Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study

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Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study

by

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March 2006

Waterbody Numbers (see Table 1)

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Abstract

As part of the Henderson Inlet watershed Total Maximum Daily Load (TMDL) project, the Department of Ecology conducted a water quality monitoring and modeling study from 2002 to 2005. This report summarizes the findings.

Fecal coliform bacteria criteria were not met throughout Henderson Inlet and its six tributaries: Woodland, Woodard, Meyer, Sleepy, Dobbs, and Goose creeks. The critical period for most areas was during winter storm events, but some areas such as Woodland Creek and lower Henderson Inlet had high bacteria levels during the dry season as well. Fecal coliform bacteria reductions are recommended for all sites. Areas for bacteria clean up are prioritized based on bacterial loading and concentrations.

The Woodland Creek temperature TMDL includes the lower portion of Woodland Creek which meets temperature standards. Originally the temperature TMDL included the upper portion of Woodland Creek. However, more analysis is required to determine a background/natural temperature condition for the upper portion of Woodland Creek.

Henderson Inlet shows evidence of low dissolved oxygen levels, but this report does not set load or wasteload allocations. This study quantifies the geographic and temporal extent of low levels of dissolved oxygen and recommends several actions to improve water quality.

Woodland, Woodard, Sleepy, and Dobbs creeks did not meet the dissolved oxygen criterion of 9.5 mg/L. Natural conditions are largely the cause in these four creeks. Woodland Creek dissolved oxygen levels start out low at Beatty Springs but should meet the dissolved oxygen criterion at river mile 1.6. Model simulations showed that nutrient reduction had little or no effect on dissolved oxygen levels. Increased shading and lowering biochemical oxygen demand to the creek would slightly improve dissolved oxygen levels. Woodard Creek dissolved oxygen levels are low at the headwater and increase downstream. A target dissolved oxygen level of 9.0 mg/L should be met at river mile 2.9.

For all six creeks sampled, pH levels fell slightly below the standard. This was due to natural conditions.

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Introduction

The Washington State Department of Ecology (Ecology) is required by the federal Clean Water Act to conduct a Total Maximum Daily Load (TMDL) study for waterbodies on the 303(d) list. The 303(d) list is a set of waterbodies that are not meeting water quality standards.

The TMDL evaluation begins with a water quality technical study. The technical study determines the loading capacity of the waterbody to absorb pollutants and still meet water quality standards. The loading capacity is allocated among load and wasteload sources.

- If pollution comes from diffuse (nonpoint) sources, that share of the load is called a *load allocation.*
- If the pollutant comes from a discrete (point) source, such as a wastewater treatment plant discharge, that facility's share of the loading capacity is called a *wasteload allocation*.

The TMDL must also consider seasonal variation and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or a waterbody's loading capacity. The sum of the load and wasteload allocations and the margin of safety must be equal to or less than the loading capacity of the system.

The technical study also evaluates the likely sources of those pollutants and the amount of pollutant sources that needs to be reduced to reach that capacity. The study becomes the basis for water-quality-based controls. This document summarizes the findings of the technical study for the Henderson Inlet watershed area and recommends total maximum daily pollutant loads.

Ecology will work with Thurston County and other agencies and local citizens to identify best management practices and actions needed to control water pollution, based on the sources found in the study.

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Study Area

Henderson Inlet (Figure 1), located in Thurston County, is one of five inlets that form the southern terminus of Puget Sound. It is located between Budd Inlet on the west and Nisqually Reach on the east. The five-mile long inlet ranges from one-fourth to three-fourths miles in width, averaging about 25 feet in depth. A large portion of the lower inlet is exposed mudflats at low tide. Since the 1980s, commercial shellfish harvesting in the lower third of Henderson Inlet has been prohibited or restricted due to high fecal coliform bacteria levels in the water. Tidal elevations in this area (South Puget Sound) range from +16 to -4 feet (Cleland, 2000).

The 30,000-acre Henderson Inlet basin is the second largest basin in Water Resource Inventory Area (WRIA) 13. Woodland and Woodard creeks are the largest of the five main tributaries to Henderson Inlet, draining 80% of the basin. The other three streams in the watershed, Dobbs Creek (East Creek), Meyer Creek (Snug Creek), and Sleepy Creek (Libby Creek), drain small areas of the Dickerson Point and Johnson Point peninsulas (Thurston County WWM, 1995).

Henderson Inlet and several of its tributaries are on the 303(d) list of waterbodies not meeting water quality standards for at least one water quality parameter (Table 1). Some waterbodies listed in Table 1 are not currently on the 303(d) list, but they do not meet water quality standards. The parameters of concern include fecal coliform bacteria, dissolved oxygen, pH, and temperature.

The objectives in the Quality Assurance Project Plan for this study (Sargeant et al., 2003) called for setting TMDLs for fecal coliform bacteria, dissolved oxygen, and pH. However the current report does not set allocations for dissolved oxygen for some areas as explained later. The temperature listings are addressed in a separate Quality Assurance Project Plan (Zalewsky, 2002). Only the temperature in lower Woodland Creek, between Beatty Springs and the mouth, is addressed in this report.

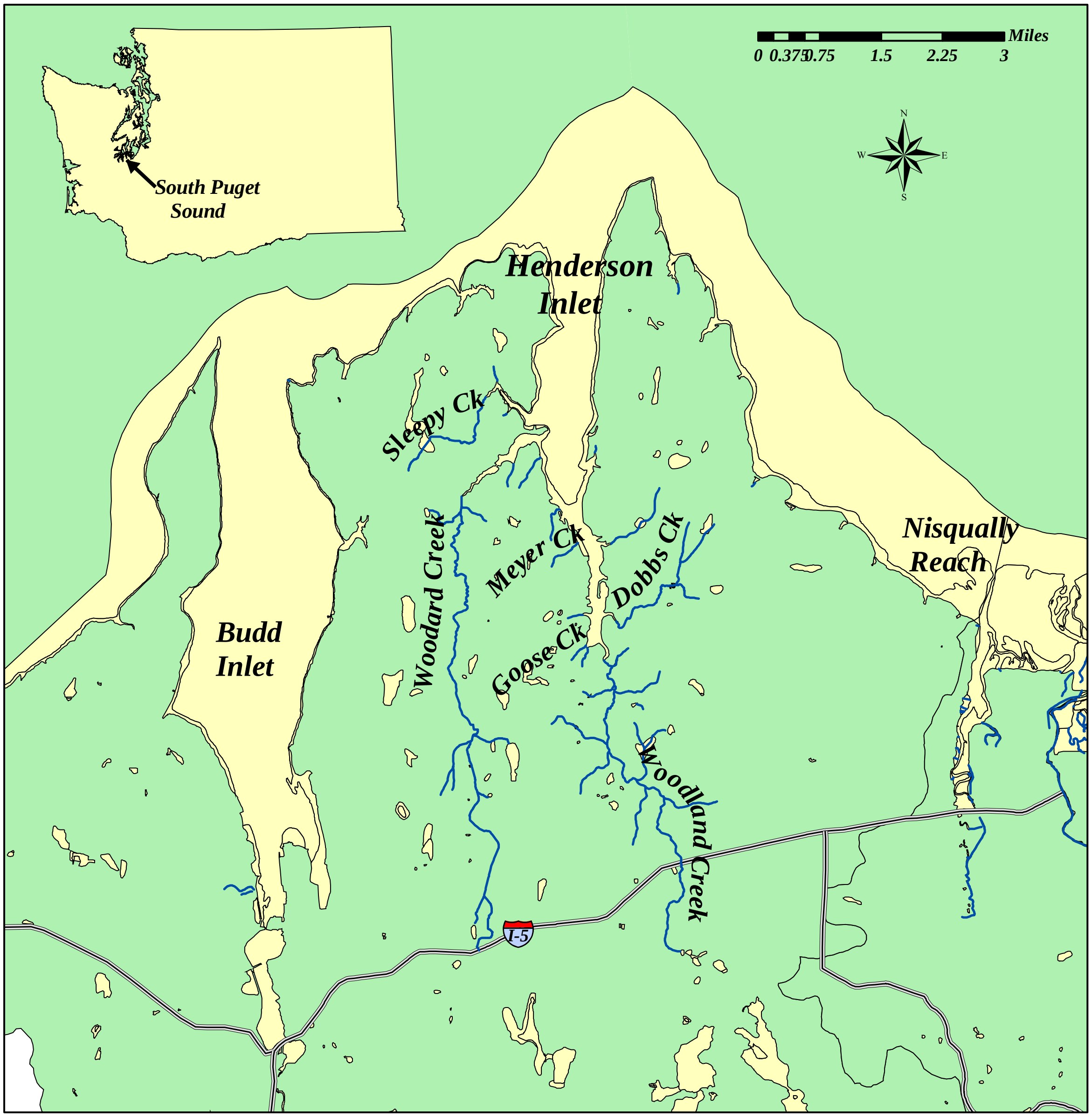

Figure 1. Henderson Inlet and tributaries study area.

Table 1. Henderson Inlet and tributaries on the 303(d) list and impaired waterbodies that do not meet water quality standards.

Waterbody	Parameter	Lat/Long or Township/Range/Section	2004 303(d) list ID	1998 303(d) list ID	1996 303(d) list ID
Marine Water					
Henderson Inlet	FC	47.115, 122.835	39766	390KRD	WA-13-0010
	FC	47.105, 122.825	39756	390KRD	WA-13-0010
	FC	47.115, 122.825	39755	390KRD	WA-13-0010
	FC	47.135, 122.835	39763	390KRD	WA-13-0010
	FC	47.125, 122.835	39767	390KRD	WA-13-0010
	FC	47.125, 122.825	39770	390KRD	WA-13-0010
	DO	47.155, 122.825	*	390KRD	WA-13-0010
Freshwater					
Dobbs Creek	FC	19N 01W 28	40612	UNK000	WA-13-1400
	pH	19N 01W 28	40613	UNK000	WA-13-1400
Sleepy Creek	FC	19N 01W 18	40614	UNK000	WA-13-1700
	DO	19N 01W 18	40616	UNK000	WA-13-1700
	pH	19N 01W 18	40615	UNK000	WA-13-1700
Woodard Creek	FC	19N 01W 19	3772	MJ83ZH	WA-13-1600
	DO	19N 01W 19	3771	MJ83ZH	WA-13-1600
	pH	19N 01W 19	40587	MJ83ZH	WA-13-1600
Woodland Creek	FC	18N 01W 16	6657	JH31LN	WA-13-1500
	DO	18N 01W 16	3774	JH31LN	WA-13-1500
	Temp	18N 01W 33	36180	JH31LN	WA-13-1500
	Temp	18N 01W 15	36184	JH31LN	WA-13-1500
	Temp	18N 01W 22	36185	JH31LN	WA-13-1500
	Temp	18N 01W 16	3773	JH31LN	WA-13-1500
	Temp	18N 01W 04	36181	JH31LN	WA-13-1500
	Temp	18N 01W 09	36182	JH31LN	WA-13-1500
	Temp	18N 01W 10	36183	JH31LN	WA-13-1500
College Creek	FC	18N 01W 16	*	**	**
Eagle Creek	FC	18N 01W 09	*	**	**
Palm Creek	FC	18N 01W 04	*	**	**
Fox Creek	FC	18N 01W 04	*	**	**
Jorgenson Creek	FC	18N 01W 04	*	**	**
	FC	18N 01W 05	*	**	**
Quail Creek	FC	19N 01W 32	*	**	**
	FC	19N 01W 33	*	**	**
Meyer (Snug) Creek	FC, pH	19N 01W 20	*	**	**
Goose Creek	FC	19N 01W 32	*	**	**

* does not meet standards, but not on 2004 303(d) list.
** does not meet standards, but not on either the 1998 or 1996 303(d) lists.
FC – Fecal coliform bacteria
DO – Dissolved oxygen
Temp – Temperature

Woodland Creek

Woodland Creek, with an area of approximately 29.7 square miles (76.8 square kilometers), is the largest creek draining to Henderson Inlet. The creek flows through northeast Olympia and central Lacey before emptying into Henderson Inlet (Figure 1). Three lakes connected by extensive wetlands form a horseshoe-shaped chain which makes up the headwaters of Woodland Creek. Hicks Lake flows into Pattison Lake and then Long Lake; all three lakes lie between 152 and 157 feet above sea level (USGS, 1999).

From Long Lake to Martin Way, Woodland Creek includes one mile of perennial stream to Lake Lois. From Lake Lois to Martin Way, Woodland Creek is an intermittent channel that often dries during the summer. Downstream of Martin Way, several springs provide perennial flow to the lower Woodland Creek.

The Woodland Creek basin is one of the fastest growing areas in the county (Thurston County WWM, 1995). Ninety percent of the Woodland Creek watershed lies within an Urban Growth Area (UGA), primarily Lacey but also Olympia (Clingman, 2001). The basin still contains substantial areas of undeveloped forests, although the dominant land use is suburban-density, residential development. Residential subdivisions are spreading rapidly in the area around the headwater lakes and near the mouth of the stream basin. Residential development is most dense in the southern (upper) portion of the basin. In 1987, approximately 80% of the lake shorelines and 16% of the creek shorelines in the Henderson basin were developed (Thurston County WWM, 1995). Due to the rapid growth in this area, those percentages are higher today.

A description of Woodland and Woodard creek basin geology, soils, hydrology, vegetation, fish habitat, and critical areas can be found in the Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1995).

Woodard Creek

Woodard Creek (Figure 1), the second largest creek in the Henderson basin, is 7.5 miles in length and drains a basin of 5090 acres (Thurston County PHSS and WWM, 2000). Groundwater feeds a large wetland at the headwaters of Woodard Creek just south of Interstate 5 at the Pacific Avenue interchange. Industrial and commercial development on Fones Road surrounds the wetland at the creek's headwaters. Large portions of high-density commercial areas in Lacey and Olympia, including the South Sound Mall and Olympia Square, drain into the wetland through the Fones Road ditch. The mouth of Woodard Creek is an estuarine wetland that is currently protected as a natural area by the Washington State Department of Natural Resources.

Meyer Creek

Meyer Creek (Figure 1) is approximately 1.0 mile in length (Thurston County PHSS and WWM, 1999a). The headwaters of the creek originate in a wetland at Schincke Road south of 56^{th} Avenue. The creek flows northeast through pastureland and into Henderson Inlet at

Snug Harbor, approximately one mile south of Woodard Bay. Streamflows in 1984 averaged 0.19 cubic feet per second (cfs) at the head to 0.46 cfs at the mouth (Taylor, 1984). Near the mouth of the creek, 1983-98 flows ranged from 0.002 - 7.44 cubic feet per second (cfs) with an average flow of 0.5 cfs. Primary land uses are rural, residential, and agricultural.

Sleepy Creek

Sleepy Creek is 1.1 miles in length, with primary land uses of rural, residential, and agricultural. This creek originates in a wetland, flows through a series of gullies and wooded ravines, and enters Henderson Inlet at Chapman Bay (Figure 1) (Thurston County PHSS and WWM, 1999a). Coho and chum salmon use Sleepy Creek (Thurston County WWM, 1997). Near the mouth of the creek, 1987-98 flows ranged from no flow to 64 cfs, averaging 5.0 cfs (Thurston County PHSS and WWM, 2001).

Dobbs Creek

Dobbs Creek is 1.5 miles in length, with primary land uses being rural, residential, and agricultural. The creek flows through wooded terrain as well as open pastures near the headwaters (Thurston County PHSS and WWM, 1999a) (Figure 1). Pleasant Forest Campground, a large recreational vehicle park, is located along the mid-stem of the creek. Near the mouth of the creek, 1983-98 flows ranged from 0.3 to 16.2 cfs, averaging 3.3 cfs (Thurston County PHSS and WWM, 2001). Coho and chum salmon use Dobbs Creek (Thurston County WWM, 1997).

Goose Creek

Goose Creek is approximately 1.0 mile in length and empties into the southern-most portion of Henderson Inlet (Figure 1). The headwaters originate from a large pond off Schincke Road, and the creek flows northeast through a narrow channel crossing Sleater-Kinney Road. In a 1984 study, average flows on Goose Creek ranged from 0.24 cfs at the head to 0.14 cfs at the mouth (Taylor, 1984). In 1983-84, Thurston County reported flows ranging from no flow to 0.6 cfs, with an average flow of 0.09 cfs (Thurston County PHSS and WWM, 2001).

Geology and Hydrogeology

The geology and hydrogeology of the area, including groundwater flow, are included in Appendix A.

Fisheries Resource

The Washington State Conservation Commission report on Habitat Limiting Factors for WRIA 13 (Haring and Konovsky, 1999) reported salmon and winter steelhead distribution information for Henderson Inlet streams (Table 2). The City of Lacey staff also observed chum salmon spawning in Eagle Creek, a tributary of Woodland Creek in the fall of 2001 (Rector, 2002).

Table 2. Salmon and winter steelhead distribution for Henderson Inlet streams.

Stream Name	Species	Uppermost Distribution River Mile (RM)
Woodland Creek	Chinook salmon	RM 3.10
	Coho salmon	RM 5.10
	Chum salmon	RM 5.00
	Winter steelhead	RM 5.10
	Sockeye salmon	RM 4.40
Woodland Creek (tributaries)		
Fox Hollow Creek	Coho salmon	RM 0.40
Jorgenson Creek	Coho salmon	RM 0.40
Fox Creek	Chum salmon	RM 0.30
Eagle Creek	Coho salmon	RM 1.10
Woodard Creek	Coho salmon	RM 7.00
	Chum salmon	RM 3.60
	Winter steelhead	RM 7.00
Sleepy Creek	Coho salmon	RM 1.00
Dobbs Creek	Coho salmon	RM 1.50
	Chum salmon	RM 1.50

From the Washington State Conservation Commission report on Habitat Limiting Factors for WRIA 13 (Haring and Konovsky, 1999)

Shellfish Area Classifications

Henderson Inlet is a productive shellfish harvesting area. In 1986, more that 250,000 pounds of oysters were harvested. In 1984, the Washington State Department of Health (DOH) changed the classification of 180 acres of shellfish growing areas in Henderson Inlet from *Approved* to *Conditionally Approved*, citing contamination from rural nonpoint sources. At that time, the designated area was closed to shellfish harvest for five days following a rainfall of greater than one inch in a 24-hour period. In 1985, 120 acres in the southern portion of the *Conditionally Approved* area was reclassified to *Prohibited*.

In 1999, in response to declining water quality, DOH adjusted the criterion for the *Conditionally Approved* classification to the more restrictive 0.5" of rain in 24 hours. Based on the results of water samples collected between September 1996 and December 1999, DOH downgraded an additional eight acres of the *Conditionally Approved* area to *Prohibited* in November 2000 (Puget Sound Action Team, 2001). In 2001, an additional 300 acres of *Approved* shellfish growing areas was downgraded to *Conditional Approved*. In June 2005, an additional 49 acres were reclassified from *Conditionally Approved* to *Prohibited*, moving the closure line north (Figure 2).

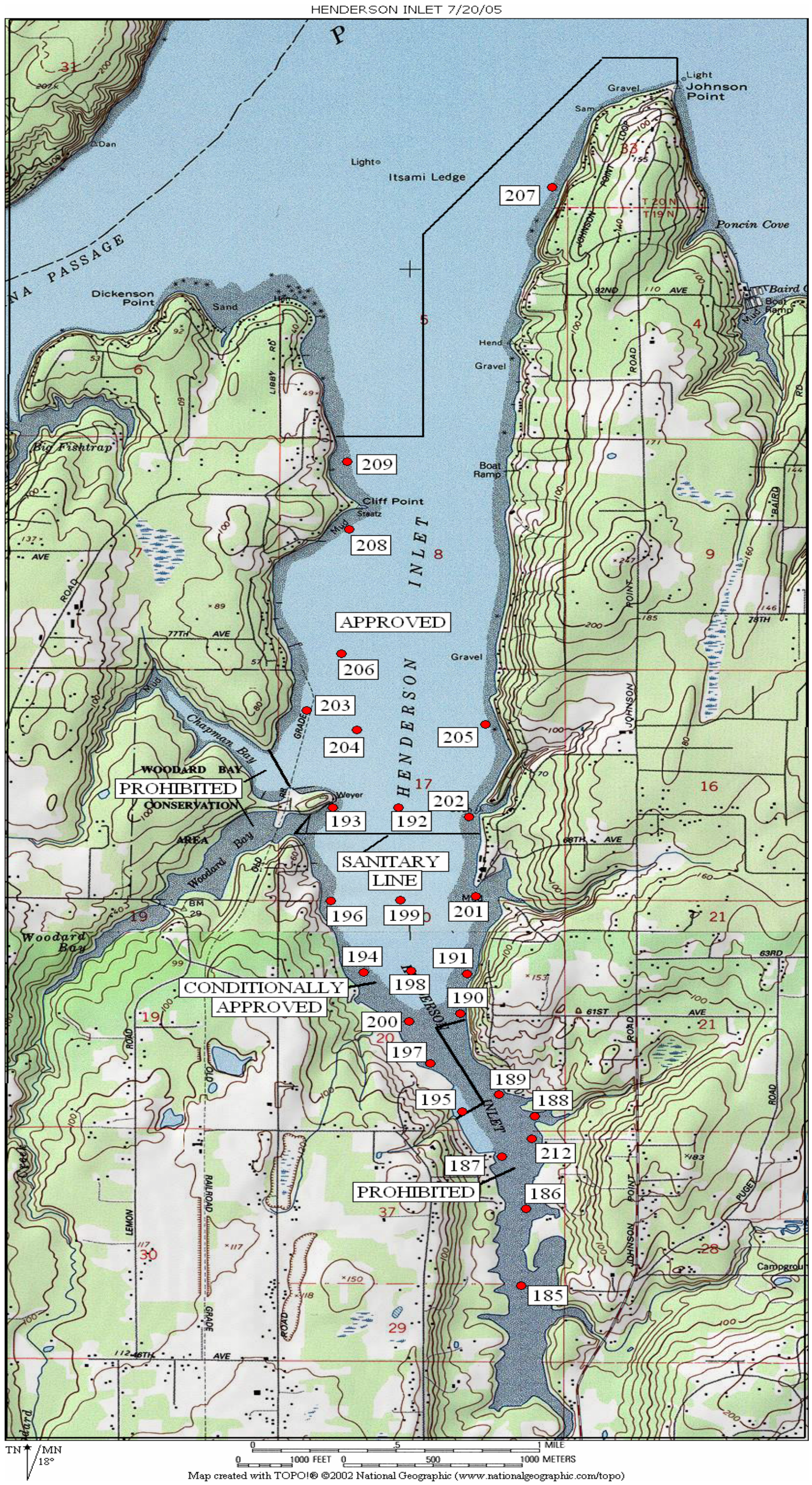

Figure 2. DOH shellfish growing area classification and sampling sites for Henderson Inlet.

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Water Quality Classifications and Applicable Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), includes designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state. A revised water quality standards rule (Chapter 173-201A WAC) was adopted on July 1, 2003 (this version is not yet approved by EPA). In the revised rule, the waterbody classification system is replaced by a beneficial use based designation.

Under the new rule, waterbodies are required to meet water quality standards based on the beneficial uses of the waterbody. For fecal coliform bacteria, former Class AA waterbodies become *Extraordinary Primary Contact Recreation* (with the same fecal coliform criterion as Class AA). The same is true for the dissolved oxygen, pH, and temperature criterion, with Class AA being *Extraordinary* quality water. The water quality criteria for *Extraordinary* quality water for the parameters of concern in this TMDL, both fresh and marine, are summarized in Table 3.

Table 3. Fecal coliform bacteria, dissolved oxygen, pH, and temperature water quality standards.

Parameter/Class	Freshwater	Marine
Fecal Coliform Bacteria		
Extraordinary Primary Contact Recreation	GM* ≤ 50 fc/100 mL, with not more than 10% of all samples for calculating the GM value > 100 fc/100 mL.	GM* ≤ 14 fc/100 mL, with not more than 10% of all samples for calculating the GM value > 43 fc/100 mL**
Dissolved Oxygen	*Lowest 1-day minimum*	
Salmon and Trout Spawning, Core Rearing, and Migration	≥ 9.5 mg/L	N/A
Extraordinary Quality Water	N/A	≥ 7.0 mg/L
pH	*pH shall be within the following range, with a human-caused variation within the range of < 0.2 units.*	
Salmon and Trout Spawning, Core Rearing, and Migration	6.5-8.5 units	N/A
Extraordinary Quality Water	N/A	7.0-8.5 units
Temperature		
Salmon and Trout Spawning, Core Rearing, and Migration	16°C	N/A
Extraordinary Quality Water	N/A	13°C

* Geometric mean
** Washington State Department of Health uses the estimated 90th percentile value rather than the actual percent of samples exceeding 43 MPN/100 mL. Both results are reported for marine bacteria monitoring in this report.

Puget Sound through Admiralty Inlet and South Puget Sound, south and west to longitude 122°52’30”W (Brisco Point) and longitude 122°51’W (northern tip of Hartstene Island), is designated *Extraordinary* quality marine water, formerly Class AA. This includes Henderson Inlet. Beneficial uses include *Extraordinary* aquatic life use and primary contact recreation, as well as shellfish harvest.

Tributaries to Henderson Inlet are considered *Extraordinary* quality water, formerly Class AA, as described in WAC 173-201A-600(a). All fresh surface waters that are tributaries to *Extraordinary* quality marine waters are to be protected for the designated uses of salmon and trout spawning, core rearing, and migration; as well as *Extraordinary* primary contact recreation.

As stated in WAC 173-201A-260(a), "*It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria.*" The standards define "natural conditions" or "natural background levels" as surface water quality that was present before any human-caused pollution.

The Washington State Department of Health (DOH) classifies commercial shellfish beds in Washington State using the National Shellfish Sanitation Program criteria. To meet these criteria, bacteria concentrations in commercial shellfish harvesting areas can be no higher than 14 most probable number (MPN)/100 mL as a geometric mean, and the estimated 90^{th} percentile value must be less than 43 MPN/100 mL.

Methods

Study Design

The study design is described in detail in the Quality Assurance Project Plan for the Henderson and Nisqually TMDL Study (Sargeant et al., 2003).

Field and Laboratory Methods

Henderson Inlet Tributary Streams

Synoptic Surveys

Eight storm-event and four dry-season sample surveys were conducted for each tributary. The criterion for storm-event surveys, conducted November through April, was 0.30 inches of rain in the previous 24 hours. Dry-season events were conducted from June through September. Sample dates are given in Appendix B, and sampling sites are presented in Figures 3 and 4.

Sampling was conducted for fecal coliform and *E. coli* bacteria, *E. coli* sampling was discontinued after September 2003. Nutrient sampling was conducted at all sites during the dry-season surveys (June - September) including total persulfate nitrogen (TPN), ammonia-nitrogen (NH3), nitrate+nitrite nitrogen (NO2+3/N), total phosphorus (TP), and orthophosphate (ortho-P). Additional nutrient sampling was conducted at some sites as presented in Appendix B. Field measurements for temperature, pH, conductivity, and dissolved oxygen were obtained at each site when possible.

Continuous In-situ Monitoring

In-situ continuous monitoring was conducted at several sites on Woodland and Woodard creeks and near the mouths of Meyer, Sleepy, and Dobbs creeks. Monitoring was conducted for temperature, pH, conductivity, and dissolved oxygen. Continuous monitoring sampling sites, sampling periods, and parameters of concern are described in Table 4.

Table 4. Continuous monitoring sampling sites, sampling periods, and field parameters of concern.

Monitoring Site	Sampling Periods	Parameter(s) of Concern
Woodland Creek		
RM 3.4 (behind Top Foods)	12/31/02-1/2/03; 3/31-4/3/03; 7/24-7/28/03; 8/22-8/26/03; 9/17-9/19/03	Dissolved oxygen, Temperature
RM 3.1 (at Interstate 5)	7/9-7/13/02; 7/26-7/29/02; 12/30/02-1/2/03; 3/31-4/3/03; 7/24-7/28/03; 8/22-8/26/03; 9/17-9/19/03	
RM 1.6 (Pleasant Glade Road)	7/10-7/13/02; 7/26-7/29/02; 7/29-8/1/03; 8/15-8/18/03; 10/2-10/6/03	
Woodard Creek		
RM 6.8 (Pacific Avenue)	8/6-8/11/03; 9/10-9/13/03	Dissolved oxygen, pH
RM 6.2 (Ensign Road)	8/2-8/7/02; 1/3-1/6/03; 7/16-7/19/03; 9/29-10/2/03; 2/20-2/23/04	
RM 5.1 (Lindell Road)	8/7-8/11/03; 9/10-9/13/03	
RM 2.9 (Libby Road)	7/10-7/13/02; 1/3-1/6/03; 3/14-3/17/03; 7/16-7/19/03; 8/7-8/11/03; 9/26-9/30/03; 2/20-2/23/04	
Meyer Creek		
RM 0.6	4/20-4/22/05	pH
RM 0.1	3/14-3/17/03; 2/10-2/13/04	
Sleepy Creek		
RM 0.1	4/18-4/21/03; 8/1-8/4/03; 8/19-8/22/03; 9/9-9/12/03	Dissolved oxygen, pH
Dobbs Creek		
RM 0.1	1/6-1/10/03; 4/25-4/28/03; 8/1-8/4/03; 9/9-9/12/03	pH

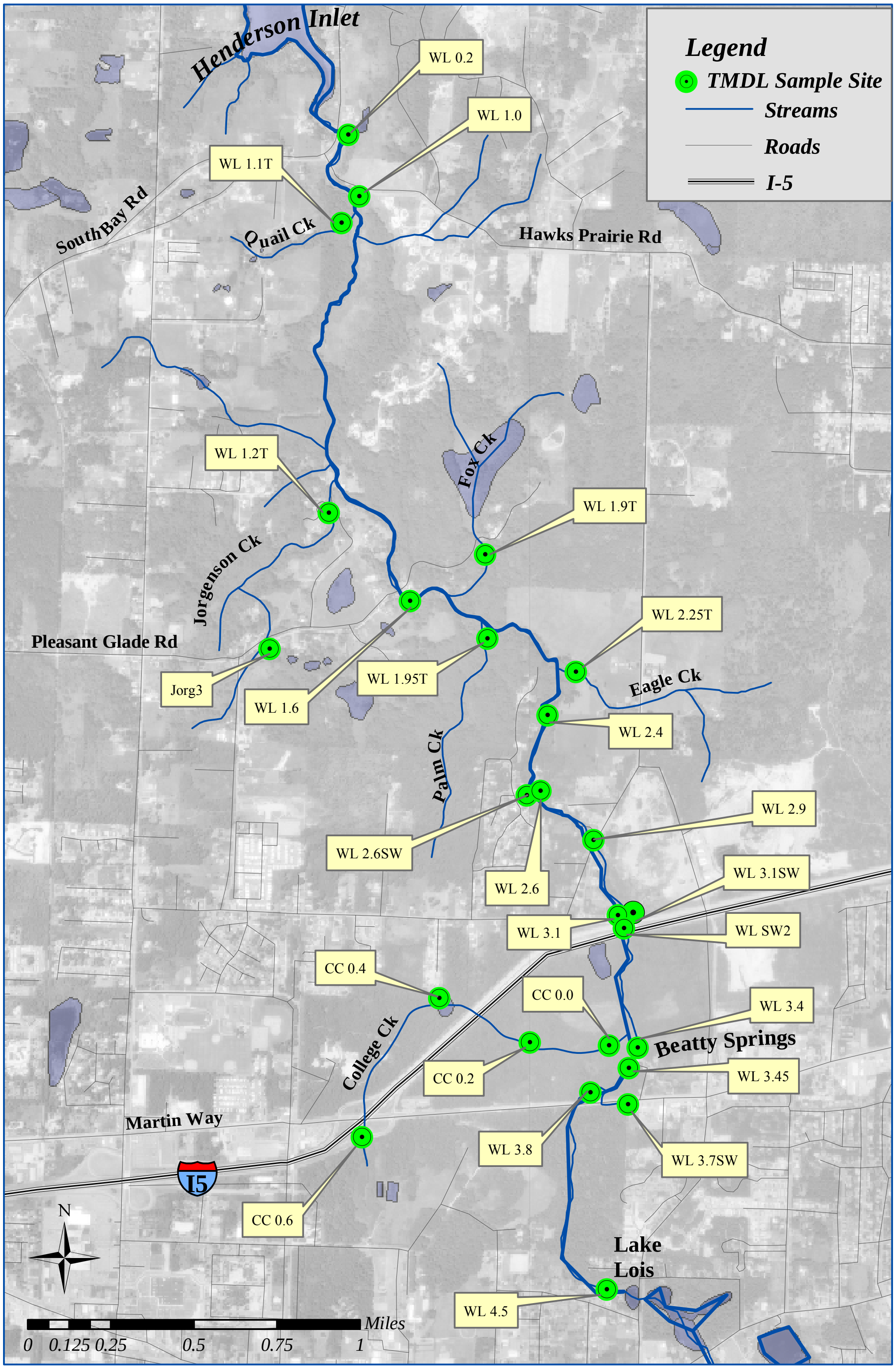

Figure 3. Woodland Creek sampling sites.

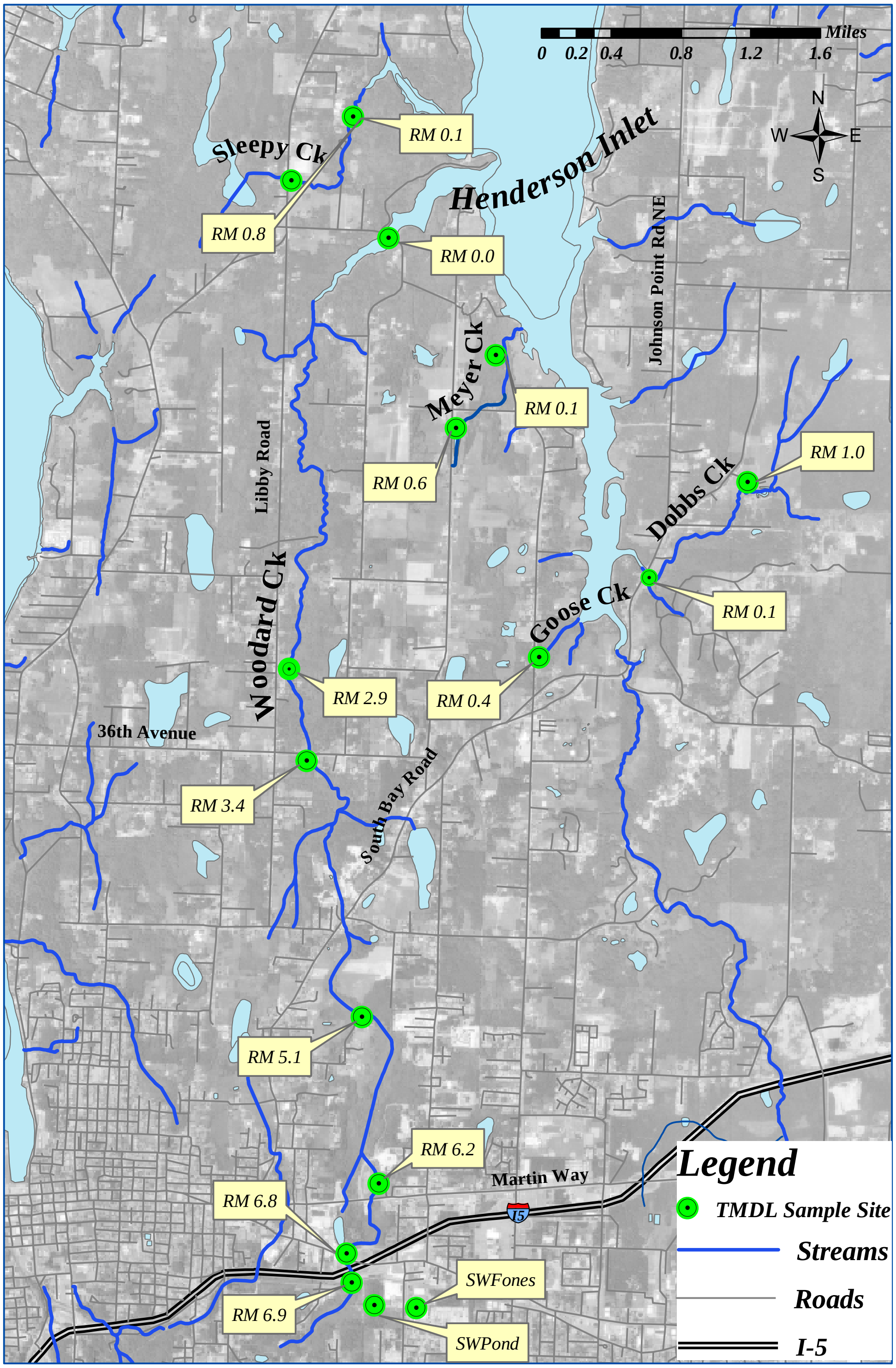

Figure 4. Woodard, Meyer, Sleepy, Dobbs, and Goose creek sampling sites.

Continuous *In-situ* Temperature Survey

Water and air temperatures in the Woodland Creek watershed were monitored continuously during the summer and fall of 2002. The Quality Assurance Project Plan (Zalewsky, 2002) and Appendix C describe the data collection methods.

Groundwater Survey

Groundwater sampling was conducted at Beatty Springs and St. Martin's College Spring to determine groundwater quality entering Woodland Creek. Existing groundwater data related to flow and quality, as well as the methods and results of groundwater sampling, are included in Appendix A.

Stream Flow Data

Continuous streamflow data were available for two sites on Woodland Creek: a Department of Ecology site south of Interstate 5, and a Thurston County site at Pleasant Glade Road. For Woodard Creek, a Thurston County continuous flow monitoring site is located at 36th Avenue.

- Department of Ecology flow results are available on the internet at: https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=13B170 (Ecology, 2004)
- Thurston County streamflow data are available on the internet at: www.co.thurston.wa.us/monitoring/ (Thurston County WWM, 2004)

For all other sites, two methods were used to determine flow: instantaneous flow measurements and flow estimates from a flow discharge-rating curve.

Flow results are available in Appendix B.

Woodland Creek Time-of-Travel Survey

A time-of-travel study was conducted on August 22, 2003 to quantify water transport characteristics of Woodland Creek downstream of Martin Way. Two reaches were evaluated to estimate low-flow transport time from Martin Way to the creek outlet at Henderson Inlet.

A pulse injection of approximately one liter of saturated salt solution was used as a tracer. Conductivity was monitored at 30-second to 2-minute intervals with Hannah Instruments or Orion conductivity meters at three locations downstream.

Station 1 was located at Pleasant Glade Road, approximately 100 feet downstream of the injection location. Station 2 was located at Jorgensen Road, approximately 2300 feet downstream of Station 1. Station 3 was located off 31st Avenue and just upstream of Quail Creek, approximately 1300 feet downstream of Station 2. A discharge of 13.4 cfs was measured at Station 2. Estimated discharge of Woodland Creek at Interstate 5 was 8.0 cfs.

Tim-of-travel survey results are described in detail in Appendix D.

Sargeant et al. (2003) describes the Henderson Inlet monitoring program, which was designed to build from the extensive marine bacteria data collection program conducted by DOH. Travel time and flow paths were determined under ebbing tide conditions using drogues released at several shore locations near tributaries. Two studies were conducted in the southern inlet and one in the central inlet to determine the time-of-travel from watershed sources of bacteria through the shellfish zones.

Two *in-situ*, die-off experiments were conducted in the summer of 2003. The initial experiment was inconclusive. In the second experiment, ambient Boston Harbor[1] marine water was collected in six glass vessels. The six replicate vessels were spiked with fresh dog feces and suspended at the surface or at 1-m depth for a total of three at each depth. Subsamples were collected in the morning and afternoon for three days after the vessels were placed in the water column. Only summer conditions were monitored.

Wildlife bacteria contributions were based on literature values provided in Sargeant et al. (2003). Domestic animal bacteria contributions were included in watershed loads to the inlet. No studies were conducted to estimate sediment resuspension.

Historical dissolved oxygen levels reached minimum values in the late fall at the Ecology ambient monitoring station. Additional water column profiles were recorded at four stations on a north-south transect during five monitoring periods from September through November 2003. Surface and at-depth grab samples were analyzed for fecal coliform bacteria, total phosphorus, orthophosphate, total persulfate nitrogen, nitrate, ammonium, and chlorophyll *a* during three sampling events.

Data Analysis Methods

Field and laboratory data were compiled and organized using Excel® spreadsheet software (Microsoft Corporation, 2001). Water quality results from field and laboratory work were also entered into Ecology's Environmental Information Management database. Statistical analyses, plots, and mass balance calculations were made using Excel® software. For statistical trend analysis, WQHYDRO software (Aroner, 2001) was used.

For the purposes of data analysis and comparison to water quality standards, laboratory duplicate results were arithmetically averaged, as were field duplicate results.

For analysis of dissolved oxygen data, Winkler titration results were used, where available, in preference to meter results.

[1] Initially the experiment was conducted in Henderson Inlet, but the bottles broke under wave and current action. The second experiment was conducted in more protected waters at the northern end of Budd Inlet.

For comparison to standards, salinity levels were evaluated at Woodland Creek RM 0.2 and Woodard Creek RM 0.0. Marine standards apply at salinities of 10 parts per thousand (ppt) or greater for fecal coliform and *E. coli* bacteria, and at 1 ppt or greater for all other parameters. Both sites, Woodland Creek at RM 0.2 and Woodard Creek at RM 0.0, were the only sites measured that met the criteria for application of marine standards for all parameters.

A non-parametric Wilcoxon paired sample test was used to compare water quality between upstream and downstream sites. Sites were evaluated for differences in fecal coliform concentration and loading. A two-tailed test with a significance level of $\alpha = 0.05$ was used.

Specific data analysis methods for fecal coliform bacteria, temperature, dissolved oxygen, and pH are described in the sections of this report specific to each parameter.

Quality Assurance and Quality Control Results

A complete discussion of the quality assurance and quality control (QA/QC) results for the synoptic surveys and continuous monitoring are included in Appendix E. For groundwater sampling, QA/QC results are included in Appendix A.

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Survey Results

Synoptic and Continuous Monitoring Surveys

Summaries of the survey results for each area, including field measurements and laboratory results, are presented in Appendix B. Continuous *in-situ* Hydrolab data are presented in Appendix F. Thurston County Environmental Health Division conducted storm-event monitoring of several sites on Woodland Creek from April 2001 through March 2002. Their data are included in Appendix G and are used for statistical and TMDL analysis where available. Appendix G also includes fecal coliform bacteria data that the City of Lacey collected from November 2000 through June 2005 for Woodland Creek RM 2.9 at Draham Road.

Appendix H describes compliance with the fecal coliform standard at all sites. Woodard Creek and tributaries must meet the freshwater standards, with the exception of the Woodard Creek site at RM 0.0 which must meet marine standards for all parameters. During four storm events, a site was sampled in the stormwater conveyance ditch, upstream of City of Olympia constructed stormwater ponds. A site downstream of the ponds was also sampled. Discharge from the ponds flows into Taylor wetland, the headwaters of Woodard Creek. The upstream site represents human-created waters managed primarily for the removal or containment of pollution, and thus the numeric water quality criteria do not apply to this site. The water quality standards do apply to the downstream site which represents post-treatment.

Meyer and Goose creeks are seasonal creeks with flow occurring only during the wetter period of the year. No dry-season sampling was conducted on these creeks. Due to access difficulties, Meyer Creek was sampled at 56^{th} Road (approximately RM 0.6) for the first two storm events. For the rest of the sample events, Meyer Creek was sampled as close to the mouth as possible while being out of the tidally influenced zone. Sleepy Creek at RM 0.8 was dry during the dry-season sample events, and flow was so low at RM 0.1 that it could not be measured during this period.

Continuous *In-situ* Temperature Survey

A full description of summer and fall 2002 temperature results is included in Appendix C.

Groundwater Survey

A full description of groundwater results is included in Appendix A.

Time-of-Travel Surveys

Time-of-travel surveys were conducted on Woodland Creek and Henderson Inlet. A full description of the results is described in Appendix D.

Woodland Creek travel time from Martin Way to Henderson Inlet varies from 3.4 to 4.6 hours during low-flow conditions. Time-of-travel during winter conditions is likely faster, given the higher flow rates.

A large tidal volume passes through southern Henderson Inlet; velocities can exceed 0.3 m/s during moderately large tidal exchanges. At these speeds, Woodland Creek and Dobbs Creek water can traverse the *Prohibited* shellfish zone within two hours and could reach the southern extent of the *Approved* shellfish zone at Woodard Bay within 4 to 5 hours. Therefore, all freshwater that enters southern Henderson Inlet could reach the *Approved* shellfish zone within a single tidal cycle.

Fecal Coliform Bacteria *In-Situ*, Die-off Study

Of the six at-depth or surface vessels deployed in Budd Inlet in August 2003, four provided a time series of bacteria concentrations, shown in Figure 5. Bacteria die-off is generally modeled as exponentially declining concentrations. First-order decay rates, developed from a best-fit exponential equation to the data in Figure 5, ranged from 1.4 to 2.0 per day, with 95% to 99% of the variability explained by the relationship. The increasing concentrations after 2.1 days in series Surface (2A) were likely an artifact of insufficient mixing; the vessel results were discarded. The at-depth and surface rates did not differ. Measured die-off rates per day (e.g., the exponents in Figure 5) are consistent with those reported by Mancini (1978) for seawater with temperatures similar to those in South Puget Sound.

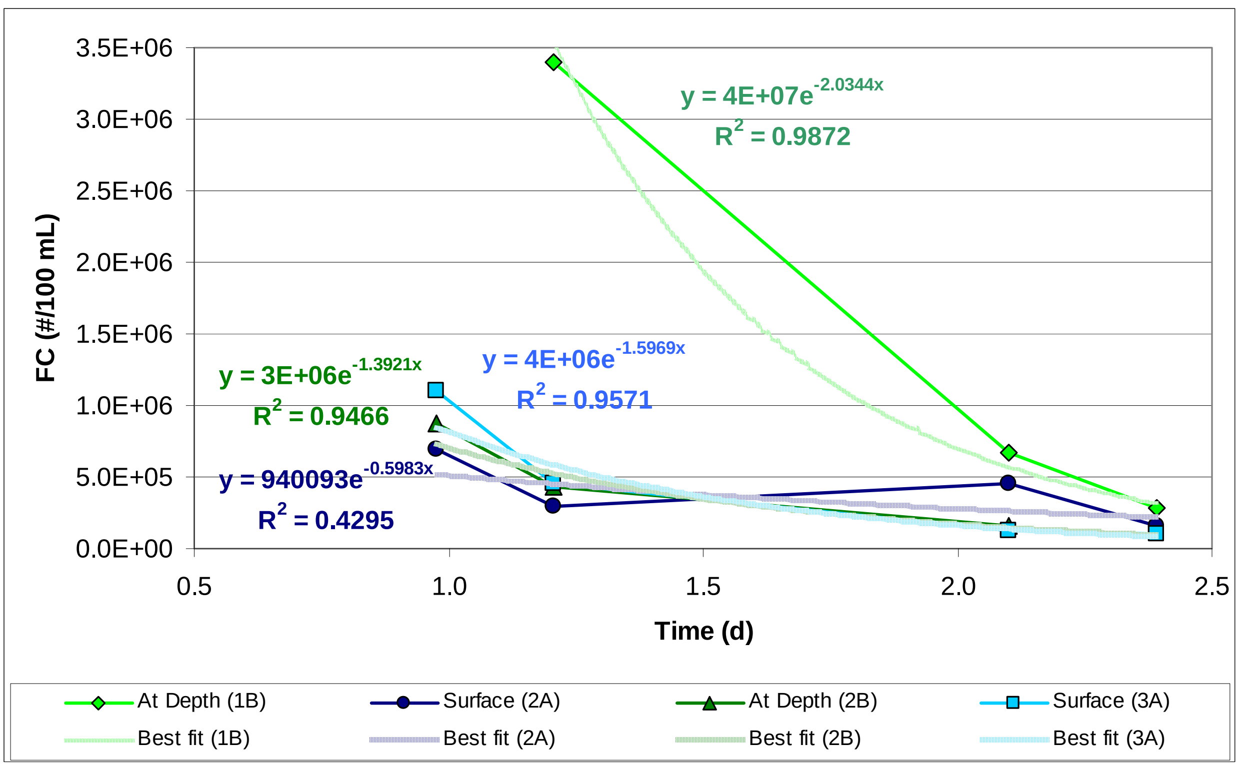

Figure 5. *In-situ* fecal coliform die-off in glass vessels with ambient Budd Inlet marine water spiked with dog feces.

Seasonal Variation, Critical Conditions, and Trends

Seasonal Variation and Critical Conditions

Seasonal patterns in fecal coliform concentrations and loading were evaluated for all sites annually and seasonally. The full discussion of this review is presented in the *Results* section by tributary and site.

The beneficial use with the most restrictive fecal coliform criteria is shellfish harvesting in Henderson Inlet. The critical period, Total Maximum Daily Load (TMDL) targets, and fecal coliform reductions for the tributaries need to be protective of all downstream beneficial uses, including shellfish harvesting in Henderson Inlet.

Woodland Creek

The critical period for state Department of Health (DOH) shellfish harvesting Station 185 drives the critical period for the mouth of both Woodland and Dobbs creeks (Figure 2). The critical period for Station 185 is both storm events (November through March) and the dry season (June through September). In examining storm-event (wet) and dry-season data for Woodland Creek at RM 0.2 (the mouth station), high 90^{th} percentiles were seen during the storm-event period while high geometric mean concentrations were seen during the dry season. Both periods, storm-event and dry-season, required significant bacteria reductions to meet the water quality standard, a 93% reduction in 90^{th} percentile concentrations during the storm-event period and a 92% reduction in geometric mean concentrations during the dry season at RM 0.2 (marine water site). Due to high bacteria concentrations during the storm-event period and dry season, Woodland Creek RM 0.2 and the DOH Station 185 have two critical periods: storm-event and dry.

For the upper portions of Woodland Creek in the study area, the critical period is the wet storm-event period, due to stormwater discharges to the upper portion of the creek. Most of the tributaries also had higher bacterial levels and concentrations during the wet season.

Dry-season bacterial reductions still need to occur, and it is likely different sources input bacteria to the creek during the storm-event and wet periods. Dry-season sources along the mainstem of Woodland Creek must also be addressed to meet water quality standards.

As discussed in the *Results* section, the mainstem of Woodland Creek and most of the tributaries showed higher concentrations and loading during storm events. For all the mainstem sites and most tributaries, storm events are the critical period.

The critical period for two of the tributaries, Eagle Creek and Jorgenson Creek, is the dry low-flow period (June through September) when both creeks had the highest bacterial concentrations.

The critical period for pH is during periods of high flow (December through March). For dissolved oxygen, the critical period is during low-flow (July through September).

Woodard Creek

The DOH station closest to Woodard Creek is DOH 193 at the mouth of Woodard Bay (Figure 2). Bacterial concentrations at this station meet DOH *Approved* criteria for shellfish harvesting. The highest bacteria concentrations at this site are seen during rainfall events.

The critical period for Woodard Creek is during storm events due to high 90th percentile fecal coliform levels. While the lower mainstem sites, including the mouth site at Woodard Creek RM 0.0, have higher geometric mean concentrations during the dry season, the high 90th percentile concentrations during the wet storm-event period require the most stringent reductions in bacterial concentrations.

During the study, only one site located amidst the large wetland complex upstream showed a minimal excursion from the pH minimum of 6.5 SU. A review of historical data shows that pH values were lowest from November through March (Sargeant et al., 2003). The lowest dissolved oxygen levels were seen during the critical low-flow period (July - September).

Dobbs Creek

The critical period for Dobbs Creek is during storm events when the highest bacterial concentrations and loading were seen. Historical data support a November through March critical period for pH, when flows are higher and discharge from the headwater wetlands occurs (Sargeant et al., 2003).

Sleepy Creek

Sleepy Creek had high bacteria concentrations during both the dry season and storm events. The highest bacterial loading occurs during storm events. It is questionable that there is any bacterial loading from Sleepy Creek during the dry season due to low or no flow in the creek. Therefore, to protect the downstream beneficial use of shellfish harvesting, the critical period for bacteria in Sleepy Creek is during storm events.

The critical period for dissolved oxygen is during low-flow when the lowest levels of dissolved oxygen were seen. For pH, the critical period is during the wet storm-event period when there is flow in the creek and discharge from the headwater wetland.

Meyer and Goose Creeks

The critical period for bacteria in Meyer and Goose creeks is during storm events due to no flow during the dry season. The critical period for pH in Meyer Creek is also the winter season when there is flow in the creek and discharge from the headwater wetland.

Henderson Inlet

DOH monitoring results indicate that bacteria concentration reductions are necessary during both the dry season and wet season during storm events. Load capacity and load allocations are developed for both seasons, since the relative magnitude of sources may be different. Therefore, the critical period for Henderson Inlet stations is during both the storm-event and dry season.

Tidal condition also was evaluated as a potential critical condition. However, the seasonal analysis likely describes varying sources better than a tidal condition. The tidal condition, where ebbing tides generally are associated with higher concentrations and higher load reductions, is used to understand the relative area of influence of southern inlet bacteria sources.

Effect of Rainfall

Data from several DOH stations at the southern end of Henderson Inlet were analyzed to determine seasonal variation and critical conditions. Figures 6, 7, and 8 present the geometric mean and 90th percentile for DOH Stations 185, 186, and 187 in the *Prohibited* for shellfish harvesting area. Figure 2 presents a map of the DOH shellfish harvesting stations.

For the southern-most DOH Station 185, the highest bacteria concentrations are seen during two periods, during previous 24-hour rainfall > 0.20" and during the June through September dry season. Freshwater inputs that influence this station are Woodland and Dobbs creeks. Station 186 is still in the *Prohibited* area and approximately 0.4 miles north of Station 185. This site shows the greatest bacteria concentrations occur during previous rainfall of > 0.20". Data from Stations 212 and 188, also in the *Prohibited* area, showed the same pattern as Station 186 with the highest bacteria concentrations during previous rainfall of > 0.20". Station 188 is near the outlet of Swayne Creek.

Station 187 bacteria levels were generally lower but still did not meet marine standards for several periods, with the highest concentrations occurring during previous rainfall of > 0.20".

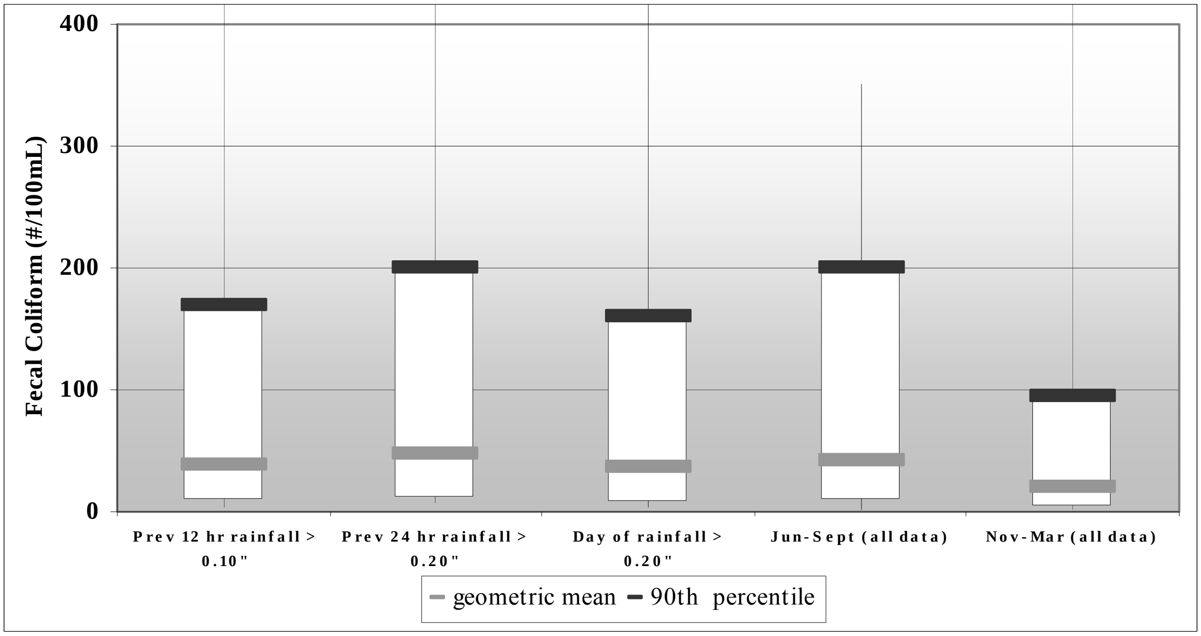

Figure 6. DOH fecal coliform bacteria results for marine Station 185, 1999-2004.

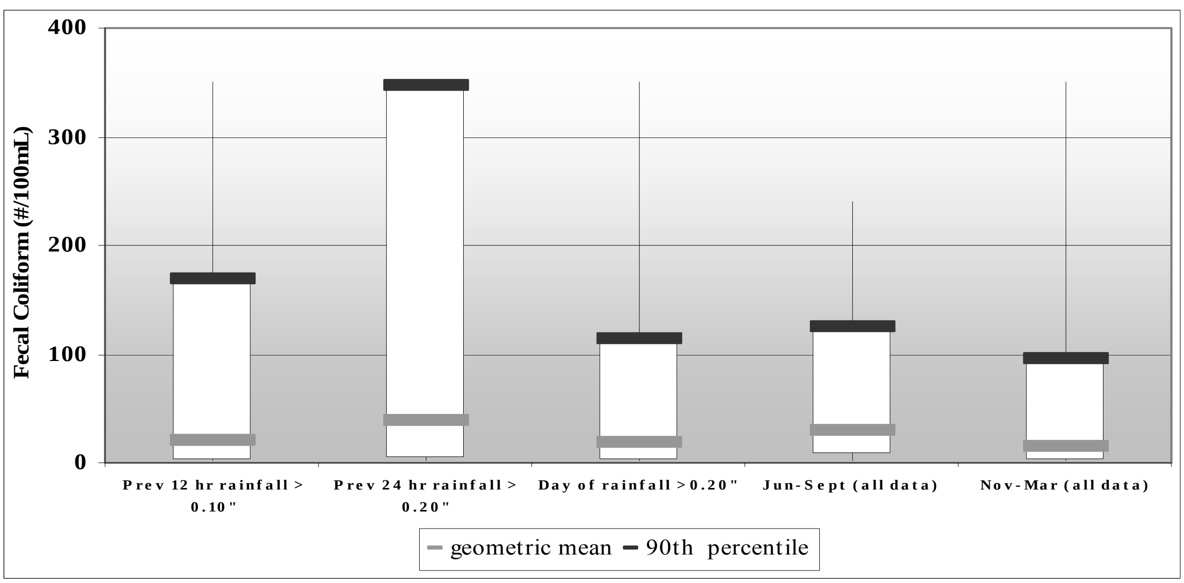

Figure 7. DOH fecal coliform bacteria results for marine Station 186, 1999-2004.

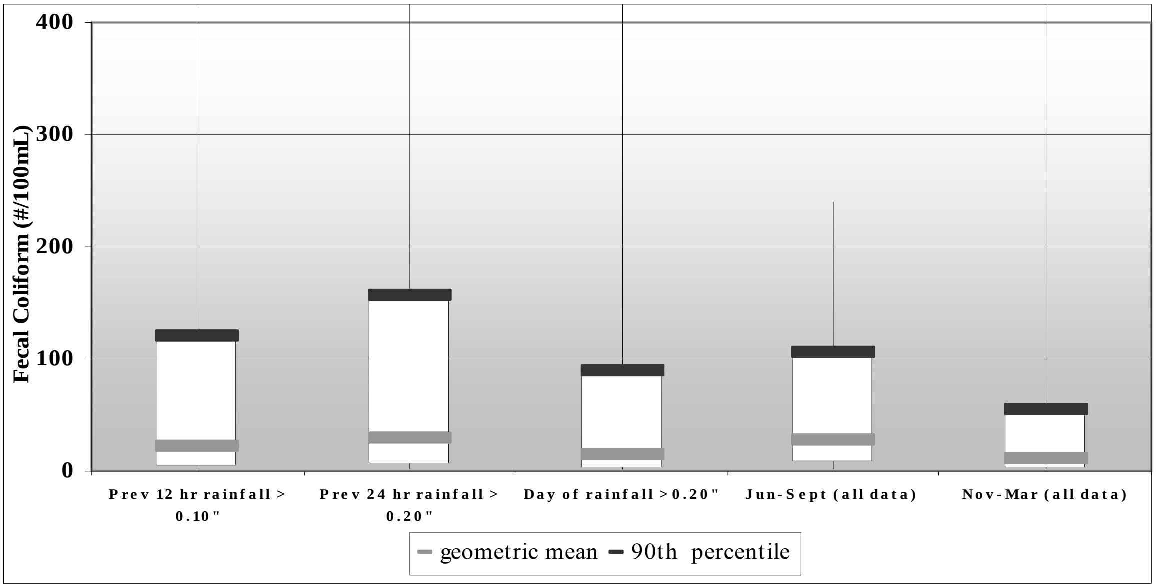

Figure 8. DOH fecal coliform bacteria results for marine Station 187, 1999-2004.

Trends

A complete historical data summary for the area is included in the Quality Assurance Project Plan for the Henderson and Nisqually TMDL Study (Sargeant et al., 2003). These data were used to evaluate trends.

Henderson Inlet Tributaries

Thurston County has been conducting monthly monitoring of Woodland Creek at RM 1.0 and Woodard Creek at RM 2.9 since 1988. The City of Lacey has been conducting ambient and storm-event monitoring of Woodland Creek at RM 2.9 (Draham Road). Monitoring data from both jurisdictions (August 1994 through September 2004) were analyzed to determine trends at each site. Thurston County data were analyzed from August 1994 through September 2004, and City of Lacey data from November 2000 through June 2005. A nonparametric Seasonal Kendall statistical test (alpha ≤ 0.20) was used to determine whether significant trends in bacteria are seen at any of the sites (Figures 9 – 16). Thurston County data for Woodland and Woodard creeks were also examined for the September 1999 to 2004 period. No significant bacteria trends were seen at any sites.

Department of Health data for the same period were also examined for trends. Station 185 showed no significant trend while Station 186 showed a trend toward increasing levels of bacteria. Station 185 is not in the flow path of Woodland and Dobbs creeks, but Station 186 is.

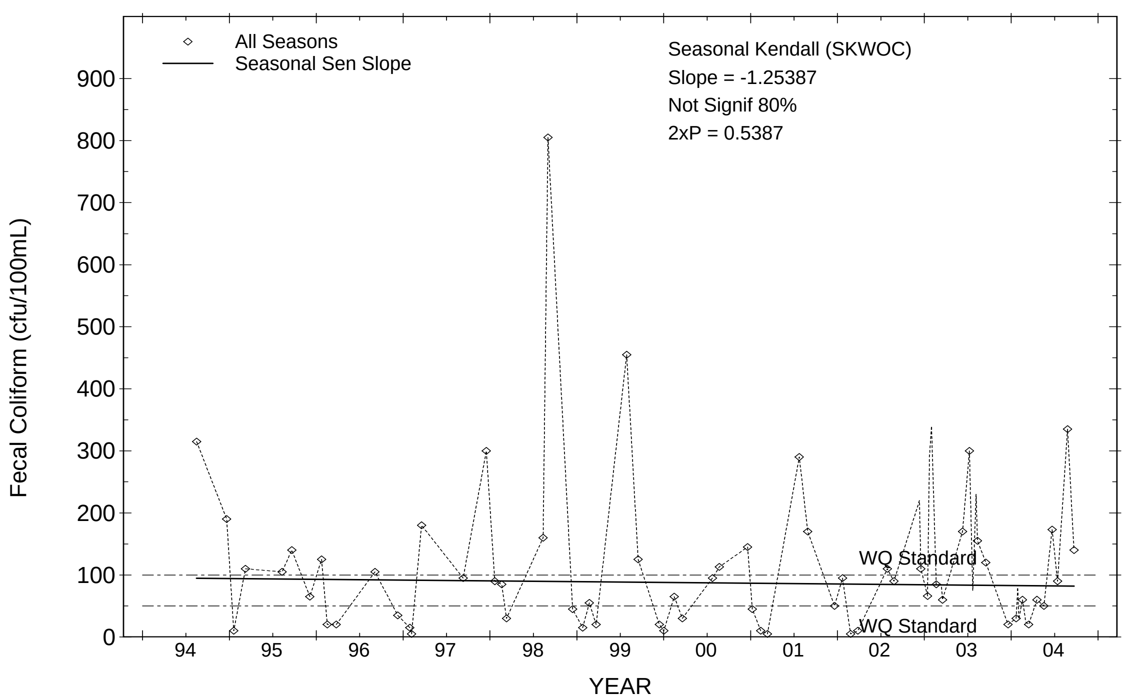

Figure 9. Woodland Creek RM 1.0 fecal coliform bacteria concentration trends, August 1994 - September 2004.

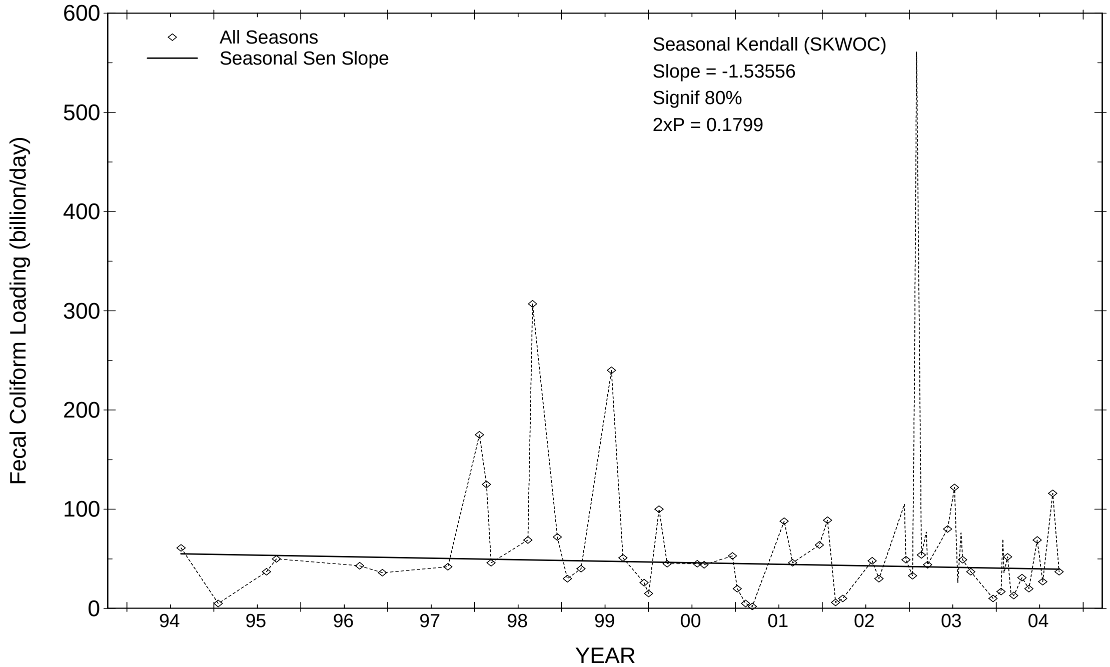

Figure 10. Woodland Creek RM 1.0 fecal coliform bacteria loading trends, August 1994 - September 2004.

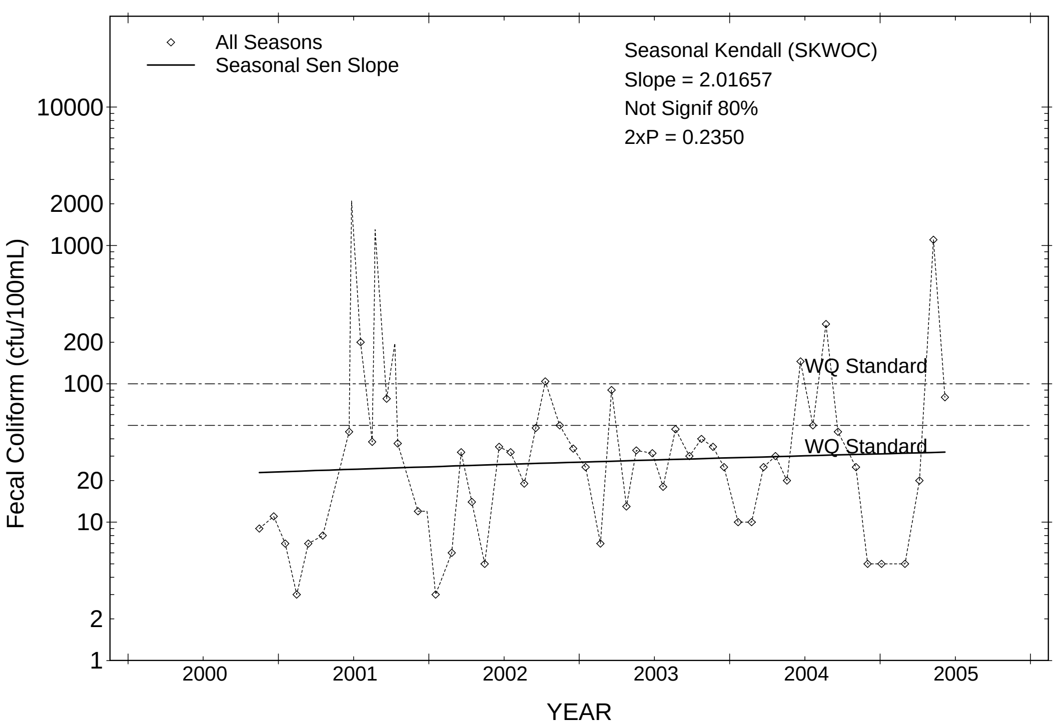

Figure 11. Woodland Creek RM 2.9 fecal coliform bacteria concentrations, November 16, 2000 - June 7, 2005 (City of Lacey data).

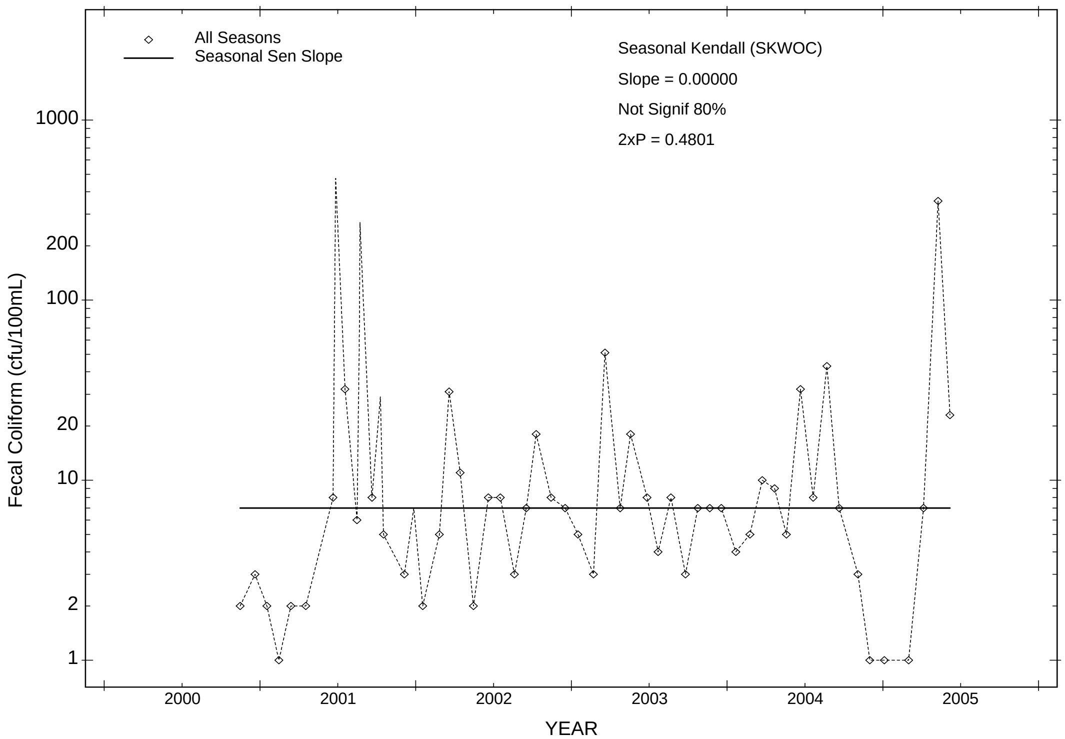

Figure 12. Woodland Creek RM 2.9 fecal coliform loading trends, November 16, 2000 - June 7, 2005 (City of Lacey data).

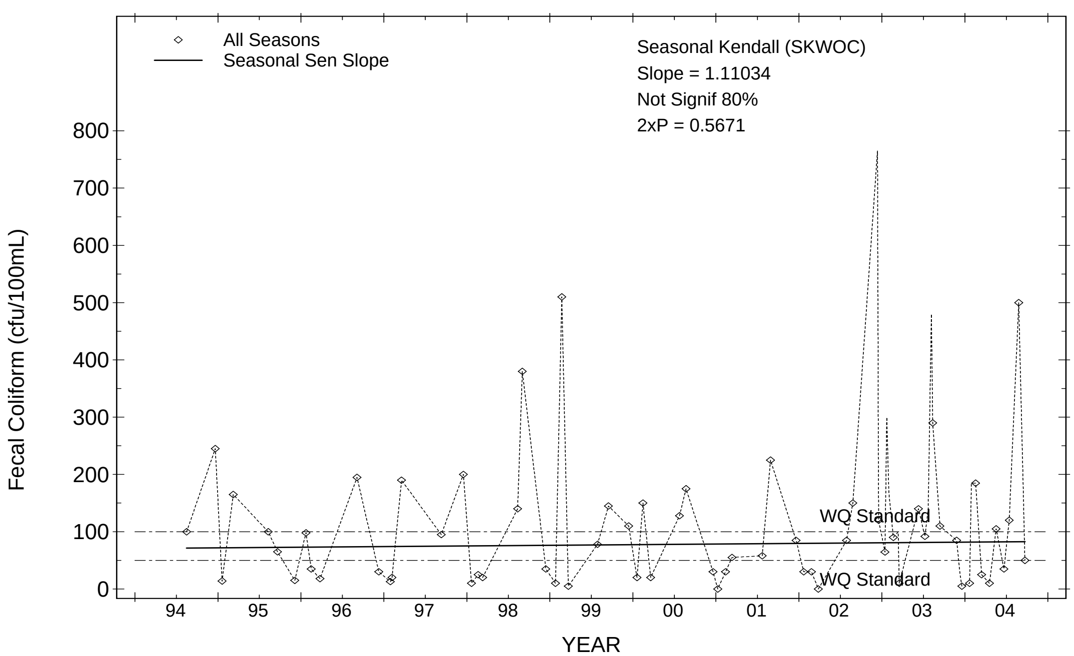

Figure 13. Woodard Creek RM 2.9 fecal coliform bacteria concentration trends, August 1994 - September 2004.

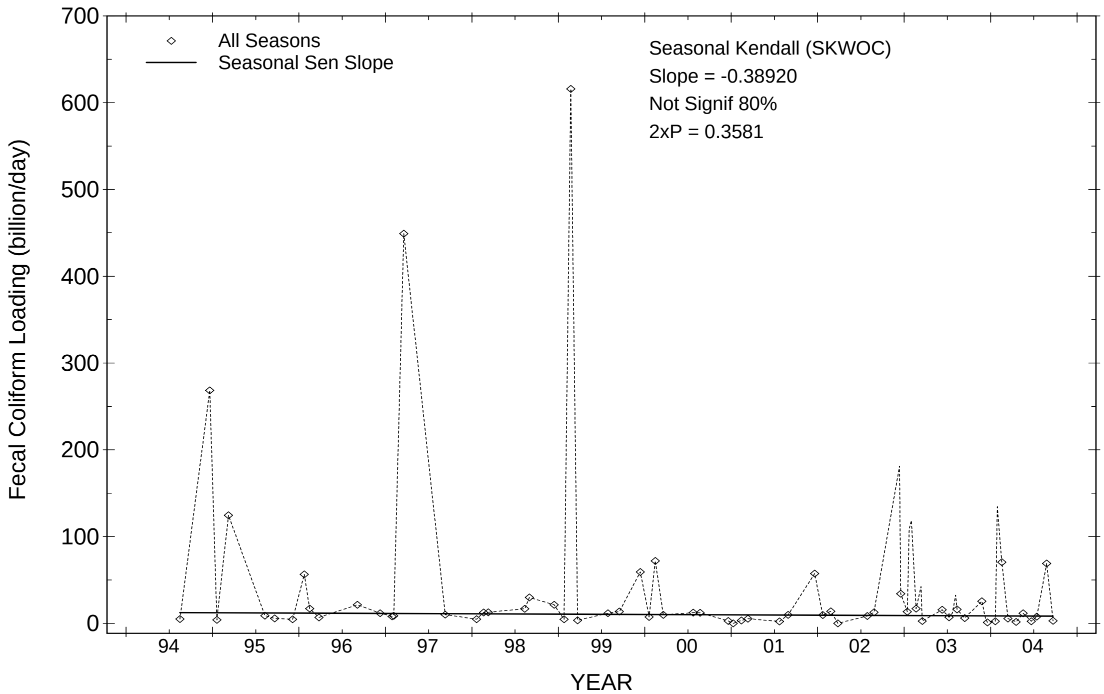

Figure 14. Woodard Creek RM 2.9 fecal coliform bacteria loading trends, August 1994 - September 2004.

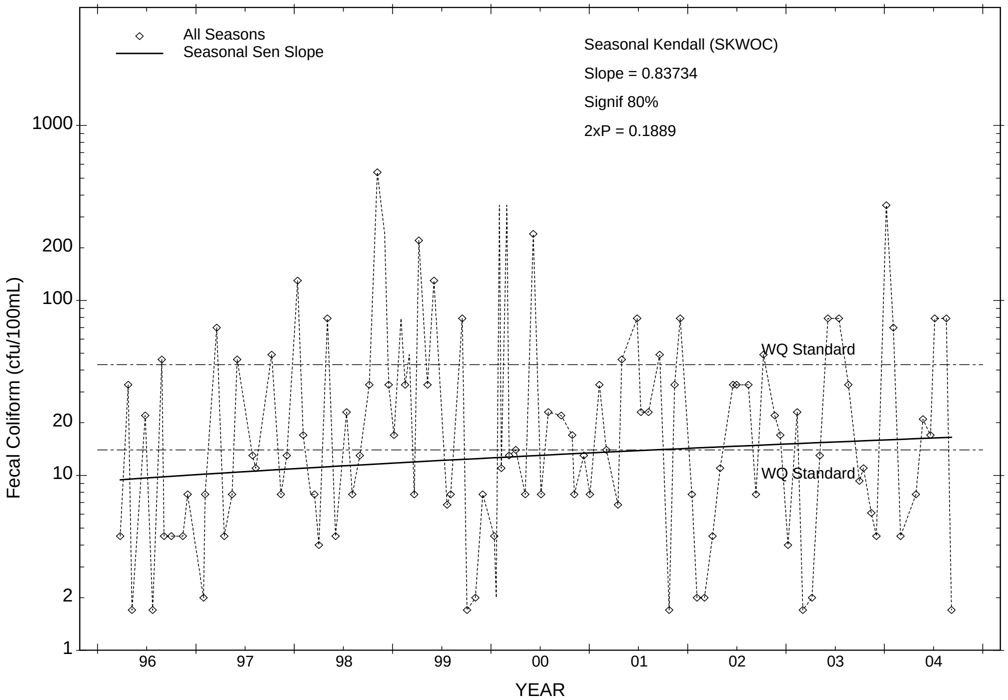

Figure 15. Department of Health Station 186 fecal coliform concentrations, March 1996 - September 2004.

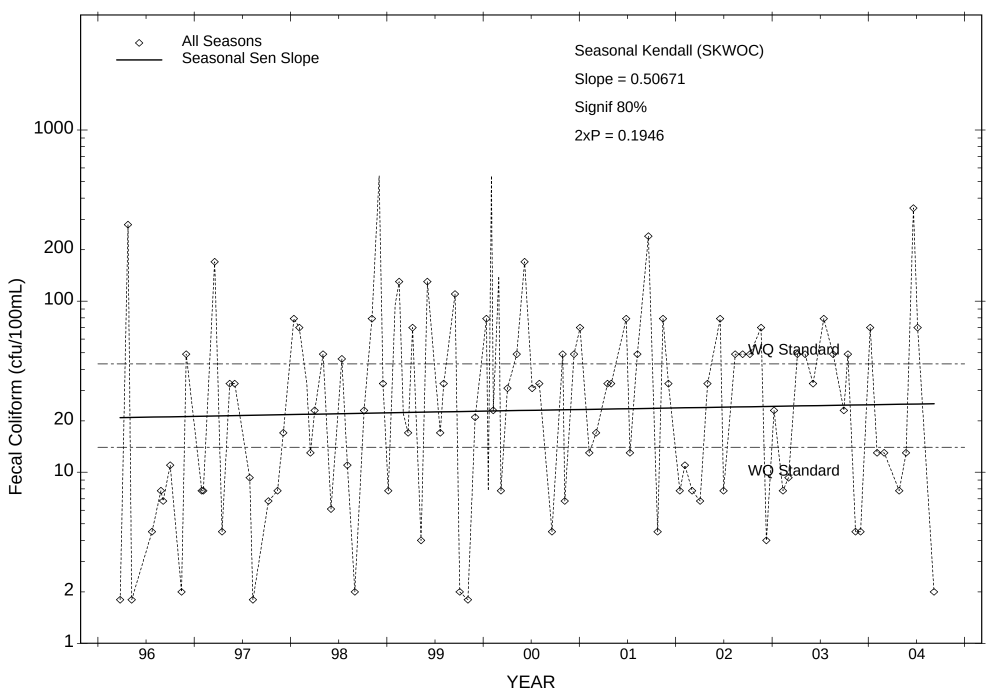

Figure 16. Department of Health Station 185 fecal coliform concentrations, March 1996 - September 2004.

