg/L	mg/L	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	MPN/ 100mL	field mg/L	mg/L	ug/L
BERT ditch	10/25/04	--	--	--	324	11	--	--	--	--	--	--	--	--	<.06	--	--	--	--	--	--	--	--

Assink Site, Fishtrap Creek

The six-mini-piezometer spatial grid Assink site, located near river mile 8 on Fishtrap Creek, was sampled for field parameters and bacteria content, and measured for hydraulic gradient four times between October 2003 and May 5, 2004. The grid was configured as two lines of piezometers crossing Fishtrap Creek, with one piezometer on either side of the Creek accessing the shallow groundwater within 20 feet of the shoreline(s), and one located midstream. The two lines were parallel, located approximately 50 feet apart. Results showed low dissolved oxygen content in groundwater, moderately high specific conductance values (260 to 480 uS/cm), and relatively high ferrous iron content (12 of 13 measurements exceeding 2 mg/L). Bacteria were detected in one sample collected on October 20, 2003 at the lower center mini-piezometer. Temperatures measured in groundwater on October 20 were relatively high (above 13 C). The hydraulic gradients measured are listed in Table 4-7, and the groundwater quality data is shown in Table

Table 4-7 Assink Site vertical hydraulic gradients measured in six mini-piezometers

left and right bank piezometers access groundwater near each shore, center piezometers accesses groundwater below stream bottom

date	Upper Right Bank		Upper Center		Upper Left Bank	
	head difference	*gradient*	*head difference*	*gradient*	*head difference*	*gradient*
10/1/03	4.44	0.03	2.52	0.02	4.03	0.03
11/18/03	-1.40	-0.01	No data	No data	-1.76	-0.01
2/19/04	7.98	0.05	5.24	0.04	7.26	0.06
3/31/04	8.24	0.05	5.42	0.04	7.95	0.07
5/6/04	6.25	0.04	4.65	0.04	6.40	0.05
	Lower Right Bank		Lower Center		Lower Left Bank	
	head difference	*gradient*	*head difference*	*gradient*	*head difference*	*gradient*
10/1/03	-0.83	-0.01	-0.50	0.00	-0.90	-0.01
11/18/03	-0.03	0.00	-0.03	0.00	0.42	0.00
2/19/04	7.98	0.05	2.63	0.02	11.77	0.08
3/31/04	6.95	0.05	2.44	0.02	11.28	0.08
5/6/04	3.98	0.03	1.48	0.01	7.22	0.05

Table 4-8 Assink Site Field Water Quality Measurements

Site Name	DATES	Dissolved oxygen	Spec cond, field	Temp	*E. coli*, Coliler	*E. coli*, m-TEC,	Iron(II), field	Hydrualic Gradient
		mg/L	uS/cm @ 25C	degrees C	MPN/100mL	MPN/ 100mL	mg/L	
FT	10/6/03	–	--	–	<1	<1	--	–

Site Name	DATES	Dissolved oxygen	Spec cond, field	Temp	*E. coli*, Coliler	*E. coli*, m-TEC,	Iron(II), field	Hydrualic Gradient
		mg/L	uS/cm @ 25C	degrees C	MPN/100mL	MPN/ 100mL	mg/L	
ASINK	10/20/03	<.1	484	13.2	<1	<1	–	–
LOWER	3/31/04	0.1	260	8.3	<1	–	2	0.045
RB	5/6/04	0.4	437	11.9	<1	–	4	0.026
FT	10/6/03	–	–	–	<1	<1	–	–
ASSINK	10/20/03	–	304	13.8	23	–	–	–
LOWER	3/31/04	0	440	5.4	<1	–	>10	0.02
CTR	5/6/04	0.2	448	15.7	<1	–	>10	0.012
FT	10/6/03	–	–	–	<1	<1	–	–
ASSINK	10/20/03	<.1	152	13.5	<1	–	–	–
LOWER	3/31/04	–	472	9.2	<1	–	>10	0.076
LB	5/6/04	0.3	798	10.5	<1	–	0	0.048
FT ASSINK	10/6/03	–	–	–	<1	<1	–	–
UPPER	3/31/04	0	403	9.9	<1	–	>10	0.054
RB	5/6/04	0.3	442	11.2	<1	–	>10	0.041
FT ASSINK	10/6/03	–	–	–	<1	<1	–	–
UPPER	3/31/04	0	–	10.4	<1	–	>10	0.044
CTR	5/6/04	–	373	11.2	<1	–	>10	0.038
FT ASSINK	10/6/03	–	–	–	<1	<1	–	–
UPPER	3/31/04	0	476	9.5	<1	–	>10	0.065
LB	5/6/04	0	480	10.8	<1	–	>10	0.053

Fishtrap Creek Longitudinal Characterization

Field measurements were collected at nine locations along the approximate 10-mile length of Fishtrap Creek within the United States boundary, at sites numbered PZF-1 (upstream most location) to PZF-9 (downstream). Measurements of dissolved oxygen specific conductance, temperature nitrate, bacteria and iron content were collected from October 2003 through October 2004, and are shown in Table 4-9. Temperature measurements range from 10.5 to 17.0 C, higher temperatures than are normally encountered in groundwater. Nitrate and nitrate measurements vary over a very large range, from non-detections to 3.5 mg/L. Similarly ferrous iron varies over a large range of concentrations, from non-detections to 26 mg/L. Some of the he highest values for temperature and dissolved iron were recorded at the PZF-9, downstream most location measured.

