WASHINGTON STATE DEPARTMENT OF ECOLOGY

Nisqually River Basin Fecal Coliform Bacteria and Dissolved Oxygen Total Maximum Daily Load Study

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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Nisqually River Basin Fecal Coliform Bacteria and Dissolved Oxygen Total Maximum Daily Load Study

by

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Olympia, Washington 98504-7710

May 2005

Waterbody Numbers: see Table 1

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Abstract

From March 2002 through September 2003, the Department of Ecology conducted a Total Maximum Daily Load (TMDL) study for fecal coliform bacteria in the Nisqually River, the Nisqually Reach of Puget Sound, Ohop Creek, Red Salmon Creek, and McAllister Creek. A TMDL analysis was also conducted for dissolved oxygen in McAllister Creek.

Results showed that the Nisqually River and most of the Nisqually Reach met fecal coliform water quality standards and showed improving trends. Therefore, no load reductions are recommended; however, continued monitoring is suggested.

Bacteria levels in Ohop Creek have improved greatly since the early 1990s; however, load allocations were needed for several sites downstream of Ohop Lake (dry season) and one tributary, Lynch Creek (wet season).

Three of four sites on Red Salmon Creek required more stringent bacteria targets to meet freshwater and downstream marine standards.

Bacteria levels have improved in the marine water near the mouth of McAllister Creek; however, although two of the upstream sites on McAllister Creek met standards, many of the downstream sites did not. To meet stringent marine bacteria standards, a bacteria target was set at river mile 4.3. Recommendations are made for bacterial reductions in tributaries and tide gates that discharge to the creek.

Best management practices for bacteria reduction are recommended for all load reduction sites.

Low dissolved oxygen levels found in McAllister Creek were determined to be largely due to natural conditions, from a combination of low dissolved oxygen in the groundwater, wetland influence, and physical conditions that impede reaeration of water. It was not possible to quantify the anthropogenic contribution to low dissolved oxygen compared to natural background conditions. High nutrient levels in the creek may contribute to excessive plant growth and thus lower dissolved oxygen levels. Recommendations are made for control of nutrients to the creek and investigation of high nitrate+nitrite nitrogen levels in groundwater.

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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 variations 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 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 technical study becomes the basis for water-quality-based controls. This document recommends total maximum daily pollutant loads based on the results of the study. Ecology will work with 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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Background

The Nisqually River, Nisqually Reach, and McAllister and Ohop creeks are on the 303(d) list of waterbodies that do not meet water quality standards. These are all listed for fecal coliform bacteria, with McAllister Creek listed for dissolved oxygen as well. In addition, review of historical data on Red Salmon Creek, a tributary to Nisqually Reach, shows that Red Salmon Creek does not meet water quality standards for fecal coliform bacteria.

Table 1 lists the waterbodies in the Nisqually Reach and basin that are on the 303(d) list or do not meet water quality standards. The table also shows the water quality parameters of concern for each waterbody.

Table 1. Nisqually basin waterbodies on the 303(d) list or not meeting water quality standards.

Waterbody	Parameter	Location	New ID #	Old ID #
Marine Water – WRIA 11		*Latitude/Longitude*		
Nisqually Reach	Fecal coliform bacteria	47.115, 122.695	390KRD	WA-PS-0290
Freshwater – WRIA 11		*Township/Range/Section*		
Nisqually River	Fecal coliform bacteria	18N 01E 08	OE72JI	WA-11-1010
McAllister Creek	Fecal coliform bacteria and dissolved oxygen	18N 01E 37 and 18N 01E 38	LD26OX	WA-11-2000
Ohop Creek	Fecal coliform bacteria	16N 03E 25	MW64EV	WA-11-1024
Red Salmon Creek	Fecal coliform bacteria	19N 01E 01 and 19N 01E 09	No ID	WA-PS-0290

WRIA – Water Resource Inventory Area

Nisqually River

The Nisqually basin covers 761 square miles within the greater Puget Sound watershed (Watershed Professionals Network, 2002). The basin includes portions of Thurston, Pierce, and Lewis counties. The Nisqually River flows generally in a northwesterly direction. At its origin, the Nisqually River is formed from the melt waters of the Nisqually and other glaciers on Mount Rainier. From the headwaters to the Nisqually River's discharge to Puget Sound, the river is approximately 78 miles long. Two dams in the upper Nisqually River watershed regulate river flow for electrical power generation for the City of Tacoma.

The United States Geological Survey (USGS) has maintained a continuous discharge record for the Nisqually River since 1947 at McKenna. The average annual discharge is 2100 cubic feet per second (cfs), providing approximately half the total freshwater discharge to southern Puget Sound (Whiley et al., 1994).

For this study, the area of interest is primarily Ohop Creek, a tributary to the Nisqually River (Figure 1). In addition, a site on the lower Nisqually River, at river mile (RM) 3.4, was sampled to verify that fecal coliform water quality standards are being met (Figure 2).

Nisqually Reach

The Nisqually Reach is the area where the Nisqually Delta and deeper waters of Puget Sound meet. The reach includes those waters inside a line from Johnson Point to Gordon Point, Anderson Island, Ketron Island, and Drayton and Balch passages (Figure 1). The Nisqually Delta, formed by the Nisqually River, consists of broad mudflats and salt marsh. Three smaller creeks flow into the Nisqually Reach in water resource inventory area (WRIA) 11: McAllister, Red Salmon, and Sequalitchew creeks.

The Fort Lewis wastewater treatment plant discharges northeast of the Nisqually Reach approximately four miles from the Nisqually River mouth. The U.S. Environmental Protection Agency (EPA) administers the National Pollution Discharge Elimination System (NPDES) permit for this federal facility (permit number WA0021954).

Ohop Creek

Ohop Creek joins the Nisqually River at RM 37.3. It is the second largest tributary in the lower Nisqually basin in terms of flow, and third in drainage area (Figure 1). The average annual discharge is 67 cfs, and the basin covers 44 square miles. The main tributaries include Twenty-five Mile and Lynch creeks. The dominant hydrologic feature in this sub-basin is Ohop Lake (RM 6.3).

Relatively dense residential development has occurred around Ohop Lake. The lower Ohop valley, downstream of Ohop Lake, is currently in transition from commercial agricultural use (primarily dairy farms) to non-commercial farms and rural residential development. The lower valley reach is low gradient with no intact natural riparian zone. The lower 0.3 miles include some hardwood forests.

Lynch Creek joins Ohop Creek at RM 6.2, flowing from commercially-owned timberlands to rural residential and non-commercial farms in the lower mile. The town of Eatonville's stormwater collection system discharges into Lynch Creek. Eatonville will not be considered for a Phase II municipal stormwater NPDES permit as an individual entity; stormwater discharge from Eatonville will be incorporated into a load allocation for Lynch Creek. Twenty-five Mile Creek flows from commercially-owned timberlands through an area of non-commercial farms and a recently abandoned clay mining operation before joining Ohop Creek at RM 9.9 (Kerwin, 1999).

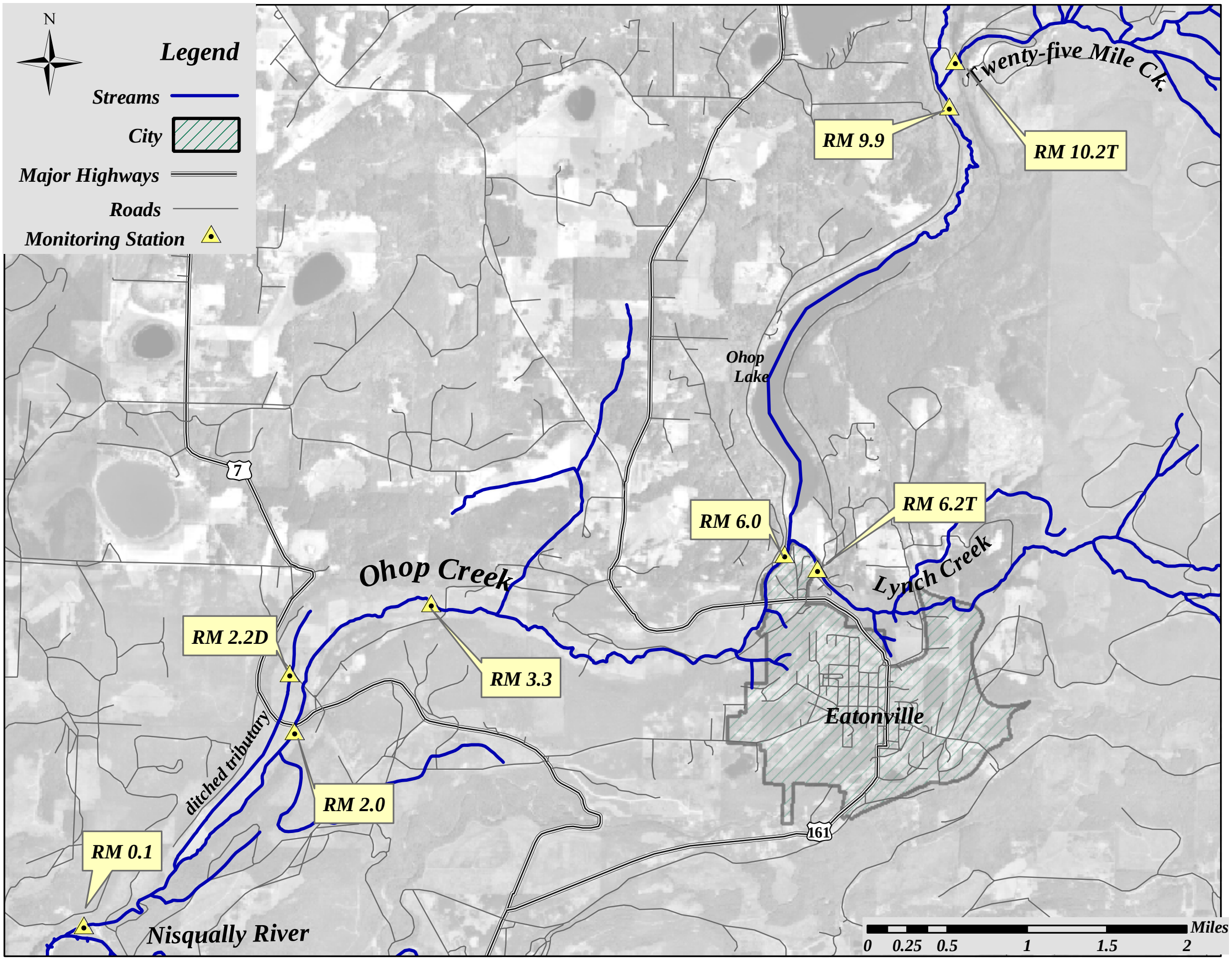

Figure 1. Ohop Creek sampling sites.

Red Salmon Creek

Red Salmon Creek is a small independent tributary on the eastern edge of the Nisqually Delta (Figure 2). The creek originates from a series of diffuse springs and seeps in wetlands north of Interstate-5 (I-5). From its origin, the creek flows westerly through an area of low-density residential houses, non-commercial farms, and agricultural lands before flowing under the Burlington Northern railroad tracks. It is joined by a small tributary that drains agricultural lands from the west and south. The creek drains to the eastern portion of the Nisqually River delta as well as being connected to the Nisqually River though an eastern tributary of the mainstem Nisqually River. The saltwater wedge penetrates at least up to RM 1.2, with tidal influence extending above this point (Kerwin, 1999).

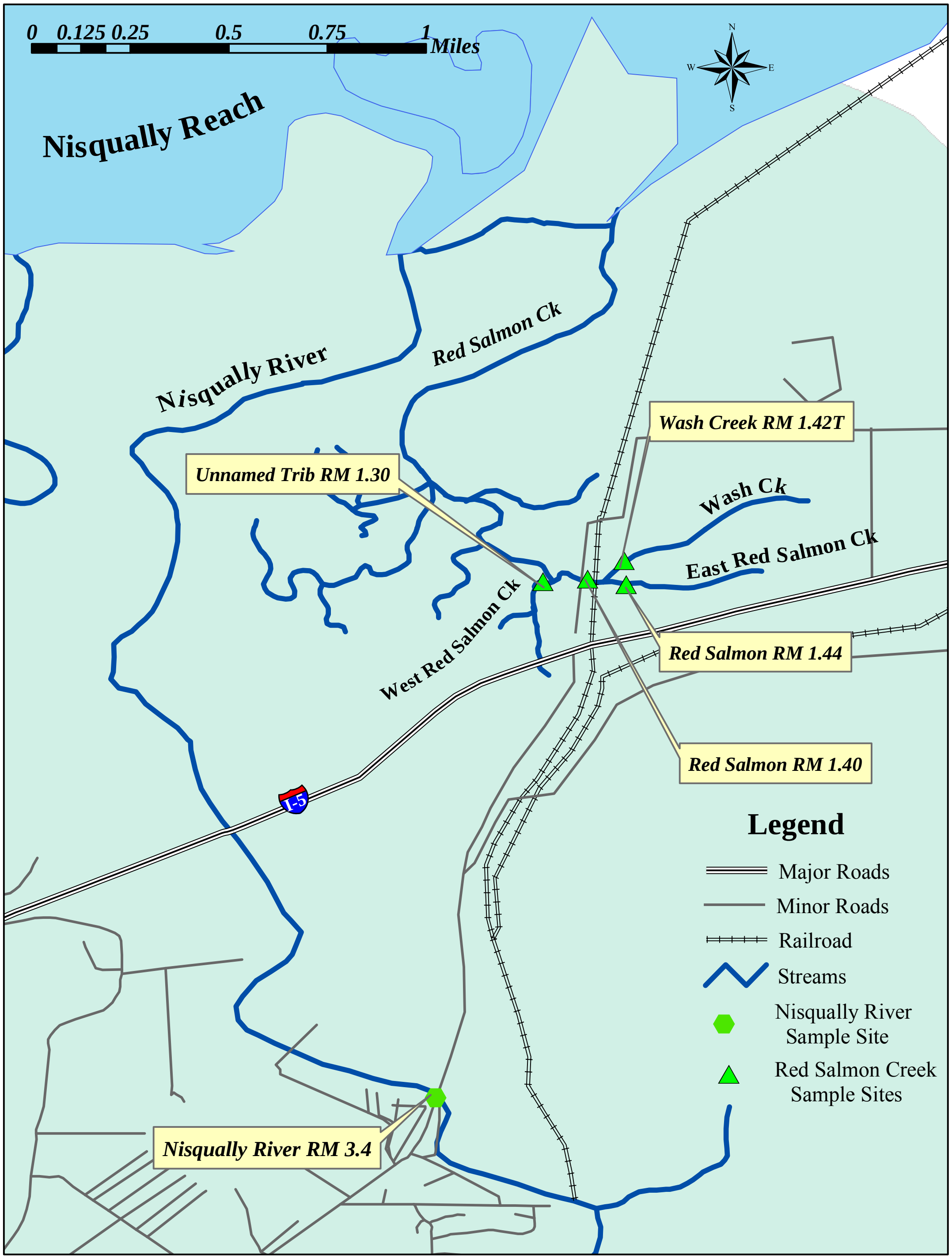

Figure 2. Red Salmon Creek and Nisqually River sampling sites.

McAllister Creek

McAllister Creek (Figure 3) originates in a low-lying, horseshoe-shaped basin fed by three large springs and many small ones. The estimated average annual discharge is 62 cfs, and the basin covers 39.2 square miles (Watershed Professionals Network, 2002). The creek flows north for 6.3 miles to empty into Nisqually Reach near Luhr Beach. McAllister Springs, at the stream's headwaters, is the major source of drinking water for the City of Olympia, providing approximately 80% of the city's total water demand. The springs are only 6.7 feet above mean sea level. From the springs to RM 5.6, the creek flows through a large undisturbed wetland owned by the City of Olympia. Several springs join McAllister Creek in this stretch including the larger Abbott and Lodge springs.

Between RM 5.6 and 4.3, the creek flows through agricultural pasture until it reaches the Steilacoom Road bridge. This reach is lined by dikes with almost no tree or shrub cover for most of its length. The dikes and tide gates prevent saltwater from entering the adjacent agricultural lands. Numerous agricultural ditches drain into the creek on both banks in this reach. The flow direction changes with the tide from RM 5.6 to the mouth, and water level fluctuates up to five feet at RM 4.3. Little McAllister Creek enters McAllister Creek in this stretch at RM 5.3 through a double tide gate. Its flow originates from springs near the Meadows subdivision at the top of the bluff and from wetland drainage to the south of Highway 510. The Meadows stormwater detention ponds contribute flow to the creek during peak storm periods. The combined flow travels down a heavily eroded ravine to the lower valley. Once there, Little McAllister Creek has been routed through a drainage ditch to McAllister Creek. Just upstream of Steilacoom Road is the McAllister Creek Fish Hatchery owned by Washington Department of Fish & Wildlife (WDFW). Due to budget constraints, this hatchery closed operations in June 2002.

Below Steilacoom Road is the only residential development adjacent to the creek, located along its west side between RM 4.7 and 4.4. Large trees shade most of this reach and vegetation is fairly undisturbed. There is agricultural land along the east side of the creek that is drained by tide gates.

Medicine Creek enters McAllister Creek at RM 4.4. Medicine Creek is 3.5 miles long. The creek has been extensively ditched and altered. The creek has been highly disturbed as it passes through nine culverts in an area used for agriculture and residences. Currently there is almost no canopy cover, and the channel is narrow, weed-choked, and frequently dry above the Steilacoom Road crossing (Thurston County WWM, 1993).

Just downstream of RM 4.3, McAllister Creek enters a diversion channel that flows under Martin Way, then flows into a newer diversion channel under Interstate-5, and finally re-enters the natural channel at RM 2.4. Rock rip-rap lines the channel throughout this reach. Occasional trees provide some high cover, but there is almost no low overhanging vegetation. Land use in this reach includes a recreational vehicle park and commercial development located near I-5. Two stormwater discharges enter the creek in this reach. Thurston County stormwater discharge from Martin Way and the surrounding area drains to a stormwater pipe that enters the creek just

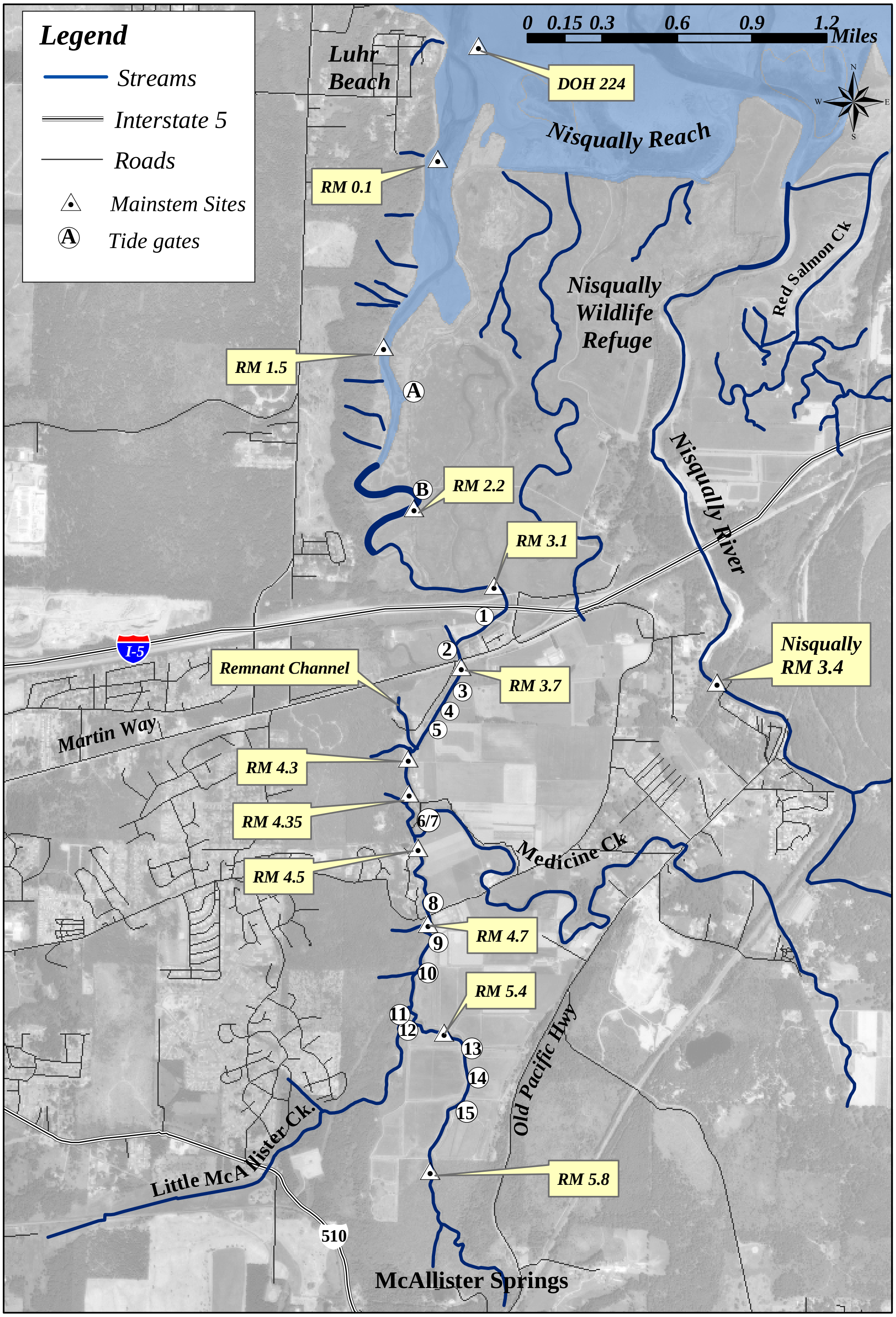

Figure 3. McAllister Creek sampling sites and tide gates.

upstream of Martin Way. Washington State Department of Transportation (WSDOT) stormwater discharge from I-5 flows into the creek under the I-5 bridge.