Fecal Coliform Bacteria TMDL Analysis

Data Analysis Approach

The statistical rollback method was used to determine the load reduction necessary to achieve fecal coliform water quality standards and Total Maximum Daily Load (TMDL) targets. The statistical rollback method (Ott, 1995) has been used by Ecology to determine the necessary reduction for both the geometric mean (GM) and 90th percentile bacteria concentration (Roberts, 2003; Joy, 2000) to meet water quality standards. Compliance with the most restrictive of the dual fecal coliform criteria determines the bacteria reduction needed.

Fecal coliform sample results for each site in this study were found to follow lognormal distributions. The 90th percentile was calculated as the antilog of the mean of the log-transformed data plus 1.28 times the standard deviation of the log-transformed data.

The rollback method uses the statistical characteristics of a known data set to predict the statistical characteristics of a data set that would be collected after pollution controls have been implemented and maintained. In applying the rollback method, the target fecal coliform geometric mean (GM) and the target 90th percentile are set to the corresponding water quality standard. The reduction needed for each target value to be reached is determined. The rollback factor, $f_{rollback}$, is

$$f_{rollback} = \text{minimum } \{(\text{fecal coliform water quality standard GM/sample GM}), \\ (\text{fecal coliform water quality standard 10\% value not to exceed/sample } 90^{th} \text{ percentile})\}$$

The percent reduction ($f_{reduction}$) needed is

$$f_{reduction} = (1 - f_{rollback}) \times 100\%$$

which is the percent reduction that allows both GM and 90th percentile target values to be met.

The result is a revised target value for the GM or 90th percentile. In most cases, a reduction of the 90th percentile is needed, and application of this reduction factor to the study GM yields a target GM that is usually less (i.e., more restrictive) than the water quality criterion. The 90th percentile is often used as an equivalent expression to the "*no more than 10%*" criterion found in the second part of the water quality standards for fecal coliform bacteria. The reduction factors and description of sources are included under the *Loading Capacity* section of this report.

Survey Results

Woodland Creek

Woodland Creek and tributaries must meet the freshwater standards, with the exception of the Woodland Creek site at RM 0.2 which must meet marine standards for all parameters.

During storm-event (wet-season) sampling, none of the sites sampled met water quality standards for fecal coliform bacteria (Figure 17). All sites had 90th percentile values greater than 100 cfu/100 mL, and most sites did not meet a geometric mean of 50 cfu/100 mL. The highest bacterial concentrations are seen at the Martin Way stormwater outfall that flows into the creek at river mile (RM) 3.7. Concentrations are lowest near the Lake Lois outlet, but still exceed water quality standards.

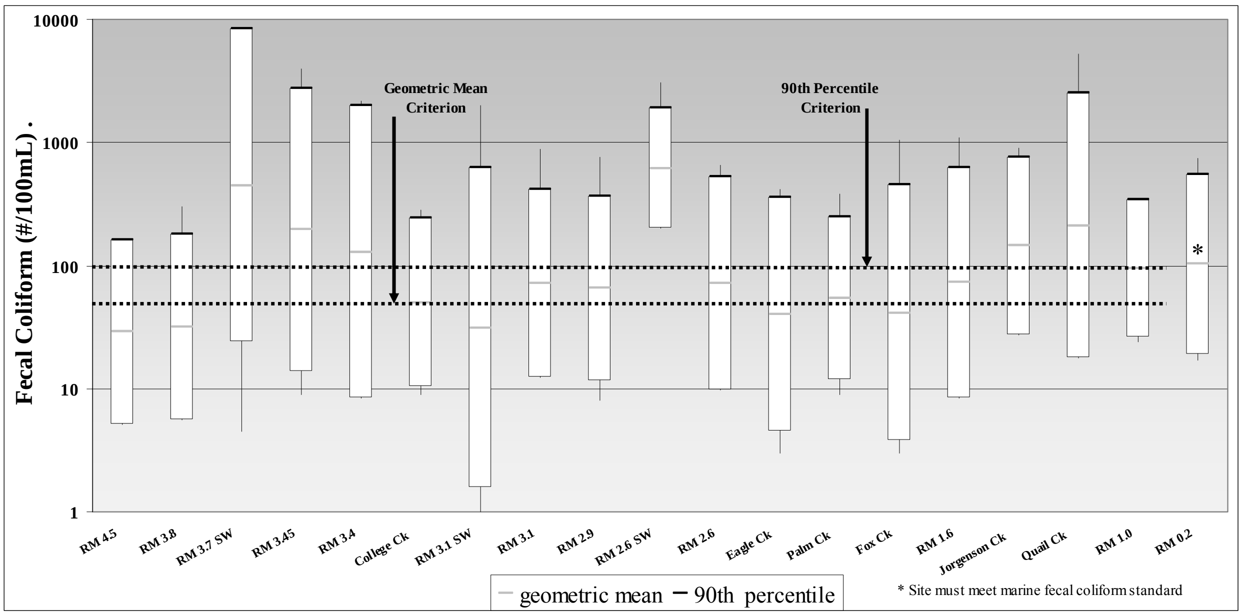

Figure 17. Storm-event fecal coliform levels for Woodland Creek and tributaries, December 2002 - March 2004.

College Creek, a tributary that discharges to Woodland Creek just downstream of RM 3.4, also has high concentrations of bacteria during the wet storm-event period. Figure 18 presents fecal coliform geometric means and 90th percentiles for College Creek sites. Only the mouth site had flow during the dry season.

During the dry season, flow and bacterial loading is lower than during the wet storm-event period. There is no flow in Woodland Creek from the Lake Lois outlet to Beatty and St. Martin's springs just upstream of RM 3.45. During the dry season, Woodland Creek upstream sites (RM 3.45 to 3.1) met fecal coliform standards as did Fox Creek and the stormwater tributary at RM 3.1. The downstream mainstem sites and tributaries did not meet fecal coliform standards (Figure 19).

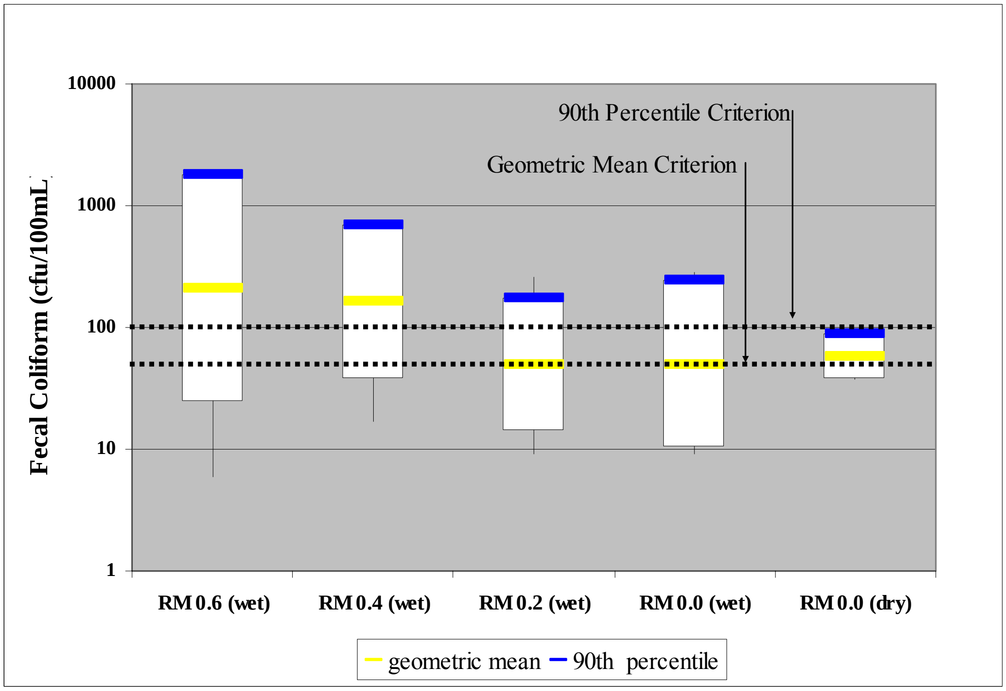

Figure 18. Fecal coliform levels for College Creek, December 2002 - March 2004.

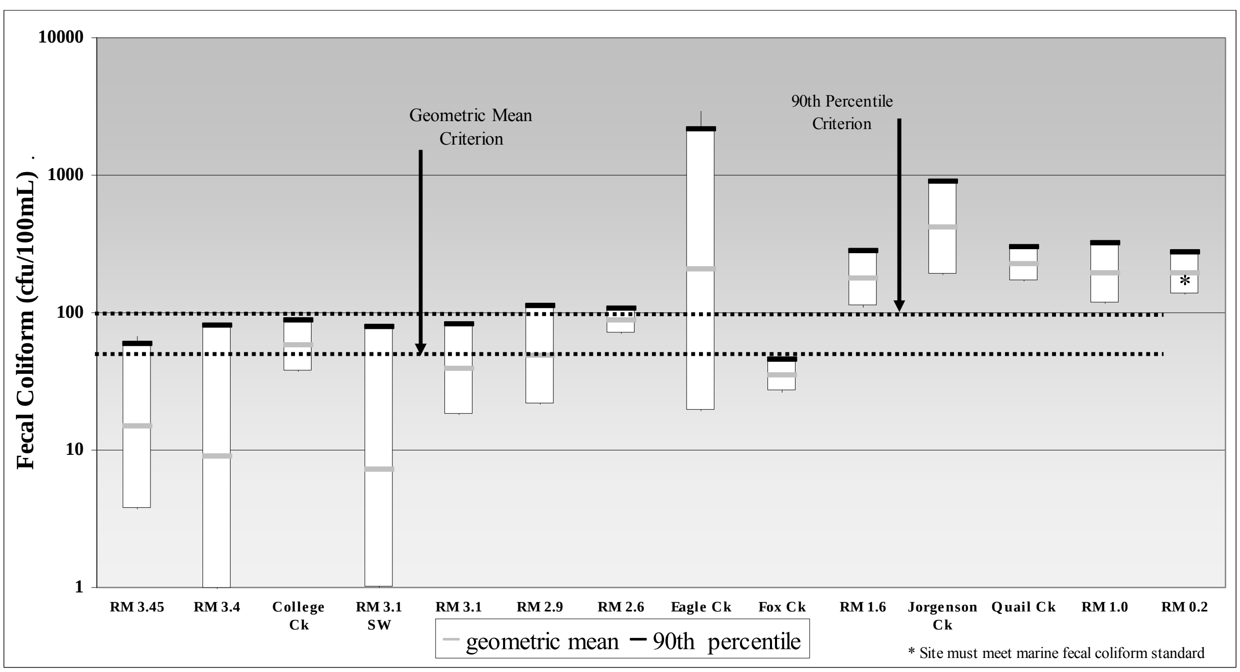

Figure 19. Dry-season fecal coliform levels for Woodland Creek and tributaries, June - September 2003.

Flow and loading increase from upstream to downstream. Figure 20 illustrates average flow and fecal coliform loading for the wet and dry seasons during the study. Loading from tributaries and stormwater is included in the loading estimates.

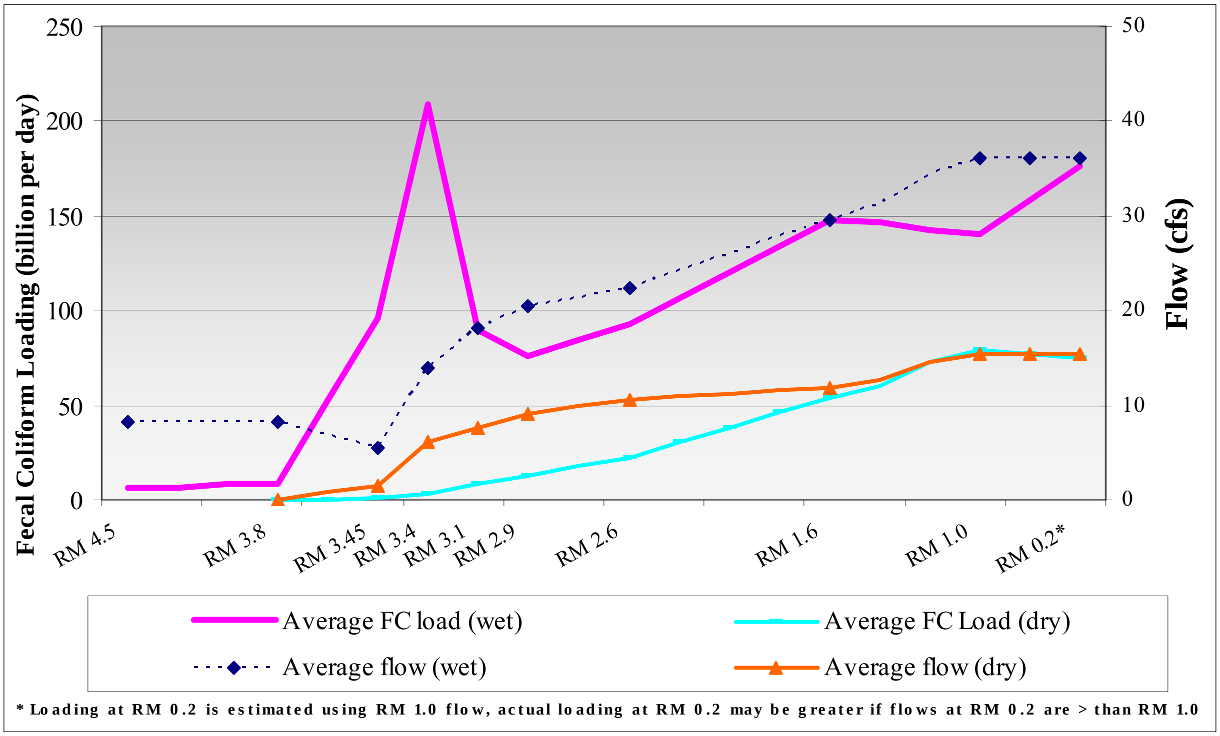

Figure 20. Woodland Creek mean fecal coliform loading and flows for the storm-event and dry periods.

During the wet season, there is a large increase in loading between Woodland RM 4.5 and 3.4. This increase is due to stormwater input at RM 3.7 (RM 3.7T) and bacterial inputs from College Creek. The upstream portion of College Creek above RM 0.4 is stormwater from City of Lacey developed areas. Downstream of College Creek RM 0.4, the creek flows into a large wetland where the channel becomes dispersed throughout the wetland. Some of the stormwater from College Creek may flow into Woodland Creek between RM 3.7 and 3.4. The St. Martin's Spring also flows to the creek in this reach and supplements College Creek upstream of the mouth.

Another increase in fecal coliform loading occurs between Woodland RM 2.6 and 1.6. Several tributaries and residential development occur along this reach.

During the dry season, flow and bacterial loading decrease with significantly less bacterial loading.

To determine the location of bacterial loading sources to Woodland Creek, average loading for each site during the wet and dry seasons was estimated. Negative loading estimates indicate loading loss in this reach. Figure 21 presents wet season (storm-event) bacterial loading contributions for the creek, and Figure 22 presents storm-event loading for College Creek.

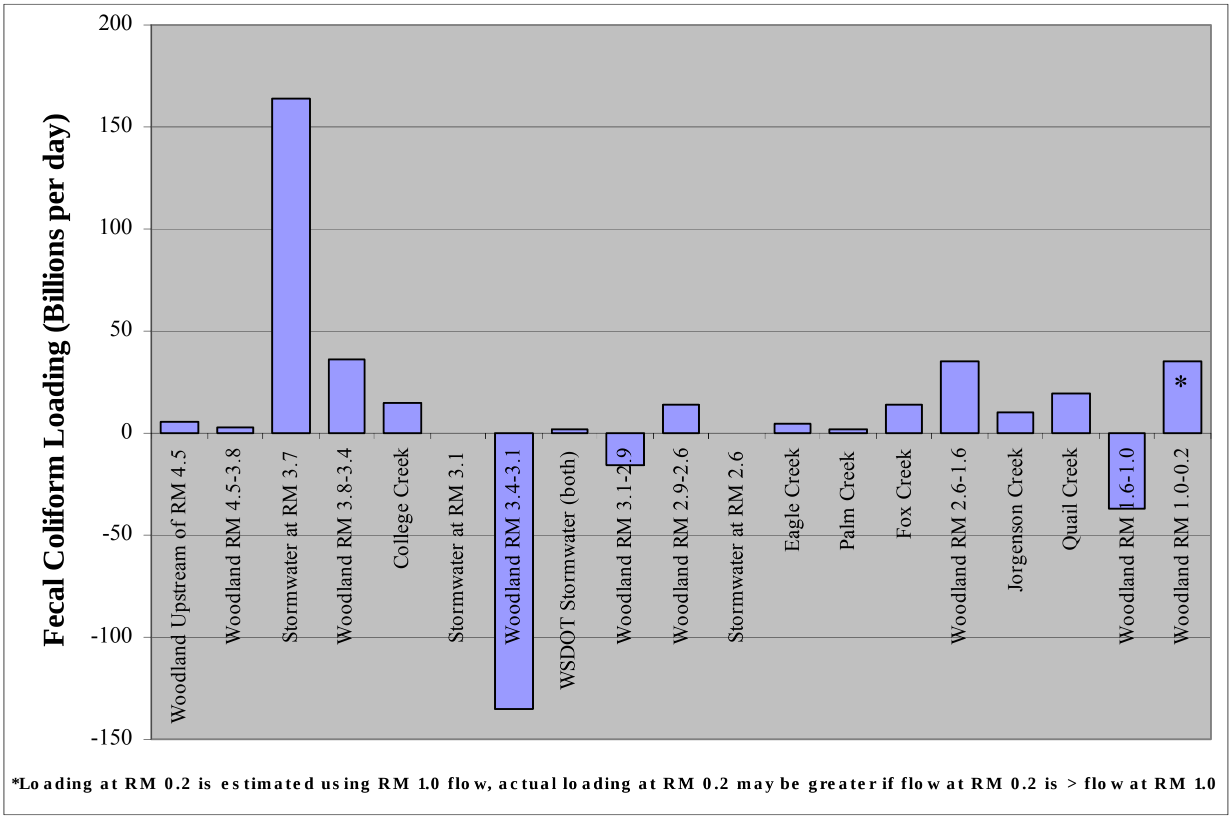

Figure 21. Estimated relative contributions of fecal coliform loading to Woodland Creek during storm events.

During storm events, the largest bacterial loading comes from Martin Way stormwater outfall entering the creek at RM 3.7. The second largest contributors are Woodland Creek between RM 3.8 and 3.4 (this is in addition to stormwater from RM 3.7), Woodland Creek between RM 2.6 and 1.6, and between RM 1.0 and 0.2. Woodland Creek between RM 3.8 and 3.1 is a non-channelized wetland with inputs from Beatty and St. Martin's springs, and stormwater input from Martin Way and College Creek. Between Woodland Creek RM 2.6 and 1.6, there is residential development along the creek as well as stormwater entering at RM 2.6. Loading from the creeks along this reach (RM 2.6-1.6) is accounted for in Figure 21. Between Woodland Creek 1.0 and 0.2, there is a large development and a stormwater pond or wetland that may drain to the creek during the wet season. Bacterial loading for this reach is an estimate; no flows were obtained at RM 0.2.

Figure 22 presents estimated bacterial loading for College Creek during the wet (storm-event) period. Bacterial loading decreases in the wetland seen at the mouth of the creek. The wetland may be serving to treat bacterial pollution, and portions of College Creek may flow into Woodland Creek along the RM 3.8 to 3.1 wetland reach.

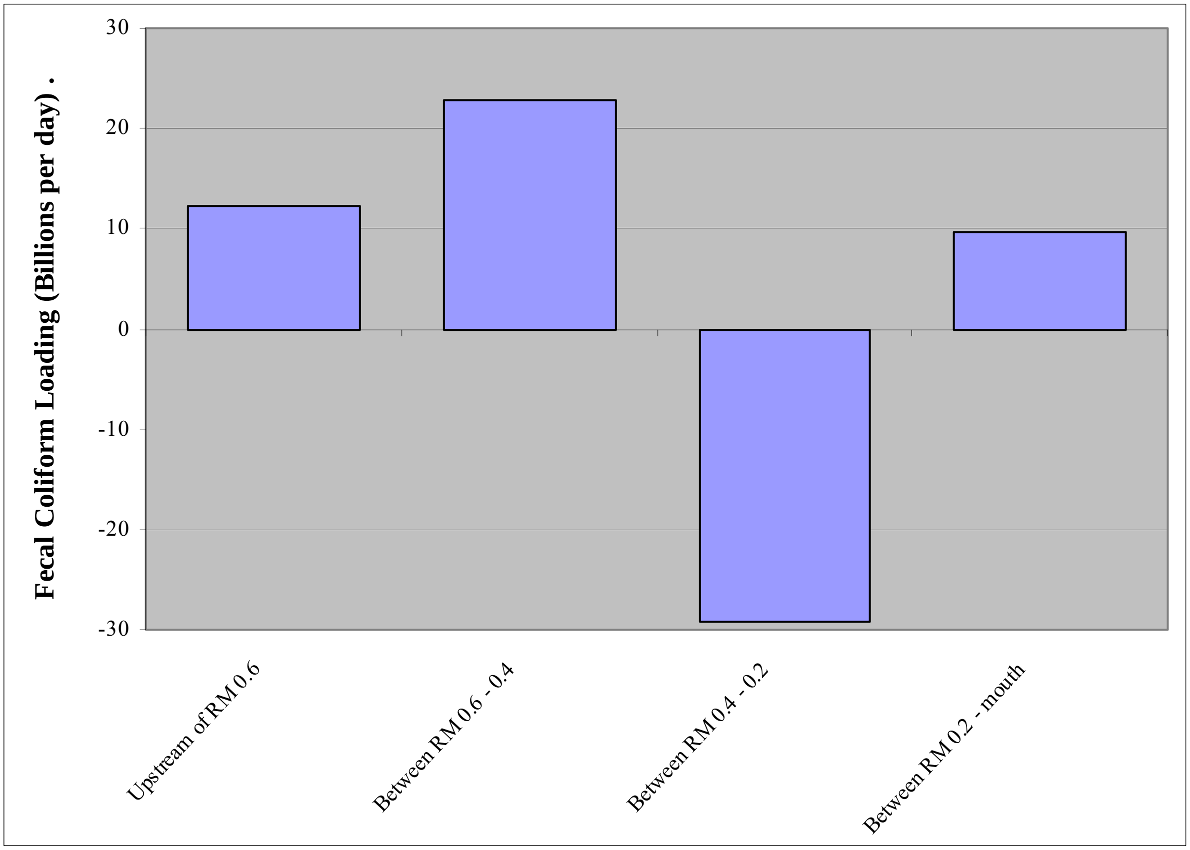

Figure 22. Estimated relative contributions of fecal coliform loading to College Creek during storm events.

Figure 23 presents average dry-season (low-flow) loading for Woodland Creek. Dry-season bacteria loading to Henderson Inlet from Woodland Creek is much less than during storm events. Woodland Creek dry-season bacterial concentrations meet water quality standards from RM 3.1 to its headwaters during the dry season. The greatest loading occurs along Woodland Creek between Woodland Creek RM 2.9 to 1.0. Eagle and Jorgensen creeks also contribute bacterial loading during the dry season.

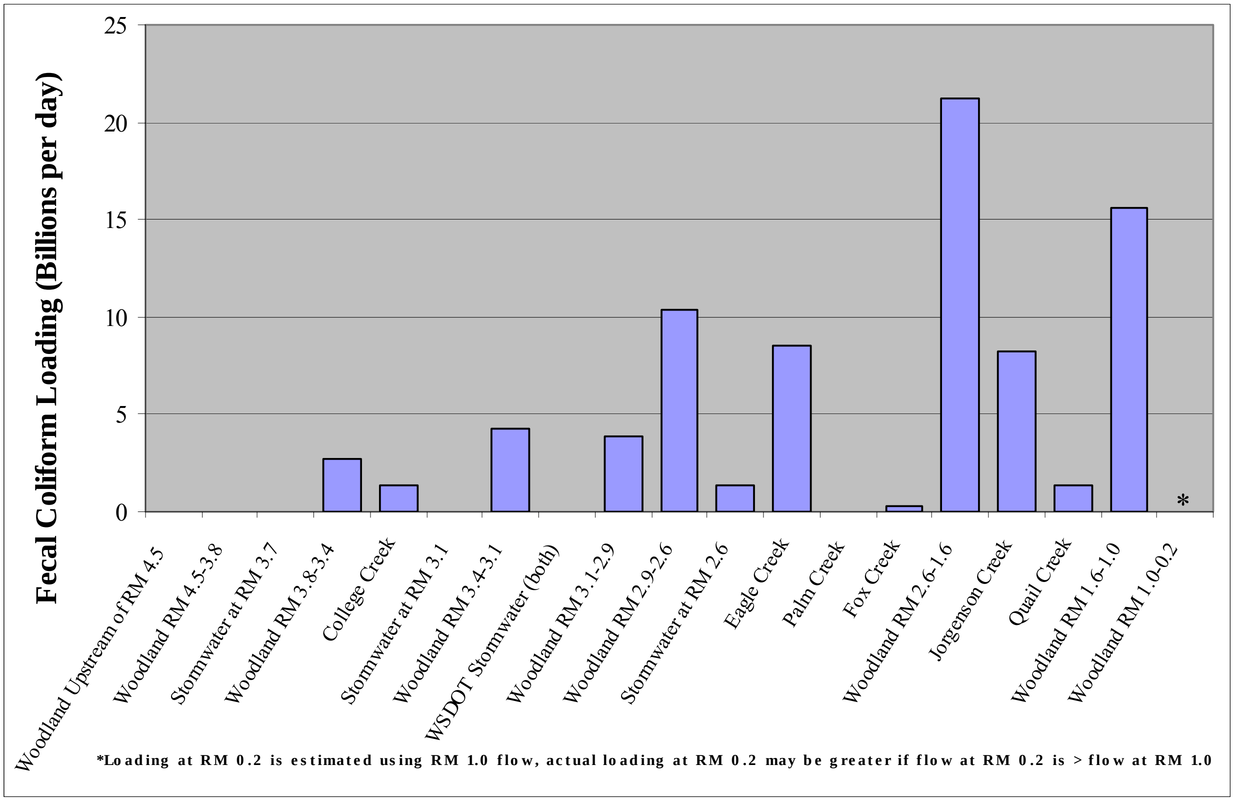

Figure 23. Estimated relative contributions of fecal coliform loading to Woodland Creek during the dry season, June through September.

Critical Period and Seasonality

Bacterial loading for Woodland Creek reaches and tributaries was generally greater during the storm-event (wet) period. Eagle Creek had higher dry-season bacterial loading as did Woodland Creek reaches between RM 3.4 - 2.9 and RM 1.6-1.0. These Woodland Creek reaches had no average net loading during the wet storm-event period.

Higher bacterial concentrations are seen during the storm-event period for sites upstream of Woodland Creek RM 2.6 and for Palm and Quail creeks. For Eagle and Jorgenson creeks, bacteria concentrations are higher during the dry season. For Woodland Creek at RM 2.6 and downstream, higher 90th percentile concentrations are seen during the wet season and higher geometric means are seen during the dry season.

Bacteria Rainfall Relationships

Several Woodland Creek sites were analyzed to determine if there is a relationship between bacterial concentrations and/or loading. Rainfall patterns examined consisted of: rainfall the day of sampling, rainfall the day before sampling, combined day of and previous day rainfall, and previous 48-hour rainfall. Each day was considered to be midnight to midnight. At the mainstem sites and for the stormwater discharge at RM 3.7, there was a moderate relationship between bacteria and rainfall the day of and day before sampling (Table 5).

Table 5. Bacteria-rainfall relationships at selected sites in Woodland Creek.

Site	Relationship	r^2 of regression
Stormwater discharge at RM 3.7	Fecal coliform concentration and combined day of and previous day rainfall	r^2=0.63, moderate relationship
Woodland Creek RM 3.1	Fecal coliform loading and combined day of and previous day rainfall	r^2=0.69, moderate relationship
Woodland Creek RM 2.6		r^2=0.62, moderate relationship
Woodland Creek RM 1.0		r^2=0.52, moderate relationship

Woodard Creek

Woodard Creek and tributaries must meet the freshwater standards, with the exception of the Woodard Creek site at RM 0.0. This site must meet marine standards for all parameters.

During wet-season, storm-event sampling, none of the sites sampled met water quality standards for fecal coliform bacteria (Figure 24). All sites had 90th percentile values greater than 100 cfu/100 mL, and a geometric mean of greater than 50 cfu/100 mL. The highest bacterial concentrations were seen in stormwater at Fones Road. Fones Road stormwater flows to a stormwater treatment facility then into Taylor wetland. The wetland extends to just south of Ensign Road (Woodard Creek RM 6.2). Bacteria concentrations improve as water moves through the wetland, likely due to dilution and treatment in the wetlands. Bacteria concentrations increase from Woodard Creek RM 6.2 to 3.4, then decrease from RM 3.4 to the mouth.

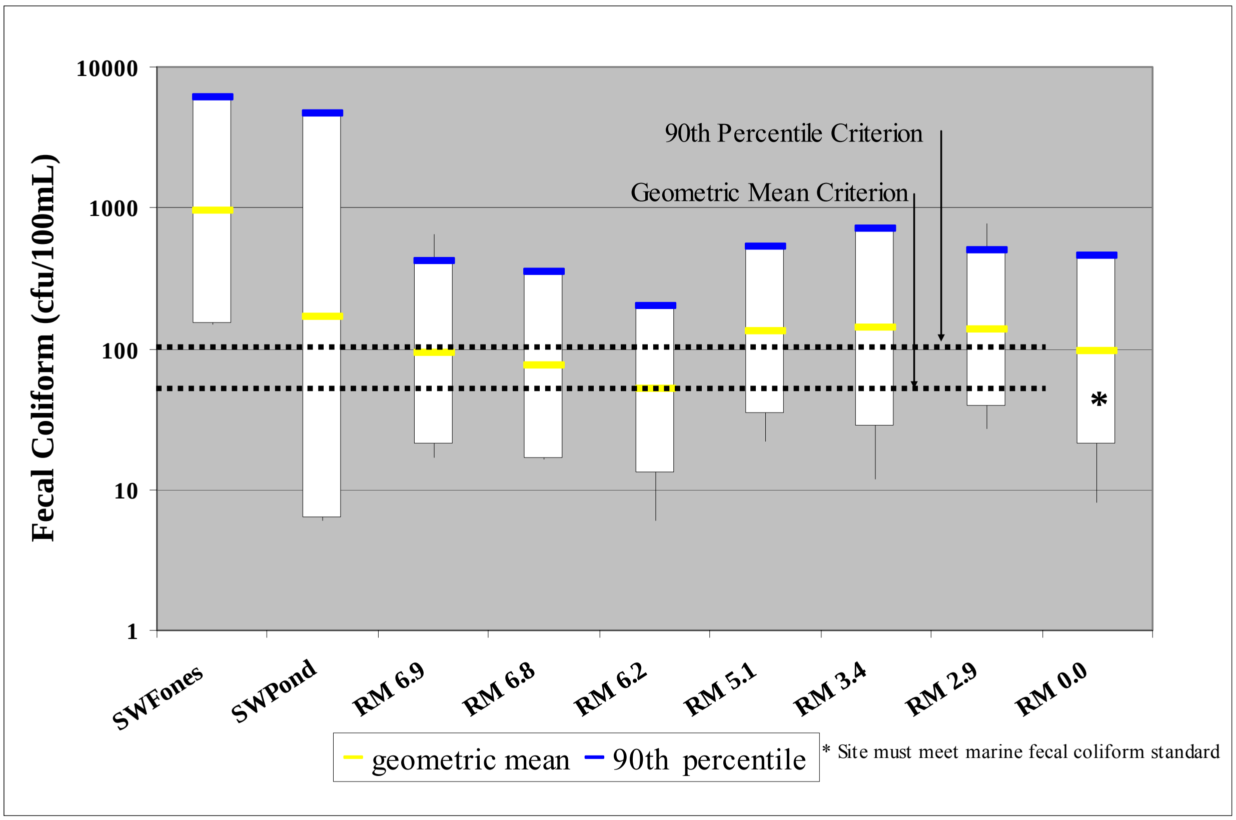

Figure 24. Wet-season fecal coliform levels for Woodard Creek, December 2002 - March 2004.

Figure 25 presents dry-season fecal coliform bacteria levels in Woodard Creek. During the dry season, Woodard Creek at RM 6.2 (the downstream end of Taylor wetland) was the only site to meet fecal coliform standards. Bacteria concentrations are high at RM 6.9 and decrease at RM 6.2, likely due to dilution in the wetland. Bacteria levels at Woodard RM 6.8 appear higher, but this site was added during the dry season and only two dry-season samples were obtained. During the wet storm-event period, fecal coliform concentrations increase from RM 6.2 to 5.1. During the dry season, fecal coliform concentrations decrease downstream of RM 5.1.

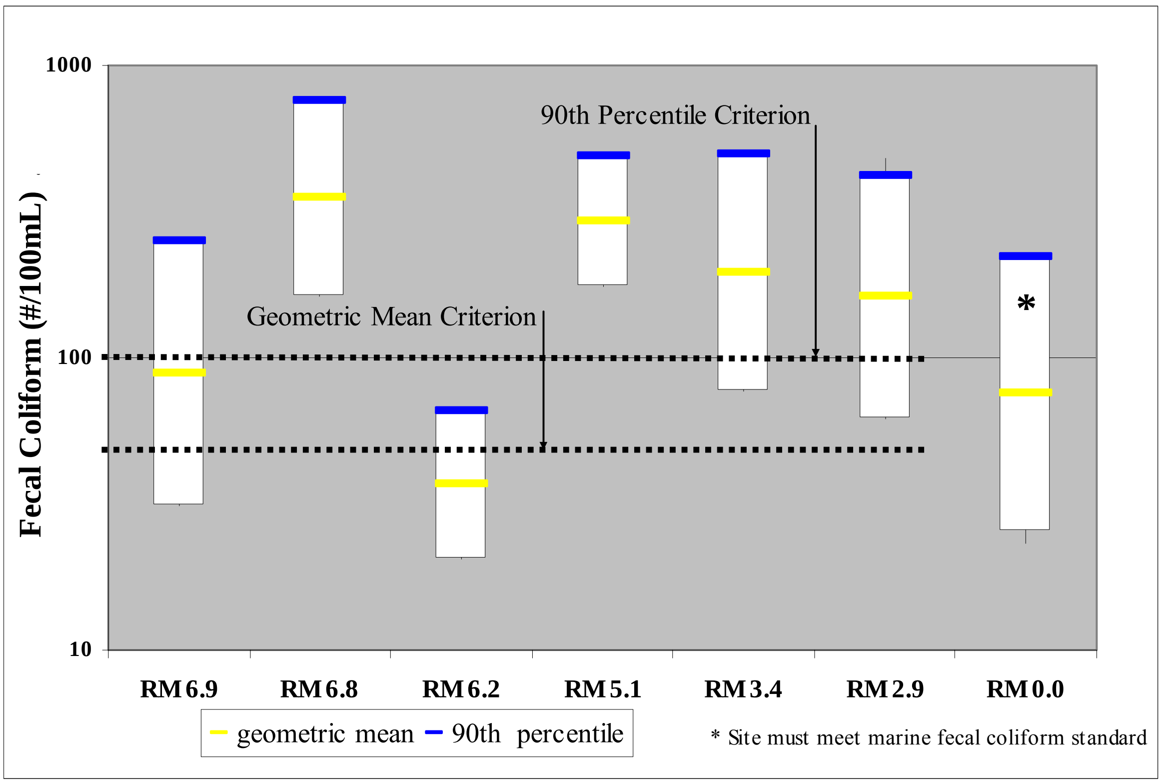

Figure 25. Dry-season fecal coliform levels for Woodard Creek, June - September 2003.

Flow and fecal coliform loading increase from upstream to downstream. Figure 26 illustrates average flow and fecal coliform loading for the wet and dry seasons during the study.

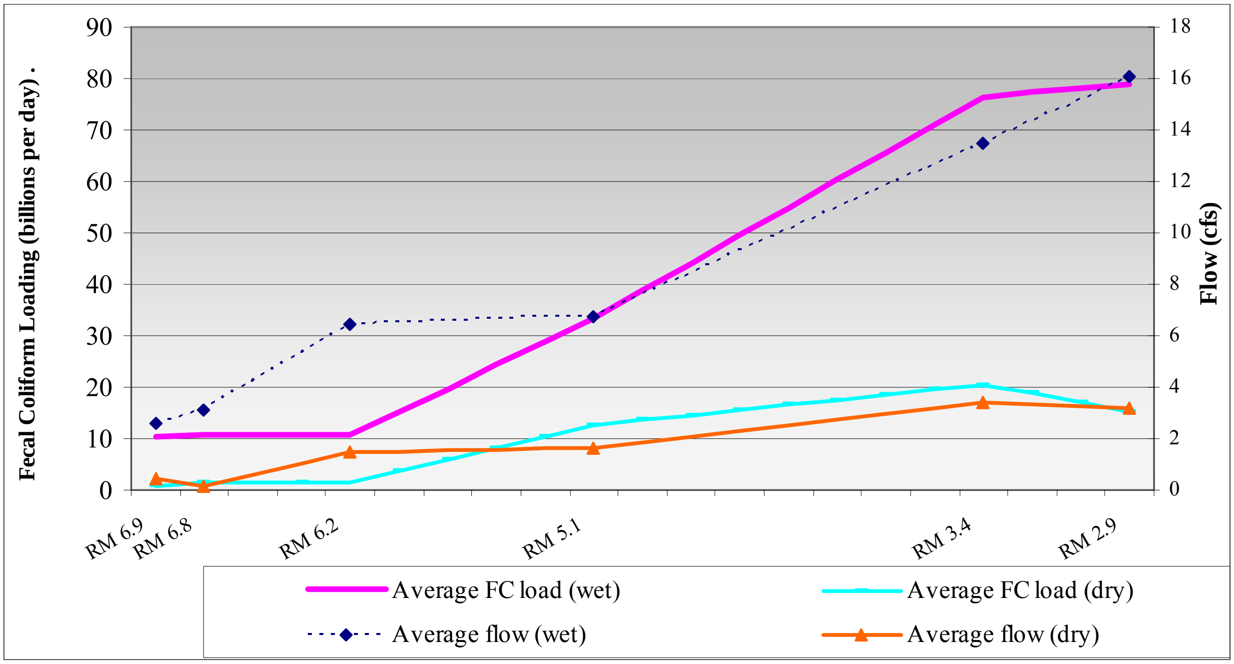

Figure 26. Woodard Creek mean flow and fecal coliform loading during the storm-event and dry periods.

As with bacterial concentrations, there is a large increase in bacterial loading during both the dry season and during storm events between Woodard RM 6.2 and 3.4.

To determine bacterial loading sources to Woodard Creek, average loading for each site during the wet and dry seasons was estimated. Figure 27 presents wet-season (storm-event) bacterial loading contributions for the creek, and Figure 28 presents dry-season loading. Negative loading values indicate a loss in loading.

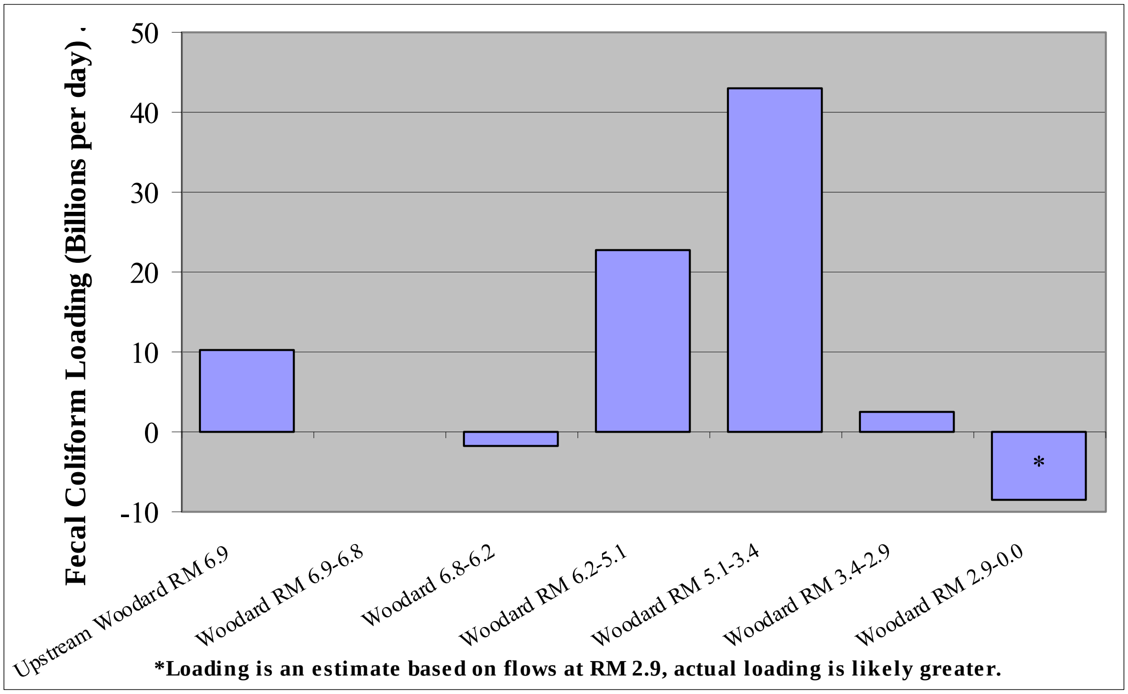

Figure 27. Estimated contributions of fecal coliform loading to Woodard Creek during storm events.

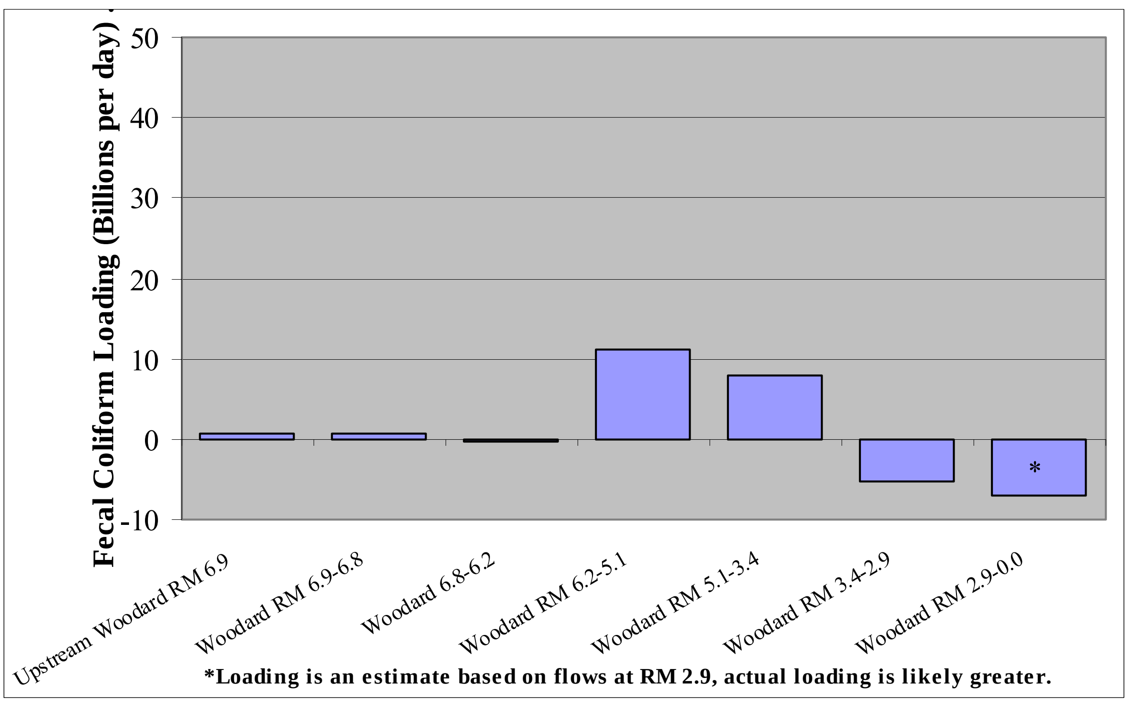

Figure 28. Estimated contributions of fecal coliform loading to Woodard Creek during the dry season.

The biggest bacterial loading contribution during the wet season occurs between Woodard RM 5.1 and 3.4, with the second largest loading contribution between Woodard RM 6.2 and 5.1. During the dry season, the opposite occurs, with the highest loading between RM 6.2 and 5.1 and the second highest loading between RM 5.1 and 3.4.

Critical Period and Seasonality

Bacterial loading for Woodard Creek was greater during the wet storm-event period. The sites at Woodard RM 6.2 and upstream had slightly higher bacterial concentrations during this season. From RM 5.1 downstream, 90th percentile fecal coliform values were higher during the storm-event period while geometric mean values were higher during the dry season.

Bacteria Rainfall Relationships

As described for Woodland Creek, Woodard Creek sites were analyzed to determine if a relationship exists between rainfall and bacterial concentrations and/or loading. Most sites had a weak relationship between rainfall and fecal coliform loading. The upstream sites tended to have a stronger relationship with previous 48-hour rainfall and loading, while at the most downstream sites, fecal coliform loading correlated best with combined day-of and previous 24-hour rainfall (Table 6).

Table 6. Bacteria rainfall relationships at selected sites in Woodard Creek.

Site	Relationship	R^2 of regression
Woodard RM 6.9	Fecal coliform concentration and previous 48-hour rainfall	R^2=0.32, weak relationship
	Fecal coliform loading and previous 48-hour rainfall	R^2=0.40, weak relationship
Woodard RM 5.1	Fecal coliform loading and previous 48-hour rainfall	R^2=0.34, weak relationship
Woodard RM 3.4	Fecal coliform loading and previous 24-hour rainfall	R^2=0.46, weak relationship
	Fecal coliform loading and previous 48-hour rainfall	R^2=0.40, weak relationship
Woodard RM 0.0	Fecal coliform loading and combined day of and previous day rainfall	R^2=0.58, moderate relationship

Meyer, Sleepy, Dobbs, and Goose Creeks

Meyer, Sleepy, Dobbs, and Goose creeks must meet freshwater standards, with the exception of a site located within marine waters on Meyer Creek. Appendix H describes compliance with the water quality standards for all sites.

Meyer and Goose creeks are seasonal creeks with flow occurring only during the wetter period of the year. No dry-season sampling was conducted on Meyer or Goose creeks. Due to access difficulties, Meyer Creek was sampled at 56th Road (approximately RM 0.6) for the first two storm events. For the rest of the sample events, it was sampled as close to the mouth as possible while being out of the tidally influenced zone. Sleepy Creek at RM 0.8 was dry during the dry-season sample events, with flow so low at RM 0.1 that it could not be measured during this period.

During the storm-event sampling, none of the tributaries met water quality standards for fecal coliform bacteria (Figure 29). Dobbs Creek had higher bacteria concentrations during the wet storm-event period, and Sleepy Creek had slightly higher concentrations during the dry season.

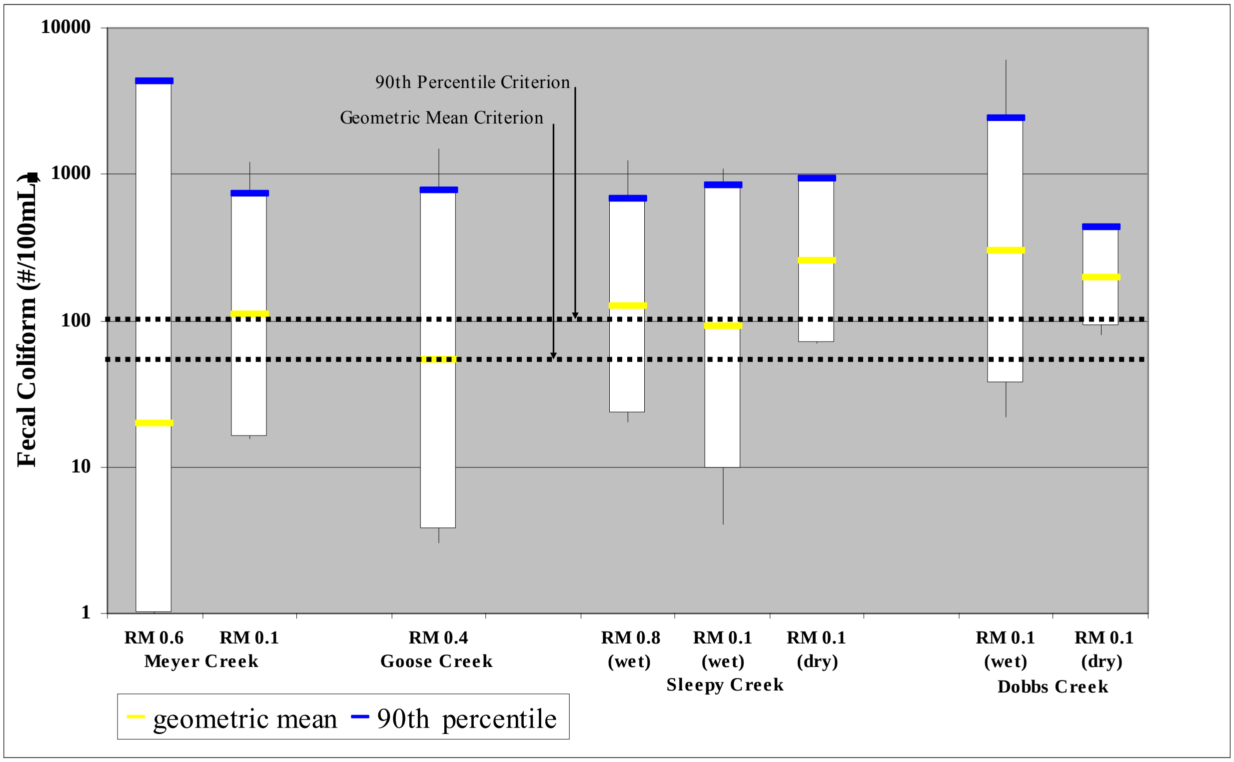

Figure 29. Henderson Inlet tributaries fecal coliform concentrations, 2002 - 2004.

Figure 30 presents storm-event and dry-season fecal coliform loading for the smaller tributaries. Dobbs Creek has the greatest loading and flow, while Goose Creek has the least loading and flow. For Dobbs and Sleepy creeks, the greatest bacterial loading occurs during storm events (wet season).

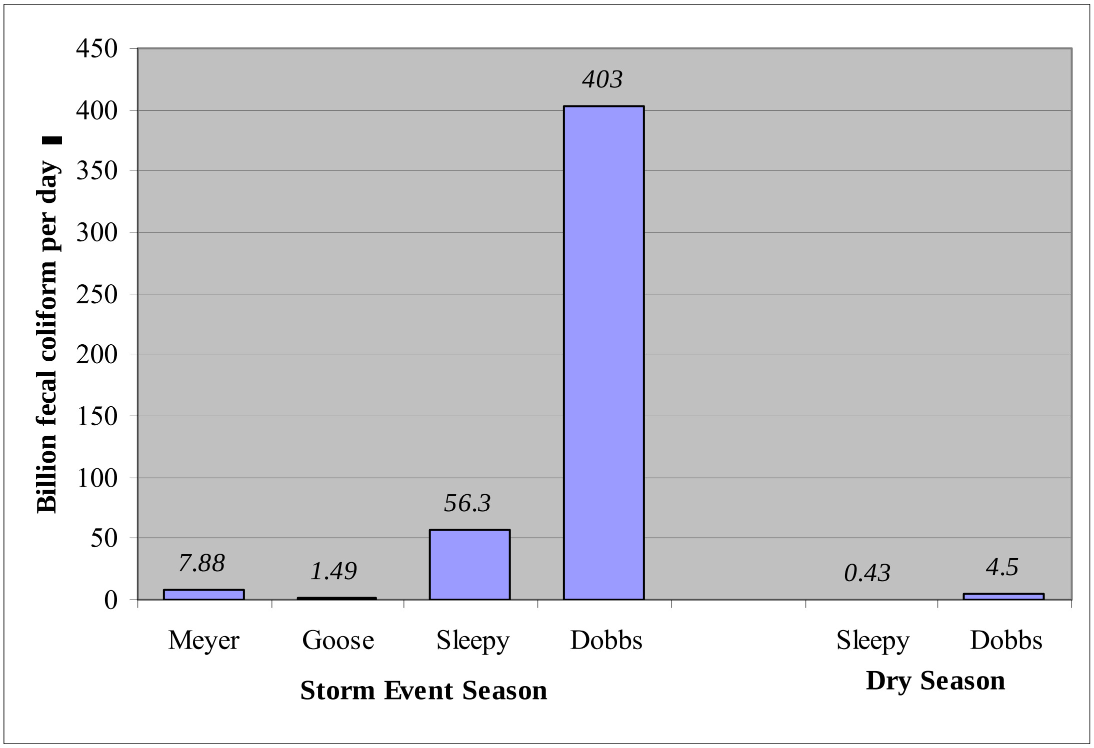

Figure 30. Estimated storm-event and dry-season bacterial loading from Meyer, Goose, Sleepy, and Dobbs creeks.

Upstream and Downstream Comparison of Bacterial Levels

A non-parametric Wilcoxon paired sample test was used to compare bacteria between Dobbs and Sleepy creeks upstream and downstream sites where data were available. A two-tailed test with a significance level of $\alpha = 0.05$ was used; for both creeks n=8. No statistically significant difference in concentrations was seen between Dobbs and Sleepy creeks' upstream and downstream sites.

Figure 31 presents upstream/downstream geometric mean and 90th percentiles for Dobbs and Sleepy creek sites. Upstream and downstream fecal coliform values are very similar for Sleepy Creek. For Dobbs Creek, a slightly higher 90th percentile is seen at the upstream site.

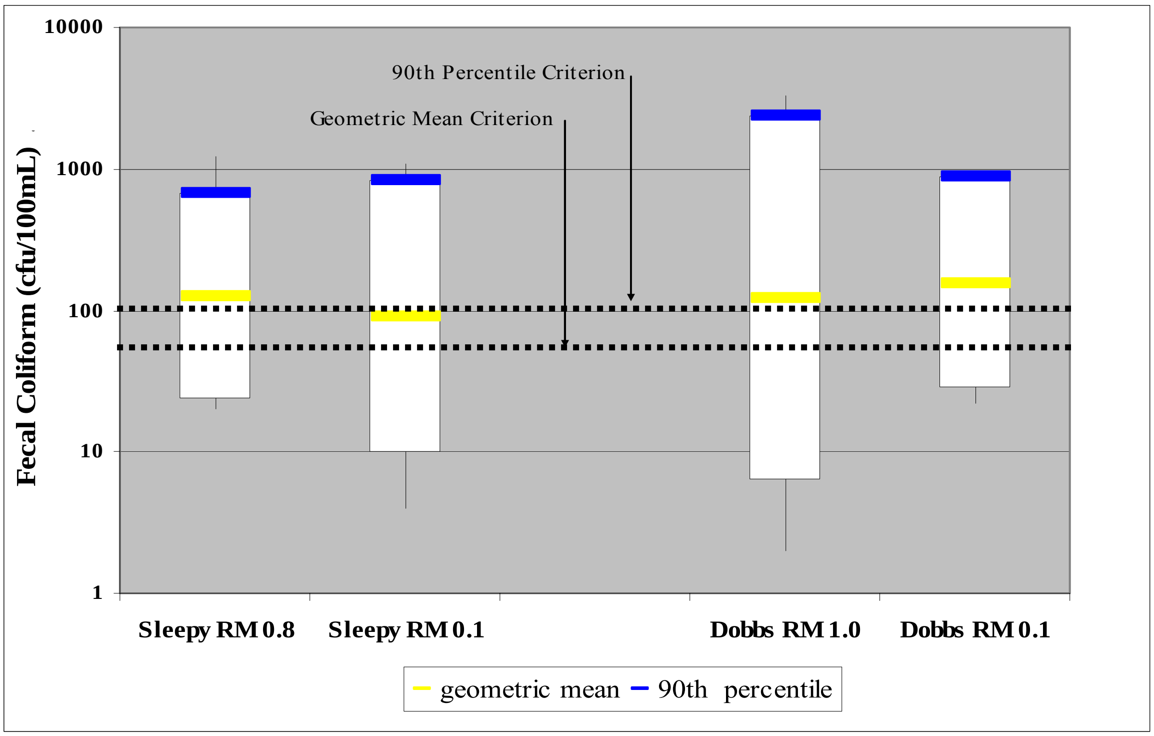

Figure 31. Upstream/downstream fecal coliform levels for Sleepy and Dobbs creeks during storm events.

Bacteria Rainfall Relationships

As described for Woodland Creek, the tributary sites were analyzed to determine if a relationship exists between rainfall and bacterial concentrations and/or loading. For Goose Creek, there was a moderately strong relationship with day of rainfall and fecal coliform concentrations, as well as with combined day-of and previous 24-hour rainfall and fecal coliform loading. There was a weak relationship seen with bacterial concentrations and day of rainfall in Meyer Creek. For Dobbs and Sleepy creeks, no relationship with bacteria and rainfall was seen.

Department of Health Bacteria Monitoring

DOH staff monitors stations within shellfish areas in Henderson Inlet (Figure 2). The following analysis uses all data collected from January 1999 through December 2004 (DOH, 2005).

Tidal Condition Influence

Table 7 summarizes bacteria results for the 26 DOH monitoring stations within Henderson Inlet for samples collected during flood-tide conditions. Highlighted values do not meet the state or shellfish water quality standards. One site has a geometric mean concentration >14/100 mL, but all six sites within the *Prohibited* shellfish zone have estimated 90th percentile concentrations > 43/100 mL, and >10% of samples exceed 43/100 mL. In addition, two stations (190 and 195) had >10% samples exceed 43/100 mL, although the estimated 90th percentile concentrations did not exceed 43/100 mL; therefore, while these sites do meet the DOH shellfish criteria, they do not meet the state water quality standards. Figure 32 presents the information in graphical form.

Table 7. DOH monitoring station results for flood-tide samples. All fecal coliform values are in most probable number (MPN)/100 mL. Highlighted values violate water quality standards.

	Station	Geometric mean	90th percentile	%>43	Count
Approved	192	3.6	10.3	0.0%	38
	193	4.1	13.6	0.0%	37
	202	6.3	22.0	2.5%	40
	203	4.9	18.0	2.7%	37
	204	3.6	10.7	2.8%	36
	205	6.1	26.0	4.8%	42
	206	2.6	6.4	0.0%	36
	207	2.0	3.2	0.0%	44
	208	3.8	12.8	0.0%	37
	209	3.5	15.7	2.6%	39
Conditionally Approved	190	9.4	40.4	11.6%	43
	191	6.7	28.9	7.5%	40
	194	5.8	24.1	5.4%	37
	195	9.1	38.9	10.4%	48
	196	4.1	14.5	2.6%	38
	197	6.9	22.6	2.5%	40
	198	5.4	23.4	2.6%	38
	199	3.9	11.9	2.6%	38
	200	5.1	19.2	5.1%	39
	201	7.2	34.4	9.5%	42
Prohibited	185	20.7	101.0	38.0%	50
	186	12.7	64.9	16.0%	50
	187	11.8	57.3	18.8%	48
	188	13.8	65.8	18.4%	49
	189	11.9	60.7	14.3%	49
	212	10.8	47.6	11.9%	42

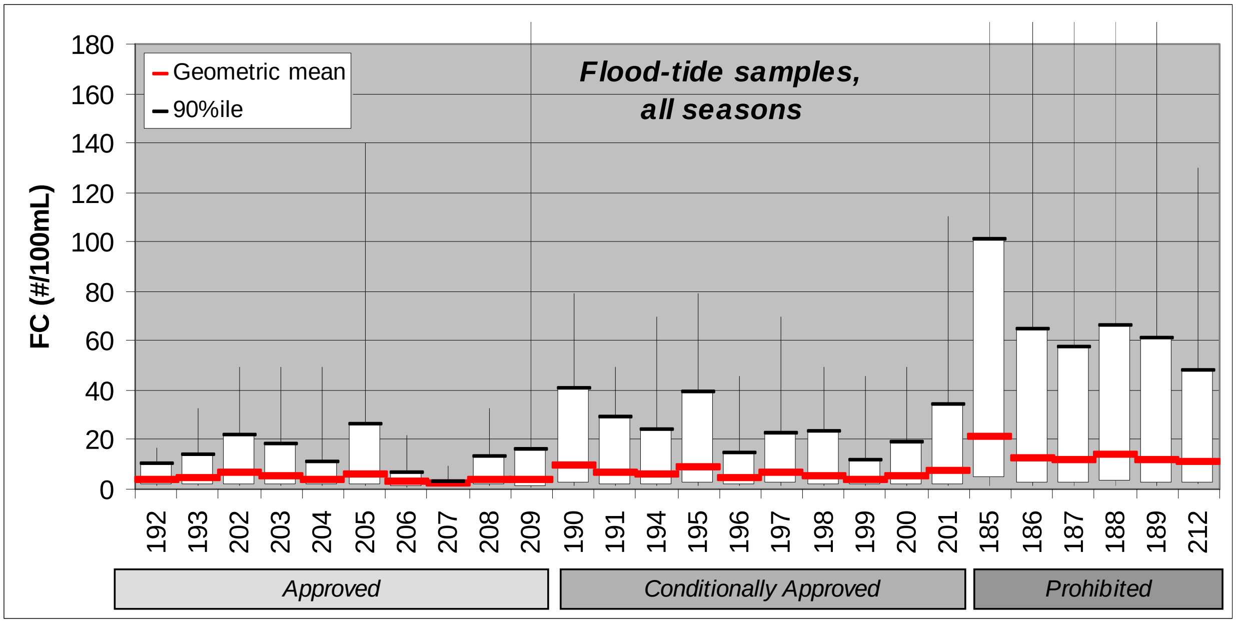

Figure 32. DOH monitoring station results for flood-tide samples.

During ebb tides, shown in Table 8, all six stations within the *Prohibited* shellfish zone have geometric means >14/100 mL, estimated 90th percentile concentrations >43/100 mL, and >10% of samples exceeding 43/100 mL. However, six additional stations within the southern part of the *Conditionally Approved* shellfish zone also have concentrations above these levels. One station within the *Approved* shellfish area had an estimated 90th percentile concentration >43/100 mL, but the site meets the state water quality standard of no more than 10% of samples >43/100 mL. Figure 33 presents the information in graphical form.

Table 8. DOH monitoring station results for ebb-tide samples. All fecal coliform values are in MPN/100 mL. Highlighted values violate water quality standards.

	Station	Geometric mean	90th percentile	%>43	Count
Approved	192	5.1	24.7	8.7%	23
	193	8.7	35.9	8.3%	24
	202	12.8	62.5	10.0%	20
	203	7.0	30.6	8.3%	24
	204	4.7	13.6	0.0%	25
	205	5.7	21.8	5.3%	19
	206	3.7	20.0	8.0%	25
	207	3.4	11.4	0.0%	17
	208	4.3	15.5	0.0%	24
	209	3.2	11.3	3.7%	27
Conditionally Approved	190	10.5	55.5	10.5%	19
	191	6.3	22.2	5.0%	20
	194	10.1	67.3	16.7%	24
	195	10.9	45.7	16.1%	31
	196	6.2	20.6	0.0%	23
	197	13.6	99.1	20.0%	20
	198	9.9	54.3	17.4%	23
	199	5.8	21.6	4.2%	24
	200	13.6	88.9	18.2%	22
	201	9.1	35.5	10.0%	20
Prohibited	185	36.1	157.6	42.3%	26
	186	31.4	166.7	44.4%	27
	187	18.4	88.1	24.1%	29
	188	16.3	111.7	17.2%	29
	189	19.6	124.4	24.1%	29
	212	21.2	161.5	27.3%	22

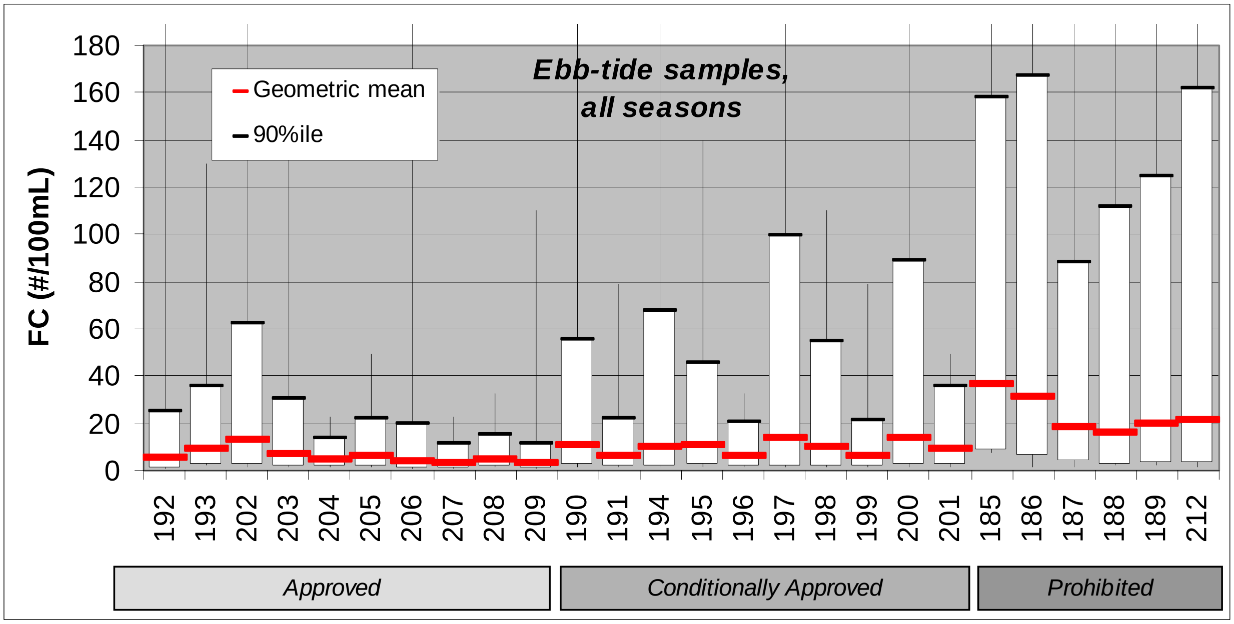

Figure 33. DOH monitoring station results for ebb-tide samples.

Figure 34 compares the spatial distribution of geometric mean concentrations between flood- and ebb-tide conditions. During ebb tides, all stations within the southern inlet have geometric mean concentrations >14/100 mL, while only the southernmost station does not meet the geometric mean criteria during flood tides. The 90th percentile concentrations in Figure 35 indicate an even larger area within the southern inlet does not meet the state and shellfish water quality standards. Figure 36 illustrates the same pattern in terms of the percent of samples exceeding 43/100 mL. The patterns suggest that sources in the southern inlet affect water quality throughout the *Prohibited* shellfish zone and into the *Conditionally Approved* area. Ebb-tide water quality controls overall water quality throughout Henderson Inlet.

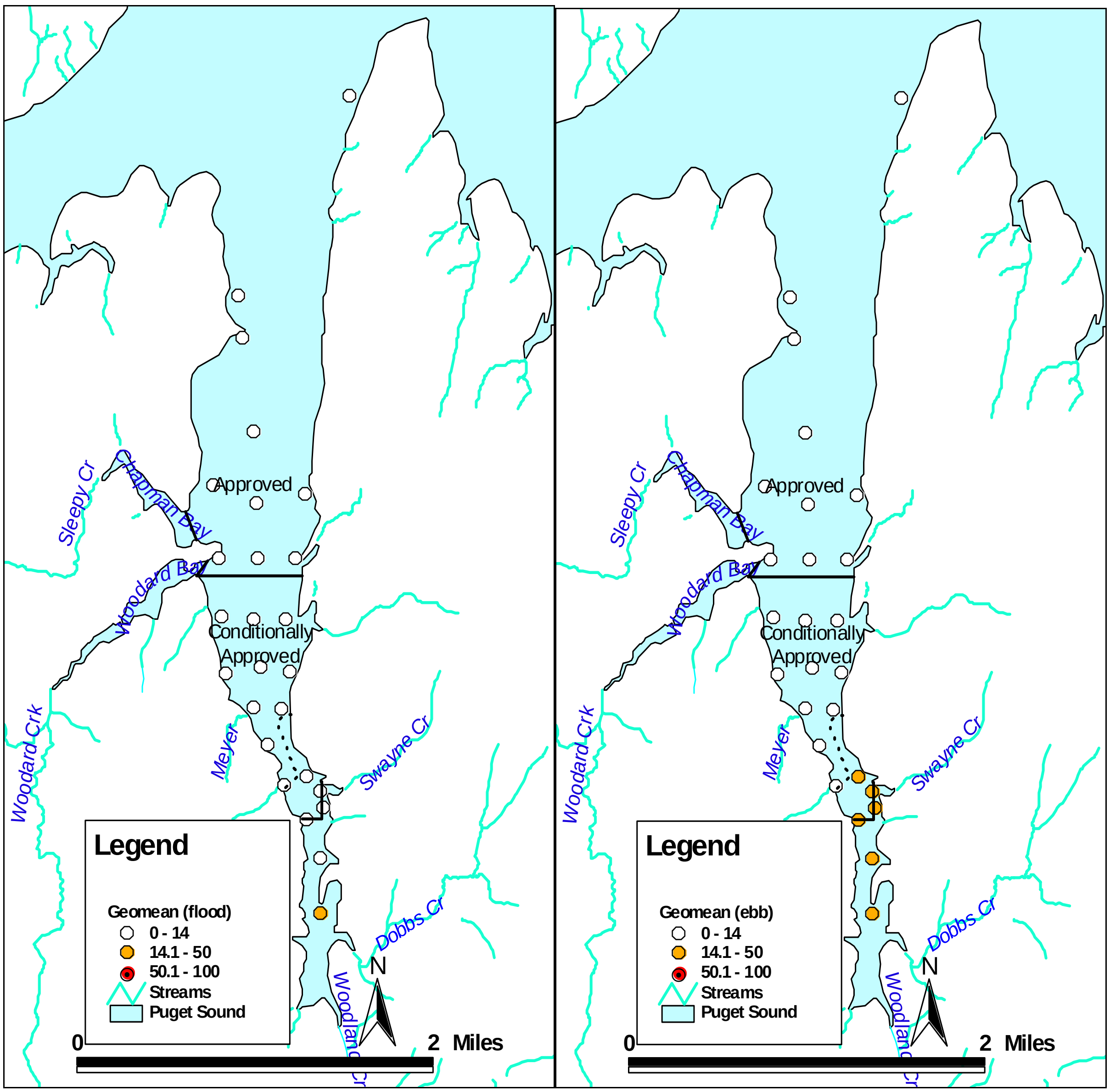

Figure 34. Geometric mean concentrations (#/100 mL) at DOH monitoring stations during flood-tide and ebb-tide conditions.

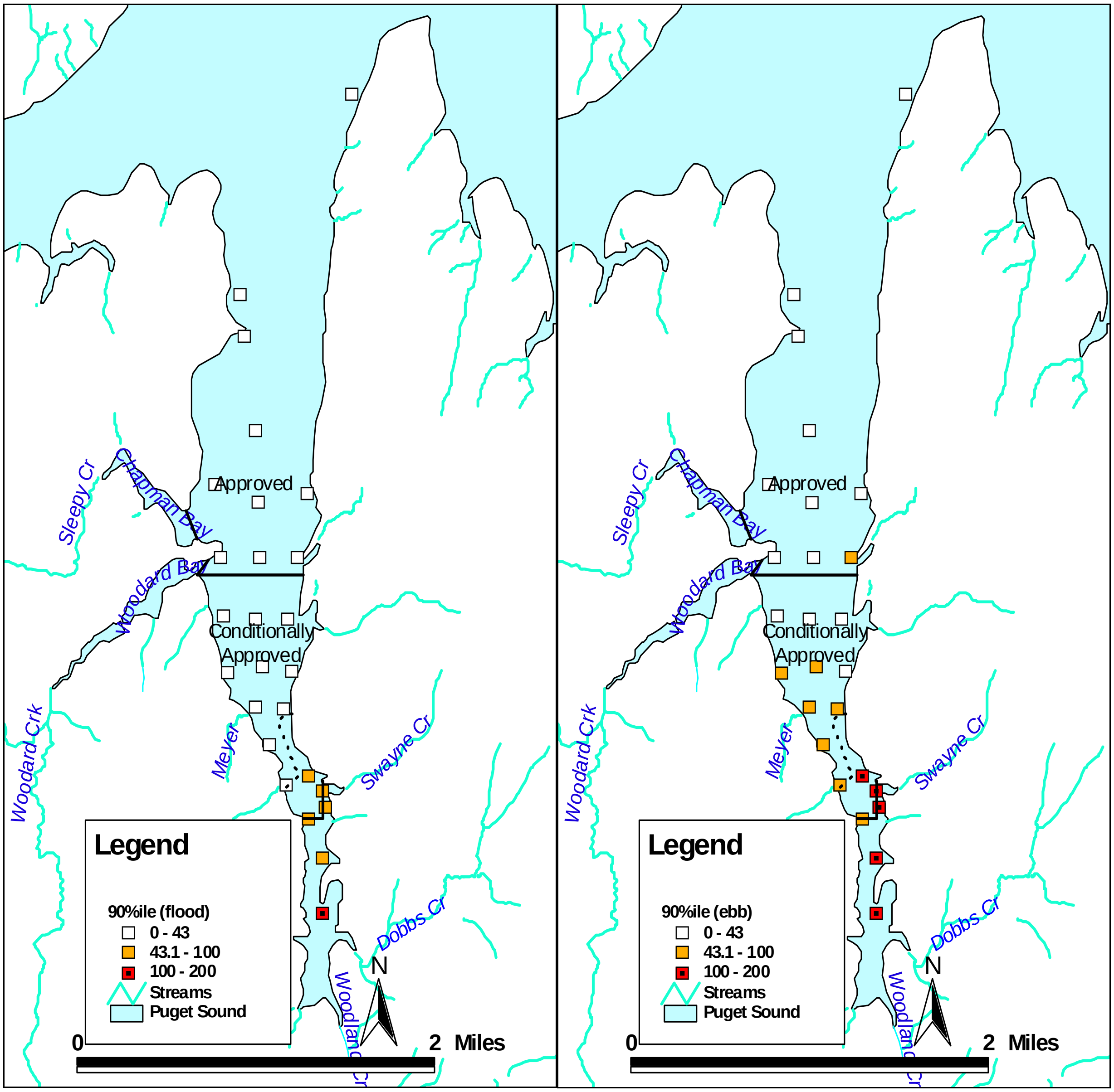

Figure 35. 90th percentile concentrations (#/100/mL) at DOH monitoring stations during flood-tide and ebb-tide conditions.

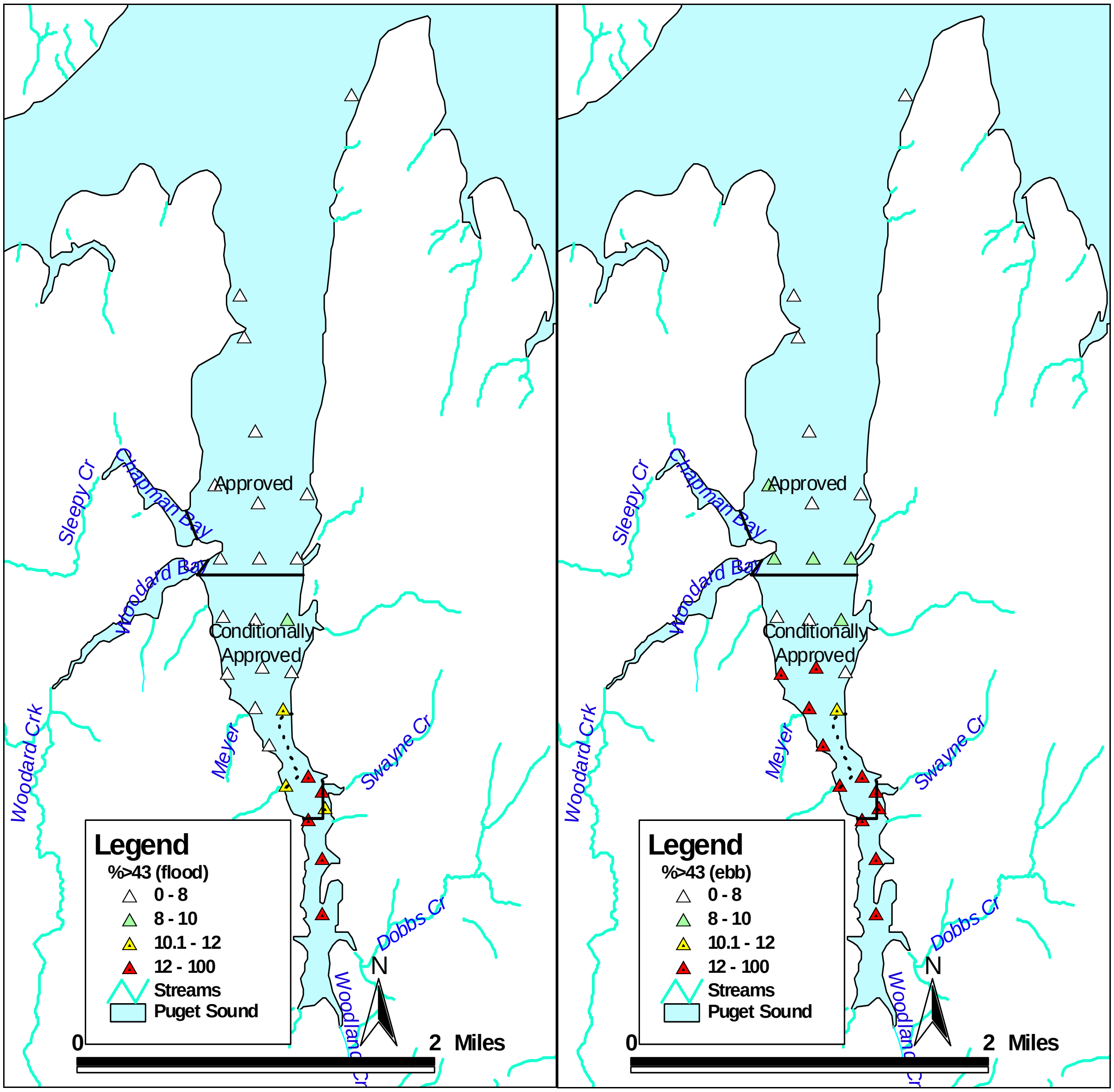

Figure 36. Percent of samples > 43 fc /100 mL at DOH monitoring stations during flood-tide and ebb-tide conditions.

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Seasonal Influence

Table 9 presents DOH monitoring results for dry-season samples collected from June through September. All six stations within the *Prohibited* shellfish zone have geometric mean concentrations >14/100 mL, estimated 90th percentile concentrations >43/100 mL, and >10% of samples exceed 43/100 mL, as do stations 195 and 201 within the *Conditionally Approved* zone. Two more stations have estimated 90th percentile concentrations >43/100 mL with >10% of samples exceeding 43/100 mL. One station each within the *Conditionally Approved* and *Approved* shellfish zones (stations 198 and 202) had estimated 90th percentile concentrations >43/100 mL, although not more than 10% of the samples exceeded 43/100 mL. Therefore, these stations do not meet the shellfish water quality standards but meet the state water quality standards. Figure 37 presents the information in graphical form.

Table 9. DOH monitoring station results for dry-season (June-September) samples. All fecal coliform values are in MPN per 100 mL. Highlighted values violate water quality standards.