Table 4-9 Fishtrap Creek Longitudinal Profile Water Quality Data

Site Name	DATE	Dissolved oxygen mg/L	Spec C field uS/cm	Temp degrees C	NO2+NO3 mg/L as N	E. coli, Coliler MPN/100mL	Iron(II), field mg/L
PZF-01	10/20/03	0.3	138	13.4	–	9	–
	5/6/04	0.3	243	11.7	–	<1	0.6

Site Name	DATE	Dissolved oxygen mg/L	Spec C field uS/cm	Temp degrees C	NO2+NO3 mg/L as N	E. coli, Coliler MPN/100mL	Iron(II), field mg/L
	5/22/04	0.3	217	11.7	<.06	<1	0.05
	7/1/04	0.1	–	13.6	–	–	–
PZF-02	10/20/03	<.1	396	13.1	–	–	–
	5/6/04	0	410	11.9	–	<1	>10
	5/22/04	0	426	10.5	<.06	<1	1.37
	7/1/04	0	393	11.9	–	–	–
PZF-03	5/22/04	0	288	11.5	–	<1	10
	5/22/04	0.2	287	11.2	<.06	<1	0.1
	7/1/04	0.1	279	13.5	–	–	–
PZF-04	5/6/04	0.1	279	12.2	–	<1	0.1
	5/22/04	1	285	12.7	3.53	<1	0.01
	7/1/04	>1.0	299	15.9	–	–	–
	10/1/04	>1	280	13.6	–	–	<.01
PZF-05	5/6/04	0	191	11.6	–	<1	5
	5/22/04	0.1	168	11.2	<.06	<1	2.25
	7/1/04	–	183	12.1	–	–	–
	10/1/04	0.05	182	12.3	–	–	5
PZF-06	5/6/04	>1	288	12.9	–	1	0
	5/22/04	0.8	289	13.3	2.92	<1	0.01
	7/1/04	–	305	17.0		–	–
PZF-7	5/6/04	0	245	12.3			>10
	5/22/04	0	251	12.2	<.06	<1	4.96
	7/1/04	0	246	13.7		–	–
	10/1/04	0	259	12.3		–	–
PZF-08	5/22/04	–	269	–	0.08	<1	3
	7/1/04	0	236	13.4	–	–	–
	10/1/04	0	323	13.2	–	–	>10
PZF-09	5/22/04	0.2	1085	11.9	E .03	<1	26
	7/1/04	0	1080	16.3	–	–	–

Sediment Quality Data

Nitrate and temperature measured at four locations in the agricultural field in the vicinity upgradient of the Everson site, and in the riparian area adjacent to piezometers are presented in Table 4-10. Sample locations are shown in Figure 3-3. Nitrate concentration in soil shows a decreasing trend during the late fall months, when crops are dormant or dead.

Table 4-10 Nitrate content in soil and soil temperature at Everson Site, August through December, 2004

Date	Crop	Location	Temp (F) (6" depth)	NO_3-N ppm
8/3/2004	Grass	Close to the River	66	53
8/3/2004	Corn	Close to the Lagoon	66	68
8/9/2004	Grass	Close to the River		50

Date	Crop	Location	Temp (F) (6" depth)	NO_3-N ppm
8/9/2004	Grass	Close to the House		33
8/9/2004	Corn	Close to the Lagoon		88
8/9/2004	Corn	Close to the River		45
8/16/2004	Grass	Close to the River	65	54
8/16/2004	Grass	Close to the House	64	66
8/16/2004	Corn	Close to the Lagoon	66	88
8/16/2004	Corn	Close to the River	62	58
8/23/2004	Grass	Close to the River	63	54
8/23/2004	Grass	Close to the House	64	30
8/23/2004	Corn	Close to the Lagoon	62	80
8/23/2004	Corn	Close to the River	62	73
9/2/2004	Grass	Close to the River	60	60
9/2/2004	Grass	Close to the House	59	28
9/2/2004	Corn	Close to the Lagoon	57	93
9/2/2004	Corn	Close to the River	60	57
9/8/2004	Grass	Close to the River	56	61
9/8/2004	Grass	Close to the House	56	17
9/8/2004	Corn	Close to the Lagoon	54	83
9/8/2004	Corn	Close to the River	56	96
9/17/2004	Grass	Close to the River	53	42
9/17/2004	Grass	Close to the House	52	25
9/17/2004	Corn	Close to the Lagoon	53	65
9/17/2004	Corn	Close to the River	53	93
9/24/2004	Grass	Close to the River	53	52
9/24/2004	Grass	Close to the House	53	28
9/24/2004	Corn	Close to the Lagoon	53	56
9/24/2004	Corn	Close to the River	52	60
9/30/2004	Grass	Close to the River	57	40
9/30/2004	Grass	Close to the House	56	33
9/30/2004	Corn	Close to the Lagoon	56	56
9/30/2004	Corn	Close to the River	56	71
9/30/2004	Riverbank		54	5
10/8/2004	Grass	Close to the River	52	35
10/8/2004	Grass	Close to the House	52	45
10/8/2004	Corn	Close to the Lagoon	50	25
10/8/2004	Corn	Close to the River	50	60
10/8/2004	Riverbank		52	8
10/15/2004	Grass	Close to the River	54	35
10/15/2004	Grass	Close to the House	53	19
10/15/2004	Corn	Close to the Lagoon	52	21
10/15/2004	Corn	Close to the River	52	44
10/15/2004	Riverbank		54	6
10/22/2004	Grass	Close to the River	47	22
10/22/2004	Grass	Close to the House	46	21
10/22/2004	Corn	Close to the Lagoon	46	18
10/22/2004	Corn	Close to the River	45	25
10/22/2004	Riverbank		48	5
10/31/2004	Grass	Close to the River	43	30
10/31/2004	Grass	Close to the House	43	20
10/31/2004	Corn	Close to the Lagoon	42	29
10/31/2004	Corn	Close to the River	42	30