The remnant channel enters McAllister Creek mainstem just downstream of RM 4.3. A small privately-owned, trout-rearing operation, Nisqually Trout Farm #1, is located at the end of the remnant channel. The trout farm receives water input from a small spring that flows off of the west bluff. The facility is divided into upper and lower ponds. Discharge from the facility flows through a tide gate (not numbered) and into the remnant channel. During TMDL sampling, the trout farm was under Ecology's threshold size requirements for a General NPDES Fish Hatchery permit and was not a permitted facility.

At RM 2.4, after leaving the artificial channel, McAllister creek flows through the U.S. Fish & Wildlife Nisqually National Wildlife Refuge to the mouth near Luhr Beach. The east bank is diked all the way to the mouth. Tides have a major influence on the creek in this reach. The stream opens into a broad estuarine lagoon which becomes a network of braided distributaries and mud flats at low tide (Thurston County WWM, 1993). Two tide gates discharge to the creek in this reach, draining water from the Nisqually Wildlife Refuge.

Two times a day in McAllister Creek, during the flood tide, a complete flow reversal occurs. This has the effect of pushing creek water back upstream, causing considerable mixing throughout the length of the creek. Tidal dynamics have required the use of drainage ditches linked to tide gates and extensive diking in order for lands lying to the east of the creek to be drained for agricultural use (Whiley and Walter, 1996). The locations of the major tide gates are included in Figure 3.

The City of Olympia records water levels at the McAllister Springs weir, where flows averaged 16.7 cfs in the mid-1980s. During peak water-demand periods, Olympia withdraws as much as 70% of the springs' flow (Thurston County WWM, 1993).

USGS maintained a continuous recording gaging station near McAllister Springs from 1951 to 1964 (Thurston County WWM, 1993), with flow averaging 24 cfs, as well as an intermittent gage at Steilacoom Road from 1941 to 1949, where flow ranged from 48 to 132 cfs.

The geology and hydrogeology, including groundwater flow, in the vicinity of Nisqually Reach and McAllister Creek are described in Appendix A.

Applicable Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include 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), and former Class A waters become *Primary Contact Recreation* (same fecal coliform criterion as Class A). The same is true for the dissolved oxygen, pH, and temperature criterion, with Class AA becoming *Extraordinary quality water*, and Class A becoming *Excellent quality water*. The criteria for *Extraordinary quality water* for the parameters of concern in this TMDL, both fresh and marine, are summarized in Table 2.

Table 2. Fecal coliform bacteria, dissolved oxygen, pH, and temperature water quality standards.

Parameter/Class	Freshwater	Marine
Bacteria		
Extraordinary Primary Contact Recreation	Geometric mean (GM) ≤ 50 col/100 mL, with not more than 10% of all samples for calculating the GM value > 100 col/ 100 mL.	Geometric mean (GM) ≤ 14 col/100 mL, with not more than 10% of all samples for calculating the GM value > 43 col/100 mL.
Primary Contact Recreation	Geometric mean (GM) ≤ 100 col/100 mL, with not more than 10% of all samples for calculating the GM value > 200 col/100 mL.	N/A
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 above 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

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 marine water,* formerly Class AA. This includes Nisqually Reach. Beneficial uses include extraordinary aquatic life use, primary contact recreation, and shellfish harvest.

Nisqually River from the mouth to Alder Dam (RM 44.2) is designated *Excellent quality water,* formerly Class A, and includes beneficial uses such as non-core salmon/trout rearing and primary contact recreation, among others.

Ohop Creek does not have a specific designation as described in Table 602 (WAC 173-201A-602). In accordance with WAC 173-201A-600(1), surface waters not named in Table 602 are to be protected for the designated uses such as non-core salmon/trout rearing, spawning and migration, as well as primary contact recreation, among others.

The other tributaries to Nisqually Reach and McAllister and Red Salmon creeks 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.

If natural water quality conditions are of less quality than the criteria, then the natural condition shall constitute the water quality criteria. The standards define "natural conditions" or "natural background levels" as surface water quality that was present before any anthropogenic (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, a commercial shellfish harvesting area must have a geometric mean value of no more than 14 most probable number (MPN)/100mL, with an estimated 90^{th} percentile value less than 43 MPN/100mL.

Water Quality and Resource Impairments

The Nisqually River, Nisqually Reach, and Ohop Creek were on the 1996 303(d) list of waterbodies that do not meet water quality standards for fecal coliform bacteria. The 1998 303(d) list included the aforementioned waterbodies as well as McAllister Creek for excursions of dissolved oxygen and fecal coliform bacteria. In addition, review of historical data on Red Salmon Creek, a tributary to Nisqually Reach, shows that Red Salmon Creek does not meet water quality standards for fecal coliform. Table 1 lists the waterbodies in the Nisqually Reach and basin that are on the 303(d) list or do not meet water quality standards, as well as the water quality parameters of concern for each waterbody.

Fisheries Resource

Classification of DOH Commercial Shellfish Growing Areas

In 1992, the Washington State Department of Health (DOH) reclassified 1000 acres of commercial shellfish growing areas in the Nisqually Reach from *Approved* to *Conditionally Approved*, with closures occurring after 0.50" of rain in 24 hours. One year later DOH adjusted the closure criterion to 1" in 24 hours based on improvements seen in water quality. In 1999, in response to declining water quality and after consultation with local shellfish growers, DOH established a one-year voluntary "no harvest zone" in the vicinity of the eastern-most water quality monitoring stations of the growing area.

In 2000, improved conditions at the western end of the *Conditionally Approved* area allowed DOH to upgrade 20 acres of geoduck tracts there to the *Approved* status. At the same time, however, conditions at the east end of the area continued to decline. In November 2000, DOH reclassified about 74 acres at the east end of the area from *Conditionally Approved* to *Restricted*. In 2002, DOH upgraded 960 acres from *Conditionally Approved* and *Restricted* to *Approved* (Washington State Department of Health, 2004). This change in classification was prompted by the results of a comprehensive review of shoreline sanitary conditions and marine water quality data.

About 40 acres of the commercial shellfish growing area currently remain *Restricted*; these 40 acres are located west of the mouth of McAllister Creek. Also, recreational shellfish beds located in the mouth of McAllister Creek continue to be unsafe for consumption (Thurston County, 2002).

Types of Fish

The lower Nisqually River serves as a transport corridor for all the anadromous (sea-run) salmonids in the Nisqually River basin and provides important spawning habitat for chum, coho, chinook, and steelhead.

In Ohop Creek, anadromous fish are present from the confluence and upstream. Coho, chinook, and pink salmon, along with steelhead and coastal cutthroat, use Ohop Creek. Ohop Lake contains significant populations of self-sustaining, warm-water fish species such as yellow perch, largemouth bass, and bluegill (Kerwin, 1999).

Red Salmon Creek supports natural runs of coho, chum, steelhead, and anadromous cutthroat.

McAllister Creek supports natural runs of chinook, coho, chum, steelhead, and anadromous cutthroat. Spawning is limited to the upper reaches due to the salt wedge and poor habitat in the lower reaches.

Methods

Study Design

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

Nisqually River

Fifteen sampling surveys were conducted on the Nisqually River at RM 3.4 from May 2002 through September 2003. The sample site is shown in Figure 2, and sample dates and results are described in Appendix B. Sampling was conducted for fecal coliform and *E. coli* bacteria, and field measurements for conductivity were initially obtained at this site. Daily flow discharge measurements for the Nisqually River were obtained from a USGS station at RM 21.8.

The Nisqually River at RM 3.4 is a station included in the Department of Ecology's monthly water quality monitoring program. Ecology's Freshwater Monitoring Unit has been conducting monthly ambient monitoring at Nisqually RM 3.4 since 1975. Monthly sampling includes a number of field and laboratory parameters including fecal coliform bacteria. Results are available on the internet at: http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?sta=11A070.

Nisqually Reach

As described in the QA Project Plan (Sargeant, Roberts, and Carey, 2003), additional monitoring was conducted to determine dominant flow paths in the Nisqually Reach. In addition to the time-of-travel monitoring near the mouth of McAllister Creek, surface drogues were tracked on a flood tide from the shoreline east of the Nisqually Flats on July 1, 2004.

Ecology also developed a hydrodynamic and water quality model of South Puget Sound (Albertson et al., 2002) for a previous study. The model and the drogue study were used to understand potential areas of influence for bacteria levels. The model was used to simulate a release of bacteria from the Fort Lewis wastewater treatment plant at Tatsolo Point.

DOH conducts monthly sampling near the Nisqually Flats at four locations. The protocols are described below with the McAllister Creek data. In addition, Ecology maintains two monitoring locations in the Nisqually Reach. Monthly data are available for a site on the north side of the Reach near Devil's Head, but the data are not representative of the Nisqually Flats. The Nisqually River delta site is part of the rotating monitoring locations, and the most recent data are for 1996, which are not necessarily representative of current conditions. Therefore, only the DOH bacteria data were used in this assessment.

Ohop Creek

Sixteen water quality surveys were conducted on Ohop Creek. Sample sites are presented in Figure 1, and sample dates and results are described in Appendix C. No sampling was conducted at RM 0.1 on March 25 and July 31, 2002 due to lack of access to the site. Twenty-five Mile Creek at RM 10.2T was initially included in the study but was discontinued because of low bacteria levels, and a downstream Ohop Creek sample site captures the influence of this tributary.

Sampling was conducted for fecal coliform and *E. coli* bacteria at each site. Flow discharge measurements were obtained at the mouth of Ohop and Lynch creeks and at Ohop Creek just below Ohop Lake. Daily flow discharge for Ohop Creek below Ohop Lake was obtained from a USGS gage site. To determine flow discharge at the mouth of Ohop and Lynch creeks, instantaneous flow measurements were taken at the time of sampling. When flow measurements were not obtained, flows were calculated using relationships with the USGS gage site.

Red Salmon Creek

Fifteen water quality surveys were conducted on Red Salmon Creek at two sites: RM 1.40 and at the mouth of an unnamed tributary at RM 1.30. Later in the study, two sites were added upstream of RM 1.40 to further delineate pollution sources. These two sites were sampled six times and included Wash Creek at RM 1.42 and Red Salmon Creek just upstream of Wash Creek at RM 1.44. Sample sites are presented in Figure 2, and sample dates and results are described in Appendix D.

Sampling was conducted for fecal coliform and *E. coli* bacteria at each site, and field measurements for conductivity or salinity were obtained at the two downstream sites. Instantaneous flow measurements were obtained at each site when possible, and flow was estimated for Red Salmon Creek RM 1.44 by subtracting the flow at Wash Creek from that at Red Salmon Creek RM 1.40. All sampling was conducted at or near low tide.

McAllister Creek

A preliminary two-day bacteria survey was conducted on McAllister Creek on June 25-26, 2002. The purpose of the survey was to determine sampling logistics and the range of bacteria levels. In addition, ten synoptic water quality surveys were conducted on McAllister Creek for bacteria, nutrients, and field measurements during low tide. Sampling dates and results are described in Appendix E.

Sampling was conducted from McAllister Creek RM 5.8 to Luhr Beach near the mouth, including 17 tide gates, Little McAllister and Medicine creeks, and numerous small tributaries. Sampling sites are presented in Figure 3.

Sampling was conducted by four teams during the critical low tide period. Teams included staff from Ecology sampling upper and lower McAllister Creek by boat, Thurston County

Environmental Health sampling tide gates and stormwater discharge points, and Thurston Conservation District (TCD) sampling tide gates.

Due to extremely low tides, sites near the mouth of McAllister Creek and several mainstem sites upstream of the mouth could not be accessed on the following dates: April 16, May 13, and July 15, 2003. On August 27, 2003, samples from the two downstream sites on McAllister Creek were switched, and it was unclear as to sample station origin. These sample results were discarded.

For the synoptic surveys, fecal coliform and *E. coli* bacteria samples were collected for laboratory analysis. Where possible, field measurements were obtained for temperature, dissolved oxygen, conductivity, and pH. For the April 16, May 13, July 15, and August 27, 2003 surveys, nutrient samples were collected for laboratory analysis including total persulfate nitrogen, ammonia nitrogen, nitrate+nitrite nitrogen, total phosphorus, and orthophosphate. On August 27, 2003, several of the tide gates were sampled for biochemical oxygen demand.

DOH conducts monthly sampling of two marine stations near the mouth of McAllister Creek that correspond with two of Ecology's TMDL stations. DOH data from July 2002 (when TMDL sampling began) to March 2004 was combined with the TMDL data set for data analysis. DOH uses the most probable number (MPN) method for fecal coliform laboratory analysis, and Ecology used the membrane filter (MF) technique for this study. While the MF method may be biased low, a comparison of the two methods was conducted for a marine site at the mouth of the Dungeness River (Sargeant, 2002), and the two data sets were found to be not significantly different using a non-parametric paired Wilcoxon signed rank test (n=13).

When samples were collected on the same day, the TMDL data were used for data analysis. For dissolved oxygen data analysis, Winkler titration results were used when both field meter and Winkler results were available. This is due to the greater accuracy of the Winkler results.

The TCD continued to collect fecal coliform data at several sites after August 2003. These additional data on the tide gates were used in data analysis. The Thurston County Laboratory conducted MF fecal coliform analysis on the TCD samples. In addition, Ecology staff assisted with several TCD sample runs to obtain instantaneous flows at the tide gates where possible. The TCD conducted additional sample events on select tide gates on October 22 and December 8, 2003 and February 23, March 22, April 19, May 19, and June 17, 2004. The additional TCD and DOH data are included in Appendix E.

Nisqually Trout Farm #1 was sampled on September 22 and October 26, 2004. Three sites were sampled: an artesian spring flowing into the farm, mid farm, and the discharge from the farm to the remnant channel of McAllister Creek. Samples were obtained for total suspended solids, settleable solids, fecal coliform bacteria, ammonia nitrogen, nitrate+nitrite-N, total persulfate nitrogen, total phosphorus, pH, conductivity, dissolved oxygen, and biochemical oxygen demand. Field measurements for temperature were obtained at all sites, and flow measurements were obtained at the downstream site. Results are presented in Appendix E.

Salinity Survey

To determine where fresh and marine water quality standards apply, a salinity survey was conducted on October 29, 2003 during a maximum high tide event (+ 14.5 feet at Dupont Wharf, Nisqually Reach). In 2003, the tide was higher than this elevation only during 11% of all high tide events, so this is representative of an extreme event. Vertical profiles for field measurements including salinity were obtained for RM 3.7 to 4.7 on McAllister Creek. Results are described in Table 3.

Table 3. Salinity results for McAllister Creek (ppt; parts per thousand).

Site	Surface	1 meter	1.5 meter	2.0 meter	Vertical average
RM 3.7	14.9	21.8	22.7		19.8
RM 4.1	7.3	10.9	18.5		12.2
RM 4.3	6.2	8.1	11.7		8.7
RM 4.35	5.2	7.3		8.1	6.9
RM 4.5	3.6	3.7	4.0		3.8
RM 4.7	0.3	1.3	1.4		1.0

The freshwater dissolved oxygen criterion applies at all locations where 95% of the vertically averaged salinity values are less than or equal to 1 part per thousand (ppt), and the freshwater criteria for bacteria applies when the salinity is less than 10 ppt. Using the results of the salinity survey, the marine criteria for all parameters except bacteria apply downstream of McAllister RM 4.7, and for bacteria, the marine criteria apply downstream of McAllister RM 4.2.

Six times during the year-long TMDL survey, continuous reading Hydrolabs were deployed at McAllister RM 4.7. During three of the six deployment periods, conductivity exceeded 4000 µS/cm, with the highest calculated salinities for those three periods being 2.8, 13.5, and 12.1 ppt. The conductivity results confirm that McAllister RM 4.7 must meet marine criteria for all parameters except bacteria.

Dissolved Oxygen Monitoring

To better understand dissolved oxygen levels in McAllister Creek, several methods were used:

1. *In-situ* continuous dissolved oxygen monitoring was conducted at three sites on McAllister Creek numerous times throughout the study (Table 4).
2. Field measurements for dissolved oxygen were obtained during all synoptic surveys, and nutrient samples for phosphorus and nitrogen were obtained for four of the synoptic surveys.
3. Groundwater sampling was conducted to determine levels of dissolved oxygen and nutrients in the groundwater (Appendix A).

Table 4. Monitoring sites and time periods for continuous recording Hydrolabs installed in McAllister Creek.

RM 6.0 (McAllister Springs)
June 21 - 26, 2002
RM 5.8
July 30 - August 2, 2002
January 21- 27, 2003
January 28 - 31, 2003
March 19 - 24, 2003
July 11 - 14, 2003
August 27 - 31, 2003
RM 4.7
June 21 - 27, 2002
July 30 - August 2, 2002
January 28 - 31, 2003
March 19 - 24, 2003
July 11 - 14, 2003
August 27 - September 2, 2003
RM 3.7
January 28 - 31, 2003
March 19 - 24, 2003
July 11 - 14, 2003
August 27 - September 2, 2003

Continuous Hydrolab data for each site is presented in Appendix F, and quality control results are discussed in Appendix G.

Study design and sampling methods for the groundwater survey are described in Appendix A.

Data Analysis

Field and laboratory data were compiled and organized using Excel® spreadsheet software. 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 either Excel® or Systat® software. The statistical analysis software WQHYDRO (Aroner, 2001) was also used for statistical trend analysis.

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

The fecal coliform bacteria modeling approach used the statistical rollback method to determine the load reduction necessary to achieve fecal coliform water quality standards and 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 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 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 in the *Loading Capacity* section (under *Technical Analysis*) of this report.

Quality Assurance and Quality Control

A complete discussion of the quality assurance and quality control (QA/QC) results is included in Appendix G. For groundwater sampling, QA/QC results are included in Appendix A.

Survey Results

Summaries of the survey results for each area are presented in Appendices B through E. Groundwater survey results are described in Appendix A, and *in-situ* continuous Hydrolab data are presented in Appendix F. The data summary includes tables of field measurements and laboratory analytical results. Data were compared to the surface water quality standards. Results are described below.