	Station	Geometric mean	90^{th} percentile	%>43	Count
Approved	192	5.1	14.0	0.0%	24
	193	5.9	19.4	0.0%	23
	202	10.3	49.8	8.7%	23
	203	6.6	26.2	4.3%	23
	204	3.9	11.7	0.0%	23
	205	8.0	30.2	4.3%	23
	206	3.7	22.0	8.7%	23
	207	2.6	6.7	0.0%	23
	208	3.8	12.6	0.0%	23
	209	3.4	9.0	0.0%	25
Conditionally Approved	190	13.4	66.6	21.7%	23
	191	11.6	46.3	13.0%	23
	194	8.3	36.9	8.7%	23
	195	17.6	66.3	16.7%	24
	196	5.6	23.3	4.3%	23
	197	10.5	31.5	4.5%	22
	198	9.4	43.7	8.7%	23
	199	5.9	20.5	4.3%	23
	200	9.3	37.1	8.7%	23
	201	14.4	65.5	17.4%	23
Prohibited	185	41.5	199.6	56.5%	23
	186	28.8	124.7	37.5%	24
	187	26.9	105.9	37.5%	24
	188	23.2	85.1	33.3%	24
	189	20.1	104.8	20.8%	24
	212	20.3	69.7	25.0%	20

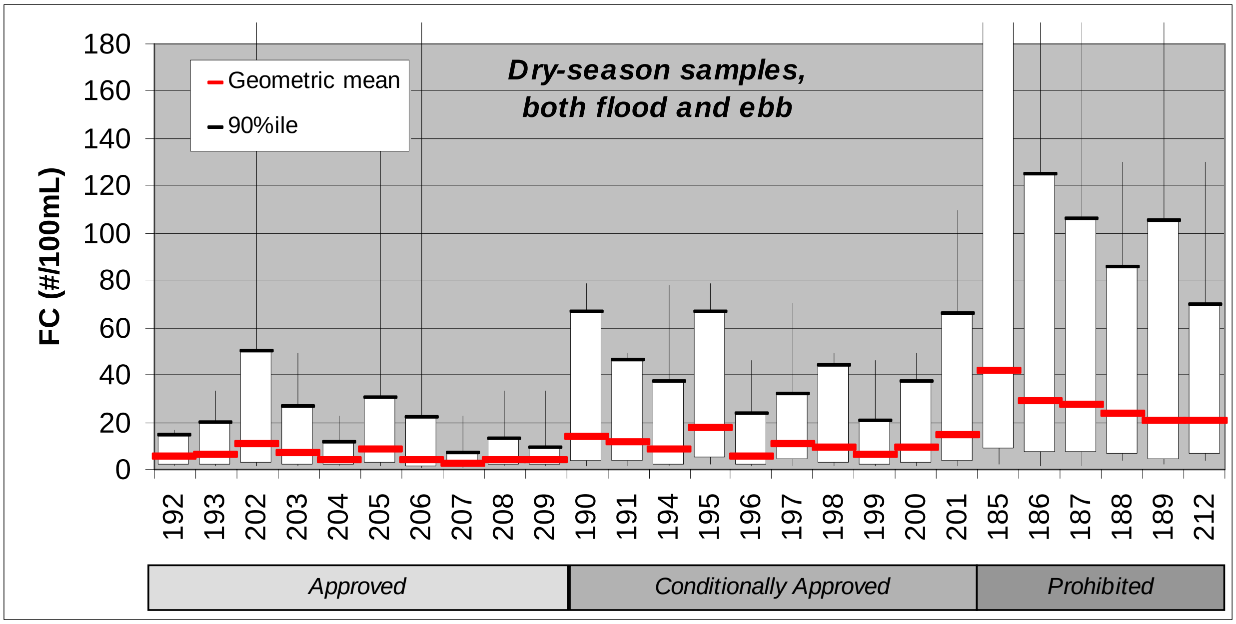

Figure 37. DOH monitoring station results for dry-season (June through September) samples.

Table 10 presents the wet-season monitoring results. Two stations have geometric mean concentrations >14/100 mL, seven stations have 90th percentile concentrations >43/100 mL, and ten stations have >10% of samples exceeding 43/100 mL. Figure 38 presents the same information in graphical form.

Table 10. DOH monitoring station results for wet-season (November through March) samples. All fecal coliform values are in MPN per 100 mL. Highlighted values violate water quality standards.

	Station	Geometric mean	90th percentile	%>43	Count
Approved	192	4.5	23.5	8.7%	23
	193	6.4	29.0	8.3%	24
	202	8.2	31.3	4.3%	23
	203	6.4	27.6	8.3%	24
	204	5.0	16.0	4.2%	24
	205	5.5	20.0	4.2%	24
	206	2.8	7.0	0.0%	24
	207	2.4	5.6	0.0%	24
	208	3.9	12.2	0.0%	24
	209	4.0	26.3	8.3%	24
Conditionally Approved	190	8.6	39.7	8.0%	25
	191	5.9	20.3	4.2%	24
	194	7.4	36.7	12.5%	24
	195	7.7	31.9	13.5%	37
	196	5.0	14.9	0.0%	24
	197	9.0	69.4	16.7%	24
	198	7.5	39.1	8.3%	24
	199	4.7	17.0	4.2%	24
	200	7.9	40.2	12.5%	24
	201	6.3	23.0	8.0%	25
Prohibited	185	19.9	97.2	28.6%	35
	186	15.0	97.6	22.9%	35
	187	11.0	55.6	14.3%	35
	188	12.5	86.4	13.9%	36
	189	13.3	92.0	22.2%	36
	212	13.6	104.8	17.2%	29

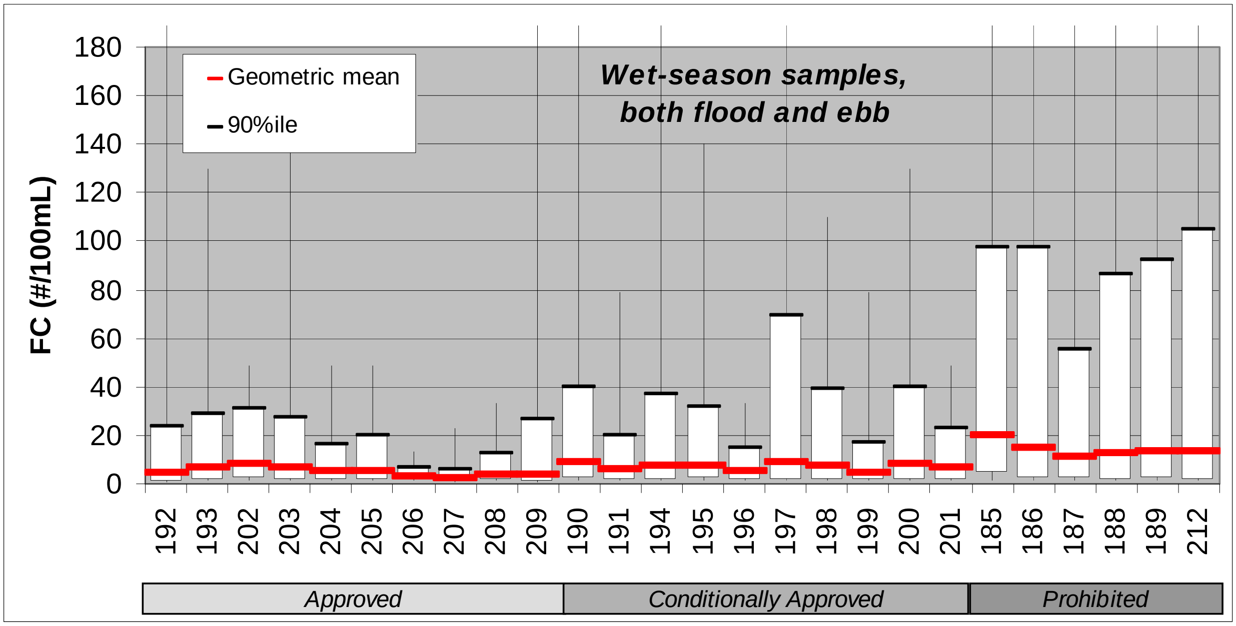

Figure 38. DOH monitoring station results for wet-season (November through March) samples.

The geographic distribution is evident in Figures 39 through 41. More stations have geometric mean concentrations >14/100 mL during the dry season than during the wet season. The entire southern inlet has estimated 90th percentile concentrations >43/100 mL, as does the eastern shore of the *Conditionally Approved* shellfish zone. The southern inlet and the eastern shore of the *Conditionally Approved* shellfish zone has >10% of samples exceeding 43/100 mL during dry weather, while the southern inlet and the western shore exceed the 10% criterion during wet weather.

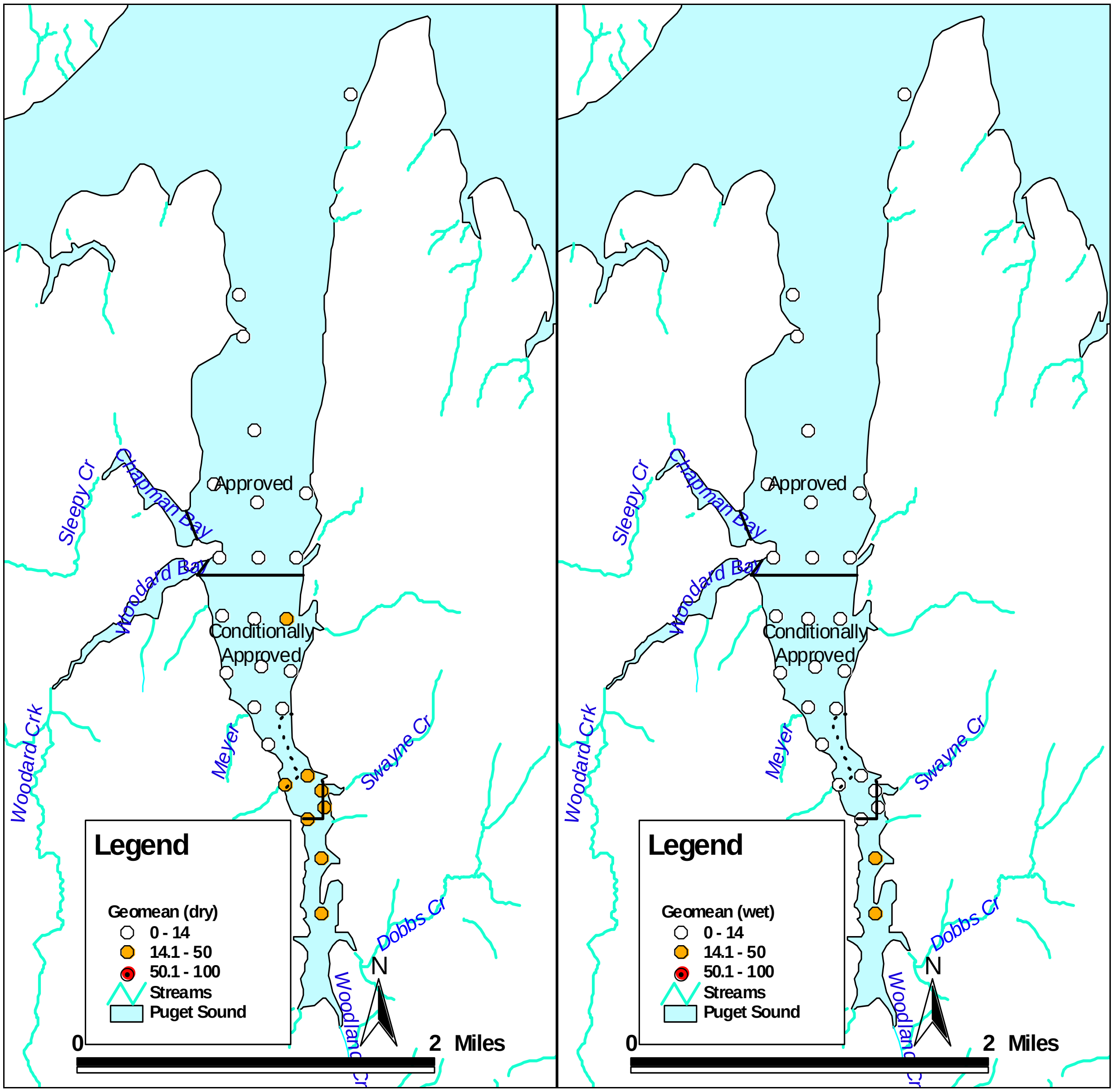

Figure 39. Geometric mean concentrations during the dry (June-September) and wet (November-March) seasons.

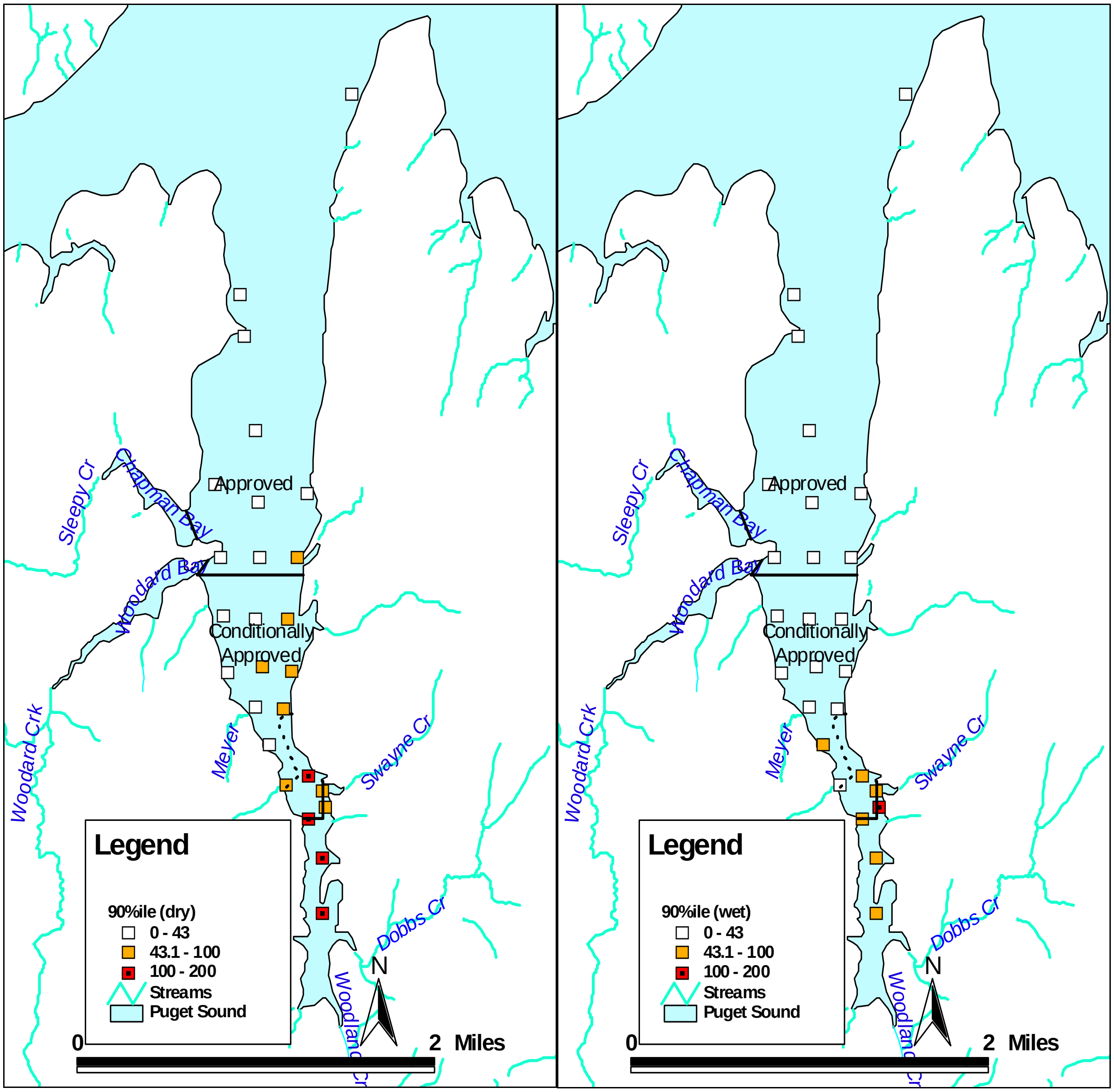

Figure 40. 90th percentile concentrations during the dry (June-September) and wet (November-March) seasons.

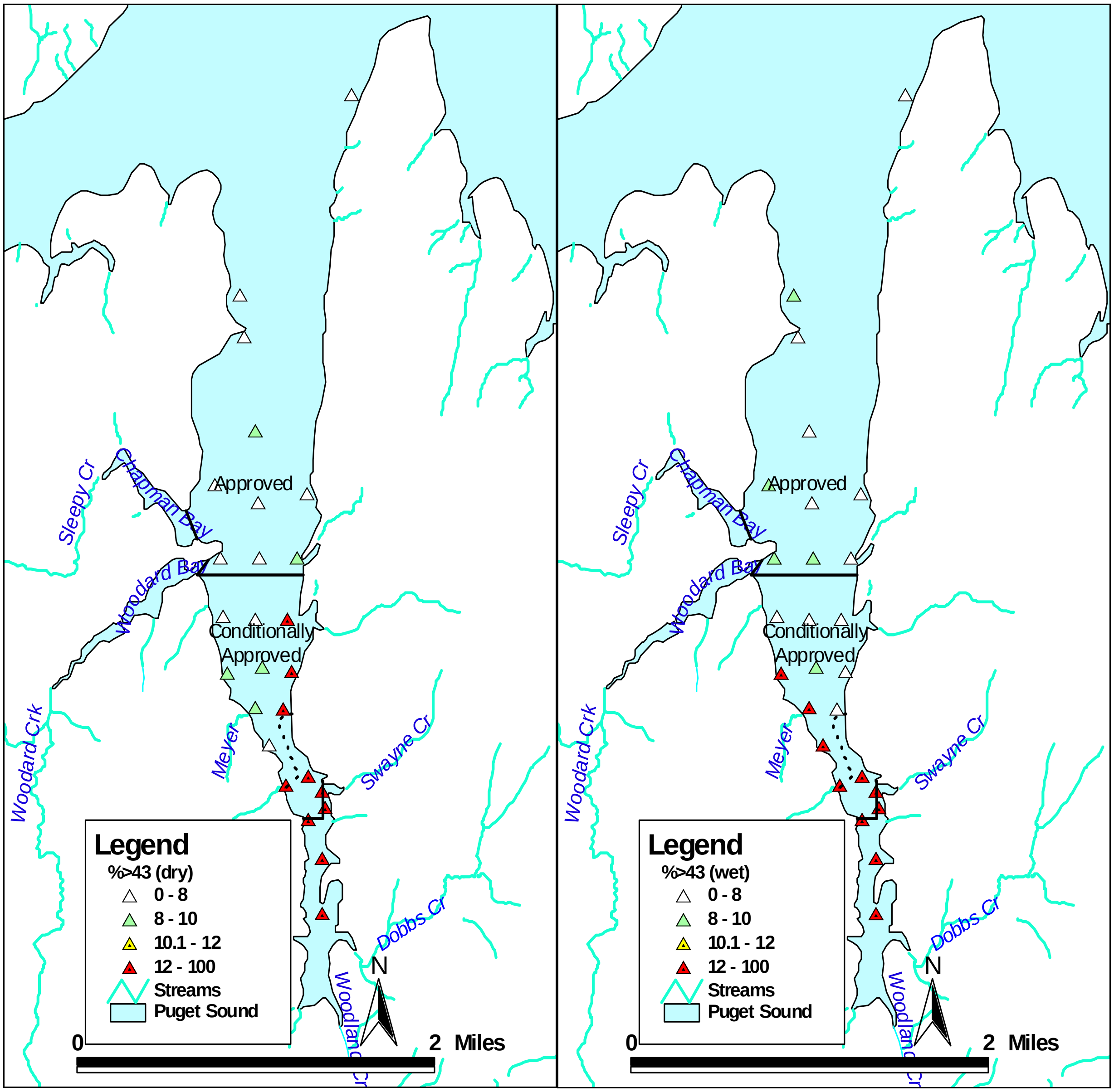

Figure 41. Percent of samples >43/100 mL during the dry (June-September) and wet (November-March) seasons.

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Wildlife Bacteria Load Estimates

Henderson Inlet and the Woodard Bay Natural Area are home to various wildlife, including seals and seabirds. Table 11 summarizes the individual counts and a range of fecal coliform bacteria loads contributed by wildlife to Henderson Inlet.

Table 11. Wildlife counts and fecal coliform bacteria load estimates for Henderson Inlet.

Daily FC load (10^6/day/ individual)	Gulls	Canada geese	Other birds and bats[2]	Seals
	150	10	50	5000
Source (loads)	Gould and Fletcher, 1978; Nixon and Oviatt, 1973; Alderisio and DeLuca, 1999	Fleming and Fraser, 2001; Alderisio and DeLuca, 1999	Estimate; current study	Calambokidis et al., 1989
Source (counts)	Estimate; Nysewander, 2005	Estimate; Nysewander, 2005	Estimate; Nysewander, 2005 and Tirhi, 2005	Jeffries et al., 2000
Numbers of Individuals Present				
Summer Low	100	10	100	100
Summer High	1000	100	1000	500
Winter Low	100	10	100	100
Winter High	1000	100	10000	500
Fecal Coliform Loads (billion/day)				
Summer Low	15	0.1	5	500
Summer High	150	1	50	2500
Winter Low	15	0.1	5	500
Winter High	150	1	500	2500

Washington Department of Fish and Wildlife (WDFW) has estimated that the Woodard Bay seal population ranges in size from 100 to 500 individuals, with peak numbers associated with pupping in July and August (Jeffries et al., 2000 and Lambourn, 2005). The group size also varies with the condition of historical and recently placed log booms in the area.

The Black Hills Audubon Society coordinates the annual Christmas bird count in the region; however, the published numbers combine bird counts from Woodard Bay with portions of the Nisqually Reach, Budd Inlet, and Eld Inlet. Therefore results could not be used to estimate summer or winter bird counts in Henderson Inlet.

Under the Puget Sound Ambient Monitoring Program, WDFW has conducted aerial surveys of marine birds since 1992. Data are summarized by summer and winter seasons. Figure 42 presents summer densities while Figure 43 presents winter densities for the sum of all bird species. Gulls and terns represent 73% of all birds identified in summer surveys (WDFW, 2005). Summer bird densities range from <25 birds/km^2 on the eastern shore to 200 to 400 birds/km^2 in the central inlet, as shown in Figure 42. In Figure 43, winter bird densities are higher, ranging

[2] M. Tirhi (2005) estimates marten use at Woodard Bay at 50 boxes and 2 birds per box. The heron colony has disbanded but may be growing; currently, 30 to 50 herons use the Woodard Bay area. As of 2000, 1700 to 2000 female bats roost in the Woodard Bay Natural Area; the count does not include pups.

from 200 to 400 birds/km^2 in the northern inlet to >1000 birds/km^2 in the southern inlet. Summer gull densities, shown in Figure 44, range from <25 birds/km^2 in the northeastern inlet to >500 birds/km^2 in the central inlet. In summer, the highest bird densities occur in and near Woodard and Chapman bays in the central inlet, while winter bird densities peak in the southern inlet.

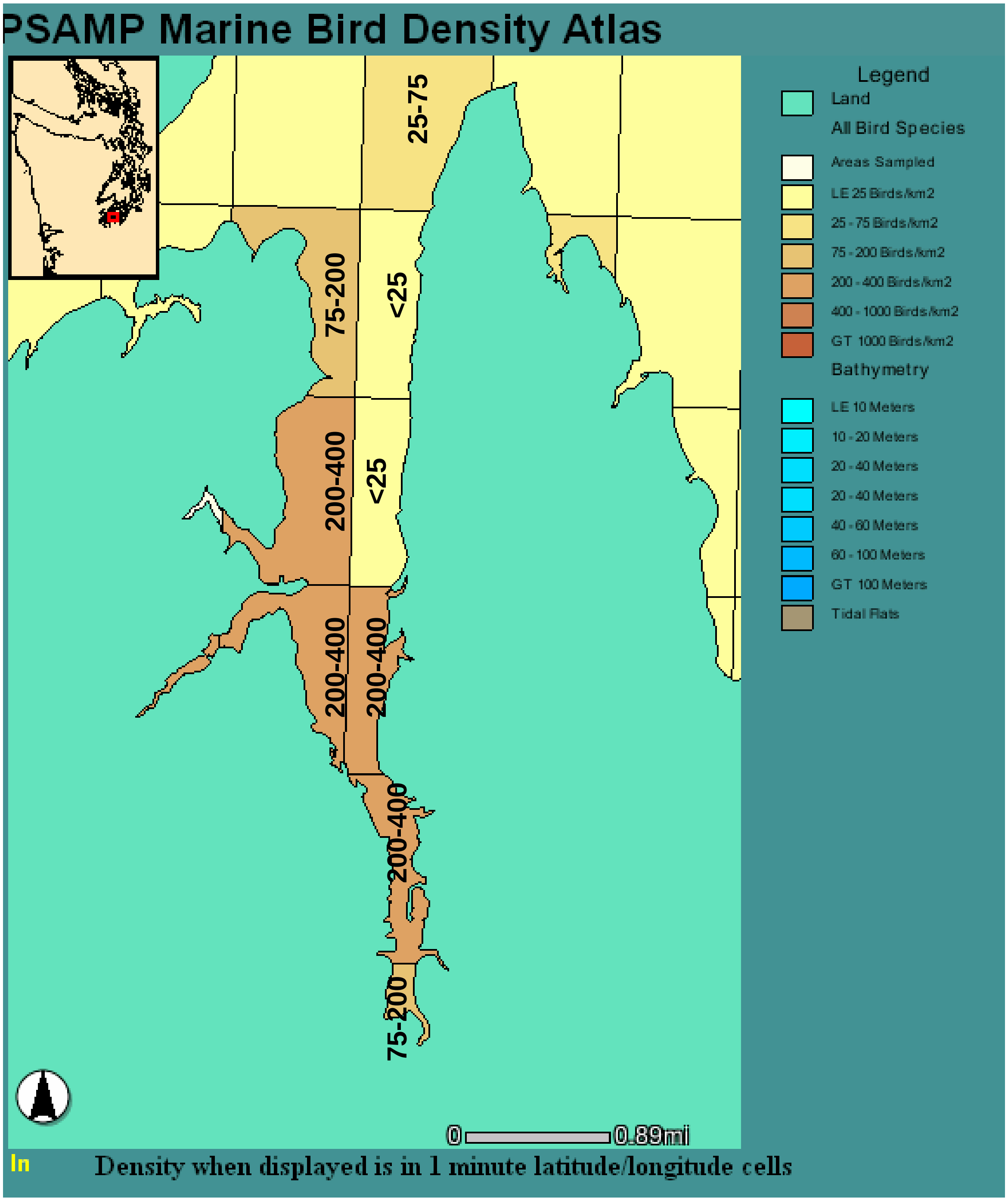

Figure 42. WDFW aerial bird survey results for all birds in the summer season (WDFW, 2005).

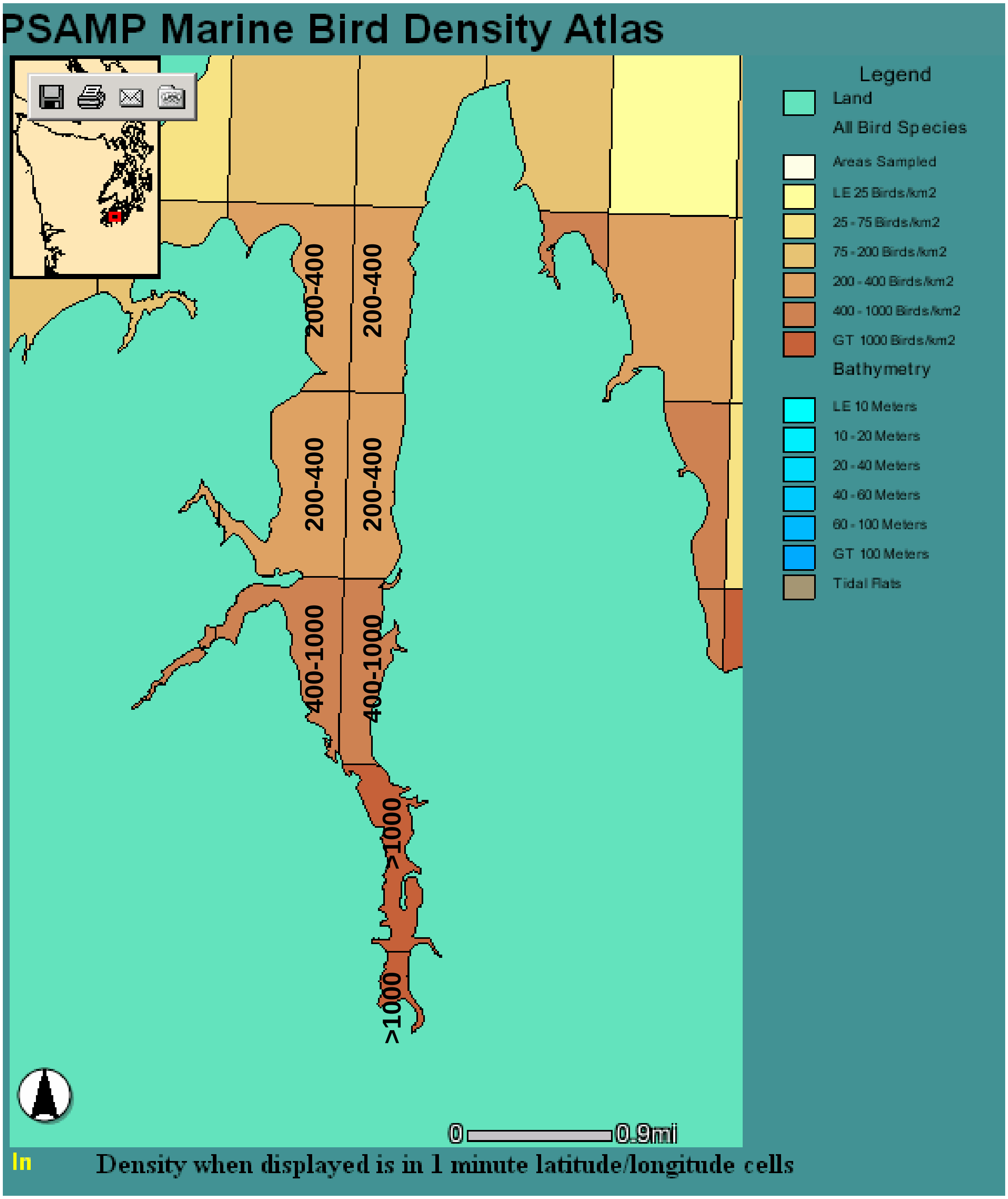

Figure 43. WDFW aerial bird survey results for all birds in the winter season (WDFW, 2005).

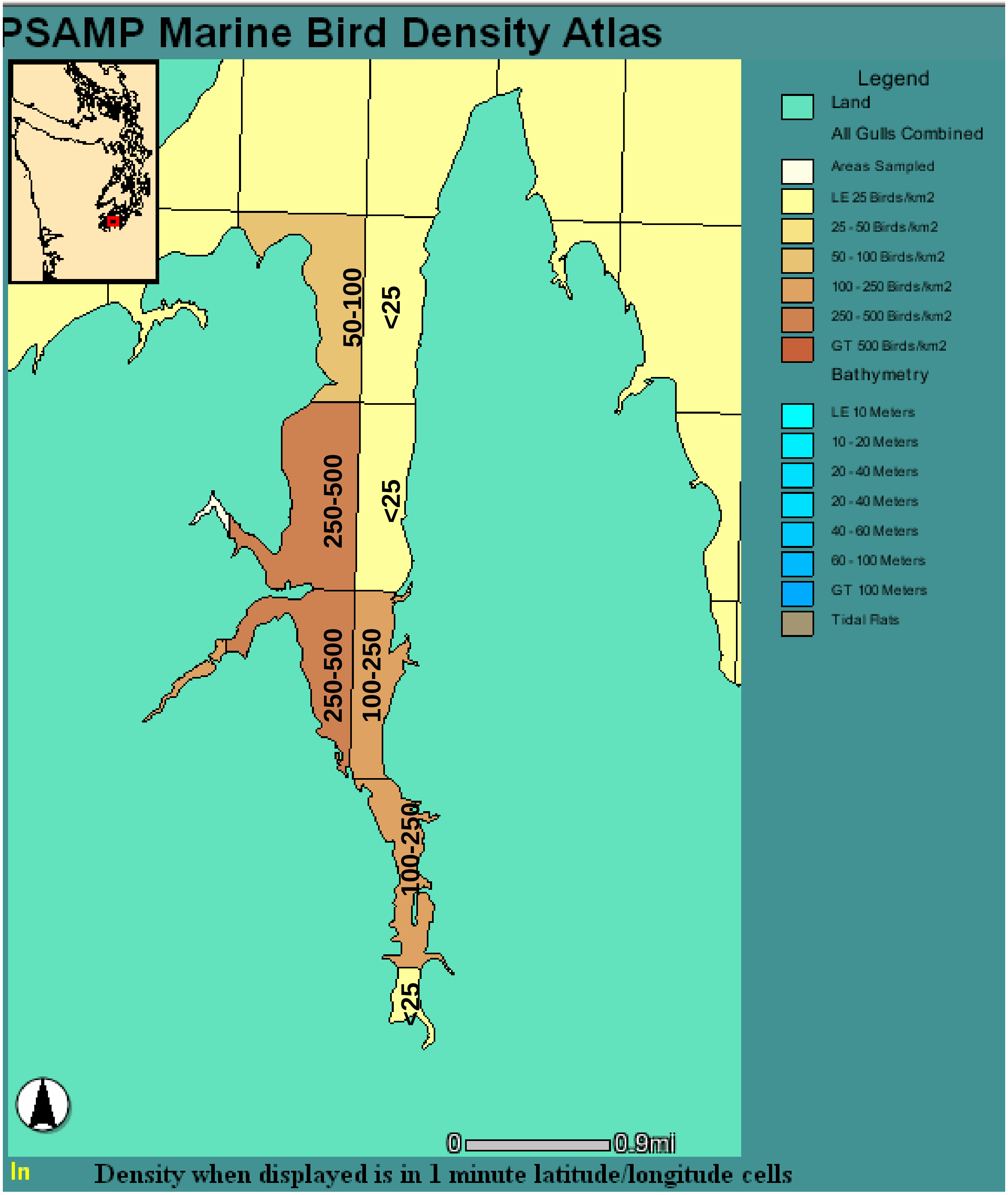

Figure 44. WDFW aerial bird survey results for gulls in the summer season (WDFW, 2005).

Load and Wasteload Allocations

The loading capacity is the maximum load of a pollutant that can be assimilated by the receiving water without violating water quality standards. The loading capacity is allocated among load and wasteload sources. Load allocations are set for diffuse (nonpoint) sources, and wasteload allocations are set for discrete (point) sources.

Fecal Coliform Wasteload Allocations

Since 2002, EPA requires that all TMDLs in jurisdictions with National Pollution Discharge Elimination System (NPDES) permits for stormwater systems include the pollutant loads from those systems as a wasteload allocation (EPA, 2002).

The Washington Sate Department of Transportation (WSDOT) has a Phase I NPDES permit for their stormwater systems. A Phase II NPDES stormwater permit will be required for the urbanized portions of Thurston County. Depending on the location of the stormwater discharges, wasteload allocations will be assigned to stormwater discharge in Thurston County, City of Lacey, or City of Olympia in preparation for the Phase II NPDES permit. Ecology has developed maps that illustrate the census urbanized areas and jurisdictional boundaries. These maps were used to tentatively identify Phase II jurisdictions. Ecology's website at: www.ecy.wa.gov/programs/wq/stormwater/phase_2/maps.html identifies possible Phase II areas.

In Woodland Creek, Nisqually Trout Farm #2 has a fish hatchery general permit (number WAG131002C) to discharge to Woodland Creek. Permit limits are currently set for the following parameters: settleable solids, total suspended solids, and chlorine. The permit also has conditions on chemical and drug use.

Determining Fecal Coliform Loading Capacity

Fecal coliform *concentrations* are important for evaluating a waterbody's compliance with water quality criteria. Fecal coliform *loading* calculations can provide a more comprehensive water quality analysis than fecal coliform concentrations. Loading is a function of both concentration (bacteria density) and flow. Loading analysis can reveal the presence of additional contaminant sources, dilution and dispersion characteristics, as well as transport mechanisms.

Fecal coliform has a two-part water quality standard for concentration. For most areas, the criterion that is not met is that 10% of samples are not to exceed a given value, which is interpreted as must not exceed the 90th percentile. To calculate the fecal coliform bacteria loading capacity, the following formula is used:

$$LC_{90\%tile} = Q \times (90^{th} \text{ percentile fc standard/100mL}) \times f_{convert}$$

where

LC is the load capacity in billion fecal coliform per day, Q is discharge in cubic feet per second (cfs), and $f_{convert}$ is a unit conversion value (0.0246) to convert cfs x #fc/100mL to billion fecal coliform per day.

Load allocations are determined using the rollback method to calculate reduction factors necessary to meet both parts of the water quality standard. In most cases, application of the rollback method yields a more stringent target for one part of the standard (geometric mean or 90th percentile) than the applicable water quality standard. If the 90th percentile is limiting, then the goal would be to meet the 90th percentile goal (e.g., 50 fc/100 mL in freshwater). No goals would be set for the geometric mean since, with the implementation of target reductions, the already low geometric mean would only get better. Similarly, if the geometric mean is limiting, the goal would be to achieve a geometric mean that meets standards with no goal set for the 90th percentile.

Fecal Coliform Loading Capacity

Woodland Creek

Loading capacities for Woodland Creek, tributaries, and stormwater discharge are presented in Figures 45 and 46 for the wet storm-event period and dry period, respectively. For most sites, the load and wasteload allocations are set for the critical storm-event period. For all sites, with the exception of stormwater discharge at Interstate 5 (RM 3.1), the 90th percentile (the portion of the criteria that most deviated from the water quality standard) is set as the target to meet. While percent reductions are based on the critical period, target reduction values apply year-round.

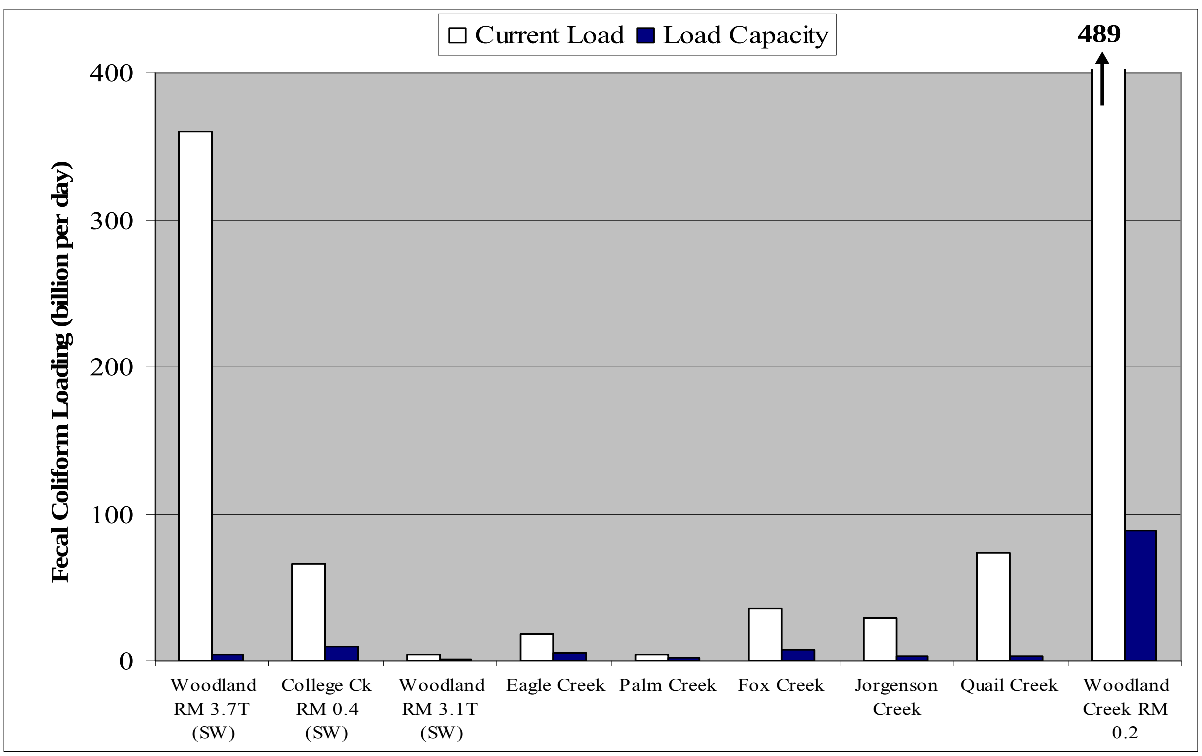

Figure 45. Fecal coliform bacteria storm-event period loading capacity for Woodland Creek sites, tributaries, and stormwater discharges based on 90th percentiles.

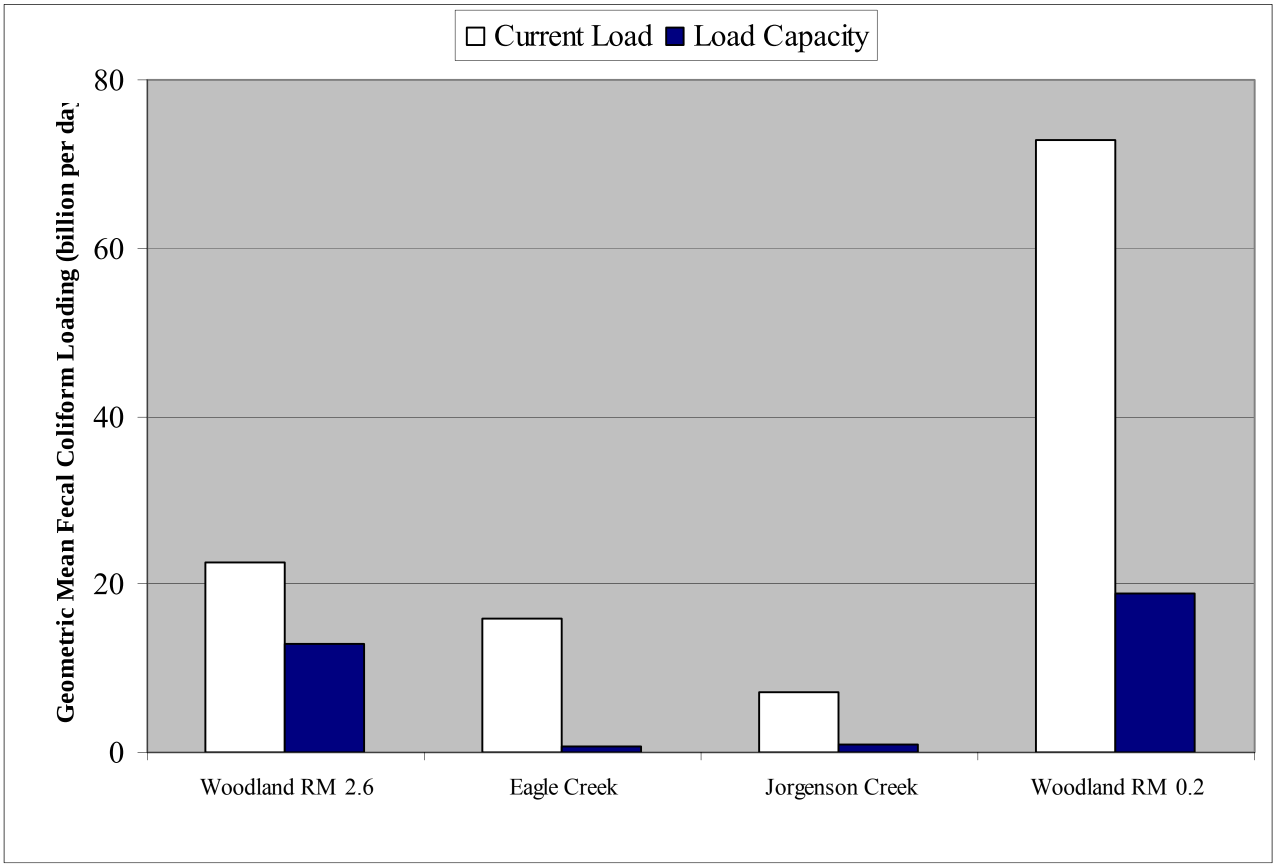

Figure 46. Fecal coliform bacteria dry-season loading capacity for Woodland Creek sites and tributaries. Woodland Creek reductions are based on geometric mean concentrations while Eagle and Jorgenson Creek reductions are based on the 90^{th} percentile fecal coliform concentration.

For Eagle and Jorgenson creeks, the critical period is the dry season, and the load allocation is based on lower dry-season flows. Woodland Creek at RM 2.6 is given a load allocation for the dry season because it is the most upstream site not to meet bacterial water quality standards during this period. Woodland Creek at RM 0.2 is given a load allocation during the dry-season and storm-event critical periods due to high bacteria concentrations during both these periods and to protect the beneficial use of shellfish harvesting in Henderson Inlet. For both storm-event and dry seasons, flow at Woodland RM 0.2 was assumed to be equivalent to flow at Woodland RM 1.0.

Table 12 describes load and wasteload bacteria reductions needed for the critical period by site.

Fecal Coliform Bacteria Wasteload Allocations

Stormwater discharges from NPDES Phase II areas in Thurston County and city of Lacey were given wasteload allocations as shown in Table 12. Bacteria reductions for Thurston County stormwater discharges to Woodland Creek at RM 3.7 and RM 2.6, and the city of Lacey stormwater discharge at College Creek RM 0.4 are also described in Table 12.

Table 12. Woodland Creek tributaries and stormwater bacterial reductions and targets.

Site	Critical season	# of sample events in period	Geometric mean	90th percentile	FC reduction needed to meet standards	Limiting criterion	Target value fc/100 mL
Storm-event (November – March) bacterial load and wasteload allocations and reductions							
Stormwater discharge at Woodland RM 3.7	Storm event	11	446	8370	99%	90th percentile	100
College Creek at RM 0.4	Storm event	8	161	694	86%	90th percentile	100
WSDOT stormwater discharge at Woodland RM 3.1	Storm event	9	31	624	84%	90th percentile	100
Stormwater pipe from at Interstate 5 at Woodland RM 3.1	Storm event	3	539	659	91%	Geometric Mean	50
Stormwater pipe at Woodland RM 2.6	Storm event	6	617	1920	95%	90th percentile	100
Palm Creek at Woodland RM 1.95	Storm event	8	54	246	59%	90th percentile	100
Fox Creek at Woodland RM 1.9	Storm event	8	41	451	78%	90th percentile	100
Quail Creek at Woodland RM 1.1	Storm event	8	212	2510	96%	90th percentile	100
Woodland Creek at RM 0.2	Storm event	8	102	552	92%	90th percentile	43
Dry-season (June – September) bacteria load allocations and reductions							
Woodland Creek at RM 2.6	Dry season	4	87	108	43%	Geometric Mean	50
Eagle Creek at Woodland RM 2.25	Dry season	4	204	2180	95%	90th percentile	100
Jorgenson Creek at Woodland RM 1.2	Dry season	4	412	904	89%	90th percentile	100
Woodland Creek at RM 0.2	Dry season	4	192	271	93%	Geometric Mean	14

For stormwater discharges to Woodland Creek that were not sampled directly, stormwater best management practices, including programmatic measures, must be applied to meet water quality standards. Discharges to Woodland Creek and tributaries must meet a geometric mean target of 50 fc/100 mL and a 90th percentile fecal coliform target of 100 fc/100 mL. Woodland Creek currently does not meet water quality standards for bacteria and thus has no capacity for increasing bacteria levels above the standard. All wasteload allocations to the creek must meet fecal coliform standards.

Fecal coliform concentrations from WSDOT stormwater at Woodland Creek RM 3.1 and the stormwater discharge at Interstate 5 are described in Table 12, and loading for the stormwater discharge at RM 3.1 is presented in Figure 45. Data for these sites are included in Appendix B. WSDOT must apply best management practices (including programmatic measures) to stormwater discharges to meet water quality standards. The stormwater discharge to Woodland Creek must meet a geometric mean value of 50 fc/100 mL and a 90th percentile fecal coliform target of 100 fc/100 mL. An 84% reduction in bacterial levels is needed for the stormwater discharge at RM 3.1, and a 91% reduction is needed at the stormwater pipe at Interstate 5.

Nisqually Trout Farm #2 was not sampled for fecal coliform bacteria. There are no sources of fecal coliform bacteria associated with the fish hatchery; therefore no fecal coliform bacteria wasteload allocation is set.

Woodard Creek

Loading capacities for Woodard Creek, its tributaries, and stormwater discharges are presented in Figure 47. For all sites, load and wasteload allocations are set for the critical storm-event (wet) period. While Woodard Creek at RM 3.4 and 2.9 had higher geometric means in the dry season, the high 90th percentile fecal coliform bacteria concentrations required the greater bacteria reductions. Therefore the 90th percentile was the most limiting portion of the criteria for all sites. Flow at Woodard RM 0.0 was assumed to be equivalent to flow at RM 2.9. Table 13 describes bacteria reductions needed for the critical period by site.

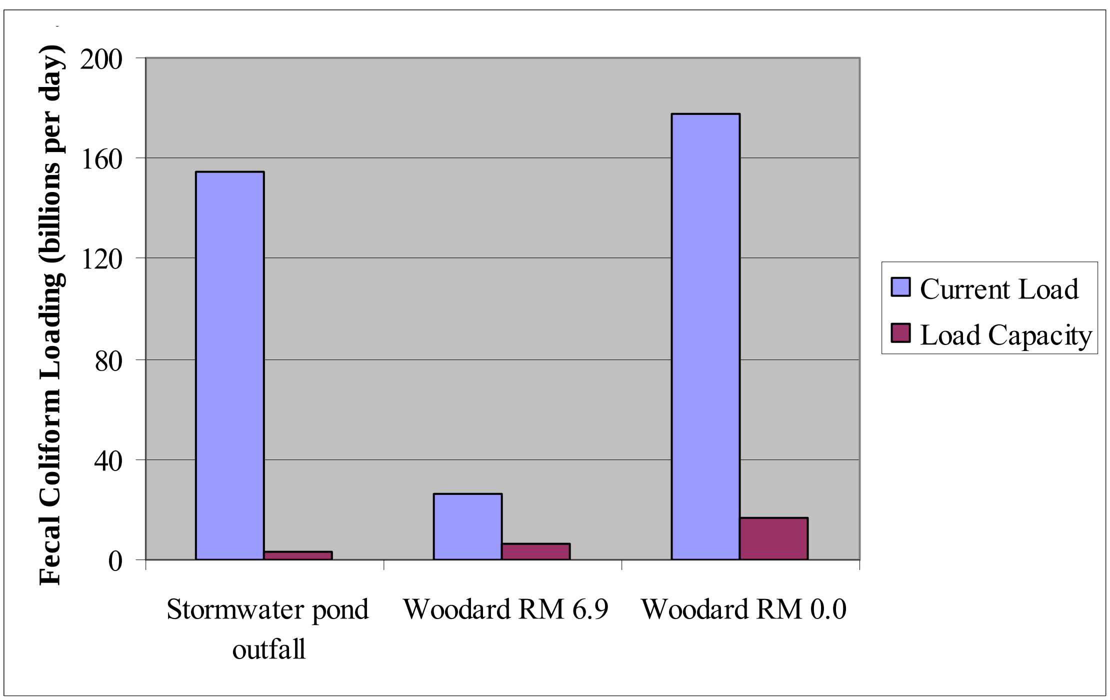

Figure 47. Fecal coliform bacteria storm-event load and wasteload capacity for Woodard Creek.

Table 13. Woodard Creek tributaries and stormwater bacterial reductions and targets.

Site	Critical season	# of sample events in period	Geometric mean	90^{th} percentile	FC reduction needed to meet standards	Limiting criterion	Target value fc/100 mL
Stormwater discharge to Taylor wetland	Storm event	4	168	4590	98%	90^{th} percentile	100
Woodard Creek at RM 6.9	Storm event	8	92	415	76%	90^{th} percentile	100
Woodard Creek at RM 0.0	Storm event	8	97	450	90%	90^{th} percentile	43

Fecal Coliform Wasteload Allocations

Stormwater discharges from NPDES Phase II areas in Thurston County and the city of Olympia were given wasteload allocations. Bacteria reductions for the City of Olympia stormwater discharge to Taylor wetland (headwaters of Woodard Creek) are described in Table 13.

For stormwater discharges to Woodard Creek that were not sampled directly, stormwater best management practices, including programmatic measures, must be applied. Discharges to Woodard Creek and tributaries must meet a geometric mean target of 50 fc/100 mL and a 90^{th} percentile fecal coliform target of 100 fc/100 mL.

Meyer, Sleepy, Dobbs, and Goose Creeks

Loading capacities for Meyer, Sleepy, Dobbs, and Goose creeks are presented in Figure 48. Load allocations are set for the critical storm-event (wet) period. Sleepy Creek also had a dry-season critical period, and a similar bacteria reduction was needed (89%) to meet dry-season water quality standards. However, storm-event bacteria load is much greater than during the dry season, so the storm-event period is the critical period for reductions. For all sites, the 90^{th} percentile (the portion of the criteria that most deviated from the water quality standard) is set as the target to meet. Table 14 describes bacteria reductions needed for the critical period by site.

Fecal Coliform Wasteload Allocations

Meyer, Sleepy, Dobbs, and Goose creeks are not in the NPDES Phase II stormwater permit areas of Thurston County, and no wasteload allocations are required for these areas.

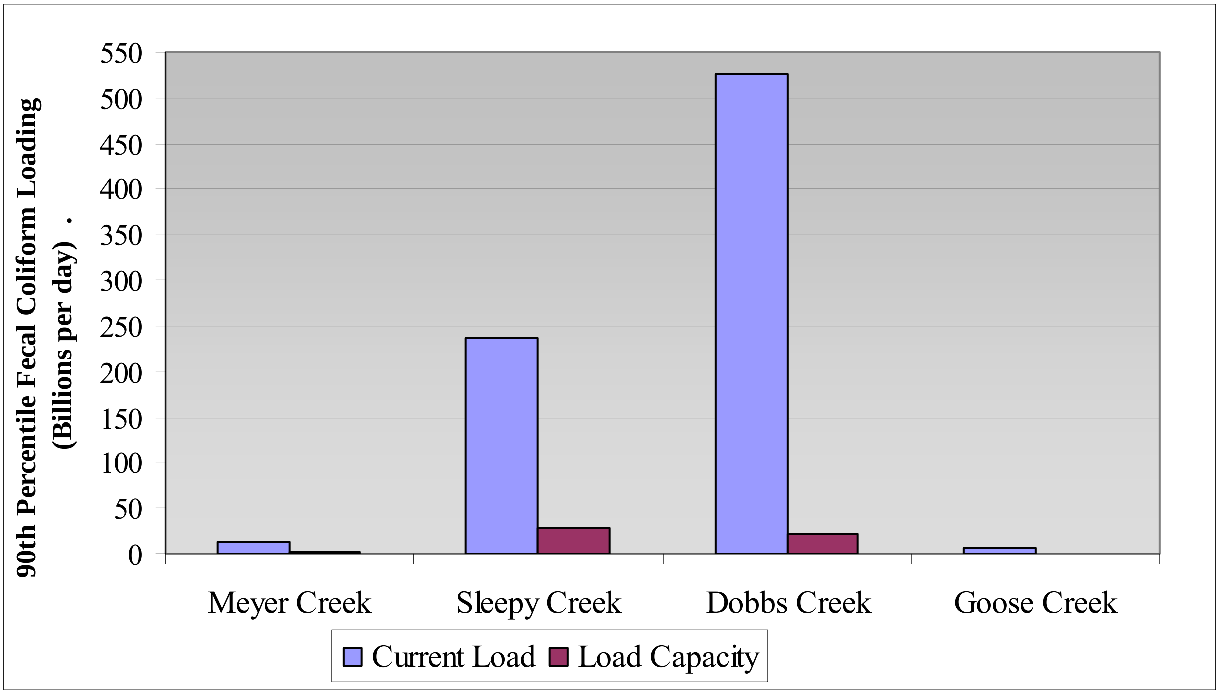

Figure 48. Estimated fecal coliform bacteria storm-event load capacity for tributaries to Henderson Inlet.

Table 14. Bacteria reductions needed for Henderson Inlet tributaries.

Site	Critical season	# of sample events in period	Geometric mean	90^{th} percentile	FC reduction needed to meet standards	Limiting criterion	Target value fc/100 mL
Meyer Creek	Storm event	6	109	741	87%	90^{th} percentile	100
Sleepy Creek	Storm event	8	90	835	88%	90^{th} percentile	100
Dobbs Creek	Storm event	10	299	2420	96%	90^{th} percentile	100
Goose Creek	Storm event	7	54	773	87%	90^{th} percentile	100

Henderson Inlet

Loading capacity for Henderson Inlet is presented in Figure 49 for the dry season for 90th percentile fecal coliform bacteria concentrations. Figure 50 presents the loading capacity for the wet storm-event period 90th percentile fecal coliform bacteria concentrations. For all sites, the reductions are based on levels necessary to meet the second part of the bacteria water quality standards, considering both ebb-tide and flood-tide conditions. Thus, critical conditions are based on seasons. At three stations during the wet season, the estimated 90th percentile does not exceed 43/100 mL; however, more than 10% of the samples exceeded 43/100 mL. Therefore, nominal reductions are necessary such that the second part of the bacteria water quality standards is met.

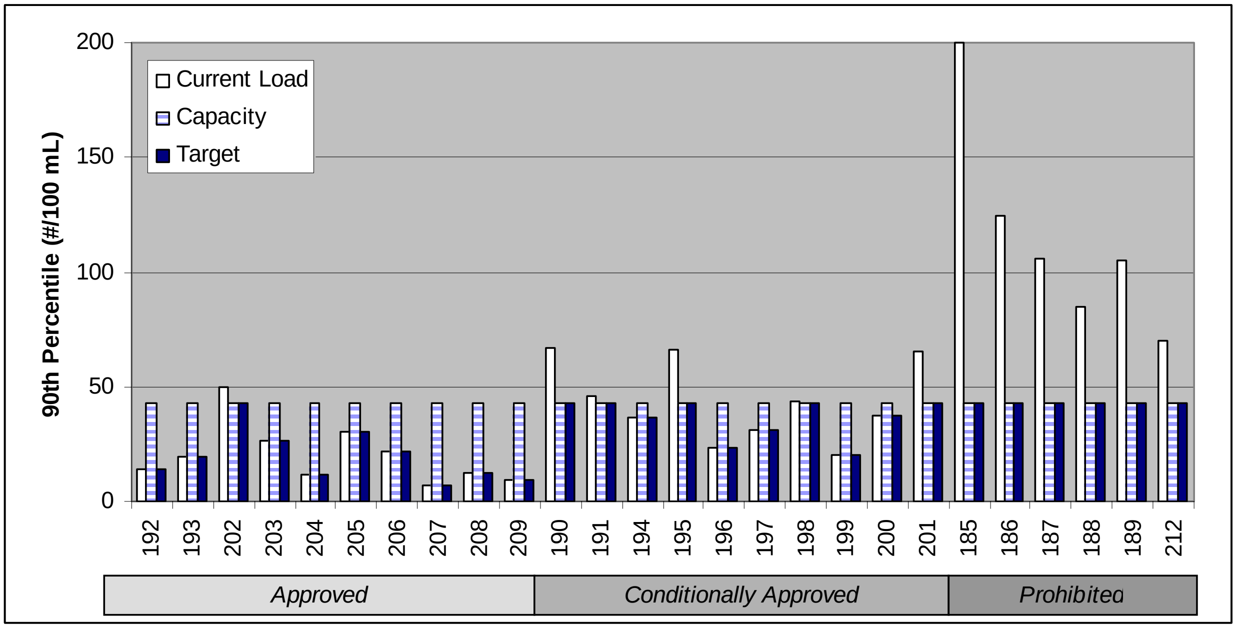

Figure 49. Fecal coliform bacteria dry-season loading capacity for 90th percentile concentrations within Henderson Inlet.

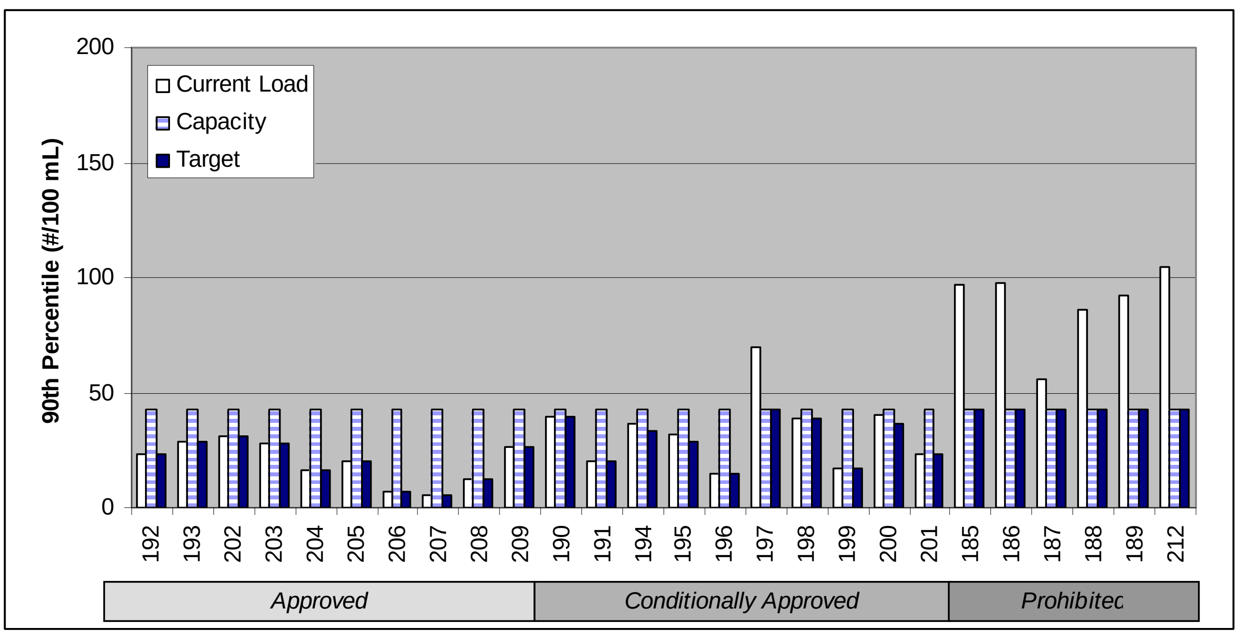

Figure 50. Fecal coliform bacteria wet-season loading capacity for 90th percentile concentrations within Henderson Inlet.

Table 15 summarizes the dry-season and the wet-season load reductions as well as the target 90th percentile concentrations once reductions are achieved.

Table 15. Henderson Inlet fecal coliform bacteria reductions and targets for DOH monitoring stations.

	Station	Meets standards?	Dry percent reduction	Limiting criterion	Target 90th percentile	Wet percent reduction	Limiting criterion	Target 90th percentile
Approved	192	YES						
	193	YES						
	202		14%	90th percentile	43			
	203	YES						
	204	YES						
	205	YES						
	206	YES						
	207	YES						
	208	YES						
	209	YES						
Conditionally Approved	190		35%	90th percentile	43			
	191		7%	90th percentile	43			
	194					10%	10% criterion	33
	195		35%	90th percentile	43	10%	10% criterion	29
	196	YES						
	197					38%	90th percentile	43
	198		2%	90th percentile	43			
	199	YES						
	200					10%	10% criterion	36
	201		34%	90th percentile	43			
Prohibited	185		78%	90th percentile	43	56%	90th percentile	43
	186		66%	90th percentile	43	56%	90th percentile	43
	187		59%	90th percentile	43	23%	90th percentile	43
	188		49%	90th percentile	43	50%	90th percentile	43
	189		59%	90th percentile	43	53%	90th percentile	43
	212		38%	90th percentile	43	59%	90th percentile	43

Relationship between Freshwater and Marine Reduction Targets

Patterns of fecal coliform bacteria concentrations, together with the travel time study results, indicate that tributary fecal coliform concentrations control marine concentrations. Marine fecal coliform bacteria concentrations are highest within the Prohibited shellfish harvest zone in the southern inlet and decrease northward through the inlet. In order to meet marine water quality standards at each of the DOH monitoring stations, bacteria reductions of 50 to 78% (Table 15) are necessary in both dry and wet conditions. However, the tributaries require even higher reductions (87 to 96% in Tables 12, 13, and 14) to meet the freshwater quality standards at the stations closest to the mouths. Because the numerical load reductions necessary in freshwater are greater than those necessary to meet marine water quality standards, the tributaries should not receive targets more stringent than the freshwater quality standards. Achieving the freshwater fecal coliform bacteria water quality standards should be protective of marine water quality.

Station 202, on the east side of Henderson Inlet north of 68th Avenue (Figure 2), may reflect local shoreline sources in addition to tributary bacteria sources from the southern inlet. In order to meet the marine water quality standards at this station, shoreline sources should be investigated.

Summary of Tributary and Wildlife Contributions

Wildlife do not receive load reduction targets, since the watershed is the primary source of bacteria contributing to violations of the water quality standards. Figure 51 summarizes the relative contributions of the tributaries to Henderson Inlet to wet and dry season fecal coliform loads, which total 730 and 100 billion fecal coliform per day, respectively. During the wet season, Dobbs Creek contributes 55% of the mean total load to Henderson Inlet, while in the dry season, Woodland Creek contributes 77% of the total load.

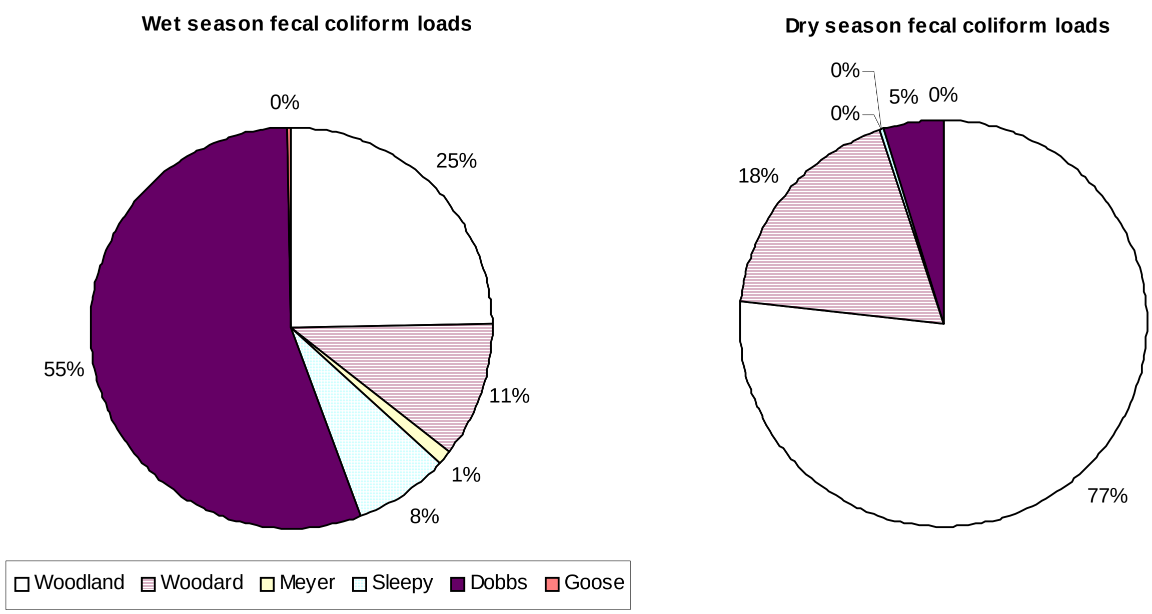

Figure 51. Tributary fecal coliform load contributions to Henderson Inlet.

Although fecal coliform loads from seals may contribute the same order of magnitude (500 to 2500 billion per day in Table 11) as storm loading from Dobbs Creek (400 billion per day) and Woodland Creek (180 billion per day), there is no indication that seals induce violations of the fecal coliform water quality standards. The seals congregate at the Woodard Bay Natural Area on the western side of Henderson Inlet. However, the DOH monitoring stations near the areas frequented by seals meet the water quality standards. The southern inlet, not known to be frequented by seals in great numbers, experiences the highest fecal coliform concentrations. Therefore, seals do not receive a load allocation.

Patterns of summer bird usage (Figures 42 and 44) also do not coincide with patterns of marine fecal coliform concentrations. Highest summer usage occurs near the Woodard Bay Natural Area and other areas on the western side of Henderson Inlet. These areas do not have the high fecal coliform concentrations found in the southern inlet. Because peak summer bird usage does not coincide with peak fecal coliform concentrations geographically, and because the net transport in the inlet is northward and not southward, birds do not contribute to high summer fecal coliform concentrations in the southern inlet.

During the winter months, birds do congregate in the southern inlet (Figure 43). However, if their presence does not induce water quality standards violations during the summer months, there is no justification that they cause violations in the winter months. Therefore, birds do not receive a winter load allocation.

In addition, there is no evidence that wildlife counts are enhanced by anthropogenic activities. Any fecal coliform load that wildlife contribute would be part of the natural conditions in the area. Wildlife would receive part of the load capacity and anthropogenic activities would need to reduce levels even further. However, because neither seal nor bird usage patterns coincide with high fecal coliform bacteria levels in Henderson Inlet and net transport is northward away from the area of highest fecal coliform concentrations, there is no evidence that wildlife contribute significantly to fecal coliform violations in southern Henderson Inlet. Anthropogenic activities are assigned the loading capacity, accounting for the margin of safety as well.

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Temperature, Dissolved Oxygen, and pH TMDL Analysis

Continuous In-situ Temperature Data Analysis Approach

The technical analysis for temperature in Woodland Creek focuses primarily on documentation of the current temperature and flow regime, and on effective shade and is fully described in Appendix C.

Water Quality Modeling for Dissolved Oxygen in Streams

Water quality (dissolved oxygen, pH, and nutrients) was simulated in Woodland Creek using the QUAL2K numerical model. QUAL2K is a one-dimensional, steady-state numerical model capable of simulating a variety of conservative and non-conservative water quality parameters (Chapra and Pelletier, 2003). QUAL2K is supported by EPA, and the model and documentation are available at the following EPA website: www.epa.gov/ATHENS/wwqtsc/html/qual2k.html. The State of Washington also supports a version of QUAL2K which has enhanced features and can be downloaded at www.ecy.wa.gov/programs/eap/models/index.html.

QUAL2K assumes steady-state flow and hydraulics; however, the heat budget and temperature are simulated on a daily time scale. Diel variations in all water quality variables are simulated as well.

The model was used to predict dissolved oxygen levels for naturally occurring and anthropogenic (human-caused) sources. For Woodland Creek, low dissolved oxygen levels in the groundwater and possible nutrient inputs from the fish farm, stormwater, and nonpoint sources were examined.

QUAL2K Model Structure and Approach

QUAL2K was calibrated to model Woodland Creek between Beatty Springs (approximately RM 3.45) to near the mouth at RM 0.2. The following variables were used to simulate steady-state water quality conditions: water temperature, conductivity, dissolved oxygen, nitrogen, and phosphorus. Alkalinity values were estimated based on data from the Deschutes River, and values for carbonaceous biochemical oxygen demand for the trout rearing operation were estimated using 1988 data collected from the trout farm (Kendra, 1989).

The study portion of the Woodland Creek was divided into 20 0.2-0.4 kilometer reaches for QUAL2K modeling. Tables of reaches are presented in Appendix I. Each reach was assumed to have uniform steady-state flow conditions.

The Woodland Creek model was calibrated using data collected in September 2003 (continuous monitoring and field synoptic surveys). The September survey data provided a unique critical condition (i.e., low-flow period) data set for dissolved oxygen. After an optimum calibration was achieved, the model was used to simulate dissolved oxygen critical conditions for Woodland Creek.

QUAL2K Model Calibration

Fixed Model Inputs

Hydrology

QUAL2K uses flow-exponent power equations to functionally represent the hydraulic routing of the river. The flow-exponent equations relating velocity (V in m/sec), depth (D in m), and width (W in m) with flow (Q in cms) are written as follows (McCutcheon, 1989):

$$V = a\,Q^b \qquad D = c\,Q^d \qquad W = eQ^f \qquad \text{(equation 1)}$$

Flow and channel-width relationships and flow balances were developed using data collected during the synoptic surveys. Residual inflows and outflows were calculated from differences in the flow mass balance between measured values. Residual flows were entered into the QUAL2K model as distributed diffuse inflows or outflows.

Water velocity and time-of-travel on Woodland Creek was confirmed with a time-of-travel salt tracer study conducted August 22, 2003 from Woodland Creek RM 1.6 to RM 1.1. Time-of-travel results are described in Appendix D, and Appendix I includes the flow exponents and coefficients used for all the reaches.

Meteorology

QUAL2K simulates diel variations in stream temperature and water quality for a steady flow condition. QUAL2K assumes that flow remains constant but allows meteorological variables to vary with time over the course of a day. Solar radiation (and shade), air temperature, and relative humidity were specified or simulated as diurnally varying functions. Meteorological data were estimated from data recorded at the Olympia Airport weather station. QUAL2K uses kinetic formulations for the components of the surface water heat budget described in Chapra and Pelletier (2003).

Water Quality Inputs

Headwater, tributary, and point source water quality input conditions for the QUAL2K simulations were taken from data collected during synoptic surveys, including diel temperature, dissolved oxygen, and pH data collected from data-loggers.

The water quality characteristics of diffuse inflows (i.e., groundwater) were obtained from groundwater sampling conducted at Beatty Springs and St. Martin's Spring, and are described in Appendix A.

Calibrated Model Inputs

Appendix I contains the calibration coefficients and the rate parameters selected to fit observed conditions during the September 2003 surveys on Woodland Creek. The same coefficients were applied to the sampling survey conducted in August 2003 to test the robustness of the QUAL2K calibration (to confirm its ability to accurately simulate water quality under a different set of low-flow conditions).

Calibration was accomplished by adjusting the model coefficients and rates iteratively until optimum goodness-of-fit between predicted model results and observed field values for September 2003 was achieved. Goodness-of-fit was measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values. It is similar to a standard deviation of the error. All model coefficients were adjusted within acceptable ranges as described by Pelletier and Chapra (2004), and Chapra (1997).

Calibration Coefficients

Temperature correction factors are used in QUAL2K for most chemical and biological kinetic rates since those processes are temperature-dependent. Temperature correction factors were from a commonly accepted range of values from scientific literature and model default values.

There are numerous options in QUAL2K for calculating atmospheric reaeration rates. The internal option was used and is based on a method developed by Covar (1976), where reaeration rate is based on depth and velocity.

Other dissolved oxygen coefficients and rate parameters, including the stoichiometric amounts of dissolved oxygen required per unit of ammonia nitrified or carbon oxidized, were model default values.

Periphyton growth was modeled using a zero-order growth rate and allowed to run until a steady-state maximum area biomass was achieved. A variable-stoichiometry and luxury-uptake algorithm for nutrients is used in QUAL2K that separates periphyton growth from nutrient uptake. Maximum nutrient uptake rates, subsistence cell quotas, and internal half-saturation constants for algal cells, plus external nutrient half-saturation constants, were iteratively selected from published ranges summarized in Pelletier and Chapra (2004) until an optimized goodness-of-fit to the observed data was achieved.

Nutrients are modeled in QUAL2K using organic and dissolved inorganic forms as the state variables. Dissolved inorganic phosphorus was measured as ortho-phosphate, and dissolved inorganic nitrogen was measured as ammonia nitrogen and nitrate+nitrite-nitrogen. Organic phosphorus and nitrogen were calculated as the total fractions minus the inorganic fractions (e.g., total phosphorus minus ortho-phosphate equals the organic phosphorus). For non-detectable data (i.e., values below the reporting limits), the reporting limit value was used in the model.

Comparison of Observed and Simulated Water Quality Results for Woodland Creek

After the QUAL2K model was calibrated using September 2003 data, the model was applied to the August 2003 survey data for confirmation of model performance under a different set of conditions. Only observed inputs and climate inputs were changed for the model confirmation run. Comparison of the overall performance of calibration and confirmation models using root mean square error (RMSE) and coefficient of variation (CV) are included in Table I-3, Appendix I. Figures I-1 through I-3 present comparison of model-simulated and observed temperature, pH, dissolved oxygen, total phosphorus, and nitrogen for Woodland Creek for the August and September 2003 synoptic surveys.

Temperature, Nutrients, Dissolved Oxygen, and pH Analysis

Woodland Creek

Continuous In-situ Temperature Data Analysis

Analysis results of 2002 continuous temperature monitoring are included in Appendix C.

Nutrient Results

Woodland Creek had some of the highest nitrate+nitrite nitrogen values in the Henderson basin. Figure 52 presents dry-season nutrient loading levels for the tributaries and mainstem of Woodland Creek. Nutrient samples were obtained primarily during the dry season due to dissolved oxygen concerns. Based on a few samples obtained during the wet season, loading is greater during storm events than during the dry season (Figure 53), but concentrations are lower at Woodland Creek RM 1.0 during storm events.

The highest nitrate+nitrite nitrogen levels were seen at the stormwater discharge to Woodland Creek RM 3.7T. Six samples were obtained at this site during storm events and the mean nitrate+nitrite nitrogen value was 4.5 mg/L, with the highest value at 7.9 mg/L. The Woodland Creek sites adjacent to Beatty Springs (RM 3.45) and just downstream (RM 3.4) also had high nitrate+nitrite nitrogen levels during the dry season, averaging 2.8 mg/L adjacent to the spring and 2.0 mg/L just downstream of the spring. Total nitrogen levels at these sites were 3.1 and 2.3 mg/L, respectively.

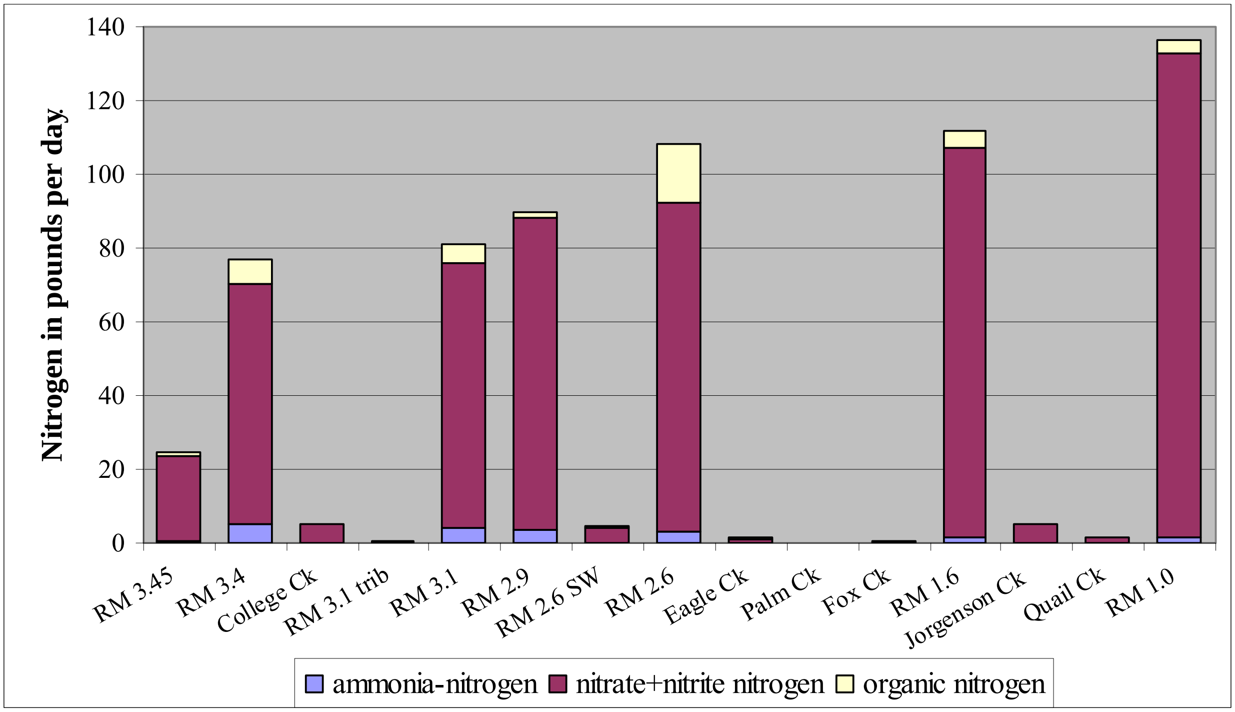

Figure 52. Average nitrogen loading in Woodland Creek, June - September 2003.

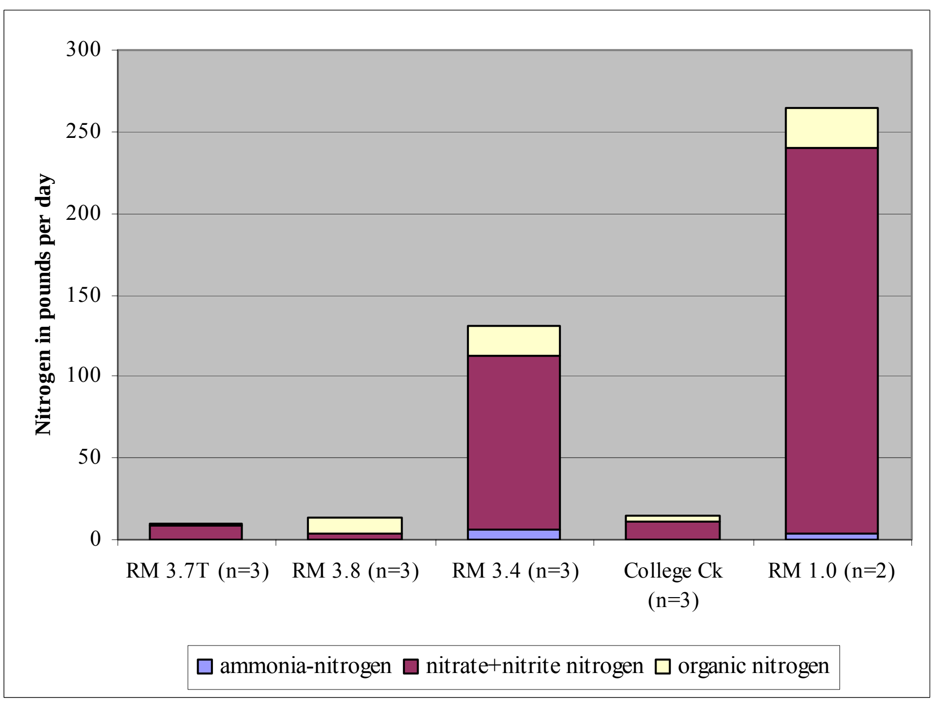

Figure 53. Average nitrogen loading for Woodland Creek during storm events, January - March 2004.