Date	Crop	Location	Temp (F) (6" depth)	NO_3-N ppm
10/31/2004	Riverbank		44	6
11/5/2004	Grass	Close to the River	40	20
11/5/2004	Grass	Close to the House	40	22
11/5/2004	Corn	Close to the Lagoon	40	14
11/5/2004	Corn	Close to the River	40	12
11/5/2004	Riverbank		40	7
11/12/2004	Grass	Close to the River	40	17
11/12/2004	Grass	Close to the House	40	14
11/12/2004	Corn	Close to the Lagoon	38	11
11/12/2004	Corn	Close to the River	39	10
11/12/2004	Riverbank		41	6
11/19/2004	Grass	Close to the River	40	15
11/19/2004	Grass	Close to the House	40	13
11/19/2004	Corn	Close to the Lagoon	40	8
11/19/2004	Corn	Close to the River	40	10
11/19/2004	Riverbank		42	8
11/27/2004	Grass	Close to the River	40	16
11/27/2004	Grass	Close to the House	40	11
11/27/2004	Corn	Close to the Lagoon	40	9
11/27/2004	Corn	Close to the River	40	11
11/27/2004	Riverbank		40	7
12/16/2004	Grass	Close to the River	38	13
12/16/2004	Grass	Close to the House	38	8
12/16/2004	Corn	Close to the Lagoon	38	9
12/16/2004	Corn	Close to the River	36	10
12/16/2004	Riverbank		40	4

5 Discussion

Each of the project objectives is addressed in a separate section of the discussion, where the data from various sites characterized are grouped together to draw interpretations related to the specific project objectives. These objectives, for which a section of the discussion is devoted, are as follows:

- Groundwater-surface water hydraulic communication
- Bacteria transport pathways
- Nitrate transport in groundwater
- Nitrate degradation in groundwater

The overall goals of the project, to examine the influence of groundwater discharge on surface water quality with respect to fecal bacteria and nitrate, rely upon the main interpretation presented in the section on hydraulic communication; for the vast majority of the data collected groundwater is indeed discharging to surface water, and the groundwater quality can be assumed to influence the quality of the surface water measured. In general, we found little to no discharge of groundwater containing bacteria or nitrate to surface water.

The original goals for this project included quantification of the relative magnitude of the bacteria and nitrate contribution of groundwater loading to surface water by means of a hydrograph separation. Because bacteria was not detected in groundwater discharging to surface water, and nitrate was detected in only a very small percentage of samples, a hydrograph separation was not required to quantify the loading from groundwater. The data indicated that loading of bacteria from groundwater to surface water was not occurring. Nitrate loading was occurring in small enough quantities, that flux was essentially zero. Further analyses were unnecessary to estimate the (nonexistent) flux and magnitude of groundwater loading. Site-specific aspects of groundwater loading are discussed in more detail in the sections that follow.

Other pathways for transport for discharge of bacteria and nitrate to surface water were also evaluated in assessing the relative importance of groundwater discharge on the loading to surface water; agricultural field drain discharge and stormwater runoff. The data collected to evaluate these pathways was of significantly smaller number, and so interpretation related to these pathways is more tenuous.

Tile drains were found to discharge nitrate to Fourmile Creek via one of the two tile drains sampled. Discharge from each tile drain was measured twice, making a total of four measurements from which to draw interpretations. Both of the samples from the Downstream Tile Drain contained relatively high concentrations of nitrate (over 8 mg/L) in May and June of 2004. Shortly after the last sample date discharge stopped emitting from the tile drains and additional sample collection wasn't possible. Nitrate was detected in the surface water sample collected on May 28, and October 25, 2004 from Fourmile Creek, suggesting that nitrate loading to surface water from tile drains may be a significant contribution. Bacteria was not found in any of the Fourmile tile drain samples. Additional characterization of the tile drain discharge pathway for nitrate and not bacteria transport will require additional study to confirm conclusively.