Nisqually River

The Nisqually River must meet the freshwater classification for *Excellent waters* (Class A). The fecal coliform standard calls for a geometric mean of 100 colonies (col)/100 mL with no more than 10% of samples used for calculating the geometric mean being greater than 200 col/100 mL. Data from Ecology's monthly ambient sampling program and the TMDL data set were combined for the May 2002 through September 2003 period for a total of 30 sample events. The geometric mean for the period is 14 col /100 mL and the 90th percentile is 27 col/ 100 mL, with a maximum fecal coliform value of 45 col/100 mL. The Nisqually River at RM 3.4 meets water quality standards for fecal coliform bacteria.

Nisqually Reach

South Puget Sound Model and Drogue Study

The Environmental Fluid Dynamics Code (EFDC), a three-dimensional linked hydrodynamic and water quality model, was applied to South Puget Sound for a previous Ecology study. The curvilinear grid size varies by location but averages 630 m by 630 m. Four layers represent the water column at mean lower low water. As described in Albertson et al. (2002), the model simulates the hydrodynamic responses to tidal forcing, wind, and river inflows.

The model was applied to the current TMDL 2002-03 study to determine whether the Fort Lewis wastewater treatment plant fecal coliform loads affect water quality within Nisqually Reach.

The hydrodynamic components were used to simulate a conservative tracer released from the Fort Lewis wastewater treatment plant at Tatsolo Point. The model, coupled with drogue studies, describes the likelihood that Fort Lewis discharges reach the Nisqually Reach.

The model simulated conditions from January 2003 to July 2004. The early start eliminated the influence of initial conditions during the period of interest. Model input data included the initial density structure, river inflows, and meteorological parameters.

The King County Department of Natural Resources monitors water column temperature and salinity profiles throughout central Puget Sound, including a station near the South Puget Sound Model tidal boundary. These data were used to drive the boundary condition (Adams, 2004).

Measured discharges from the USGS gaging stations along the Nisqually, Puyallup, and Deschutes rivers were corrected for the downstream, ungaged areas using tributary area and average annual precipitation. Additional inflows from Sequalitchew (Figure 4) and McAllister creeks were estimated from USGS stations along Chambers Creek and the Nisqually River.

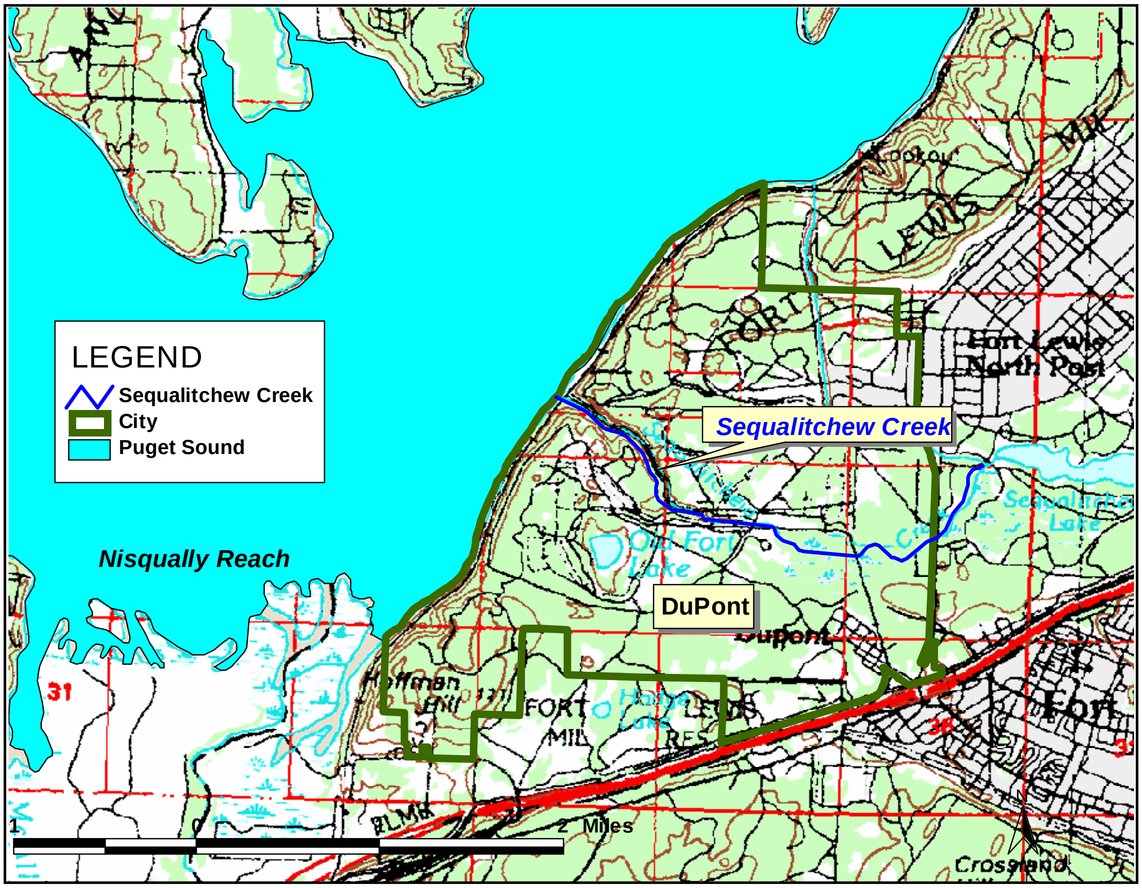

Figure 4. Location of Sequalitchew Creek.

River temperature data were available for the Ecology ambient monitoring stations on the Nisqually, Puyallup, and Deschutes rivers. These were related to air temperature at the Olympia Airport using the equations in Table 5 to create a daily time series for the entire simulation period.

Table 5. Best-fit relationships between river temperatures and air temperatures recorded at the Olympia Airport, based on 2003 data.

River	Equation	R^2
Nisqually	$T_{nisq} = 0.3525 \bullet T_{oly} + 10.1$	0.58
Puyallup	$T_{puy} = 0.1987 \bullet T_{oly} + 11.8$	0.63
Deschutes	$T_{des} = 0.2906 \bullet T_{oly} + 10.4$	0.60

Olympia Airport meteorological data – including air temperature, dew point, relative humidity, atmospheric pressure, wind speed, and wind direction – were used to represent conditions within the model domain. However, the nearest station for which solar radiation data were available was the University of Washington Atmospheric Sciences Building. These data were assumed representative of South Puget Sound. Cloud cover was assumed to be 50% to calculate the incident radiation reflected by clouds.

The Fort Lewis wastewater treatment plant NPDES permit, issued by EPA, does not have an effluent limit for flow. Actual flows varied from 1.9 to 4.3 million gallons per day (mgd) for April 2001 through February 2004, the most recent period for which data were available (Hetherington, 2004). For worst-case purposes, a flow rate of 4.3 mgd was used in the tracer simulation. Effluent fecal coliform levels cannot exceed 200/100 mL as a monthly geometric mean or 400/100 mL as a weekly geometric mean. For a worst-case scenario, an equivalent fecal coliform concentration of 400/100 mL was used. The load represents the highest load permitted under the highest flows in recent years, or 65 billion fecal coliform per day. The load was evenly distributed through the water column to simulate the outfall at Tatsolo Point. Only advection and dispersion of the conservative tracer were simulated, with no die-off of bacteria. Bacteria are expected to die off when exposed to sunlight, salinity, predation, and other environmental factors, and a conservative tracer discounts these mechanisms.

A drogue study was conducted on July 1, 2004 to coincide with a high-predicted maximum flood-tide current of 1.6 knots at mid-channel. Nisqually Reach currents estimated from the Tides & Currents program (Nautical Software, Inc., ©1993-1995) were tallied for January 1, 2003 through July 7, 2004. A flood-tide current of ≥1.6 knots (2.7 ft/s or 0.8 m/s) occurred during 51 flood-tide events out of 1069 for the entire period, or 4.8% of the time. During the July 1, 2004 event, oranges were released at the surface near the Tatsolo Point outfall as well as at the mouth of Sequalitchew Creek within one hour of slack tide. Figure 5 summarizes the trajectories of the drogues' center of mass.

Drogues released from the outfall location traveled 4,600 ft in 3 hours 43 minutes, for an average speed of 0.34 ft/s (0.10 m/s). The drogues were not tracked beyond the peak flood-tide velocity; however, velocities are expected to increase around the headlands. Drogues released near the mouth of Sequalitchew Creek traveled 11,300 ft in 2 hours 34 minutes, for an average velocity of 1.2 ft/s (0.37 m/s) around the headlands between Dupont Wharf and Hoffman Hill. The drogues traveled upstream in a distributary of the Nisqually River, indicating that Sequalitchew Creek could influence water quality in this area.

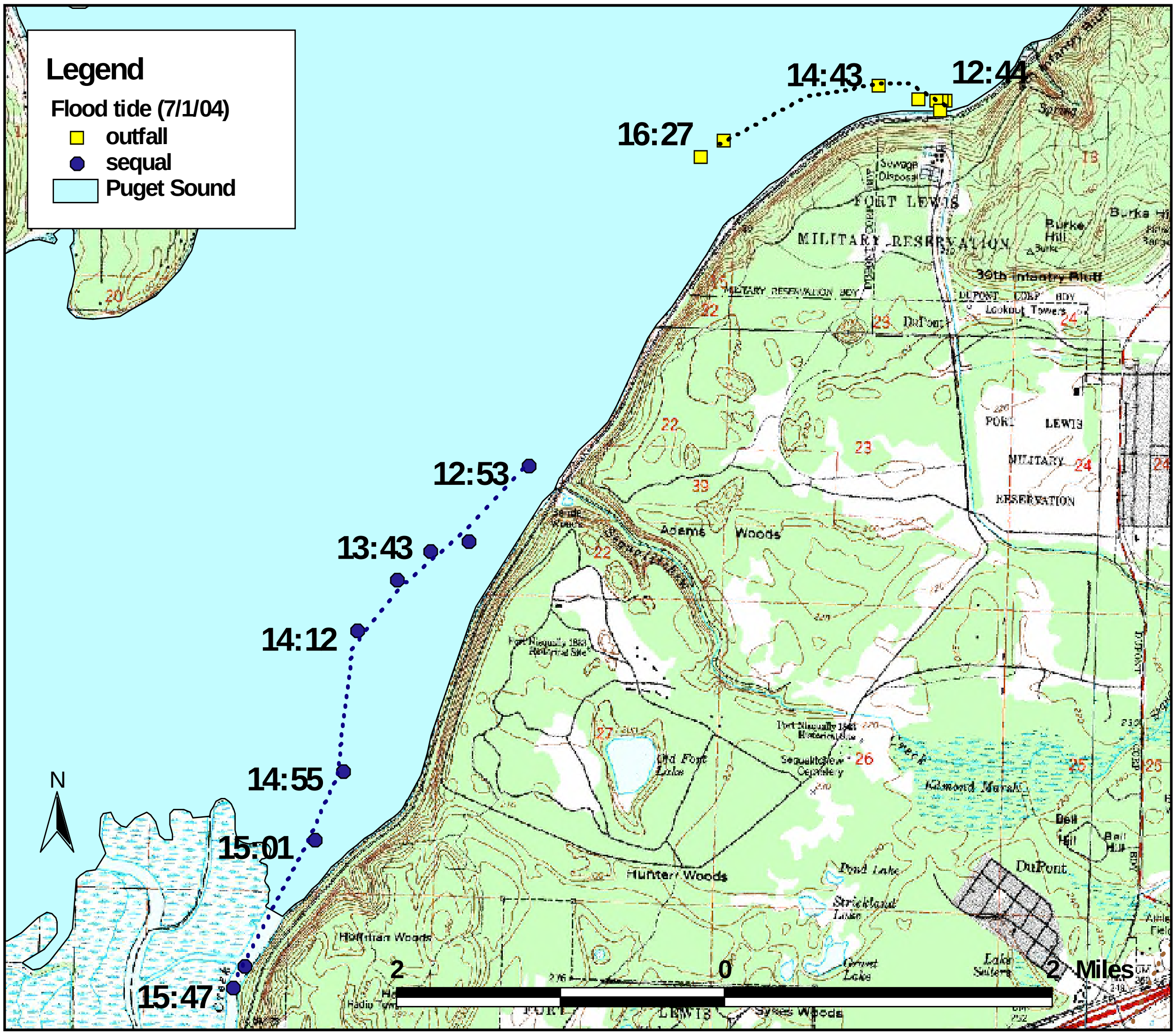

Figure 5. Drogue trajectory during high flood-tide releases at the Fort Lewis wastewater treatment plant (outfall) and Sequalitchew Creek (sequal). Times are given adjacent to the leading or trailing edge of the drogue cloud.

The EFDC model run for July 1, 2004 confirms the trajectory and relative speed of particles released from Tatsolo Point. Figure 6 shows that the plume travels southwest along the headlands toward the Nisqually River delta just after low tide. However, the predicted concentrations of the tracer, initially 400/100 mL to represent fecal coliform, peak at 0.01 col/100 mL in the grid cell closest to the mouth of the Nisqually River just after slack tide. As the tidal velocity increases, the effluent is mixed over a greater volume; therefore, peak marine concentrations occur just following low tide. The simulation neglects the die-off of bacteria or other biological mechanisms that remove bacteria from the marine environment. Therefore, actual concentrations resulting from the Fort Lewis wastewater treatment plant are expected to be much lower. Thus, the wastewater treatment plant, operating under the current flow regime and within the permit limits, is not expected to contribute to elevated bacteria levels found historically at the DOH monitoring locations within the Nisqually Flats. Therefore, no wasteload allocation is established for the facility under this study.

No bacteria data are available for Sequalitchew Creek. While the creek was monitored for nutrients in the summer of 1999 during the South Puget Sound study (Albertson et al., 2002), no samples were analyzed for fecal coliform bacteria. Albertson et al. (2002) estimated an annual average discharge of 111 cfs (3.1 cms) based on a tributary area of 55 mi^2 (143 km^2). However, during deployment of the drogues, no significant flow was noted at the creek site. Due to the complicated hydrogeology in the region, flows could differ significantly from those estimated based on USGS stations in the Chambers Creek watershed. However, the drogue study results suggest that Sequalitchew Creek water quality could affect water quality of the easternmost DOH monitoring stations.

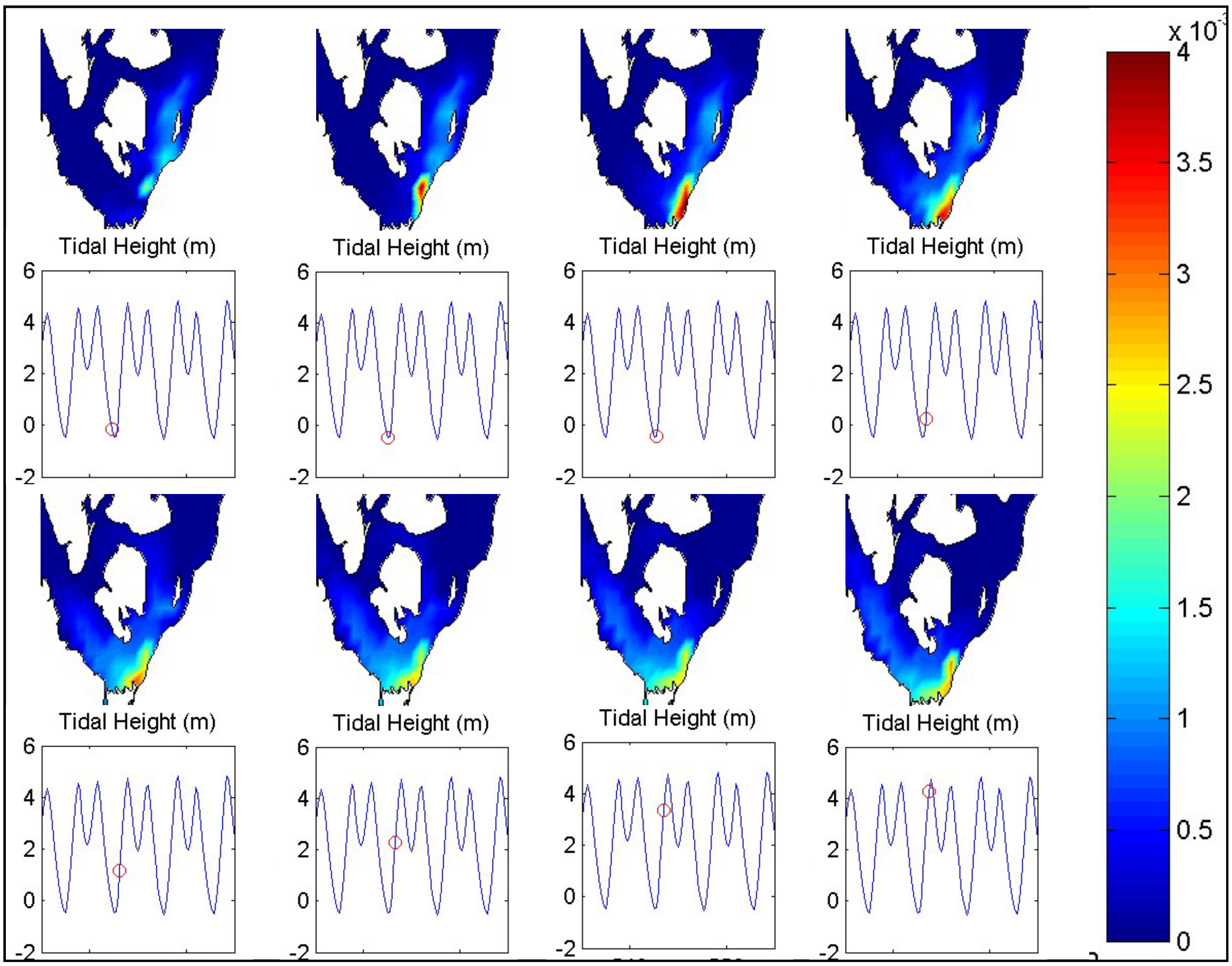

Figure 6. Predicted tracer concentrations following a simulated release of a conservative tracer from the Tatsolo Point outfall. Units are fecal coliform bacteria per 100 mL.

Ohop Creek

Ohop Creek must meet the freshwater classification for *Excellent* waters (Class A). The fecal coliform standard calls for a geometric mean of 100 col/100 mL with no more than 10% of samples used for calculating the geometric mean being greater than 200 col/100 mL. Table H-2 in Appendix H describes compliance with the fecal coliform standard based on data collected during this study.

Figure 7 presents the geometric mean and 90th percentile for each site for March 2002 - June 2003. The two sites above the lake, Ohop Creek at RM 9.9 and a tributary at RM 10.2T, met water quality standards for bacteria. Below the lake, Lynch Creek (RM 6.2T) met bacteria standards annually; but not during November through April. Bacteria levels downstream of the lake outlet did not meet water quality standards, with increases in bacteria seen from Ohop Creek RM 6.0 to RM 3.3. Downstream of Ohop Creek RM 3.3, bacterial concentrations decreased. Bacterial improvements upstream of Ohop RM 3.3 are likely to result in downstream sites meeting water quality standards.