The results of groundwater sampling of Beatty Springs showed that the mean nitrate+nitrite nitrogen concentrations in the spring were 2.5 mg/L, somewhat higher than at St. Martin's Spring which was 1.8 mg/L. In a 1989 USGS study, the median nitrate+nitrite nitrogen (N) value for wells near Woodland Creek was somewhat lower than the means for the springs in 2002-2003 with a well median of 1.08 mg/L (Appendix A). The trout farm at Beatty Springs would not be expected to account for the higher nitrate+nitrite nitrogen, because the spring discharge is upgradient of the fish pens and other facilities. Higher nitrate+nitrite levels were also seen in some of the tributaries during the dry season including: stormwater from Interstate 5 (RM 3.1T) (mean of 1.74 mg/L), Jorgenson Creek (mean of 1.32 mg/L), and Quail Creek (mean of 1.14 mg/L). It is likely that high nitrate+nitrite nitrogen values in the groundwater are the main cause of high values at the surface water sites.

All sites met the ammonia nitrogen criteria set forth in the standards. Ammonia nitrogen levels were generally low, with the highest levels seen at Woodland Creek RM 3.4 just downstream from Beatty Springs and the fish farm.

Phosphorus levels in Woodland Creek were generally less than 0.10 mg/L for total phosphorus. Groundwater mean total phosphorus concentrations were similar at both Beatty and St. Martin's College springs, ranging from 0.036 and 0.041 mg/L. Figure 54 presents phosphorus loading in pounds per day for the dry season.

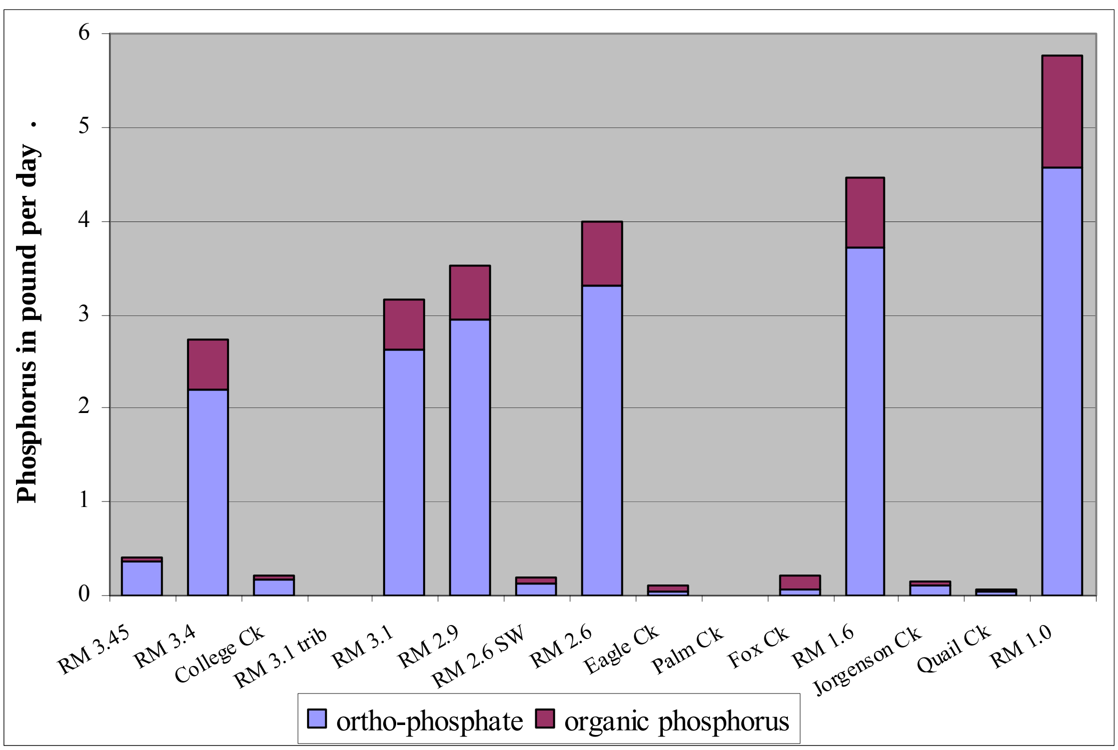

Figure 54. Mean phosphorus loading in Woodland Creek, June - September 2003.

The U.S. Environmental Protection Agency (EPA) provided guidance for nutrient levels in rivers and streams in this region: Nutrient Ecoregion II, level III, the Puget Sound lowlands (EPA, 2000). Table 16 summarizes the EPA guidance recommendations for rivers and streams.

The EPA guidance also summarized summer (June - August) data for this region. The mean total phosphorus level was 0.051 mg/L with a 25^{th,} 50th, and 75th percentile of 0.010, 0.030, and 0.056 mg/L, respectively. For ortho-phosphate, the mean was 0.017 mg/L, and the 25th, 50th, and 75th percentiles were 0.008, 0.013, and 0.020 mg/L, respectively. Total phosphorus and ortho-phosphate values for Woodland Creek tended to be on the higher end of values for the region, as did total nitrogen and nitrate+nitrite nitrogen values.

Table 16. EPA nutrient guidance for Ecoregion II, level III.

Parameter	Number of streams sampled	Reported Values		25th percentiles based on all seasons data for the decade
		Min	Max	
Total Phosphorus (mg/L)	133	0.0025	0.33	0.02
Total Nitrogen (mg/L)	37	0.08	2.6	0.24
NO_2/NO_3 (mg/L)	129	0.01	3.7	0.08

Limiting Nutrients

Nutrients are required for algal growth. The nutrients of primary importance are phosphorus and nitrogen. The ratio of nitrogen to phosphorus (N:P) is generally accepted as an indicator of which nutrient is more limiting or more likely to become limiting to algal growth. The N:P ratio in algal biomass is approximately 7 to 1 on a mass basis. Hence, an N:P ratio in stream water that is less than 7 suggests that nitrogen is the limiting nutrient (Chapra, 1997), and a ratio substantially greater than 7 suggests that phosphorus is the limiting nutrient. In this study, the N:P ratio was found to be greater than 20:1 which suggests a phosphorus-limited system.

Figure 55 presents the available nitrogen (ammonia and nitrate+nitrite nitrogen) to available phosphorus (ortho-phosphate) ratio for the Woodland Creek sites during the dry season. All of the sites sampled, with the exception of Fox Creek at Woodland RM 1.9T, were phosphorus limited. This confirms excess nitrogen, mainly in the form of nitrate+nitrite, is present in the system.

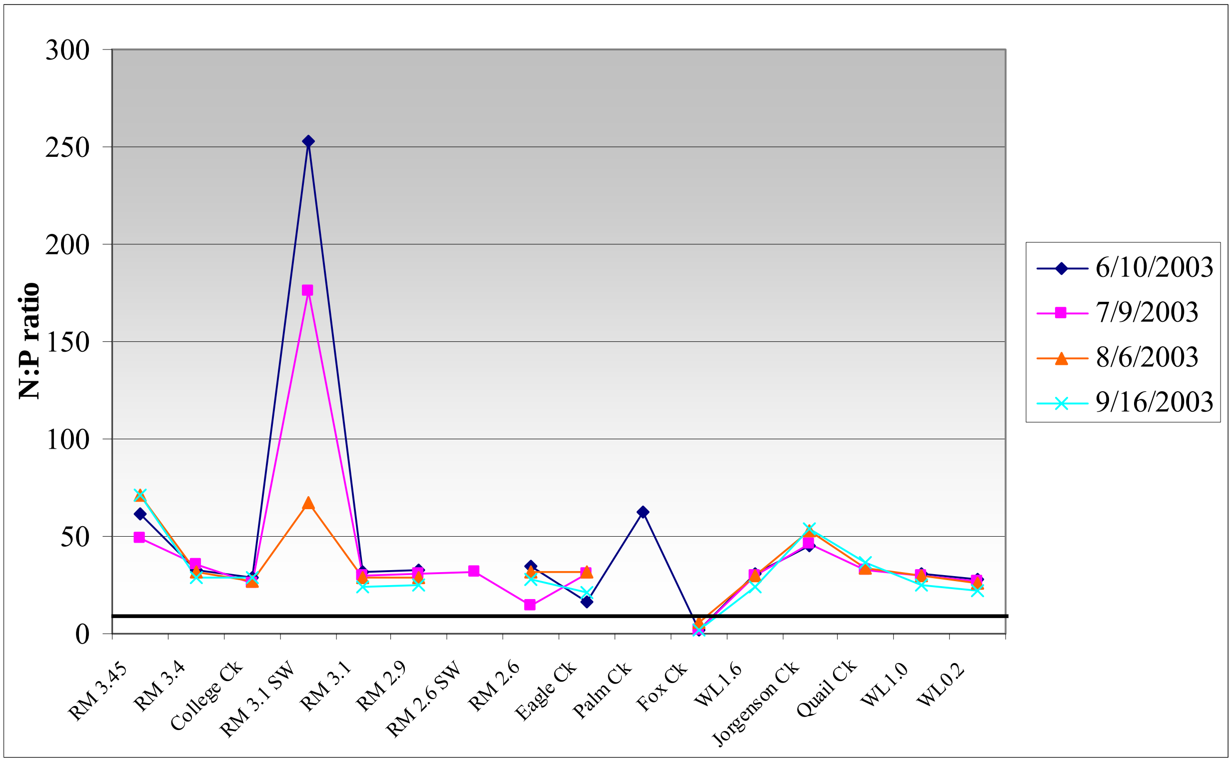

Figure 55. Nitrogen:phosphorus ratios (dissolved constituents) in Woodland Creek, June - September 2003.

Field Parameters

Synoptic Survey

Field parameters measured during the synoptic survey included temperature, pH, conductivity, and dissolved oxygen. Appendix H summarizes compliance with water quality standards at each site. All sites met the temperature criterion, not to exceed 16°C in freshwater and 13°C in marine water. Most sites did not meet the freshwater dissolved oxygen criteria, and the mouth site (RM 0.2) did meet the marine criteria for dissolved oxygen.

There were a few excursions below the pH standard of 6.5 SU, mostly at sites associated with the large wetland complex between RM 3.8 and 3.1.

In-situ Continuous Monitoring

In-situ continuous monitoring was conducted at three sites on the Woodland Creek mainstem, at RM 3.4, 3.1, and 1.6. Dissolved oxygen, pH, conductivity, and temperature were measured for 3-5 different time periods during 2003. The results are presented in Appendix F. Table 17 summarizes the monitoring period for each site as well as minimum and maximum values for each parameter. Freshwater temperature criteria were met at all three sites. While dissolved oxygen criteria were not met at any of the sites, levels improve from upstream to downstream.

PH levels fell slightly below the standard of 6.5 SU at the sites in and immediately downstream of the large wetland complex (Woodland Creek RM 3.4 and 3.1).

Table 17. Woodland Creek minimum and maximum values for dissolved oxygen, pH, temperature, and conductivity for each time period monitored.

Sites and Monitoring Period	D.O. (mg/L) min-max	D.O. (% saturation) min-max	pH (SU) min-max	Temperature (°C) min-max	Conductivity (µmhos) min-max
Woodland Creek RM 3.4					
March 31 - April 3, 2003	7.8 - 9.7	72 - 89	6.6 - 7.3	8.5 - 12.7	72 - 89
July 24 - 28, 2003	4.2 - 7.6	38 - 73	6.4 - 6.8	11.0 - 14.6	122 - 126
August 22 - 26, 2003	4.6 - 8.0	42 -77	6.5 - 6.8	10.6 - 14.3	Failed QA
September 17 - 19, 2003	5.2 - 11.5	47 - 105	6.4 - 7.6	11.1 - 15.4	Failed QA
Woodland Creek RM 3.1					
December 30, 2002 - January 2, 2003	7.0 - 9.5	61 - 78	6.5 - 7.2	6.8 - 9.4	Failed QA
March 31 - April 3, 2003	7.6 - 9.2	69 - 84	6.9 - 7.1	9.0 - 12.3	53 - 69
July 24 - 28, 2003	7.2 - 8.4	65 - 79	7.5 - 7.7	10.9 - 14.1	146 - 149
August 22 - 26, 2003	6.6 - 8.0	60 - 75	6.8 - 7.0	10.4 - 13.8	104 - 124
September 17 - 19, 2003	6.5 - 7.5	60 -72	6.4 - 6.9	11.2 - 13.6	Failed QA
Woodland Creek RM 1.6					
July 29 - August 1, 2003	9.9 - 11.6	93 - 109	7.2 - 7.4	11.2 - 14.1	Failed QA
August 15 -18, 2003	9.4 - 10.0	90 - 93	7.3 - 7.4	11.5 - 13.6	146 - 149
October 2 - 6, 2003	9.1 - 10.0	83 - 90	7.4 - 7.6	10.6 - 11.6	126 - 128

Woodard Creek

Nutrients

Woodard Creek nitrogen and phosphorus loading was much less than in Woodland Creek. Figures 56 and 57 present dry-season nitrogen and phosphorus loading for Woodard Creek. All sites met the ammonia-nitrogen criteria set forth in the standards. Dry-season mean nutrient levels are presented in Table 18. There is an increase in nitrate+nitrite nitrogen levels from Woodard RM 6.2 to 3.4. This reach also has the highest bacteria loading.

In comparison to the EPA guidance, total phosphorus concentrations tended to be about average for the region, while ortho-phosphate levels tended to be slightly higher than average. The EPA study found that summertime (June - August) total nitrogen levels in this region had a mean concentration of 0.40 mg/L, with a 25th percentile, median, and 75th percentile of 0.11, 0.27, and 0.51 mg/L, respectively. Average summer levels of nitrate+nitrite nitrogen were 0.23 mg/L, with a 25th percentile, median, and 75th percentile of 0.01, 0.05, and 0.19 mg/L, respectively. Total nitrogen levels in Woodard Creek were slightly higher than the average for this region, and nitrate+nitrite nitrogen values were higher than for most areas in the region.

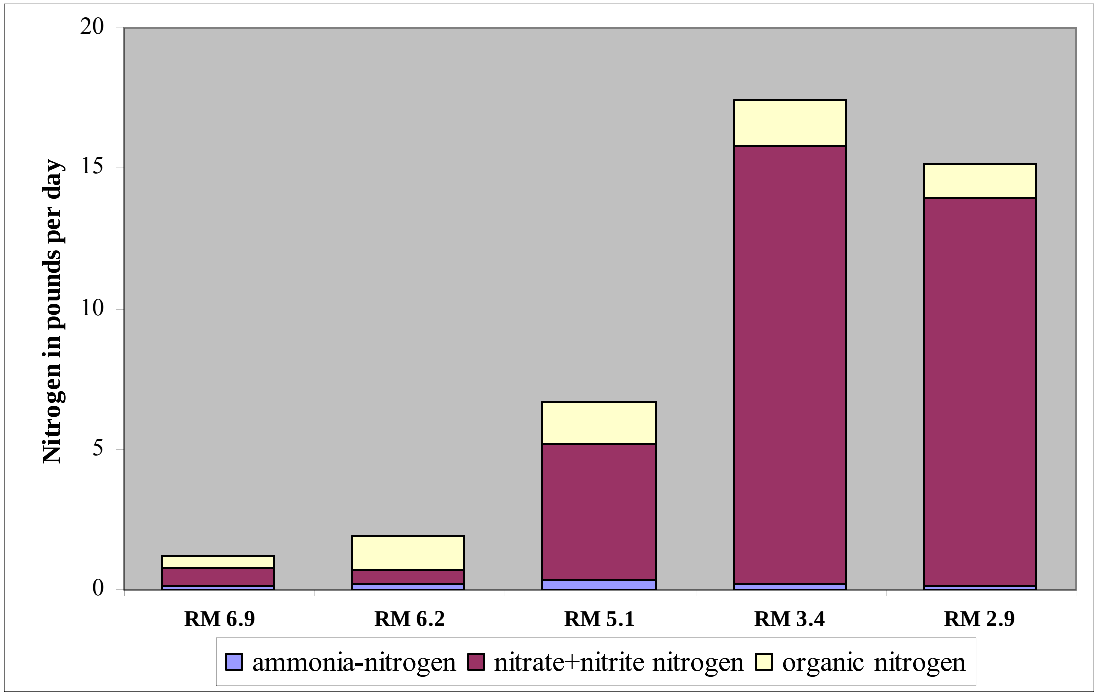

Figure 56. Average nitrogen loading in Woodard Creek, June - September 2003.

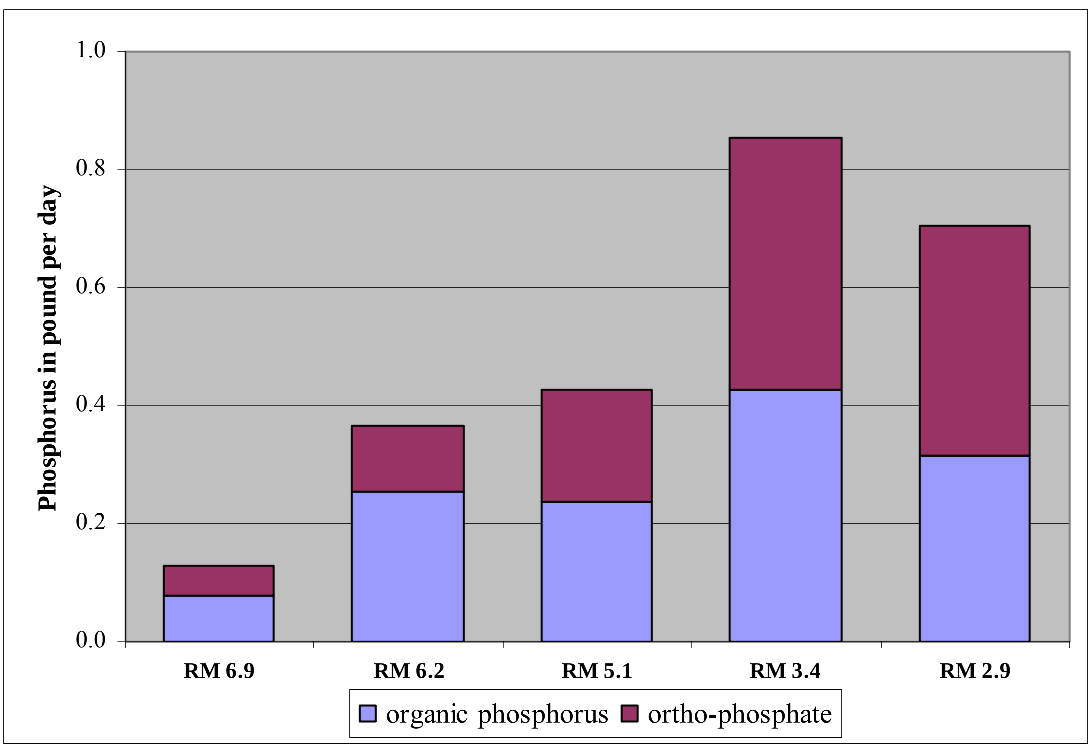

Figure 57. Average phosphorus loading in Woodard Creek, June - September 2003.

Table 18. Woodard Creek dry-season mean nutrient concentrations (mg/L).

Woodard Creek Sites	Ammonia-Nitrogen	NO3+2-Nitrogen	Total Nitrogen	Total Phosphorus	Ortho-Phosphate
RM 6.9	0.094	0.210	0.520	0.067	0.022
RM 6.2	0.025	0.053	0.238	0.046	0.014
RM 5.1	0.043	0.543	0.758	0.049	0.022
RM 3.4	0.009	0.844	0.949	0.044	0.023
RM 2.9	0.005	0.814	0.887	0.041	0.023
RM 0.0	0.092	0.419	0.623	0.074	0.075

Limiting Nutrients

Limiting nutrients for algal growth was examined for Woodard Creek. Figure 58 presents the available nitrogen (ammonia and nitrate+nitrite nitrogen) to available phosphorus (ortho-phosphate) ratio for the Woodard Creek sites during the dry season. Woodard Creek RM 5.1, 3.4, and 2.9 were limited for phosphorus; the other sites were inconclusive.

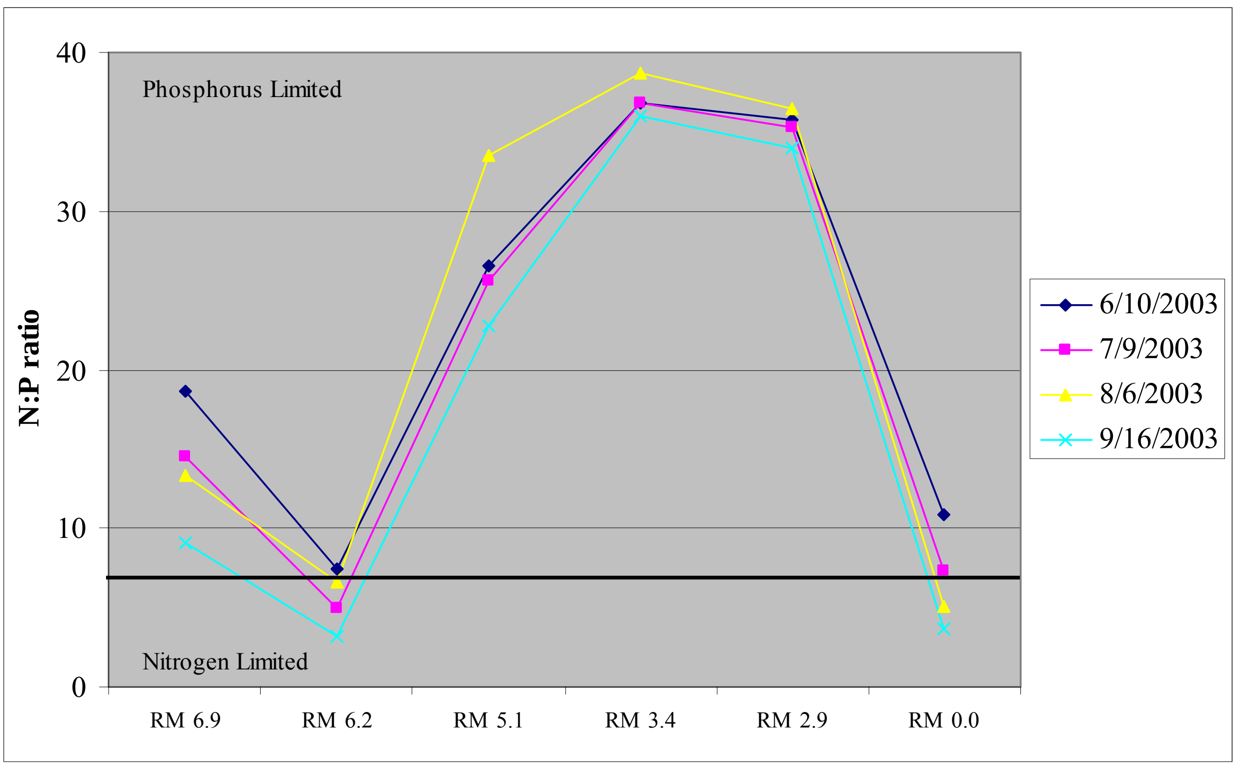

Figure 58. Nitrogen:phosphorus ratios (dissolved constituents) in Woodard Creek, June - September 2003.

Field Parameters

Synoptic Survey

Field parameters measured during the synoptic survey included temperature, pH, conductivity, and dissolved oxygen. Appendix H summarizes compliance with water quality standards at each site. During the synoptic surveys, all sites met water quality standards for temperature. None of the sites met the dissolved oxygen standard except the site at RM 2.9.

During the synoptic surveys, all sites met the pH standard, with the exception of RM 2.9 which fell slightly below the standard during a storm event with a pH of 6.3.

Continuous In-situ Monitoring

In-situ continuous monitoring was conducted at four sites on the Woodard Creek mainstem, RM 6.8, 6.2, 5.1, and 2.9. Dissolved oxygen, pH, conductivity, and temperature were measured for two to six different time periods during 2003 and 2004. The results are presented in Appendix F. Table 19 summaries monitoring periods for each site, and minimum and maximum values for each parameter.

Table 19. Summary of Woodard Creek continuous monitoring results.

Sites and Monitoring Period	D.O. (mg/L) min/max	D.O. (% saturation) min/max	pH (SU) min/max	Temperature (°C) min/max	Conductivity (µmhos) min/max
Woodard Creek RM 6.8					
August 6 - 11, 2003	4.7 - 5.5	46 - 54%	6.6 - 6.7	13.8 - 15.5	90 - 128
September 10 - 13, 2003	5.1 - 7.6	46 - 68%	6.4 - 6.7	10.1 - 11.8	Failed QA
Woodard Creek RM 6.2					
August 2 - 7, 2002	1.2 - 2.3	12 - 22%	6.5 - 6.6	13.2 - 15.4	125 - 153
January 3 - 6, 2003	5.6 - 6.7	45 - 56%	6.7 - 7.0	5.2 - 8.3	Failed QA
July 16 - 19, 2003	0.4 - 1.9	4 - 19%	6.5 - 6.6	14.2 -16.3	132 -136
September 29 - October 2, 2003	3.6 - 5.0	33 - 45%	6.8 - 7.0	10.8 - 12.0	Failed QA
February 20 - 23, 2004	5.9 - 7.7	49 - 64%	6.5 - 6.9	6.5 - 8.5	123 - 133
Woodard Creek RM 5.1					
August 7 - 11, 2003	7.3 - 8.0	72 - 77%	7.0 - 7.1	13.1 -15.3	Failed QA
September 10 - 13, 2003	7.2 -8.6	66 - 78%	6.8 - 7.3	10.3 - 11.7	Failed QA
Woodard Creek RM 2.9					
January 3 - 6, 2003	10.0 - 11.5	85 - 92%	6.6 - 7.1	5.5 - 8.5	Failed QA
March 14 - 17, 2003	9.7 - 7.1	87 - 93%	6.9 - 7.1	7.1 - 10.6	Failed QA
July 16 - 19, 2003	9.8 - 11.4	92 - 106%	7.6 - 7.7	11.9 - 14.6	Failed QA
August 7 - 11, 2003	9.1 - 9.9	88 - 96%	7.5 - 7.7	12.9 - 15.1	143 - 146
September 26 - 30, 2003	8.3* - 10.6	76* - 97%	7.5 - 7.5	11.1 - 12.2	125 - 128
February 20 - 23, 2004	10.4 - 11.0	87 - 91%	7.1 - 7.2	6.2 - 8.5	112 - 119

* The minimum reading of 8.3 mg/L is likely an anomaly; the readings one half-hour before and after this one were 9.4 mg/L with a saturation of 86% (more within the observed minimum range found at this site). This anomaly may be due to interference with the probe or due to a pollutant plume moving downstream.

None of the sites met the dissolved oxygen criterion. Woodard Creek at RM 6.2 did not meet (exceeded) the temperature criteria during mid-July, with a maximum temperature of 16.3°C. The marine site at RM 0.0 did not meet the marine temperature standard.

All sites, with the exception of Woodard Creek RM 6.8, met the pH criteria. Woodard Creek RM 6.8 fell slightly below the pH standard with a low of 6.4 SU.

Woodard Creek RM 6.8 and 6.2 are located within a large wetland complex. At RM 6.2 the creek is channelized, then downstream flow becomes dispersed as it flows through another wetland. At RM 5.1 there is more water in the creek, but flow is very slow due to beaver dams and wetlands on either side of the channel. Downstream of RM 5.1 the creek becomes more channelized, and at RM 4.3 the creek is confined to a channel. A long-time resident of the area said historically the channel was not confined, but many years ago he had used machinery to provide a more defined channel for the creek in the RM 4.3 area. At RM 3.4 and downstream, Woodard Creek has a definite creek channel and flows more quickly, likely due to topography.

Dissolved oxygen levels are lowest in the wetland at RM 6.2 and steadily improve downstream (Figure 59). At RM 2.9 dissolved oxygen levels meet the water quality standard of 9.5 mg/L during most of the year, with the exception of the lower flow months, August and September. During the synoptic surveys, flows in August and September 2003 were 1.4 and 0.9 cfs at RM 6.2, and 2.7 and 2.3 cfs at RM 6.2, respectively. During a continuous monitoring survey conducted in August and September (Figure 59), dissolved oxygen levels did not reach the criterion at RM 2.9 with daily lows of 9.1 and 9.4 mg/L. The 8.3 mg/L one-time September reading is not considered reliable.

The lowest dissolved oxygen levels at RM 6.2 were seen during July and August (Figure 59). During the July continuous monitoring, dissolved oxygen levels never rose above 2.0 mg/L; during the June through August synoptic surveys, instantaneous dissolved oxygen levels ranged from 2.3 to 2.7 at the site.

Low dissolved oxygen levels in Woodard Creek are largely due to natural conditions. Dissolved oxygen levels at RM 2.9 can meet the 9.5 mg/L standard during periods when flows allow for sufficient reaeration of creek water.

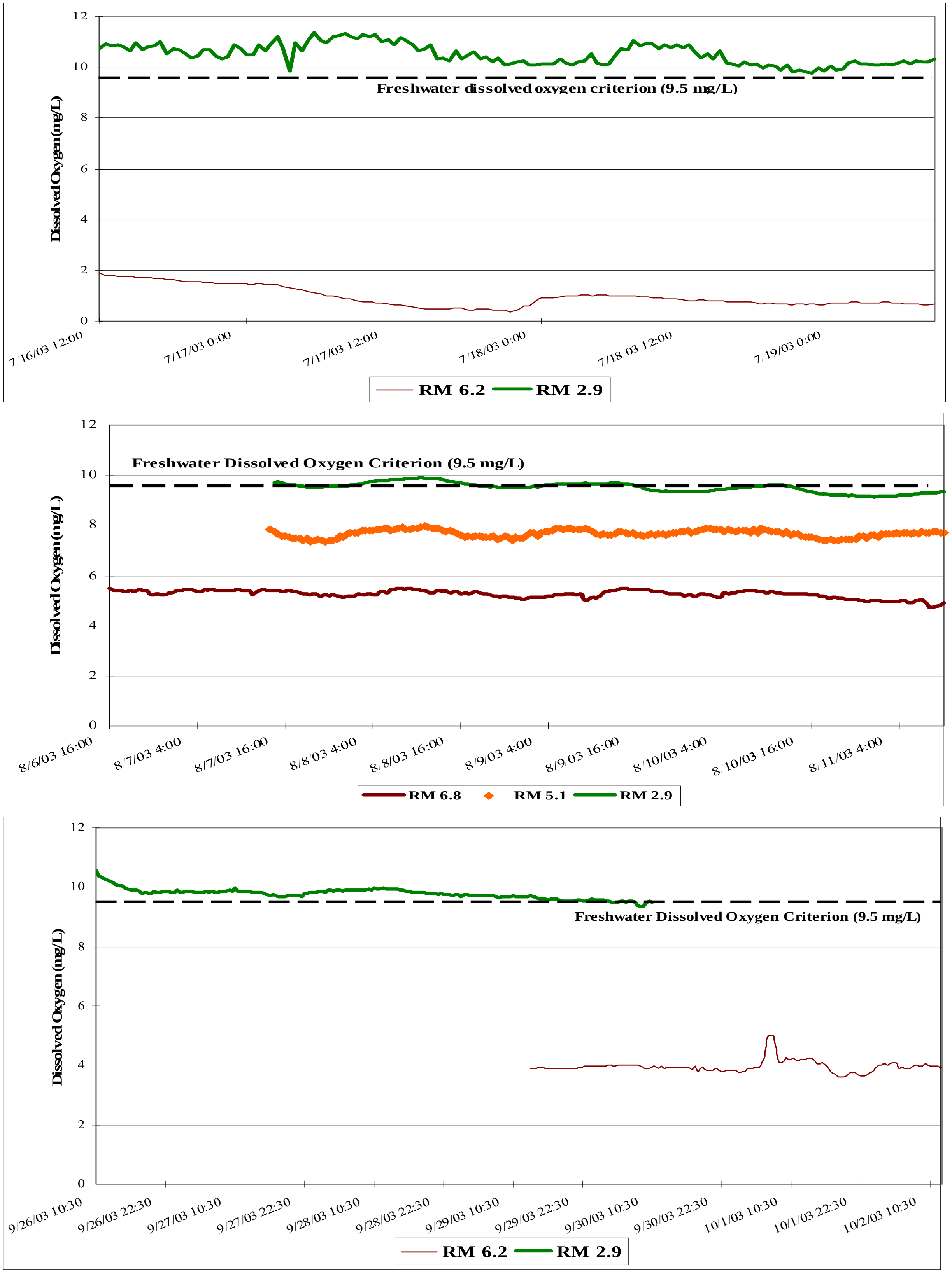

Figure 59. Dissolved oxygen levels during the critical period for Woodard Creek.

Nutrients

All sites met the ammonia-nitrogen criteria set forth in the standards, with ammonia nitrogen levels generally being low. Table 20 summaries mean nutrient concentrations for the tributaries.

Table 20. Mean nutrient concentrations for tributaries to Henderson Inlet (mg/L).

Tributary	Monitoring Period (number of samples)	Ammonia-Nitrogen	NO3+2-Nitrogen	Total Nitrogen	Ortho-Phosphate	Total Phosphorus
Meyer Ck	January - March 2004 (n=3)	0.019	0.477	0.769		
Goose Ck	January - March 2004 (n=3)	0.023	0.174	0.807		
Sleepy Ck	January - March 2004 (n=3)	0.011	0.057	0.299		
	June - September 2003 (n=4)	0.013	0.139	0.280	0.084	0.106
Dobbs Ck	January - March 2004 (n=3)	0.013	0.409	0.612		
	June - September 2003 (n=4)	0.025	0.644	0.724	0.045	0.049

In comparison to the EPA nutrient guidance observed, low-flow (June - August) total nitrogen and nitrate+nitrite levels tended to be high in Dobbs Creek, while Sleepy Creek tended to be about average. Sleepy and Dobbs creeks had higher than average ortho-phosphate levels, and Sleepy Creek had higher total phosphorus values as well.

Meyer and Dobbs creeks tended to have higher nitrogen levels than reported regionally during the wet storm-event period.

While Dobbs Creek had flow during the dry season, Meyer and Goose have no flow and Sleepy Creek very little or no flow.

Figures 60 and 61 present dry-season nitrogen and phosphorus loading from the mouths of the tributaries to Henderson Inlet. Nitrogen and phosphorus loading from the tributaries is minimal compared to Woodland Creek.

Figure 62 presents January - March nitrogen loading for some of the tributaries to Henderson Inlet (data for the same period were not available for Woodland and Woodard creeks).
Dobbs Creek, with the highest flows, also had the highest loading levels.

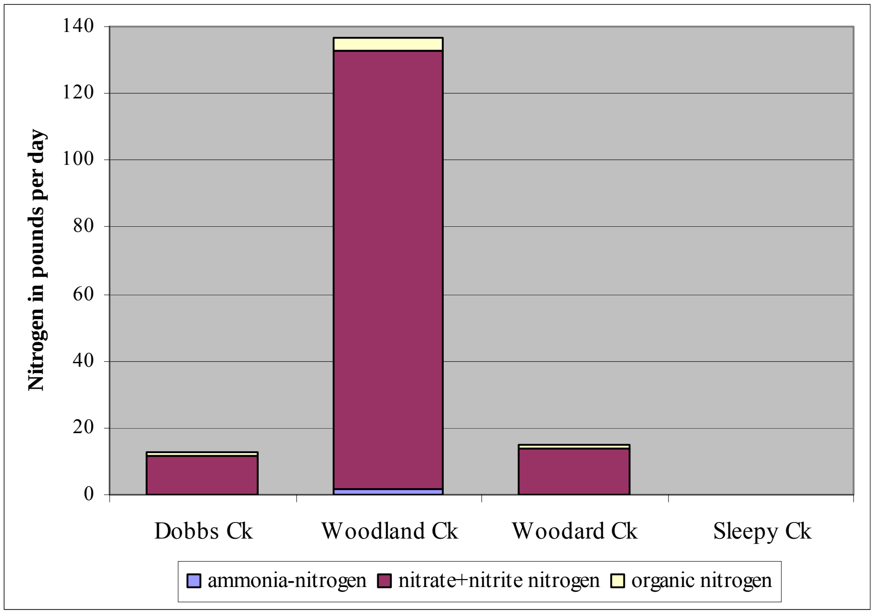

Figure 60. Dry-season nitrogen loading to Henderson Inlet, June - September 2004.

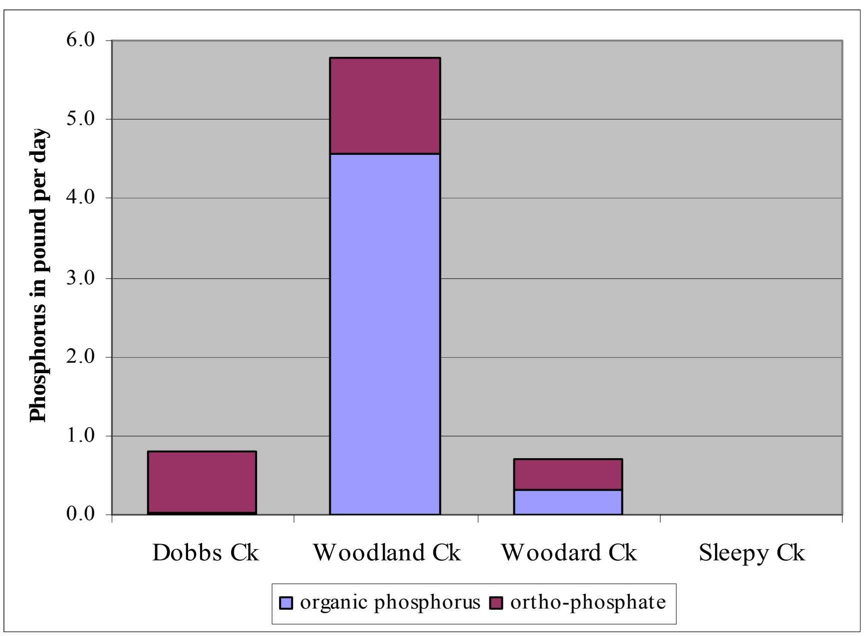

Figure 61. Dry-season phosphorus loading to Henderson Inlet, June - September 2004.

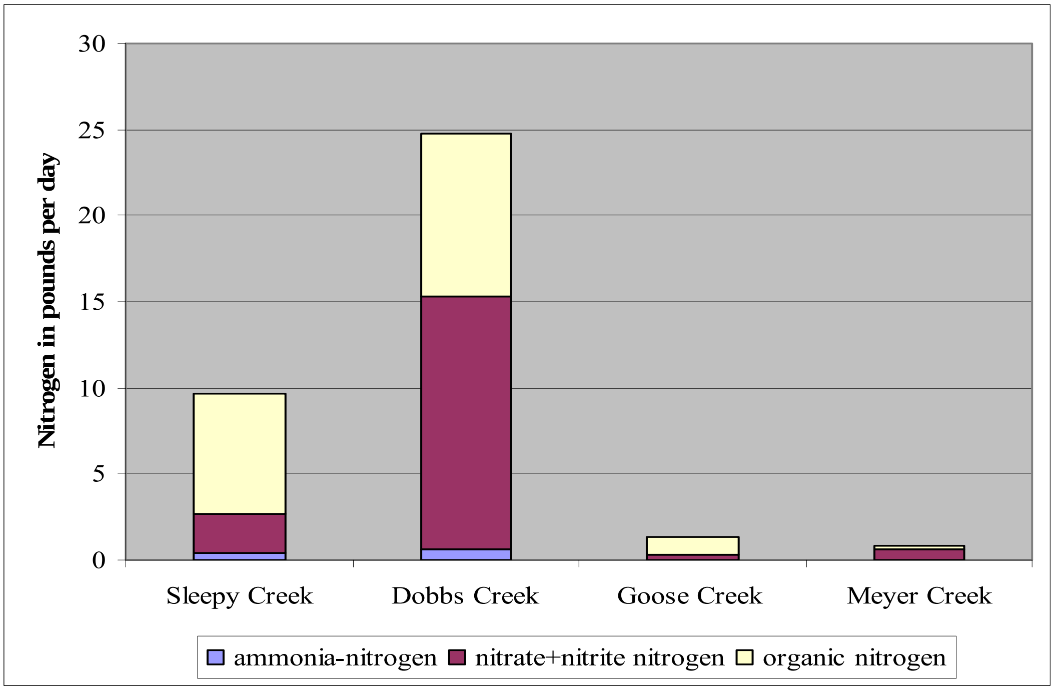

Figure 62. Nitrogen levels at the mouth of tributaries to Henderson Inlet, January - February 2004.

Limiting Nutrients

Limiting nutrients for algal growth were examined for sites where data were available. Figure 63 presents the available nitrogen (ammonia and nitrate+nitrite nitrogen) to available phosphorus (ortho-phosphate) ratio for the creeks during the dry season. The only site with notable nutrient limitation was a nitrogen limitation at Sleepy Creek RM 0.1. Dobbs Creek is indeterminate with both nutrients available.

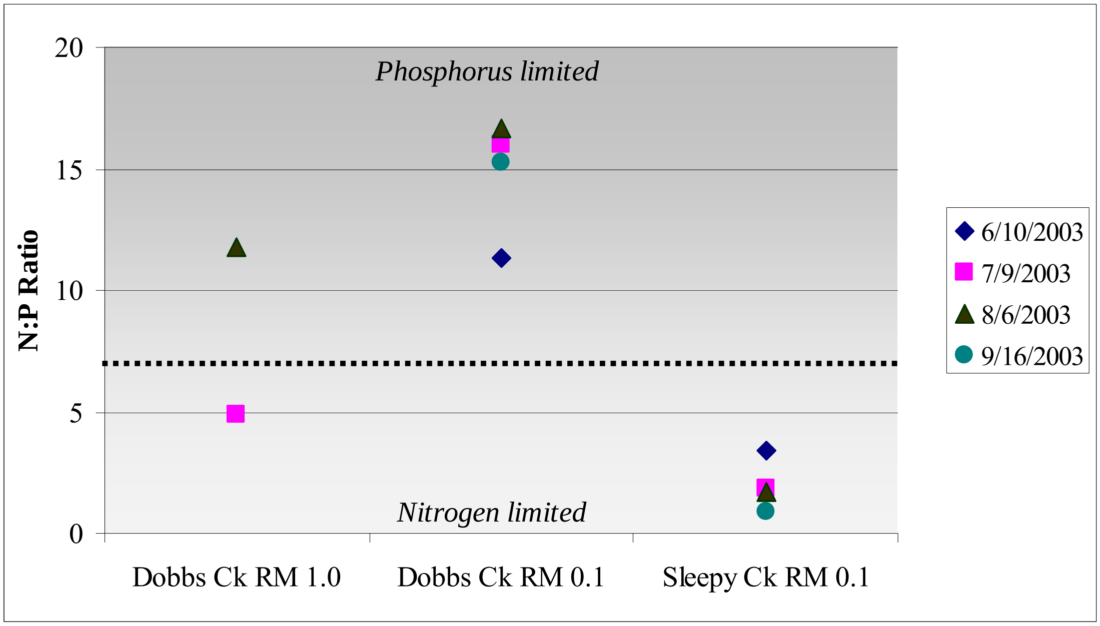

Figure 63. Nitrogen:phosphorus ratios (dissolved constituents) in Dobbs and Sleepy creeks, June - September 2003.

Field Parameters

Synoptic Survey

Field parameters measured during the synoptic survey included temperature, pH, conductivity, and dissolved oxygen. Appendix H summarizes compliance with water quality standards at each site. During the synoptic surveys, Meyer Creek met water quality standards for temperature. Meyer Creek at RM 0.6 did not meet dissolved oxygen or pH standards, but at RM 0.1 it met both. Sleepy Creek met the temperature standard at both RM 0.8 and 0.1 during synoptic surveys, but did not meet dissolved oxygen or pH standards at either site. Dobbs Creek met temperature, pH, and dissolved oxygen standards at both sites during the synoptic surveys. Goose Creek met temperature and dissolved oxygen standards, but pH levels fell below the standard.

Continuous In-situ Monitoring

In-situ continuous monitoring was conducted at Sleepy Creek RM 0.1, Dobbs Creek RM 0.1, and Meyer Creek RM 0.1 and 0.6. Dissolved oxygen, pH, conductivity, and temperature were measured for different time periods during 2003 - 2005. The results are presented in Appendix F. Table 21 summarizes minimum and maximum values for each parameter at each site.

None of the sites met the dissolved oxygen criterion. All sites, with the exception of Sleepy Creek at RM 0.1, met temperature standards. Sleepy Creek did not meet the temperature standard in August 2003. There was little or no flow in the creek during this period. Most sites met the pH standard, with the exception of Meyer Creek RM 0.6; during the wet season pH fell below the standard of 6.5 SU.

Table 21. Summary of continuous monitoring results for Meyer, Sleepy, and Dobbs creeks.

Sites and Monitoring Period	D.O. (mg/L) min/max	D.O. (% saturation) min/max	pH (SU) min/max	Temperature (°C) min/max	Conductivity (µmhos) min/max
Meyer Creek RM 0.6					
April 20 - 22, 2005	6.4 - 8.0	57 - 70%	5.5 - 5.6	9.3 - 11.4	47 - 50
Meyer Creek RM 0.1					
February 10 - 13, 2004	7.0 - 8.2	52 - 64%	6.7 - 6.8	3.5 - 6.0	105 - 108
Sleepy Creek RM 0.1					
April 18 - 21, 2003 No flow or little flow in creek	QA not met	QA not met	6.7 - 7.0	8.1 - 11.2	22 - 33
August 1 - 4, 2003 No flow or little flow in creek	7.7 - 8.8	77 - 86%	7.6 - 7.8	12.9 - 16.6	219 - 223
August 19 - 22, 2003	QA not met	QA not met	7.6 - 7.8	13.3 - 17.2	216 - 221
September 9 - 12, 2003	4.9 - 6.7	50 - 67%	7.4 - 7.8	13.2 - 15.0	QA not met
Dobbs Creek RM 0.1					
August 1 - 5, 2002	QA not met	QA not met	7.8 - 8.1	10.1 - 11.6	106 - 109
January 6 - 10, 2003	11.6 - 12.3	92 - 95%	6.7 - 7.4	3.6 - 6.2	QA not met
April 25 - 28, 2003	9.6 - 10.4	88 - 92%	7.1 - 7.4	8.9 - 11.5	QA not met
August 1 - 4, 2003	9.9 - 10.7	89 - 99%	7.5 - 7.6	10.6 - 13.1	139 - 143
September 9 - 12, 2003	8.2 - 9.1	80 - 88 %	7.5 - 7.7	11.2 - 13.0	147 - 149

Henderson Inlet Dissolved Oxygen Technical Analysis

Sargeant et al. (2003) did not propose to model dissolved oxygen dynamics in Henderson Inlet. Data collection activities were designed to quantify the geographic extent and intensity of low dissolved oxygen levels, given the minor impairments suggested by historical monitoring data. The technical analysis is limited to data collected during the present program.

Henderson Inlet Marine Water Column Profiles and Nutrient Grab Samples

In-situ profiles were recorded at five locations along Henderson Inlet throughout fall 2003 to increase the temporal and spatial resolution of dissolved oxygen data. Figure 64 identifies the monitoring locations, and Figure 65 presents the data. On September 30 and October 27, 2003, dissolved oxygen levels fell below the water quality standard throughout the inlet, with the lowest concentrations recorded near the bottom. Stratification is evident in October at Cliff Point (HEND_2) and in both months opposite Woodard and Chapman bays (HEND_3). September concentrations reached 4 mg/L at the two southern stations. Concentrations met water quality standards throughout the inlet in November, but levels were still below standards in the southern inlet (HEND_4 and HEND_5) in late October.

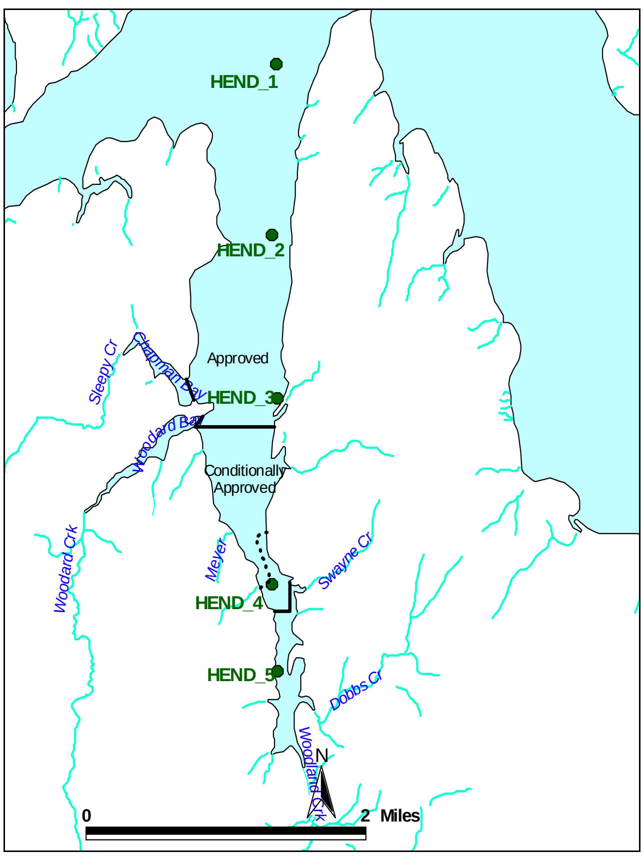

Figure 64. Locations of fall 2003 water column profiles and nutrient grab samples.

Table 22 lists the nutrient and chlorophyll *a* results for grab samples collected at the surface (S) and near the bottom (D). The ratio of dissolved inorganic nitrogen to reactive phosphorus does not exceed 10, less than the theoretical Redfield ratio of 16:1; results verify that Henderson Inlet productivity is nitrogen limited. Dissolved inorganic nitrogen levels are 0.1 mg/L lower during September 30, 2003 than during the November monitoring period, likely reflecting the higher productivity in September. This coincides with the lowest dissolved oxygen levels of the monitoring program.

Table 22. Nutrient and chlorophyll *a* results for Henderson Inlet.

Station	Date	FC (#/100 mL)	TP (mg/L)	OP (mg/L)	NH4N (mg/L)	NO23N (mg/L)	TPN (mg/L)	Chl (ug/L)
HEND_1_S	9/30/2003	1 UJ	0.0734 J	0.0653	0.069	0.206	0.489	3.5
HEND_1_D	9/30/2003	1 UJ	0.0775 J	0.0676	0.023	0.214	0.441	2.5
HEND_2_S	9/30/2003	1	0.0663 J	0.0660	0.021	0.120	0.330	6.1
HEND_2_D	9/30/2003	1	0.0705 J	0.0648	0.022	0.148	0.355	7.4
HEND_3_S	9/30/2003	1 UJ	0.0779 J	0.0668	0.021	0.100	0.342	11.5
HEND_3_D	9/30/2003	2	0.2370 J	0.0737	0.052	0.119	0.341	14.9
HEND_4_S	9/30/2003	5	0.0899 J	0.0835	0.117	0.130	0.379	6.5
HEND_5_S	9/30/2003	21	0.0990 J	0.0903	0.171	0.274	0.627	1.7
HEND_1_S	11/5/2003	1 UJ	0.1400	0.0800	0.029	0.305	0.525	3.22 J
HEND_1_D	11/5/2003	1 UJ	0.1400	0.0806	0.026	0.307	0.467	7.14 J
HEND_2_S	11/5/2003	4 J	0.0960	0.0769	0.018	0.285	0.462	5.53
HEND_2_D	11/5/2003	1	0.1000	0.0779	0.022	0.289	0.430	55.8
HEND_3_S	11/5/2003	1 UJ	0.0990	0.0776	0.046	0.273	0.464	3.9
HEND_3_D	11/5/2003	5	0.1000	0.0735	0.034	0.273	0.451	4.88
HEND_4_S	11/5/2003	1 U	0.1100	0.0812	0.132	0.328	0.639	1.72
HEND_5_S	11/5/2003	3	0.1200	0.0802	0.094	0.272	0.628	1.4
HEND_1_S	11/12/2003	1 U	0.0970	0.0788	0.021	0.308	0.482	3.04 J
HEND_1_D	11/12/2003	1 U	0.1000	0.0791	0.019	0.316	0.458	2.13
HEND_2_S	11/12/2003	1 U	0.0970	0.0758	0.023	0.289	0.520	5.03
HEND_2_D	11/12/2003	1 U	0.2200	0.0781	0.022	0.262	0.408	7.23
HEND_3_S	11/12/2003	2	0.1200	0.0726	0.010 U	0.274	0.450	36
HEND_3_D	11/12/2003	1 U	0.0940	0.0758	0.019	0.283	0.455	1.49
HEND_4_S	11/12/2003	3	0.0920	0.0763	0.071	0.348	0.594	3.86
HEND_5_S	11/12/2003	25	0.0810	0.0725	0.060	0.611	0.821	1.02

Nutrient levels tend to be higher in the southern inlet than in the central or northern inlets in September (Figure 66) and November (Figure 67).

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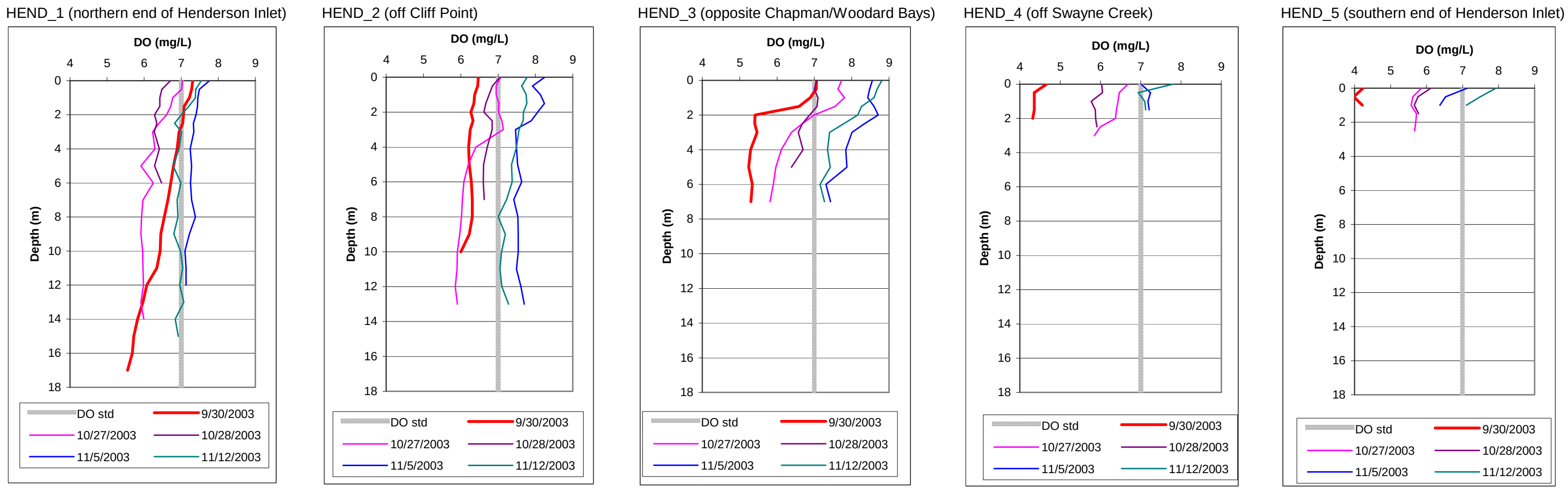

Figure 65. Profiles of dissolved oxygen for Henderson Inlet.

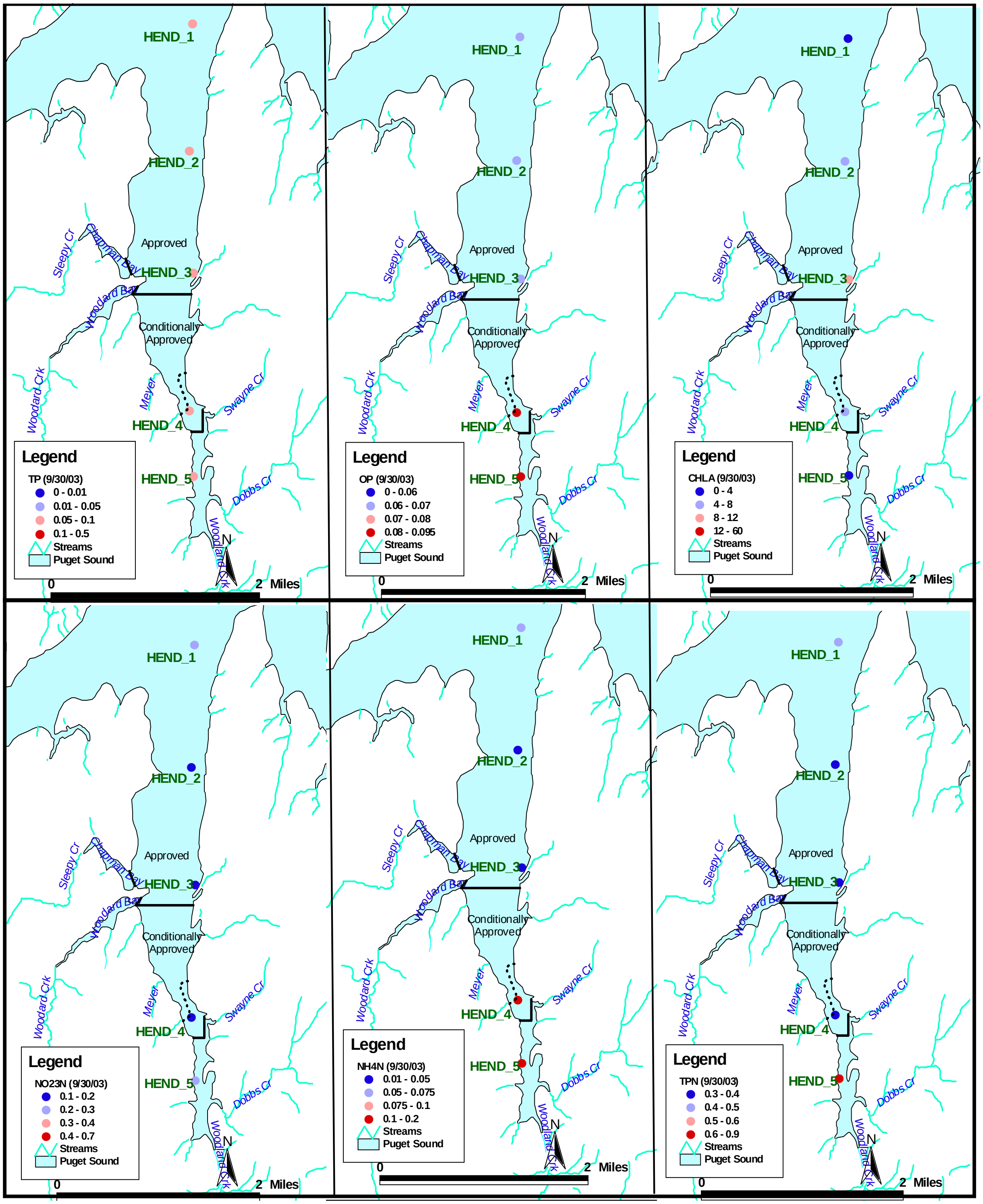

Figure 66. Surface nutrient and chlorophyll *a* levels, September 28, 2003.

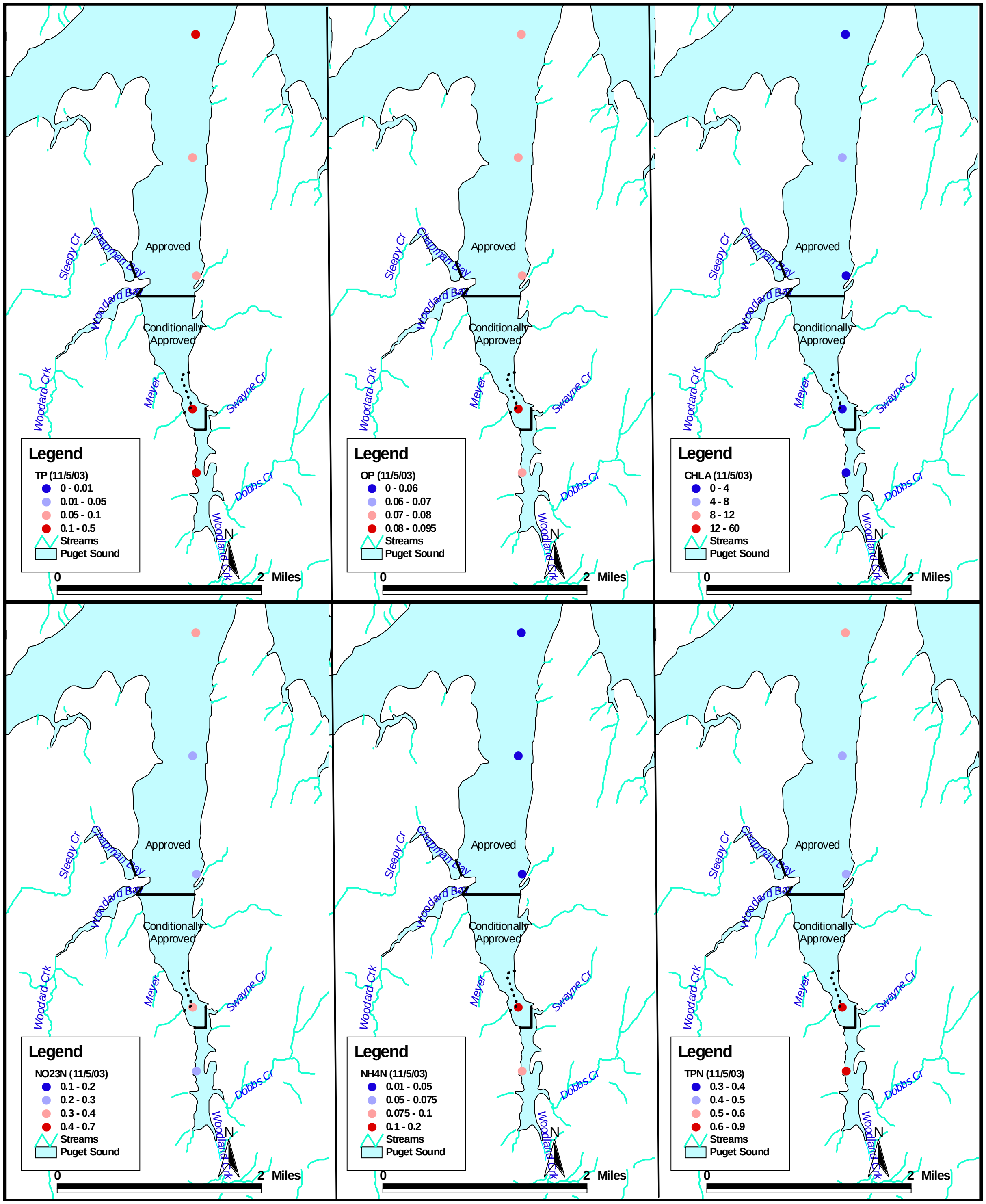

Figure 67. Surface nutrient and chlorophyll *a* levels, November 15, 2003.

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Load and Wasteload Allocations

The loading capacity is the maximum load of a pollutant that can be assimilated by the receiving water without violating water quality standards. The loading capacity is allocated among load and wasteload sources. Load allocations are set for diffuse (nonpoint) sources, and wasteload allocations are set for discrete (point) sources.

pH

Woodard, Dobbs, Sleepy, and Meyer creeks are on the 303(d) list of waterbodies that do not meet water quality standards for pH. The pH values on Woodland and Goose creeks also fell below the pH standard of 6.5 SU.

While stream pH levels usually fall between 6.5 and 8.5, variation can occur because of local watershed geology. Streams that drain soils with a high mineral content usually are alkaline, whereas streams that drain coniferous forests are usually acidic. In addition, most rainwater has a pH of 5.6 to 5.8 due to the presence of carbonic acid (H_2CO_3). Normally these acids are neutralized as rainwater passes through the soil. However, in watersheds with heavy rainfall, little buffering capacity, and acidic soils, surface water may be largely reflective of the rainwater pH values. Anthropogenic factors including industrial runoff and acid rain may also impact surface water pH within a watershed (Oregon DEQ, 2002).

Wetland soils and overlying water can occur over a wide range of pH. Organic soils in wetlands often tend to be acidic, particularly in peatlands in which there is little groundwater inflow (Mitsch and Gosselink, 2000). During a study to calibrate methods for assessing wetland function in Washington wetlands, pH data collected from 1996-2004 normally ranged from 5.0-6.0, with some pH as high as 7.0 (Hruby, 2004).

The pH violations that occurred were just slightly below the pH standard of 6.5 SU, with the lowest values seen on Meyer Creek at 5.4 SU. A large wetland complex forms the headwater of all of the creeks in the study. Woodland Creek flows through a large wetland between RM 3.7 and 3.1; during the dry season, this wetland is the headwaters of the creek.

The pH violations that occur are likely due to a variety of natural conditions including acidic wetland and coniferous forest soils, and systems driven at times by heavy rainfall (the upstream portions of College Creek).

The period when lowest pH occurs (December through March) coincides with the period of low conductivity, indicating low-ionic strength waters in the study area creeks. Several studies have found that it is difficult to accurately measure pH in low-ionic strength streams (Batts, 2002; Oregon DEQ, 2002). Low-ionic strength results in low buffering capacity. Absorption of carbon dioxide from the atmosphere will cause a slow change in the pH, observed as drifting pH. It is important when measuring pH in low-ionic strength waters that field meters be calibrated and checked with low-ionic strength pH standards, and that pH measurement occur *in-situ*.

Occasional excursions below the pH standard are considered natural for the creeks sampled in this study. No load or wasteload allocations are assigned.

Temperature

Woodland Creek

Woodland Creek is on the 303(d) list of waterbodies that do not meet (exceeded) water quality standards for temperature. The temperature listing in the upper portion of Woodland Creek is not addressed in this report, but findings including load and wasteload allocations for Woodland Creek from RM 3.4 downstream are included in Appendix C.

Woodard Creek

A slight exceedance of 16.3°C to the temperature standard occurred at Woodard Creek RM 6.2 during a mid-July continuous monitoring period. It is likely that this exceedance is natural. The upland wetland has low canopy cover (wetland vegetation) and no obvious channel. The creek flows through a wide dispersed shallow area allowing heating of water due to direct solar radiation (from sunlight hitting the surface).

The marine site, Woodard RM 0.0, met freshwater temperature criteria, although it did not meet the more stringent marine criteria of 13.0°C. This sample site is located downstream of a wide portion of the Woodard Bay estuary. At low tide, the creek flows through a narrow channel, but during moderate to high tides, marine water flows into this area. During the study, this site did not meet marine temperature standards because it was sampled during low tide and because there is no canopy cover in this area due to the open nature of the estuary. The creek is heated by direct solar radiation. This site will not meet marine standards during certain portions of the tidal cycle due to natural conditions at the site.

No temperature load or wasteload allocations are set for Woodard Creek. Occasional exceedance of the temperature standard is likely due to natural conditions.

Sleepy Creek

Sleepy Creek at RM 0.1 did not meet the temperature standard during the August continuous monitoring periods, with a high of 17.2 °C. During this period, Sleepy Creek is dry at RM 0.8 and there is very little or no flow at RM 0.1. Aerial photos (Thurston County Geodata Center, 2002) show that Sleepy Creek from RM 0.6 to the mouth has a good riparian corridor and is well shaded. It is likely that low or no flow in the creek during the dry season is the cause of increased temperatures in August. It is possible that full effective shade that would result from fully established 100-year-old riparian vegetation would lower temperature in the creek.

Dissolved Oxygen

Woodland Creek

Determining Loading Capacity for Dissolved Oxygen

The Woodland Creek QUAL2K model was calibrated to the critical September 2003 period and verified with the critical August 2003 period. Several QUAL2K model runs were conducted to determine the effect of the following conditions on dissolved oxygen:

1. Full site potential shade from RM 3.45 to the mouth.
2. Phosphorus, nitrogen, and biochemical oxygen demand removal from the Nisqually Trout Farm.
3. Phosphorus reduction (the limiting nutrient) from diffuse and point sources at the following levels: soluble reactive phosphorus at 0.020 mg/L and organic phosphorus at 0.020 mg/L.
4. Combination of full shade and phosphorus reduction at the levels described above.

Table 23 describes the model-predicted, minimum dissolved oxygen levels for Woodland Creek in September 2003, and for the same critical period for each of the scenarios described above. The mean root, mean square error for dissolved oxygen for the calibrated and verified model is 0.6 mg/L. While different scenarios show some improvement in dissolved oxygen levels, none of the scenarios show improvements of greater than 0.6 mg/L. In the scenarios described, the dissolved oxygen level of 9.5 mg/L cannot be met at Woodland Creek RM 2.6 and upstream. Woodland Creek RM 1.6 and downstream should meet the dissolved oxygen standard.

During the synoptic surveys, dissolved oxygen levels at Woodland Creek at RM 1.6 and 1.0 fell below standards once during March and January, respectively. There was no upstream to downstream pattern in the lower dissolved oxygen levels. It is unknown why these slightly lower levels occurred, but perhaps due to a stormwater biochemical oxygen demand (BOD) loading source.

During the continuous monitoring surveys, dissolved oxygen at Woodland at RM 1.6 during August and October 2003 fell to 9.4 and 9.1 mg/L. During both surveys, Winkler dissolved oxygen checks were consistently 0.1 - 0.2 mg/l higher than the field meter.

Table 23. QUAL2K model predictions for Woodland Creek dissolved oxygen scenarios.

Site	Current Conditions Sept 2003	Full Shade RM 3.45 to mouth	No nutrient or BOD discharge from Trout Farm	Phosphorus reduction*	Full shade, nutrient reduction from all sources*	Full shade, nutrients set at detection limit, no discharge from Trout Farm
RM 3.45	5.19	5.19	5.19	5.19	5.19	5.19
RM 3.4	5.85	5.85	6.23	5.85	5.85	6.06
RM 3.2	6.12	6.12	6.59	6.12	6.12	6.44
RM 3.1	6.58	6.58	7.05	6.58	6.58	6.94
RM 2.9	7.20	7.20	7.59	7.19	7.20	7.52
	7.73	7.73	8.06	7.73	7.73	8.01
RM 2.6	8.66	8.67	8.89	8.66	8.67	8.87
	9.19	9.20	9.37	9.19	9.20	9.39
	9.45	9.47	9.60	9.45	9.47	9.63
	9.60	9.62	9.73	9.60	9.62	9.78
	9.49	9.52	9.62	9.49	9.52	9.67
RM 1.6	9.55	9.58	9.67	9.54	9.58	9.73
	9.55	9.60	9.67	9.55	9.60	9.75
	9.56	9.61	9.67	9.55	9.61	9.76
RM 1.0	9.54	9.60	9.65	9.54	9.60	9.76
	9.52	9.59	9.63	9.52	9.59	9.74
	9.50	9.58	9.60	9.50	9.58	9.73
	9.48	9.57	9.58	9.48	9.57	9.72
RM 0.2	9.50	9.59	9.60	9.50	9.59	9.74
	9.57	9.67	9.67	9.57	9.67	9.83
	9.65	9.76	9.75	9.65	9.76	9.94
	9.65	9.76	9.75	9.65	9.76	9.94

* Phosphorus reduction from diffuse and point sources at the following levels: soluble reactive phosphorus at 0.020 mg/L and organic phosphorus at 0.020 mg/L. Running the model at 0.010 mg/L soluble reactive phosphorus and organic phosphorus produced the same results.

Dissolved Oxygen Loading Capacity for Woodland Creek

Numerous scenarios (Table 23) were run to determine the effects on dissolved oxygen levels in Woodland Creek. Even under a natural condition scenario, dissolved oxygen levels will not reach water quality standards until RM 1.6 during the critical period. During this period, when Beatty Springs and St. Martin Springs provide the majority of flow to the creek, low dissolved oxygen levels in the groundwater (the springs) drive dissolved oxygen levels in the creek. Downstream reaeration increases dissolved oxygen levels so that by RM 1.6 the creek is capable of meeting water quality standards.

Woodland Creek currently has no assimilative capacity for oxygen-demanding activities. Nutrient removal has little effect on dissolved oxygen levels in the creek under low-flow conditions. Full site potential shade will improve dissolved oxygen levels in the creek slightly, as would removal of biochemical oxygen demand from Nisqually Trout Farm #2.

In order to maintain or improve dissolved oxygen levels in Woodland Creek, Nisqually Trout Farm #2 five-day biochemical oxygen demand should be kept to a minimum, and full site potential shade should occur from RM 3.45 downstream.

Woodard Creek

Woodard Creek currently has no assimilative capacity for oxygen-demanding activities. Dissolved oxygen levels start out low in the headwater wetland and increase steadily downstream. Low dissolved oxygen levels in Woodard Creek are largely due to natural conditions. Dissolved oxygen levels at RM 2.9 can meet the 9.5 mg/L standard during periods when flows allow for reaeration of creek water to that standard. During the critical low-flow period, dissolved oxygen at RM 2.9 should not fall below 9.0 mg/L.

From Woodard RM 5.1 to 2.9, the limiting nutrient for algal growth is phosphorus. Control of phosphorus sources to the creek could protect and possibly improve dissolved oxygen levels in this reach.

Meyer Creek

There were two sample sites on Meyer Creek: one at the mouth and one at 56th Avenue just downstream of a large wetland. Dissolved oxygen levels were fairly low at 56th Avenue just downstream of the wetland and improved (but did not meet standards) at the downstream site. Little to no fluctuations were seen in diel oxygen values, indicating minimal or no plant photosynthesis or respiration. Meyer Creek also had low pH, with the lowest values seen downstream of the wetland. It is likely both pH and dissolved oxygen levels lower than the standards are largely due to natural wetland conditions.

Sleepy Creek

Sleepy Creek at RM 0.1 did not meet the dissolved oxygen standard during August and September. During this period, Sleepy Creek is dry at RM 0.8, and there is very little or no flow at RM 0.1. It is likely that low or no flow in the creek during the dry season is the cause of low dissolved oxygen in the creek. During the dry season, the creek is largely fed by groundwater seeps. While groundwater levels of dissolved oxygen were not measured in the Sleepy Creek aquifer, groundwater dissolved oxygen levels from nearby Woodland Creek were in the 5.3 - 6.9 mg/L range. The combination of low or no aeration of creek water due to no flow and low dissolved oxygen levels in the groundwater can result in low dissolved oxygen levels in Sleepy Creek. Lower dry-season dissolved oxygen levels are due in part to natural conditions, low dissolved oxygen in the groundwater, and no flow in the creek. It is uncertain if low-flow conditions are a natural occurrence on this creek. There could be some improvement in dissolved oxygen levels if the creek had full effective shade that would result from fully established 100-year-old riparian vegetation. Lower temperatures would result in a slight improvement in dissolved oxygen levels.

Dobbs Creek

Dobbs Creek generally had good levels of dissolved oxygen during the synoptic and continuous monitoring surveys with the exception of the September 2003 continuous survey. Dissolved oxygen levels during that period ranged from 8.2 - 9.1 mg/L. During that period, there were no observable diel variations in pH or dissolved oxygen, indicating very little plant production. There was flow at the site during the September continuous monitoring period. It is unknown as to why low dissolved oxygen levels occurred at that time.

Henderson Inlet

No load or wasteload allocations were developed for dissolved oxygen and nutrients in Henderson Inlet. Previous data collected by Ecology indicated the potential for minor impairment of dissolved oxygen in the marine areas. Therefore, the study plan (Sargeant et al., 2003) included additional surveys in the critical fall period to assess the geographic extent and intensity of low dissolved oxygen levels.

Results indicate low dissolved oxygen concentrations exist throughout the inlet in the early fall. Lowest levels are found near the bottom and toward the southern end of Henderson Inlet, with concentrations approaching 4 mg/L. Factors potentially contributing to low concentrations include high nutrient loads from tributaries, due to residential, commercial, or agriculture sources that include poorly operating or failing on-site sewage systems along the shoreline, water column stratification, and slow flushing or exchange with Puget Sound. In addition, an infiltration facility for treated wastewater[3] is under construction in the Hawks Prairie area, and groundwater modeling indicates that the plume will move toward Woodland Creek and southern Henderson Inlet over a period of several years (Brown and Caldwell, 2003). Kimsey (2004) calculated that if the facility meets its planned consumption rate, the increase in nitrogen loads to Henderson Inlet is not likely to exceed 10% of the current levels. However, no groundwater quality modeling was conducted.

Modeling will be necessary to develop load and wasteload allocations of nutrients in order to complete a Total Maximum Daily Load analysis of dissolved oxygen in Henderson Inlet.

Under the present study, several of the load reductions recommended for fecal coliform bacteria and stream nutrient levels will likely reduce nutrient loads to Henderson Inlet, with a concomitant improvement in marine dissolved oxygen levels. The benefit of these related reductions to marine dissolved oxygen cannot be quantified explicitly.

[3] The Hawks Prairie Water Reclamation Facility will have an ultimate capacity of 5 mgd, with effluent treated to reduce nitrogen levels to approximately 3 to 4.5 mg-N/L. Most of the treated wastewater is intended to be reused for irrigation, and only the amount not sold will be discharged to ground under a State of Washington Discharge to Groundwater permit.

Margin of Safety

A margin of safety to account for scientific uncertainty must be considered in TMDLs for load allocations to be protective. The margin of safety for this TMDL is implicit; it is contained within conservative assumptions used to develop the TMDL.

Factors contributing to a margin of safety for fecal coliform bacteria are:

- Sampling at marine sites was restricted to low tide; no other tidal cycles were sampled. Sampling did not include periods when the marine water would provide dilution and a bactericidal effect. By not sampling during all tidal regimes, the marine sites close to freshwater were biased high. This provides a margin of safety if targets are met.

- The rollback method assumes that the variance of the pre-management data set will be equivalent to the variance of the post-management data set. As pollution sources are managed, the occurrence of high fecal coliform values is likely to be less frequent, and thus reduces the variance and the 90^{th} percentile of the post-management condition.

- The smaller the sample set used for the rollback calculation, the more stringent the reduction necessary. A smaller sample set has greater variability in the data set, causing higher 90^{th} percentiles.

The margin of safety for the dissolved oxygen portion of this study was implicitly provided by using a combination of conservative modeling assumption that tend to err on the side of a smaller loading capacity (e.g., combining low-flow conditions and warmer meteorological conditions favorable for stream productivity).

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TMDL Schedule, Actions, and Monitoring

Schedule

The Total Maximum Daily Load (TMDL) process allows an iterative approach to improving water quality when diffuse (nonpoint) sources predominate. However, compliance with the standards must be achieved within a reasonable schedule. The allocation targets are calculated using the best available data, but the data are only an estimate of a complex ecological system. The margin of safety used to set the targets reflects some of the uncertainty in the interpretation, but other problems with the interpretation often are not known until abatement actions are underway. Monitoring the effectiveness of the fecal coliform bacterial control measures and the rate of reduction in bacteria loads will provide additional data to adjust compliance targets and establish realistic compliance dates. Ecology must review these data at regular intervals, and targets or actions can be adjusted through the TMDL public process.

The compliance schedule will be part of Ecology's TMDL water cleanup plan. The plan will be drafted by Ecology's Southwest Regional Office and reviewed under the TMDL public process. The compliance schedule will be closely coordinated with the Henderson Shellfish Protection District Stakeholder Group and other local initiatives. The Stakeholder Group makes bacteria cleanup recommendations to the Thurston County Commissioners for the Henderson Shellfish Closure Response area. A complete evaluation of monitoring data should occur to judge the effectiveness of the plan and the appropriateness of the TMDL targets.

Monitoring

Fecal Coliform Bacteria

To determine the success of fecal coliform control strategies, regular water quality monitoring is recommended. Stations recommended for continued fecal coliform monitoring include:

Woodland Creek

Wet, Storm-event Season (November - March)

- Stormwater discharge at RM 3.7T
- College Creek at RM 0.4
- WSDOT stormwater discharge at RM 3.1T
- Palm Creek (mouth)
- Fox Creek (near mouth)
- Quail Creek (mouth)
- Woodland Creek at RM 0.2

Dry Season (June - September)

- Eagle Creek (mouth)
- Jorgenson Creek (mouth)
- Woodland Creek at RM 0.2

Woodard Creek

- Woodard Creek at RM 2.9

While not part of the TMDL monitoring, it is also recommended that the stormwater pond outfall to Taylor wetland, and Woodard Creek at RM 6.9, be monitored during the wet season to determine the effectiveness of stormwater treatment upstream of Woodard RM 6.9.

Henderson Tributaries

- Meyer Creek (mouth)
- Sleepy Creek (mouth)
- Dobbs Creek (mouth)
- Goose Creek (mouth)

Henderson Inlet

- DOH stations

Dissolved Oxygen

Woodland Creek

Dry Season (June – September)

- Woodland Creek at RM 1.6
- Fox Creek

Woodard Creek

Low-flow Period (August and September)

- Woodard Creek at RM 2.9

A complete evaluation of the TMDL follow-up monitoring data should be conducted in 2012, after five years of data have been collected. By 2012, Henderson Inlet and tributaries to the inlet should meet Class AA fecal coliform bacteria standards.