High bacteria concentrations were detected from in surface water at the Fourmile site and at the Bertrand agricultural ditch during the storm event of May 27, 2004. High bacteria content during a storm confirms the surface water runoff pathway for bacteria transport to surface water.

Groundwater / Surface Water Hydraulic Communication

In all five sites examined in this study ground-water discharge was found to be variable in both space and time. Spatial variability of ground-water discharge along the South Fork of the Nooksack appears to be closely related to the geologic materials adjacent to the streambed. Coarse-grained alluvial fan deposits are likely in connection with the streambed and are therefore capable of contributing localized flow. In settings like Fishtrap Creek where geologic materials are more homogenous, spatial variations are more subtle with slightly larger vertical gradients in the upper parts of the watershed. Changes in topography or incision of the streambed may cause localized downward flow that either remains in the hyporheic zone or recharges the aquifer. At the field scale spatial variability is even more subtle. Detailed study sites on Fishtrap Creek and Fourmile Creek had variations in vertical hydraulic gradients that suggest differences from one field to the next or from one side of the stream to the other. Such differences may be due local site conditions such as topography, tile drains, or even beavers.

Temporal variability was much more pronounced at each site. In general, vertical hydraulic gradients were more positive in the winter and gradually became less positive through the spring and summer. In the late summer, especially during drought conditions, sites such as Fishtrap Creek and Bertrand Creek may have negative vertical hydraulic gradients for a period of time until the next rainy season. Flood events can temporarily reverse the flow of water across the streambed as surface water stages exceed local ground-water levels. During these short-duration events surface water can recharge the aquifer or be held in bank storage until the flood crest passes.

The spatial and temporal variability of surface water-ground-water interactions strongly influence the movement of contaminants into and out of the surface-water system. A better understanding these processes is critical to any assessment of contaminant transport through the ground-water pathway. For example, the groundwater measurements along the Fishtrap Creek longitudinal profile show variability in the parameters of specific conductance, temperature, nitrate and nitrite content that do not indicate a progressive trend along the Creek length. High temperatures suggest thermal conductance between groundwater and surface water that is not necessarily linked to hydraulic communication (see Figure 4-2 plot of Fishtrap Creek hydraulic gradient measurements at these sites). The high values of temperature and ferrous iron content measured at the downstream most monitored site (PZF-9) suggest that the groundwater constituents concentrations are influenced by different hydraulic properties or influenced by different land use practices than are present at the other sites measured along Fishtrap Creek.

Bacteria Transport Pathways

E. coli bacteria were rarely observed in ground water discharging to streams in the Nooksack River lowlands. Of the 145 samples of ground water that were analyzed, *E. coli* were only found in only nine samples and in those instances concentrations of *E. coli* were typically much lower than concentrations of *E. coli* in the overlying surface water. Additionally, when sampling ground water for *E. coli* at the ground water discharge monitoring sites typically from 6 to 9 individual samples of ground water were analyzed for E. coli. When E. coli was present it usually was found in one or two of the ground water samples. However, all samples of surface water from the Nooksack River, Fishtrap and Four Mile Creeks, and the tributary to Bertrand Creek contained *E. coli* concentrations varied from 5 to 5000 bacteria per deciliter. Comparison of the concentration of *E. coli* in surface and ground water samples collected from the ground water discharge monitoring sites indicate that for lowland streams of the Nooksack River basin ground water discharging to streams through the stream bed is not likely the primary source of fecal contamination observed in those surface waters.

Assessment of bacteria transport via field drains (also referred to as tile drains) was hampered by difficulties with collecting water samples emitting from agricultural drains. The results of samples analyses from two field drains discharging to Fourmile Creek suggest that field drains do not transmit a significant portion of bacteria to surface water; only a single bacteria detection with a low (1 colony/100 mL) content was found. Other field drains intended for sample collection were not observed to be discharging at all during the summer months. While not conclusive, data collected for this project suggest that the source for the high bacteria concentrations measured by others during relatively dry summer months is not from bacteria transported in water discharging through field drains.

The original project goals included an assessment of the relative importance of surface runoff during storm events from surrounding agricultural fields as a pathway for bacteria loading to streams. Sampling during stormwater events that was intended to characterize this pathway was obstructed by the loss of stormwater collection equipment during the major storm event of October 17, 2003. Most of the subsequent samples collected during the storm event of May 27 & 28, 2004 were damaged during transport to the laboratory.