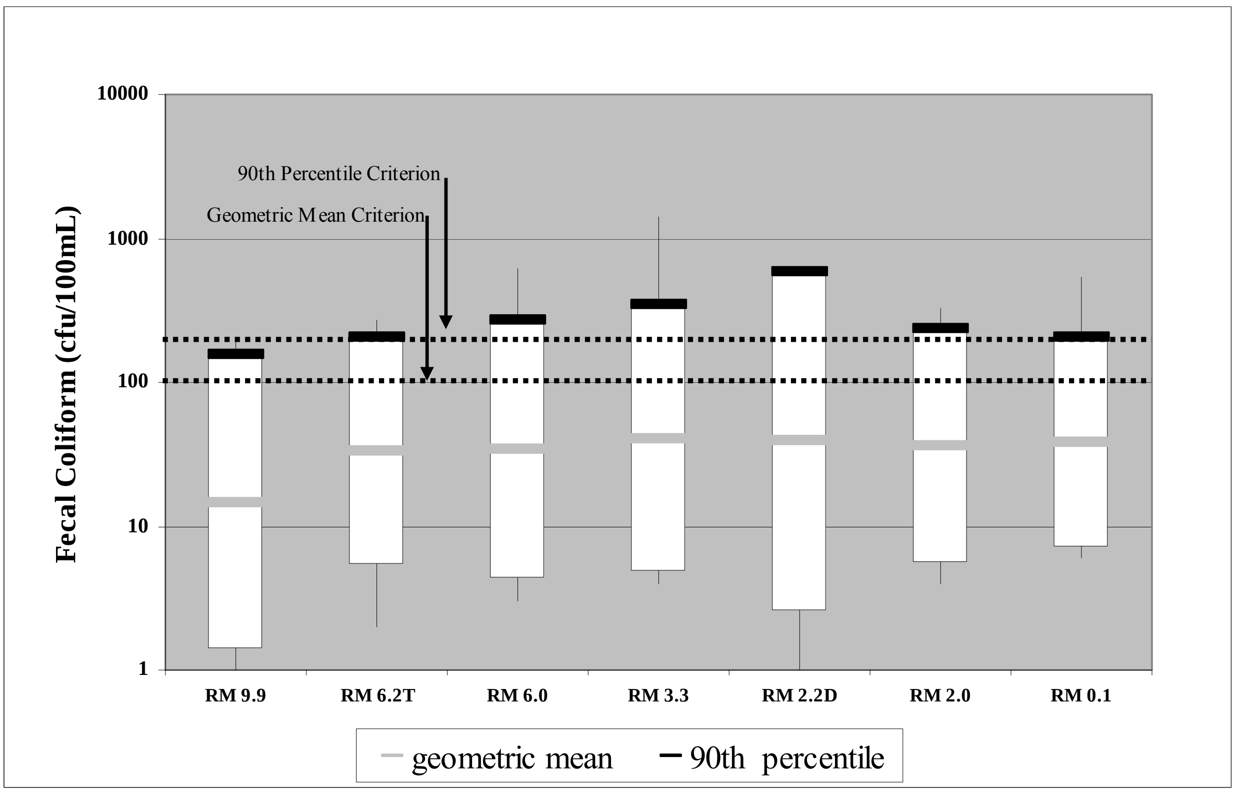

Figure 7. Fecal coliform bacteria geometric mean and 90th percentile values for Ohop Creek, March 2002 - June 2003.

Red Salmon Creek

Red Salmon Creek must meet the criteria for *Extraordinary* quality waters (Class AA). The downstream samples sites at RM 1.40 and the unnamed tributary at RM 1.30T are both classified as marine water due to salinity, while the upstream sites are freshwater. Table H-3 in Appendix H describes compliance with the fecal coliform standard, both at marine and freshwater sites. The most upstream site on Red Salmon, RM 1.44, is the only site that meets water quality standards for fecal coliform.

McAllister Creek

McAllister Creek must meet the criteria for *Extraordinary* quality waters (Class AA). McAllister Creek from RM 4.2 downstream is classified as marine water for fecal coliform because it is the point where 95% of the daily maximum vertically averaged salinity values are 10 ppt or greater (Table 3). For all other parameters, including dissolved oxygen, the marine water standards are applied at McAllister Creek RM 4.7 and downstream where 95% of the daily maximum vertically averaged salinity values are 1 ppt or greater. The marine *Extraordinary* criterion for dissolved oxygen (lowest 1-day minimum of 7.0 mg/L) applies at RM 4.7, at Steilacoom Road bridge, and downstream. Upstream sites must meet the *Extraordinary* freshwater quality criteria (lowest 1-day minimum of 9.5 mg/L).

The tributaries, all stormwater discharges, and tide gates 1 - 15 must meet freshwater standards for fecal coliform bacteria; and tide gates A and B must meet marine water standards for bacteria. For all other parameters, tide gates A, B, 1, and 2 must meet marine water standards, but the other tributaries and tide gates must meet freshwater standards.

Fecal Coliform Results

Table H-4 in Appendix H describes compliance with the fecal coliform standard, both at marine and freshwater sites. The McAllister Creek mainstem sites meeting water quality standards for fecal coliform include McAllister Creek RM 5.8 and 4.7 and the most downstream site, DOH shellfish station 224. Tide gates 15, 2, and B also met standards. Little McAllister Creek and the mouth of Medicine Creek did not meet standards. Both the inflow and outflow to Nisqually Trout Farm #1 met fecal coliform standards.

Dissolved Oxygen and Related Parameters

Synoptic Survey - Dissolved Oxygen Results

During the synoptic surveys, dissolved oxygen profiles were obtained for McAllister Creek sites. In general, most sites did not meet dissolved oxygen water quality standards. The only sites to meet standards were McAllister Creek at RM 4.5 and 2.2 (Table H-5 in Appendix H); marine standards apply at both sites. The only tributary or tide gate to meet the dissolved oxygen criteria was tide gate 1 (Table H-6, Appendix H). Most of the tide gates had very low dissolved oxygen levels, much lower than the McAllister Creek mainstem. The Nisqually Trout Farm inflow met dissolved oxygen standards but the outflow from the farm did not.

Synoptic Survey - Nutrients and Biochemical Oxygen Demand Results

Synoptic survey results for nutrients and biological oxygen demand (BOD) are presented in Appendix E. For the April 16, May 13, July 15, and August 27, 2003 surveys, nutrient samples were collected for laboratory analysis. These included total persulfate nitrogen, ammonia-nitrogen, nitrate+nitrite-N, total phosphorus, and orthophosphate. On August 27, 2003, several of the tide gates were sampled for BOD. The only direct water quality criterion that applies to nutrients, excluding lakes, is ammonia-nitrogen. Indirectly, nutrients must be low enough such that the dissolved oxygen criteria are met. All sites met the ammonia-nitrogen criteria.

Samples were obtained for BOD on August 27, 2003 at tide gate sites where possible. The only sites to have BOD levels above detection limits were tide gates A, B, 2, and 13-15. It was difficult to obtain tide gate samples due to low water levels and the amount of algal growth in the tide gates.

Inflow and outflow sampling of the Nisqually Trout Farm on September 22 and October 26, 2004 showed slight increases in total phosphorus and nitrogen, with the increases in total nitrogen due mostly to increasing ammonia-nitrogen levels. BOD levels increased from background levels at the outflow.

Synoptic Survey - pH and Temperature Results

All freshwater sites met pH standards, with the exception of one excursion below the standard at tide gate 4. Tide gates A and B occasionally fell below the marine pH range of 7.0-8.5, with values as low as 6.2. Excursions below the standard for all three sites is likely within the pH range for western Washington wetlands. All three sites drain wetland areas on the eastern portion of McAllister Creek. 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 from1996-2004 normally ranged from 5.0-6.0, with some pH as high as 7.0 (Hruby, 2004). Values seen from tide gates appear to be within normal range for areas draining wetlands and are within natural conditions for this area.

During the synoptic survey, the mainstem sites from McAllister RM 4.7 downstream were marine sites and are required to meet the marine pH standard of 7.0-8.5 standard units. The McAllister Creek site at RM 4.7 fell below the marine pH standard three times, with a pH of 6.9. During the synoptic surveys, RM 4.7 was sampled at low tide when there was no marine water influencing this site. Slight excursions below the standard are due to freshwater influences, and this site did meet freshwater standards.

During the synoptic surveys, all freshwater stations on McAllister Creek met temperature criteria. None of the marine stations met the marine temperature criterion of 13°C during

July and August. The two most downstream stations had very high temperatures during July, exceeding 20°C.

A number of tide gates and tributaries did not meet temperature criteria (either marine or freshwater) during July and August. Tide gates 4, 5, 9, 10, 11, 12, 13, 15, Medicine Creek at RM 0.3 and 0.1, and the tributary at RM 4.3 did not meet freshwater temperature criteria. Tide gates A, B, 1, 2, and 3 did not meet marine temperature criteria.

In-situ Continuous Monitoring Results

To further examine dissolved oxygen in McAllister Creek, three to four days of continuous dissolved oxygen monitoring was conducted at RM 5.8, 4.7, and 3.1. Appendix F summarizes the data collected for each site including dissolved oxygen, temperature, conductivity, and pH. None of the sites met the *Extraordinary* water quality standard for dissolved oxygen. Table 6 presents minimum and maximum dissolved oxygen readings for *in-situ* continuous monitoring conducted over several time periods on McAllister Creek.

Table 6. Minimum and maximum dissolved oxygen levels for continuous recording Hydrolabs installed in McAllister Creek.

Site and Time Period	Minimum DO (mg/L)	Maximum DO (mg/L)	Range of Percent DO Saturation *
RM 6.0 (McAllister Springs)			
June 21 - 26, 2002	5.8	7.9	53-75 %
RM 5.8			
July 30 - August 2, 2002	4.9	10.1	45-96 %
January 21- 27, 2003	5.2	7.4	46-64 %
January 28 - 31, 2003	6.1	7.6	54-65 %
March 19 - 24, 2003	5.4	8.0	47-71 %
July 11 - 14, 2003	5.8	9.9	53-99 %
August 27 - 31, 2003	3.9	8.6	35-83 %
RM 4.7			
June 21 - 27, 2002	5.6	9.7	55-97 %
July 30 - August 2, 2002	5.2	11.0	49-107 %
January 28 - 31, 2003	6.1	7.8	53-72 %
March 19 - 24, 2003	5.4	7.9	46-72 %
July 11 - 14, 2003	5.5	10.8	52-108 %
August 27 - Sept 2, 2003	4.3	9.4	41-92 %
RM 3.7			
January 28 - 31, 2003	6.3	7.8	55- ? %**
March 19 - 24, 2003	6.6	9.0	57-87 %
July 11 - 14, 2003	5.2	9.9	54-? %**
August 27 - Sept 2, 2003	5.0	10.6	50-127 %

* Dissolved oxygen % saturation corrected for temperature but not salinity. The oxygen content of water decreases exponentially as salinity increases, such that the difference between solubility in seawater and freshwater is about 20% (Wetzel, 1983)

** Probe out of water at high tide; highest saturation levels unknown.

At RM 5.8, freshwater pH and temperature standards were met. At RM 4.7, pH levels fell slightly below the marine standard, with a low pH of 6.9, as with the synoptic survey results. Low conductivity results indicate that pH values fell below 7.0 only during low tide periods when this site is primarily freshwater. As with the synoptic survey results, slight excursions below the standard are due to freshwater influence upstream. McAllister Creek at RM 3.7 met pH standards for marine water.

McAllister Creek at RM 4.7 and 3.7 did not meet the marine temperature criteria (Figure 8). The marine temperature standard of 13°C is lower than the freshwater standard for temperature of 16°C. During the summer, high tides cause higher temperatures at both RM 4.7 and 3.7, and even cause some temperature effects at RM 5.8. Higher temperatures at both sites are likely due somewhat to natural conditions. The shallow depths at the mouth of McAllister Creek allow for warming of marine water during summer months, then flooding tides bring the warmer marine water into McAllister Creek. The majority of the lower reaches of McAllister Creek from approximately RM 5.6 downstream are diked with limited riparian cover. Higher temperatures in the mainstem, especially at RM 4.7, should be investigated.

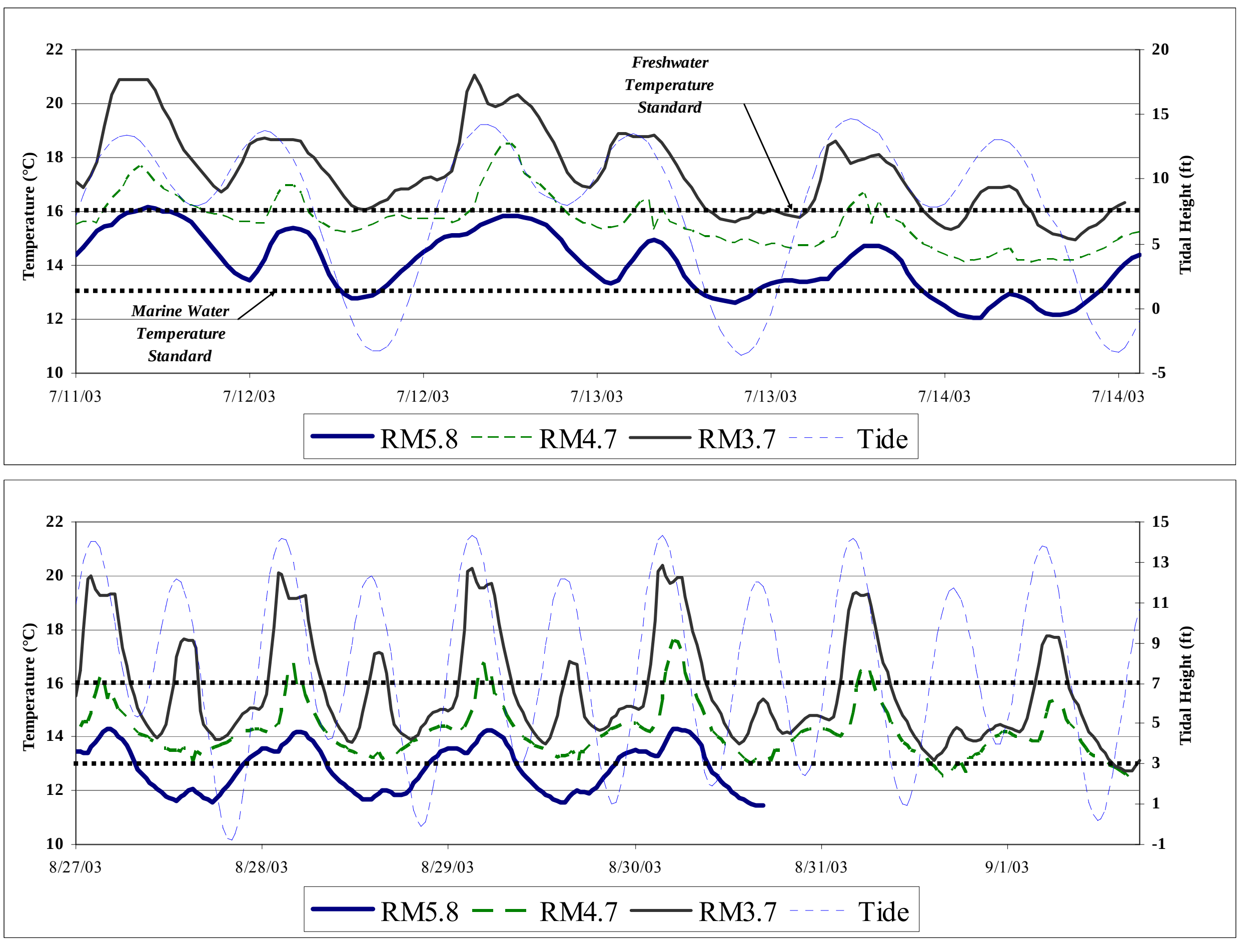

Figure 8. Water temperatures for McAllister Creek, July and August 2003.

Time-of-Travel Results

To understand how quickly water parcels move and in what direction for a given tide condition, several travel-time surveys were conducted in McAllister Creek and its estuary, as well as west of Luhr Beach. Appendix I presents the detailed results, which are summarized here. These results help identify areas potentially influencing water quality in particular areas.

During strong ebbing tides, McAllister Creek water parcels travel from tide gate 15 at RM 5.7 to the Interstate-5 (I-5) overpass at 0.7 to 0.8 ft/s. Thus, water parcels travel from tide gate 15 to Steilacoom Road in 2 hours, from Steilacoom Road at RM 4.7 to Blue bridge at RM 4.3 in 40 minutes, and from Blue bridge to I-5 (RM 3.1) in 2 hours 20 min, or 5 hours total. Estuarine velocities ranged from 0.6 to 1.4 ft/s, due to the narrow shape, and water parcels traveled from just downstream of I-5 to where the estuary widens in an hour, then north another 2 miles in another hour.

During moderate ebbing tides, McAllister Creek water parcels travel from tide gate 15 to Martin Way (RM 3.7) 0.6 to 0.9 ft/s. Water parcels travel from tide gate 15 to Steilacoom Road in 2 hours 10 minutes, from Steilacoom Road to Blue bridge in 36 minutes, and from Blue bridge to Martin Way in 1 hour and 30 minutes, or 4 hours. From Luhr Beach, water parcels travel about 1.5 miles to the northeast in 1 hour 50 minutes. Even during an expected low-velocity ebbing tide event, drogues traveled 0.5 to 1.3 ft/s.

In summary, the travel-time data indicate that during most ebbing tide events, water parcels travel from McAllister Springs upstream of RM 5.8 to the I-5 bridge within 5 or 6 hours, or within a single high-to-low-tide cycle. Therefore, sources of bacteria to McAllister Creek along the entire riverine section can affect the southern extent of the estuary within a single tidal cycle, and relatively little attenuation of concentrations is expected until bacteria reach higher salinity estuarine waters. Travel time in the estuary also can be very rapid, since drogues reached Luhr Beach from I-5 within 3 to 4 hours. Thus, in a single 6-hour period from high tide to low tide, bacteria sources between the Medicine Creek/McAllister Creek confluence (approximately 2 hours upstream of I-5) and Luhr Beach have the greatest influence on McAllister estuary bacteria levels. Sources upstream of Medicine Creek also affect water quality at Luhr Beach and beyond over two ebb-tide events, or within 18 hours.

Nearshore circulation patterns, developed using multiple drogue releases northwest of Luhr Beach, indicate a series of somewhat independent circulation cells with boundaries near headlands. These cells are consistent with net shore drift cells identified in Schwartz and Hatfield (1982), which were based on sediment accumulation near natural and artificial protrusions into the surf zone.

Drogues released from Luhr Beach on an ebbing tide travel very quickly to the northeast and represent a strong boundary between McAllister estuary flow paths to the east and nearshore flow paths to the west. Nearshore releases from Meridian and DeWolf Bight travel slowly to the west on the ebbing tide. The low velocities found west of Luhr Beach contribute to the accumulation of fines that have built extensive mudflats near DOH stations 225 through 233 (Figures 9 and 10). Thus, nearby shoreline conditions likely govern water quality in the circulation cells west of Luhr Beach, and the shape of the shoreline prevents Tolmie-area sources from affecting water quality in Hogum Bay, for example.

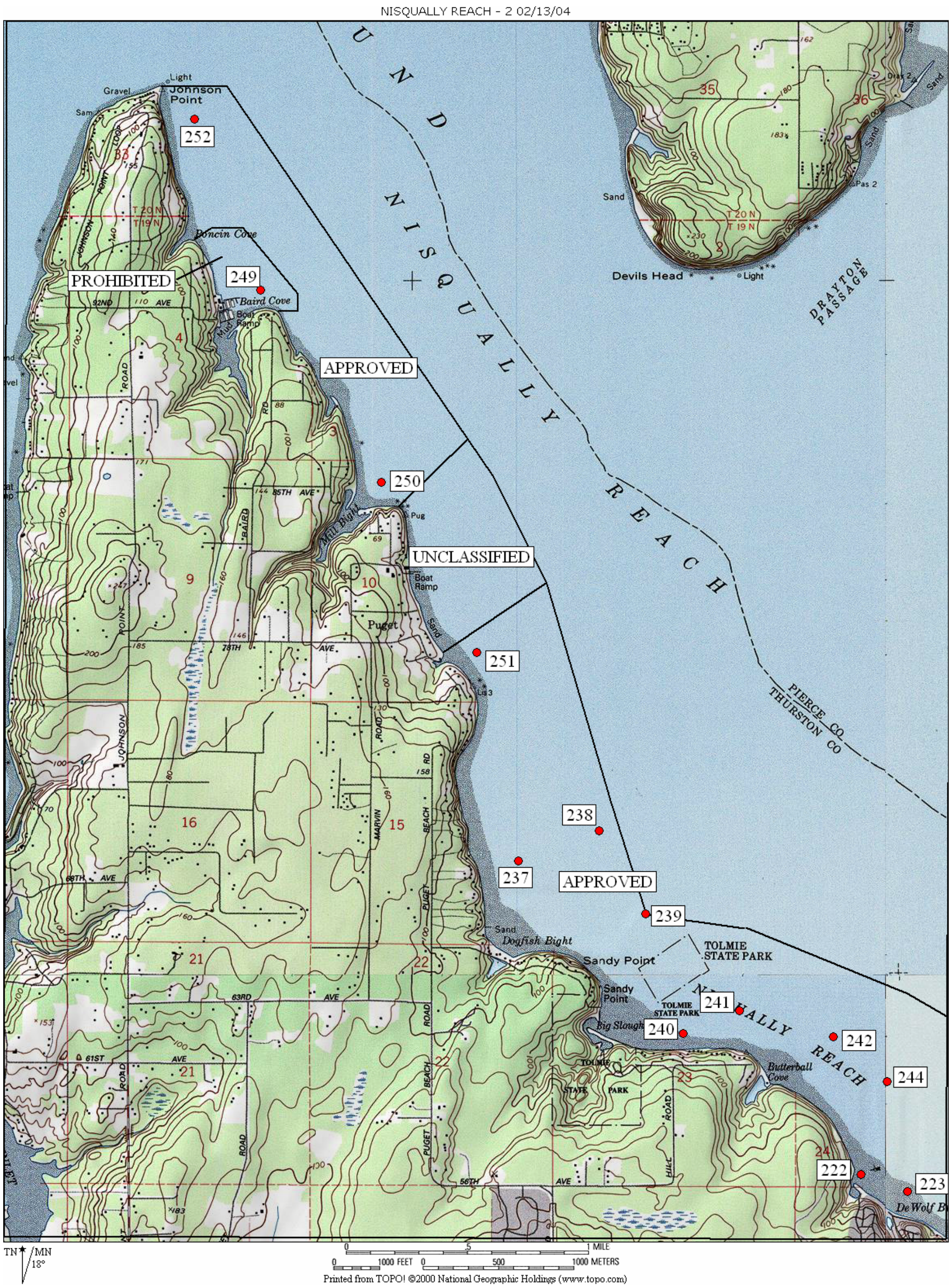

Figure 9. Department of Health (DOH) shellfish monitoring stations: Nisqually Reach area.