Conclusions and Recommendations

Fecal Coliform Bacteria

Woodland Creek

During the storm-event period, November through March, the largest source of loading to Woodland Creek (approximately 50%) is from stormwater discharging to the creek at RM 3.7. In addition, this site had some of the highest nitrate+nitrite nitrogen concentrations detected during this 2002-2004 study. Time-of-travel studies indicate that, during low-flow conditions, it can take from 3.4 to 4.6 hours for water to flow from Martin Way (RM 3.8) to Henderson Inlet. Time-of-travel during winter conditions is likely faster, given higher flow rates. Therefore, the 3.4 to 4.6 hour estimate represents the slowest travel time likely to occur during storm conditions. The bacterial die-off during storm conditions is negligible. The stormwater discharge at RM 3.7 is one of the greatest fecal coliform loading sources to Henderson Inlet, and is the highest priority for pollution-reduction activities.

Woodland Creek RM 4.3 to 3.8 (downstream of Lake Lois to Martin Way)

Water flows in this reach only during the wet season, December through March, when Lake Lois water levels are high enough to spill into the creek. For the 2002-2004 study period, this reach flowed from mid-January through mid-May in 2003 and 2004. Bacteria levels in this reach were slightly above the water quality standard for bacteria. While most of this reach has good riparian buffer, there is some residential development with on-site sewage treatment systems near the upper end of the reach. At RM 4.3, dissolved oxygen levels were occasionally below the standard but met standards at RM 3.8. Nitrogen values at RM 3.8 were low compared to downstream observations. Possible bacteria sources in this reach include wildlife and Lake Lois, as well as failing on-site sewage systems and pet waste in the upper portion of the reach.

Most of Woodland Creek between RM 4.3 and 3.1 is in a wooded area owned by St. Martin's Abbey. Homeless individuals occasionally camp in this area, and public bathroom facilities are not readily available. Homeless campers and wildlife in this area are possible sources of bacterial pollution.

Woodland Creek RM 3.8 to 3.1 (Martin Way to Interstate 5)

As described above, the largest source of bacterial loading and some of the highest nitrogen concentrations to Woodland Creek are from stormwater discharges to the creek at RM 3.7. The Tanglewilde development drains to the stormwater pipe at RM 3.7. Tanglewilde is one of the largest, most densely concentrated developments on on-site sewage treatment. It is likely that on-site sewage systems in this drainage are contributing to high nitrogen levels, and that stormwater from the development contributes to high bacteria levels.

From February 11 through May 27, 2004, Thurston County Environmental Health staff collected water samples from the stormwater pipe that drains the Tanglewilde development. Eight sample events were conducted during the four-month period. Five water samples were collected during each event for a total of 40 water samples. The Thurston County Environmental Health laboratory cultured and isolated the *E. coli* bacteria. All *E. coli* isolates were sent to the Institute for Environmental Health for DNA analysis.

A total of 109 isolates were analyzed; 80% were matched with known sources in the DNA library. Within these sources, there were 36 source types identified: avian (11), rodent (9), unknown (6), dog (5), canine (3), and raccoon (2). In other words, of the avian sources, for example, there were 11 different avian source types or distinct patterns.

Data were evaluated for the frequency that a source is identified (e.g., if the source is always or infrequently present). Of the 8 sample events, avian and unknown sources were present 7 times, rodents 5 times, dogs 4 times, and canine and raccoons were present 2 times.

The county staff concluded that sources identified represent typical urban sources: birds, rodents, dogs, and the occasional night visitors, coyotes (canine) and raccoons. The fecal matter from these sources is washed off streets and lawns, and easily enters the stormwater system (Davis, 2005).

College Creek also contributes high bacteria levels and loading in this reach, either directly via the channel or through channels in the wetland. Stormwater upstream of College Creek RM 0.4 is the most likely source of bacteria in this reach. During the dry, low-flow period (June through September, when no stormwater flow is occurring), College Creek at the mouth slightly exceeds the geometric mean of 50 fc/100 mL. This may occur because the wetland filters and reduces stormwater loading during the wet season. During the low-flow period, bacteria in the sediments may be released at a constant rate (thus the slightly higher geometric mean). Storm-event bacteria reductions to the wetland will likely improve low-flow period concentrations.

Woodland Creek RM 3.1 to 2.9 (Interstate 5 to Draham Road)

During the wet storm-event period, sources include the stormwater discharges at Interstate 5. During the dry period, both sites meet bacteria standards.

Woodland Creek RM 2.9 to 2.6 (Draham Road to 21st Court)

Slight increases in bacteria occur during the storm-event and dry periods. Likely sources include on-site sewage treatment systems, pet waste, stormwater, and wildlife.

Woodland Creek RM 2.6 to 1.6

During both the storm-event and dry periods, this reach has some of the highest bacteria loading. Sources along the creek include on-site sewage treatment systems, pet waste, stormwater, agricultural activities, and wildlife. Several smaller creeks discharge to Woodland Creek in this reach, including Eagle, Palm, and Fox creeks.

Eagle Creek contributes bacteria during the dry season; likely sources include agricultural activities. Palm Creek flows only during the wet season. The headwaters of the creek are located just west of the Woodland Creek Estates development. The rest of the creek flows through forest with no nearby development. Sources in Palm Creek could include upland stormwater and wildlife. Fox Creek flows through rural areas and wetlands; sources are unknown but could include wildlife.

Woodland Creek RM 1.6 to 0.2

During the wet storm-event period, no increase in bacteria loading was observed between RM 1.6 and 1.0. Quail and Jorgenson creeks contribute bacteria loading in this reach, during both the storm-event and dry seasons. Woodland creek provides less dilution during the dry season, and loading from these creeks is more noticeable during this period. On Jorgenson Creek, limited upstream/downstream sampling showed occasional high bacteria values upstream of Pleasant Glade Road. Likely sources along this creek include failing on-site sewage systems and stormwater discharge to the creek.

The most likely bacteria source on Quail Creek is upstream agricultural activities. There are three horse farms on Quail Creek.

For one horse farm, the farm plan was signed in December 2001. The farm plan was not implemented, and in January 2004 Thurston County issued a notice of violation requiring full implementation by October 2004. The county reported almost full implementation of the farm plan by December 31, 2004 (Davis, 2005).

In April 2001, Thurston County issued a notice of violation to a second horse farm in the Quail Creek drainage requiring farm plan implementation by October 2002 for a plan that was approved in January 2002. The county held an administrative hearing in December 2002 for not implementing the farm plan. Most of the recommended best management practices detailed in the plan were implemented during 2003 following the administrative hearing (Davis, 2005).

There is an increase in bacterial loading between Woodland RM 1.0 and 0.2 during storm events but not during the low-flow period. Possible sources in this reach include the Hollywood development stormwater ponds.

Recommendations

Recommendations for addressing fecal coliform violations in Woodland Creek are detailed below. Priority areas are based on estimated fecal coliform loading as well as bacteria concentrations. Table 24 presents bacterial loading estimates for Woodland Creek sites.

- On-site sewage systems in the Woodland Creek basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.
- Stormwater discharge at Martin Way is the highest priority for bacterial source control, including, but not limited to, investigation of on-site sewage sources in the Tanglewilde

development and stormwater treatment. It is likely that sources between Woodland RM 3.8 and 3.4, in part, reflect loading from the stormwater discharge at Martin Way.

- Stormwater discharge to College Creek should be addressed including (1) looking at stormwater treatment options and (2) working with neighborhoods adjacent to College Creek from RM 0.6 to 0.3 regarding on-site sewage treatment and pet waste.
- The Woodland Creek Estates neighborhood should be strongly considered for sewering. Stormwater and pet waste issues should also be addressed.
- Corrective measures have been taken related to possible agricultural sources on Quail Creek. Quail Creek and agricultural sites should be monitored to determine if bacteria levels have improved and if farm plan recommendations are being followed.
- Domestic animal access to Eagle Creek should be limited, especially during the dry season.
- The state Department of Transportation must update stormwater facilities at Interstate 5.
- On-site sewage treatment sources on Jorgenson Creek should be investigated, especially upstream of Pleasant Glade Road.
- Possible storm-event sources from stormwater facilities between Woodland Creek RM 1.0 and 0.2 should be investigated.

Table 24. Ranked Woodland Creek average estimated fecal coliform (FC) loading during storm events (November through March) and the dry season (June through September).

Woodland Creek Site	During Storm Events (billions FC per day)	Woodland Creek Site	During Dry Season (billions FC per day)
Stormwater discharge at RM 3.7	164.3	RM 2.6 - 1.6	21.2
RM 3.8 - 3.4	36.0	RM 1.6 - 1.0	15.6
RM 2.6 - 1.6	35.5	RM 2.9 - 2.6	10.4
RM 1.0 - 0.2**	35.5	Eagle Creek	8.5
College Creek RM 0.6 - 0.4	22.9	Jorgenson Creek	8.2
Quail Creek	19.1	RM 3.4 - 3.1 *	4.3
College Creek RM 0.2 - 0.0	15.1	RM 3.1 - 2.9 *	3.9
RM 2.9 - 2.6	14.1	RM 3.45 - 3.4*	2.0
Fox Creek	13.7	Quail Creek	1.4
Upstream of College Creek RM 0.6	12.2	College Creek at mouth	1.4
Jorgenson Creek	9.8	Headwaters at RM 3.45 *	0.7
Upstream at Woodland Creek RM 4.5	5.9	Fox Creek	0.3
Eagle Creek	5.1		
RM 4.5 - 3.8	2.8		
WSDOT stormwater (both discharges)	2.2		
Palm Creek	1.4		
Stormwater discharge at RM 2.6	0.2		

* These reaches or sites meet fecal coliform bacteria standards.
** Flows used to calculate loading at RM 0.2 are based on flows at RM 1.0; no flow data are available for RM 0.2.

Woodard Creek

Headwaters to RM 6.2 at Ensign Road

High levels of bacteria are found in waters flowing out of Taylor wetland. The likely sources of bacteria are stormwater and wildlife. As with Woodland Creek, homeless encampments have been observed near Taylor wetland and could be a source of bacteria to the wetland.

In 2003, the cities of Lacey and Olympia began construction of several large stormwater facilities to treat stormwater that formerly discharged to the Taylor wetland. The facilities consist of two treatment trains. The upstream wet pond treats Lacey's discharge; this facility is behind Colonial Estates on 14th Avenue to the east of Fones Road. Downstream of this pond, water flows under Fones Road to a large facility behind Home Depot. This facility consists of two ponds, a small upper wet pond and a large lower pond. Originally the lower pond was designed as a constructed wetland, but it functions as an infiltration pond. Since the facilities came on-line in late 2003, no discharge has been observed from the lower pond. It is likely that there will be no discharge to Taylor wetland from this stormwater facility except in extreme storm events (Heilema, 2005).

Woodard Creek RM 6.2 to 5.1 (Ensign Road to Lindell Road)

During storm events and dry periods, this reach has the greatest bacterial loading. Increases in nitrogen are also seen in this reach. A homeless encampment has been observed just downstream of Ensign Road. The remainder of the reach appears to be well buffered with good riparian area. The reach occasionally loses and gains water, so there are no significant water inputs. It is unlikely that a homeless encampment and wildlife account for all bacteria increases in this reach. This reach should be investigated more closely. This area is a good candidate for bacterial source tracking techniques.

Woodard Creek 5.1 to 3.4 (Lindell to 36th Avenue)

There is an increase in bacterial concentrations and load, as well as nutrient concentrations, in this reach. There is a two-fold increase in flow in this reach. While aerial maps (Thurston County Geodata Center, 2002) show no residential areas near the creek, large open areas on both the left and right banks are seen in the lower end of the reach. Possible sources include tributaries draining to the creek from surrounding areas and agricultural activities.

Woodard Creek RM 3.4 to 0.0 (36th Avenue to Woodard Bay Road)

Bacteria and nutrient concentrations decrease from RM 3.4 to the mouth.

Recommendations

Priority recommendations for addressing fecal coliform violations in Woodard Creek are detailed below. Priority areas are based on estimated fecal coliform loading as well as bacteria concentrations. Table 25 presents bacterial loading estimates for Woodard Creek sites.

- Highest priority is investigation and control of bacterial sources between Woodard Creek RM 6.2 - 3.4. Possible sources include wildlife, stormwater, agriculture, failing on-site sewage systems, leaking sewer lines, and homeless campers. Bacterial source tracking techniques could be used in this reach.
- On-site sewage systems in the Woodard Creek basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.
- Stormwater discharge to Taylor wetland was a high priority for bacterial source control. Stormwater facilities were installed to treat stormwater discharge after TMDL sampling was completed. Discharge from the stormwater treatment facility should be monitored at regular intervals during the wet season (December - March) to determine effectiveness of treatment.

Table 25. Ranked Woodard Creek estimated average fecal coliform (FC) loading during storm events (November – March) and the dry season (June – September).

Woodard Creek Site	During Storm Events (billions FC per day)	Woodard Creek Site	During Dry Season (billions FC per day)
RM 5.1 - 3.4	43.1	RM 6.2 - 5.1	11.1
RM 6.2 - 5.1	22.7	RM 5.1 - 3.4	7.9
Upstream of 6.9 (Taylor wetland)	10.2	Upstream of 6.9 (Taylor wetland)	0.8
RM 3.4 - 2.9	2.6	Woodland Creek RM 6.9 - 6.8	0.6
Woodland Creek RM 6.9-6.8	0.01		

Meyer Creek

The headwaters of Meyer Creek flow through a horse pasture, then under 56th Avenue NE to a wooded riparian area. Aerial photos (Thurston County Geodata Center, 2002) show no development along the creek in the lower end. The source of high bacteria values is likely pastured animals in the uplands.

Recommendations

- Exclude domestic animal access to the creek and wetland.
- On-site sewage systems in the basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.

Sleepy Creek

During the storm-event period (November – March), both Sleepy Creek sites did not meet bacteria standards. No significant difference in bacteria concentrations between upstream and downstream was observed. Flows were not obtained at the upstream site, so loading information is not available. While the upstream site is immediately downstream of the headwater wetlands, aerial photos (Thurston County Geodata Center, 2002) show pasture land upstream. There is also one residential home on site located adjacent to the creek. Possible sources to the upstream site include pastured animals, a residential home adjacent to the creek on an on-site sewage system, stormwater from Libby Road, and wildlife. Downstream, the creek flows through a wooded riparian area; sources in this area are unknown.

Recommendations

- On-site sewage systems in the basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.
- Upland on-site sewage systems adjacent to the creek and domestic animal access issues should be investigated.

Dobbs Creek

Dobbs Creek had the highest storm-event bacterial loading to Henderson Inlet of any creek sampled. During a portion of the study, upstream sampling was conducted to delineate sources. During this sampling, bacteria levels were low. Initial sampling showed that the upstream agricultural operation was not a contributor. Other possible sources on the creek include a horse boarding operation and a large recreational vehicle (RV) campground.

Recommendations

To better determine sources on this creek, more segmented sampling of the creek with flow and bacteria sampling needs to be done. Segmenting sampling should include sites just downstream of the agricultural operation, the horse boarding facility, the RV facility, and the mouth of the creek. Additional sites may need to be added, based on bacterial loading data.

- On-site sewage systems in the basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.
- Segmented monitoring should be conducted to determine sources as described above.
- Possible sources at the horse boarding facility should be investigated and referred to the Conservation District if needed.
- Possible sources in the RV park should be investigated.

Goose Creek

Goose Creek has minimal bacterial loading to Henderson Inlet. Possible sources of bacteria include stormwater run-off from the road, failing on-site sewage systems, and wildlife.

Recommendation

- On-site sewage systems in the basin should have mandatory septic system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.

Henderson Inlet

Table 15 presents load reductions necessary to achieve water quality standards throughout Henderson Inlet. The area of influence of particular bacteria sources is more complicated in marine areas, compared with streams where "upstream" and "downstream" are well defined. While no computer model was applied to Henderson Inlet to dynamically simulate the motion of fecal coliform bacteria, the results from the various monitoring programs indicate that the primary sources contributing to poor water quality are located in the southern inlet.

The drogue studies indicate that on moderately fast ebbing tides, water parcels travel from Woodland and Dobbs creeks through the southern inlet, as defined by the *Prohibited* shellfish zone, within two hours, indicating little time for die-off of bacteria. Using a first-order decay coefficient of 1.5/day from the *in-situ* die-off study, only 12% of the bacteria die in that two hours, and the load receives little attenuation. Dilution will reduce concentrations to some extent, however. Water quality patterns and travel time results confirm that watershed sources control water quality in Henderson Inlet, and reducing tributary loads is necessary to meet marine water quality standards.

While wildlife do use the southern inlet, the patterns of wildlife densities do not coincide with patterns of high fecal coliform concentrations. The Woodard Bay Natural Area represents one of the highest regional wildlife densities (Tirhi, 2005). No bacteria sampling is conducted within the preserve, and the area remains unclassified for shellfish. However, fecal coliform bacteria levels at the nearest state Department of Health (DOH) stations (193, 203, and 204) meet both components of the state water quality standards and the shellfish standards. Therefore, while wildlife are expected to contribute to the natural bacteria load within Henderson Inlet, the effect of wildlife is believed to be within the loading capacity. Wildlife do not receive an explicit load allocation.

Shoreline on-site sewage systems are another potential source of bacteria. A simple GIS analysis was used to estimate potential septic system loads to Henderson Inlet. There are 320 parcels directly adjacent to Henderson Inlet. Assuming an occupancy rate of 90%, 100% for on-site sewage systems, 2.5 people per household, and a failure rate of 14% (Thurston County PHSS and WWM, 1999b), on-site sewage systems could contribute over 200 billion fecal coliform bacteria per day to Henderson Inlet. The potential load is of the same order of magnitude as Woodland Creek loads.

In summary, watershed loads of fecal coliform bacteria control marine concentrations in the southern inlet. If the tributaries, especially Woodland and Dobbs creeks, meet the water quality standards for freshwater at the mouths, bacteria levels within Henderson Inlet should meet the marine water quality standards. The creeks need reductions in excess of 90% to meet the freshwater quality standards, while DOH marine stations require up to 80% reductions to meet the marine water quality standards. One potential exception may be around DOH Station 202, where local shoreline sources may contribute bacteria.

Recommendations

Fecal coliform bacteria levels in Henderson Inlet are controlled by watershed sources in the southern inlet. Therefore, the recommendations described above to reduce watershed bacteria sources apply to Henderson Inlet as well. In addition, the following relates to direct sources to Henderson Inlet:

- On-site sewage systems along the Henderson Inlet shoreline should have mandatory on-site sewage system operation and maintenance inspections on a regular basis.
- Henderson Inlet should remain on the 303(d) list of impaired waters for dissolved oxygen. Monitoring confirmed that low dissolved oxygen levels occur throughout the inlet in the early fall. In the southern inlet, dissolved oxygen concentrations approach 4 mg/L, violating the water quality standards. Future studies should include an explicit dissolved oxygen model of Henderson Inlet.
- While no nutrient load reductions can be developed without an explicit dissolved oxygen model of Henderson Inlet, watershed management should include activities that reduce nutrient loads, and nitrogen loads in particular, to Henderson Inlet. Watershed recommendations relating to animal waste, on-site sewage systems, and stormwater apply for Henderson Inlet water quality as well.

Temperature, Dissolved Oxygen, and pH

Woodland Creek

Woodland Creek is on the 303(d) list of impaired waters for fecal coliform, temperature, and dissolved oxygen.

Temperature

Recommendations

In addition to the recommendations for effective shade and the wasteload allocations, other management activities are recommended for compliance with Washington State water quality standards. The management recommendations described below would help to prevent degradation of temperature conditions in Woodland Creek between Beatty Springs and Henderson Inlet.

- Continue to encourage watershed residents to use water wisely.
- The City of Lacey and Thurston County should continue to carefully manage stormwater runoff from impervious surfaces in accordance with the minimum requirements and technical guidance provided by the Stormwater Management Manual of Western Washington.
- Measures should be taken to protect springs and tributaries in lower Woodland Creek from further degradation, including measures to protect riparian vegetation and groundwater in hydraulic continuity.
- Practice Low Impact Development principles for new development, to the extent possible.
- It is preferable to avoid drilling new exempt wells within the Woodland Creek basin. The City of Lacey is currently considering the possibility of prohibiting new exempt wells within Lacey city limits.

pH

Occasional excursions below the pH standard are considered natural, due to the acidic nature of wetlands in western Washington. The Woodland Creek channel becomes dispersed in the large wetland between Martin Way and Interstate 5. pH levels can drop slightly below the standard in the wetland, and lower levels are due to natural conditions.

Dissolved Oxygen

Low dissolved oxygen levels from Woodland Creek RM 3.45 (where Beatty and St. Martin's springs discharge to Woodland Creek) are due to natural conditions. Various scenarios, including more shade, less nutrients, and removal of biochemical oxygen demand (BOD) and nutrient discharge from the Nisqually Trout Farm, were run using the QUAL2K model. Results showed that addition or removal of nutrients to the creek has little impact on freshwater dissolved oxygen levels. There is a slight increase in dissolved oxygen levels when the creek is at full site potential shade and when BOD is removed from the trout farm.

While most of the tributaries did not meet the dissolved oxygen criterion of 9.5 mg/L, none of the tributaries fell below 8.0 mg/L except of College and Fox creeks. The upper reach of College Creek is fed by stormwater during both the wet and dry seasons. The lower reach of College Creek is primarily fed by groundwater from the springs. Low dissolved oxygen in College Creek is likely due to oxygen demand from stormwater in the upper end and naturally low dissolved oxygen in the springs downstream. Dissolved oxygen in Fox Creek is low especially during the dry season, with a mean of 3 mg/L. Just upstream of the Fox Creek sample site is an impounded wetland draining through a small culvert under Pleasant Glade Road. While wetlands may naturally have very low dissolved oxygen levels, the impoundment of water likely causes even lower levels of dissolved oxygen.

Recommendations

Recommendations for dissolved oxygen on Woodland Creek include:

- Woodland Creek should meet a dissolved oxygen level of 9.5 mg/L at RM 1.6 during the dry, low-flow period.
- Effective shade recommendations should be implemented to improve dissolved oxygen levels.
- Biochemical oxygen demand (BOD) limits should be set for Nisqually Fish Farm #2; monitoring 5-day BOD may be required to determine permit limits.
- While low dissolved oxygen in Fox Creek may be a natural condition due to upland wetlands, low dissolved oxygen levels and possible BOD sources in this watershed should be investigated further.
- To ensure future limited algal growth in Woodland Creek, stormwater treatment should include nutrient attenuation or removal.

Nitrogen

Woodland Creek and some inputs to the creek had some of the highest nitrate+nitrite nitrogen concentrations of any of the creeks that discharge to Henderson Inlet. Excessive nitrogen to marine systems like Henderson Inlet may cause excessive algal growth which, in turn, can create low dissolved oxygen levels. Marine sampling for this TMDL project was not adequate to address the effects of nitrogen on the low dissolved oxygen levels in Henderson Inlet. As a precaution, nitrogen reduction to Woodland Creek is recommended.

Recommendations

Recommendations to control nitrogen to Woodland Creek include:

- Convert on-site sewage systems to sewer in high-density residential areas within the urban growth area.

- Investigate possible widespread changes in groundwater nitrate concentrations in the Woodland Creek basin.
- Investigate possible anthropogenic (human-caused) sources of nitrogen to groundwater, including inputs from on-site sewage systems and fertilizer use.
- Homeowners and farmers should apply fertilizers at agronomic rates, with a no-application buffer zone adjacent to waterways.

Woodard Creek

Woodard Creek is on the 303(d) list of impaired waters for fecal coliform, pH, and dissolved oxygen.

Lower pH levels were detected at both RM 6.9 and 6.2; extensive wetlands upstream of these sites are likely the cause. Occasional lower pH values in these areas are considered a natural condition.

Woodard Creek currently has no assimilative capacity for oxygen-demanding activities. Dissolved oxygen levels start low in the headwater wetland and increase steadily downstream. Low dissolved oxygen levels in Woodard Creek are largely due to natural conditions. Dissolved oxygen levels at RM 2.9 can meet the 9.5 mg/L standard during periods when flows allow for reaeration of creek water to that standard. During the critical dry, low-flow period, dissolved oxygen at RM 2.9 should not fall below 9.0 mg/L.

On Woodard Creek from RM 5.1 to 2.9, the limiting nutrient for algal growth is phosphorus. While no load or wasteload allocations are recommended for Woodard Creek, control of phosphorus sources to the creek could protect and possibly improve dissolved oxygen levels in this reach and downstream.

Meyer Creek

Meyer Creek is not on the 303(d) list for impaired waters, but it is impaired for fecal coliform. There were two sampling sites on Meyer Creek: one at the mouth and one at 56th Avenue just downstream of a large wetland. Dissolved oxygen levels were low upstream, just downstream of the wetland, and improved (but did not meet standards) at the downstream site. Meyer Creek also had low pH, with the lowest values detected downstream of the wetland. It is likely that both pH and dissolved oxygen levels lower than the standards are largely due to natural wetland conditions.

Sleepy Creek

Sleepy Creek is on the 303(d) list of impaired waters for fecal coliform, dissolved oxygen, and pH. In addition, temperature standards were not met during the dry season.

A large wetland west of Libby Road is the headwaters for Sleepy Creek. During the dry season when water no longer discharges from the wetland, dissolved oxygen levels were low at the mouth of Sleepy Creek, with the lowest values during August and September. Temperature standards were also not met during August. Flow measurements could not be obtained during the June through September period due to very little or no flow in the creek. During this dry period, pH was stable, and there was very little diel variation in dissolved oxygen. This indicates that there is likely very little plant productivity in the creek. Standing water has little chance to aerate. It is likely that low dissolved oxygen levels in Sleepy Creek during August and September are due to little or no flow in the creek.

During the December- March wet season when the wetland is providing flow to the creek, pH values drop occasionally below the standard. During the dry low-flow period when the wetland is not contributing flow to the creek, pH standards are met. Lower pH values during the wet season are due to natural conditions.

Dobbs Creek

Dobbs Creek is on the 303(d) list of impaired waters for fecal coliform and pH.

No pH excursions were found during the study. One of the tributary headwater streams flows out of a wetland, and it is possible there could be occasional excursions below the pH standard.

Dobbs Creek generally had good levels of dissolved oxygen during the synoptic and continuous monitoring surveys, with the exception of the September 2003 continuous survey when levels ranged from 8.2 - 9.1 mg/L. During that period, there were no observable diel variation in pH or dissolved oxygen, indicating very little plant production. There was flow at the site during the September continuous monitoring period. It is unknown as to why low dissolved oxygen levels occurred at that time.

Goose Creek

Occasional excursions below the pH standard in Goose Creek are considered natural due to the acidic nature of wetlands in western Washington. The headwaters of Goose Creek are located in a wetland. pH levels can drop slightly below the standard in the wetland, and lower levels are due to natural conditions.

Henderson Inlet

Dissolved oxygen levels did not meet water quality standards in September and October 2003. The lowest concentrations occur near the bottom of the water column and at the southern end of the inlet, but the entire inlet is subject to low dissolved oxygen levels. No load or wasteload allocations could be developed, however, without the use of a marine model. Several of the load reductions determined for fecal coliform bacteria in the marine areas and nutrients in the tributaries likely will benefit marine dissolved oxygen levels. However, the benefit of these related reductions on marine dissolved oxygen levels cannot be quantified explicitly.

Recommendations

Recommendations to improve dissolved oxygen in Henderson Inlet include the following:

- Implement the nitrogen-related recommendations for Woodland Creek (above)
- Implement the fecal-coliform-related recommendations for Henderson Inlet (above)
- Continue monitoring ammonia, nitrogen, and total nitrogen in Woodland Creek on a regular basis to quantify trends over time.
- Periodically review the operation and planned expansion of the Hawks Prairie Water Reclamation Facility, including any on-site and off-site monitoring conducted by LOTT (Lacey, Olympia, Tumwater, and Thurston County) or its consultants.
- Continue to monitor dissolved oxygen levels in Henderson Inlet, particularly using profiles developed during fall conditions.
- As part of a future South Puget Sound study, develop a model of Henderson Inlet to evaluate the relative influence of factors contributing to low dissolved oxygen levels in the marine areas, and determine load and wasteload allocations such that the inlet meets water quality standards in the future.
- Henderson Inlet should remain on the 303(d) list of impaired waters for dissolved oxygen. Monitoring confirmed that low dissolved oxygen levels occur throughout the inlet in the early fall. In the southern inlet, dissolved oxygen concentrations approach 4 mg/L, violating the water quality standards. Future studies should include an explicit dissolved oxygen model of Henderson Inlet.
- While no nutrient load reductions can be developed without an explicit dissolved oxygen model of Henderson Inlet, watershed management should include activities that reduce nutrient loads, and nitrogen loads in particular, to Henderson Inlet. Watershed recommendations relating to animal waste, on-site sewage systems, and stormwater apply for Henderson Inlet water quality as well.

TMDL Summary and Recommendations

To protect the beneficial uses of shellfish harvesting and recreational use in the Henderson Inlet basin, and to improve water quality, the following actions must occur:

- On-site sewage systems in the Henderson basin must have mandatory on-site sewage system operation and maintenance inspections on a regular basis, with emphasis on systems located along shorelines and waterways.
- Stormwater discharges to surface water must meet wasteload allocations.
- Agricultural pollution sources should be addressed in areas mentioned in the report.
- Dobbs Creek bacteria sources must be investigated and addressed.

Table 26 summaries fecal coliform bacteria load and wasteload allocations for Henderson Inlet and tributaries based on the critical condition data meeting Washington State water quality standards.

Dissolved oxygen load and wasteload shade allocations for Woodland Creek are presented in Appendix C. In addition, a wasteload allocation for 5-day biochemical oxygen demand (BOD) should be set for Nisqually Trout Farm #2 in their NPDES permit to protect dissolved oxygen levels in Woodland Creek.

Table 26. Summary of fecal coliform bacteria load and wasteload allocations for Henderson Inlet and tributaries, based on the critical condition data meeting water quality criteria.

Location	Class	Critical Period*	Fecal Coliform Reduction	Target Capacity		Allocation
				Limiting Criterion	Target Value (#/100 mL)	
Henderson Inlet						
Station 202	Marine Extraordinary	Dry	14%	90th percentile	43	Load
Station 190	"	Dry	35%	"	43	Load
Station 191	"	Dry	7%	"	43	Load
Station 194	"	Wet	10%	10% critical	33	Load
Station 195	"	Dry	35%	90th percentile	43	Load
Station 195	"	Wet	10%	10% critical	29	Load
Station 197	"	Wet	38%	90th percentile	43	Load
Station 198	"	Dry	2%	"	43	Load
Station 200	"	Wet	10%	10% critical	36	Load
Station 201	"	Dry	34%	90th percentile	43	Load
Station 185	"	Dry	78%	"	43	Load
Station 185	"	Wet	56%	"	43	Load
Station 186	"	Dry	66%	"	43	Load
Station 186	"	Wet	56%	"	43	Load
Station 187	"	Dry	59%	"	43	Load
Station 187	"	Wet	23%	"	43	Load
Station 188	"	Dry	49%	"	43	Load
Station 188	"	Wet	50%	"	43	Load
Station 189	"	Dry	59%	"	43	Load
Station 189	"	Wet	53%	"	43	Load
Station 212	"	Dry	38%	"	43	Load
Station 212	"	Wet	59%	"	43	Load

* Dry season is June-September
Wet season is November-March
Storm-event period is storm events during November-March

Table 26 (cont.). Summary of fecal coliform bacteria load and wasteload allocations for Henderson Inlet and tributaries, based on the critical condition data meeting water quality criteria.

Location	Class	Critical Period*	Fecal Coliform Reduction	Target Capacity		Allocation
				Limiting Criterion	Target Value (#/100 mL)	
Woodland Creek						
Stormwater discharge at Woodland Cr RM 3.7	Freshwater Extraordinary Primary Cont	Storm event	99%	90th percentile	100	Wasteload (Stormwater)
College Creek at RM 0.4	"	Storm event	86%	"	100	Wasteload (Stormwater)
WSDOT Stormwater discharge at Woodland Ck RM 3.1	"	Storm event	84%	"	100	Wasteload (Stormwater)
Stormwater discharge (I-5) at Woodland Cr RM 3.1	"	Storm event	91%	Geometric mean	50	Wasteload (Stormwater)
Stormwater discharge at Woodland Cr RM 2.6	"	Storm event	95%	90th percentile	100	Wasteload (Stormwater)
Palm Creek	"	Storm event	59%	"	100	Load
Fox Creek	"	Storm event	78%	"	100	Load
Quail Creek	"	Storm event	96%	"	100	Load
Woodland Creek at RM 0.2	Marine Extraordinary	Storm event	92%	"	43	Load
Woodland Creek at RM 2.6	Freshwater Extraordinary Primary Cont	Dry	43%	Geometric mean	50	Load
Eagle Creek	"	Dry	95%	90th percentile	100	Load
Jorgenson Creek	"	Dry	89%	"	100	Load
Woodland Creek at RM 0.2	Marine Extraordinary	Dry	93%	Geometric mean	14	Load
Woodard Creek						
Stormwater discharge to Taylor wetland	Extraordinary Primary Cont	Storm event	98%	90th percentile	100	Wasteload (Stormwater)
Woodard Creek at RM 6.9	"	Storm event	76%	"	100	Load
Woodard Creek at RM 0.0	Marine Extraordinary	Storm event	90%	"	43	Load
Henderson Inlet Tributaries						
Meyer Creek	Extraordinary Primary Cont	Storm event	87%	90th percentile	100	Load
Sleepy Creek	"	Storm event	88%	"	100	Load
Dobbs Creek	"	Storm event	96%	"	100	Load
Goose Creek	"	Storm event	87%	"	100	Load

* Dry season is June-September
Wet season is November-March
Storm-event period is storm events during November-March

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Appendices

Appendix A

Henderson Inlet and Tributaries Groundwater Survey

Geology and Hydrogeology

The Henderson Inlet watershed study area is composed of glacially-derived sediments overlying tertiary sedimentary rock. The area is located close to the southernmost extent of recent glacial advances. The geologic description for the study site is based on Drost et al. (1998) and Pacific Groundwater Group (1998 and 2000). Figure A-1 shows the surficial hydrogeology.

The unconsolidated material in the study area can be divided into six units. The most recent material is alluvial and deltaic sand deposited in the bottom of the Nisqually Valley. Below the alluvial and deltaic material lies the uppermost glacial unit in the area, the Vashon recessional outwash (Qvr), which is made up of sand and gravel. The Qvr covers much of the study area and, where saturated, forms unconfined or perched aquifers.

A thick layer of Vashon till underlies the recessional outwash in most areas. This "hardpan" layer consists of poorly sorted sand, gravel, and boulders that are held in a mixture of silt and clay. The till forms a confining layer that typically restricts upward flow from the underlying Vashon advance outwash (Qva) aquifer except in the McAllister Springs corridor.

The Qva aquifer underlying the till consists of gravel in a matrix of sand and is a major water source for the area. Figure A-2 shows the general groundwater flow direction in the Qva aquifer in 1988. A non-glacial silt and clay layer underlies the Vashon outwash and forms a second confining layer.

Below the non-glacial silt and clay is a second aquifer composed of undifferentiated Pre-Vashon deposits including the Salmon Springs Drift (?) and materials older and younger than Salmon Springs Drift (?). The aquifer is also referred to as the sea level (Qc) aquifer system (Pacific Groundwater Group, 2000). The Qc aquifer is composed of coarse sand and gravel and is confined in most places except in the McAllister Springs area.

Groundwater flow direction and model simulations indicate that the Qc aquifer underlying the Woodland Creek watershed flows toward McAllister Springs (Figure A-3) rather than north as the topography would indicate (USGS, 1998 and 1999). AquaTerra (1994) suggests that most of the recharge occurring in the upper Woodland Creek basin flows to McAllister Creek or Puget Sound, completely skirting Woodland Creek.

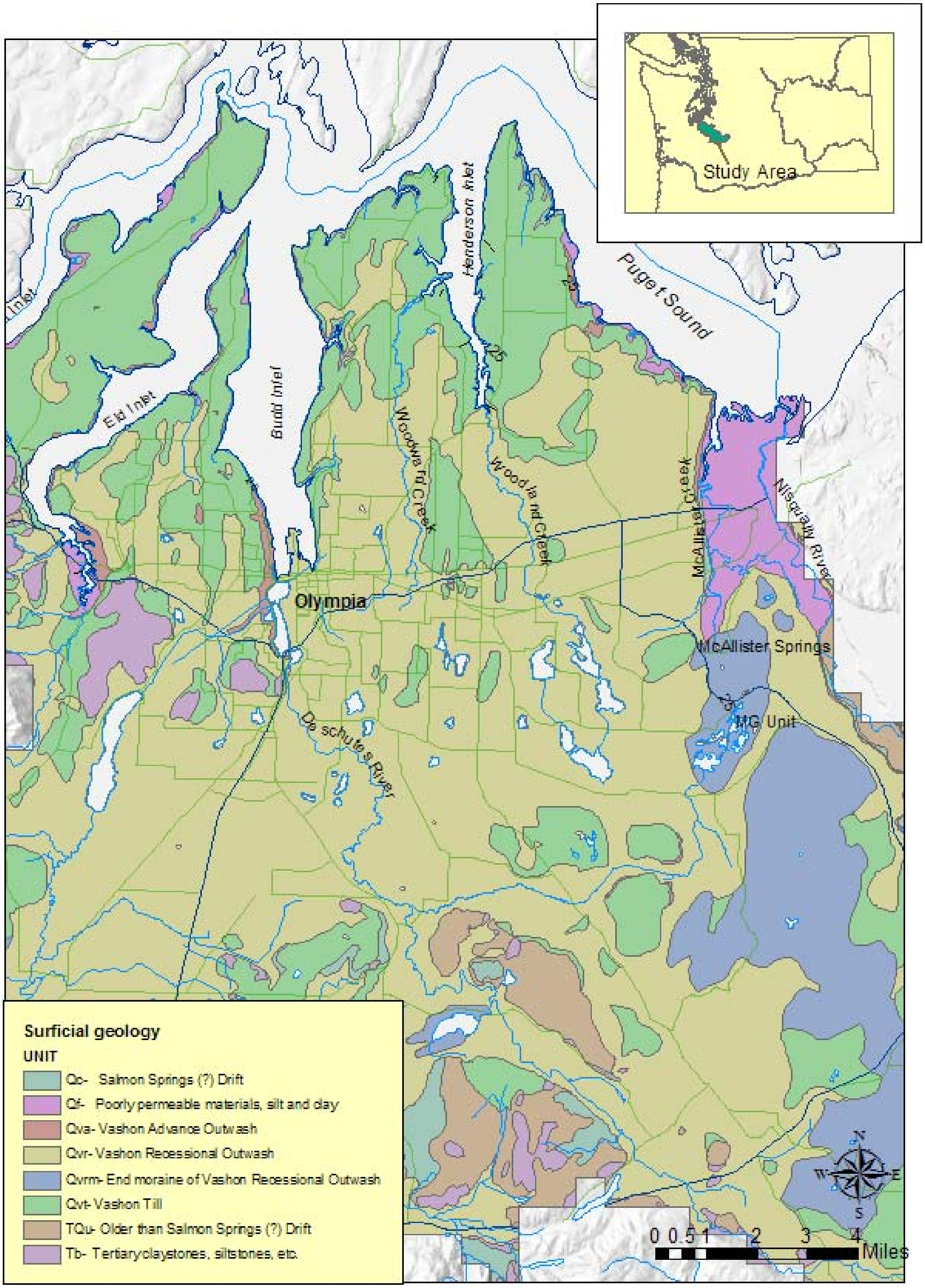

Figure A-1. Surficial geology of the Henderson-Nisqually study area (from Drost et al., 1998).

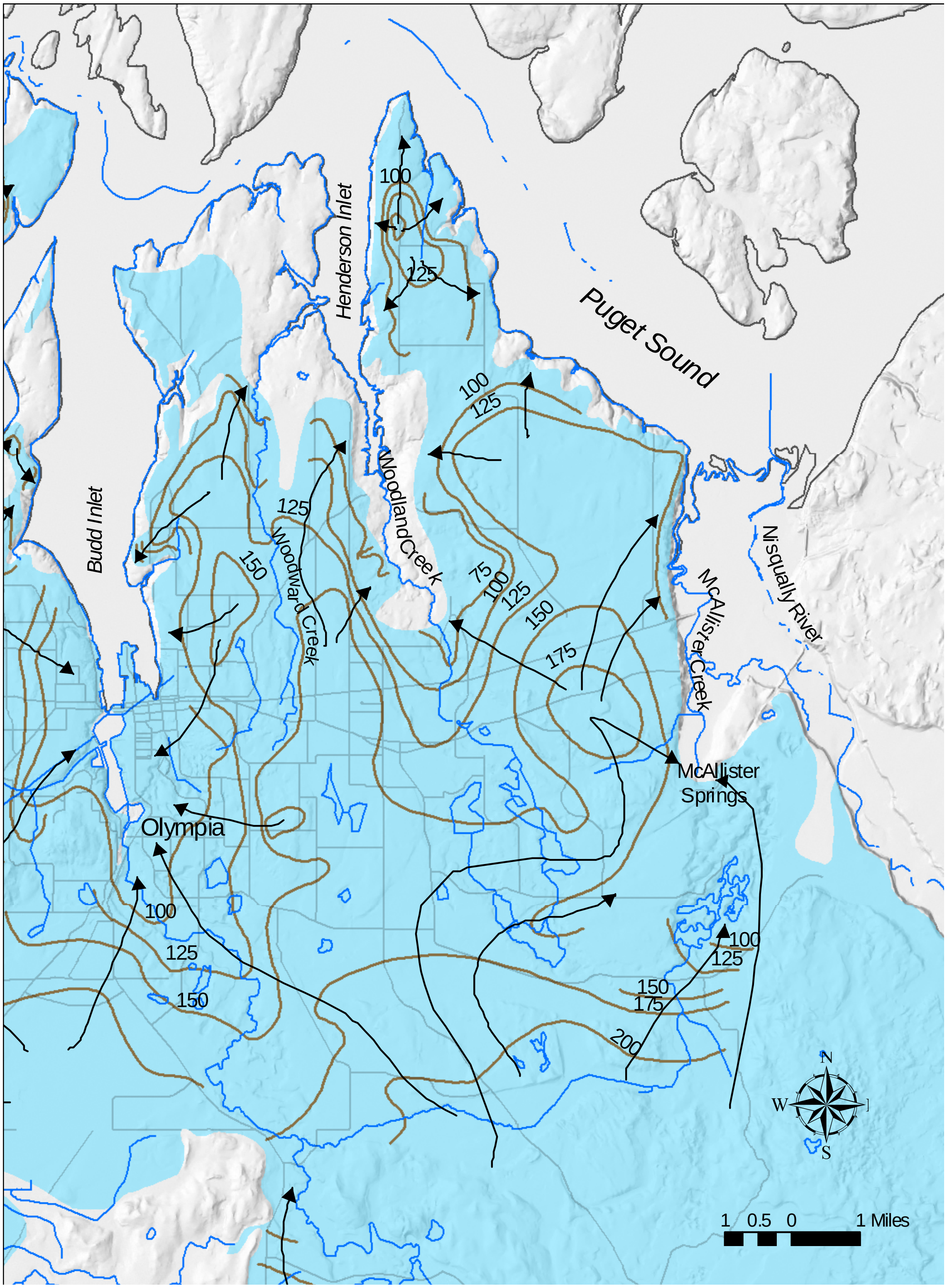

Figure A-2. Water level contours and flow direction in the Qva aquifer in 1988 (from Drost, et al, 1998).

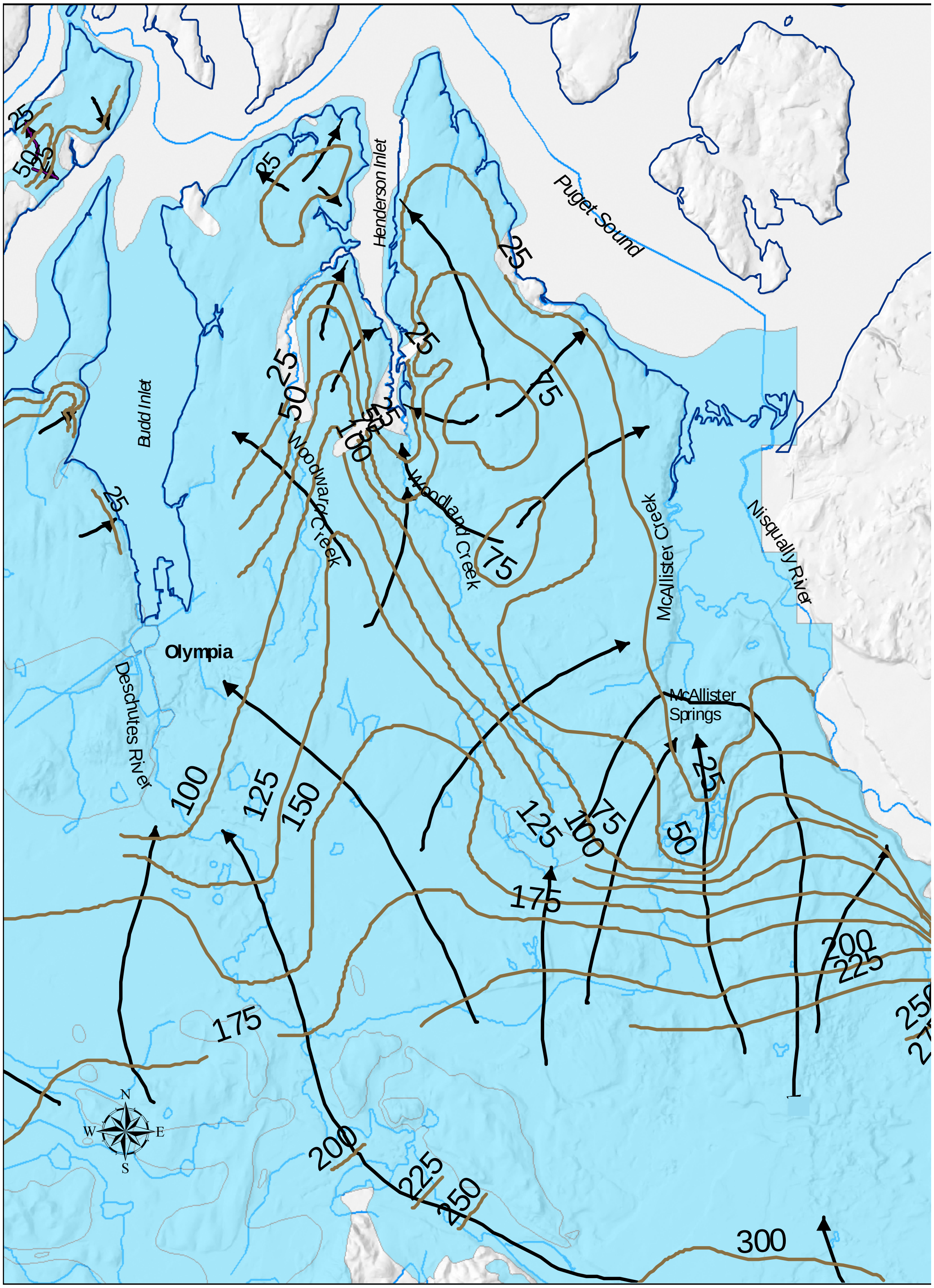

Figure A-3. Water level contours and flow directions in the Qc aquifer in 1988 (from Drost, et al., 1998).

Objectives

The objectives for groundwater analysis were to (1) assemble existing data related to groundwater flow and quality in the area and (2) sample springs representative of groundwater entering Woodland Creek or subsurface flow. This information was needed to help interpret the influence of groundwater on Total Maximum Daily Load (TMDL) analyses for Woodland Creek. Constituents investigated included temperature, conductivity, dissolved oxygen, ammonia-nitrogen, nitrate-+nitrite nitrogen, total persulfate nitrogen, total phosphorus, and orthophosphate.

Methods

Spring Selection

The criteria for selecting springs for sampling were the following:

- The spring is located near Woodland Creek and is hydraulically connected to the creek.
- The well or spring owner grants access to the well.

Groundwater Sampling

Springs selected for monitoring were field located on U.S. Geological Survey (USGS) 1:24,000 quad maps. A global positioning system (GPS) was used at each site to determine latitude and longitude for analysis and plotting via Arcview GIS software. Locations of spring sampling sites are shown in Table A-1.

Table A-1. Woodland Creek latitude and longitude references for sample sites. Values are in degrees, minutes, seconds (NAD 27).

Woodland Creek Site ID	Latitude	Longitude
St. Martin's College Spring	47 03 04 N	122 48 19 W
Beatty Springs	47 03 08 N	122 48 00 W

Figure A-4 shows the springs that were sampled in the fall of 2002 and spring of 2003. Field measurements for temperature, pH, conductivity, and dissolved oxygen were made using a WTW Multimeter.

At St. Martin's College Spring, field probes were lowered into the water in the spring house as close to the spring discharge areas as possible, and measurements were recorded until stable. Surface grab samples for laboratory analysis were collected by hand near the top of the standing water at St. Martin's College. Samples were collected on October 2, 2002 and February 26, 2003 for all parameters. Dissolved oxygen measurements were also made on April 1 and 22, 2003.

At Beatty Springs, field probes were placed in the spring discharges flowing out of the ground directly above the hatchery ponds. Laboratory samples were also collected carefully from the springs by hand. Two springs were sampled for field parameters on October 29, 2002, one near the hatchery pumphouse designated “N” for north, and the other about 20 feet south of the pumphouse designated “S” for south. The “N” site was sampled again on April 1, 2003. To protect the hatchery fish from harmful contaminants, the hatchery owner waded into the fish ponds to access the springs, took field measurements, and collected samples as requested by Washington State Department of Ecology (Ecology) staff on site.

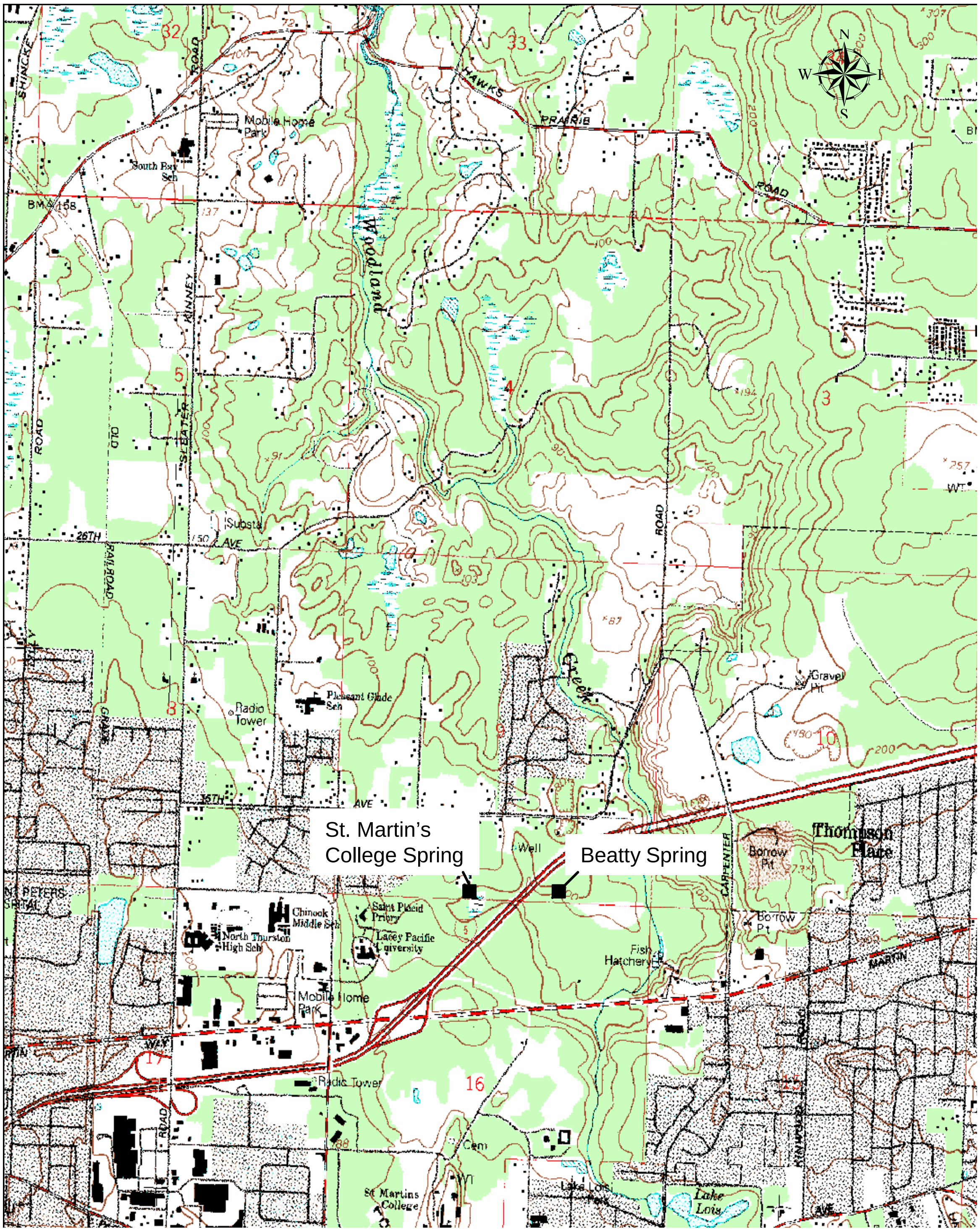

Figure A-4. Springs sampled near Woodland Creek.

Samples were analyzed for specific conductivity, ammonia-N (NH3), nitrate+nitrite-N (NO2/3), total persulfate nitrogen (TPN), total phosphorus (TP) and orthophosphate (ortho-P), chloride (Cl), and total dissolved solids (TDS). Table A-2 lists the analytical methods used. Samples were collected directly into bottles supplied by Manchester Environmental Laboratory (MEL). Sample bottles were placed on ice, maintained at 4ºC, and delivered to MEL for analysis.

Dissolved oxygen samples were collected on two dates for analysis by the Winkler Titration Method (APHA, 1998). Results of the Winkler Method were compared with results obtained with the WTW Multimeter on two occasions (see *Quality Assurance* section below).

Table A-2. Field and laboratory analysis methods used.

Analyte	Standard Methods Test Method [1]
Field	
Temperature	WTW Field Meter
pH	WTW Field Meter
Specific Conductivity	WTW Field Meter
Dissolved Oxygen	WTW Field Meter/4500-O[C]
Laboratory	
Ammonia-Nitrogen	4500-NH3 H
Nitrate+Nitrite-N	4500-NO3 I
Total Persulfate Nitrogen	4500-NO3 B Modified
Orthophosphate	4500-P G
Total Phosphorus	4500-P I
Chloride	EPA 300
Total Dissolved Solids	2540 C

[1] APHA, 1998. Standard Methods for the Examination of Water and Wastewater (20th Edition)

Quality Assurance

Laboratory Duplicates

A study of groundwater in the McAllister Creek area was conducted in tandem with the Woodland Creek groundwater study. The studies had similar objectives and methods. Therefore, quality assurance information for samples from McAllister Springs is presented as representative of Woodland Creek spring data.

Blind duplicate samples were submitted to the MEL for one well sampled in October 2002 and for samples from McAllister Springs in March 2003. Differences between the duplicate samples represent the combined variability from sampling and analysis. Results are shown in Table A-3.

Table A-3. Relative percent differences for duplicate samples from McAllister Springs, March 3, 2003.

	Conductivity Lab (uS/cm)	NH3 (mg/L)		NO2/3 (mg/L)	TPN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Cl (mg/L)	TDS (mg/L)
Sample 1	149	0.010	U	1.21	1.22	0.130	0.101	3.84	106
Sample 2	149	0.010	U	1.20	1.22	0.131	0.102	3.79	112
RPD %	0.0	0.0		0.8	0.0	0.8	1.0	1.3	5.5

U: Below the detection limit shown.

Relative percent differences (RPDs) were low for all constituents, indicating that variability due to sampling and analysis was well within acceptable limits for this study (Sargeant et al., 2003). For constituents of particular interest, the difference between both nitrate+nitrite-N and total phosphorus duplicates was 0.8%. No difference was found in conductivity values for the two sets of samples.

Dissolved Oxygen Methods Comparison

The Winkler Titration Method (APHA, 1998) for dissolved oxygen measurement was used for comparison with the WTW Multimeter on October 29, 2002 at Beatty Springs and on March 3, 2003 at McAllister Springs. In the range of interest, 4-7 mg/L, the RPD for dissolved oxygen was about 7%. The differences were not consistent on the two dates. The October 2002 multimeter result was higher than the Winkler result, and the March 2003 multimeter result was lower than the Winkler. However, the differences are within the defined accuracy limit for dissolved oxygen in this study, 15% (Sargeant et al., 2003). The Winkler Method was considered more reliable and, when both measurements were available, was used for data analysis.

Results

Results for St. Martin's College and Beatty Springs obtained during this study are shown in Appendix B, Table B-3. Mean concentrations of selected constituents are shown in Table A-4.

Table A-4. Mean values for selected constituents from St. Martin's College and Beatty Springs.

Location	Temp ^{0}C	Lab Conductivity	DO mg/L	NO2/3 mg/L	TPN mg/L	Ortho-P mg/L	TP mg/L
St Martins College Spring	10.3	177	5.3	1.75	1.82	0.036	0.036
Beatty Springs	11.6	150	6.9	2.51	2.49	0.020	0.041

Dissolved Oxygen

The mean dissolved oxygen (DO) value for Beatty Springs, 6.9 mg/L, was slightly higher than that for the St. Martin's College Spring, 5.3 mg/L. The Beatty Springs sample was taken where the spring discharges from a bank, possibly allowing some aeration before the sample was collected. The St. Martin's College Spring sample was collected in an enclosed spring house where the springs discharge several feet below the sampling site, allowing less aeration prior to sampling.

Nitrate+nitrite Nitrogen

The mean nitrate+nitrite-N concentration at Beatty Springs was 2.51 mg/L, somewhat higher than that at St. Martin's College Spring which was 1.75 mg/L. The trout farm at Beatty Springs would not be expected to account for higher nitrate+nitrite-N, because the spring discharge is upgradient of the fish pens and other facilities. However, a home site upgradient of the spring discharge, along with other further upgradient potential sources, may account for the higher nitrate+nitrite-N concentration.

Phosphorus

The mean total phosphorus concentrations were similar at the two springs, ranging from 0.036 to 0.041 mg/L.

Temperature

The mean temperature at Beatty Springs, 11.6°C, was somewhat higher than that at St. Martin's College Spring, which was 10.3°C.

Conductivity

The mean specific conductivity value at St. Martin's College Spring, 177 uS/cm, was slightly higher than that at Beatty Springs, which was 150 uS/cm.

Discussion

Groundwater Flow into Woodland Creek

Groundwater is a major contributor to streamflow in Woodland Creek, especially during the summer when precipitation is typically minimal. Because the upper portion of the creek from the outlet of Lake Lois to Martin Way is often dry from May through September, Beatty Springs is the headwater for Woodland Creek during this low-flow period. Brock and Zalewsky (2006) found that Beatty Springs contributed 49% of the flow at the mouth of the creek from May through September of 2002.

Groundwater-fed tributaries below Beatty Springs add flow to the lower part of Woodland Creek. Just below Beatty Springs, St. Martin's College Spring flows into College Creek which then flows into Woodland Creek. Flow analysis by Sargeant (2004) indicates that the St. Martin's College Spring contributes 0.9-2.5 cfs to College Creek. Water quality from this spring is assumed to be representative of spring and groundwater inputs to lower Woodland Creek and its tributaries.

During the winter when the water table rises, groundwater flow into the creek and its tributaries increases, including the upper portion between Lake Lois and Martin Way (Brock and Zalewsky, 2006).

Comparison of Ecology 2002-2003 results with 1989 USGS data for wells near Woodland Creek

Drost et al. (1998) sampled several wells in the Woodland Creek area in the spring of 1989 as part of a larger USGS study of northern Thurston County. Six of the wells were completed in the Qva and Qvr aquifers which discharge to Woodland Creek either through springs or seepage into the creek bottom and tributaries.

Table A-5 shows the results including mean and median concentrations for temperature, conductivity, dissolved oxygen (DO), and nitrate+nitrite-N for the six Woodland Creek area wells (Drost et al., 1998).

Table A-5. USGS groundwater data for eight of nine wells near Woodland Creek (USGS, 1998). Results are in mg/L except conductivity which is in uS/cm.

Well ID	Date	Geohydro-logic Unit	Depth of well (feet)	Temp C°	Conduc-tivity, Lab	DO	DO % saturation	NO3+ NO2-N	Dissolved phosphorus
18N/01W-04M01	4/27/89	Qva	77	9.5	162	3.6	31.4	1.4	0.06
18N/01W-05E03	5/1/89	Qva	46	11.5	381	0.1	0.9	<0.10	0.09
18N/01W-05G02	4/27/89	Qva	56	10.5	153	8.2	73.2	1.4	0.02
18N/01W-09J01	5/3/89	Qc	195	10.0	209	1.0	8.8	0.44	0.06
18N/01W-16Q03	6/6/89	Qf	137	11.0	105	8.4	75.7	0.75	0.03
18N/01W-22K01	5/4/89	Qvr	56	13.5	227	5.1	48.6	9.3	0.01
19N/01W-33K03	5/10/89	Qva	110	10.0	157	8.6	76.1	1.6	0.03
19N/01W-33K05	4/18/89	Qva	150	9.5	113	2.4	21.0	0.13	0.04
			Means	10.7	188	4.7	42.0	1.88	0.04
			Medians	10.3	160	4.4	40.0	1.08	0.04

A summary of the water quality in all the northern Thurston County wells (Drost et al., 1998) indicated a tendency for higher dissolved oxygen in wells completed in the Qvr unit (median = 6.7 mg/L) compared to wells in the Qva (median = 5.7 mg/L). Results from the current study are compared with USGS results below.

Temperature

Temperature values were lowest in the St. Martin's College Spring and wells near Woodland Creek sampled in 1989 (Drost et al, 1998). Both averages were 10.3°C. In contrast, the mean temperature at Beatty Springs was 11.6°C during this study. Brock and Zalewsky (2006) found a similar mean outflow temperature at the Nisqually Trout Farm discharge point to Woodland Creek. Beatty Springs flows through the trout farm. The elevated temperature at Beatty Springs could be a natural occurrence or the result of upgradient perturbation.

Dissolved oxygen

The mean dissolved oxygen at Beatty Springs was 6.8 mg/L (62% of saturation). This concentration is higher than that from all other groundwater sources evaluated, including St. Martin's College Spring with a mean of 5.2 mg/L (47% of saturation), nearby wells sampled in 1989 with a median of 4.4 mg/L (40% of saturation), and McAllister Spring where the mean in 2002-2003 was 4.5 mg/L (41% of saturation) (Sargeant et al., 2005).

Based on Drost et al. (1998) results for the larger group of northern Thurston County wells, differences in dissolved oxygen between the two springs may indicate different aquifer sources, Beatty Springs being more similar to Qvr and St. Martin's College Spring more similar to Qva.

Nitrate+nitrite nitrogen

The median nitrate+nitrite-N value for wells near Woodland Creek in 1989 was somewhat lower than the means for the springs in 2002-2003. The well median was 1.08 mg/L, while the mean for Beatty Springs was 2.5 mg/L, and that for St. Martin's College Spring was 1.8 mg/L. There was more variability in the well results than in the springs. Wells values ranged from <0.10 to 9.3 mg/L. The well with nitrate+nitrite-N below the detection also had very low dissolved oxygen concentrations, indicative of denitrifying conditions.

Phosphorus

Phosphorus results from the current study were similar to those from the 1989 sampling. The median dissolved phosphorus value for the USGS wells near Woodland Creek was 0.04 mg/L, while means for Beatty and St. Martin's College springs were between 0.03 and 0.04 mg/L.

Conductivity

Conductivity averages were similar in the three groundwater sources evaluated. Beatty Springs had the lowest mean, 150 uS/cm, about the same as that at McAllister Springs (Sargeant et al, 2005). The median for nearby wells sampled in 1989 was about 160 uS/cm. The highest mean conductivity, 177 uS/cm, was found at the St. Martin's College Spring.

The higher conductivity in some nearby wells and in the St. Martin's College Spring may be related to upgradient land uses.

Fecal coliform and fecal streptococci

Fecal coliform and fecal streptococci were not sampled for in this study. Drost et al. (1998) did not find fecal coliform or fecal streptococcus bacteria in the wells near Woodland Creek.

Conclusions

Groundwater makes up most of the summer flow in Woodland Creek downstream of Beatty Springs. The creek is usually dry upstream of Beatty Springs during the summer low-flow season. Beatty Springs makes up about one-half of the summer discharge at the mouth of the creek and is vital to maintaining current flows in the creek.

Besides its role as a major contributor to streamflow, Beatty Springs is also key in maintaining current dissolved oxygen (DO) levels in Woodland Creek. The DO concentration at Beatty Springs in the fall and spring of 2002-2003 was higher than that in all other groundwater sources evaluated. The mean DO was 6.9 mg/L or about 62% of saturation. DO inputs from groundwater seepage and other springs to the creek were roughly 15%-20% lower than those at Beatty Springs, based on results from the St. Martin's College Spring and nearby wells sampled previously.

Temperature and nitrate+nitrite-N were of somewhat lower quality in the Beatty Springs discharge than in the other groundwater inputs. The mean temperature at Beatty Springs was 11.6°C, more than 1° C higher than results from St. Martin's College Spring and nearby wells. Likewise, the median nitrate+nitrite-N concentration in Beatty Springs, 2.5 mg/L, was about 0.5 mg/L higher than at St. Martin's College Spring, McAllister Spring, and nearby wells. Phosphorus concentrations in groundwater and spring samples averaged 0.03-0.04 mg/L.

Recommendations

Beatty Springs is the backbone of Woodland Creek in terms of year-round continuous flow and relatively high dissolved oxygen. Protection measures may be needed to ensure that the quantity and quality of the spring is maintained.

Temperature and nitrate concentrations in Beatty Springs and elevated conductivity at St. Martin's College Spring may indicate upgradient effects. Potential problem sources should be investigated, and best management practices should be implemented where needed.

Appendix B

Field and Laboratory Results

Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Woodland Creek just downstream of Lake Lois outlet															
WL4.5	1/31/2003	80	50	40	30										
WL4.5	3/13/2003	49		44 J											
WL4.5	6/10/2003	no flow													
WL4.5	7/9/2003	no flow													
WL4.5	8/6/2003	no flow													
WL4.5	9/16/2003	no flow													
WL4.5	1/28/2004	130 J													
WL4.5	2/2/2004	6													
WL4.5	3/3/2004	8													
Woodland Creek downstream of Martin Way															
WL3.8	1/31/2003	300		380											
WL3.8	3/13/2003	32		28											
WL3.8	3/20/2003	21		17											
WL3.8	6/10/2003	no flow													
WL3.8	7/9/2003	no flow													
WL3.8	8/6/2003	no flow													
WL3.8	9/16/2003	no flow													
WL3.8	1/28/2004	67 J		56 J		0.010 U		0.084		0.332					
WL3.8	2/2/2004	11				0.010 U		0.094		0.309					
WL3.8	3/3/2004	7		7		0.010 U		0.033		0.270					
Stormwater discharge from pipe south side Martin Way															
WL3.7T	1/14/2003	11 J		3J											
WL3.7T	1/22/2003	7550 J		NAF											
WL3.7T	1/31/2003	4600		4500											
WL3.7T	3/13/2003	1200 J	830 J	1200 J	800										
WL3.7T	3/20/2003	880J		NAF											
WL3.7T	4/15/2003	5	4	5	5	0.010 U	0.010 U	7.91	7.94	16.10	8.54				
WL3.7T	4/21/2003	550	660	490	610	0.048	0.046	4.91	5.19	5.20	6.41				
WL3.7T	6/10/2003	no flow													
WL3.7T	7/9/2003	no flow													
WL3.7T	8/6/2003	no flow													
WL3.7T	9/16/2003	no flow													
WL3.7T	10/20/2003	1000	900	1000		0.021	0.021	0.110	0.109	0.210	0.220				
WL3.7T	1/28/2004	1200 J		1200 J		0.033		1.47		1.59					
WL3.7T	2/2/2004	590 J	970 J			0.019		4.21		4.57					
WL3.7T	3/3/2004	170				0.010 U		7.97		7.39					
Woodland Creek near headwater of Beatty Springs															
WL3.45	12/11/2002	4000 J		4000 J											
WL3.45	1/14/2003	80 J		59 J											
WL3.45	1/22/2003	2100		2000											
WL3.45	1/31/2003	1300		700											
WL3.45	3/13/2003	44	41	35	37										
WL3.45	3/20/2003	280		NAF											
WL3.45	6/10/2003	6 J		7 J		0.047		2.61		3.00		0.050		0.043	
WL3.45	7/9/2003	8	8	7	7	0.041	0.109	2.86	2.10	3.01	2.35	0.059	0.082	0.042	0.062
WL3.45	8/6/2003	15 J		15 J		0.037		3.09		3.05		0.049		0.044	
WL3.45	9/16/2003	75 J	59 J	74 J	59 J	0.033	0.035	3.23	2.80	3.82	3.51	0.044	0.044	0.043	0.043
WL3.45	1/28/2004	120 J		96 J											
WL3.45	2/2/2004	9		9											
WL3.45	3/3/2004	36		36											
Woodland Creek downstream of Nisqually Trout Farm #2															
WL3.4	12/11/2002	1100 J		770											
WL3.4	1/14/2003	9 J		6 J											
WL3.4	1/22/2003	1500		1400											
WL3.4	1/31/2003	2200		1900											
WL3.4	3/13/2003	21		18											
WL3.4	3/20/2003	220		140											
WL3.4	6/10/2003	3	1 UJ	3	1 UJ	0.154		1.94		2.38		0.083		0.064	
WL3.4	7/9/2003	2		2		0.106		2.08		2.34		0.081		0.061	
WL3.4	8/6/2003	36 J		36 J		0.174		1.93		2.02		0.076		0.066	
WL3.4	9/16/2003	43 J		39 J		0.196		1.89		2.53		0.086		0.074	
WL3.4	1/28/2004	160 J		140 J		0.074		1.08		1.37					
WL3.4	2/2/2004	14		14		0.048		1.10		1.33					
WL3.4	3/3/2004	26	33	18		0.058		1.11		1.32					

J: For bacteria indicates estimated count, samples analyzed over 24 hours after collection.
NAF: Not analyzed for.
U: Analyte was not detected at or above the reported result.

Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
College Creek (mouth), left bank tributary															
CC0.0	12/11/2003	320 J	250 J	230 J	180 J										
CC0.0	1/14/2003	57 J		51 J											
CC0.0	1/22/2003	160 J		150 J											
CC0.0	1/31/2003	170		170											
CC0.0	3/13/2003	11		11											
CC0.0	3/20/2003	27	33	16	22										
CC0.0	6/10/2003	85 J	77 J	85 J	76 J	0.010 U	0.010 U	1.05	1.03	1.07	1.07	0.054	0.043	0.036	0.036
CC0.0	7/9/2003	39		31		0.010		0.98		1.14		0.057		0.039	
CC0.0	8/6/2003	71 J		71 J		0.010 U		1.01		1.02		0.035		0.038	
CC0.0	9/16/2003	49 J		49 J		0.010 U		0.92		0.97		0.030		0.033	
CC0.0	1/28/2004	69 J				0.011		0.45		0.66					
CC0.0	2/2/2004	22		22		0.010 U		0.34		0.52					
CC0.0	3/3/2004	9		5		0.015		0.64		0.86					
College Creek at RM 0.2, behind Top Foods															
CC0.2	12/11/2002	260 J		140 J											
CC0.2	1/14/2003	69 J		66 J											
CC0.2	1/22/2003	42 J	55	NAF	43										
CC0.2	1/31/2003	145		215											
CC0.2	3/13/2003	34		26											
CC0.2	3/20/2003	28		16											
CC0.2	6/10/2003	no flow													
CC0.2	7/9/2003	no flow													
CC0.2	8/6/2003	no flow													
CC0.2	9/16/2003	no flow													
CC0.2	1/28/2004	29 J		27 J											
CC0.2	2/2/2004	57													
CC0.2	3/3/2004	9													
College Creek at RM 0.4 behind Century Court constructed stormwater ponds															
CC0.4	12/11/2002	530		530											
CC0.4	1/14/2003	17		14											
CC0.4	1/22/2003	390		370											
CC0.4	1/31/2003	390		340											
CC0.4	3/13/2003	130		120											
CC0.4	6/10/2003	no flow													
CC0.4	7/9/2003	no flow													
CC0.4	8/6/2003	no flow													
CC0.4	9/16/2003	no flow													
CC0.4	1/28/2004	220													
CC0.4	2/2/2004	63													
CC0.4	3/3/2004	130	240												
College Creek at RM 0.6 at bike path near Lacey City hall															
CC0.6	12/11/2002	200 J		120 J											
CC0.6	1/14/2003	6		3											
CC0.6	1/22/2003	420		70											
CC0.6	1/31/2003	290		240											
CC0.6	3/13/2003	1800 J		1800 J											
CC0.6	6/10/2003	no flow													
CC0.6	7/9/2003	no flow													
CC0.6	8/6/2003	no flow													
CC0.6	9/16/2003	no flow													
CC0.6	1/28/2004	230 J													
CC0.6	2/2/2004	620													
CC0.6	3/3/2004	92 J													

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Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Small stormwater pipe discharges from above I-5 culvert (north) to Woodland Creek															
WL3.1SW2	12/11/2003	630 J		630 J											
WL3.1SW2	3/13/2003	460		430											
WL3.1SW2	1/28/2004	540 J													
No flow during all other sample events															
Tributary from WSDOT vault, north I-5 culvert, right bank															
WL3.1SW	12/11/2003	2000 J		2000 J											
WL3.1SW	1/14/2003	12		12											
WL3.1SW	1/22/2003	23		15											
WL3.1SW	1/31/2003	410		250											
WL3.1SW	3/13/2003	88 J		84											
WL3.1SW	3/20/2003	21		20											
WL3.1SW	6/10/2003	3		3		0.010 U		2.52		2.93		0.035		0.010	
WL3.1SW	7/9/2003	61		57		0.016		2.09		1.96		0.056		0.012	
WL3.1SW	8/6/2003	2		2		0.131		0.61		0.73		0.097		0.011	
WL3.1SW	9/16/2003	63000 J		63000 J											
WL3.1SW	1/28/2004	23 J													
WL3.1SW	2/2/2004	1 UJ													
WL3.1SW	3/3/2004	3													
Woodland Creek just downstream of I-5															
WL3.1	12/11/2002	880	880	380	880 J										
WL3.1	1/14/2003	14	32	11	25										
WL3.1	1/22/2003	140	77	92	77										
WL3.1	1/31/2003	410		250											
WL3.1	3/13/2003	30		24											
WL3.1	3/20/2003	100	84	84	84										
WL3.1	6/10/2003	19		14		0.104		1.83		2.14		0.074		0.062	
WL3.1	7/9/2003	35		32		0.081		1.72		1.94		0.079		0.061	
WL3.1	8/6/2003	79		76		0.106		1.75		1.88		0.074		0.063	
WL3.1	9/16/2003	43		41		0.107		1.61		1.81		0.082		0.071	
WL3.1	1/28/2004	55 J	53 J	47											
WL3.1	2/2/2004	25													
WL3.1	3/3/2004	15		14											
Woodland Creek at Draham Road (downstream)															
WL2.9	12/11/2002	750	780	750	370										
WL2.9	1/14/2003	31	32	27	28										
WL2.9	1/22/2003	260	150	240	120										
WL2.9	1/31/2003	160	130	110	90										
WL2.9	3/13/2003	36		35											
WL2.9	3/20/2003	89		73											
WL2.9	6/10/2003	32		25		0.090		1.79		1.95		0.073		0.057	
WL2.9	7/9/2003	26	24	21	20	0.064	0.062	1.79	1.70	1.88	1.63	0.074	0.077	0.059	0.058
WL2.9	8/6/2003	94	92	92	92	0.075	0.078	1.72	1.70	1.80	1.77	0.069	0.068	0.061	0.061
WL2.9	9/16/2003	79	76	72	72	0.070		1.59		1.78		0.070		0.066	
WL2.9	1/28/2004	52													
WL2.9	2/2/2004	8													
WL2.9	3/3/2004	22													
Woodland Creek at 21st Court (downstream from bridge)															
WL2.6	12/11/2002	650		300											
WL2.6	1/14/2003	39	28	36	24										
WL2.6	1/22/2003	420		420											
WL2.6	1/31/2003	265		185											
WL2.6	3/13/2003	41		41											
WL2.6	6/10/2003	80		48		0.065		1.89		2.05		0.072		0.056	
WL2.6	7/9/2003	72		68		0.044		0.738		1.74		0.075		0.055	
WL2.6	8/6/2003	100		100		0.053		1.84		1.89		0.066		0.059	
WL2.6	9/16/2003	100		100		0.046		1.73		1.89		0.067		0.065	
WL2.6	1/28/2004	29	60												
WL2.6	2/2/2004	12	8												
WL2.6	3/3/2004	16													

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Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Stormwater pipe entering Woodland Creek just downstream of 21st Court NE bridge, left bank															
WL2.6SW	12/11/2002	3100 J		3100 J											
WL2.6SW	1/22/2003	380		380											
WL2.6SW	1/31/2003	530		610											
WL2.6SW	3/13/2003	880 J		880 J											
WL2.6SW	6/10/2003	not flowing													
WL2.6SW	7/9/2003	440 J	430 J	440 J	430 J	0.010 U		1.55		1.63		0.073		0.049	
WL2.6SW	8/6/2003	not flowing													
WL2.6SW	9/16/2003	not flowing													
WL2.6SW	1/28/2004	360													
WL2.6SW	2/2/2004	280													
WL2.6SW	3/3/2004	not flowing													
Woodland Creek in the Covington development															
WL2.4	1/28/2004	43													
WL2.4	2/2/2004	15													
WL2.4	3/3/2004	28													
Eagle Creek (mouth), right bank tributary															
WL2.25T	12/11/2002	420		240											
WL2.25T	1/14/2003	11		9											
WL2.25T	1/22/2003	240		220											
WL2.25T	1/31/2003	180		150											
WL2.25T	3/13/2003	29		14											
WL2.25T	6/10/2003	2900 J		2900 J		0.032		0.686		1.24		0.080		0.043	
WL2.25T	7/9/2003	130		75		0.029		0.749		1.05		0.118		0.025	
WL2.25T	8/6/2003	120	110	120	110	0.011		0.713		0.776		0.035		0.023	
WL2.25T	9/16/2003	40		37		0.010 U		0.464		0.541		0.034		0.022	
WL2.25T	1/28/2004	17													
WL2.25T	2/2/2004	3													
WL2.25T	3/3/2004	22	23												
Palm Creek (upstream from mouth), left bank tributary															
WL1.95T	12/11/2002	380		100											
WL1.95T	1/14/2003	38		8 U											
WL1.95T	1/22/2003	85		62											
WL1.95T	1/31/2003	80		70											
WL1.95T	3/13/2003	46		31											
WL1.95T	6/10/2003	180		56		0.015		2.38		2.38		0.056		0.038	
WL1.95T	7/9/2003	not flowing													
WL1.95T	8/6/2003	not flowing													
WL1.95T	9/16/2003	not flowing													
WL1.95T	1/28/2004	120													
WL1.95T	2/2/2004	9													
WL1.95T	3/3/2004	15													
Fox Creek (at Pleasant Glade Road), right bank tributary															
WL1.9T	12/11/2003	1200	880	200	100										
WL1.9T	1/14/2003	20		3											
WL1.9T	1/22/2003	130		38											
WL1.9T	1/31/2003	170		180											
WL1.9T	3/13/2003	34		20											
WL1.9T	6/10/2003	37		23		0.052		0.017		0.266		0.096		0.035	
WL1.9T	7/9/2003	26		16		0.047		0.011		0.331		0.113		0.033	
WL1.9T	8/6/2003	42		38		0.045		0.169		0.455		0.159		0.037	
WL1.9T	9/16/2003	37		33		0.035		0.010 U		0.211		0.074		0.027	
WL1.9T	1/28/2004	3													
WL1.9T	2/2/2004	10	5												
WL1.9T	3/3/2004	24													

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Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Woodland Creek at Pleasant Glade Road															
WL1.6	12/11/2002	1100		450											
WL1.6	1/14/2003	46		37											
WL1.6	1/22/2003	490		410											
WL1.6	1/31/2003	200		220											
WL1.6	3/12/2003	37		33											
WL1.6	6/10/2003	240		240		0.032		1.72		1.80		0.067		0.056	
WL1.6	7/9/2003	230		210		0.021		1.64		1.78		0.078		0.056	
WL1.6	8/6/2003	110		100		0.022		1.70		1.73		0.068		0.058	
WL1.6	9/16/2003	160		160		0.015		1.53		1.70		0.068		0.064	
WL1.6	1/28/2004	28													
WL1.6	2/2/2004	10													
WL1.6	3/3/2004	23	9												
Jorgenson Creek (mouth), left bank tributary															
WL1.2T	12/11/2002	900 J		900											
WL1.2T	1/14/2003	200		69											
WL1.2T	1/22/2003	680		490											
WL1.2T	1/31/2003	320		380											
WL1.2T	3/13/2003	46J	60 J	23	57										
WL1.2T	6/10/2003	280	225 J	160	225 J	0.010 U		1.30		1.34		0.041		0.029	
WL1.2T	7/9/2003	470		430		0.010 U		1.33		1.42		0.050		0.029	
WL1.2T	8/6/2003	930		930		0.010 U		1.37		1.36		0.031		0.026	
WL1.2T	9/16/2003	250	270	190	240	0.010 U		1.28		1.38		0.031		0.024	
WL1.2T	1/28/2004	40	35 J												
WL1.2T	2/2/2004	57	75												
WL1.2T	3/3/2004	32	42.5												
Jorgenson Creek at Pleasant Glade Road															
JORG3	9/16/2003	1400		1400											
JORG3	1/28/2004	14													
JORG3	2/2/2004	13													
JORG3	3/3/2004	410													
Quail Creek (just upstream from mouth), left bank tributary															
WL1.1T	12/11/2002	5200 J		5200 J											
WL1.1T	1/14/2003	60 J		51											
WL1.1T	1/22/2003	2300		1200											
WL1.1T	1/31/2003	265	290	258	280										
WL1.1T	3/13/2003	240		40											
WL1.1T	6/10/2003	***not sampled***													
WL1.1T	7/9/2003	190 J		190 J		0.010 U		1.13		1.15		0.055		0.035	
WL1.1T	8/6/2003	290		270		0.010 U		1.15		1.17		0.046		0.035	
WL1.1T	9/16/2003	210		200		0.010 U		1.14		1.29		0.040		0.031	
WL1.1T	1/28/2004	100	96												
WL1.1T	2/2/2004	33				0.020		0.491		0.732					
WL1.1T	3/3/2004	26													
Woodland Creek in Hollywood Development															
WL1.0	12/11/2002	220 J		120 J											
WL1.0	1/14/2003	66		43											
WL1.0	1/22/2003	290		120											
WL1.0	1/31/2003	360	320	270	370										
WL1.0	3/12/2003	84		49											
WL1.0	6/10/2003	160	180	130	130	0.027	0.023	1.65	1.62	1.74	1.72	0.069	0.067	0.054	0.054
WL1.0	7/9/2003	230	370 J	210 J	340 J	0.017	0.017	1.57	1.59	1.51	1.69	0.077	0.074	0.053	0.053
WL1.0	8/6/2003	210 J	250 J	200 J	240 J	0.017	0.020	1.62	1.60	1.60	1.61	0.067	0.065	0.055	
WL1.0	9/16/2003	120		110		0.010 U	0.010 U	1.45	1.48	1.59	1.61	0.070	0.064	0.059	0.059
WL1.0	1/28/2004	80													
WL1.0	2/2/2004	33	25			0.018	0.019	1.07	1.07	1.07	1.07				
WL1.0	3/3/2004	24				0.024		1.27		1.35					

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Table B-1: Woodland Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L	Nitrite/Nitrate mg/L	Total Persulfate Nitrogen mg/L	Total Phosphorus mg/L	Ortho-Phosphate mg/L
Woodland Creek at Hawks Prairie Road										
WL0.2	12/11/2003	310 J		210 J						
WL0.2	1/14/2003	120		80						
WL0.2	1/22/2003	740		630						
WL0.2	1/31/2003	290		210						
WL0.2	3/12/2003	80		52						
WL0.2	6/10/2003	170		130		0.028	1.50	1.59	0.072	0.055
WL0.2	7/9/2003	250 J		200 J		0.022	1.43	1.37	0.080	0.054
WL0.2	8/6/2003	230 J		220 J		0.023	1.47	1.48	0.078	0.057
WL0.2	9/16/2003	140		120		0.014	1.32	1.47	0.082	0.060
WL0.2	1/28/2004	39	40.5			0.022	1.08	1.22		
WL0.2	2/2/2004	17		16.5						
WL0.2	3/3/2004	28		25		0.023	1.18	1.29		

Table B-2: Woodland Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity (μmhos) field	Conductivity (μmhos) lab	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Woodland Creek just downstream of Lake Lois outlet										
WL4.5	1/31/2003	8:30	8.6	84			**9.0**	9.3	80	7.38
WL4.5	3/13/2003	8:40	9.8	*		7.8	**9.0**		79	7.10
WL4.5	1/28/2004	9:20	5.5		119			10.7	85	6.21
WL4.5	2/2/2004	10:35	5.2	108		6.9	12.3	12.2	96	10.78
WL4.5	3/3/2004	12.56	7.9	*		*	9.9		84	7.39
Woodland Creek downstream of Martin Way										
WL3.8	1/31/2003	9:35	8.8	75		7.1	11.2		96	10.06
WL3.8	3/13/2003	9:51	9.9	*	112	7.3	10.6	10.6	94	7.51
WL3.8	3/20/2003	10:40	*Field measurements not obtained*					11.6	93	8.23
WL3.8	1/28/2004	10:15	5.7		118					6.02
WL3.8	2/2/2004	9:15	5.1	105		7.2	11.4		90	11.38
WL3.8	3/3/2004	15.14	8.0	*		*	*	12.7	107	8.21
Stormwater discharge from pipe south side Martin Way										
WL3.7T	1/14/2003	8:41	10.2	*		7.6	11.3		101	0.05
WL3.7T	1/22/2003	8:40	6.9	*			12.6		104	2.44
WL3.7T	1/31/2003	9:00	9.7	8		6.8	11.0		97	6.81
WL3.7T	3/13/2003	9:38	10.7	*		6.9	**9.5**		85	0.38
WL3.7T	3/20/2003	10:20	*Field measurements not obtained*							2.05
WL3.7T	4/15/2003	14:40	*Field measurements not obtained*							0.19
WL3.7T	4/21/2003	11:30	*Field measurements not obtained*							0.25
WL3.7T	10/20/2003	13:30	*Field measurements not obtained*							5.51
WL3.7T	1/28/2004	9:40	7.8		46.8			12.1	102	0.71
WL3.7T	2/2/2004	8:53	7.7	101		6.9	11.5		96	0.81
WL3.7T	3/3/2004	14:50	9.6	*		*	10.9		95	0.04
Woodland Creek near headwater of Beatty Springs										
WL3.45	12/11/2002	9:25	6.6	17		6.7	10.7		87	3.30 e[1]
WL3.45	1/14/2003	10:09	9.9	*		6.7	**9.0**		79	1.40 e[1]
WL3.45	1/22/2003	10:35	7.3	*		6.4	10.2		85	4.15 e[1]
WL3.45	1/31/2003	10:35	9.1	65		6.8	9.9		86	7.59 e[1]
WL3.45	3/13/2003	11:07	10.4	*		7.0	9.9		88	5.31
WL3.45	3/20/2003	12:05	*Field measurements not obtained*							6.90
WL3.45	6/10/2003	9:40	11.5	151		7.2	**7.3**		67	1.22
WL3.45	7/9/2003	10:25	11.9	134		6.7	**6.9**		64	0.93
WL3.45	8/6/2003	8:40	11.5	139		6.7	**4.6**		43	2.94
WL3.45	9/16/2003	9:25	11.4	*		6.9	**6.5**		59	0.84
WL3.45	1/28/2004	9:20	6.7	*		6.8	10.2		83	7.15
WL3.45	2/2/2004	12:00	6.0	109		6.9	10.8		86	5.73
WL3.45	3/3/2004	11:30	7.7	99		6.9	10.3		86	6.97
Woodland Creek downstream of Nisqually Trout Farm #2										
WL3.4	12/11/2002	9:00	8.1	47		6.5	**7.4**	7.1	60	8.60
WL3.4	1/14/2003	10:00	10.1	*		6.8	**6.8**		60	3.75 e[2]
WL3.4	1/22/2003	10:22	8.0	*		6.5	**9.1**		77	10.81
WL3.4	1/31/2003	10:25	9.6	72		6.6	**9.1**		80	19.77 e[2]
WL3.4	3/13/2003	10:45	10.6	*		6.9	**8.7**		78	14.21
WL3.4	3/20/2003	11:40	*Field measurements not obtained*							14.09
WL3.4	6/10/2003	10:05	11.4	141		6.8	**6.9**		63	10.53
WL3.4	7/9/2003	10:55	11.9	129		6.5	**5.9**		55	3.59 e[2]
WL3.4	8/6/2003	8:50	11.2	130		6.5	**5.4**	5.7	52	6.21
WL3.4	9/16/2003	9:40	11.2	*		6.6	*	6.0	55	4.44
WL3.4	1/28/2004	9:55	7.8	*		6.7	**8.6**		72	19.49
WL3.4	2/2/2004	12:25	7.1	118		6.9	9.7		81	16.03
WL3.4	3/3/2004	12:05	*Field meter not functioning*					9.9	84	18.89

* Field parameter did not meet quality control objectives.

e[1:] flow estimates based on flows at WL 3.4 (r^2=0.89, n=8)

e[2:] flow estimates for 1/14 and 7/9/03 based on flows at WL 3.45 (r^2=0.89, n=8); for 1/31/03 estimates based on on-site gauge (r^2=0.67, n=14)

Table B-2: Woodland Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity field (µmhos)	Conductivity lab (µmhos)	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
College Creek (mouth), left bank tributary										
CC0.0	12/11/2002	8:35	7.0	38		6.5	**8.9**		73	4.16
CC0.0	1/14/2003	9:54	6.4	*		6.7	10.4		84	3.12
CC0.0	1/22/2003	9:45	7.0	*		6.4	**9.2**		76	6.47
CC0.0	1/31/2003	10:00	9.5	37		6.4	**9.3**		81	13.88 e3
CC0.0	3/13/2003	10:30	10.2	*		6.3	**8.6**		76	7.56
CC0.0	3/20/2003	11:24	*Field measurements not obtained*							7.00
CC0.0	6/10/2003	9:18	10.6	153		7.9	**8.3**		75	1.05
CC0.0	7/9/2003	10:00	10.7	139		7.3	**8.6**		78	0.82
CC0.0	8/6/2003	8:30	10.6	139		7.2	**7.7**		69	0.93
CC0.0	9/16/2003	9:00	10.3	*		7.5	**8.1**		72	0.86
CC0.0	1/28/2004	9:04	7.1	*	111	6.6	**9.4**		78	4.49
CC0.0	2/2/2004	11:55	5.8	79		6.8	10.1		80	6.03
CC0.0	3/3/2004	11:10	7.9	112		6.8	**9.0**		76	2.79
College Creek at RM 0.2, behind Top Foods										
CC0.2	12/11/2002	8:13	6.2	17		5.9	**7.9**		64	1.73
CC0.2	1/14/2003	9:30	5.4	*	38	6.1	*	8.2	65	1.72
CC0.2	1/22/2003	9:25	6.4	*		6.4	**8.5**	8.7	71	3.96
CC0.2	1/31/2003	10:00	9.8	18		6.4	**9.1**	8.8	78	7.14 e4
CC0.2	3/13/2003	10:17	10.1	*		6.8	**7.8**		69	2.76
CC0.2	3/20/2003	11:05	*Field measurements not obtained*							1.57
CC0.2	1/28/2004	8:40	5.9	*		6.2	**7.5**		60	0.63
CC0.2	2/2/2004	11:40	5.1	32		6.9	10.1		79	0.89
CC0.2	3/3/2004	10:50	5.3	33		6.5	**8.0**		63	0.12
College Creek at RM 0.4 behind Century Court constructed stormwater ponds										
CC0.4	12/11/2002	11:55	6.4	8		6.1	11.0		89	10.16
CC0.4	1/14/2003	12:10	6.2	*		6.3	10.5		85	0.16
CC0.4	1/22/2003	12:20	7.0	*		6.0	11.3		93	6.07
CC0.4	1/31/2003	12:35	9.5	19		6.1	9.5		84	5.89
CC0.4	3/13/2003	12:30	10.3	*		6.8	**9.2**		82	2.68
CC0.4	1/28/2004	11:40	7.0	*		6.5	10.3		85	3.3
CC0.4	2/2/2004	13:45	5.6	27		7.1	12.7		101	1.25
CC0.4	3/3/2004	11:55	6.1	*		*	**9.2**		75	1.22
College Creek at RM 0.6 at bike path near Lacey City hall										
CC0.6	12/11/2002	10:26	6.4	2		6.2	11.4		92	6.00
CC0.6	1/14/2003	11:33	7.3	*		6.0	**7.1**		59	0.02
CC0.6	1/22/2003	11:30	7.7	*		6.0	11.5		96	0.84
CC0.6	1/31/2003	11:15	9.4	25		5.9	**7.9**		69	1.57 e5
CC0.6	3/13/2003	9:05	10.2	*		7.7	**9.0**		80	0.77
CC0.6	1/28/2004	10:40	7.7		27			11.6	97	0.63
CC0.6	2/2/2004	10:00	5.7	26		6.1	10.3		82	0.70
CC0.6	3/3/2004	13:31	7.9	*		*	**8.4**		71	0.05
Small stormwater pipe discharges from above I-5 culvert (north) to Woodland Creek										
WL3.1SW2	12/11/2002	11:22	*Field measurements not obtained*							
WL3.1SW2	3/13/2003	11:50	*Field measurements not obtained*							
WL3.1SW2	1/28/2004	10:35	*Field measurements not obtained*							

* Field parameter did not meet quality control objectives.

e3: flow estimates based on on-site gauge (r^2=0.90, n=14)

e4: flow estimates based on on-site gauge (r^2=0.87, n=8)

e5: flow estimates based on flows at CC0.4 (r^2=0.80, n=7)

Table B-2: Woodland Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity (µmhos) field	Conductivity (µmhos) lab	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Tributary from WSDOT vault, north I-5 culvert, right bank										
WL3.1SW	12/11/2002	11:28	9.7	52		6.6	10.5		92	nd
WL3.1SW	1/14/2003	10:55	*Field meter malfunction*							nd
WL3.1SW	1/22/2003	16:40	*Field measurements not obtained*							0.11
WL3.1SW	1/31/2003	11:52	9.9	84		6.5	10.5		93	0.47
WL3.1SW	3/13/2003	11:50	9.9	*		6.9	10.3		91	0.24
WL3.1SW	3/20/2003	12:50	*Field measurements not obtained*							0.31
WL3.1SW	6/10/2003	11:00	*Field measurements not obtained*							0.04
WL3.1SW	7/9/2003	11:30	*Field measurements not obtained*							lf
WL3.1SW	8/6/2003	10:30	*Field measurements not obtained*							lf
WL3.1SW	9/16/2003	10:55	*Field measurements not obtained*							lf
WL3.1SW	1/28/2004	10:50	9.9	*		6.7	10.6		94	0.28
WL3.1SW	2/2/2004	11:10	10.0	115		6.7	10.8		95	0.54
WL3.1SW	3/3/2004	12:40	9.9	101		6.8	10.5		93	0.19
Woodland Creek just downstream of I-5										
WL3.1	12/11/2002	11:20	7.8	45		6.5	**8.8**	8.4	71	13.8 e6
WL3.1	1/14/2003	10:55	8.7	*		6.9	**8.4**	8.2	71	7.5 e6
WL3.1	1/22/2003	16:45	8.5	*		6.6	**8.7**	8.9	76	13.1 e6
WL3.1	1/31/2003	11:45	9.7	63		6.6	**8.6**		76	36.1 e6
WL3.1	3/13/2003	12:00	10.7	*		7.0	**8.7**		78	18.44
WL3.1	3/20/2003	12:50	*Field measurements not obtained*							19.95
WL3.1	6/10/2003	11:00	11.2	147		7.1	**7.9**	8.0	73	8.73
WL3.1	7/9/2003	11:45	11.5	131		7.0	**7.6**		70	7.47
WL3.1	8/6/2003	10:30	11.2	132		6.9	**6.9**		63	8.84
WL3.1	9/16/2003	10:55	11.0	*		7.2	**7.0**		63	5.66
WL3.1	1/28/2004	10:41	8.5	*		6.9	**8.4**	8.5	73	19.25
WL3.1	2/2/2004	11:05	7.6	113		6.9	**9.2**		77	16.9 e6
WL3.1	3/3/2004	12:35	9.2	116		6.9	**8.9**		77	18.20
Woodland Creek at Draham Road (downstream)										
WL2.9	12/11/2002	12:25	7.9	47		6.6	**8.2**		69	17.75
WL2.9	1/14/2003	14:47	8.8	*		6.9	**8.6**	8.8	76	11.24
WL2.9	1/22/2003	13:34	8.4	*		6.7	**8.9**		76	19.70
WL2.9	1/31/2003	13:50	9.7	67		6.7	**9.0**		79	31.95 e7
WL2.9	3/13/2003	12:50	10.8	*		6.9	**9.1**	8.7	79	25.15
WL2.9	3/20/2003	13:50	*Field measurements not obtained*							24.42
WL2.9	6/10/2003	12:00	11.2	152		7.0	**8.4**	8.6	78	11.10
WL2.9	7/9/2003	12:25	11.6	135		7.0	**8.4**	8.4	78	8.90
WL2.9	8/6/2003	11:05	11.3	137		6.8	**8.2**		75	9.75
WL2.9	9/16/2003	12:15	11.1	*		7.2	**7.8**		71	6.64
WL2.9	1/28/2004	12:34	8.7	*		6.6	**8.9**	9.1	78	25.54
WL2.9	2/2/2004	13:25	7.5	113		6.8	10.4	10.2	85	21.28
WL2.9	3/3/2004	12:30	9.1	118		6.9	9.6		84	20.09

* Field parameter did not meet quality control objectives.

lf: low flow could not measure flow.

e6: flow estimate for 2/2/04 based flows at WL 3.1 (r2=0.97, n=8), flow estimates for 12/02-1/03 based on SHU estimates.

e7: flow estimates based on on-site gauge (r^2=0.88, n=12)

Table B-2: Woodland Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity field (µmhos)	Conductivity lab (µmhos)	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Woodland Creek at 21st Court (downstream from bridge)										
WL2.6	12/11/2002	13:25	7.9	42		6.7	**9.1**		77	19.35
WL2.6	1/14/2003	13:20	8.9	*	140	7.0	9.7		84	12.66
WL2.6	1/22/2003	12:47	8.4	*	102	6.6	12.8	12.9	110	18.67 e8
WL2.6	1/31/2003	13:30	9.7	71		6.6	11.2	9.5	84	24.24 e8
WL2.6	3/13/2003	13:10	10.8	*	126	7.0	**9.3**		84	24.71
WL2.6	6/10/2003	12:25	11.3	156		7.1	**9.3**		85	12.81
WL2.6	7/9/2003	13:00	11.9	140		7.0	9.7		90	10.23
WL2.6	8/6/2003	11:30	11.5	142		6.9	10.1	9.9	91	11.02
WL2.6	9/16/2003	12:35	11.2	*		7.0	**9.4**		86	8.20
WL2.6	1/28/2004	13:00	8.8	*		6.7	9.9		85	23.28
WL2.6	2/2/2004	14:10	7.6	116		6.8	11.2		94	32.44
WL2.6	3/3/2004	13:25	9.1	124		6.9	9.6	9.9	86	23.65
Stormwater pipe entering Woodland Creek just downstream of 21st Court NE bridge, left bank										
WL2.6SW	12/11/2002	13:26	7.0	9		6.7	11.3			
WL2.6SW	1/22/2003	12:40	*Field measurements not obtained*					12.9		
WL2.6SW	1/31/2003	13:30	*Field measurements not obtained*							
WL2.6SW	3/13/2003	13:10	*Field measurements not obtained*							
WL2.6SW	1/28/2004	12:50	*Field measurements not obtained*							
WL2.6SW	2/2/2004	14:10	*Field measurements not obtained*							
Woodland Creek in the Covington development										
WL2.4	1/28/2004	13:15	8.8	*		6.8	9.9		85	nd
WL2.4	2/2/2004	14:35	7.6	118		6.9	10.4		87	nd
WL2.4	3/3/2004	13:40	9.1	127		7.0	9.7		84	nd
Eagle Creek (mouth), right bank tributary										
WL2.25T	12/11/2002	12:55	7.4	57		6.8	**8.5**		71	0.49
WL2.25T	1/14/2003	13:43	7.4	*		7.2	10.7		89	0.84
WL2.25T	1/22/2003	13:13	7.6	*		6.8	10.3		86	1.29
WL2.25T	1/31/2003	13:05	9.2	59		6.4	9.7		84	5.56
WL2.25T	3/13/2003	13:40	10.6	*		7.2	**9.3**		83	1.57
WL2.25T	6/10/2003	13:05	11.6	139		7.2	9.6		88	0.45
WL2.25T	7/9/2003	14:00	12.6	129		7.5	9.6	9.5	89	0.23
WL2.25T	8/6/2003	12:05	12.3	126		7.2	9.8		91	0.33
WL2.25T	9/16/2003	13:10	11.5	*		7.3	**9.3**		85	0.18
WL2.25T	1/28/2004	13:30	8.6	*		6.8	10.4		89	1.85
WL2.25T	2/2/2004	14:40	7.5	82		6.9	10.9		91	3.15
WL2.25T	3/3/2004	13:50	8.1	102		7.0	10.2		87	1.75
Palm Creek (upstream from mouth), left bank tributary										
WL1.95T	12/11/2002	15:08	7.4	74		6.8	**9.3**		77	0.16
WL1.95T	1/14/2003	14:45	6.9	*		7.0	9.8		80	0.09
WL1.95T	1/22/2003	14:30	6.8	*		6.5	10.0		82	0.55
WL1.95T	1/31/2003	14:50	8.6	58		6.4	**9.1**	9.0	77	2.63
WL1.95T	3/13/2003	15:10	10.4	*		7.2	**9.0**		80	0.70
WL1.95T	6/10/2003	15:15	10.8	144		7.5	**8.9**		80	0.01
WL1.95T	1/28/2004	16:00	7.1	*		6.8	9.6		79	0.76
WL1.95T	2/2/2004	16:40	5.5	62		6.8	10.5		83	0.91
WL1.95T	3/3/2004	16:10	6.9	89		6.9	**9.3**		76	0.39

* Field parameter did not meet quality control objectives.

nd: parameter not measured

e8: flow estimates based on on-site gauge (r^2=0.81, n=7)

Table B-2: Woodland Creek Field Data

Station	Date	Time	Temperature	Conductivity		pH	Dissolved Oxygen			Flow
Name			°C	field	lab	SU	Field	Winkler	saturation	Discharge
				(µmhos)			mg/L		%	cfs
Fox Creek (at Pleasant Glade Road), right bank tributary										
WL1.9T	12/11/2003	14:45	5.8	62		6.9	**9.2**		74	2.63
WL1.9T	1/14/2003	15:15	5.7	*		6.8	**8.8**		70	1.59
WL1.9T	1/22/2003	13:56	6.2	*		6.7	**7.9**		64	3.17 e9
WL1.9T	1/31/2003	14:20	8.8	58		6.6	**7.5**		64	6.46 e9
WL1.9T	3/13/2003	14:30	9.8	*		7.0	**8.5**		75	3.00
WL1.9T	6/10/2003	14:05	14.1	120		6.9	**4.6**		45	0.32
WL1.9T	7/9/2003	15:10	14.3	107		6.8	*	< 1.0	10	0.33
WL1.9T	8/6/2003	12:55	14.2	119		6.9	**4.5**		44	0.40
WL1.9T	9/16/2003	14:30	12.0	*		7.0	**1.9**		17	0.32
WL1.9T	1/28/2004	14:36	6.9	*		6.7	**9.0**		74	3.16
WL1.9T	2/2/2004	15:50	6.0	70		6.8	10.4		84	4.51
WL1.9T	3/3/2004	15:40	6.9	81		6.9	**8.7**	10.9	90	1.00
Woodland Creek at Pleasant Glade Road										
WL1.6	12/11/2002	14:15	7.0	53		7.0	9.9	9.9	81	21.27 e10
WL1.6	1/14/2003	15:30	8.3	*		7.3	10.5	10.4	88	9.81 e10
WL1.6	1/22/2003	14:05	8.1	*		6.9	10.0		85	23.56 e10
WL1.6	1/31/2003	14:15	9.4	69		6.8	10.8		95	49.36 e10
WL1.6	3/13/2003	14:40	10.7	89		7.2	**9.1**	9.0	81	32.80
WL1.6	6/10/2003	14:20	11.4	156		7.1	9.9	9.8	90	14.01
WL1.6	7/9/2003	15:45	12.9	142		7.3	9.6	9.7	92	10.55
WL1.6	8/6/2003	13:20	11.9	145		7.2	10.1		93	12.78
WL1.6	9/16/2003	14:05	11.3	*		7.4	9.9	9.9	91	9.92
WL1.6	1/28/2004	15:00	8.6	*		6.8	10.3	10.4	89	30.54
WL1.6	2/2/2004	16:20	7.4	108		7.0	11.2	11.4	95	42.86
WL1.6	3/3/2004	15:05	8.9	123		7.1	10.2		88	26.48
Jorgenson Creek (mouth), left bank tributary										
WL1.2T	12/11/2002	13:55	7.7	62		6.7	10.1		85	1.12
WL1.2T	1/14/2003	14:20	8.0	*		7.1	10.9		91	0.96
WL1.2T	1/22/2003	13:46	8.1	*		6.8	10.5		89	1.22 e11
WL1.2T	1/31/2003	14:04	9.0	61		6.8	10.7		93	2.62 e11
WL1.2T	3/13/2003	14:00	9.9	*		7.1	*	9.4	83	1.49
WL1.2T	6/10/2003	13:35	10.4	132		7.3	10.0		90	0.89
WL1.2T	7/9/2003	14:40	11.2	125		7.3	9.9		90	0.61
WL1.2T	8/6/2003	12:30	10.9	130		7.2	10.2	10.1	91	0.73
WL1.2T	9/16/2003	13:40	10.4	*		7.3	10.0	10.2	91	0.55
WL1.2T	1/28/2004	14:20	8.5	*		6.6	10.3	10.6	91	1.36
WL1.2T	2/2/2004	15:25	7.2	80		6.8	11.1	11.2	93	2.17
WL1.2T	3/3/2004	14:50	7.9	100		6.8	10.3	10.6	89	1.34
Jorgenson Creek at Pleasant Glade Road										
JORG3	9/16/2003	14:00	*no field data collected*							
JORG3	1/28/2004	13:50	7.9	43		6.7	10.4		88	0.35
JORG3	2/2/2004	15:05	7.3	56		6.5	10.6		88	0.71
JORG3	3/3/2004	14:35	7.6	51		6.5	10.6		89	0.24

* Field parameter did not meet quality control objectives.

e9: flow estimates based on on-site gauge (r^2=0.90, n=9)

e10: flow estimates based on Thurston County Water and Waste Management Program estimates.

e11: flow estimates based on on-site gauge (r^2=0.90, n=9)

Table B-2: Woodland Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity field (µmhos)	Conductivity lab (µmhos)	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Quail Creek (just upstream from mouth), left bank tributary										
WL1.1T	12/11/2002	15:45	7.1	68		6.8	10.0		82	0.33
WL1.1T	1/14/2003	15:30	6.4	*		6.9	10.9		89	0.41
WL1.1T	1/22/2003	13:30	6.5	*		6.9	11.2		92	1.30
WL1.1T	1/31/2003	10:30	9.2	55		7.1	*	11.0	96	3.89
WL1.1T	3/13/2003	12:20	10.1	*		7.1	10.7		95	1.16
WL1.1T	6/10/2003	*not sampled*								
WL1.1T	7/9/2003	11:30	11.7	162		7.2	9.6		89	0.16
WL1.1T	8/6/2003	11:40	12.3	156		7.3	**8.4**		78	0.44
WL1.1T	9/16/2003	14:40	11.6	*		7.2	10.2		94	0.06
WL1.1T	1/28/2004	12:15	7.0	*		6.8	13.3	13.2	109	0.75
WL1.1T	2/2/2004	11:25	5.7	56		6.4	11.4		91	1.54
WL1.1T	3/3/2004	15:50	7.6	*		*	**9.5**		79	0.11
Woodland Creek in Hollywood Development										
WL1.0	12/11/2002	7:25	7.9	67		6.7	10.3	10.2	86	19.32 e[12]
WL1.0	1/14/2003	11:15	7.7	*		7.4	10.7		89	20.27
WL1.0	1/22/2003	16:07	8.2	*		7.0	**8.3**		70	31.44 e[12]
WL1.0	1/31/2003	12:45	9.6	78		6.3	*	10.2	90	67.08
WL1.0	3/13/2003	12:50	10.5	107		7.3	10.4		93	37.48
WL1.0	6/10/2003	11:45	11.2	168		ND	10.3	10.1	92	19.22
WL1.0	7/9/2003	9:35	10.8	165		7.5	11.0		100	16.47
WL1.0	8/6/2003	9:50	11.3	163		7.5	*	10.5	96	13.48
WL1.0	9/16/2003	15:15	11.6	*		7.6	11.4		105	12.56
WL1.0	1/28/2004	12:45	8.5	*	128	7.1	13.3		114	35.57
WL1.0	2/2/2004	13:00	7.3	114		6.9	13.1		109	50.63
WL1.0	3/3/2004	11:00	8.4	*		*	10.4		89	26.34
Woodland Creek at Hawks Prairie Road										
WL0.2	12/11/2003	7:00	7.6	234		6.8	10.8		90	nd
WL0.2	1/14/2003	11:00	7.5	*		7.4	10.8		90	nd
WL0.2	1/22/2003	15:30	8.1	*		7.0	10.2		86	nd
WL0.2	1/31/2003	12:00	9.5	155		7.1	*		107	nd
WL0.2	3/13/2003	13:20	10.4	128		7.3	10.9		98	nd
WL0.2	6/10/2003	11:20	11.6	275		*	10.5		97	nd
WL0.2	7/9/2003	9:10	11.5	317		7.6	11.2		103	nd
WL0.2	8/6/2003	9:30	11.9	353		7.7	9.5		88	nd
WL0.2	9/16/2003	16:00	12.7	*		7.6	11.6		110	nd
WL0.2	1/28/2004	14:35	8.6	*		7.0	10.4		89	nd
WL0.2	2/2/2004	17:20	7.3	161		7.1	11.0		91	nd
WL0.2	3/3/2004	10:30	8.1	*		*	10.7	11.0	93	nd

* Field parameter did not meet quality control objectives.

nd: parameter not measured

e12: flow estimates based on on-site gauge (r^2=0.97, n=9)

Table B-3: Woodland Creek Area Groundwater Data

Site ID	Date	Time	Owner	Lab No.	Temp °C	pH	Conductivity uS/cm (Field)	Conductivity uS/cm (Lab)	D.O. mg/L	NH3-N mg/L	NO3+NO2 N mg/L	TPN mg/L	TP mg/L	Ortho P mg/L	Cl mg/L	TDS mg/L	FC cfu/100mL)
STM SPR	10/02/02	13:10	St. Martins College	40-8022	10.2		172	175	6.6 (M)	0.010 U	1.70	1.77	0.0355	0.0386	4.31	122	
STM SPR	02/26/03	14:20	St. Martins College	09-8005	10.4	5.98	179	179	5.5 (W)	0.010 U	1.80	1.86	na	0.0335	4.43	118	
STM SPR	04/01/03	10:08	St. Martins College						4.1 (M))								
STM SPR	04/22/03	11:15	St. Martins College		10.4	6.48	176		5.05(M)								
NTF-S	10/29/02	9:15	Nisqually Trout Farm--Closer to pump	44-8020	11.9	6.37	149	149	8.0 (W)	0.010 U	2.38	na	0.043	0.022	5.79	101	
NTF-S	10/29/02	9:15	Nisqually Trout Farm--Farther from pump						6.3 (W)								
NTF-S	04/01/03	8:50	Nisqually Trout Farm--Closer to pump	14-8005	11.2	6.55		150	6.28 (M)	0.010 U	2.64	2.49	0.038	0.018	5.65	98	1 UJ
BL-1	04/01/03	9:30	Field Blank (Lab DI H20)							0.010 U	0.010 U	0.025	0.010 U		0.10		

M= Multimeter
W= Winkler Method
U= Below detection limit shown
J= Estimate

Table B-4: Woodard Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Stormwater ditch east side of Fones Road															
SWFones	10/20/2003	2300 J		2300 J											
SWFones	11/25/2003	330													
SWFones	12/10/2003	4600 J													
SWFones	1/29/2004	240 J													
Discharge from City of Olympia stormwater ponds west of Fones Road															
SWPond	10/20/2003	2500 J		2500 J											
SWPond	11/25/2003	530													
SWPond	12/10/2003	6													
SWPond	1/29/2004	100													
Woodard Creek at bike path, Taylor wetland outlet															
WD 6.9	12/12/2002	170		150											
WD 6.9	1/14/2003	6		4											
WD 6.9	1/22/2003	120 J		72 J											
WD 6.9	1/31/2003	85		65											
WD 6.9	3/13/2003	33	43	24	35										
WD 6.9	6/10/2003	27		25		0.060		0.351		0.619		0.044		0.022	
WD 6.9	7/9/2003	57	51	40	47	0.086		0.219		0.438		0.063		0.021	
WD 6.9	8/6/2003	51	57	51	40	0.095		0.185		0.461		0.075		0.021	
WD 6.9	9/16/2003	23		23		0.137	0.137	0.086	0.086	0.556	0.564	0.087	0.081	0.024	0.025
WD 6.9	11/25/2003	34													
WD 6.9	12/10/2003	88	120												
WD 6.9	1/29/2004	36	31												
Woodard Creek between I-5 and Pacific Avenue															
WD 6.8	8/6/2003	525	550	520	540	0.078	0.079	0.251	0.252	0.498	0.505	0.0684	0.0664	0.021	0.020
WD 6.8	9/16/2003	230		200		0.113		0.161		0.562		0.0723		0.023	
WD 6.8	11/25/2003	200													
WD 6.8	12/10/2003	20													
WD 6.8	1/29/2004	110													
Woodard Creek at Ensign Road															
WD 6.2	12/12/2002	170		150											
WD 6.2	1/14/2003	6		4											
WD 6.2	1/22/2003	120 J		72 J											
WD 6.2	1/31/2003	80	90	60	70										
WD 6.2	3/13/2003	33	43	24	35										
WD 6.2	6/10/2003	27		25		0.020		0.107		0.279		0.038		0.017	
WD 6.2	7/9/2003	57	51	40	47	0.033	0.034	0.031	0.031	0.240	0.230	0.073	0.072	0.013	0.013
WD 6.2	8/6/2003	51	57	51	40	0.033	0.037	0.047	0.047	0.210	0.210	0.048	0.048	0.012	0.013
WD 6.2	9/16/2003	23		23		0.012		0.026		0.229		0.024		0.012	
WD 6.2	11/25/2003	34													
WD 6.2	12/10/2003	88	120												
WD 6.2	1/29/2004	36	31												
Tributary to Woodard Creek joins just downstream of RM 6.2															
WD 6.2T	11/25/2003	34													
WD 6.2T	12/10/2003	18													
WD 6.2T	1/29/2004	29 J													
Woodard Creek at Lindell Road															
WD 5.1	12/12/2002	130	660	130	550										
WD 5.1	1/14/2003	74	54	66	51										
WD 5.1	1/22/2003	460	570	390	530										
WD 5.1	1/31/2003	290		310											
WD 5.1	3/13/2003	100		100											
WD 5.1	6/10/2003	230		170		0.027		0.556		0.732		0.046		0.022	
WD 5.1	7/9/2003	190		160		0.116		0.473		0.842		0.078		0.023	
WD 5.1	8/6/2003	380		320		0.023		0.648		0.765		0.0390		0.020	
WD 5.1	9/16/2003	400	485	380	470	0.010 U	0.010 U	0.497	0.496	0.693	0.691	0.0339	0.0316	0.021	0.023
WD 5.1	11/25/2003	170													
WD 5.1	12/10/2003	22													
WD 5.1	1/29/2004	71													

J: For bacteria indicates estimated count, samples analyzed over 24 hours after collection.
NAF: Not analyzed for.
U: Analyte was not detected at or above the reported result.

Table B-4: Woodard Creek Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Woodard Creek at 28th Lane															
WD 4.3	11/25/2003	85													
WD 4.3	12/10/2003	20													
WD 4.3	1/29/2004	61													
Woodard Creek at 36th Avenue															
WD 3.4	12/12/2002	690		640											
WD 3.4	1/14/2003	92		84											
WD 3.4	1/22/2003	610		500											
WD 3.4	1/31/2003	210		310											
WD 3.4	3/13/2003	77	150	77	100										
WD 3.4	6/10/2003	360	430	330	430	0.010 U	0.011	0.805	0.793	0.928	0.957	0.041	0.041	0.022	0.022
WD 3.4	7/9/2003	100		85		0.011		0.835		0.870		0.058		0.023	
WD 3.4	8/6/2003	340		330		0.010		0.918		1.00		0.047		0.024	
WD 3.4	9/16/2003	110		100		0.010 U		0.824		0.985		0.032		0.023	
WD 3.4	11/25/2003	110													
WD 3.4	12/10/2003	12													
WD 3.4	1/29/2004	130													
Woodard Creek off of Libby Road															
WD 2.9	12/12/2002	680	850	660	660										
WD 2.9	1/14/2003	104	54	99	49										
WD 2.9	1/22/2003	300		280											
WD 2.9	1/31/2003	170		170											
WD 2.9	3/13/2003	100		62											
WD 2.9	6/10/2003	180	100	120	96	0.010 U	0.010 U	0.787	0.774	0.521	0.912	0.040	0.0425	0.022	0.022
WD 2.9	7/9/2003	92		72		0.010 U		0.807		0.958		0.054		0.023	
WD 2.9	8/6/2003	480	480	450	480	0.010 U	0.010 U	0.900	0.879	0.947	0.944	0.0366	0.036	0.025	0.024
WD 2.9	9/16/2003	110		92		0.010 U		0.777		0.927		0.0311		0.023	
WD 2.9	11/25/2003	85				0.010		0.428		0.753					
WD 2.9	12/10/2003	27	27			0.014		0.47		0.904					
WD 2.9	1/29/2004	220	150			0.021		0.498		0.835					
Woodard Creek at Woodard Bay Road															
WD 0.0	12/12/2002	80		70											
WD 0.0	1/14/2003	69 J		63 J											
WD 0.0	1/22/2003	480 J	495 J	460	485										
WD 0.0	1/31/2003	220		220											
WD 0.0	3/13/2003	92		69											
WD 0.0	6/10/2003	170 J		92 J		0.010 U		0.709		0.772		0.057		0.066	
WD 0.0	7/9/2003	100 J		88 J		0.156		0.375		0.666		0.022		0.072	
WD 0.0	8/6/2003	81 J		73 J		0.042		0.397		0.593		0.126		0.086	
WD 0.0	9/16/2003	23		20		0.078		0.197		0.463		0.090		0.076	
WD 0.0	11/25/2003	100 J				0.032		0.340		0.709					
WD 0.0	12/10/2003	9				0.055		0.321		0.726					
WD 0.0	1/29/2004	180				0.025		0.367		0.687					

J: For bacteria indicates estimated count, samples analyzed over 24 hours after collection.

NAF: Not analyzed for.

U: Analyte was not detected at or above the reported result.

Table B-5: Woodard Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity (µmhos)		pH SU	Dissolved Oxygen			Flow Discharge cfs
				field	lab		Field (mg/L)	Winkler (mg/L)	saturation (%)	
Stormwater ditch east side of Fones Road										
SWFones	10/20/2003	14:05	nd	nd		nd	nd			6.24
SWFones	11/25/2003	9:30	4.3	7		7.3	12.4		95	1.14
SWFones	12/10/2003	11:56	6.3	18		*	8.7	8.6	70	0.03
SWFones	1/29/2004	11:35	9.2	4		7.1	9.6	9.9	86	1.09
Discharge from City of Olympia stormwater ponds west of Fones Road										
SWPond	10/20/2003	14:35	nd	nd		nd	nd			3.37
SWPond	11/25/2003	9:54	4.3	10		7.1	12.4		95	0.85
SWPond	12/10/2003	12:12	7.9	98		*	5.6		48	0.01
SWPond	1/29/2004	12:05	9.1	14		6.8	10.7		93	1.24
Woodard Creek at bike path, Taylor wetland outlet										
WD 6.9	12/12/2002	13:30	7.7	74		6.6	6.0	5.9	50	0.75
WD 6.9	1/14/2003	14:30	5.5	107		6.6	5.8	5.6	45	0.36
WD 6.9	1/22/2003	9:45	7.2	91		7.0	8.2		68	1.55
WD 6.9	1/31/2003	8:30	10.0	59		6.8	*	5.5	49	5.45
WD 6.9	3/13/2003	9:30	9.8	97		6.7	5.9	5.4	48	1.47
WD 6.9	6/10/2003	16:10	14.1	59		6.7	4.6		45	0.82
WD 6.9	7/9/2003	14:45	14.4	131		6.8	4.5		44	0.41
WD 6.9	8/6/2003	16:00	15.8	142		6.8	3.5		35	0.27
WD 6.9	9/16/2003	9:40	11.9	142		6.7	4.8		44	0.15
WD 6.9	11/25/2003	5:02	4.8	59		6.6	7.5	7.3	57	4.35
WD 6.9	12/10/2003	12:40	5.9	90		*	5.1	4.8	39	0.96
WD 6.9	1/29/2004	12:30	8.1	84		6.7	7.5		64	5.71
Woodard Creek between I-5 and Pacific Avenue										
WD 6.8	8/6/2003	14:15	14.4	123		6.8	5.5	5.6	54	0.19
WD 6.8	9/16/2003	11:22	11.9	132		7.1	*	6.7	62	0.08
WD 6.8	11/25/2003	11:00	5.0	57		6.8	7.7	7.4	58	4.49
WD 6.8	12/10/2003	13:15	5.9	90		*	7.2		58	1.23
WD 6.8	1/29/2004	13:05	8.2	76		6.5	7.1		61	3.58
Woodard Creek at Ensign Road										
WD 6.2	12/12/2002	14:20	8.0	60		6.5	5.5		46	4.68
WD 6.2	1/14/2003	14:00	6.5	108		6.7	6.7		54	2.70
WD 6.2	1/22/2003	10:30	7.2	92		7.0	8.3		68	5.64
WD 6.2	1/31/2003	9:30	9.7	75		6.9	7.8		69	8.16
WD 6.2	3/13/2003	10:10	10.3	72		6.9	6.8		61	5.26
WD 6.2	6/10/2003	15:30	14.8	159		6.8	3.2	2.7	27	2.19
WD 6.2	7/9/2003	13:20	15.2	131		6.7	2.3	2.3	23	1.38
WD 6.2	8/6/2003	15:20	15.2	152		6.7	2.2	2.4	24	1.42
WD 6.2	9/16/2003	10:20	12.6	130		6.8	*			0.89
WD 6.2	11/25/2003	11:30	5.4	71		7.0	8.1	8.0	63	8.37
WD 6.2	12/10/2003	14:20	6.5	88		*	6.4	6.3	51	3.50
WD 6.2	1/29/2004	13:35	8.6	95		6.7	6.8	7.0	60	13.27
Tributary to Woodard Creek joins just downstream of RM 6.2										
WD 6.2T	11/25/2003	11:16	5.4	94		7.0	8.5		67	0.53
WD 6.2T	12/10/2003	14:30	5.8	103		*	8.0		64	0.19
WD 6.2T	1/29/2004	13:25	8.5	98		6.8	7.6		65	0.57

* Field parameter did not meet quality control objectives.

nd: parameter not measured

Table B-5: Woodard Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity (µmhos)		pH SU	Dissolved Oxygen			Flow Discharge cfs
				field	lab		Field mg/L	Winkler mg/L	saturation %	
Woodard Creek at Lindell Road										
WD 5.1	12/12/2002	13:05	8.6	68		6.7	5.7		49	6.62 e
WD 5.1	1/14/2003	13:30	6.5	112		6.9	9.4	9.3	76	2.62 e
WD 5.1	1/22/2003	10:55	7.0	103		7.1	*	8.8	73	4.30 e
WD 5.1	1/31/2003	10:00	9.6	71		7.0	8.0		70	8.57 e
WD 5.1	3/13/2003	10:45	10.1	95		6.9	8.4		75	3.12 e
WD 5.1	6/10/2003	15:05	13.6	165		7.0	8.2		79	1.62 e
WD 5.1	7/9/2003	14:00	14.5	162		7.0	2.8		27	1.52
WD 5.1	8/6/2003	14:50	14.2	161		7.5	8.2		81	1.94
WD 5.1	9/16/2003	11:00	12.2	168		7.0	*			1.45 e
WD 5.1	11/25/2003	12:10	5.6	64		6.9	*	8.3	66	12.63
WD 5.1	12/10/2003	15:10	6.7	94		*	9.1	8.8	72	5.27
WD 5.1	1/29/2004	14:05	8.4	94		6.8	7.7	7.8	67	11.09
Woodard Creek at 28th Lane										
WD 4.3	11/25/2003	12:40	6.3	75		7.0	8.4	8.2	66	nd
WD 4.3	12/10/2003	15:20	6.8	96		*	9.6	9.3	76	nd
WD 4.3	1/29/2004	14:30	8.3	91		6.8	7.3	7.5	64	nd
Woodard Creek at 36th Avenue										
WD 3.4	12/12/2002	11:45	7.9	67		6.8	8.9	8.7	73	9.49
WD 3.4	1/14/2003	12:30	6.5	105		7.1	10.5		85	7.04
WD 3.4	1/22/2003	11:25	7.1	98		7.0	11.4		94	11.00
WD 3.4	1/31/2003	15:30	9.3	69		6.5	12.2		107	22.95
WD 3.4	3/13/2003	11:00	9.9	87		7.0	9.3		82	16.64
WD 3.4	6/10/2003	14:25	12.7	155		7.4	9.8	9.9	93	3.89
WD 3.4	7/9/2003	14:30	13.7	153		7.4	10.2		98	4.29
WD 3.4	8/6/2003	14:10	13.6	153		7.5	8.7		83	3.28
WD 3.4	9/16/2003	11:35	11.6	159		7.5	*	10.3	95	2.27
WD 3.4	11/25/2003	13:40	6.2	76		7.0	9.7		79	10.43
WD 3.4	12/10/2003	15:35	6.8	90		*	9.7	9.6	79	7.55
WD 3.4	1/29/2004	14:40	8.2	92		6.8	9.2		78	22.98
Woodard Creek off of Libby Road										
WD 2.9	12/12/2002	11:00	7.8	68		6.7	*	9.5	80	9.62
WD 2.9	1/14/2003	8:45	6.4	102		7.1	10.9		89	8.45
WD 2.9	1/22/2003	11:50	7.1	93		6.9				14.70
WD 2.9	1/31/2003	15:00	9.3	67		6.3	12.9		112	28.31
WD 2.9	3/13/2003	11:35	9.9	82		7.0	10.1		89	17.18
WD 2.9	6/10/2003	13:35	12.6	155		7.6	10.3	10.0	94	4.54
WD 2.9	7/9/2003	15:05	14.3	153		7.7	*	9.8	96	3.10
WD 2.9	8/6/2003	13:40	13.5	152		7.7	*	10.3	99	2.74
WD 2.9	9/16/2003	12:20	11.5	158		7.7	*			2.25
WD 2.9	11/25/2003	13:15	6.3	75		7.0	10.7		86	12.15
WD 2.9	12/10/2003	16:05	6.8	86		*	11.0		90	8.47
WD 2.9	1/29/2004	14:40	nd	nd		nd		9.3		29.49

* Field parameter did not meet quality control objectives.

nd: parameter not measured

e: flow estimates based on tape down from bridge (r^2=0.92, n=8)

Table B-5: Woodard Creek Field Data

Station Name	Date	Time	Temperature °C	Conductivity (µmhos) field	Conductivity (µmhos) lab	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Woodard Creek at Woodard Bay Road										
WD 0.0	12/12/2002	8:50	nd	nd		nd	nd			nd
WD 0.0	1/14/2003	9:20	8.6	nd		7.5	7.3		63	nd
WD 0.0	1/22/2003	15:45	7.5	1800		7.2	*	11.2	93	nd
WD 0.0	1/31/2003	10:50	9.3	5400		7.0	11.0		96	nd
WD 0.0	3/13/2003	13:50	9.5	26000		7.6	8.8		77	nd
WD 0.0	6/10/2003	10:05	13.0	5075		7.6	9.4		89	nd
WD 0.0	7/9/2003	8:50	13.9	9400		7.6	10.5		101	nd
WD 0.0	8/6/2003	9:00		6873		7.7	10.3		100	nd
WD 0.0	9/16/2003	16:30	15.8	45305		7.5	*	4.8	48	nd
WD 0.0	11/25/2003	13:00	9.4	35715		7.7	7.6		66	nd
WD 0.0	12/10/2003	13:45	8.9	34808		*	7.1		61	nd
WD 0.0	1/29/2004	15:15	nd	nd		nd	nd			nd

* Field parameter did not meet quality control objectives.

nd: parameter not measured

Table B-6: Henderson Inlet Tributaries Laboratory Data

Station Name	Date	Fecal Coliform cfu/100 mL		*E-coli* cfu/100 mL		Ammonia Nitrogen mg/L		Nitrite/Nitrate mg/L		Total Persulfate Nitrogen mg/L		Total Phosphorus mg/L		Ortho-Phosphate mg/L	
Meyer Creek at 56th Avenue															
MY 0.6	12/12/2002	380		380											
MY 0.6	1/14/2003	1 U		NAF											
Meyer Creek near Snug Harbor Drive															
MY 0.1	1/22/2003	270		255											
MY 0.1	1/31/2003	70		110											
MY 0.1	3/12/2003	1200		1100											
MY 0.1	1/28/2004	18	13	17		0.011		0.517		0.801					
MY 0.1	2/2/2004	94				0.024		0.805		1.15					
MY 0.1	3/18/2004	51				0.022		0.109		0.356					
Goose Creek at Sleater-Kinney Road															
GO 0.4	1/14/2003	7		7											
GO 0.4	1/22/2003	1500 J		1500 J											
GO 0.4	1/31/2003	190		160											
GO 0.4	3/12/2003	46		31											
GO 0.4	1/28/2004	120		120		0.021		0.178		0.876					
GO 0.4	2/2/2004	3				0.013		0.139		0.814					
GO 0.4	3/18/2004	34	45			0.035	0.035	0.203	0.204	0.721	0.740				
Sleepy Creek at Libby Road															
SL 0.8	12/12/2002	1240		1240											
SL 0.8	1/14/2003	20 J		14 J											
SL 0.8	1/22/2003	250		240											
SL 0.8	1/31/2003	160		120											
SL 0.8	3/13/2003	310	360	270	350										
SL 0.8	1/28/2004	55 J		47 J											
SL 0.8	2/2/2004	62													
SL 0.8	3/18/2004	51													
Sleepy Creek near mouth															
SL 0.1	12/12/2002	1340	820	1340	820										
SL 0.1	1/14/2003	43 J		31 J											
SL 0.1	1/22/2003	420		400											
SL 0.1	1/31/2003	90		120											
SL 0.1	3/13/2003	290		270											
SL 0.1	6/10/2003	160		100		0.017		0.191		0.401		0.085		0.062	
SL 0.1	7/9/2003	660		560		0.010		0.134		0.250		0.112		0.078	
SL 0.1	8/6/2003	510		360		0.013		0.161		0.281		0.115		0.102	
SL 0.1	9/16/2003	77		69		0.010U		0.069		0.188		0.112		0.093	
SL 0.1	1/28/2004	55 J		52 J		0.010U		0.057		0.279					
SL 0.1	2/2/2004	40				0.010U		0.068		0.255					
SL 0.1	3/18/2004	4 J				0.014		0.047		0.363					
Dobbs Creek upstream of farm															
DB 1.7	3/18/2004	27													
DB 1.7	4/21/2004	7 J	6 J												
Dobbs Creek ditch tributary															
DB 1.4T	3/18/2004	18													
DB 1.4T	4/21/2004	3 J													
Dobbs Creek just downstream of farm															
DB 1.2	3/18/2004	36													
DB 1.2	4/21/2004	14 J													
Dobbs Creek just upstream of campground															
DB 1.0	3/12/2003	120		85											
DB 1.0	7/9/2003	260		220		0.058		0.010 U		0.349		0.046		0.014	
DB 1.0	8/6/2003	250		240		0.046		0.202		0.394		0.036		0.021	
DB 1.0	1/28/2004	3300 J		3300 J											
DB 1.0	2/2/2004	830				0.023		0.216		0.466					
DB 1.0	2/25/2004	14		14		0.040		0.105		0.373					
DB 1.0	3/18/2004	2													
DB 1.0	4/21/2004	80 J													
Small tributary near Johnson Point Road															
DB 0.1T	1/22/2003	53		37											
Dobbs Creek near Johnson Point Road															
DB 0.1	12/12/2002	270		270											
DB 0.1	1/14/2003	660		640											
DB 0.1	1/22/2003	6000 J		5800 J											
DB 0.1	1/31/2003	290		230											
DB 0.1	3/13/2003	670 J		630											
DB 0.1	6/10/2003	270 J		260 J		0.068		0.460		0.672		0.032 J		0.047	
DB 0.1	7/9/2003	80		72		0.010 U		0.704		0.775		0.068		0.045	
DB 0.1	8/6/2003	240		190		0.010 U		0.738		0.726		0.050		0.045	
DB 0.1	9/16/2003	300		270		0.010 U		0.672		0.722		0.045		0.045	
DB 0.1	1/28/2004	915		915		0.018		0.297		0.546					
DB 0.1	2/2/2004	380				0.011		0.308		0.523					
DB 0.1	2/25/2004	22		19		0.016		0.497		0.681					
DB 0.1	3/18/2004	41				0.011		0.622		0.767					
DB 0.1	4/21/2004	92 J													

J: For bacteria indicates estimated count, samples analyzed over 24 hours after collection.
NAF: Not analyzed for.
U: Analyte was not detected at or above the reported result.

Table B-7: Henderson Inlet Tributaries Field Data

Station Name	Date	Time	Temperature °C	Conductivity (µmhos) field	Conductivity (µmhos) lab	pH SU	Dissolved Oxygen Field mg/L	Dissolved Oxygen Winkler mg/L	Dissolved Oxygen saturation %	Flow Discharge cfs
Meyer Creek at 56th Avenue										
MY 0.6	12/12/2002	9:30	7.9	37		5.4	9.0		76	0.01
MY 0.6	1/14/2003	10:30	6.3	87		5.5	7.3		59	0.18
Meyer Creek near Snug Harbor Drive										
MY 0.1	1/22/2003	15:00	7.5	233		6.7	13.5		112	0.78
MY 0.1	1/31/2003	11:30	8.9	172		6.9	11.3		98	1.24
MY 0.1	3/12/2003	14:50	9.2	100		7.0	11.0		96	1.59
MY 0.1	1/28/2004	15:30	7.4	840		6.9	13.4		112	0.11
MY 0.1	2/2/2004	9:45	5.9	247		6.9	14.5		116	0.34
MY 0.1	3/18/2004	10:00	8.8	6130		7.2	11.5		99	nd*
Little or no flow in Meyer Creek for the low flow sample events (June-September 2003)										
Goose Creek at Sleater-Kinney Road										
GO 0.4	1/14/2003	10:45	nd*	nd*		nd*	nd*			nd*
GO 0.4	1/22/2003	13:50	7.5	68		5.6	9.7		81	0.14
GO 0.4	1/31/2003	13:45	8.5	58		5.8	11.4		98	0.62
GO 0.4	3/12/2003	14:25	8.9	41		6.1	9.9		86	0.34
GO 0.4	1/28/2004	12:00	5.6	32		6.2	11.3		90	0.15
GO 0.4	2/2/2004	11:10	4.8	23		5.6	10.2		79	0.73
GO 0.4	3/18/2004	10:30	8.1	33		6.8	11.4		97	nd*
No flow in Goose Creek for the low flow sample events (June-September 2003) and the December 12, 2002 sampling										
Sleepy Creek at Libby Road										
SL 0.8	12/12/2002	10:45	8.4	78		6.2	9.8		84	0.33
SL 0.8	1/14/2003	10:15	5.3	42		6.1	8.7		69	nd
SL 0.8	1/22/2003	13:10	6.7	51		5.9	10.8		89	nd
SL 0.8	1/31/2003	14:45	9.1	35		5.9	10.6		92	nd
SL 0.8	3/13/2003	16:00	9.7	39		6.2	8.9		79	nd
SL 0.8	1/28/2004	11:20	6.1	41		7.8	10.7		87	nd
SL 0.8	2/2/2004	11:00	4.8	35		6.8	10.6		83	nd
SL 0.8	3/18/2004	9:30	8.2	38		7.1	8.4		71	nd
No flow in Sleepy Creek at Libby Road for the low flow sample events (June-September 2003)										
Sleepy Creek near mouth										
SL 0.1	12/12/2002	10:10	7.9	81		6.8	10.5		88	0.33
SL 0.1	1/14/2003	9:45	5.4	45		6.7	12.0		95	4.18
SL 0.1	1/22/2003	12:40	6.8	46		6.6	12.8		104	13.58
SL 0.1	1/31/2003	14:15	9.1	36		6.0	13.2		114	33.95
SL 0.1	3/13/2003	15:30	9.7	36		6.6	10.9		96	20.10
SL 0.1	6/10/2003	10:30	12.9	151		7.8	9.4		89	nd*
SL 0.1	7/9/2003	16:00	15.4	243		7.7	9.3		93	nd*
SL 0.1	8/6/2003	13:10	14.5	243		7.6	5.9		58	nd*
SL 0.1	9/16/2003	13:15	12.3	247		7.9	11.1		103	nd*
SL 0.1	1/28/2004	10:45	6.2	41		7.0	12.0		97	6.33
SL 0.1	2/2/2004	10:20	4.9	35		6.9	11.5		90	13.72
SL 0.1	3/18/2004	9:00	8.3	66		7.4	11.8		100	0.25
Dobbs Creek upstream of farm										
DB 1.7	3/18/2004	9:30	7.7					11.3	95	0.03
DB 1.7	4/21/2004	11:20	8.5		53					0.01
Dobbs Creek ditch tributary										
DB 1.4T	3/18/2004	9:50	7.7					11.1	93	0.15
DB 1.4T	4/21/2004	11:36	9.5		38					0.05
Dobbs Creek just downstream of farm										
DB 1.2	3/18/2004	10:12	7.4					10.8	90	0.21
DB 1.2	4/21/2004	11:55	9.3		44					0.06
Dobbs Creek just upstream of campground										
DB 1.0	3/12/2003	14:00	nd	nd		nd	nd			8.64
DB 1.0	7/9/2003	11:00	nd*	nd*		nd*	nd*			nd*
DB 1.0	8/6/2003	11:15	nd*	nd*		nd*	nd*			nd*
DB 1.0	1/28/2004	14:15	6.5	45		7.0	11.1		90	3.69
DB 1.0	2/2/2004	13:30	5.4	38		6.6	12.0		95	11.24
DB 1.0	2/25/2004	15:20	field notes missing							
DB 1.0	3/18/2004	10:55	8.7	nd		nd	nd	11.5	99	0.30
DB 1.0	4/21/2004	10:36	9.5	nd	71	nd	nd			0.03
Little or no flow at this site for the low flow sample events (June-September 2003)										
Small tributary near Johnson Point Road										
DB 0.1T	1/22/2003	14:35	nd	nd		nd	nd			3.12
Dobbs Creek near Johnson Point Road										
DB 0.1	12/12/2002	15:15	8.6	78		7.0	9.7	9.7	90	1.39
DB 0.1	1/14/2003	not sampled no access							83	
DB 0.1	1/22/2003	14:30	7.0	57		7.0	12.9			13.70
DB 0.1	1/31/2003	12:15	9.0	46		nd	16.6		106	29.27
DB 0.1	3/12/2003	13:30	9.1	51		7.4	11.2		144	12.01
DB 0.1	6/10/2003	9:30	11.2	150		7.6	10.7		97	0.79
DB 0.1	7/9/2003	10:40	11.3	142		7.8	11.4		98	0.77
DB 0.1	8/6/2003	11:00	11.7	146		7.7	9.8		104	0.94
DB 0.1	9/16/2003	14:00	11.3	141		7.9	11.9	11.9	90	10.40
DB 0.1	1/28/2004	14:40	7.1	110		7.0	11.4	11.7	109	8.13
DB 0.1	2/2/2004	9:15	5.4	56		6.9	13.1		96	15.64
DB 0.1	2/25/2004	15:00	field notes missing		202				104	
DB 0.1	3/18/2004	10:40	8.9	nd		nd	nd	11.7		1.51
DB 0.1	4/21/2004	12:30	9.5	nd	158	nd	nd		101	1.19

* Field parameter did not meet quality control objectives.

nd: parameter not measured

nd*: water level too low, parameter not measured

Appendix C

Woodland Creek Temperature Recommendations for Reach between Beatty Springs to Henderson Inlet

Introduction

Originally, the analysis performed for the Woodland Creek Temperature Total Maximum Daily Load (TMDL) included a model of the current and potential riparian vegetation in order to set shade load allocations to bring the system into compliance with temperature standards. In upper Woodland Creek, from the outlet of Long Lake to just downstream of Martin Way, the amount of achievable shade alone is predicted to be insufficient to meet temperature standards. The upper segment of Woodland Creek experiences low-flow and no-flow conditions during a majority of the year. In addition, streamflow in these portions of the creek is derived from a series of shallow lakes which frequently reach temperatures of 24°C during the summer months.

The analysis did not investigate the influence of hydrology, including the interaction of groundwater or the impacts of groundwater withdrawals, on streamflow dynamics and stream temperatures in Woodland Creek or include a model to predict the background (natural) temperature condition of the system. Therefore, before a TMDL for temperature can be established for Woodland Creek, more analysis is required to determine a background temperature condition for the upper portion of Woodland Creek, from Long Lake to Beatty Springs. Once a background temperature condition has been determined for this reach of the stream, a TMDL, including load allocations and wasteload allocations, can be established.

Lower Woodland Creek, between Beatty Springs and the mouth, meets the Class AA temperature standard of 16°C. The data clearly demonstrate that water temperatures in lower Woodland Creek are stabilized by inflow from the numerous springs and groundwater-fed tributaries and a well-established riparian condition along most reaches. However, in order to continue meeting water quality standards in the future, effective shade recommendations were developed. Finally, wasteload allocations were established for the Nisqually Trout Farm and for all existing and future stormwater sources of pollution which enter this reach of Woodland Creek.

Applicable Water Quality Criteria

Within the state of Washington, water quality standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Authority to adopt rules, regulations, and standards as are necessary to protect the environment is vested with the state Department of Ecology. Under the federal Clean Water Act, the EPA regional administrator must approve the water quality standards adopted by the state (Section 303(c)(3)). Through adoption of these water quality standards, Washington has designated certain characteristic uses to be protected and the criteria necessary to protect these uses [Chapter 173-201A Washington Administrative Code (WAC)]. These standards were last adopted in November 1997.

Woodland Creek and its tributaries are designated Class AA (extraordinary) as defined by the Water Quality Standards for Surface Waters of the State of Washington (Hicks, 2000; WAC 201A-030 and WAC 173-201A-120).

The water quality standards establish beneficial uses of waters, and incorporate specific numeric and narrative criteria for parameters such as water temperature. These criteria are intended to define the level of protection necessary to support characteristic uses (Rashin and Graber, 1992). The characteristic uses of the waters in this specific area are:

- *Recreation:* Fishing and swimming.
- *Fish and Shellfish:* Anadromous salmonid species in the basin include chinook salmon, chum salmon, coho salmon, and steelhead trout.
- *Water Supply & Stock Watering:* Agriculture extracts water for irrigation and stock watering.
- *Wildlife Habitat:* Riparian areas are used by a variety of wildlife species which are dependent on the habitat.

The water quality standards establish criteria for temperature to protect these characteristic uses. The intent behind the standards is that human alterations of the watershed, or direct discharges to the waterbody, shall not cause the established criterion for any parameter to be exceeded.

This study finds that the Woodland Creek basin has been significantly altered by human activity: forest clearing for agriculture, timber harvest and development, clearing and degradation of riparian zones, changes in the historic flow regime, and decreases in groundwater recharge. These human activities, combined with what may be natural conditions in the system, explain why the current temperature criterion of 16.0°C for this Class AA waterbody is not being met at many locations.

Under these conditions the temperature criterion in the water quality standards requires that for Class AA waters:

"Numeric water quality criteria for Class AA freshwater streams state that temperature shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increases will be allowed which will raise the receiving water temperature greater than 0.3°C".

"If natural conditions are below 16.0°C, incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C or bring the stream temperature above 16.0°C at any time (Chapter 173-201A-030 WAC)".

The July 2003 proposed temperature standards do not use the Class AA and A distinction but depend on whether streams are or could be salmonid or trout core-rearing or non-core-rearing waterbodies. However, streams that were previously identified as Class AA are designated as salmonid or trout spawning, core rearing, and migration streams, which must not exceed a 7-day average maximum temperature threshold of 16°C (the previous standard also used 16°C, but as the instantaneous maximum temperature). Streams that were previously identified as Class A are designated as salmonid or trout spawning, non-core rearing, and migration streams, which must not exceed a 7-day average maximum temperature threshold of 17.5°C. This project evaluates the ability to meet the standards in effect at the time this report is written.

Temperature is a water quality concern because most aquatic organisms, including salmonids, are cold-blooded and are strongly influenced by water temperature (Schuett-Hames et al., 1999). Temperature is a concern in Woodland Creek because of the use of its waters by coho as a migration corridor and as spawning and rearing habitat. Although, 89% of the coho found in Woodland Creek are hatchery fish (Squaxin Island Tribe, 2001). Elevated temperature and altered flow regime, resulting from various land-use activities such as agriculture and urban development in the area, limit available spawning and rearing habitat for coho salmon and other anadromous salmonids.

Ecology 2002 Temperature Monitoring

Water and air temperatures in the Woodland Creek watershed were monitored continuously during the summer and fall of 2002. The Quality Assurance Project Plan (Zalewsky, 2002) describes the data collection program and methods.

Eleven mainstem and three tributary monitoring stations were established within the study area (Figure C-1). Figure C-2 summarizes the maximum daily temperatures in Woodland Creek and tributaries on the hottest day of 2002 at each station. Figure C-3 summarizes the maximum 7-day averages of daily maximum temperatures in Woodland Creek and tributaries during 2002. As expected, stream temperature regimes within the upper portion of Woodland Creek from Martin Way to the outlet of Long Lake are markedly different than those in the lower section of the creek downstream of Beatty Springs.

Lower Woodland Creek

All mainstem and tributary stations located within the lower portion of Woodland Creek, between Beatty Springs and the mouth, met the Class AA temperature standard of 16°C (Figure C-4). The only exception to this was Fox Creek, which recorded daily maximum temperatures over 16°C but below 17°C. Maximum daily stream temperatures in Fox Creek exceeded the Class AA standard of 16°C (max = 16.8°C) on nine of the 108 days sampled; however, this station was located just downstream of a wetland area, and water temperatures appear to experience the natural heating typically associated with these conditions.

The data clearly demonstrate that water temperatures in lower Woodland Creek are stabilized by inflow from the numerous springs and groundwater-fed tributaries. The average outflow temperature of Beatty Springs between May and September was 11.7°C. Flow from Beatty Springs during this same time period averages 49% of the measured flow at the mouth of Woodland Creek. Maximum stream temperatures in Eagle Creek and Jorgensen Creek were well below the Class AA criteria at 14.1°C and 11.9°C, respectively. *In-situ* temperature measurements in Quail Creek and other springs and seeps within this reach averaged 10 to 14°C.

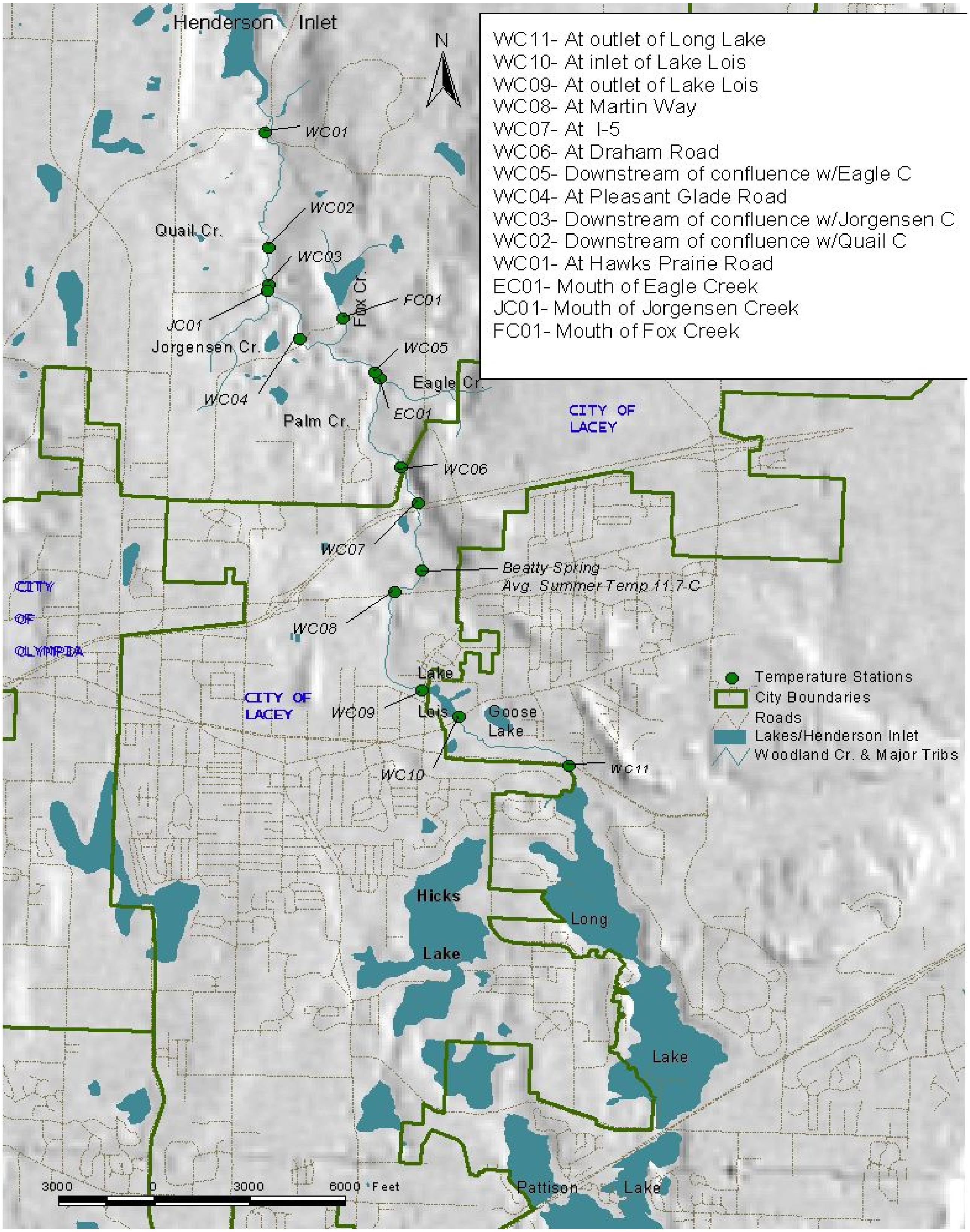

Figure C-1. Ecology 2002 temperature monitoring sites in the Woodland Creek watershed.

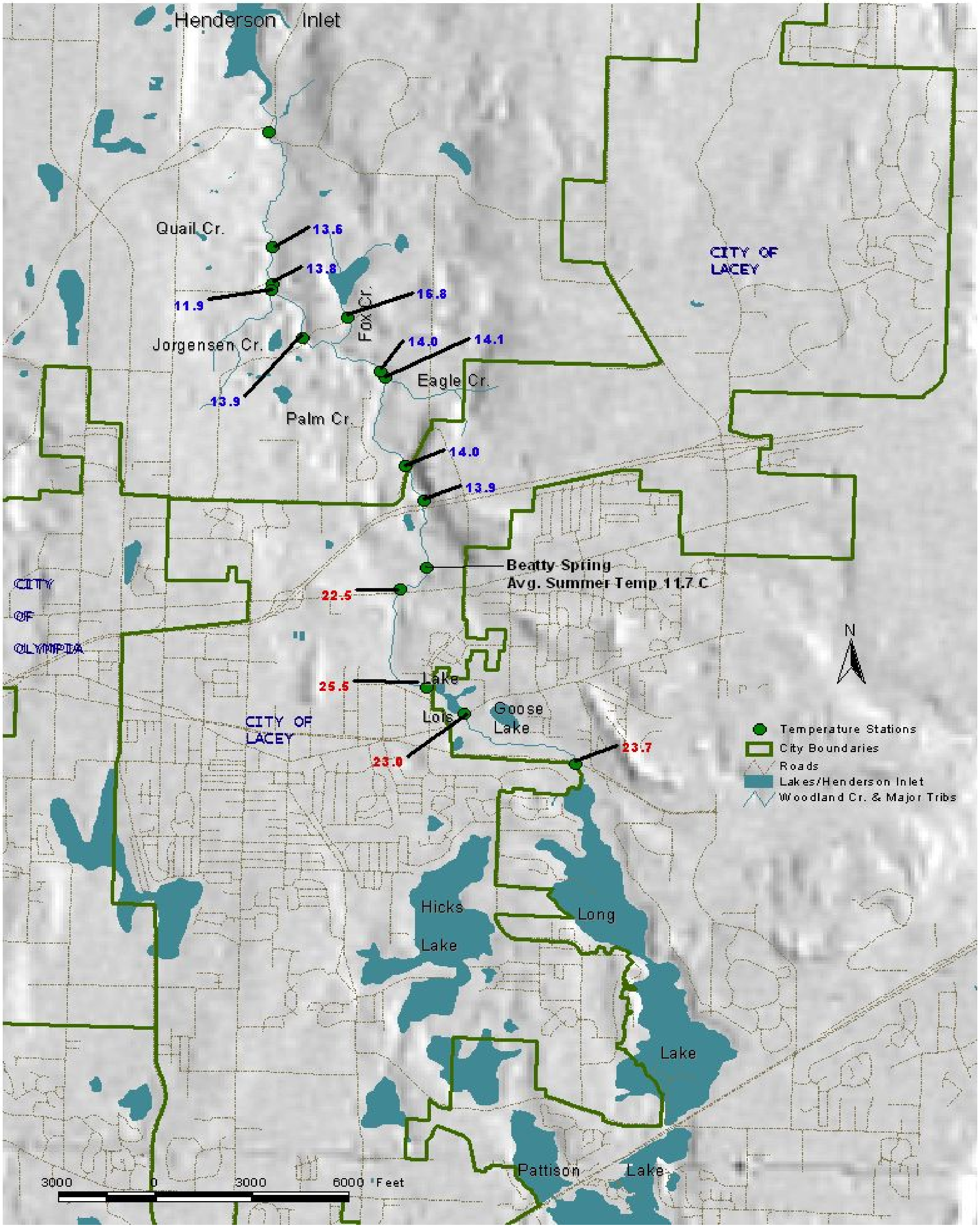

Figure C-2. Maximum daily temperatures in Woodland Creek and tributaries in 2002 on the hottest day of the year at each station. Exceedances of the numeric temperature criterion of 16°C are shown in red.

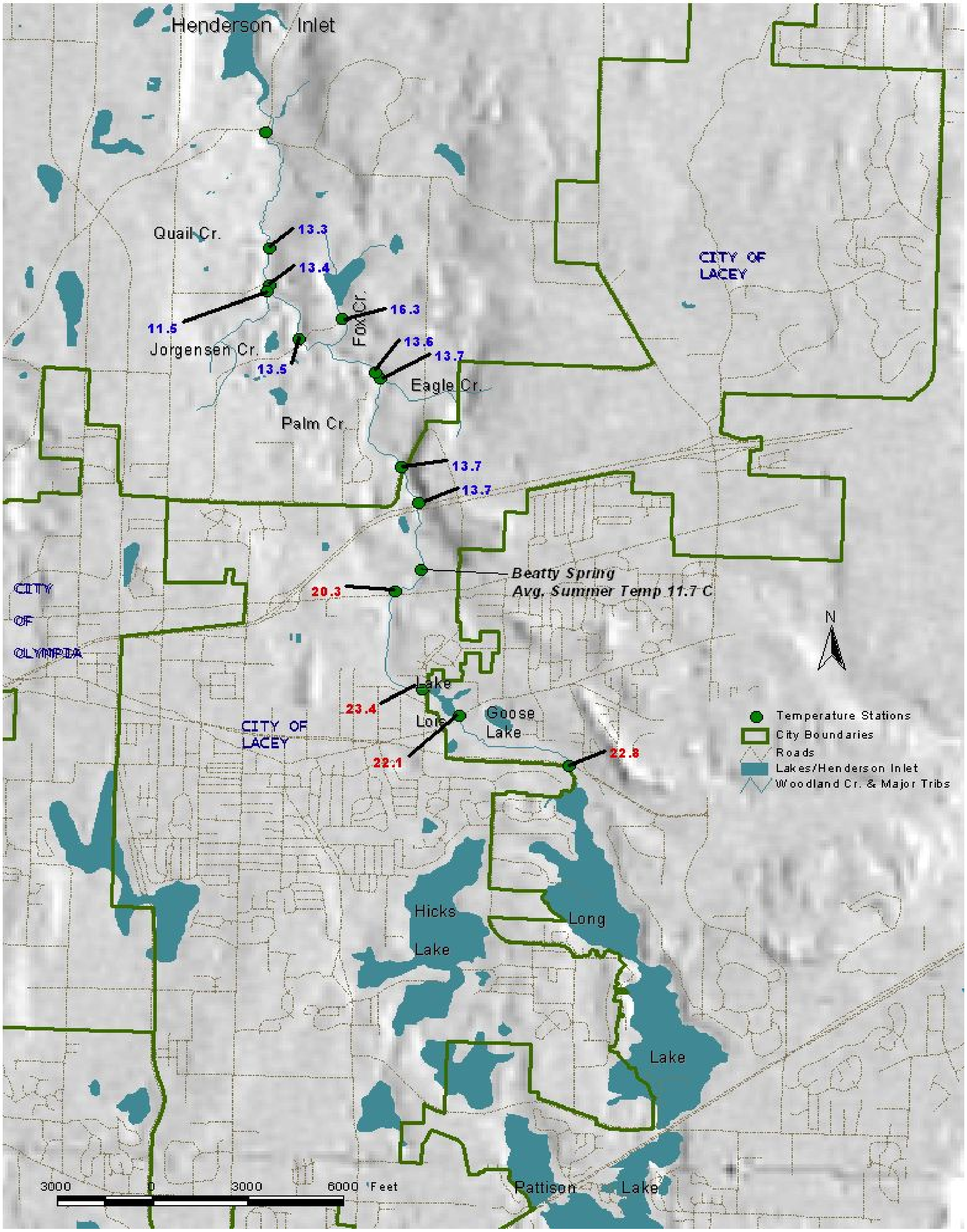

Figure C-3. Maximum 7-day averages of daily maximum temperatures in Woodland Creek and tributaries in 2002.

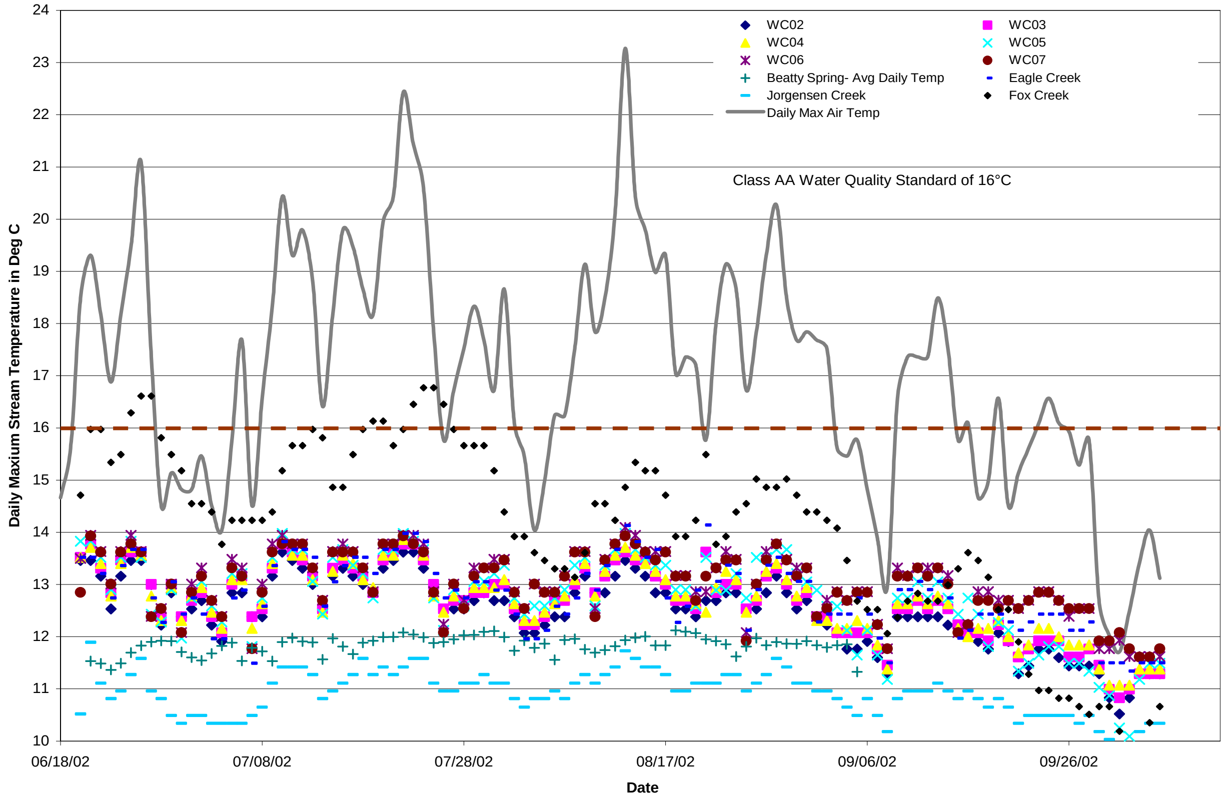

Figure C-4. Stream temperature profiles in Lower Woodland Creek.