Stormwater runoff contribution to surface water bacteria loading may be interpreted from samples collected at the Bertrand site on May 7, May 27 and June 4 (prior to, during and following the storm event of May 27). The analyses results are shown in Table 4-3. Application of manure to the forage fields surrounding the Bertrand site was initiated in early in May 2004, and repeated over the course of the summer. Analyses of samples collected from groundwater discharge collected on May 7, 27 or June 4 did not detect any bacteria. During the storm event of May 27, the specific conductance in groundwater samples increased significantly in about half of the samples, suggesting a stormwater induced increase in the groundwater component of discharge. Surface water concentrations of *E. coli* in the May 27 sample were measured at 3,470 CFU/100 ml. Surface water collected on May 7 (prior to the storm) contained 18 CFU/100 mL, and the subsequent June 4 surface water sample contained 30 CFU/100 mL of *E.coli*. While these results do not conclusively point to stormwater runoff as the cause for high bacteria content in surface water drainages of the Nooksack watershed, they do suggest that surface runoff during storm events is contributing to bacteria loading to streams.

At the most upstream Fishtrap Creek monitored site near the border between the United States and Canada (PZF1), the concentrations of E. coli in streamflow were typically less than one-half of that measured at downstream sites. The pattern of increased fecal coliform bacteria present in streamflow between the PZF1 and PZF2 sites also was detected in periodic monitoring conducted biweekly between 2002 and 2004 by the Northwest Indian College (NWIC, 2004), concentrations at the downstream site typically were larger than concentrations at the upstream site. However, NWIC also measured larger concentrations at the upstream site 22 percent of the time. The higher concentrations typically measured at the FT2 site than at the upstream FT1 site indicate bacterial loading is occurring downstream of the FT1 site and upstream of the FT2 site. Morace and McKenzie (2002) found that short-term variation in bacteria concentration from stream-water samples is site dependent and may vary by an order of magnitude or more.

The potential for dormant bacteria to reside in stream bottom sediments and become re-suspended at a later date was examined as a separate component of this study. Bacteria content was reduced by 90% after two months in a laboratory microcosm experiment that simulated submerged stream sediment conditions (Cox et al., 2005) using manure and sediment samples collected from the Fishtrap and Bertrand Creek watersheds. Re-entrainment of archived bacteria in stream bottom sediments appears to be a potential, but restricted, source of bacteria detected instream.

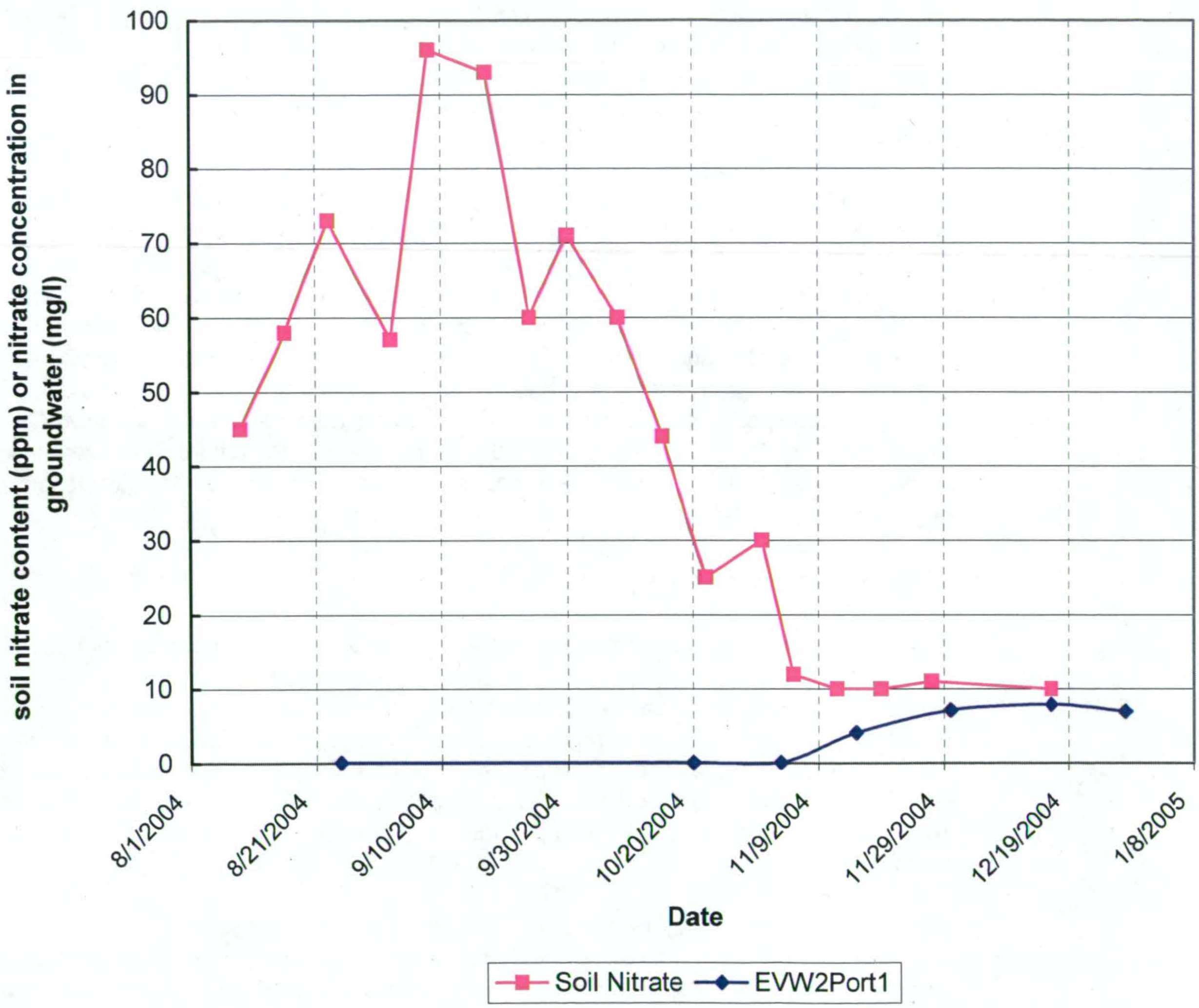
Together the results of these analyses indicate that the primary source of bacteria detected in streams and rivers of the Nooksack watershed in overland surface runoff. Groundwater transport of bacteria either through direct discharge through stream bottom sediments, or through field agricultural drains composes a very small fraction of the bacteria detected in the sampling done for this project. Agricultural fields with small vegetation buffers (like the Bertrand agricultural drain) appear to reflect the most significant impacts of bacteria loading from surface runoff processes. The short term duration of bacteria viability in stream bottoms sediments, together with the consistently low bacteria detections in groundwater discharge suggest that individual manure release events are the cause for high bacteria concentrations detected during the dry summer months. However, these results can only be interpreted as indications, and would be best evaluated with additional study if intended for use in management and resource allocation decisions.