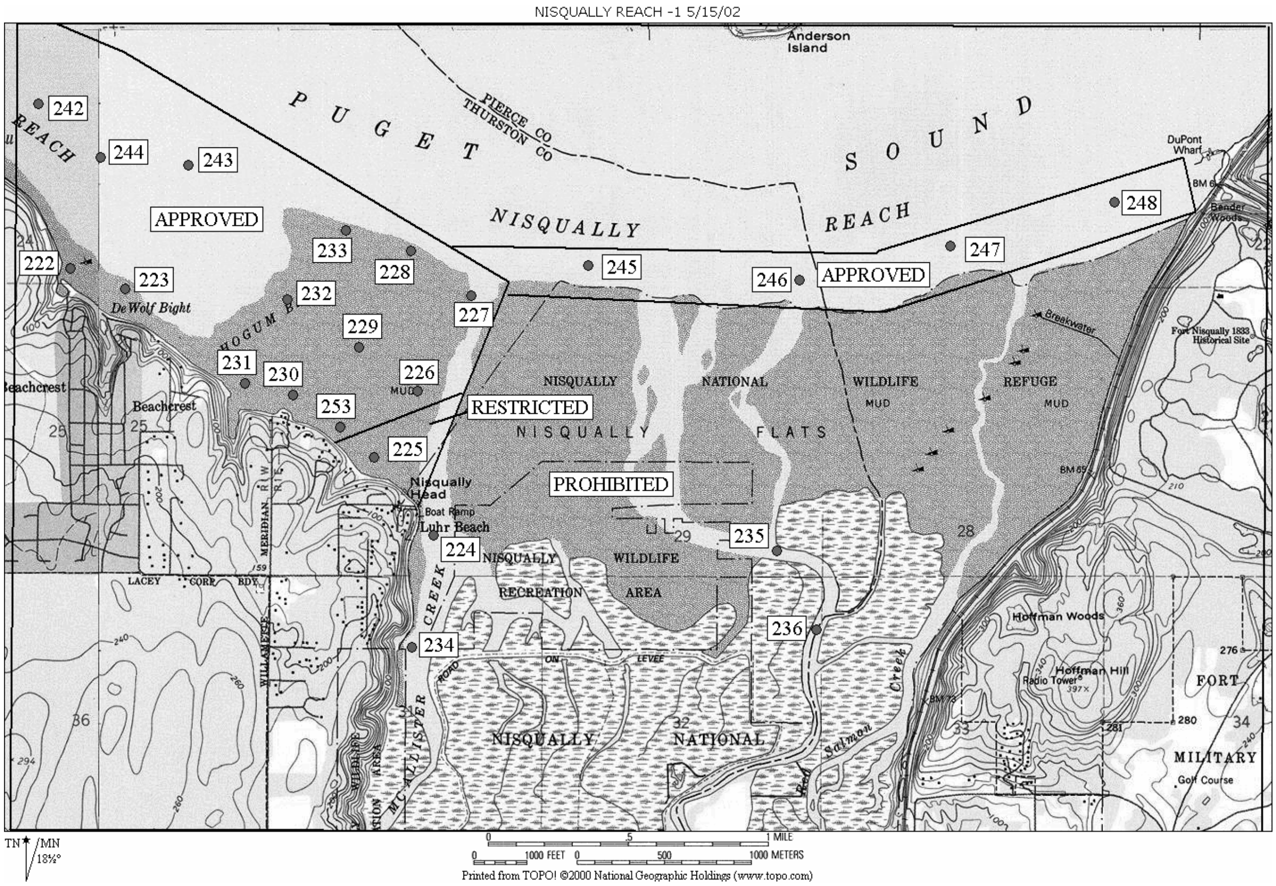

Figure 10. Department of Health (DOH) shellfish monitoring stations: Nisqually Reach, McAllister Creek, and Hogum Bay area.

Groundwater Survey

Groundwater sampling results for McAllister Creek are described in Appendix A.

Historical Data, Seasonal Variation, and Critical Conditions

A complete historical data summary for the Nisqually River, Nisqually Reach, and Ohop, Red Salmon, and McAllister creeks is presented in the Quality Assurance (QA) Project Plan for the Henderson and Nisqually TMDL Study (Sargeant, Roberts, and Carey; 2003).

Nisqually River

The monthly ambient monitoring data set (October 1975 - March 2004) was analyzed to determine trends at Nisqually RM 3.4. A nonparametric Seasonal Kendall statistical test (alpha ≤ 0.05) was used to determine that a statistically significant trend toward improving fecal coliform levels is seen at RM 3.4 (Figure 11).

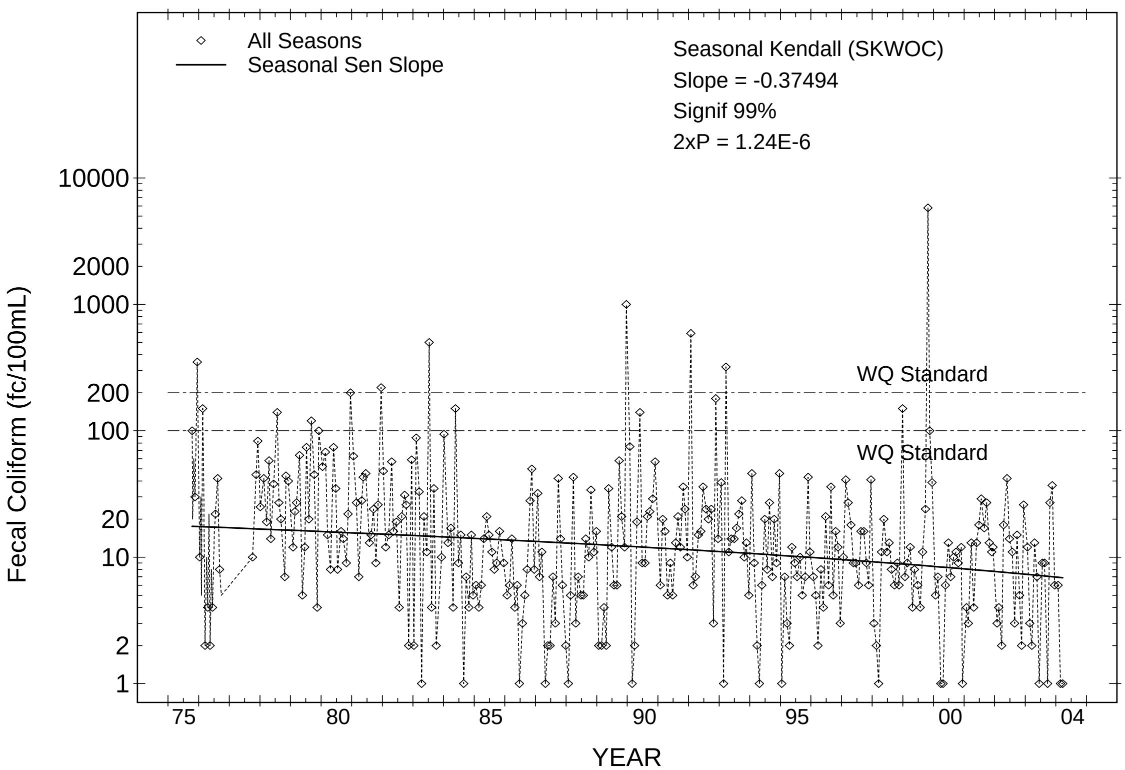

Figure 11. Results of Seasonal Kendall trend test at Nisqually RM 3.4, October 1975 - March 2004.

Since 1975, there have been seven values out of 321 sample events that have exceeded 200 col/100 mL. Three of the values greater than 200 col/100 mL occurred in December. In examining the TMDL and ambient monitoring data set (2002-2003), there were no critical periods observed, either seasonally or related to flow.

Nisqually Reach

Analysis of Department of Health Fecal Coliform Bacteria Data

Table 7 summarizes the Washington State Department of Health (DOH) data collected between January 2001 and March 2004, the most recent data available at the time of publication. Station locations are shown in Figures 9 and 10. All four sites met the water quality standards when all data were pooled, and also when flood and ebb tide data were analyzed separately. Historically, station 246, nearest the Red Salmon Creek outlet, had 11.8% of samples >43 col/100 mL during ebb tides, but the site now meets both components of the water quality standard for bacteria.

Table 7. Annual compliance with fecal coliform water quality standards for marine water for Nisqually Reach, based on DOH data for January 2001 through March 2004.

Station	Tidal condition	Number of samples	Geometric mean (<14 col/100 mL)	Percentage of samples >43 col/100 mL (<10%)	Meets fecal coliform standard
245	all	33	3.3	8.4%	yes
246	all	33	3.8	5.6%	yes
247	all	32	3.2	5.7%	yes
248	all	32	2.6	1.0%	yes
245	flood	20	2.7	8.9%	yes
246	flood	20	2.7	0.0%	yes
247	flood	19	2.9	1.8%	yes
248	flood	19	2.6	0.0%	yes
245	ebb	13	4.3	7.7%	yes
246	ebb	13	6.4	7.7%	yes
247	ebb	13	3.7	7.7%	yes
248	ebb	13	2.6	0.0%	yes

Conditions within the Nisqually Reach are strongly affected by the tidal condition, and different geographic areas may contribute to bacteria levels during flood and ebb tides. As described below, DOH fecal coliform data from the four Nisqually River delta stations were analyzed based on pooling all data and separating flood and ebb tide conditions. Therefore, the critical conditions account for tidal conditions.

In addition, DOH recently developed a trend analysis of fecal coliform bacteria levels in the Nisqually Reach (Determan, 2004). The results of the trend analysis are described below.

Washington State Department of Health Fecal Coliform Trends

DOH uses a systematic random sampling (SRS) strategy when sampling stations in shellfish growing areas. At least six samples per year are taken in *Approved* and some *Restricted* growing areas, and up to 12 samples per year in *Conditionally Approved* areas. In addition to using these data to classify commercial shellfish areas, DOH analyzes the data for status and trends of fecal pollution in shellfish growing areas for the Puget Sound Ambient Monitoring Program. To determine trends, the fecal coliform geometric mean and 90th percentiles for each station are graphed against sample dates. Spearman's *rho*, a nonparametric statistical test for trends based on ranks, is used to confirm visual evidence of temporal trend in 90th percentiles (Determan, 2001).

Tim Determan of DOH conducted five-year (1999 through 2003) trend analysis for the 32 DOH stations in the Nisqually area including Hogum Bay and the Nisqually-McAllister delta (Figures 9 and 10). Twenty-five stations showed significant reduction of 90th percentiles (Table 8). In Table 8, a negative value of *rho* means a downward trend in fecal coliform concentrations, indicating improving water quality. A positive value means an upward trend in concentrations, indicating degrading water quality. If the probability is less than 0.05, the trend is significant. Two stations showed significant increases, four stations did not change significantly, and three stations were not evaluated because their data records were too short. Based on five years of data, fecal coliform concentrations are declining at stations 245 through 248, and the trend is significant. Overall, Nisqually Reach has improved over the last five years (Determan, 2004).

Table 8. Fecal coliform bacteria levels for DOH Nisqually Reach, McAllister, and Hogum Bay shellfish areas, five-year trends (1999-2003).

Station	Spearman's Rho		Number of Samples	Trend in fecal coliform levels
	Rho	Probability		
222	(short record)		24	Not enough data
223	(short record)		26	Not enough data
224	-0.8553	0.000	45	Down
225	-0.8515	0.000	61	Down
226	-0.8730	0.000	61	Down
227	-0.9114	0.000	60	Down
228	0.1363	0.295	61	No significant trend
229	-0.7931	0.000	61	Down
230	-0.8212	0.000	61	Down
231	-0.5656	0.000	61	Down
232	-0.6832	0.000	61	Down
233	-0.0762	0.563	60	No significant trend
234	-0.7404	0.000	45	Down
235	-0.6830	0.000	39	Down
236	-0.3513	0.033	37	Down
237	0.5086	0.000	43	Up
238	-0.9042	0.000	44	Down
239	-0.4358	0.003	44	Down
240	-0.4229	0.002	50	Down
241	-0.1067	0.461	50	No significant trend
242	-0.8032	0.000	61	Down
243	-0.5946	0.000	61	Down
244	-0.8833	0.000	61	Down
245	-0.7627	0.000	45	Down
246	-0.8573	0.000	45	Down
247	-0.5904	0.000	44	Down
248	-0.4482	0.002	44	Down
249	0.3161	0.039	43	Up
250	0.2085	0.180	43	No significant trend
251	-0.2364	0.127	43	No significant trend
252	-0.5347	0.000	38	Down
253	(short record)		6	Not enough data

DOH stations 224 and 234 correspond to Ecology's two downstream TMDL stations (Figure 10). Both of these stations show a decreasing trend in fecal coliform levels over the past five years.

Ohop Creek

The report *Nisqually Indian Tribe Identification of Pollution Sources Impacting Salmon Habitat in the Mashel River and Ohop Creek Drainages* (Whiley and Walter, 1997) showed that fecal coliform levels were higher at the lower Ohop Creek sites, at RM 6.0, 3.3, 2.0, and the mouth than farther upstream. During the study, the lower Ohop Creek stations received drainage from two dairy farms that have since closed. Significantly higher levels of fecal coliform were seen in the creek during the dry season, especially at the lower stations.

Figures 12, 13, and 14 show wet season (November - April) and dry season (June - September) fecal coliform results for Ohop Creek at RM 9.9, 6.0, and 0.1 for historical and current periods of sampling.

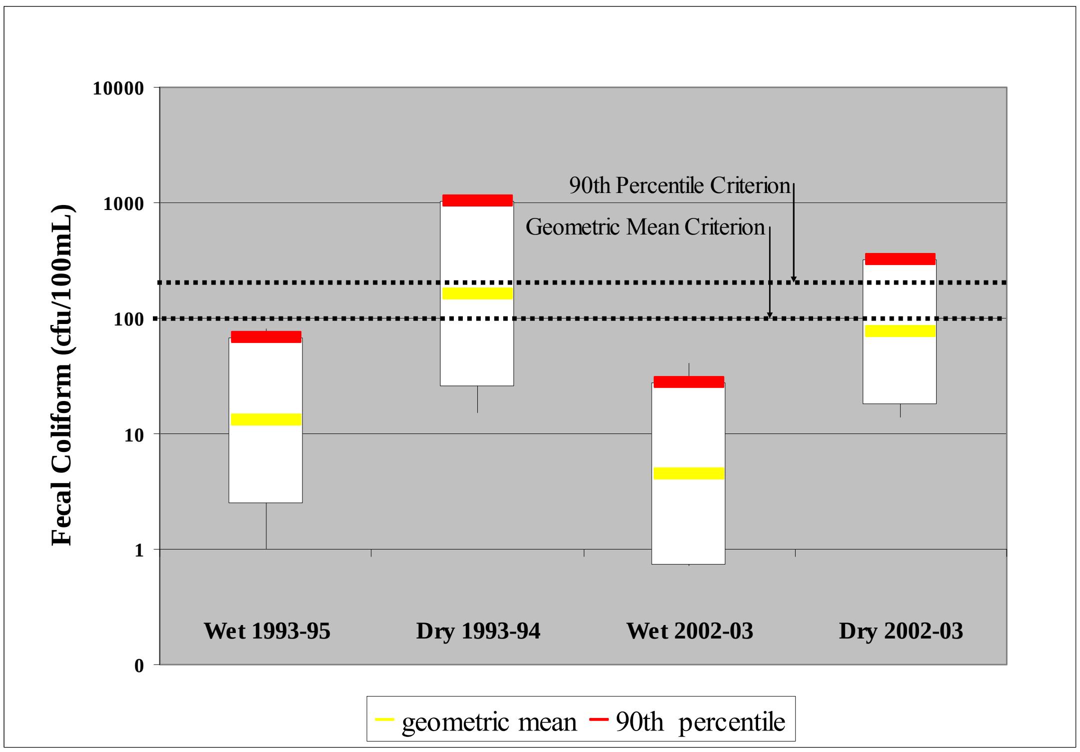

Figure 12. Wet and dry season fecal coliform levels for Ohop Creek RM 9.9, 1993-95 and 2002-03.

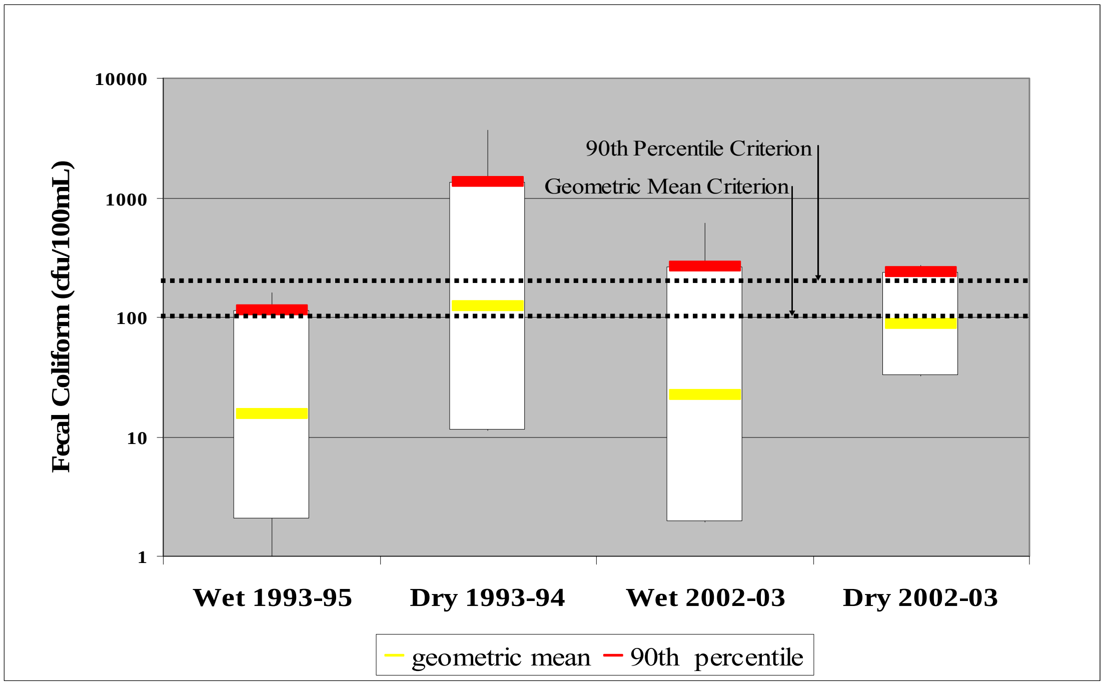

Figure 13. Wet and dry season fecal coliform levels for Ohop Creek RM 6.0, 1993-95 and 2002-03.