Station WC01, located at Hawks Prairie Road, exhibited the highest stream temperatures during the study period. Closer examination of the data revealed that the thermistor at this station was placed at a location which went dry during low tide conditions. Consequently, water temperatures during these time periods more closely reflect ambient air temperatures. Further, since this station is tidally impacted, the temperature regime is controlled to a large extent by the inflow of marine water. Effective shade recommendations for this station were not generated due to marine influence and thermistor location.

Effective Shade Technical Analysis

The technical analysis for temperature in Woodland Creek focuses primarily on documentation of the current temperature and flow regime, and on effective shade. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade is a function of several landscape and stream geometric relationships. Some of the factors that influence effective shade include the following:

- Latitude and longitude
- Time of year
- Stream aspect and width
- Vegetation buffer height, width, overhang, and canopy density
- Topographic shade angles

Riparian height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (produce shade). The solar position has a vertical component (altitude) and a horizontal component (azimuth) that are both functions of time/date (solar declination) and the earth's rotation (hour angle). While the interaction of these shade variables may seem complex, the math that describes them is relatively straightforward geometry, much of which was developed decades ago by the solar energy industry.

Percent effective shade is perhaps the most straightforward stream parameter to monitor/ calculate and is easily translated into quantifiable water quality management and recovery objectives. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The measured solar load at the stream surface can easily be measured with hemispherical photography or estimated using mathematical shade simulation computer programs (Boyd, 1996).

Effective shade was calculated for Woodland Creek using the Shade Model developed by the Oregon Department of Environmental Quality (ODEQ, 2000) and modified by Ecology (2003). Effective shade calculations were verified with field data. Table C-1 illustrates the accuracy of the effective shade calculations against hand-held densiometer measurements.

Table C-1. Comparison of calculated and measured effective shade.

Station	Average calculated effective shade (%) using Shade Model	Average effective shade (%) calculated from densiometer measurements	Percent difference
WC08	97.2	100	1.8
WC06	87.3	93	6.1
WC05	87.8	93	5.6
WC04	86.2	84	2.6
WC03	79.3	74	7.2
WC02	73.6	76	3.2
		Average % Difference	6.8

At one time, forests of Western hemlock, Western red cedar, and Douglas fir covered approximately two-thirds of the watershed area (Turner, 1993). Much of the original forests were cut in the late nineteenth century, and much of the second-growth Douglas fir was cut again during the past 50 years.

Riparian vegetation characteristics, including height and density, were used to estimate current effective shade along the mainstem of Woodland Creek. Vegetation polygons were estimated from the most recent orthophotos[1] within 300 ft (91 m) of the centerline of Woodland Creek. Vegetation species, height, and canopy-cover categories were assigned to each polygon, based on visual interpretation and field observations during the habitat surveys. Polygon attributes were verified or refined in the field using observations of vegetation type and a laser range finder for vegetation height at all accessible locations. Densiometer readings were also taken at two to three cross sections upstream of each temperature monitoring location.

[1] Woodland Creek riparian zone orthophotos were available from Thurston County, WA. The 2001 imagery covered the entire Woodland Creek riparian zone, from the mouth to Hicks, Pattison, and Long lakes.

Riparian vegetation size and density was sampled at 162-foot (50-m) intervals along the mainstem of Woodland Creek using the Ttools Extension for ArcView that was developed by ODEQ (2001). At each stream transect location, the vegetation grid was sampled orthogonal to the stream at 14-ft (4.6 m) wide riparian zone intervals, starting at the wetted edge and progressing to 135 ft (41 m) from each side of the stream. Other spatial data calculated at each transect location include stream aspect, as well as topographic shade angles to the west, south, and east. Stream widths were determined from field measurements taken during Ecology stream surveys.

Effective shade was calculated for two scenarios of vegetation:

- Current riparian vegetation based on field and spatial data for height and canopy density.
- Maximum effective shade from fully established 100-year-old riparian vegetation. Vegetation heights for riparian vegetation were obtained using soil site index (SI) information, which was taken from the Soil Survey of Thurston County, WA (USDA, 1990) (Table C-2). SI is a measure of the potential productivity of a site and is based primarily on soil conditions. SI for a soil is typically given for 50 and 100 years and describes, among other things, the dominant tree species and heights of the dominant tree species found on that site.

Table C-2. Vegetation characteristics for riparian soil types in Woodland Creek (USDA, 1990).

Landmarks	Distance downstream from headwaters (m)	Common tree species	Soil type	100-yr SI (m) Red alder	100-yr SI (m) Douglas fir	Height (m) of tallest trees
Beatty Springs (3500 m)	3200-3950	Douglas fir, Red alder	Schneider very gravelly loam		46	46
	3950-4704	Douglas fir, Red alder	Hoogdal silt loam		51	51
	4704-5856	Douglas fir, Red alder	Giles silt loam		53	53
	5856-7707	Red alder, W. Red cedar	Bellingham silty clay loam	37		37
Henderson Inlet	7707-9009	Salt tolerant grasses	Hydraquents, tidal	na	na	na

Figure C-5 presents predicted effective shade along Woodland Creek from just downstream of Martin Way near Beatty Springs to Henderson Inlet near Hawks Prairie Road. Lower Woodland Creek is fairly heavily vegetated with second- and third-growth forests and dense stands of alder and maple within the riparian zone. Riparian openings do exist and are located primarily within residential areas. Current effective shade ranges from 33 to 94% and is reflective of areas where vegetation has been cleared and where topographic shading has an influence on the stream channel. Future riparian vegetation differs little in species type and height compared to current vegetation. Canopy densities within this reach were adjusted from 80% to 85% to reflect a greater canopy closure, which was assumed to develop with time.

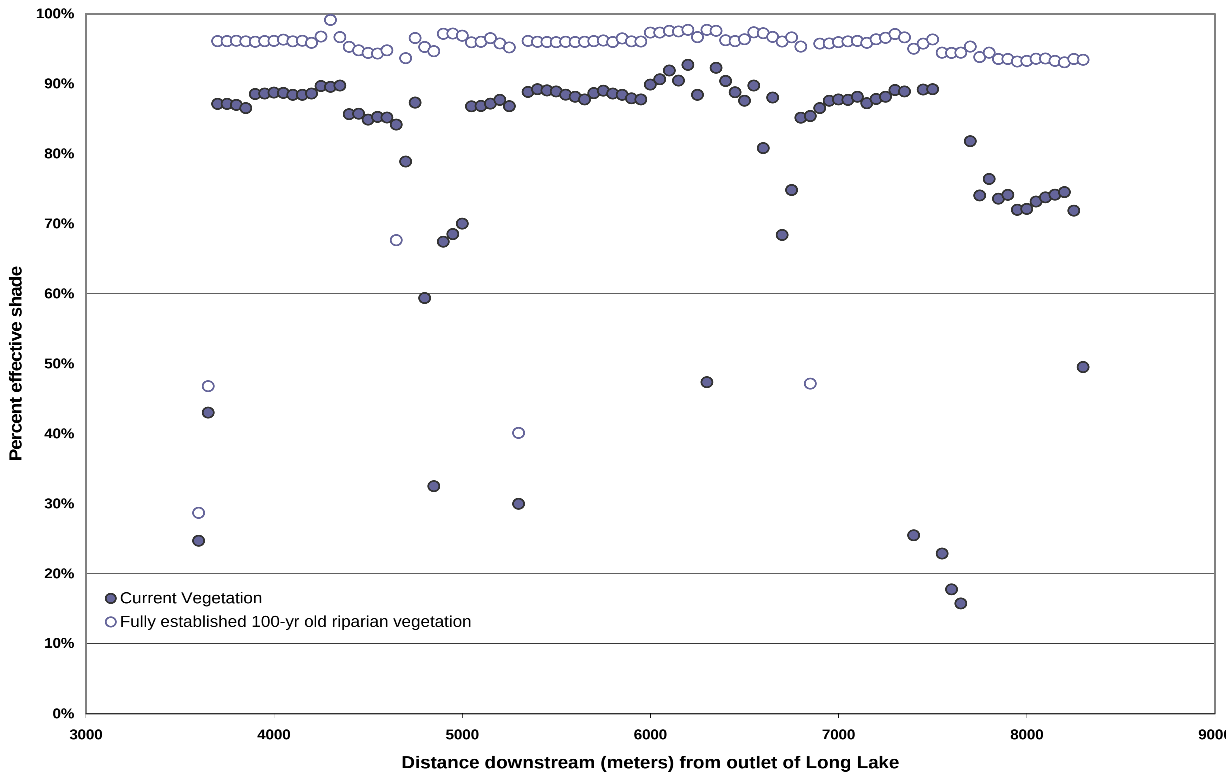

Figure C-5. Current and future condition riparian effective shade for Woodland Creek from just downstream of Beatty Springs to the zone of tidal influenced vegetation near Hawks Prairie Road.

Effective Shade Recommendations

Shade is very important as a means of intercepting sunlight and reducing the energy that is transferred to the surface of the stream. The thicker and taller the canopy, the less direct solar energy reaches the water surface over the course of the day.

A secondary consequence of near-stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures by decreasing daily maximum and increasing daily minimum air temperatures. Increases in relative humidity result from evapotranspiration that is occurring by riparian plant communities. Wind speed is reduced by the physical blockage produced by riparian vegetation.

Recommendations for effective shade were developed for Woodland Creek between Beatty Springs and Henderson Inlet. Targets are suggested for this reach of the creek, which meets Class AA water quality criteria, to prohibit degradation in the future. These effective shade targets are the effective shade that would result from fully established 100-year-old riparian vegetation (Table C-3 and Figure C-6).

Table C-3. Recommendations for effective shade in the Woodland Creek mainstem from Martin Way to Henderson Inlet (Reach 3).

River Mile (distance from mouth)	Distance in meters from outlet of Long Lake	Current condition average effective shade (percent)	Load allocation for effective shade on August 1 (percent)
2.9	3600	25%	29%
	3650	43%	47%
	3700	87%	96%
2.75	3750	87%	96%
	3800	87%	96%
	3850	87%	96%
	3900	89%	96%
	3950	89%	96%
	4000	89%	96%
	4050	89%	96%
	4100	88%	96%
	4150	88%	96%
2.5	4200	89%	96%
	4250	90%	97%
	4300	90%	99%
	4350	90%	97%
	4400	86%	95%
	4450	86%	95%
	4500	85%	94%
	4550	85%	94%
2.25	4600	85%	95%
	4650	84%	85%
	4700	79%	94%
	4750	87%	97%
	4800	59%	95%
	4850	33%	95%
	4900	68%	97%
	4950	69%	97%
2.0	5000	70%	97%
	5050	87%	96%
	5100	87%	96%
	5150	87%	97%
	5200	88%	96%
	5250	87%	95%
	5300	30%	40%
	5350	89%	96%
1.75	5400	89%	96%
	5450	89%	96%
	5500	89%	96%
	5550	89%	96%
	5600	88%	96%
	5650	88%	96%
	5700	89%	96%
	5750	89%	96%
1.5	5800	89%	96%

Table C-3 continued. Recommendations for effective shade in Woodland Creek mainstem from Martin Way to Henderson Inlet (Reach 3).

River Mile (distance from mouth)	Distance in meters from outlet of Long Lake	Current condition average effective shade (percent)	Load allocation for effective shade on August 1 (percent)
	5950	88%	96%
	6000	90%	97%
	6050	91%	97%
	6100	92%	98%
	6150	91%	98%
1.25	6200	93%	98%
	6250	88%	97%
	6300	47%	98%
	6350	92%	98%
	6400	90%	96%
	6450	89%	96%
	6500	88%	96%
	6550	90%	97%
1.0	6600	81%	97%
	6650	88%	97%
	6700	68%	96%
	6750	75%	97%
	6800	85%	95%
	6850	85%	86%
	6900	87%	96%
	6950	88%	96%
0.75	7000	88%	96%
	7050	88%	96%
	7100	88%	96%
	7150	87%	96%
	7200	88%	96%
	7250	88%	97%
	7300	89%	97%
	7350	89%	97%
0.5	7400	26%	95%
	7450	89%	96%
	7500	89%	96%
	7550	23%	94%
	7600	18%	94%
	7650	16%	95%
	7700	82%	95%
	7750	74%	94%
0.25	7800	76%	95%
	7850	74%	94%
	7900	74%	94%
	7950	72%	93%
	8000	72%	93%
	8050	73%	94%
	8100	74%	94%
	8150	74%	93%
0	8200	75%	93%

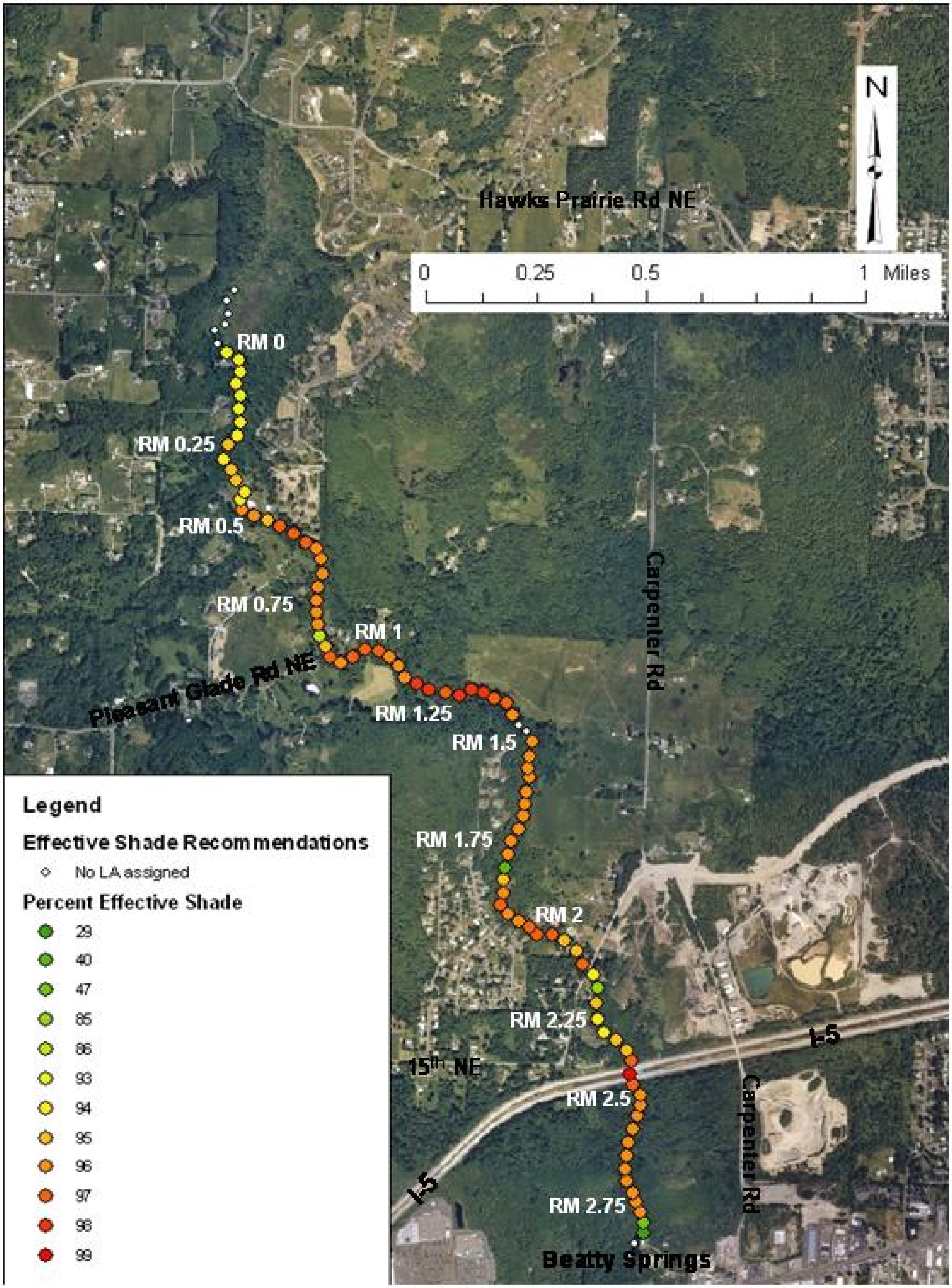

Figure C-6. Effective shade recommendations for Woodland Creek between Beatty Springs and the mouth.

Wasteload Allocations

Nisqually Trout Farm

The Nisqually Trout Farm (Trout Farm) is located at the outlet of Beatty Springs on Woodland Creek. The Trout Farm discharges to Woodland Creek under NPDES permit number WAG131002C. The general NPDES permit for upland finfish facilities does not contain temperature limitations. Operation of the trout farm consists of pumping water from the spring into holding pens that are constantly mixed and have a very low residence time. This operation does not appear to have any significant impact on the temperature of the spring water. During the summer 2003 field season, a maximum background water temperature of 14.0^{o}C was recorded and during this same period the Trout Farm effluent did not exceed the 16.0^{o}C water quality standard. The discharge of Beatty Springs water from the hatchery is the principle source of water in Woodland Creek during the critical period. Support of beneficial uses of Woodland Creek depend on the cold water and flow provided by the springs.

Although the current operation of the fish hatchery does not contribute any thermal pollution to the system during critical conditions, a wasteload allocation was calculated to protect water quality should the operation of the hatchery change in the future. Washington's surface water quality standards state that "incremental temperature increases resulting from point source activities shall not, at any time, exceed t=23/(T+5)…where t represents the maximum permissible temperature increase measured at the mixing zone boundary and T is the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge." No mixing zone is authorized because the discharge comprises a large percentage of Woodland Creek's flow during the critical period.

The wasteload allocation for the Nisqually Trout Farm was developed based on data collected during the summer 2003. The conditions in the holding pens are assumed to be background temperatures. This maximum background temperature of 14.0^{o}C was used to calculate the allowable incremental temperature increase:

$$t = 23 / (T + 5) = 23 / (14.0 + 5) = 1.2^{o}C$$

Therefore, the wasteload allocation for the Nisqually Trout Farm is the discharge temperature that does not cause the receiving water temperature to rise greater than an increment of 1.2^{o}C or above a maximum temperature of 15.2^{o}C at any time. Under the current operating practices of the Trout Farm, there appears to be no reasonable potential for the current operation to cause or contribute to violation of the water quality standards or to exceed 15.2^{o}C. As a result, it is recommended that temperature monitoring of the effluent be conducted during summer months to verify the wasteload allocation is not exceeded. If monitoring demonstrates there is a reasonable potential for the temperature wasteload allocation to be exceeded, the Nisqually Trout Farm may be required to apply for an individual NPDES permit that specifies this wasteload allocation when the statewide general permit is up for renewal.

Stormwater Sources

Stormwater sources of thermal pollution in Woodland Creek between Beatty Springs and the mouth are assigned a wasteload allocation based on the current water quality standards for Class AA freshwater systems. The wasteload allocations only apply to stormwater discharges that may occur during the critical summer low-flow period.

Although Woodland Creek below Beatty Springs currently meets the Class AA water quality criteria of 16.0°C, the wasteload allocation for municipal stormwater discharges from new developments and redevelopments is 16.0°C to prevent degradation of water quality in this portion of Woodland Creek. This wasteload allocation complies with current water quality standards which state:

"Whenever waters are of a higher quality than the criteria assigned for said waters, the existing water quality shall be protected and…. All wastes and other materials and substances discharged into said waters shall be provided with all known, available, and reasonable methods of prevention, control, and treatment by new and existing point sources before discharge."

Best management practices (BMPs) for treating municipal stormwater runoff, which include infiltration basins, have been applied to many of the developed areas that drain to Woodland Creek. The use of stormwater BMPs, such as stormwater infiltration, is anticipated to be adequate to protect water quality during the critical season because direct surface discharge from the basins does not typically occur during summertime rain events. Summer storm events which exceed the design storm for the BMPs could result in a direct surface discharge to Woodland Creek; however, these events are expected to be infrequent and are not expected to result in exceedances of the wasteload allocation.

The wasteload allocation applies during the critical summer low-flow period, typically occurring from June through September. The same wasteload allocation applies to existing stormwater discharges. As stated above, Ecology may establish a compliance schedule for the municipality to install appropriate BMPs or treatment if determined necessary to meet the wasteload allocations. Stormwater infiltration basins combined with other BMPs are anticipated to meet these wasteload allocations.

Management Recommendations

In addition to the recommendations for effective shade and the wasteload allocations, other management activities are recommended for compliance with water quality standards. The recommendations described below would help to prevent degradation of temperature conditions in Woodland Creek between Beatty Springs and Henderson Inlet.

- Watershed residents should continue to be encouraged to use water wisely.
- The City of Lacey and Thurston County should continue to carefully manage stormwater runoff from impervious surfaces in accordance with the minimum requirements and technical guidance provided by the *Stormwater Management Manual of Western Washington.*

- Measures should be taken to protect springs and tributaries in lower Woodland Creek from further degradation, including measures to protect riparian vegetation and groundwater in hydraulic continuity.
- Practice Low Impact Development principles for new development where applicable and supported by science.
- If alternative water sources are available, it is preferable to avoid drilling new exempt wells within the Woodland Creek basin. The City of Lacey is currently considering the possibility of prohibiting new exempt wells within Lacey city limits.

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Appendix D

Time-of-Travel Surveys

Woodland Creek

Figure D-1 presents the conductivity levels recorded at the three stations. Based on the time of arrival of the peak conductivity levels, time of travel was 0.75 ft/s in the upstream reach and 0.55 ft/s in the downstream reach.

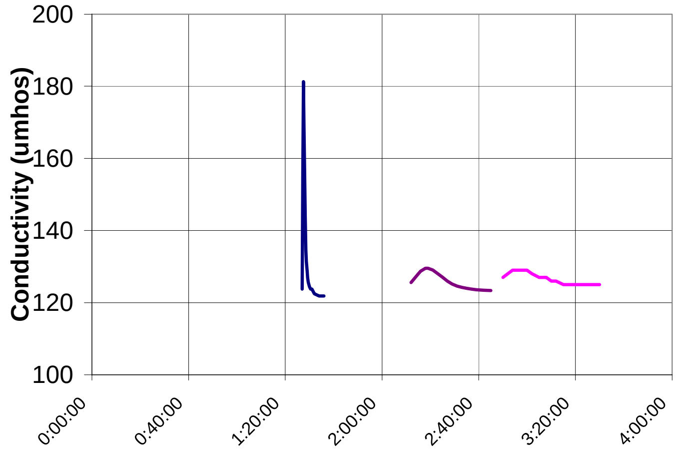


Figure D-1. Conductivity recorded at three stations in Woodland Creek.

At low flows, time of travel from Martin Way to Henderson Inlet varies from 3.4 to 4.6 hours, using the two velocities determined from the time-of-travel study. While there is no reason to believe that the channel structure is different in reaches not included in the time of travel, these estimates should be interpreted as rough estimates. Time of travel during winter conditions is likely faster, given the higher flow rates. Therefore, 3.4 to 4.6 hours represents the slowest likely travel times for storm conditions.

Henderson Inlet

Southern Inlet Travel Time

Two time-of-travel studies were conducted in southern Henderson Inlet, both during ebbing tides. On February 19, 2003, high tide occurred at 7:28 a.m. (15.3 ft), as estimated for the Nisqually Reach (Tides & Currents for Windows, version 2.1, Nautical Software, Inc.), with a maximum predicted ebbing tidal velocity of 1.5 knots (2.5 ft/s or 0.77 m/s) within the Nisqually Reach. On August 13, 2003, high tide occurred at 6:13 a.m. (12.2 ft), with a maximum predicted ebbing tidal velocity of 1.6 knots (2.7 ft/s or 0.82 m/s) within the Nisqually Reach. In calendar year 2003, these velocities occurred 18% and 12% of the time, respectively. Therefore, both events occurred during moderately fast tidal exchanges to estimate the quickest transport from watershed sources through the shellfish zones.

During the February 2003 event, 50 surface drogues were released at four locations in the southern inlet. As shown in Figure 7, drogues released nearest the Woodland Creek inflow to Henderson Inlet traveled the furthest and the quickest of all releases, with speeds exceeding 0.3 m/s. The Dobbs Creek release initially traveled more slowly but merged with the drogues from Woodland Creek at a narrow point of the inlet where velocities increase. Drogues released near the outlets of Meyer and Swayne creeks did not travel quickly or far from the release locations, as indicated in Figure D-2. Table D-1 summarizes the distances and velocities of each release.

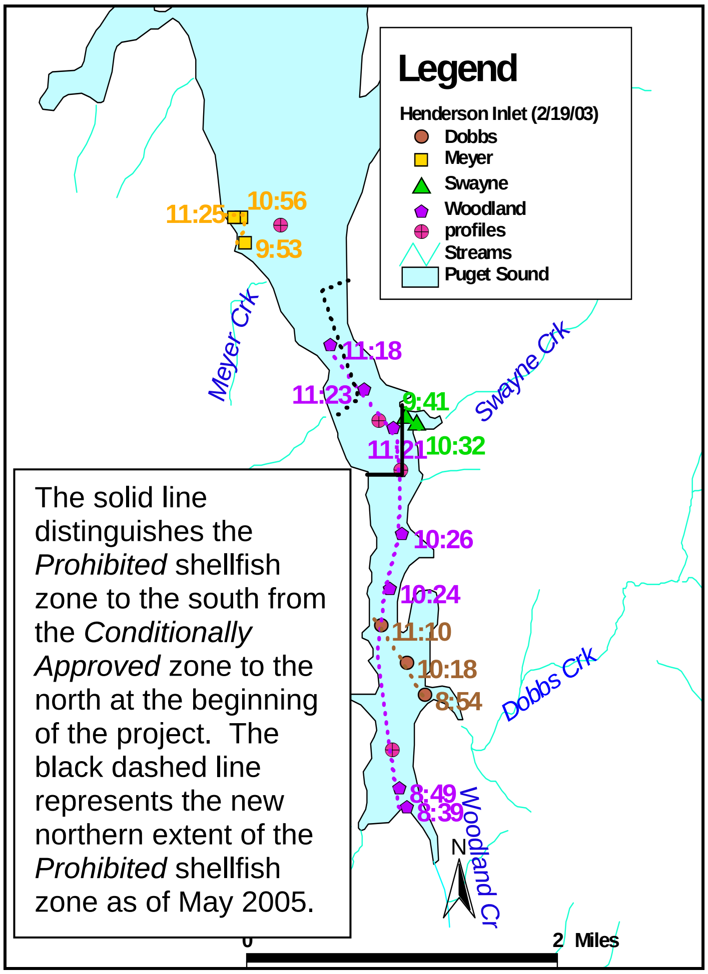


Figure D-2. Trajectories and arrival time of drogues released in southern Henderson Inlet on February 19, 2003.

During the August 2003 event, 50 drogues were released near the inlet of Woodland Creek at 9:11 a.m. and near the Dobbs Creek inlet at 9:15 a.m. Both releases traveled quickly (0.5 to 0.7 m/s) to the constriction in Henderson Inlet north of Dobbs Creek, then continued on a northward trajectory at 0.2 to 0.4 m/s, as shown in Figure D-3. Table D-2 summarizes the tracking data and calculated velocities. Ebbing velocities were similar in both the February and August 2003 surveys.

Table D-1. Drogue travel times and velocities in southern Henderson Inlet on February 19, 2003. High tide occurred at 7:28 a.m. *Italicized* values represent composite results.

Release	Time tracked (a.m.)	Time (min)	Distance (ft)	Velocity (ft/s)	Velocity (m/s)
Woodland	*8:39 – 11:18*	*159*	*7800*	*0.82*	*0.25*
	8:39 – 10:26	107	4500	0.70	0.21
	10:26 – 11:18	52	3300	1.1	0.32
Dobbs	*8:54 – 11:10*	*136*	*1400*	*0.17*	*0.052*
	8:54 – 10:18	84	600	0.12	0.036
	10:18 – 11:10	52	800	0.26	0.078
Meyer	*9:53 – 11:25*	*92*	*540*	*0.098*	*0.030*
	9:53 – 10:56	63	400	0.11	0.032
	10:56 – 11:25	29	140	0.080	0.025
Swayne	*9:41 – 10:32*	*51*	*230*	*0.075*	*0.023*

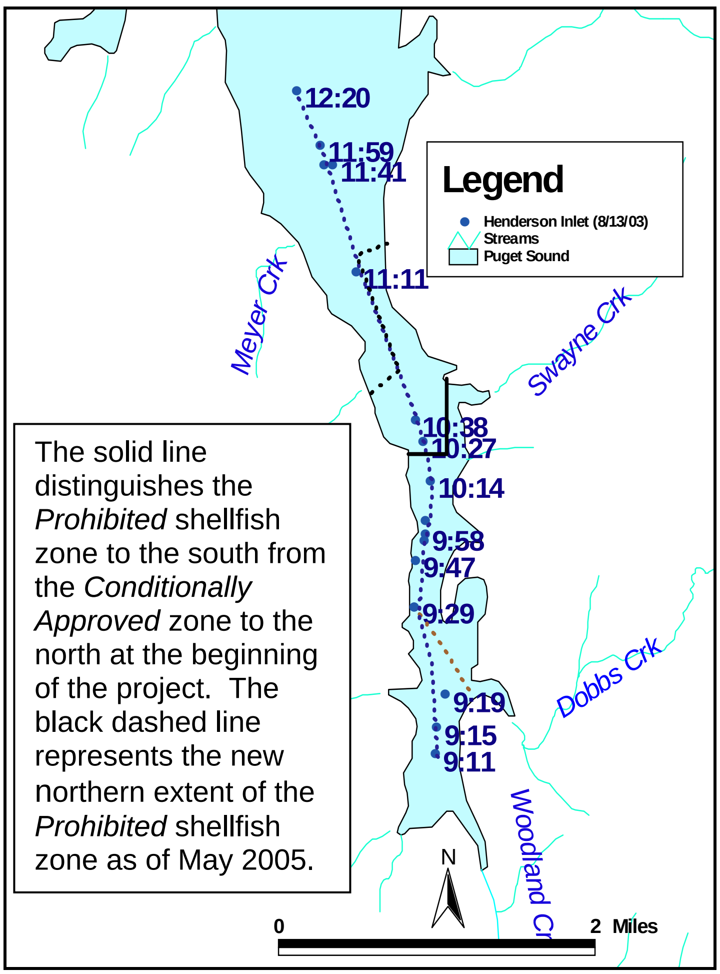


Figure D-3. Trajectories and arrival time of drogues released in southern Henderson Inlet on August 13, 2003.

Table D-2. Drogue travel times and velocities in southern Henderson Inlet on August 13, 2003. High tide occurred at 6:13 a.m. *Italicized* values represent composite results.

Release	Time tracked (a.m.)	Time (min)	Distance (ft)	Velocity (ft/s)	Velocity (m/s)
Woodland	*9:11 – 12:20*	*189*	*10,600*	*0.93*	*0.28*
	9:11 – 9:29	18	2300	2.1	0.65
	9:29 – 10:38	69	2900	0.70	0.21
	10:38 – 11:11	33	2400	1.2	0.37
	11:11 – 11:59	48	2100	0.73	0.22
	11:59 – 12:20	21	900	0.71	0.22
Dobbs	9:15 – 9:29	14	1400	1.7	0.51

Woodard and Chapman Bays Travel Time

On April 22, 2003, drogues were released at two other locations to study circulation patterns and current speeds in Woodard Bay and Chapman Bay. High tide occurred at 9:33 a.m. (11.6 ft), and ebbing currents were predicted to reach 1.5 knots in the Nisqually Reach. Velocities ≥1.5 knots occurred 18% of the time in 2003, and the condition represents a reasonably large tidal exchange. Figure D-4 and Table D-3 summarize the results.

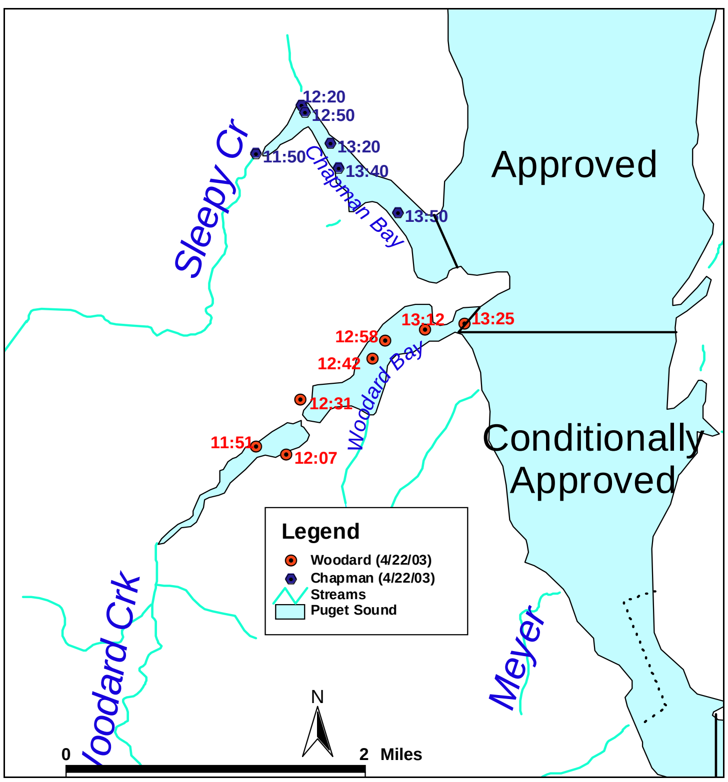


Figure D-4. Trajectories and arrival time of drogues released in Woodard and Chapman bays on April 22, 2003.

Drogues released at the inlet of Sleepy Creek to Chapman Bay initially traveled north where they were caught in the mud flats. After clearing the bend, the drogues moved at 0.2 m/s to where Chapman Bay meets Henderson Inlet. Similarly, drogues released at the inlet of Woodard Creek to Woodard Bay traveled northeasterly with the current at speeds averaging 0.2 m/s. Drogues were not tracked into Henderson Inlet.

Table D-3. Drogue travel times and velocities in Woodard and Chapman bays on April 22, 2003. High tide occurred at 9:33 a.m. *Italicized* values represent composite results.

Release	Time tracked	Time (min)	Distance (ft)	Velocity (ft/s)	Velocity (m/s)
Woodard	*11:51 – 13:25*	*94*	*4000*	*0.71*	*0.22*
	11:51 – 12:31	40	1100	0.46	0.14
	12:31 – 12:58	27	1600	0.99	0.30
	12:58 – 13:25	27	1300	0.80	0.24
Sleepy	*11:50 – 13:50*	*120*	*3400*	*0.47*	*0.14*
	11:50 – 12:20	30	1100	0.61	0.19
	12:20 – 12:50	30	100	0.056	0.017
	12:50 – 13:50	60	2200	0.61	0.19

Henderson Inlet Travel Time Summary

As the large tidal volume passes through the constricted southern Henderson Inlet, velocities can exceed 0.3 m/s during moderately large tidal exchanges. At these speeds, Woodland Creek and Dobbs Creek water can traverse the *Prohibited* shellfish zone within two hours and could reach the southern extent of the *Approved* shellfish zone at Woodard Bay in four to five hours. Therefore, all freshwater that enters southern Henderson Inlet could reach the *Approved* shellfish zone within a single tidal cycle. While dilution and die-off occur, water quality in both Woodland and Dobbs creeks influences water quality throughout southern and central Henderson Inlet. Table D-4 summarizes the results.

Table D-4. Potential travel times from freshwater streams to shellfish areas.

From	To	Distance (ft)	Velocity (ft/s)	Time (hrs)
Mouth of Woodland Creek	Northern extent of *Prohibited* shellfish area	6,500	0.9	2.0
	Northern extent of *Conditionally Approved* shellfish area	14,000	0.9	4.3
Mouth of Woodard Creek	Railroad bridge	5,800	0.6	2.3
Mouth of Sleepy Creek	Railroad bridge	4,600	0.6	2.1

During relatively large tidal exchanges, water from Sleepy or Woodard creeks pass through Chapman and Woodard bays to the Henderson Inlet *Approved* shellfish area in two to two-and-a half hours. While dilution and die-off occur, these streams influence central Henderson Inlet water quality.

Appendix E

Data Quality

Laboratory Data

Laboratory samples were analyzed according to quality assurance and quality control procedures followed by Ecology's Manchester Environmental Laboratory (MEL) (Ecology, 1994). All general chemistry samples met holding time requirements. Microbiology samples were analyzed within 30 hours, which is standard procedure for MEL. Microbiology samples were not analyzed within the 6-hour window described in Standard Methods (APHA, 1998) because of the logistical challenges in collecting and transporting samples within the given timeframe. MEL was used for all laboratory analysis of membrane filter (MF) fecal coliform and *E-coli* bacteria, nutrients, and conductivity.

Duplicate field samples were used to estimate total variation (field and laboratory), expressed as the coefficient of variation (CV). Duplicates are two field samples collected sequentially at the same site as close as possible in time. The percent CV is calculated by dividing the standard deviation by the mean of the duplicate pairs, and multiplying by 100. Field duplicates were collected for approximately 20% of all bacteria samples and 10% of the general chemistry samples analyzed by MEL.

Values below the detection limit were assumed to be the detection limit for analysis purposes. Laboratory and field replicates were arithmetically averaged for data analysis.

Precision for bacteria field duplicate results should not exceed 50% CV. At levels close to the method detection limit (less than 50 fc/100 mL), a CV greater than 50% is acceptable. For all other parameters, precision for field duplicate measurements should not exceed 20% CV for results above the reporting limit. For results close to the reporting limit, a higher CV may be acceptable. Table E-1 presents the arithmetic average CV for field duplicate samples.

Table E-1. Coefficient of variation for McAllister Creek laboratory sampling parameters.

Parameter	Average % CV for all values and number of duplicates		Average % CV for values < 50 cfu/100ML and number of duplicates		Average % CV for values ≥ 50 cfu/100ML and number of duplicates	
Fecal coliform bacteria	18.7%	n=73	22.1%	n=24	16.9%	n=49
E-coli bacteria	21.0%	n=55	25.7%	n=15	19.2%	n=40
Ammonia-nitrogen	5.5%	n=22	n/a		n/a	
Nitrate+nitrite-nitrogen	2.3%	n=22	n/a		n/a	
Total persulfate nitrogen	7.1%	n=22	n/a		n/a	
Orthophosphate	3.1%	n=16	n/a		n/a	
Total phosphorus	4.5%	n=17	n/a		n/a	

Precision for bacteria results were very good, with most % CV values greater than 50 where individual results were < 50 cfu/100 mL. On December 12, 2002, % CV was 95 and 87% for fecal coliform and *E-coli*, respectively. It is likely the difference in field duplicates is due to environmental variability, as the *E-coli* results also have a high % CV and corresponding bacteria values.

On September 16, 2003, a grab sample for fecal coliform was obtained from a stormwater tributary to Woodland Creek (RM 3.1T). Field notes indicate possible contamination of the sample with sediment, the bacteria results were discarded.

On July 9, 2003, a grab sample for fecal coliform and field measurements were obtained from the stormwater pipe and Woodland Creek RM 2.6. No precipitation had occurred the day of sampling or in the previous nine days. The City of Lacey reported that residents in the area had been flushing their drinking water systems during that period. It is unlikely that the sample obtained on July 9, 2003 is characteristic of water usually obtained at that site; therefore, the results for this day will be discarded.

Field duplicate nutrient results had a high CV for Woodland Creek RM 3.45 on July 9, 2003 ranging from 17 - 64%, and at Woodard Creek RM 2.9 on June 10, 2003, ranging from 0 - 39%. The precision (% CV) for additional nutrient duplicates obtained the same days was very good. The difference in nutrient levels at both sites for the days described is probably due to environmental variability, and results are acceptable but will be used with caution. On April 15, 2003, at a stormwater tributary to Woodland Creek at RM 3.8T, a CV of 44% for total persulfate nitrogen was obtained. Again due to the variable nature of stormwater, the difference is likely due to environmental variability and results will be used with caution.

Other than the exceptions noted above, all data were acceptable for use without qualification. Data variability will be taken into consideration in using the data for modeling and other analysis as well as interpreting results.

Field Data

Field instruments were calibrated according to the manufacturer's instructions, and pre-calibrated and post-checked with certified standards. Pre-calibrations and post-checks were done the day the field meters were used.

Winkler dissolved oxygen measurements and laboratory conductivity samples were obtained in the field to check the meters. Post calibration checks were conducted after field sampling. Field meter parameters that did not meet quality control standards are qualified in the data appendices, and values are not reported. Table E-2 lists data quality standards for field measurements.

Quality assurance results for meters used during synoptic surveys are included in the field data appendices. Quality assurance results for meters used for *in-situ* continuous monitoring are described in Table E-3.

Table E-2. Measurement quality objectives for field determinations.

Analysis	Accuracy % deviation from true value	Precision relative standard deviation	Bias % deviation from true value
pH[1]	0.2 s.u.	0.05 s.u.	0.10 s.u.
Water Temperature[1]	± 0.2°C		
Dissolved Oxygen	15	5% RSD*	5
Specific Conductivity	10	<10% RSD*	5

[1] As units of measurement, not percentages

Table E-3. Continuous monitoring sample sites, sampling period, and quality assurance results.

Sites and Monitoring Period	Met QA objectives?
Woodland Creek RM 3.4	
March 31 - April 3, 2003	Met
July 24 - 28, 2003	Met
August 22 - 26, 2003	Conductivity failed
September 17 - 19, 2003	Conductivity failed
Woodland Creek RM 3.1	
December 30, 2002 - January 2, 2003	Conductivity failed
March 31 - April 3, 2003	Met
July 24 - 28, 2003	Met
August 22 - 26, 2003	Met
September 17 - 19, 2003	Conductivity failed
Woodland Creek RM 1.6	
July 29 - August 1, 2003	Conductivity failed
August 15 -18, 2003	Met
October 2 - 6, 2003	Met
Woodard Creek RM 6.8	
August 6 - 11, 2003	Met
September 10 - 13, 2003	Conductivity failed
Woodard Creek RM 6.2	
August 2 - 7, 2002	Met, no post check
January 3 - 6, 2003	Conductivity failed
July 16 - 19, 2003	Met
September 29 - October 2, 2003	Conductivity failed
February 20 - 23, 2004	Met
Woodard Creek RM 5.1	
August 7 - 11, 2003	Conductivity failed
September 10 - 13, 2003	Conductivity failed
Woodard Creek RM 2.9	
January 3 - 6, 2003	Conductivity failed
March 14 - 17, 2003	Conductivity failed
July 16 - 19, 2003	Conductivity failed
August 7 - 11, 2003	Met
September 26 - 30, 2003	Met
February 20 - 23, 2004	Met
Meyer Creek RM 0.6	
April 20 - 22, 2005	Met
Meyer Creek RM 0.1	
February 10 - 13, 2004	Met
Sleepy Creek RM 0.1	
April 18 - 21, 2003	Very little flow in creek
August 1 - 4, 2003	Very little or no flow in creek
August 19 - 22, 2003	No flow, Winkler DOs failed
September 9 - 12, 2003	Conductivity failed
Dobbs Creek RM 0.1	
August 1 - 5, 2002	Dissolved oxygen failed
January 6 - 10, 2003	Conductivity failed
April 25 - 28, 2003	Conductivity failed
August 1 - 4, 2003	Met
September 9 - 12, 2003	Met

Appendix F

In-situ Continuous Temperature, pH, Dissolved Oxygen, and Conductivity Measurements

Figure F-1. Woodland Creek RM 3.4 - four sampling periods, 2003.

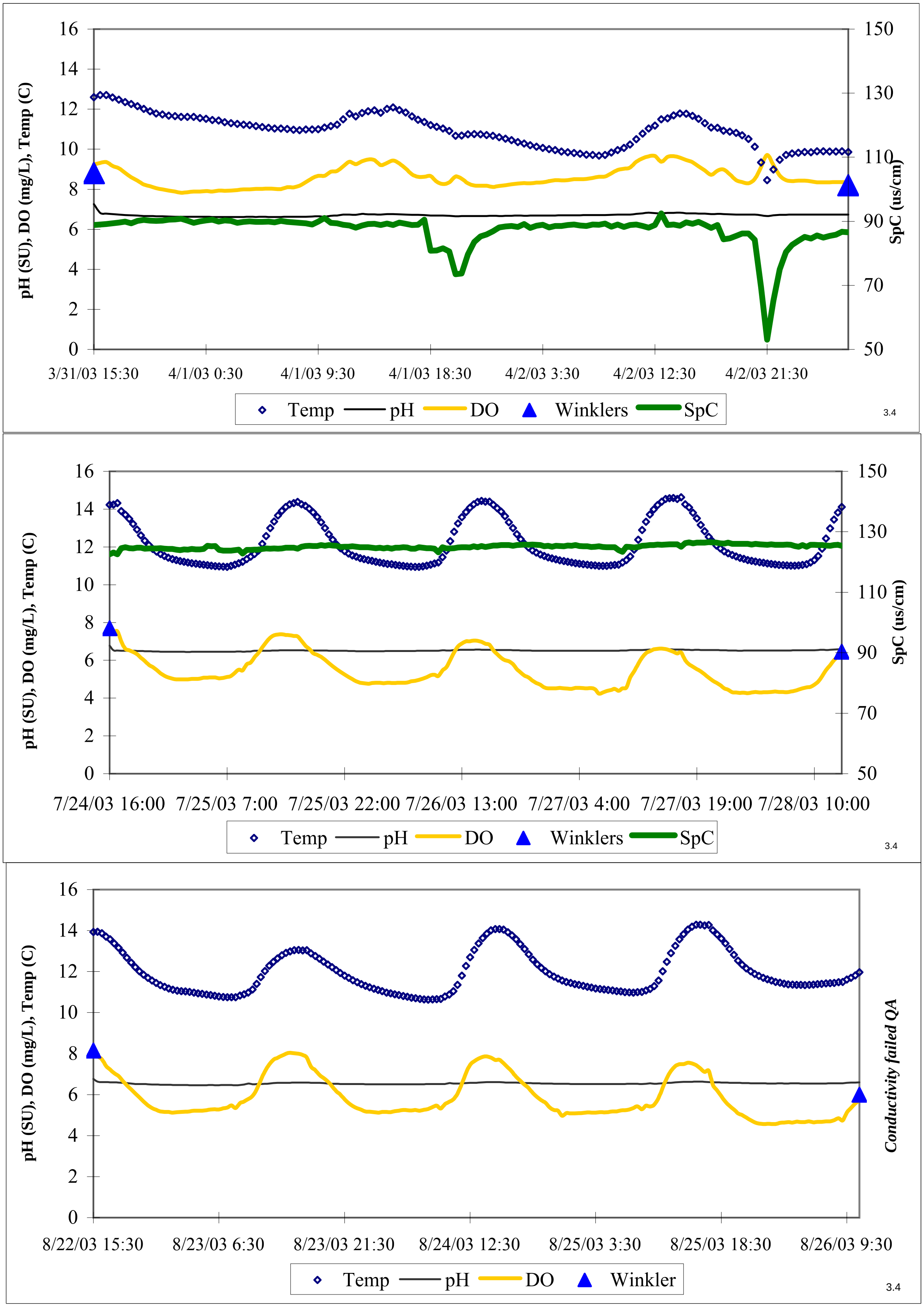


Figure F-1. Woodland Creek RM 3.4 - four sampling periods, 2003.

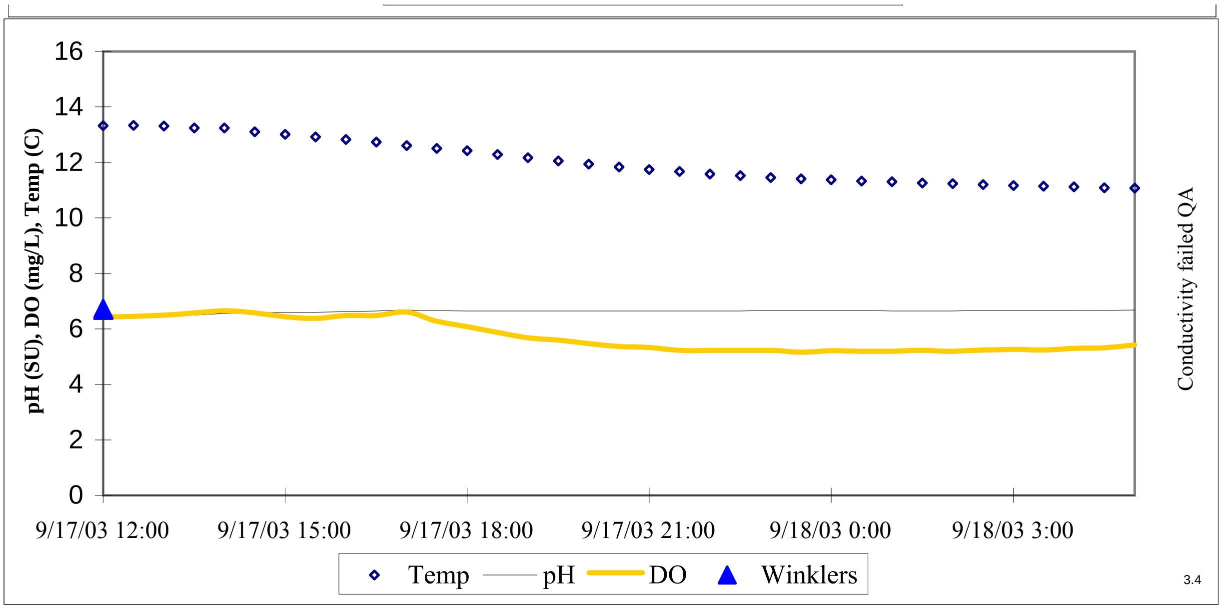


Figure F-2. Woodland Creek RM 3.1 - five sampling periods, 2002-03.

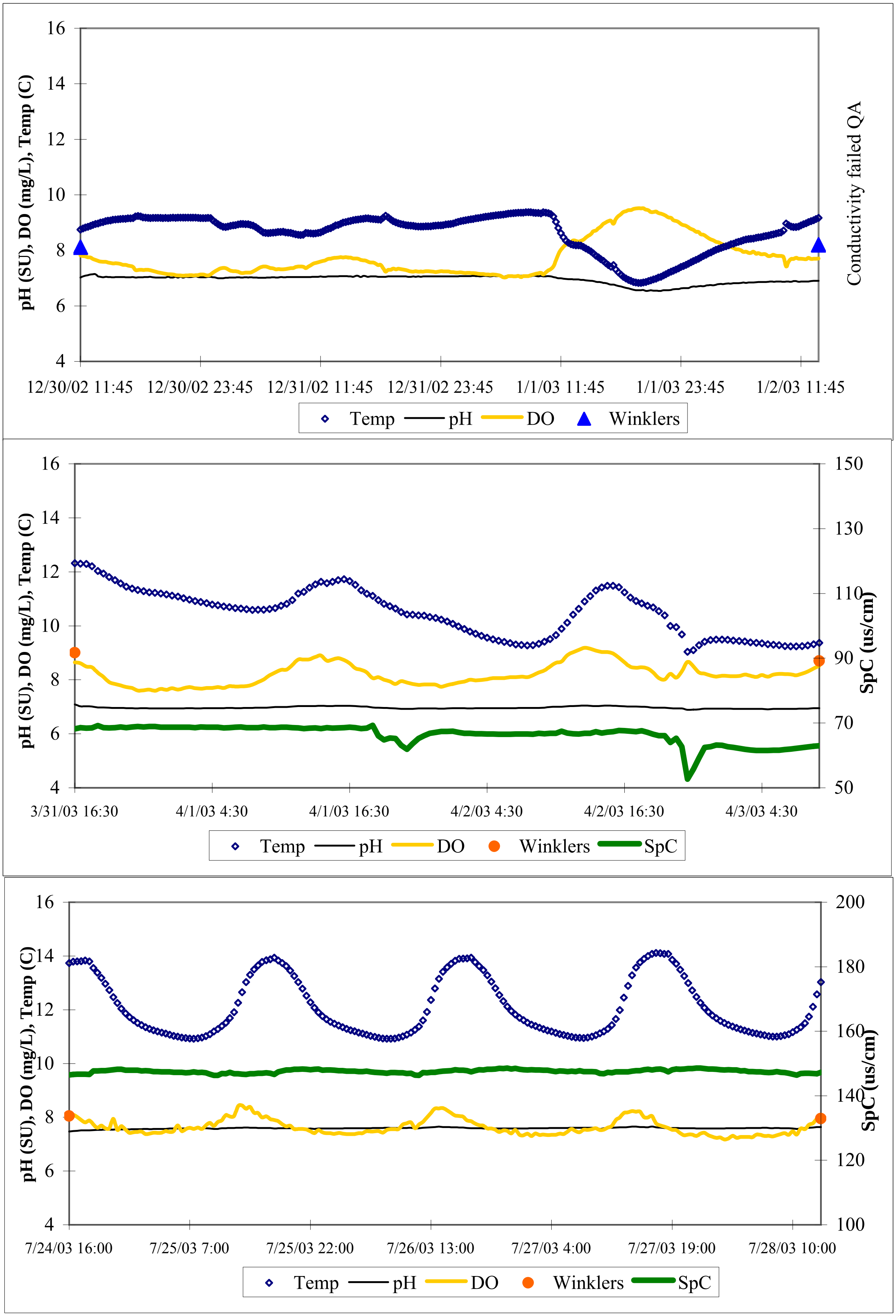
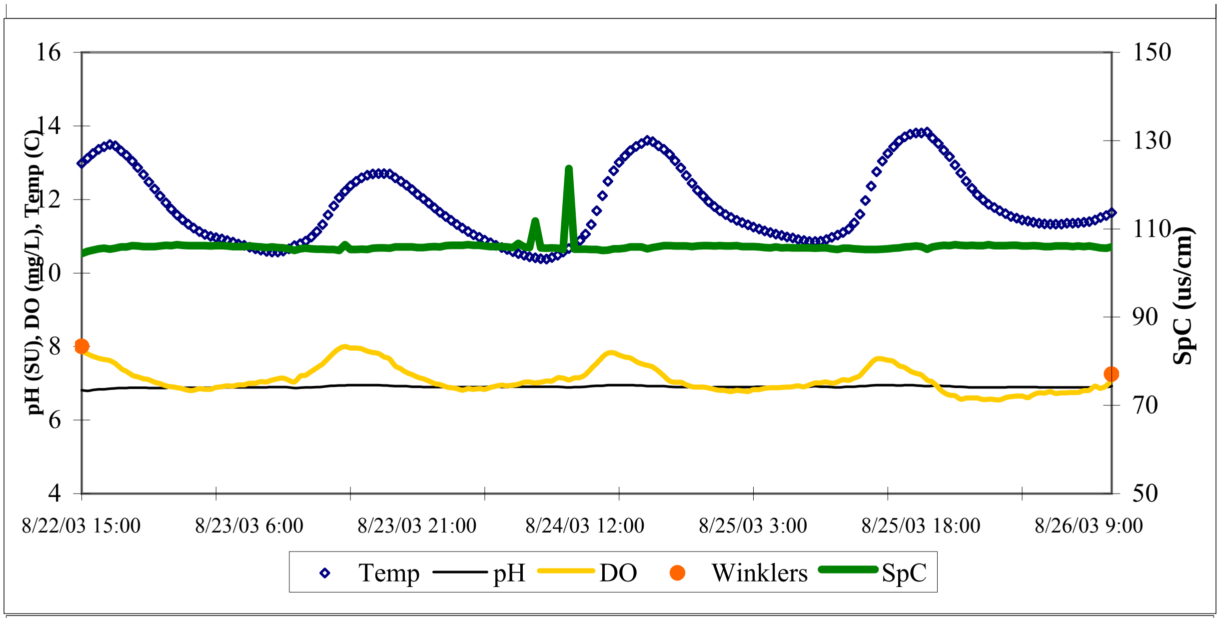


Figure F-2. Woodland Creek RM 3.1 - five sampling periods, 2002-03.



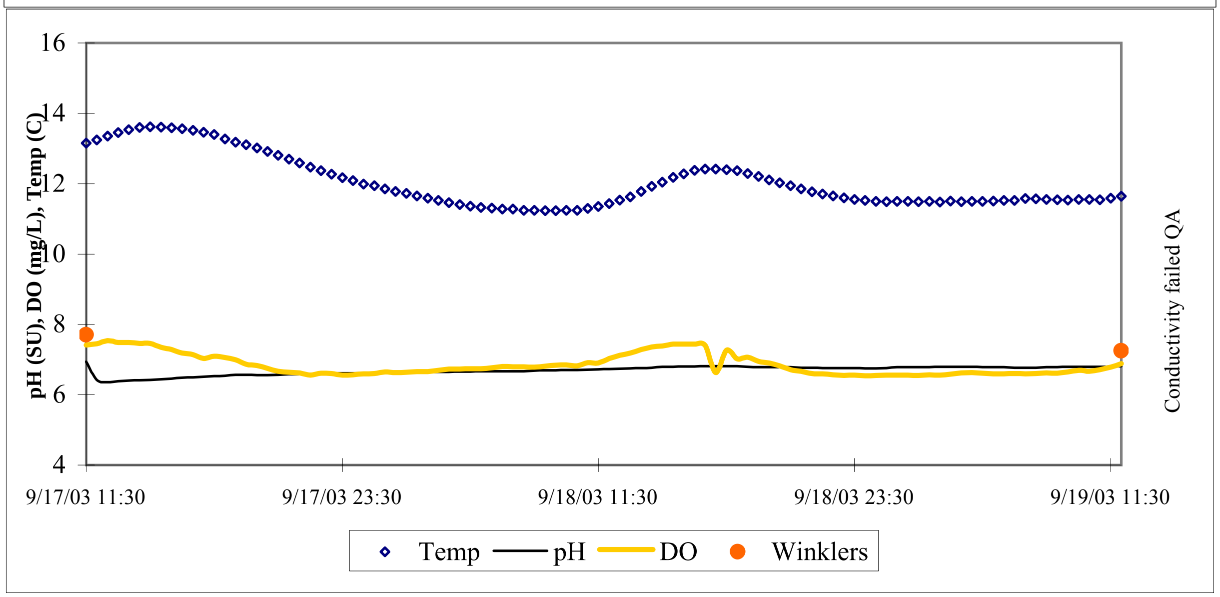
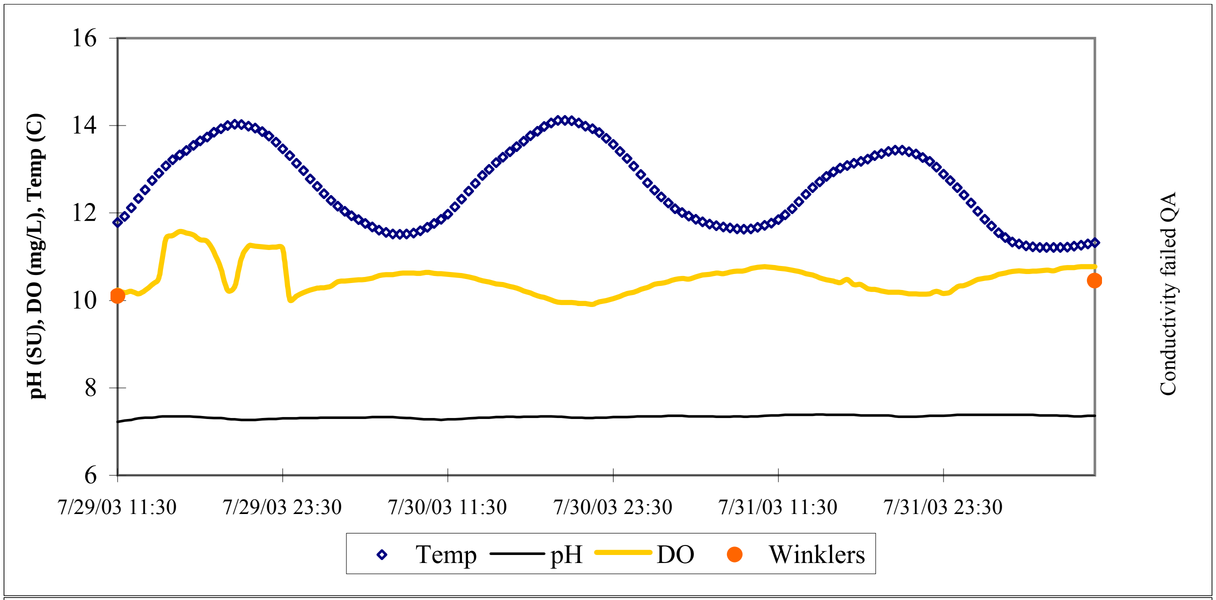
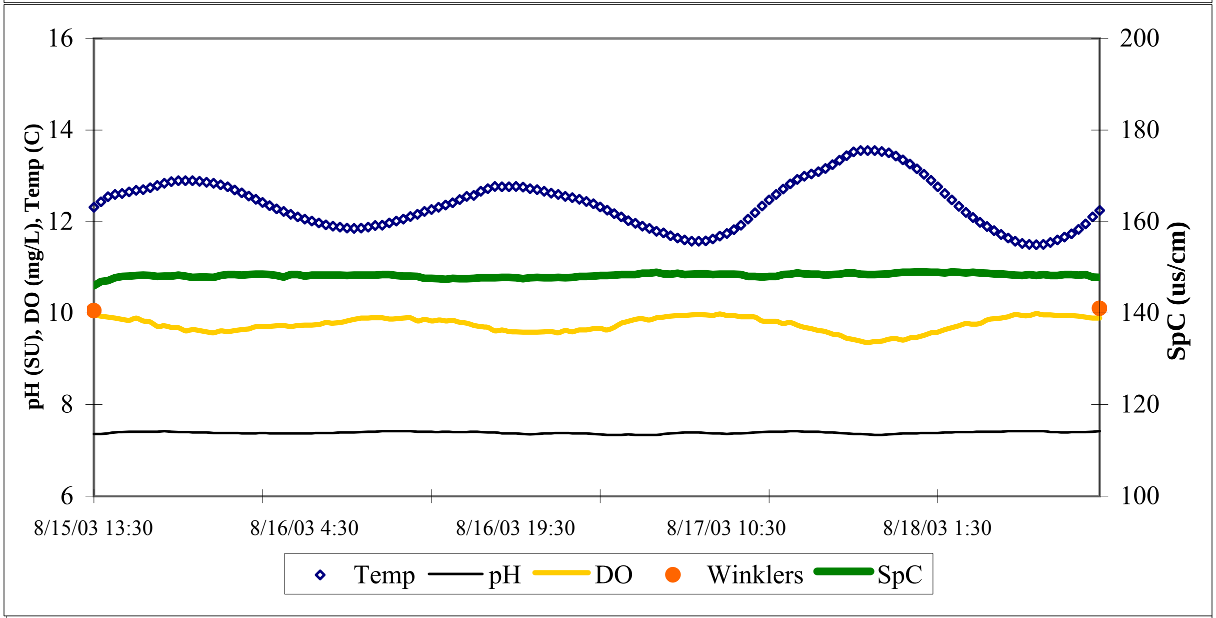
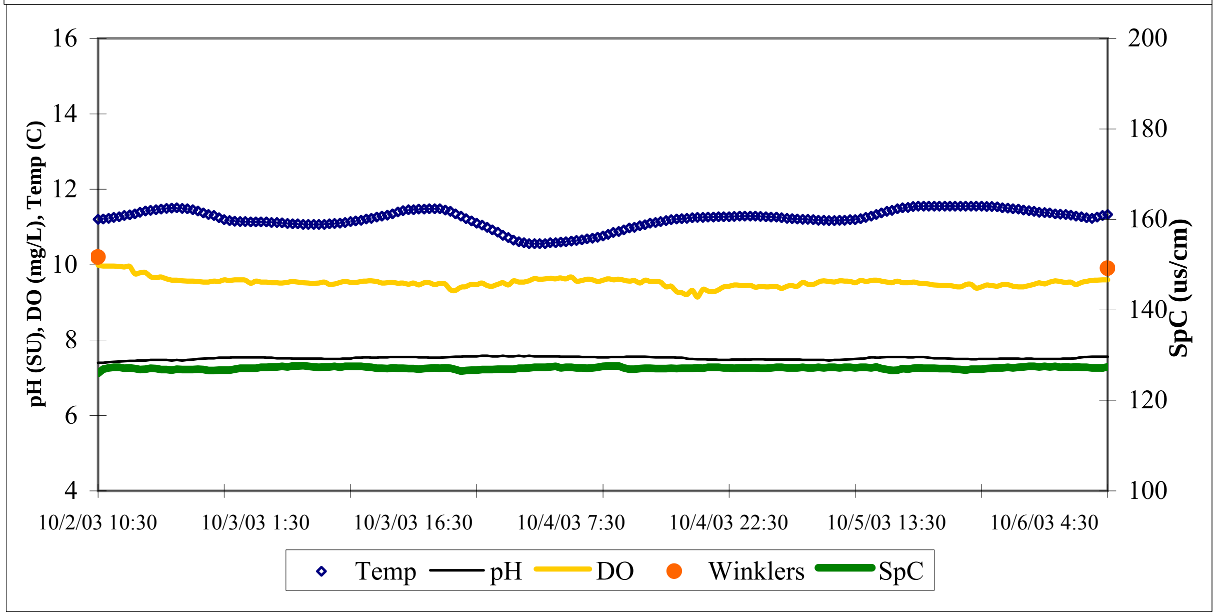


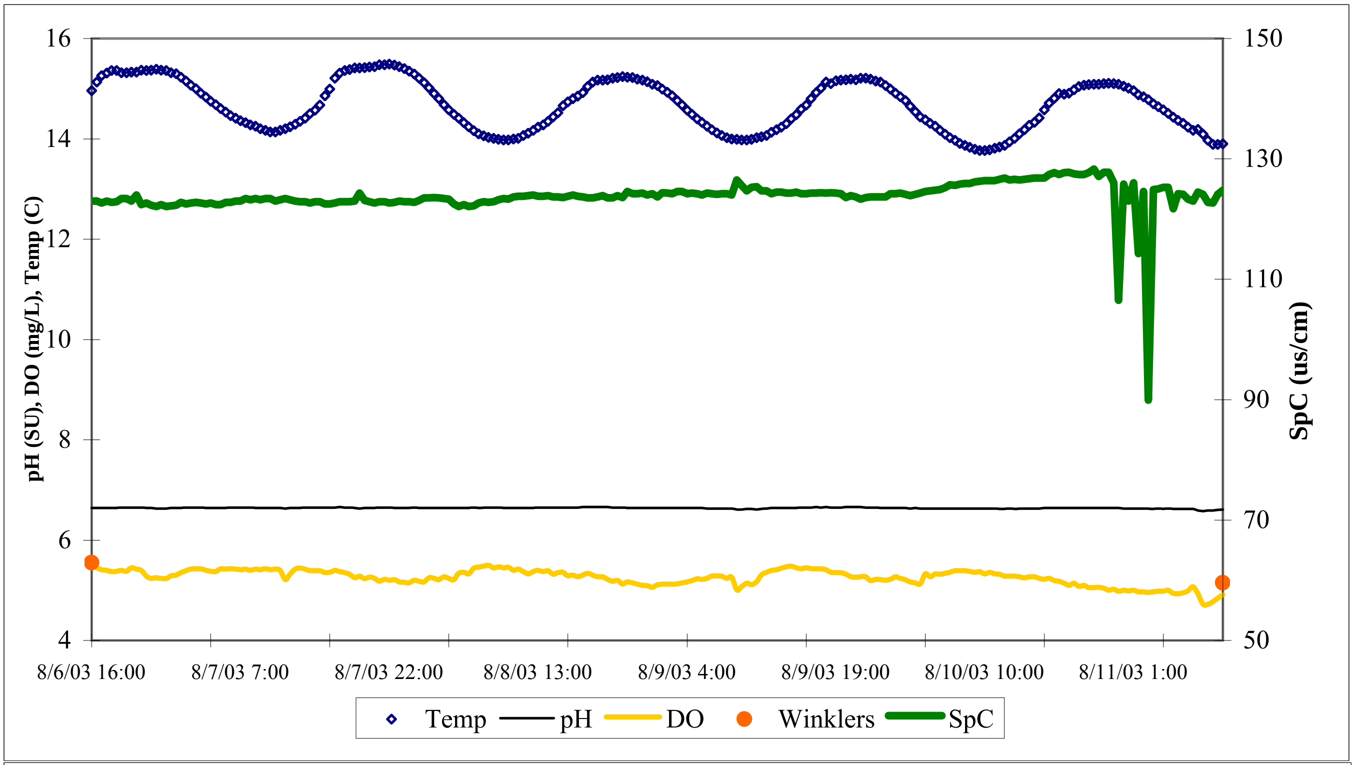
Figure F-3. Woodland Creek RM 1.6 - three sampling periods, 2003.







Figures F-4 Woodard Creek RM 6.8 - two sampling periods, 2003.



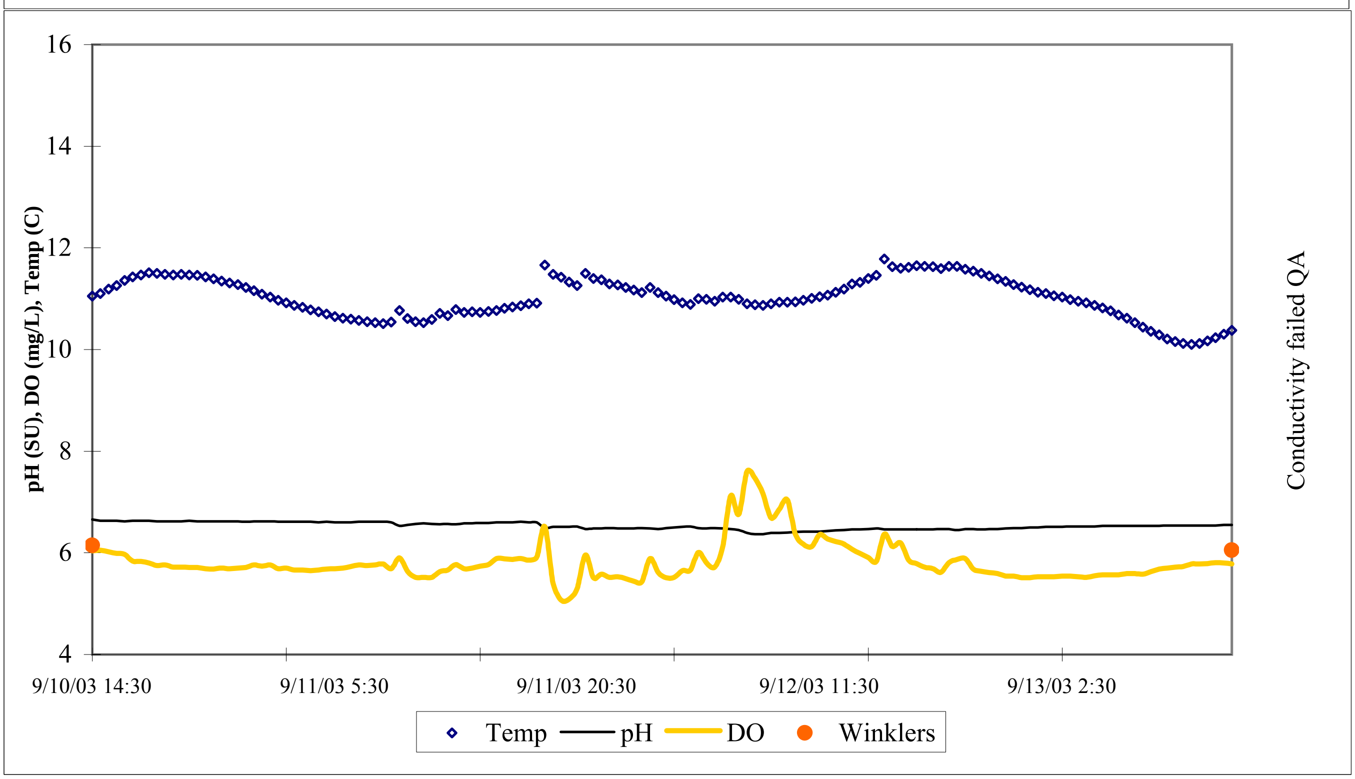
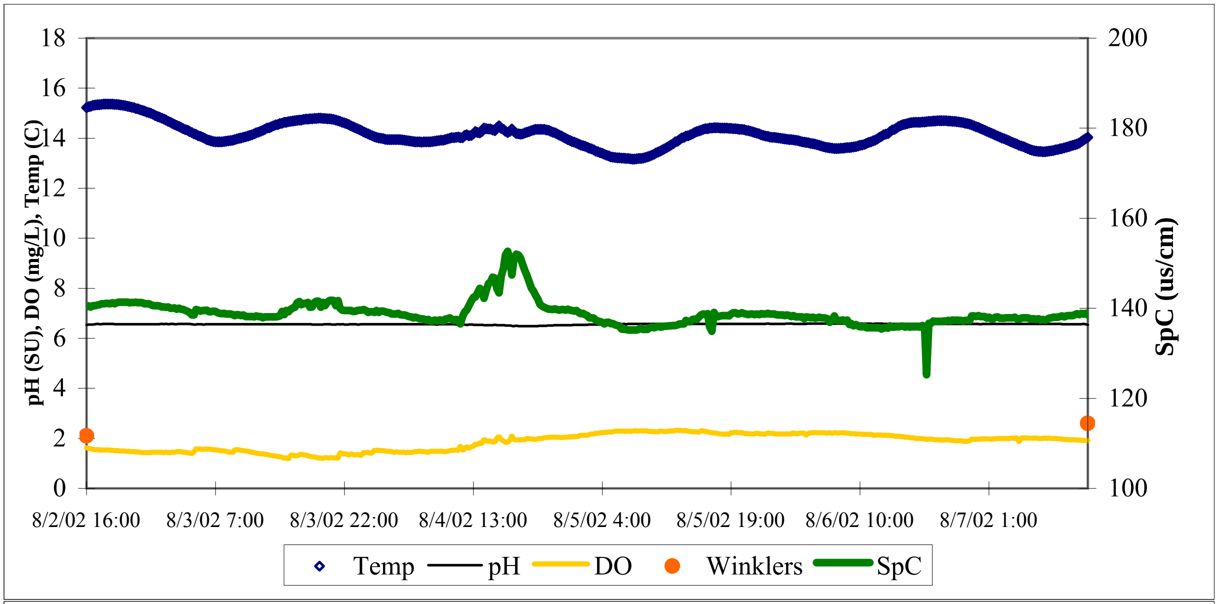
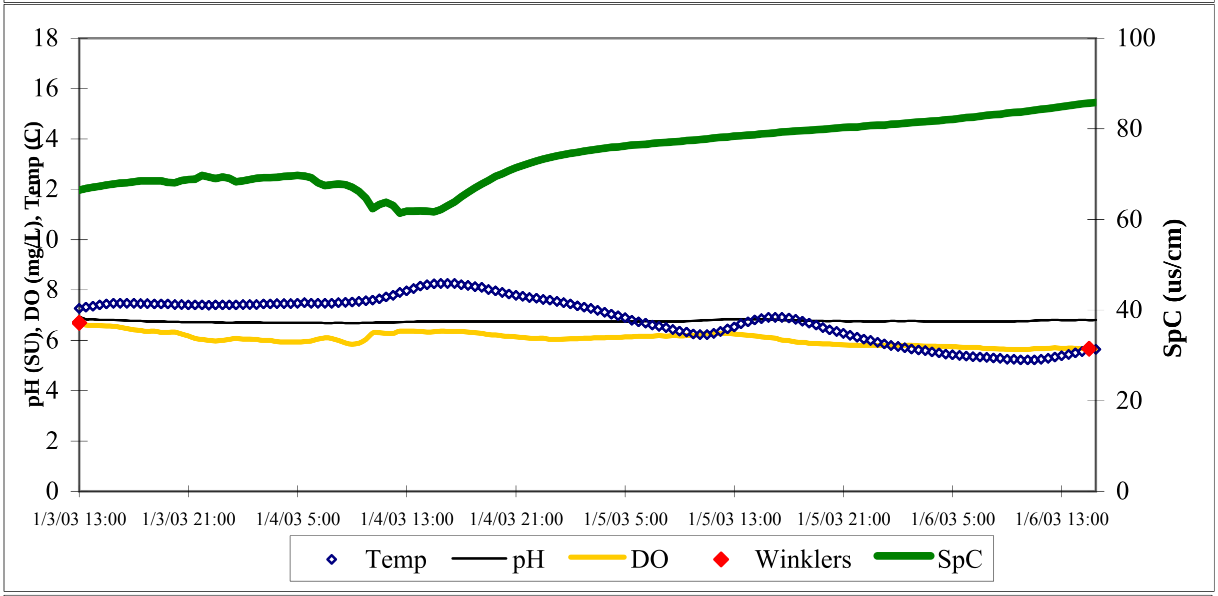


Figure F-5. Woodland Creek RM 6.2 - five sampling periods, 2002-04.





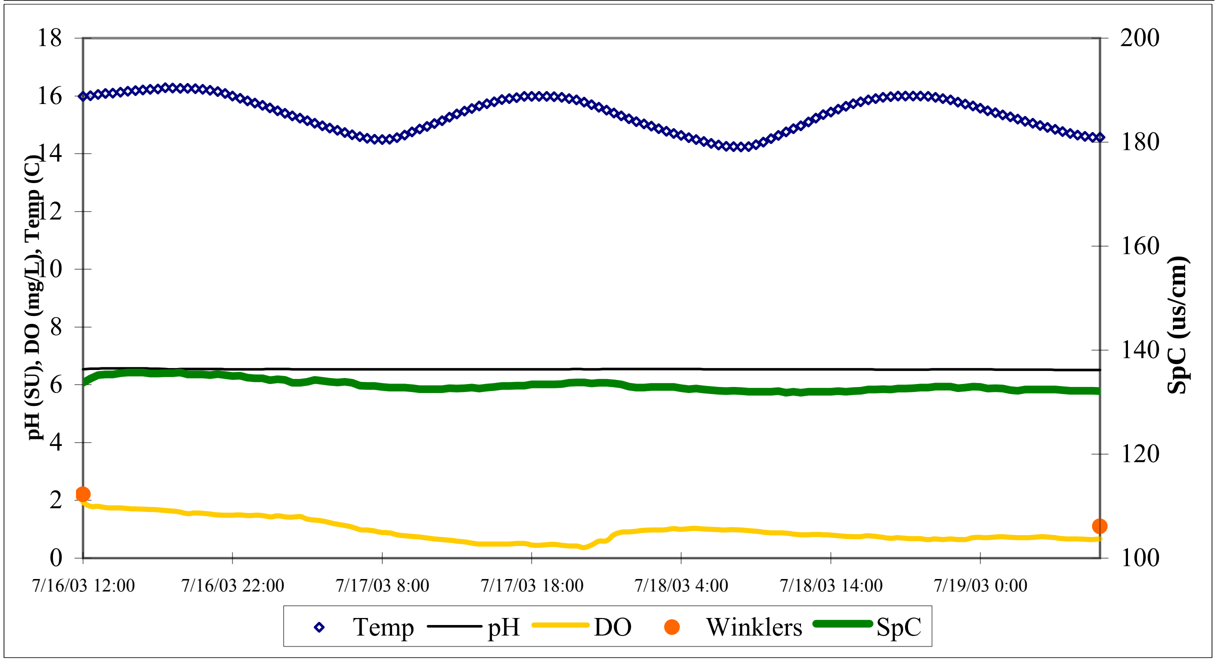
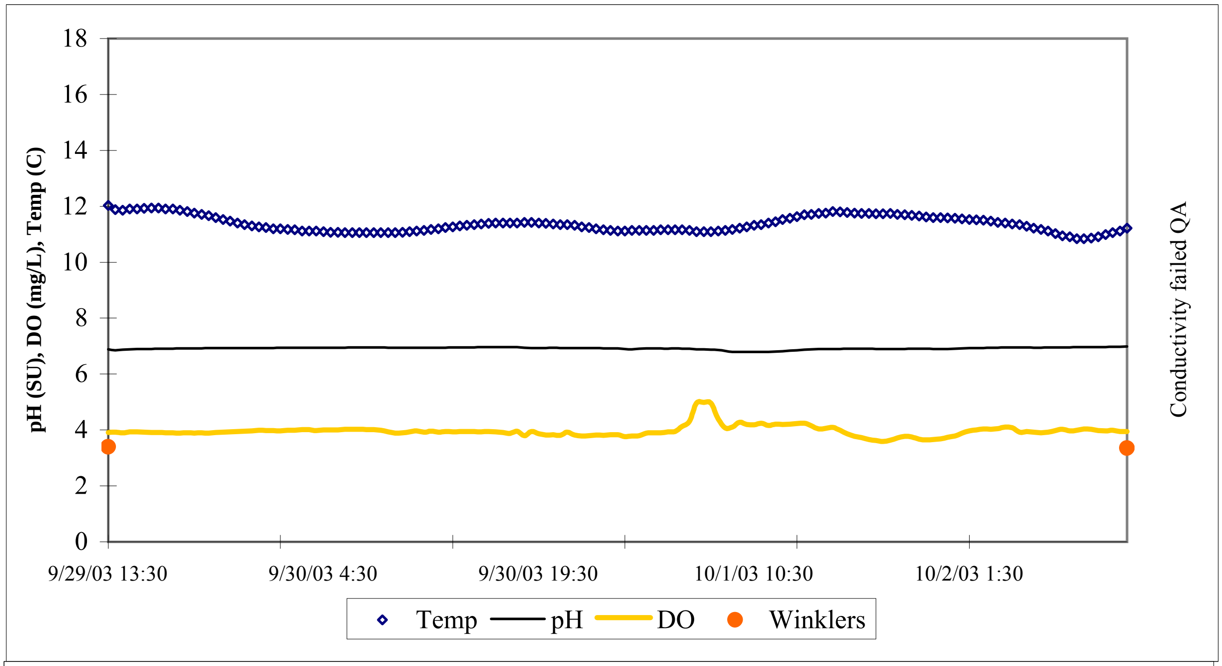


Figure F-5. Woodland Creek RM 6.2 - five sampling periods, 2002-04.