Nitrate Fate and Transport in Groundwater

Nitrate concentrations measured in mini-piezometers accessing groundwater in the sediments below and around the streambeds were found to be low in most of the samples analyzed. Nitrate was detected in groundwater at concentrations below 10 mg/L throughout the sampling time period at all sampling locations. At three of the project sites, nitrate was not detected at all in groundwater; Bertrand Creek agricultural ditch, the Assink site along Fishtrap Creek, and to Fourmile Creek. Nitrate was found in multiple samples at the Everson site along the Nooksack River, in one of the agricultural field drains discharging to Fourmile Creek, and at two of nine sites sampled for the Fishtrap Creek longitudinal profile.

Nitrate concentrations measured at the Everson site were some of the highest of any measured for this project, with the highest concentrations in shallow ground water sampled in the middle of the upgradient agricultural production field (EVW2 PORT1). This multi-port piezometer also allowed ground water sampling from 27 and 42 feet below the ground surface, where nitrate was not detected at all. Nitrate concentrations in soil, and for the EVW2 PORT1 are plotted for the groundwater pathway at the Everson site in Figure 5-1, showing an increasing ground water concentration over the fall months corresponding to a decreasing concentration in the overlying soil at the same time. The nitrate data presented Figure 5-1 are listed in Table 4-1, 4-2 and 4-10.

FIGURE 5-1 SOIL AND GROUNDWATER NITRATE CONTENT AT EVERSON SITE,GROUNDWATER DATA IS TAKEN FROM TABLE 4.7, SOIL DATA IS TAKEN FROM TABLE 4-10 FOR THE CORN FIELD CLOSE TO THE RIVER



While the highest concentration was in shallow ground water in the middle of the agricultural field, the more persistent, lower concentrations were detected in the piezometers accessing the riparian areas VNDW1-1 through VNDW 3-4) and in the groundwater discharging to the Nooksack River (VNDW2-5), from the shallow and deeper groundwater zones. There were no, or very small nitrate detections from deeper groundwater in EVW1 and EVW2, even though both of these multi-port piezometers accessed similar to the depths of the riparian area piezometers, where there were detections. The absence of nitrate detections in the deeper multi-port piezometers samples when compared with the consistent detections in the riparian areas piezometers suggest that a vertical upward gradient is present in the ground water near the Nooksack River, transporting nitrate from a regional, deeper ground water flow system upward to discharge to the River. The source for this regional groundwater system is likely from more distant and potentially more extensive in area. Nitrate transported through this regional ground water pathway is apparently not being completely degraded before it reaches to the Nooksack River. Low ferrous iron in the deeper riparian area piezometers also suggests that nitrate degradation is not proceeding through to complete mineralization in the deeper groundwater system.

While neither the temporal variation or spatial variation in tile drain discharge is well enough characterized by data collected for this study to draw conclusions, the detection of nitrate in both samples from the downstream tile drain discharging to Fourmile Creek suggests that tile drains act as a source for nitrate loading to surface water, and that nitrate transport in tile drain discharge is relatively consistent temporally.

The detection of nitrate in two of the sites sampled for the Fishtrap Creek longitudinal profile suggests that in some locations along the Creek, nitrate transport in groundwater is discharging to surface water. Detection of nitrate at only two of the nine sites suggests that either the loading of nitrate to groundwater varies along the length of the Creek, or the conditions affecting fate and transport vary with location. Consistent non-detections of nitrate in groundwater in the spatial grid at the Assink Site (PZF-2 of the Fishtrap Creek longitudinal profile) suggest that for the ground water in the Assink Site vicinity of Fishtrap Creek nitrate does consistently degrade before discharge to the Creek, despite whatever loading or transport processes variation exists along other reaches of Fishtrap Creek. These data, and the Everson site data indicate that there is some variation between sites in the Nooksack watershed with respect to the conditions governing nitrate transport and degradation in ground water.