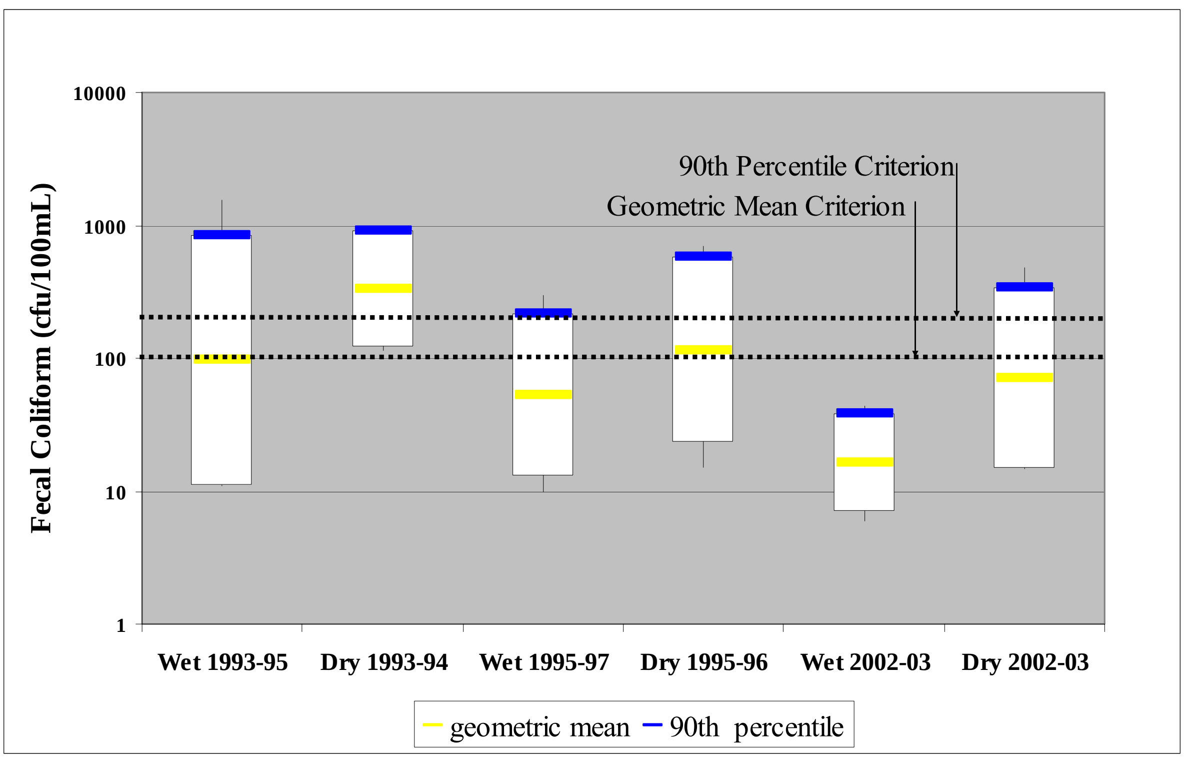

Figure 14. Wet and dry season fecal coliform levels for Ohop Creek RM 0.01, 1993-95, 1995-97, and 2002-03.

Figures 12, 13, and 14 show the critical period for Ohop RM 9.9, and 3.3 through 0.1 is the dry season, June through September. At Lynch Creek RM 6.2T (not graphed) and RM 6.0, the critical period is the wet season. At RM 6.0, a slightly higher 90th percentile is seen during the wet season.

To determine the effect of Lynch Creek on Ohop Creek at RM 6.0, fecal coliform concentrations were estimated for Ohop RM 6.0 without bacteria loading from Lynch Creek. To calculate loading at Ohop Creek RM 6.0, flow estimates were obtained by subtracting Lynch Creek flow from USGS flow at the Ohop Lake outlet. Lynch Creek fecal coliform loading estimates were subtracted from loading estimates at Ohop Creek RM 6.0. Without loading and dilution from Lynch Creek, the highest bacteria concentrations at Ohop RM 6.0 are seen during the dry season, with an estimated geometric mean of 63 col/100mL and a 90th percentile of 650 col/100 mL.

Improvements in bacteria levels from historical conditions have occurred for both seasons at RM 9.9 and 0.1. At RM 6.0, bacteria levels have improved slightly during the dry season but have increased during the wet season.

Red Salmon Creek

The Nisqually Tribe sampled Red Salmon Creek at RM 1.40 for a number of parameters, including fecal coliform bacteria, from July 1993 - April 1995 (n=31). During that period, there was a significant positive correlation between the two-day antecedent rainfall and fecal coliform levels. Fecal coliform concentrations during that period were chronically elevated, and some of the highest median fecal coliform levels were seen during storm events (Whiley and Walter, 1996).

During the 2002-03 sample period, there was no strong seasonal pattern between the wet and dry season at either Red Salmon RM 1.40 or at the tributary (RM 1.30T) (Figure 15). Due to freshwater inputs of fecal coliform from upstream sources, the critical period is the low tide period annually.

Figure 16 presents historical and current fecal coliform levels for Red Salmon Creek at RM 1.40. The historical data were divided into two periods so the sample size would be more consistent with the current data set. Red Salmon at RM 1.40 shows improvement in fecal coliform levels from historical levels but still does not meet marine water quality standards.

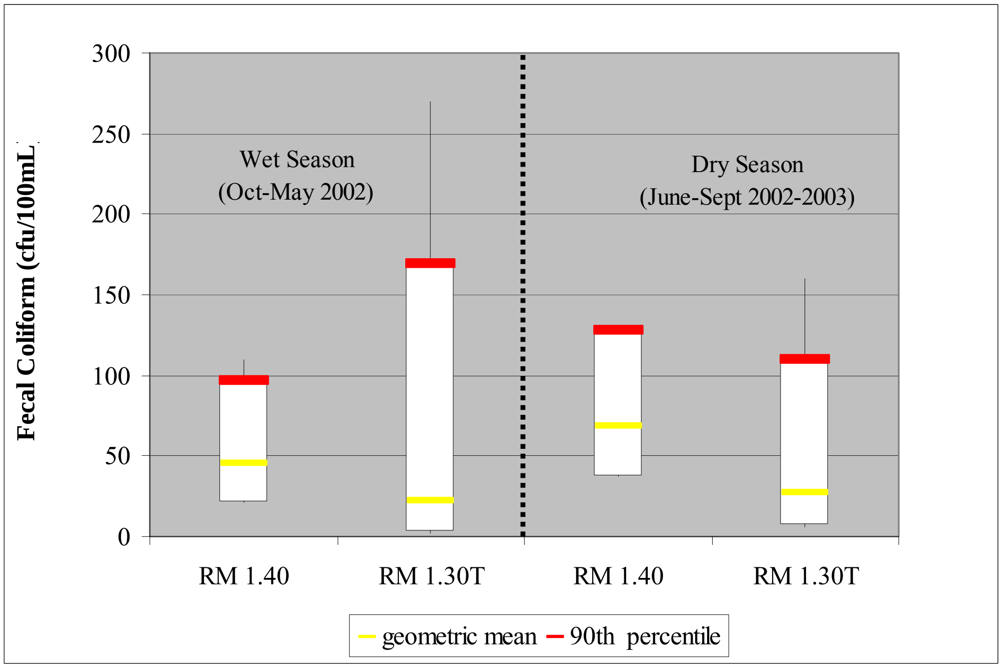

Figure 15. Seasonal fecal coliform concentrations at Red Salmon Creek RM 1.40 and 1.30T, 2002-03.

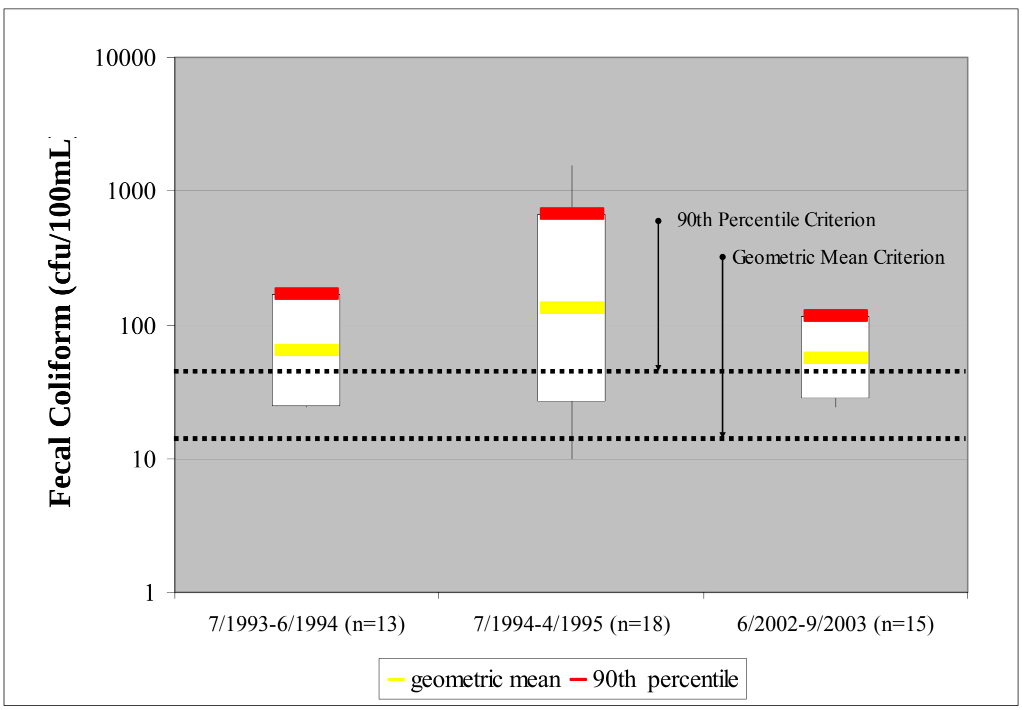

Figure 16. Historical and recent fecal coliform levels at Red Salmon Creek RM 1.40.

McAllister Creek

Fecal Coliform Bacteria

Historical data were available for several sites on McAllister Creek. From June 1992 - November 1995, the Nisqually Tribe collected baseline water quality data on the creek. Results showed that McAllister Creek provided the most continuous source of fecal coliform bacteria to the marine waters of Nisqually Reach. McAllister Creek fecal coliform concentrations were chronically elevated and positively related to rainfall. The most upstream site at McAllister Springs was the only site to meet water quality standards for fecal coliform (Whiley and Walter, 1996).

From June 1995 - April 1997, the Nisqually Tribe conducted another fecal coliform bacteria study on the Nisqually River and reach area including McAllister Creek. The study objectives included determining whether specific reaches of the Nisqually River have significantly higher fecal coliform concentrations, and evaluating the role of McAllister Creek and the Nisqually River on bacterial levels in the Nisqually Reach shellfish growing area.

From March through June 2001, Ecology conducted fecal coliform sampling on McAllister Creek. Monitoring was conducted in response to a shellfish downgrade in the Nisqually Reach area by the Washington State Department of Health (DOH). Results indicated high concentrations of bacteria, nutrients, and sediment entering the mainstem from tributaries as well as from the agricultural tide gates and stormwater. Data showed that McAllister Creek contributes high concentrations of fecal coliform bacteria into the estuary area below the I-5 bridge. Bacteria concentrations increased in the McAllister Creek mainstem in response to precipitation especially on the days with greater than 0.5" of rain (Dickes, 2002).

To evaluate trends, two sets of data were used: (1) the historical Nisqually Tribe data set from 1993-95 and 1995-97 for McAllister Creek at RM 3.1, and (2) a more recent set from 2001-2003 including the data from the current 2002-03 TMDL study and the Dickes (2002) data from March through June 2001.

To determine if there has been a statistically significant improvement in water quality since 1997, a nonparametric step trend test, Seasonal Wilcoxon Mann-Whitney, was used to determine water quality differences between the historical and more recent data set. The statistical analysis program WQHYDRO (Aroner, 2001) was used, with a significance level of 0.10 (α=0.10). No statistically significant difference in water quality was seen.

Figure 17 presents geometric mean and 90th percentile fecal coliform levels from the historical and more recent data sets. Some improvements in fecal coliform levels were seen at the upstream McAllister sites. These differences could be due to improvements in water quality or to differences in rainfall for the sample periods.

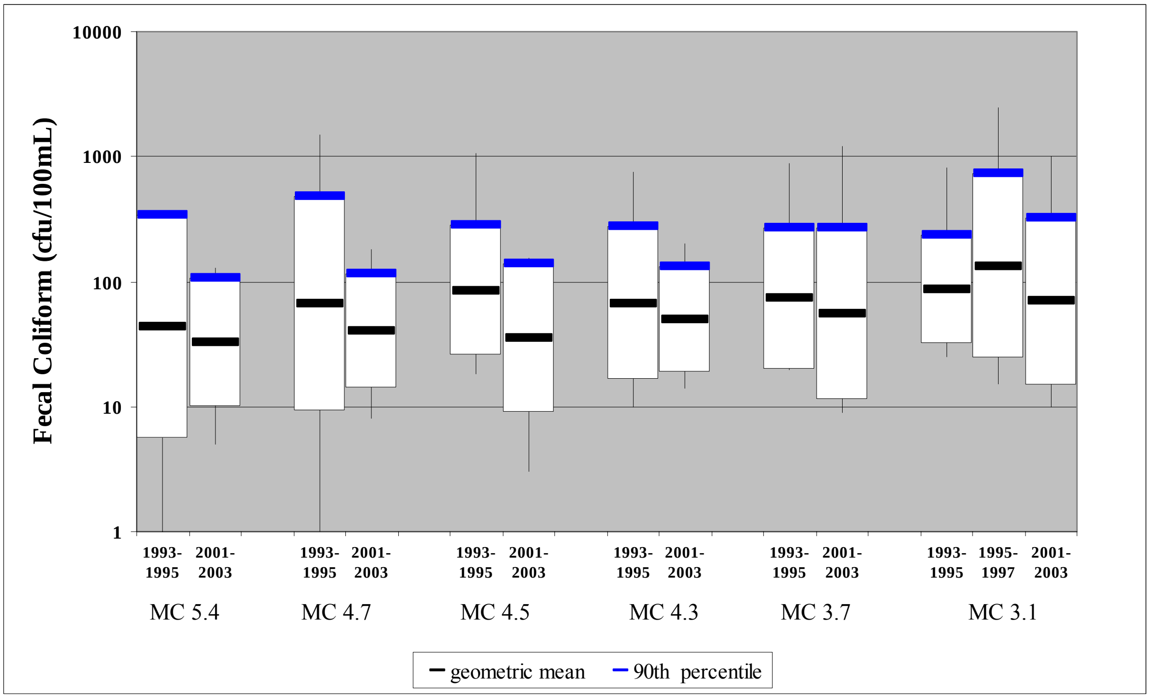

Figure 17. Historical and recent fecal coliform levels for McAllister Creek.

Figure 18 presents total rainfall data for the wet (November - April) and dry (May - October) season for the study periods. Precipitation data are from the Olympia Airport National Weather Service station. Figure 18 shows that initial sampling conducted by the Nisqually Tribe occurred during a period of below average and average precipitation (1993-95). During the second period of tribal sampling (1995-97), precipitations levels were greater than normal. This could explain the increases in bacteria levels seen during the 1995-97 period.

During Ecology's pre-TMDL sampling in 2000-2002 (Dickes, 2002), both lower and higher than average precipitation occurred. During the current TMDL sampling period, March 2002 through September 2003, precipitation totals were lower than average for the wet season. Improvements in bacteria levels seen during the current TMDL period could be due to less rainfall during the sampling period.

Both the Tribe (Whiley and Walter, 1996) and Ecology (Dickes, 2002) found elevated fecal coliform levels in McAllister Creek during rain events. A review of the entire fecal coliform data set (1993-2003) for McAllister Creek at RM 3.1 does show a positive correlation with rain events. Higher bacteria levels occur when there is rainfall the day of sampling and during the 24 hours preceding sampling. The critical period for McAllister Creek on an annual basis is during periods of ebbing tide during rain events.

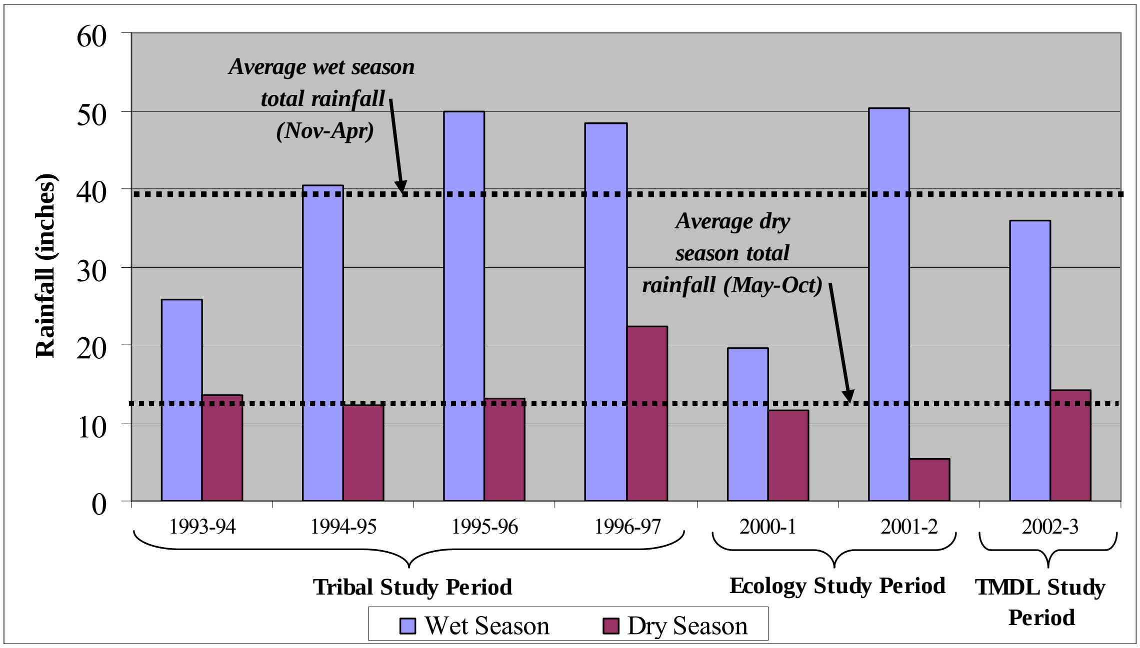

Figure 18. Average wet and dry season total rainfall for historical and recent study periods.

Dissolved Oxygen

The *Extraordinary (Class AA) marine* criteria for dissolved oxygen applies at McAllister RM 4.7, at Steilacoom Road bridge, and downstream. Upstream sites must meet the *Extraordinary (Class AA) freshwater* quality criteria.

In 1988, Ecology sampled several fish hatcheries throughout the state during the critical summer low-flow season, including the Nisqually Trout Farm #1 located at the end of the remnant channel on McAllister Creek. Influent and effluent samples were obtained from the trout farm on August 17, 1988. Effluent increases were seen in temperature, pH, total suspended solids, ammonia-nitrogen, total nitrogen, and phosphorus. Nitrate+nitrite-N decreased, and dissolved oxygen decreased from 11.6 to 5.9 mg/L, from 104 to 56% saturation (Kendra, 1989).