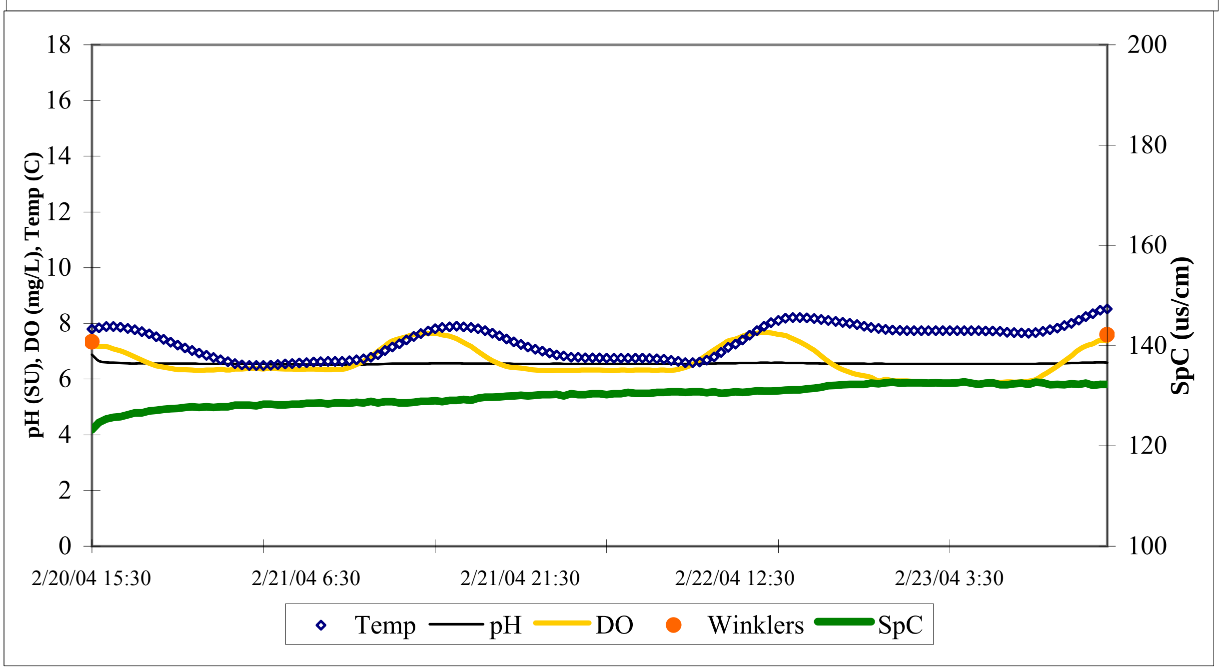
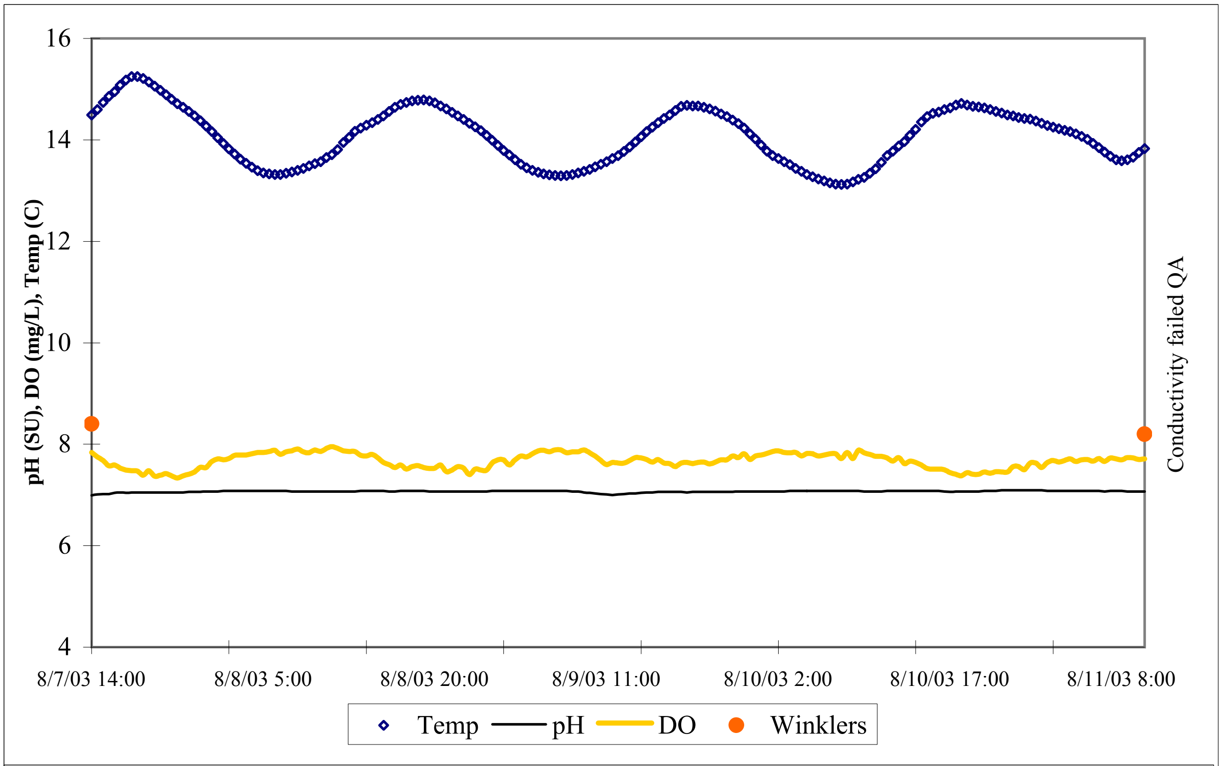


Figure F-6. Woodland Creek RM 5.1 - two sampling periods, 2003.



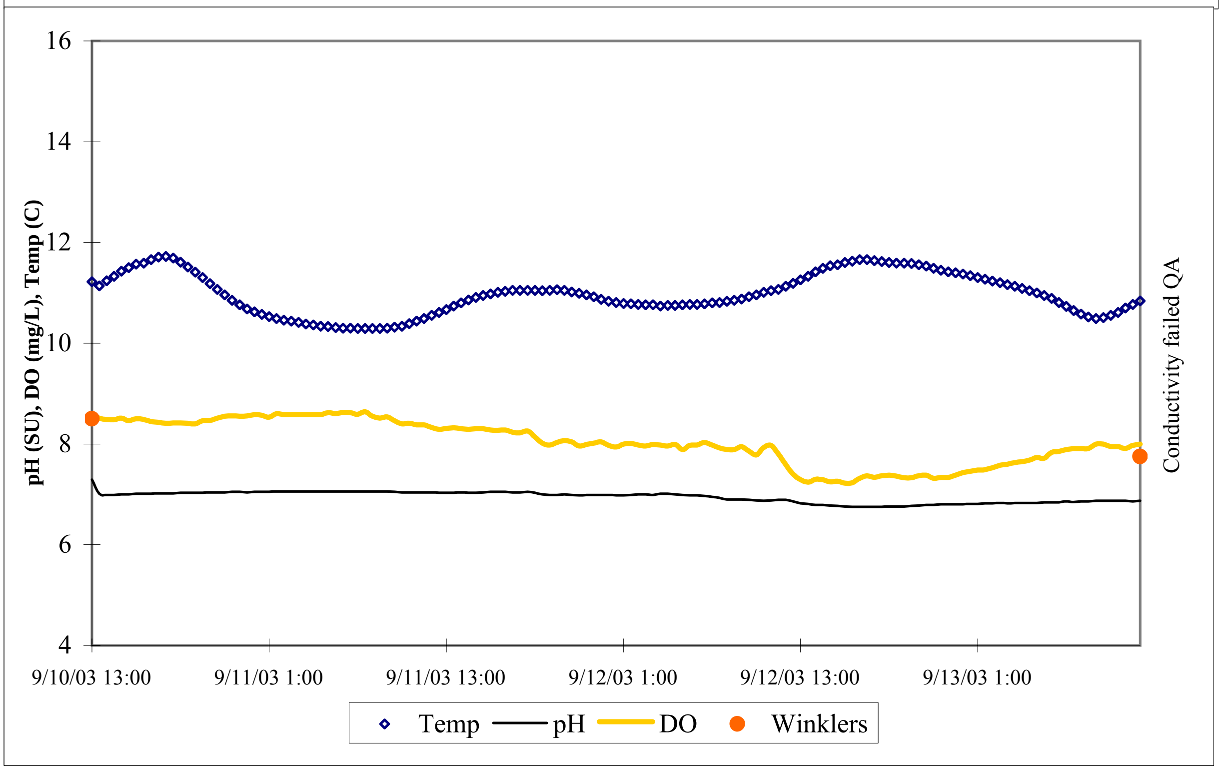
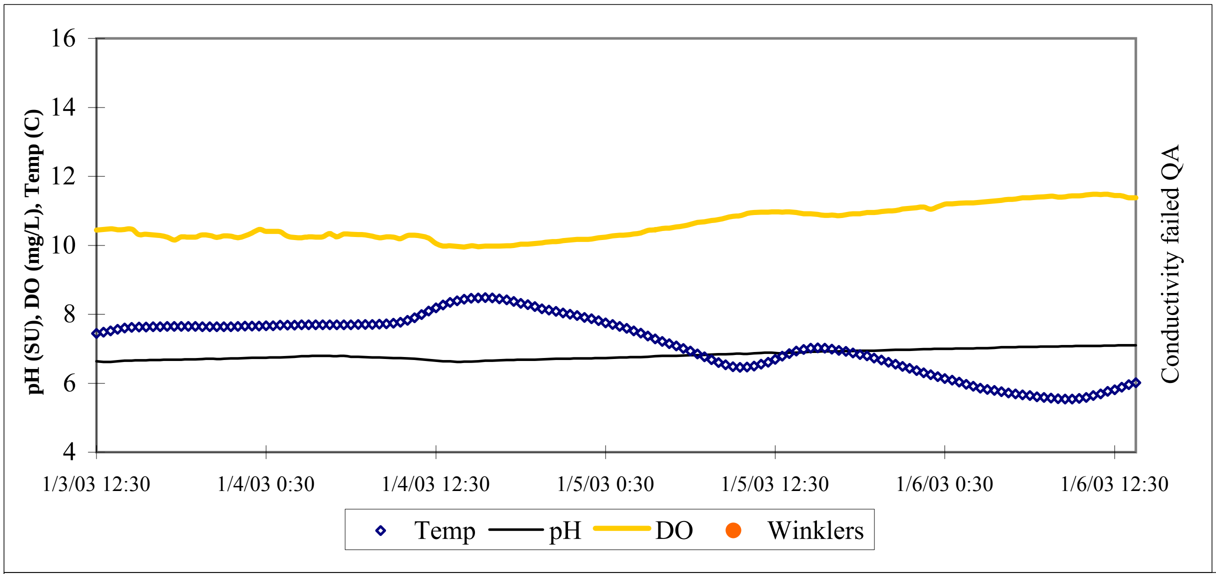
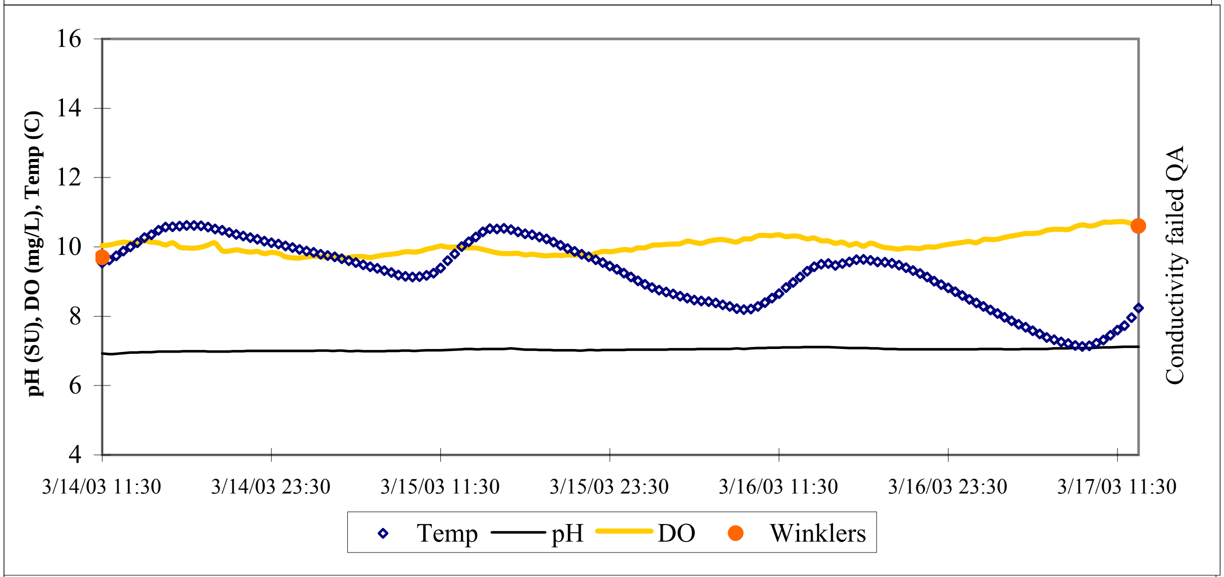


Figure F-7. Woodard Creek RM 2.9 - six sampling periods, 2003-04.





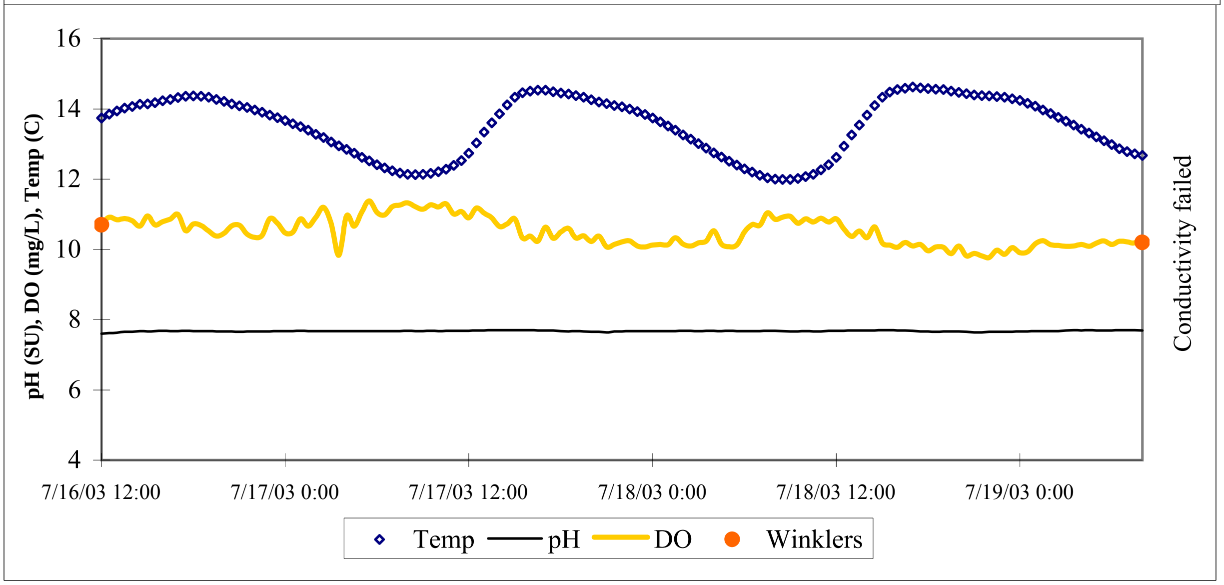
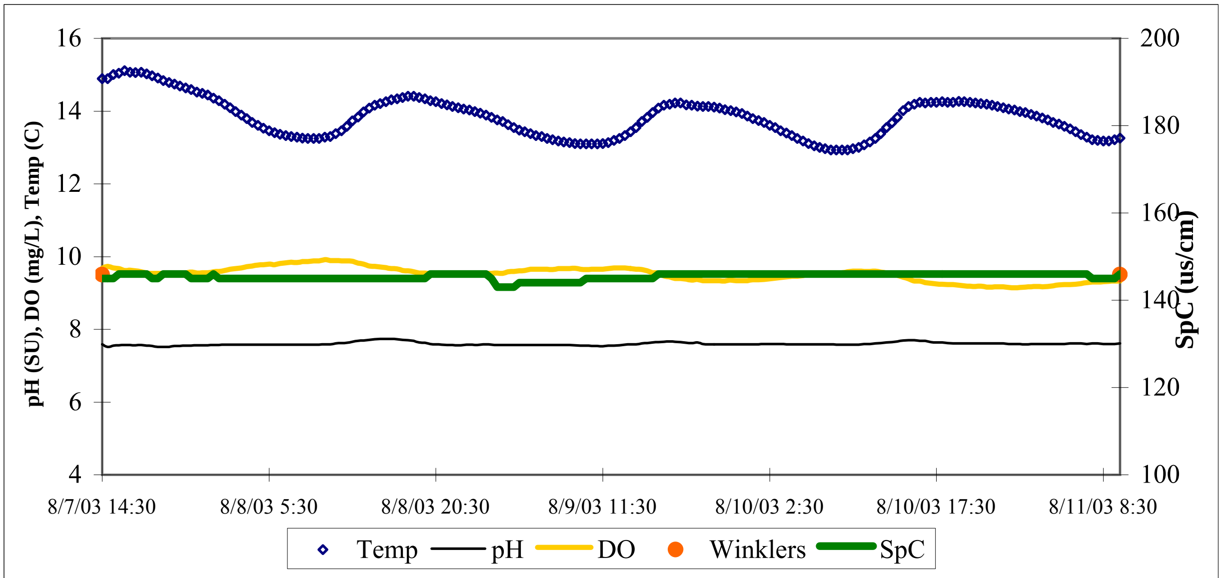
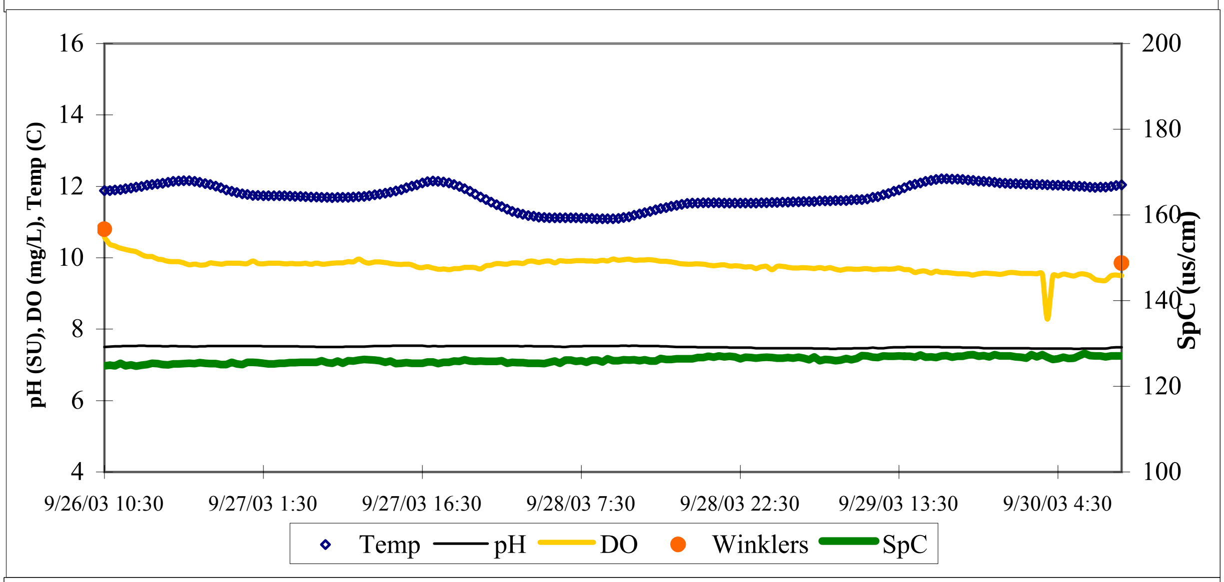


Figure F-7. Woodard Creek RM 2.9 - six sampling periods, 2003-04.





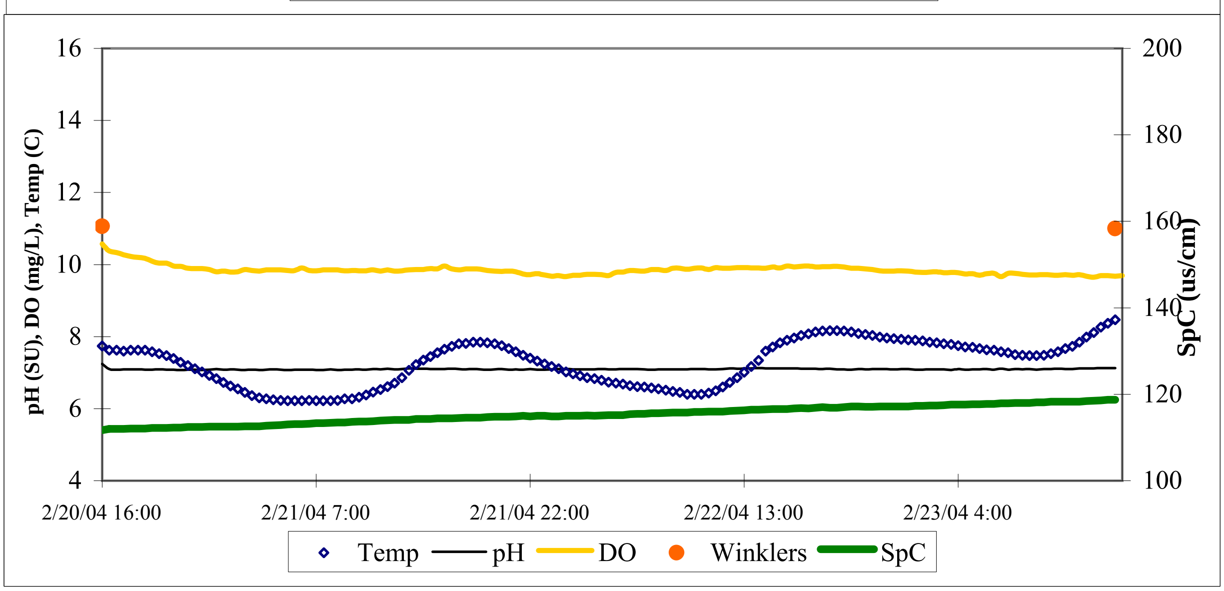
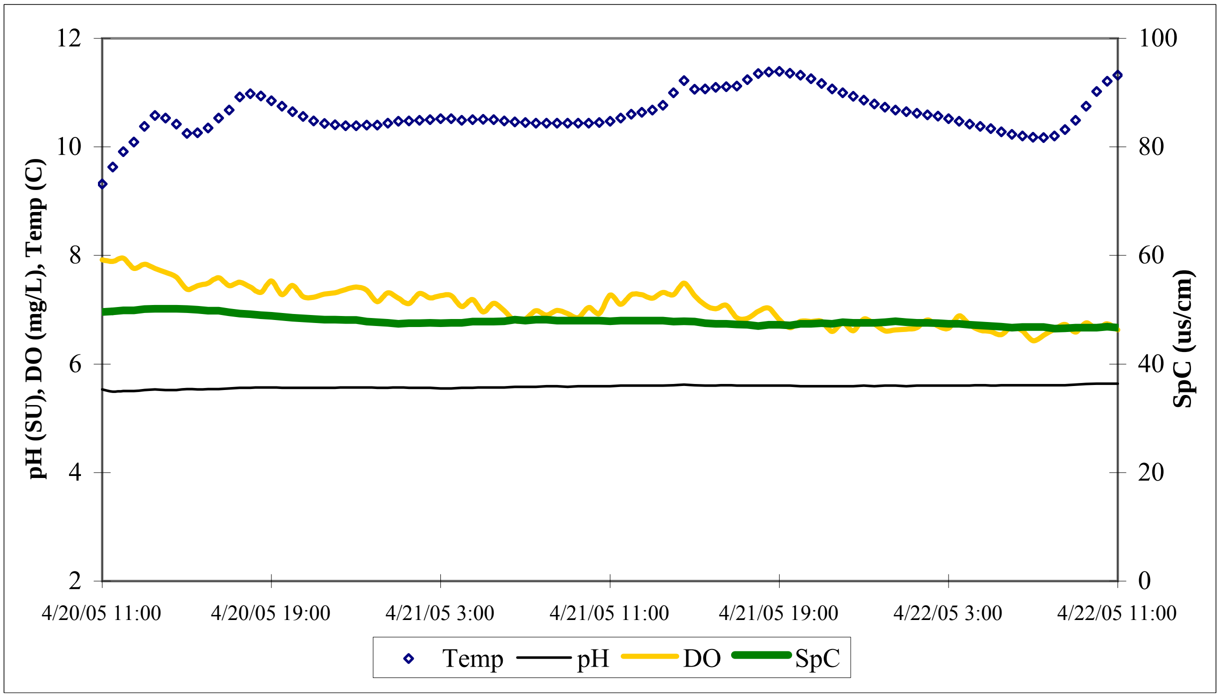
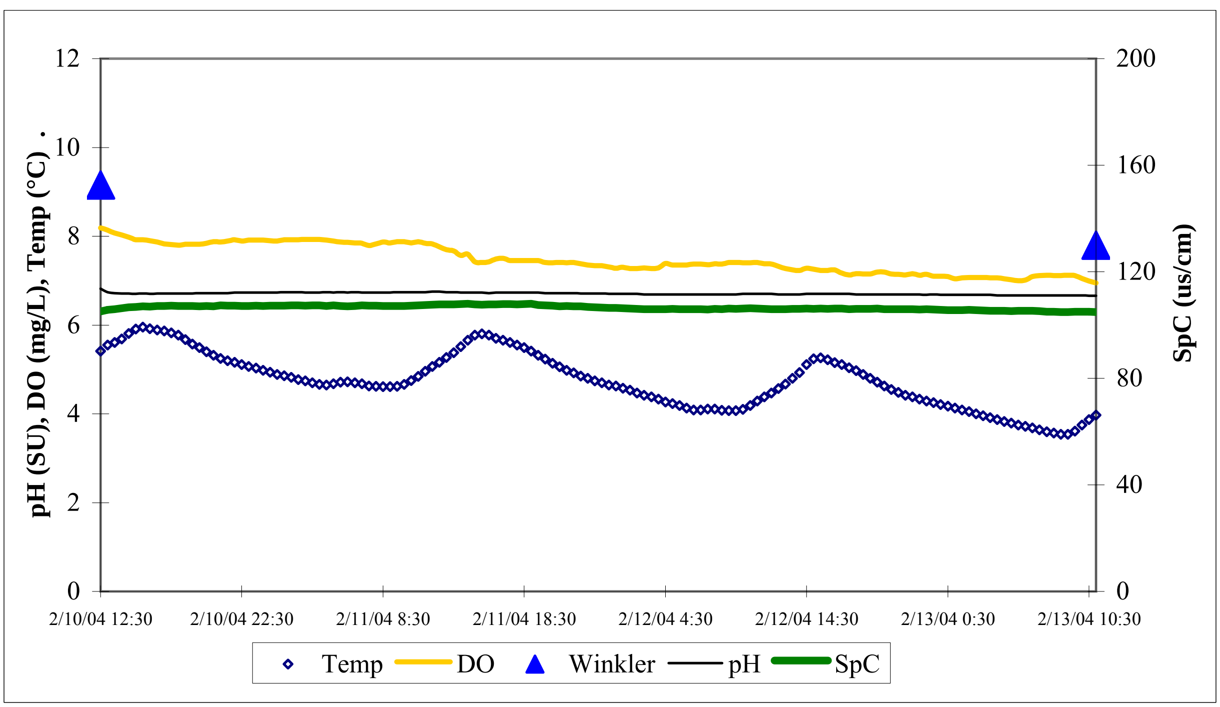


Figure F-8. Meyer Creek at RM 0.6 and 0.1 - two sampling periods, 2004-05.

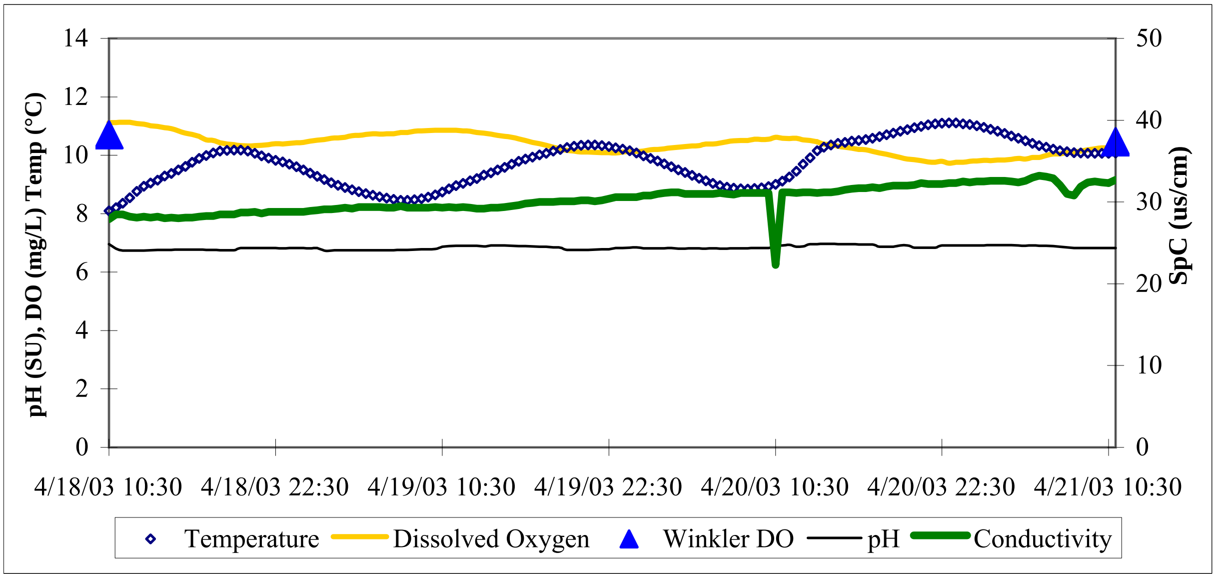


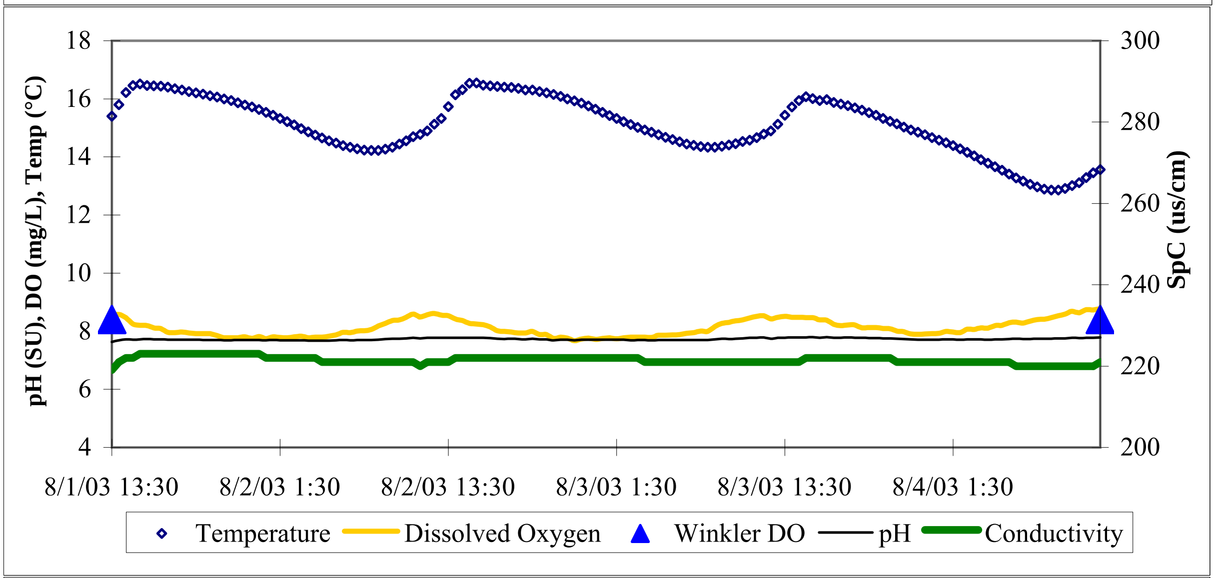
Meyer Creek at RM 0.6

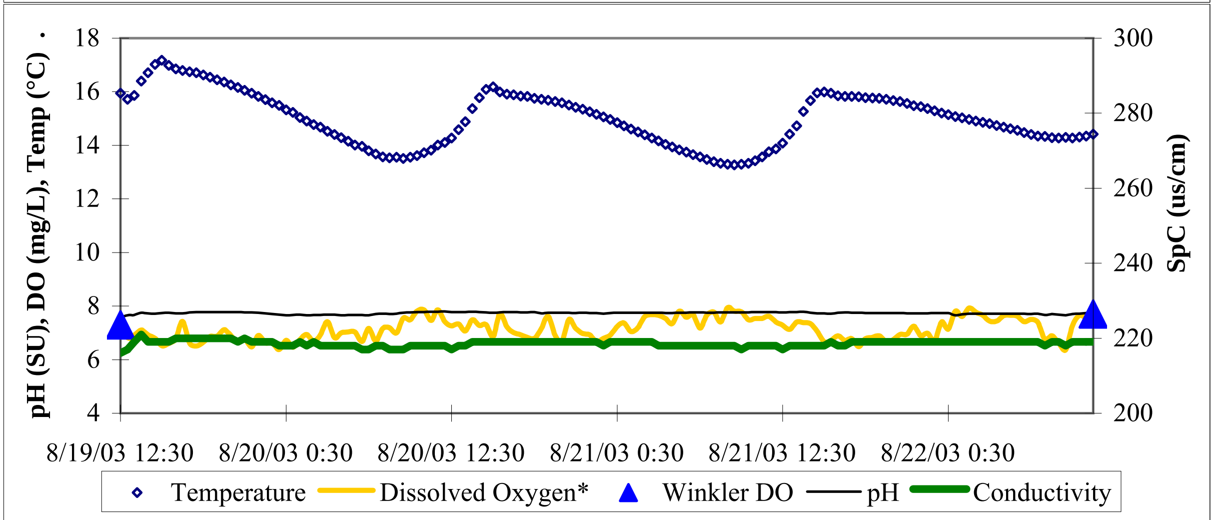


Meyer Creek at RM 0.1

Figure F-9. Sleepy Creek RM 0.1 - three sampling periods, 2003.







***dissolved oxygen values adjusted based on Winkler titration results**

Figure F-9. Sleepy Creek RM 0.1 - three sampling periods, 2003.

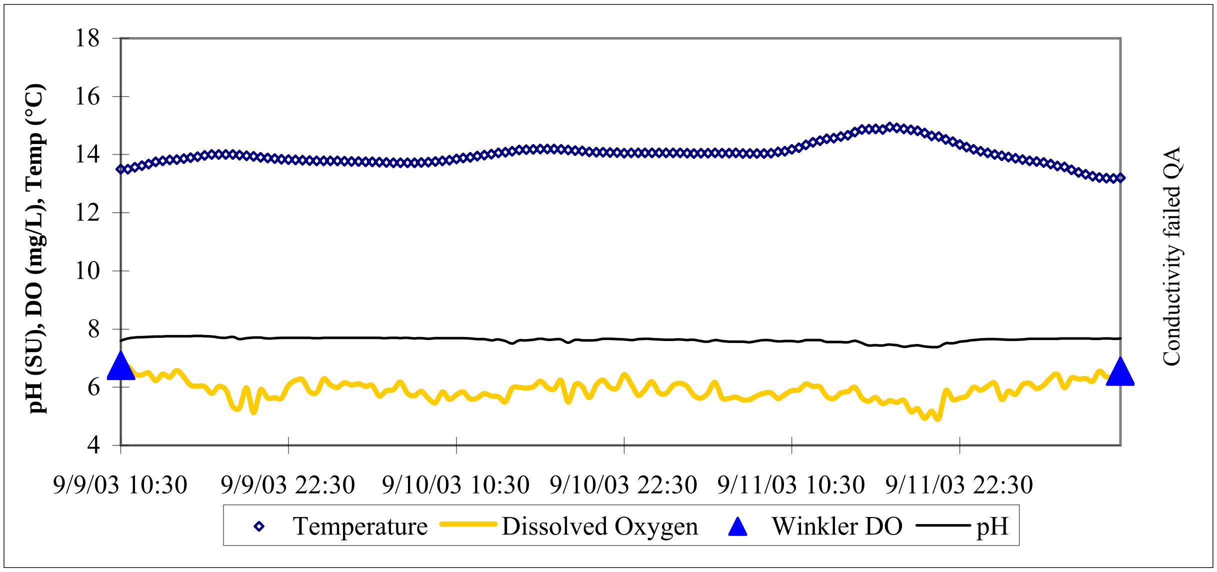
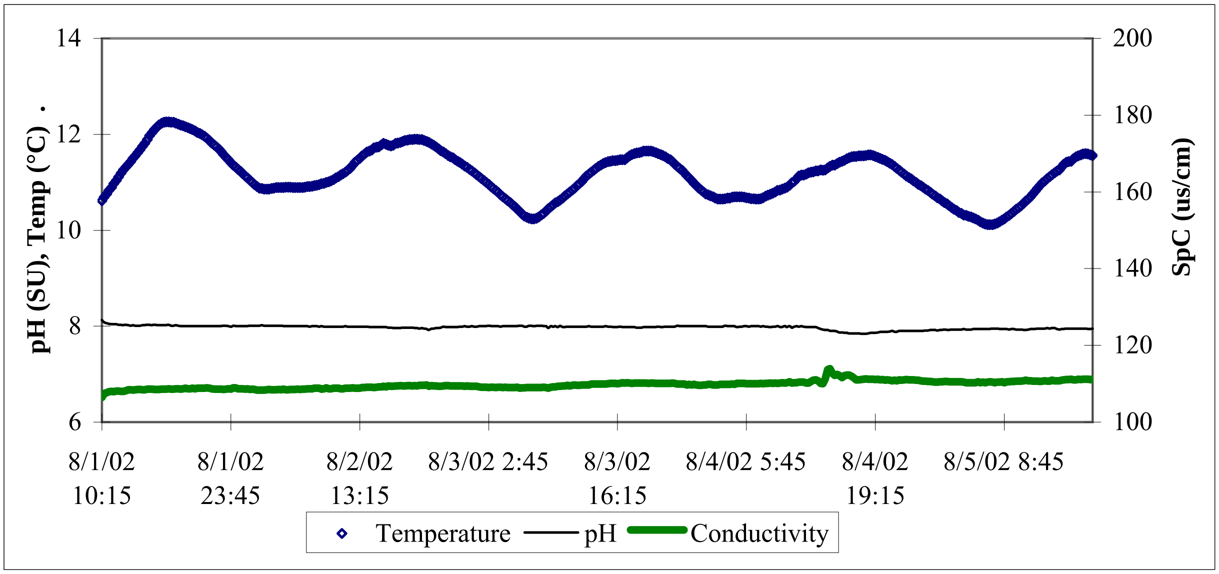
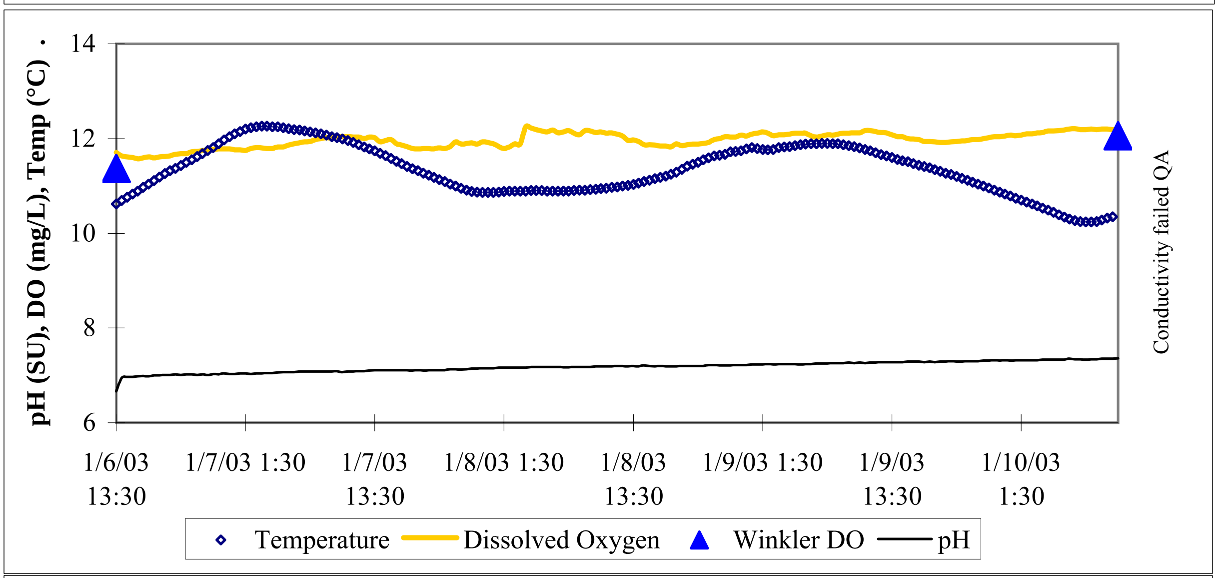


Figure F-10. Dobbs Creek RM 0.1 - five sampling periods, 2002-03.





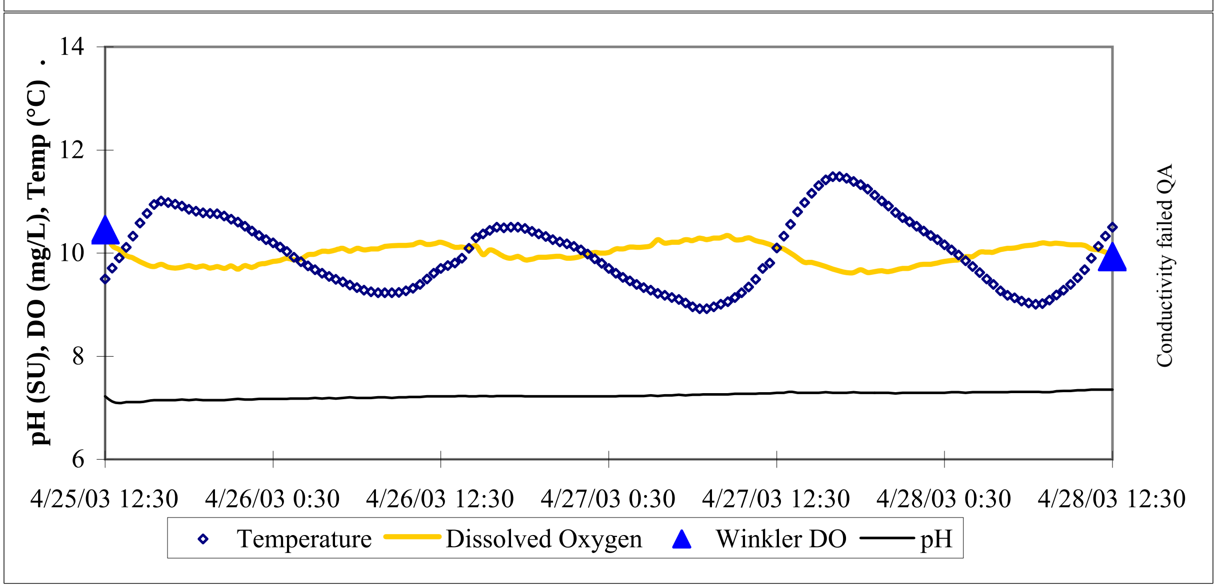
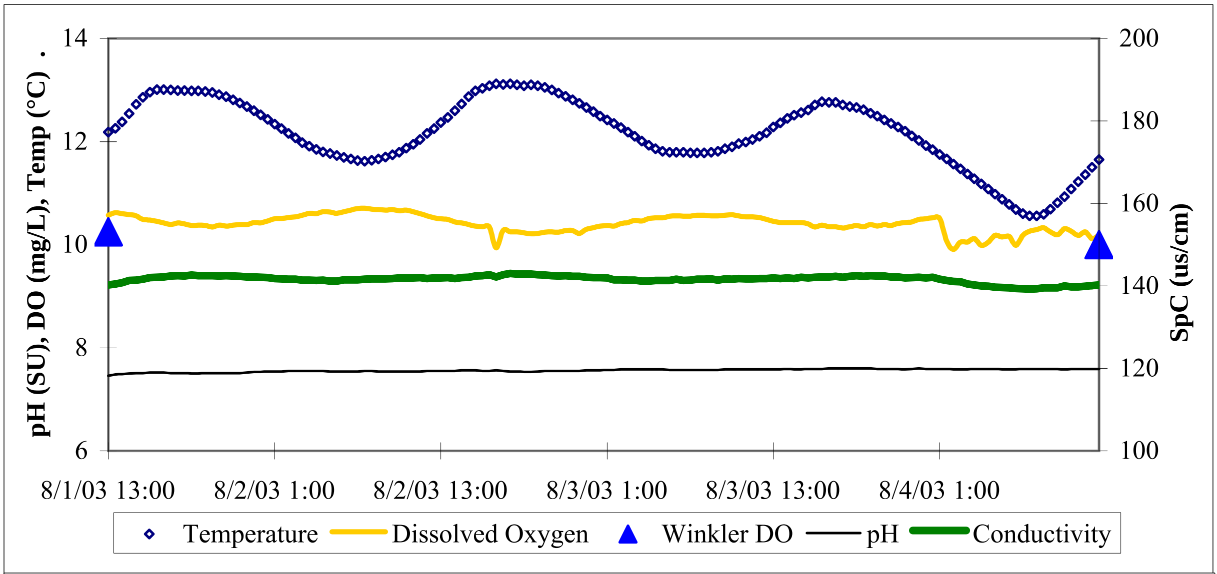
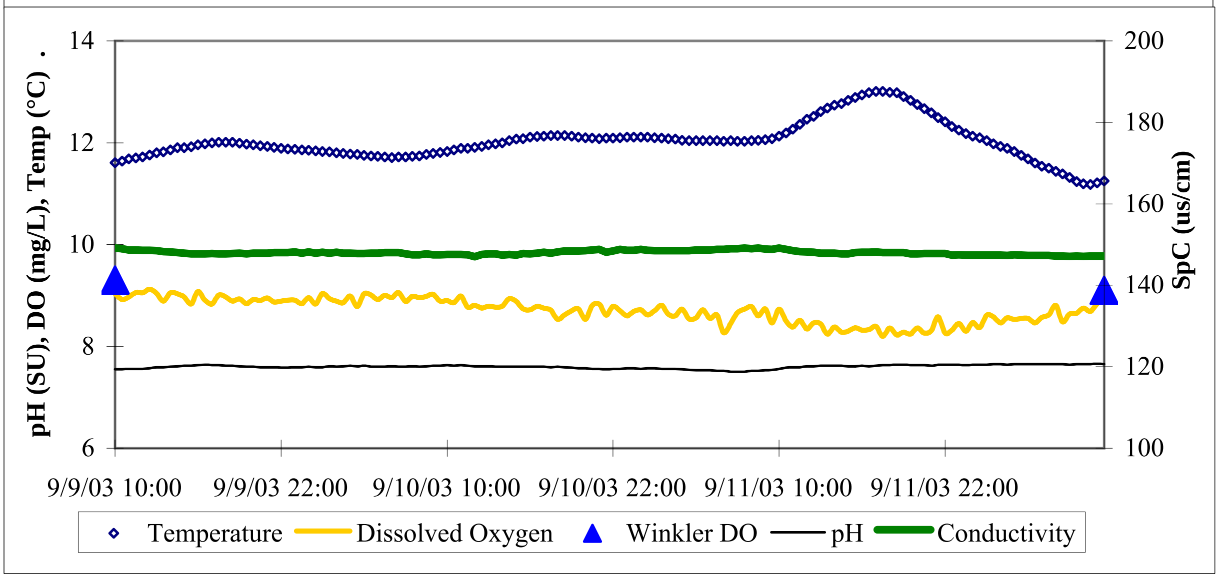


Figure F-10. Dobbs Creek RM 0.1 - five sampling periods, 2002-03.





Appendix G

Thurston County Storm Sampling Data and City of Lacey Ambient Monitoring Data for Woodland Creek

Table G-1: Thurston County Environmental Health, Stormwater Sampling Data for Woodland Creek, 2001-02.

Station Name	Date	Fecal Coliform cfu/100 mL		Flow cfs		Rainfall* inches
Woodland Creek at Long Lake outlet						
WL5.9	4/30/2001	85	90	5.38		0.60
WL5.9	5/14/2001	185	140	4.08		0.41
WL5.9	8/22/2001	No flow				0.75
WL5.9	11/14/2001	No flow				3.06
WL5.9	1/7/2002	60	40	25.52		1.28
WL5.9	2/21/2002	5	< 5	25.56		1.15
WL5.9	3/11/2002	110	100	24.60		1.26
Woodland Creek at Pacific Avenue (upstream of Lake Lois chain)						
WL5.0	4/30/2001	60	75	4.65		0.60
WL5.0	5/14/2001	90	70	3.11		0.41
WL5.0	8/22/2001	No flow				0.75
WL5.0	11/14/2001	No flow				3.06
WL5.0	1/7/2002	85	90	21.34		1.28
WL5.0	2/21/2002	50	40	23.76		1.15
WL5.0	3/11/2002	120	180	23.80		1.26
Woodland Creek at Martin Way						
WL3.8	4/30/2001	200	270	0.84		0.60
WL3.8	5/14/2001	5100	7600	0.08		0.41
WL3.8	8/22/2001	No flow				0.75
WL3.8	11/14/2001	600	900	10.74		3.06
WL3.8	1/7/2002	55	70	21.57		1.28
WL3.8	2/21/2002	50	65	18.32		1.15
WL3.8	3/11/2002	100	40	18.10		1.26
Woodland Creek just downstream of Interstate 5						
WL3.1	4/30/2001	NS				0.60
WL3.1	5/14/2001	NS				0.41
WL3.1	8/22/2001	NS				0.75
WL3.1	11/14/2001	NS				3.06
WL3.1	1/7/2002	NS				1.28
WL3.1	2/21/2002	310	260	40.37		1.15
WL3.1	3/11/2002	280	140	50.60		1.26
Woodland Creek at Draham Road (downstream)						
WL2.9	4/30/2001	1220	940	14	e	0.60
WL2.9	5/14/2001	318	315	9.53		0.41
WL2.9	8/22/2001	360	400	9.27		0.75
WL2.9	11/14/2001	1450	1200	113.17		3.06
WL2.9	1/7/2002	370	400	83.55		1.28
WL2.9	2/21/2002	300	240	51.46		1.15
WL2.9	3/11/2002	180	160	62.80		1.26
Eagle Creek (mouth), right bank tributary						
WL2.25T	4/30/2001	NS				0.60
WL2.25T	5/14/2001	110	113	0.31		0.41
WL2.25T	8/22/2001	NS				0.75
WL2.25T	11/14/2001	NS				3.06
WL2.25T	1/7/2002	NS				1.28
WL2.25T	2/21/2002	NS				1.15
WL2.25T	3/11/2002	NS				1.26
Woodland Creek at Pleasant Glade Road						
WL1.6	4/30/2001	4400	6000	24.29		0.60
WL1.6	5/14/2001	775	375	16.16		0.41
WL1.6	8/22/2001	940	820	13.88		0.75
WL1.6	11/14/2001	1700	2400	159.3		3.06
WL1.6	1/7/2002	245	230	101.07		1.28
WL1.6	2/21/2002	320	290	65.52		1.15
WL1.6	3/11/2002	335	520	85.40		1.26

Station Name	Date	Fecal Coliform cfu/100 mL		Flow cfs		Rainfall* inches
Woodland Creek in Hollywood Development						
WL1.0	4/30/2001	NS				0.60
WL1.0	5/14/2001	375	450	16.09		0.41
WL1.0	8/22/2001	1540	1460	17.56		0.75
WL1.0	11/14/2001	1600	2200	159.3	e	3.06
WL1.0	1/7/2002	230	290	101	**e**	1.28
WL1.0	2/21/2002	250	180	66	e	1.15
WL1.0	3/11/2002	NS				1.26
Woodland Creek at Hawks Prairie Road						
WL0.2	4/30/2001	3300	3600	24.29	e	0.60
WL0.2	5/14/2001	545	585	16	e	0.41
WL0.2	8/22/2001	1080	1020	17.6	e	0.75
WL0.2	11/14/2001	NS				3.06
WL0.2	1/7/2002	NS				1.28
WL0.2	2/21/2002	NS				1.15
WL0.2	3/11/2002	420	500	85	e	1.26

NS: Site not sampled
e: flow is an estimate
* Rainfall previous 12 hours before sampling

Table G-2: City of Lacey, Ambient Monitoring Data for Woodland Creek at Draham Road, 2000-05.

Station Name	Date	Sample Type*	Fecal Coliform cfu/100 mL		Flow cfs
Woodland Creek at Draham Road (downstream)					
WL2.9	11/16/2000	Ambient	9		10.77
WL2.9	12/21/2000	Ambient	11		11.14
WL2.9	01/05/2001	Storm event	68		nd
WL2.9	01/17/2001	Ambient	7		13.98
WL2.9	02/14/2001	Ambient	3	J	12.85
WL2.9	03/14/2001	Ambient	7		12.85
WL2.9	04/18/2001	Ambient	8	J	9.80
WL2.9	06/21/2001	Ambient	45		7.65
WL2.9	06/27/2001	Storm event	2100		9.18
WL2.9	07/19/2001	Ambient	200		6.57
WL2.9	08/16/2001	Ambient	38		6.06
WL2.9	08/22/2001	Storm event	540		5.64
WL2.9	08/23/2001	Storm event	1300	J	8.44
WL2.9	09/20/2001	Ambient	78	J	4.06
WL2.9	10/10/2001	Storm event	196	J	5.99
WL2.9	10/17/2001	Ambient	37		5.07
WL2.9	12/05/2001	Ambient	12	J	10.62
WL2.9	12/27/2001	Ambient	12	J	22.38
WL2.9	01/17/2002	Ambient	3	J	24.53
WL2.9	02/25/2002	Ambient	6	J	34.80
WL2.9	03/20/2002	Ambient	32		38.80
WL2.9	04/15/2002	Ambient	14	J	30.50
WL2.9	05/16/2002	Ambient	5	J	15.03
WL2.9	06/20/2002	Ambient	35		9.46
WL2.9	07/18/2002	Ambient	32		9.85
WL2.9	08/20/2002	Ambient	19	J	6.53
WL2.9	09/17/2002	Ambient	48		6.33
WL2.9	10/10/2002	Ambient	104	J	6.88
WL2.9	11/14/2002	Ambient	50	J	6.33
WL2.9	12/17/2002	Ambient	34		8.50
WL2.9	01/16/2003	Ambient	25		8.57
WL2.9	02/21/2003	Ambient	7	J	15.93
WL2.9	03/20/2003	Ambient	90	J	22.99
WL2.9	04/25/2003	Ambient	13	J	21.05
WL2.9	05/19/2003	Ambient	33		22.57
WL2.9	06/27/2003	Ambient	31.5		9.64
WL2.9	07/23/2003	Ambient	18		9.32
WL2.9	08/22/2003	Ambient	47		7.33
WL2.9	09/25/2003	Ambient	30		4.53
WL2.9	10/24/2003	Ambient	40		7.42
WL2.9	11/21/2003	Ambient	35		8.17
WL2.9	12/18/2003	Ambient	25		10.57
WL2.9	01/21/2004	Ambient	10		15.47
WL2.9	02/23/2004	Ambient	10		21.19
WL2.9	03/24/2004	Ambient	25		16.82
WL2.9	04/22/2004	Ambient	30		12.73
WL2.9	05/20/2004	Ambient	20		10.85
WL2.9	06/22/2004	Ambient	145		8.89
WL2.9	07/22/2004	Ambient	50		6.67
WL2.9	08/23/2004	Ambient	270		6.41
WL2.9	09/21/2004	Ambient	45		6.14
WL2.9	11/04/2004	Ambient	25		5.08
WL2.9	12/02/2004	Ambient	5		5.47
WL2.9	01/04/2005	Ambient	5	U	5.10
WL2.9	03/02/2005	Ambient	5		6.70
WL2.9	04/06/2005	Ambient	20		13.72
WL2.9	05/10/2005	Ambient	1100		13.12
WL2.9	06/07/2005	Ambient	80		11.93

nd: sample not obtained
* Storm event defined as 1.0" of rain or greater in the previous 24 hours.
U: Below detection limits
J: Value is an estimate

Appendix H

Compliance with Water Quality Standards

Table H-1. Woodland Creek compliance with fecal coliform water quality standard.

Woodland Creek site	Number of sample events	Geometric mean (≤ 50 fc/100mL)	Percentage of samples ≥ 100fc/100mL (10% not to exceed)	Fecal coliform 90th percentile	Meets fecal coliform standard
RM 4.5					
Storm events	5	29	20%	163	NO
June - Sept	No flow during this period				
RM 3.8					
Storm events	6	32	17%	181	NO
June - Sept	No flow during this period				
RM 3.7 T					
Storm events	11	446	73%	8370	NO
June - Sept	No flow during this period				
RM 3.45					
Annual	13	88	38%	1410	NO
Storm events	9	195	56%	2750	NO
June - Sept	4	15	0%	59	Yes
RM 3.4					
Annual	13	57	45%	1120	NO
Storm events	9	129	56%	1990	NO
June - Sept	4	9	0%	81	Yes
CC 0.0					
Annual	13	52	27%	194	NO
Storm events	9	50	33%	243	NO
June - Sept	4	58	0%	89	NO
CC 0.2					
Storm events	9	50	22%	174	NO
CC 0.4					
Storm events	8	161	63%	694	NO
CC 0.6					
Storm events	8	208	75%	1780	NO
RM 3.1 SW					
Annual	Flow in pipe only during larger storm events				
Storm events	3	539	100%	659	NO
RM 3.1 T					
Annual	12	22	17%	385	NO
Storm events	9	31	22%	624	NO
June - Sept	3	7	0%	78	Yes
RM 3.1					
Annual	13	59	23%	277	NO
Storm events	9	72	33%	421	NO
June - Sept	4	39	0%	82	Yes
RM 2.9					
Annual	13	60	23%	263	NO
Storm events	9	65	33%	368	NO
June - Sept	4	49	0%	112	Yes

Woodland Creek site	Number of sample events	Geometric mean (≤ 50 fc/100mL)	Percentage of samples ≥ 100fc/100mL (10% not to exceed)	Fecal coliform 90^{th} percentile	Meets fecal coliform standard
RM 2.6 SW					
Annual	7	587	100%	1670	NO
Storm events	6	617	100%	1920	NO
June - Sept	One event sampled				
RM 2.6					
Annual	12	77	23%	379	NO
Storm events	8	72	33%	527	NO
June - Sept	4	87	0%	108	NO
RM 2.25T					
Annual	12	69	50%	743	NO
Storm events	8	40	38%	360	NO
June - Sept	4	204	75%	2180	NO
RM 1.95 T					
Annual	9	62	25%	280	NO
Storm events	8	54	25%	246	NO
June - Sept	One event sampled				
RM 1.9 T					
Annual	12	39	25%	265	NO
Storm events	8	41	38%	451	NO
June - Sept	4	35	0%	42	Yes
RM 1.6					
Annual	12	98	58%	609	NO
Storm events	8	73	38%	633	NO
June - Sept	4	177	100%	282	NO
RM 1.2 T					
Annual	12	205	67%	953	NO
Storm events	8	145	50%	762	NO
June - Sept	4	412	100%	904	NO
RM 1.1 T					
Annual	11	215	67%	1710	NO
Storm events	8	212	50%	2510	NO
June - Sept	3	226	100%	300	NO
RM 1.0					
Annual	12	121	58%	381	NO
Storm events	8	95	38%	344	NO
June - Sept	4	194	100%	321	NO

Woodland Creek site	Number of sample events	Geometric mean (≤ 14 fc/100mL)	Percentage of samples ≥ 43 fc/100mL (10% not to exceed)	Fecal coliform 90^{th} percentile	Meets fecal coliform standard
RM 0.2	Must meet marine fecal coliform standard				
Annual	12	126	67%	519	NO
Storm events	8	102	50%	552	NO
June - Sept	4	192	100%	271	NO

Table H-2. Woodland Creek compliance with pH, dissolved oxygen, and temperature standards for synoptic and *in-situ* continuous surveys.

Woodland Creek site and type of monitoring	Met standard of dissolved oxygen > 9.5 mg/L?	Met standard of temperature ≤ 16.0 °C?	Met standard of pH range 6.5-8.5 SU?
RM 4.5 (synoptic)	NO	Yes	Yes
RM 3.8 (synoptic)	Yes	Yes	Yes
RM 3.7 T (synoptic)	NO	Yes	Yes
RM 3.45 (synoptic)	NO	Yes	NO
RM 3.4 (synoptic)	NO	Yes	Yes
RM 3.4 (*in-situ* continuous)	NO	Yes	NO
CC 0.0 (synoptic)	NO	Yes	NO
CC 0.2 (synoptic)	NO	Yes	NO
CC 0.4 (synoptic)	NO	Yes	NO
CC 0.6 (synoptic)	NO	Yes	NO
RM 3.1 T (synoptic)	Yes	Yes	Yes
RM 3.1 (synoptic)	NO	Yes	Yes
RM 3.1 (*in-situ* continuous)	NO	Yes	NO
RM 2.9 (synoptic)	NO	Yes	Yes
RM 2.6 (synoptic)	NO	Yes	Yes
RM 2.6 SW (synoptic)	Yes	Yes	Yes
RM 2.4 (synoptic)	Yes	Yes	Yes
RM 2.25 T (synoptic)	NO	Yes	NO
RM 1.95 T (synoptic)	NO	Yes	NO
RM 1.9 T (synoptic)	NO	Yes	Yes
RM 1.6 (synoptic)	NO	Yes	Yes
RM 1.6 (*in-situ* continuous)	NO	Yes	Yes
RM 1.2 T (synoptic)	Yes	Yes	Yes
RM 1.1 T (synoptic)	NO	Yes	NO
RM 1.0 (synoptic)	NO	Yes	NO

	Met standard of dissolved oxygen > 7.0 mg/L?	Met standard of temperature ≤ 13.0 °C?	Met standard of pH range 7.0-8.5 SU?
RM 0.2 (synoptic)	Yes	Yes	NO

Table H-3. Woodard Creek compliance with fecal coliform water quality standard.

Woodard Creek site	Number of sample events	Geometric mean (≤ 50 fc/100mL)	Percentage of samples ≥ 100fc/100mL (10% not to exceed)	Fecal coliform 90th percentile	Meets fecal coliform standard
SWFones*					
Storm events	4	957	100%	6110	NO
SWPond					
Storm events	4	168	50%	4590	NO
RM 6.9					
Annual	12	91	33%	340	NO
Storm events	8	92	25%	415	NO
June - Sept	4	89	50%	252	NO
RM 6.8					
Annual	5	140	80%	677	NO
Storm events	3	76	67%	352	NO
June - Sept	2	352	100%	759	NO
RM 6.2					
Annual	12	46	25%	145	NO
Storm events	8	51	38%	201	NO
June - Sept	4	37	0%	65	Yes
RM 5.1					
Annual	12	173	67%	591	NO
Storm events	8	133	50%	522	NO
June - Sept	4	293	100%	489	NO
RM 3.4					
Annual	12	158	75%	637	NO
Storm events	8	141	75%	714	NO
June - Sept	4	196	75%	497	NO
RM 2.9					
Annual	12	145	58%	455	NO
Storm events	8	138	50%	496	NO
June - Sept	4	161	75%	420	NO

Woodard Creek site	Number of sample events	Geometric mean (≤ 14 fc/100mL)	Percentage of samples ≥ 43 fc/100mL (10% not to exceed)	Fecal coliform 90th percentile	Meets fecal coliform standard
RM 0.0	Must meet marine fecal coliform standard				
Annual	12	89	33%	347	NO
Storm events	8	97	38%	450	NO
June - Sept	4	75	25%	222	NO

* This site represents water quality in a stormwater conveyance system before stormwater treatment has occurred, and thus is not required to meet water quality standards.

Table H-4. Woodard Creek compliance with pH, dissolved oxygen, and temperature standards for synoptic and *in-situ* continuous surveys.

Woodard Creek site and type of monitoring	Met standard of dissolved oxygen > 9.5 mg/L?	Met standard of temperature ≤ 16.0 °C?	Met standard of pH range 6.5-8.5 SU?
SWFones (synoptic)*	NO	Yes	Yes
SWPond (synoptic)	NO	Yes	Yes
RM 6.9 (synoptic)	NO	Yes	Yes
RM 6.8 (synoptic)	NO	Yes	Yes
RM 6.8 (*in-situ* continuous)	NO	Yes	NO
RM 6.2 (synoptic)	NO	Yes	Yes
RM 6.2 (*in-situ* continuous)	NO	NO	Yes
RM 6.2T (synoptic)	NO	Yes	Yes
RM 5.1 (synoptic)	NO	Yes	Yes
RM 5.1 (*in-situ* continuous)	NO	Yes	Yes
RM 4.3 (synoptic)	NO	Yes	Yes
RM 3.4 (synoptic)	NO	Yes	Yes
RM 2.9 (synoptic)	NO	Yes	NO
RM 2.9 (*in-situ* continuous)	NO	Yes	Yes
	Met standard of dissolved oxygen > 7.0 mg/L?	**Met standard of temperature ≤ 13.0 °C?**	**Met standard of pH range 7.0-8.5 SU?**
RM 0.0 (synoptic)	NO	NO	Yes

* This site represents water quality in a stormwater conveyance system before stormwater treatment has occurred, and thus is not required to meet water quality standards.

Table H-5. Meyer, Sleepy, Dobbs, and Goose creeks compliance with fecal coliform water quality standard.

Creek site	Number of sample events	Geometric mean (≤ 50 fc/100mL)	Percentage of samples ≥ 100fc/100mL (10% not to exceed)	Fecal coliform 90^{th} percentile	Meets fecal coliform standard
Meyer Creek RM 0.6					
Storm events	6	109	33%	741	NO
Meyer Creek RM 0.1					
Storm events	2	19	50%	4240	NO
June - Sept	No flow during this period				
Sleepy Creek RM 0.8					
Storm events	8	125	50%	1240	NO
June - Sept	No flow during this period				
Sleepy Creek RM 0.1					
Annual	12	128	50%	948	NO
Storm events	8	90	38%	835	NO
June - Sept	4	254	75%	921	NO
Dobbs Creek RM 1.0					
Storm events	7	109	43%	2600	NO
June - Sept	Little or no flow during this period, sampled once				
Dobbs Creek RM 0.1					
Annual	14	266	71%	1610	NO
Storm events	10	299	70%	2420	NO
June - Sept	4	199	75%	436	NO
Goose Creek RM 0.4					
Storm events	7	54	43%	773	NO
June - Sept	No flow during this period				

Table H-6. Meyer, Sleepy, Dobbs, and Goose creeks compliance with pH, dissolved oxygen, and temperature standards for synoptic and *in-situ* continuous surveys.

Henderson tributary sites and type of monitoring	Met standard of dissolved oxygen > 9.5 mg/L?	Met standard of temperature ≤ 16.0 °C?	Met standard of pH range 6.5-8.5 SU?
Sleepy Creek RM 0.8 (synoptic)	NO	Yes	NO
Sleepy Creek RM 0.1 (synoptic)	NO	Yes	NO
Sleepy Creek RM 0.1 (*in-situ* continuous)	NO	NO	NO
Dobbs Creek RM 1.0 (synoptic)	Yes	Yes	Yes
Dobbs Creek RM 0.1 (synoptic)	Yes	Yes	Yes
Dobbs Creek RM 0.1 (*in-situ* continuous)	NO	Yes	Yes
Goose Creek RM 0.4	Yes	Yes	NO
Meyer Creek RM 0.6 (synoptic)	NO	Yes	NO
Meyer Creek RM 0.6 (*in-situ* continuous)	NO	Yes	NO
Meyer Creek RM 0.1 (synoptic)	Yes	Yes	Yes
Meyer Creek RM 0.1 (*in-situ* continuous)*	NO	Yes	Yes

.

Appendix I

Woodland Creek QUAL2K Model Calibration Coefficients and Reach Characteristics

Table I-1. Rate parameters used for Woodland Creek QUAL2K model.

Parameter	Value	Units	Symbol	Auto-cal	Min value	Max value
Stoichiometry:						
Carbon	40	gC	gC	No	30	50
Nitrogen	7.2	gN	gN	No	3	9
Phosphorus	1	gP	gP	No	0.4	2
Dry weight	100	gD	gD	No	100	100
Chlorophyll	1	gA	gA	No	0.4	2
Inorganic suspended solids:						
Settling velocity	1.71596	m/d	v_i	Yes	0	2
Oxygen:						
Reaeration model	Internal			f(u h)		
Temp correction	1.024		$_{a}$			
Reaeration wind effect	None					
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}			
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}			
Oxygen inhib model CBOD oxidation	Exponential					
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}	No	0.60	0.60
Oxygen inhib model nitrification	Exponential					
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}	No	0.60	0.60
Oxygen enhance model denitrification	Exponential					
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}	No	0.60	0.60
Oxygen inhib model phyto resp	Exponential					
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}	No	0.60	0.60
Oxygen enhance model bot alg resp	Exponential					
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}	No	0.60	0.60
Slow CBOD:						
Hydrolysis rate	3.9988	/d	k_{hc}	Yes	0	5
Temp correction	1.047		$_{hc}$	No	1	1.07
Oxidation rate	2.03415	/d	k_{dcs}	Yes	0	5
Temp correction	1.047		$_{dcs}$	No	1	1.07
Fast CBOD:						
Oxidation rate	3.3321	/d	k_{dc}	Yes	0	5
Temp correction	1.047		$_{dc}$	No	1	1.07
Organic Nitrogen:						
Hydrolysis	1.72385	/d	k_{hn}	Yes	0	5
Temp correction	1.07		$_{hn}$	No	1	1.07
Settling velocity	0.18486	m/d	v_{on}	Yes	0	2
Ammonium:						
Nitrification	8.0321	/d	k_{na}	Yes	0	10
Temp correction	1.07		$_{na}$	No	1	1.07
Nitrate:						
Denitrification	0.75706	/d	k_{dn}	Yes	0	2
Temp correction	1.07		$_{dn}$	No	1	1.07
Sed denitrification transfer coeff	0.95469	m/d	v_{di}	Yes	0	1
Temp correction	1.07		$_{di}$	No	1	1.07

Table I-1 (page 2). Rate parameters used for Woodland Creek QUAL2K model.

Parameter	Value	Units	Symbol	Auto-cal	Min value	Max value
Organic Phosphorus:						
Hydrolysis	3.70875	/d	k_{hp}	Yes	0	5
Temp correction	1.07		$_{hp}$	No	1	1.07
Settling velocity	1.84958	m/d	v_{op}	Yes	0	2
Inorganic Phosphorus:						
Settling velocity	1.34382	m/d	v_{ip}	Yes	0	2
Sed P oxygen attenuation half sat constant	1.02188	mgO_2/L	k_{spi}	Yes	0	2
Phytoplankton:						
Max growth rate	2.5	/d	k_{gp}	No	1.5	3
Temp correction	1.07		$_{gp}$	No	1	1.07
Respiration rate	0.1	/d	k_{rp}	No	0	1
Temp correction	1.07		$_{rp}$	No	1	1.07
Death rate	0	/d	k_{dp}	No	0	1
Temp correction	1		$_{dp}$	No	1	1.07
Nitrogen half sat constant	15	ugN/L	k_{sPp}	No	0	150
Phosphorus half sat constant	2	ugP/L	k_{sNp}	No	0	50
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}	No	1.30E-06	1.30E-04
Phytoplankton use HCO3- as substrate	Yes					
Light model	Half saturation					
Light constant	57.6	langleys/d	K_{Lp}	No	28.8	115.2
Ammonia preference	25	ugN/L	k_{hnxp}	No	25	25
Settling velocity	0.15	m/d	v_a	No	0	5
Bottom Algae:						
Growth model	Zero-order					
Max growth rate	487.264	$mgA/m^2/d$ or /d	C_{gb}	Yes	100	500
Temp correction	1.07		$_{gb}$	No	1	1.07
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$	No	1000	1000
Respiration rate	0.01138	/d	k_{rb}	Yes	0	0.5
Temp correction	1.07		$_{rb}$	No	1	1.07
Excretion rate	0.40298	/d	k_{eb}	Yes	0	0.5
Temp correction	1.07		$_{db}$	No	1	1.07
Death rate	0.18916	/d	k_{db}	Yes	0	0.5
Temp correction	1.07		$_{db}$	No	1	1.07
External nitrogen half sat constant	190.17	ugN/L	k_{sPb}	Yes	0	300
External phosphorus half sat constant	78.676	ugP/L	k_{sNb}	Yes	0	100
Inorganic carbon half sat constant	1.30E-04	moles/L	k_{sCb}	Yes	1.30E-06	1.30E-04
Bottom algae use HCO3- as substrate	Yes					
Light model	Half saturation					
Light constant	73.10566	langleys/d	K_{Lb}	Yes	1	100
Ammonia preference	39.69712	ugN/L	k_{hnxb}	Yes	1	100
Subsistence quota for nitrogen	3.0209832	mgN/mgA	q_{0N}	Yes	0.0072	7.2
Subsistence quota for phosphorus	0.01284814	mgP/mgA	q_{0P}	Yes	0.001	1
Maximum uptake rate for nitrogen	7.14269	mgN/mgA/d	$_{mN}$	Yes	1	500
Maximum uptake rate for phosphorus	23.1556	mgP/mgA/d	$_{mP}$	Yes	1	500
Internal nitrogen half sat ratio	2.1723925		$K_{qN,ratio}$	Yes	1.05	5
Internal phosphorus half sat ratio	3.828351		$K_{qP,ratio}$	Yes	1.05	5

Table I-1 (page 3). Rate parameters used for Woodland Creek QUAL2K model.

Parameter	Value	Units	Symbol	Auto-cal	Min value	Max value
Detritus (POM):						
Dissolution rate	4.30685	/d	k_{dt}	Yes	0	5
Temp correction	1.07		$_{dt}$	No	1.07	1.07
Settling velocity	1.95865	m/d	v_{dt}	Yes	0	5
Pathogens:						
Decay rate	0.233156	/d	k_{dx}	Yes	0.2	1.4
Temp correction	1.07		$_{dx}$	No	1.07	1.07
Settling velocity	1	m/d	v_x	No	1	1
Alpha constant for light mortality	0.50831	/d per ly/hr	*apath*	Yes	0	1
pH:						
Partial pressure of carbon dioxide	375	ppm	p_{CO2}			
Hyporheic metabolism						
Model for biofilm oxidation of fast CBOD	Zero-order		*level 1*			
Max biofilm growth rate	5	gO2/m^2/d or /d	"	No	0	20
Temp correction	1.047		"	No	1.047	1.047
Fast CBOD half-saturation	0.5	mgO2/L	"	No	0	2
Oxygen inhib model	Exponential		"			
Oxygen inhib parameter	0.60	L/mgO2	"	No	0.60	0.60
Respiration rate	0.2	/d	*level 2*	No	0.2	0.2
Temp correction	1.07		"	No	1.07	1.07
Death rate	0.05	/d	"	No	0.05	0.05
Temp correction	1.07		"	No	1.07	1.07
External nitrogen half sat constant	15	ugN/L	"	No	15	15
External phosphorus half sat constant	2	ugP/L	"	No	2	2
Ammonia preference	25	ugN/L	"	No	25	25
First-order model carrying capacity	100	gD/m^2	"	No	100	100
Generic constituent						
Decay rate	0.8	/d		No	0.8	0.8
Temp correction	1.07			No	1.07	1.07
Settling velocity	1	m/d		No	1	1
Use generic constituent as COD?	No					

Table I-2. Reach level data for the Woodland Creek QUAL2K model.

Reach Label	Number	Reach length (km)	Downstream		Downstream location (km)	Elevation		Downstream		Rating Curves			
						Upstream (m)	Downstream (m)	Latitude Degrees	Longitude Degrees	Velocity		Depth	
			Latitude	Longitude						Coefficient	Exponent	Coefficient	Exponent
	0		47.05	122.80	0.000		22.700	47.05	122.80	0.4584	0.610	0.4800	0.123
RM 3.4	1	0.20	47.06	122.80	0.200	22.700	22.000	47.060	122.800	0.344	0.856	0.475	0.242
RM 3.2	2	0.20	47.06	122.80	0.400	22.000	21.100	47.060	122.800	0.371	0.699	0.513	0.244
RM 3.1	3	0.20	47.06	122.80	0.600	21.100	20.700	47.060	122.800	0.430	0.680	0.454	0.308
RM 2.9	4	0.30	47.06	122.80	0.900	20.700	19.600	47.060	122.800	0.672	0.728	0.452	0.339
	5	0.20	47.06	122.80	1.100	19.600	18.100	47.060	122.800	0.640	0.300	0.385	0.550
RM 2.6	6	0.30	47.06	122.81	1.400	18.100	17.200	47.060	122.810	0.538	0.039	0.342	0.777
	7	0.30	47.07	122.81	1.700	17.200	16.300	47.070	122.810	0.503	0.063	0.360	0.790
	8	0.30	47.07	122.81	2.000	16.300	15.900	47.070	122.810	0.493	0.197	0.390	0.740
	9	0.30	47.07	122.81	2.300	15.900	14.800	47.070	122.810	0.483	0.290	0.413	0.710
	10	0.40	47.07	122.81	2.700	14.800	13.900	47.070	122.810	0.475	0.345	0.435	0.685
RM 1.6	11	0.30	47.07	122.82	3.000	13.900	12.100	47.070	122.820	0.470	0.375	0.463	0.674
	12	0.40	47.07	122.82	3.400	12.100	11.000	47.070	122.820	0.468	0.418	0.439	0.573
	13	0.30	47.08	122.82	3.700	11.000	9.900	47.080	122.820	0.460	0.470	0.420	0.500
RM 1.0	14	0.30	47.08	122.82	4.000	9.900	8.700	47.080	122.820	0.455	0.490	0.409	0.440
	15	0.30	47.08	122.82	4.300	8.700	7.100	47.080	122.820	0.455	0.490	0.408	0.435
	16	0.40	47.08	122.82	4.700	7.100	3.000	47.080	122.820	0.455	0.490	0.408	0.435
	17	0.40	47.09	122.82	5.100	3.000	2.700	47.090	122.820	0.455	0.490	0.408	0.435
RM 0.2	18	0.30	47.09	122.82	5.400	2.700	0.300	47.090	122.820	0.455	0.490	0.408	0.435
	19	0.30	47.09	122.82	5.700	0.300	0.000	47.090	122.820	0.455	0.490	0.408	0.435
	20	0.40	47.09	122.82	6.100	0.000	0.000	47.090	122.820	0.455	0.490	0.408	0.435

Table I-3. Overall performance of calibration and confirmation models using root mean square error (RMSE) and coefficient of variation (CV).

Parameter	RMSE of calibration model (Sept 2003)	% CV of calibration model RMSE (Sept 2003)	RMSE of confirmation model (Aug 2003)	% CV of confirmation model RMSE (Aug 2003)
Temperature (° C)	0.521	5%	0.796	7%
Dissolved Oxygen (mg/L)	.559	6%	0.623	7%
Conductivity (µmhos)	10.3	7%	13.2	10%
pH (SU)	0.122	2%	0.148	2%
Ammonia Nitrogen (µmhos) *	32.8	5%	21.9	34%
Nitrate+nitrite Nitrogen (µmhos)	109.4	7%	111.3	6%
Organic Nitrogen (µmhos) *	109.7	48%	56.2	211%
Dissolved Phosphorus (µmhos)	7.32	12%	4.88	8%
Organic Phosphorus (µmhos) *	9.65	83%	5.95	47%

* Values for ammonia nitrogen, organic nitrogen, and organic phosphorus were at or close to detection limits. At levels close to the method detection limit, a greater % CV is expected.