Nitrate loading from soil

Soil nitrate nitrogen concentrations decreased rapidly through the month of October, 2004. During this time soil temperature declined from ~53° F to 40° F (Figure 2), and there was approximately 6 inches of rainfall. The decline in soil temperature likely reduced microbial activity that converts organic nitrogen to nitrate nitrogen. The area received six inches of rain during the month of October, which likely transported shallow nitrate from the one-foot soil layer to deeper levels. Soil nitrate concentrations were 22 ppm or lower by November 5, 2004, and remained below 20 ppm for the remainder of the sampling time period (Figure 5-1).

Grass was harvested for silage 7 times throughout the growing season. The first cutting was on April 8, 2004, and a cutting was harvested approximately every 4 weeks thereafter through October 14, 2004. Liquid manure was applied after first cutting (April 9, 2004) with a traveling big gun. Liquid manure was applied after second cutting (May 17, 2004) with a traveling big gun at a rate of ~8,571 gallons/acre. Liquid manure was applied after fourth cutting (July 16, 2004) with an aerator at a rate of ~10,000 gallons/acre. The nutrient content of the manure was not measured and recorded, making estimation of the nitrate volume loading to groundwater impossible.

Groundwater nitrate concentrations remained below 10 ppm during the sampling time period at all sampling locations. There relationship detected between soil nitrate concentrations and nitrate concentrations in the groundwater shown in Figure 5-2; for

EVW2 Port 1 suggests that decline in soil concentration corresponded with increase in groundwater concentration, and that nitrate migrated vertically from soil to groundwater during the fall period.

Nitrate loading to ground water, albeit variable, at sites characterized for this project, can be also be interpreted from the pattern of nitrate detections in the agricultural field at the Everson site (EVW2 PORT 1), the detection of nitrate in the tile drain at the Fourmile Site, and at the two sample sites the Fishtrap Creek longitudinal profile. This data, along with previously collected data indicates that nitrate loading to ground water and the lack of nitrate detections in groundwater can be interpreted to be a result of nitrate degradation in groundwater.

Ground water samples collected from instream-piezometers at the all four locations studied in the Nooksack watershed typically had low nitrate, low dissolved oxygen and high iron concentrations (greater than 10 milligrams per liter). Together these conditions suggest that nitrate in ground water has been degraded via denitrification before reaching the ground water discharge zones. However, the consistently low to non-existent nitrate content in discharging groundwater made it difficult to assess the rate of nitrate degradation, and the factors affecting nitrate degradation.

To confirm whether denitrification was the cause for the low nitrate content in groundwater, without the data on the relative concentrations of nitrate to gage the factors contributing to nitrate degradation, a new method was added to this study. The relative concentration of argon gas and nitrogen gas was compared in ground water samples collected from the shallow sediments below the streambeds. The ratio of nitrogen to argon gas in samples was compared to the standard ratio of nitrogen to argon in the atmosphere. The standard nitrogen-argon atmospheric ratio would normally be found in shallow groundwater if it wasn't affected by denitrification. Ground water with significant amounts of nitrate that had been denitrified would show an enriched ratio of nitrogen to argon due to the production of nitrogen from denitrification. We found the ratios of nitrogen gas to argon gas to be enriched in comparison to the standard from atmospheric ratio in ground water samples from all four project sites, which confirmed that denitrification was degrading nitrate in the shallow ground water (Cox and others, 2005).

The lack of nitrate and the presence of denitrification byproducts in discharging ground water indicate that denitrification is effectively reducing nitrate in the shallow subsurface before ground water is discharged to surface waters. The rate of degradation in shallow ground water appears to be quite rapid. Denitrifying bacteria quickly consume the oxygen in precipitation infiltrating to shallow ground water, proceed to denitrify nitrate transported in the infiltrating ground water, and continue the respiration process by reacting with iron in the aquifer sediments increasing ferrous iron content before ground water discharges to surface water. Denitrifying bacteria appear to be present in large concentrations throughout the shallow aquifers in the Nooksack Watershed, given the consistent low nitrate detections at all site sampled for this project. Ground water infiltrating to deeper aquifers appears to be less conducive to rapid denitrification. And, water routed through tile drains appears in some cases, to bypass the subsurface conditions that lead to denitrification.

The breakdown of nitrate prior to discharge to surface water, but the continued detection in other areas suggests that the riparian areas surrounding the discharge zones are themselves enhancing the degradation process. Increased organic matter in alluvial and riparian area sediments that make up the riparian area subsurface may provide nutrients essential to the degradation process that are lacking at other locations of the aquifer.