From June 1992 - November 1995, the Nisqually Tribe collected baseline water quality data on McAllister Creek (Whiley and Walter, 1996). The Tribe found that dissolved oxygen varied little throughout the length of McAllister Creek. Dissolved oxygen levels at McAllister Springs ranged from 5.8 to 10.6 mg/L over a year's period, with a median concentration of approximately 8.0 mg/L. Median dissolved oxygen levels were similar from McAllister Springs to McAllister Creek RM 4.7. Below RM 4.7, the creek flows through a series of riffles that serve to aerate the water. This is the first turbulent mixing zone in the creek. Below this point, the median dissolved oxygen level increased to 8.8 mg/L. Dissolved oxygen concentrations above RM 4.7 were chronically low during the winter months and increased during the summer months, perhaps due to primary production.

Minimum and maximum dissolved oxygen readings for continuous monitoring conducted over several time periods on different McAllister Creek stations for the current 2002-03 study period are presented in Table 6. For McAllister Creek RM 5.8 and 4.7, the low dissolved oxygen levels were seen in both January and late August. As concluded by the Tribe, dissolved oxygen levels tend to be chronically low in the winter months. A greater diurnal range in dissolved oxygen is seen during the summer months, with higher maximum dissolved oxygen levels and lower lows. It is likely the increases are due to primary production as evidenced by the diurnal swings in dissolved oxygen seen during July and late August (Figures 19 and 20). The lowest minimum dissolved oxygen levels are seen in late August. While McAllister Creek has chronically low dissolved oxygen levels during the winter months, the lowest values and critical period occur during the summer months. The tributaries, including tide gates, show no consistent seasonal pattern in dissolved oxygen levels.

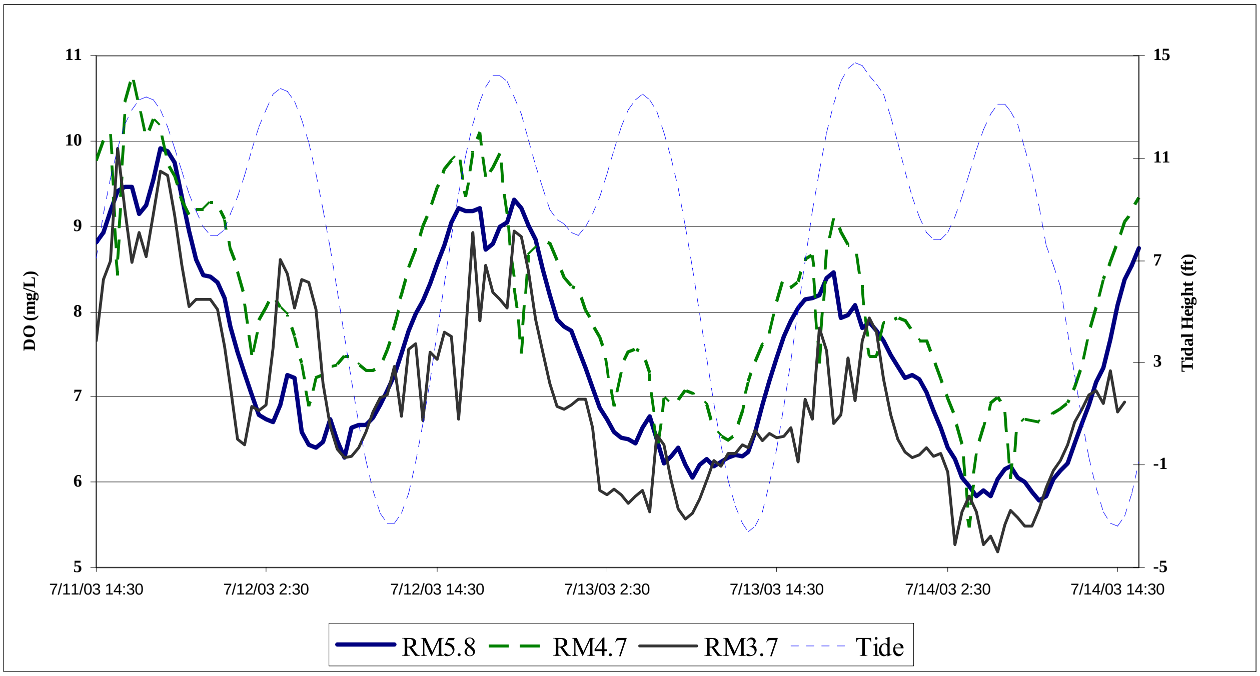

Figure 19. Continuous dissolved oxygen monitoring for McAllister Creek RM 5.8, 4.7, and 3.7, July 11-14, 2003.

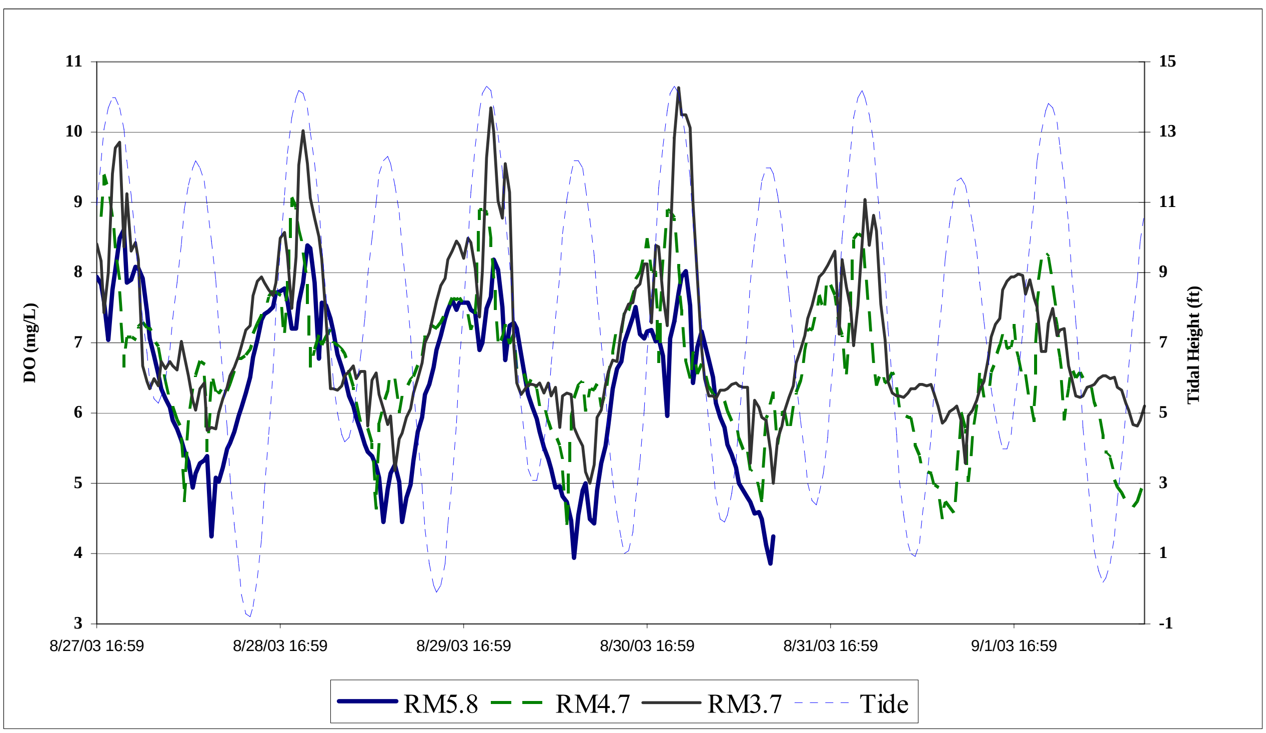

Figure 20. Continuous dissolved oxygen monitoring for McAllister Creek RM 5.8, 4.7, and 3.7, August 27 - September 1, 2003.

Technical Analysis

The technical analyses are based on historical and recent field and laboratory data collection and statistical analysis. The Quality Assurance Project Plan (Sargeant, Roberts, and Carey; 2003) describes the data collection program and methods. A discussion of field and laboratory data quality is included in Appendix G. Field and laboratory results are presented in Appendices B - E.

Fecal Coliform Bacteria

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.

The Nisqually River meets water quality standards for fecal coliform bacteria, and therefore no loading capacity determination is necessary. The Nisqually Reach stations monitored by DOH also meet water quality standards and do not require loading capacity determination.

There are no point source discharges in the Red Salmon study area; therefore, the wasteload allocation is zero, and the entire load capacity is allocated to nonpoint sources and the margin of safety in this area.

In McAllister Creek, Nisqually Trout Farm #1 discharges to a pond that discharges to a remnant channel of the creek at approximately RM 4.2. During the current sampling period, March 2002 – September 2003, the trout farm did not meet Ecology's threshold size for a General NPDES Fish Hatchery permit, and is not a permitted facility, but a wasteload allocation must still be given for the facility (Mann, 2004).

Since 2002, EPA requires that all TMDLs in jurisdictions with NPDES permits for stormwater systems include the pollutant loads from those systems as a wasteload allocation (Joy, 2004). The Washington State Department of Transportation has a Phase I NPDES permit for their stormwater systems. Pierce County has a Phase I NPDES municipal permit for their stormwater systems. Portions of the west bank of McAllister Creek are within Thurston County's Phase II NPDES permit area.

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:

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

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 0.0246 to convert cfs x #col/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 (GM 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 or 100 col/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.

Nisqually Reach and River

The Nisqually Reach stations monitored by DOH meet the water quality standards for fecal coliform bacteria. The Nisqually River at RM 3.4 also meets standards. Therefore, the reach and river do not require load allocations. However, given previous water quality problems near these important shellfish growing areas, continued attention is recommended, as described in the *Recommendations* section of this report.

Ohop Creek

Loading capacity for three sites on Ohop Creek is presented in Figure 21. For the sites at RM 6.0 and Lynch Creek, load allocations are set for the critical wet season period. For all remaining sites, including RM 0.1, the critical period is the dry season, and the load allocation is based on lower dry season flows. For all sites, the 90th percentile (the portion of the criteria that did not meet standards) is set as the target to meet.

Table 9 describes bacteria reductions needed for the critical period by site. It is likely that high wet season fecal coliform levels from Lynch Creek impact wet-season bacteria levels at Ohop RM 6.0. Improvements in Lynch Creek bacteria levels should improve bacteria levels at Ohop RM 6.0.

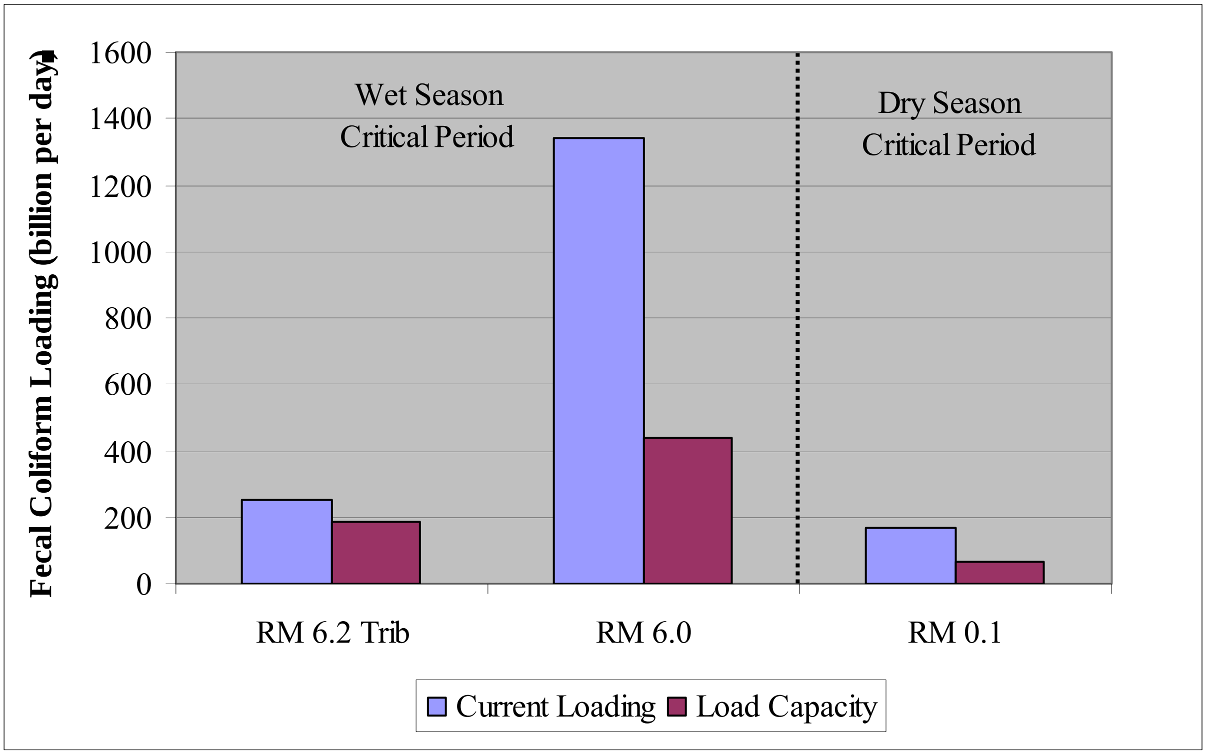

Figure 21. Fecal coliform bacteria loading capacity for Ohop Creek.

Table 9. Fecal coliform bacteria reductions and targets for Ohop Creek.

Site	Critical season	# of samples	Geometric mean (col/100 mL)	90th percentile (col/100 mL)	FC reduction needed to meet standards	Limiting criterion	Target value (col/100 mL)
Lynch Creek RM 6.2T	Wet	8	27	260	13%	90th percentile	200
Ohop Creek RM 6.0	Wet	16	22	264	24%	90th percentile	200
Ohop ditch at RM 2.2D	Dry	5	113	452	56%	90th percentile	200
Ohop Creek RM 0.1	Dry	4	102	383	48%	90th percentile	200

Fecal Coliform Wasteload Allocations

Stormwater discharges from Pierce County Phase I areas were not directly sampled. Lynch Creek receives stormwater from the city of Eatonville. Eatonville is not required to have a stormwater permit, and their stormwater discharge is covered under the load allocation. Stormwater best management practices, including programmatic measures, must be applied to stormwater discharge to meet water quality standards. Discharge to Ohop and Lynch creeks meet a 90th percentile fecal coliform target of 200 col/100 mL.

Red Salmon Creek

There is no seasonal critical period for Red Salmon Creek. The critical period on an annual basis is the low tide. The annual loading capacity for Red Salmon Creek at low tide is presented in Figure 22. The bacteria load allocations were calculated based on Red Salmon at RM 1.40 and RM 1.30T meeting the marine bacteria standard. Red Salmon Creek at RM 1.44 met fecal coliform freshwater standards, but Wash Creek at RM 1.42T did not.

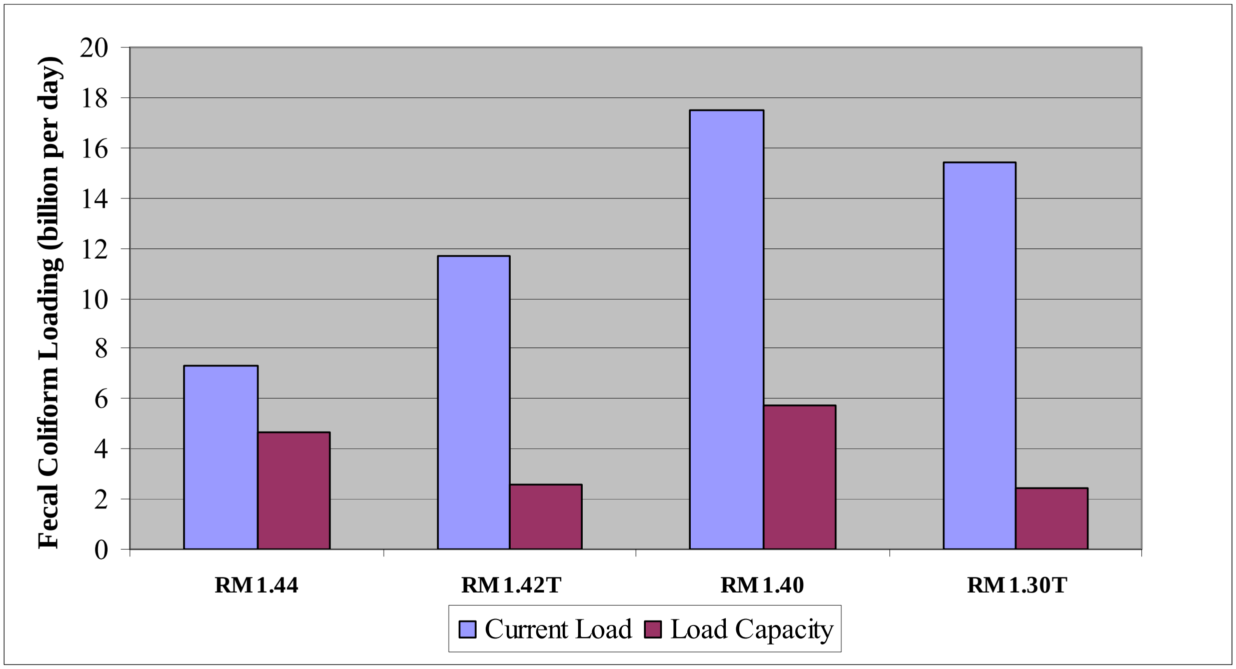

Figure 22. Fecal coliform bacteria loading capacity for Red Salmon Creek.

Even if both Red Salmon RM 1.44 and Wash Creek met the Class AA freshwater standard, Red Salmon at RM 1.40 would not meet marine standards during the low tide period because the marine criterion is more stringent. Therefore, upstream sites need to meet a more stringent water quality standard so that Red Salmon RM 1.40 can meet marine standards.

The more stringent freshwater fecal coliform criterion was derived by calculating the reduction in bacteria loading that occurs from the upstream sites (RM 1.44 and Wash Creek) to the downstream site (RM 1.40). A 10% reduction in bacteria loading occurs from upstream to downstream (n=6). At the downstream site (RM 1.40), the 90th percentile (43 col/100mL) was the limiting criteria. For equity, it was decided to set the same target bacteria concentrations for both upstream sites. If a 10% reduction in bacterial loading occurs from upstream to downstream, the upstream sites need to meet a target 90th percentile of 48 col/100 mL so that the downstream site meets marine water quality standards. Table 10 describes bacteria reductions needed for each site during the critical period.

Table 10. Fecal coliform bacteria reductions and targets for Red Salmon Creek.

Site	# of samples	Geometric mean (col/100mL)	90th percentile (col/100mL)	FC reduction needed to meet standards	Limiting criterion	Target 90th percentile (col/100mL)
Red Salmon RM 1.44	6	28	97	51%	90th percentile	48
Wash Creek RM 1.42T	6	130	285	83%	90th percentile	48
Red Salmon RM 1.40	15	25	131	37%	90th percentile	43
Unnamed Trib RM 1.30T	15	57	116	14%	90th percentile	43

McAllister Creek

Fecal Coliform Bacteria

The critical period for McAllister Creek is during low tide events when there is more freshwater input to the Nisqually Reach and Luhr Beach. The McAllister Creek mainstem also has higher bacteria levels during rain events. In accordance with state water quality standards, McAllister Creek must meet the marine fecal coliform standards at McAllister RM 3.7.

For McAllister RM 3.7 to meet marine standards, fecal coliform levels would need to be much lower throughout McAllister Creek, including the most upstream site at RM 5.8. McAllister Creek at RM 5.8 represents natural background levels with no known anthropogenic sources of fecal coliform. Upstream of RM 5.8 is a large wetland complex that extends to RM 6.3 where McAllister Springs is located. McAllister Creek at RM 5.8 meets the *Extraordinary* water primary contact recreation standard for fecal coliform, with a geometric mean of 35 col/100 mL and a 90th percentile of 98 col/100 mL.

To determine if these freshwater targets can be met at McAllister RM 4.3 with current background conditions, it was necessary to look at a flow balance and fecal coliform loading in McAllister Creek.

Fecal coliform loads in the McAllister Creek mainstem can only be estimated, due to difficulty in obtaining flow measurements. Total flow in the creek is influenced by tidal flushing, where saltwater moves upstream from Puget Sound during high tide and is released during low tide. Streamflow measurements are complicated by tidal backwater effects and associated flow reversals (Pacific Groundwater Group, 2000). Flow at the headwaters is measured at the McAllister Springs weir. Downstream from the headwaters, several springs, groundwater, tributaries, and tide gate inputs contribute to flow in the creek.