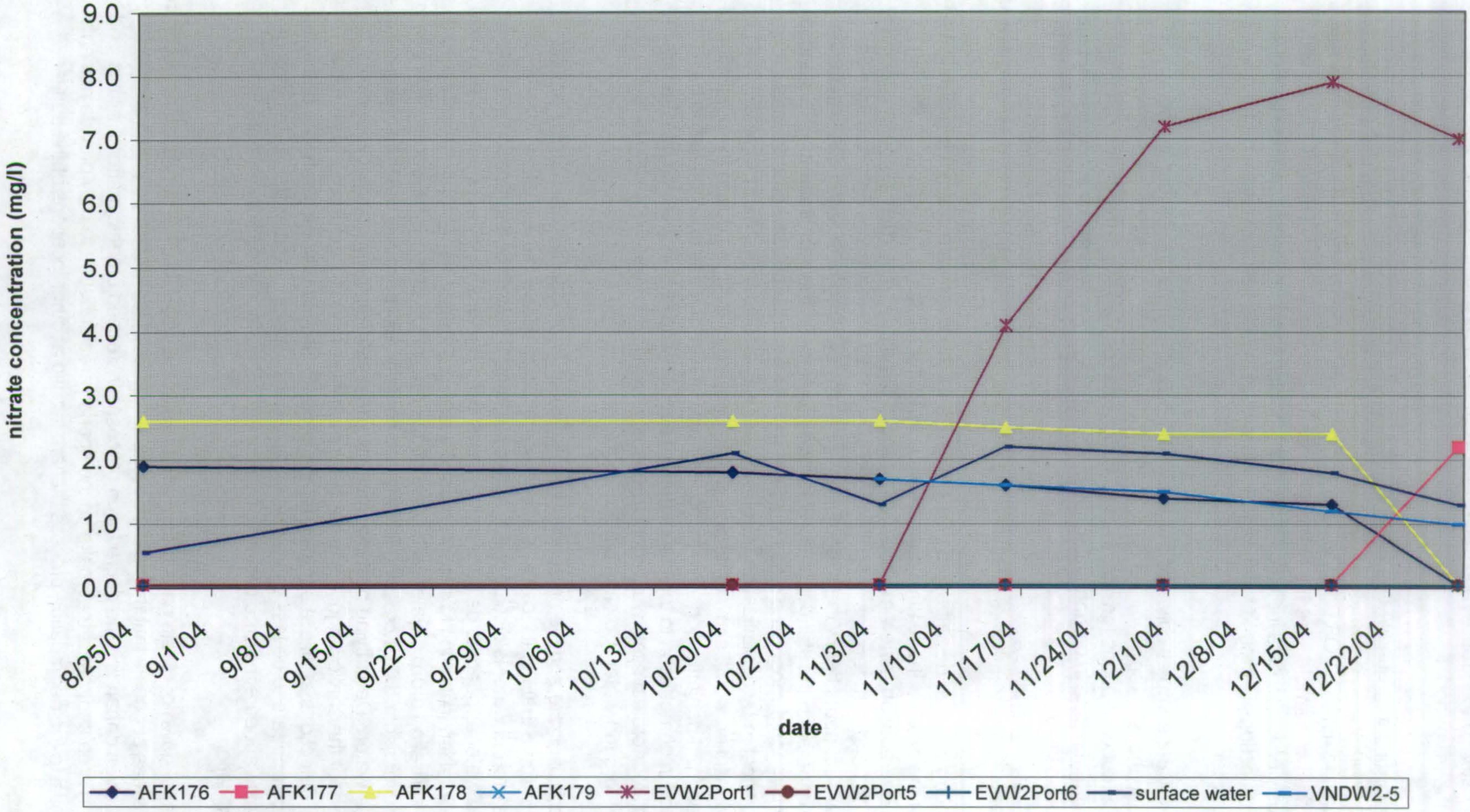


FIGURE 5-2 NITRATE MEASURED ALONG A GROUNDWATER FLOW PATH AT THE EVERSON SITE

6 Conclusions

For the five different sites characterized in the Nooksack watershed ground water was found to be discharging to surface water. Reversals in this predominant direction of flow corresponded to high stream flow conditions during storms or extremely low flow conditions during the late summer. In most cases the ground water levels maintained a close relationship to the water levels elevations in the adjacent water body responding quickly to changing surface water elevations. The close hydraulic continuity between groundwater and surface water was expressed in the consistent magnitude of the hydraulic gradients measured. Ground water discharge can be assumed to influence the water quality in the surface water bodies of the watershed.

For the most part, ground water was not found to be a significant mechanism for nitrate or bacteria loading to the surface water s of the Nooksack watershed. Bacteria is likely being transported via surface runoff processes; storm events and specific discharge events at individual sites to surface water. Nitrate is being effectively degraded in shallow groundwater before it discharges to surface water. However, nitrate loading to surface water is occurring via alternate ground water discharge pathways. Agricultural field (tile) drains were found to discharge nitrate to surface water in the small number of samples collected. Ground water discharge from regional the ground water system also transports significant, although not large, concentrations of nitrate that do not appear to degrade under the conditions present in deeper aquifers.

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