In August 2000, the consultant, Pacific Groundwater Group, conducted an intensive analysis of McAllister Creek flow to document the aquifer sources and the rates of groundwater flow (Pacific Groundwater Group, 2000). Precipitation was about 20% higher than the long-term average during the Pacific Groundwater Group study. Flow estimates to calculate bacteria loading are derived from this study.

Table 11 presents estimated flow discharge and fecal coliform loading for McAllister Creek sites based on flow estimates provided by Pacific Groundwater Group (2000). Tide gate flow discharge information was collected at low tide 1-3 times. The average of the tide gate flow data is also included in the flow balance. There are no flow data for tide gates 14, A, and B, the culvert at tide gate 11, and for several tributaries; therefore, a conservative estimate of 0.5 cfs was assigned to these tide gates for the purpose of developing a flow balance on the creek. The 90th percentile fecal coliform values were used to calculate loading.

Table 11. Estimated fecal coliform loading and reductions for McAllister Creek.

Site	Estimated flow (cfs)	90th Percentile FC (col/100 mL)	Current FC loading (billions/day)	Target FC loading (billions/day)	Estimated 90th percentile FC with reductions to meet load capacity (col/100 mL)
McAllister Springs	15.5				
Abbott Springs	7.5				
Deep groundwater inflow from upstream of RM 5.8	5.0				
McAllister RM 5.8	28.0	98	67.5	67.5	98
Tide gate 15	2.22			5.46	100
Tide gate 14	0.5			1.23	100
Tide gate 13	7.93			19.5	100
Tide gate 12	1.5			3.69	100
Little McAllister Creek and flow from TG 11	4.6			11.3	100
Culvert at TG 11	0.5			1.23	100
Tide gate 10	1.33			3.27	100
Tide gate 9	1.56			3.84	100
Tide gate 8	0.03			0.07	100
Medicine Creek at mouth	0.6			1.48	100
Tributary at RM 4.6 (LB)	0.03			0.07	100
Tributary at RM 4.42 (LB)	0.5			1.23	100
Tributary at RM 4.41 (LB)	0.5			1.23	100
Medicine Creek at mouth	0.6			1.48	100
Tributary at RM 4.34 (LB)	0.5			1.23	100
Tributary at RM 4.3 (LB)	0.5			1.23	100
Groundwater flow not accounted for by inputs above (32.2cfs - 23.4 cfs=8.8 cfs)	8.8			0.00	0
McAllister RM 4.3	60.2	123	182	125*	84
Tide gate 5	0.57			1.40	100
Tide gate 4	0.61			1.50	100
Tide gate 3	0.14			0.34	100
Groundwater (7.1cfs-1.32cfs=5.8 cfs)	5.8			0.00	0
McAllister RM 3.7	67.3	80	132		

* Loading capacity is based on McAllister RM 5.8 meeting current standards, and all tributary and tide gates meeting the Class AA fecal coliform standard.

With a natural background (RM 5.8) fecal coliform concentration of 98 col/100 mL (90th percentile) and subsequent loading value of 67.5 billion fecal coliform per day, the most downstream freshwater site at RM 4.3 could achieve a 90th percentile fecal coliform concentration of 84 col/100 mL (Table 11). This is provided that all inputs including tide gates and tributaries meet a 90th percentile fecal coliform value of 100 col/100 mL.

To determine if McAllister Creek at RM 3.7 can meet marine standards if the most downstream freshwater site at RM 4.3 met a 90th percentile fecal coliform of 84 col/100 mL, the die-off and dilution rate between the two sites (RM 4.3 and 3.7) was examined. Figure 23 presents geometric mean and 90th percentile fecal coliform concentrations for the mainstem stations on McAllister Creek; the marine and freshwater standards are included. Figure 23 shows decreasing fecal coliform values downstream of RM 4.3, with the exception of a source of bacteria between RM 3.7 and 3.1.

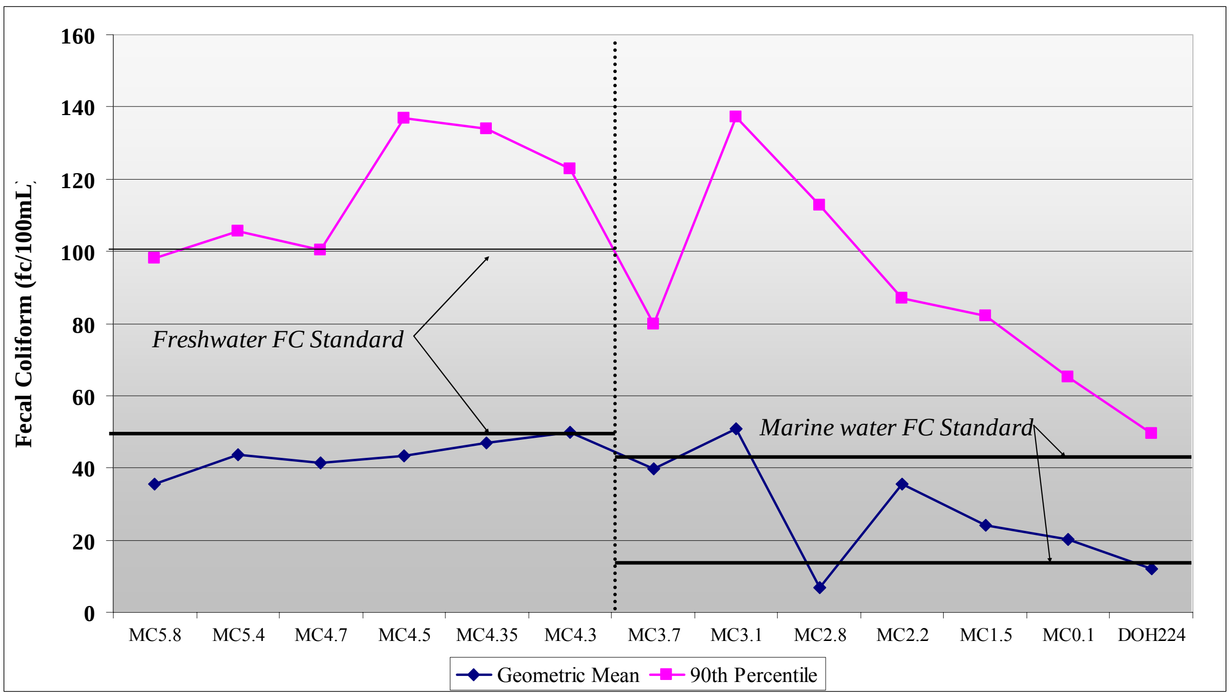

Figure 23. Mainstem geometric mean and 90th percentile fecal coliform concentrations for McAllister Creek, June 2002 - August 2003. (MC0.1 and DOH224 include data to March 2004.)

Table 11 shows that a 27% reduction in bacterial loading occurs between RM 4.3 and 3.7 (from 182 to 132 billion fecal coliform per day). Reductions in loading and concentrations are likely due to bactericidal effects and dilution from marine water.

If the freshwater site at McAllister RM 4.3 meets a 90th percentile of 84 col/100 mL, and a 27% reduction in loading occurs between RM 4.3 and 3.7, RM 3.7 could meet a 90th percentile fecal coliform concentration of 55 col/100 mL. This is slightly higher than the marine water quality standard of 43 col/100 mL. Given the natural background concentrations of bacteria in McAllister Creek, it is unlikely that McAllister Creek RM 3.7 can meet the marine standard.

Flow, and thus loading data, are not available for McAllister RM 0.1, so it is not possible to calculate downstream loading reductions. It is likely that if bacterial sources between McAllister RM 3.7 and 3.1 are cleaned-up that the downstream DOH shellfish harvesting site at RM 0.1 will meet the marine water quality standard. Table 12 describes the freshwater TMDL target for McAllister Creek at RM 4.3 and reductions needed to meet this target, as well as reductions needed at McAllister RM 0.1 to meet the marine water quality standard.

Table 12. Fecal coliform target geometric mean, 90th percentile, and percent reduction needed for McAllister Creek.

Site	Target geometric mean fecal coliform (col/100 mL)	Target 90th percentile fecal coliform (col/100 mL)	Percent fecal coliform reduction needed
RM 4.3	34	84	32%
RM 3.7	27	55	Based on RM 4.3 meeting targets
RM 0.1	14	43	34% *

* Based on DOH and Ecology TMDL sampling from July 2002 - March 2004 (n=28)

Table 13 describes bacteria reductions needed for tributaries and tide gates to McAllister Creek. Reductions are based on freshwater sites meeting a 90th percentile of 100 col/100 mL and marine sites meeting a 90th percentile of 43 col/100 mL.

Table 13. Estimated fecal coliform loading, current geometric mean and 90th percentile, and percent reduction needed to meet fecal coliform targets in McAllister Creek tributaries.

Site	Fecal coliform loading based on 90th percentile values (billions per day)	Current geometric mean fecal coliform (col/100 mL)	Current 90th percentile fecal coliform (col/100 mL)	Percent FC reduction needed to meet water quality standard
Little McAllister Creek	38.2	48	378	74%
Tide gate 13	32.8	22	168	40%
Tide gate 9	12.5	54	325	69%
Tide gate 4	7.8	36	520	81%
Tide gate 15	7.3	17	134	0%
Tide gate 5	6.4	38	545	78%
Tide gate 12	6.4	42	172	42%
Tide gate 10	4.5	20	137	27%
Tributary at RM 4.3 (LB)	3.1	51	254	61%
Culvert at TG 11	3.1	24	251	60%
Medicine Creek at mouth	3.1	59	208	52%
Tide gate 14	2.2	16	175	43%
Tide gate 2	2.1	14	51	0%
Tributary at RM 4.34 (LB)	1.2	8	99	0%
Tide gate 8	1.2	75	1615	94%
Tributary at RM 4.42 (LB)	1.2			0%
Tide gate A	**.59**	**12**	**48**	**10%**
Tributary at RM 4.41 (LB)	.48	12	39	0%
I-5 Stormwater Pipe	.41	29	212	53%
Tide gate 1	.41	84	1652	94%
Tide gate B	**.41**	**8**	**33**	**0%**
Tide gate 3	.38	22	110	9%
Tributary at RM 4.6 (LB)	.13	26	175	43%

Bold = Indicates site must meet marine bacteria standard

Current fecal coliform bacteria loading and loading capacity for McAllister Creek are presented in Figure 24. Load and wasteload allocations are included and are based on reductions described in Tables 12 and 13. The statistical rollback method was used to calculate the bacteria reductions needed to meet marine fecal coliform standards at McAllister RM 0.1, and for the TMDL targets set for RM 4.3 and 3.7.

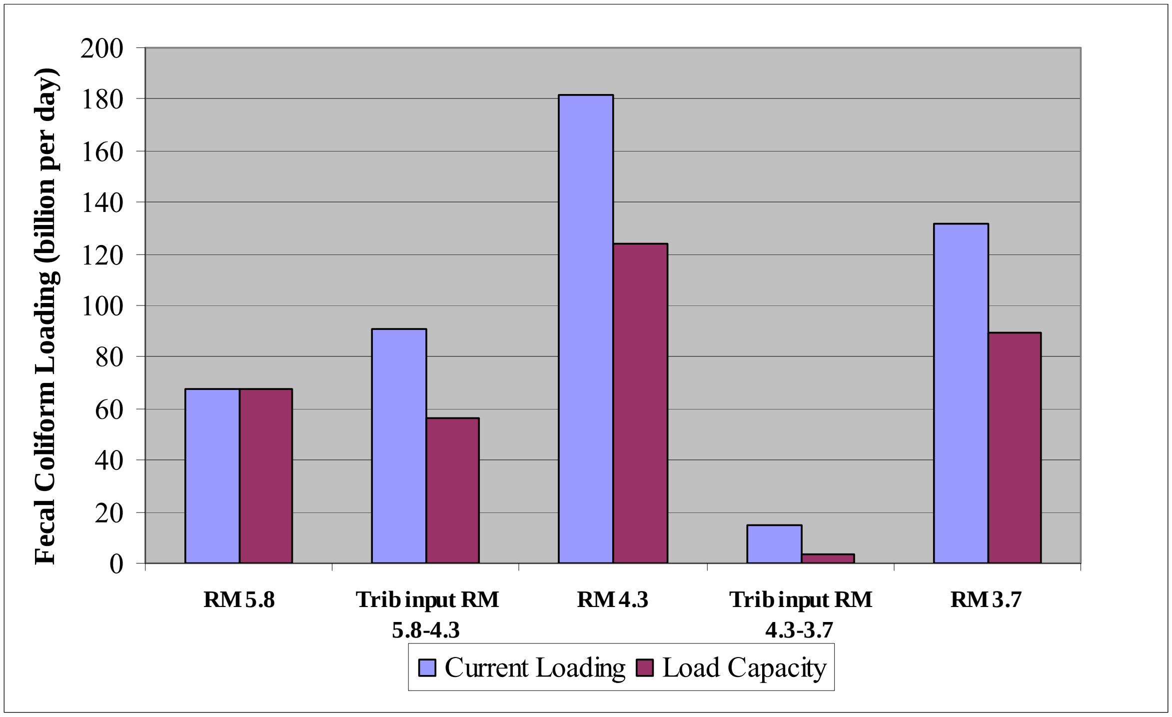

Figure 24. Fecal coliform loading capacity for McAllister Creek.

Uncertainty in Loading Estimates

To determine how natural background fecal coliform levels affect downstream fecal coliform concentrations, it is necessary to look at loading. However, there is some uncertainty associated with the loading estimates described in the section above due to the lack of flow data for McAllister Creek. The flow data used for loading estimates were obtained during a low-flow summer condition. However, precipitation was about 20% higher than the long-term average during the 2000 water year up until the flow study. Therefore, resulting dry season flow estimates shown may be about 20% higher than the long-term average, and these measurements are likely an underestimate of wet season flows.

During the current 2002-03 TMDL study, an attempt was made to measure flow in McAllister Creek; instantaneous flow measurements were obtained at RM 4.5 during several low tide events. Table 14 presents flow at RM 4.5. Note that on some days there are multiple flow values; flow measurements were obtained in sequence in an attempt to capture low tide flow. Flow measurements at RM 4.5 range from 40-93 cfs. Flows at RM 4.5 should be roughly equivalent to the McAllister RM 4.3 site described in the Pacific Groundwater Group (2000) study. The results of their study estimated a flow of 60.2 cfs at McAllister RM 4.3. Flow estimates provided by Pacific Groundwater Group for RM 4.5 are within the range of flows measured at McAllister Creek RM 4.5, but flows do vary to a great extent from season to season.

Table 14. Instantaneous flow measurements at McAllister Creek RM 4.5.

Date	Time	Flow in cfs
5/19/03	17:15	75.34
6/16/03	16:10	61.41
6/27/03	13:35	41.62
7/11/03	12:00	56.15
7/15/03	16:45	54.43
7/15/03	17:00	53.46
7/25/03	13:25	42.63
7/25/03	13:40	44.68
12/31/03	8:15	53.69
12/31/03	8:35	44.57
3/19/04	13:15	99.87
3/19/04	13:35	96.62
3/19/04	13:50	92.68

Fecal Coliform Wasteload Allocations

There are generally no sources of fecal coliform bacteria associated with a freshwater fish farm. Fecal coliform sampling showed no increases in fecal coliform bacteria above background levels. The Nisqually Trout Farm #1 wasteload allocation for fecal coliform bacteria is set at no increase above background levels.

Fecal coliform load and concentrations from Interstate-5 stormwater are described in Table 13; data for this site are included in Appendix E. The Washington State Department of Transportation (WSDOT) stormwater outfall discharges primarily during rainfall events. WSDOT must apply best management practices including programmatic measures to stormwater discharge to meet water quality standards. Stormwater discharge to McAllister Creek must meet a 90th percentile fecal coliform target of 100 col/100 mL. A 53% reduction in bacterial levels is needed to meet this target.

Stormwater discharges from Thurston County Phase II areas were not sampled for this study. Stormwater best management practices including programmatic measures must be applied to stormwater discharge to meet water quality standards. Stormwater discharge to McAllister Creek should meet a 90th percentile fecal coliform target of 100 col/100 mL.

Thurston County Environmental Health Division Nisqually Reach Pollution Source Identification

During the current 2002-03 study, Thurston County staff conducted a bacterial source tracking (BST) study using DNA ribotyping analysis. Sampling locations were chosen based on six land use categories. Water samples were collected at select tributary and tide gate sites on McAllister Creek: at the two DOH marine sites near the mouth of McAllister Creek and at Luhr Beach on Nisqually Reach. Most sampling was conducted at the same time as the TMDL sampling. *E. coli* cultures were isolated from the water samples, and the analysis of the *E. coli* DNA for source type was conducted at a private laboratory. Thurston County analyzed the results of the study and their findings are presented in the report, *Nisqually Reach Pollution Source Identification* (Thurston County, 2004).

Their conclusions include the following sources of bacteria:

- Birds are the dominant source.
- Cows are the second most frequent source in actively grazed agricultural fields.
- After birds, canine and rodents (wildlife) are predominant at sites where human activity is limited.
- Humans are the second most frequent source at residential sites.

That birds are the most dominant source means that bird DNA isolates turned up most frequently during the sampling events. Frequency means how often a particular source appeared over the course of sampling; it does not refer to the number of source isolates found in the samples. A minimum of 60 isolates were identified for each sampling event. Because of the cost of DNA source tracking, it was possible to test only a small portion of the *E. coli* isolates that were found in a water sample.

Thurston County recommendations include working with animal owners to manage animal waste, continuing to investigate the Luhr Beach neighborhood for sources accounting for the elevated bacteria levels in stormwater, and supporting improvements to the stormwater system serving the Meadows subdivision.

Dissolved Oxygen

Results

Dissolved oxygen (DO) concentrations in McAllister Creek were generally low. Appendix H Tables H-5 and H-6 summarize DO data collected during the synoptic surveys. With the exception of tide gate 1, none of the tributaries or tide gates met the *Extraordinary* water quality standards for DO. Most of the mainstem sites, with the exception of McAllister Creek RM 4.5 and 2.2, also did not meet *Extraordinary* DO standards.

Continuous DO, temperature, pH, and conductivity monitoring was conducted at McAllister Creek RM 5.8, 4.7, and 3.7 on the dates described in Table 6. Dissolved oxygen results for all sites when sampled simultaneously are presented in Figures 19, 20, and 25.

The McAllister RM 5.8 site, located at the downstream end of the wetland, generally had low DO levels. In July and August, there was a 3.5-4.7 mg/L diel range, following the normal pattern of higher DO levels during the late afternoon when plant photosynthesis is at its peak, and lowest at night when plant respiration was occurring. Temperature and DO followed the same cyclic pattern during a 24-hour period. In March, there was a 2 mg/L diel range in DO, with temperature and DO following the same pattern. There were small spikes and drops in DO due to tidal influence. In January, there was no diel variation in temperature or DO (Appendix F, Figure F-3). Dissolved oxygen levels increased slightly with higher tides.

McAllister Creek at RM 4.7 followed a similar pattern as RM 5.8, with July and August having a 3.5-5.8 mg/L diel range, and temperature and DO levels having the same pattern. Tidal influence was more notable at this site with summertime high tides causing increases in temperature and slight fluctuations in DO levels. In January, there was little or no variation in temperature and DO, with higher tides causing slight increases in DO levels. In March, there was a 2 mg/L diel range in DO. Again, temperature and DO followed the same pattern, with spikes and drops in both due to tidal influence.

Temperature and DO levels at McAllister RM 3.7 were affected by tide. March water temperatures were lower, and DO levels higher compared to upstream sites. In March, there was no noticeable diurnal pattern in DO levels. In July and August, a 3.7-5.6 mg/L diel range in DO occurred. While temperature and DO levels follow the same pattern, spikes and drops in DO levels were noted with the tide. During high tide, higher temperatures and slightly higher DO levels were seen.

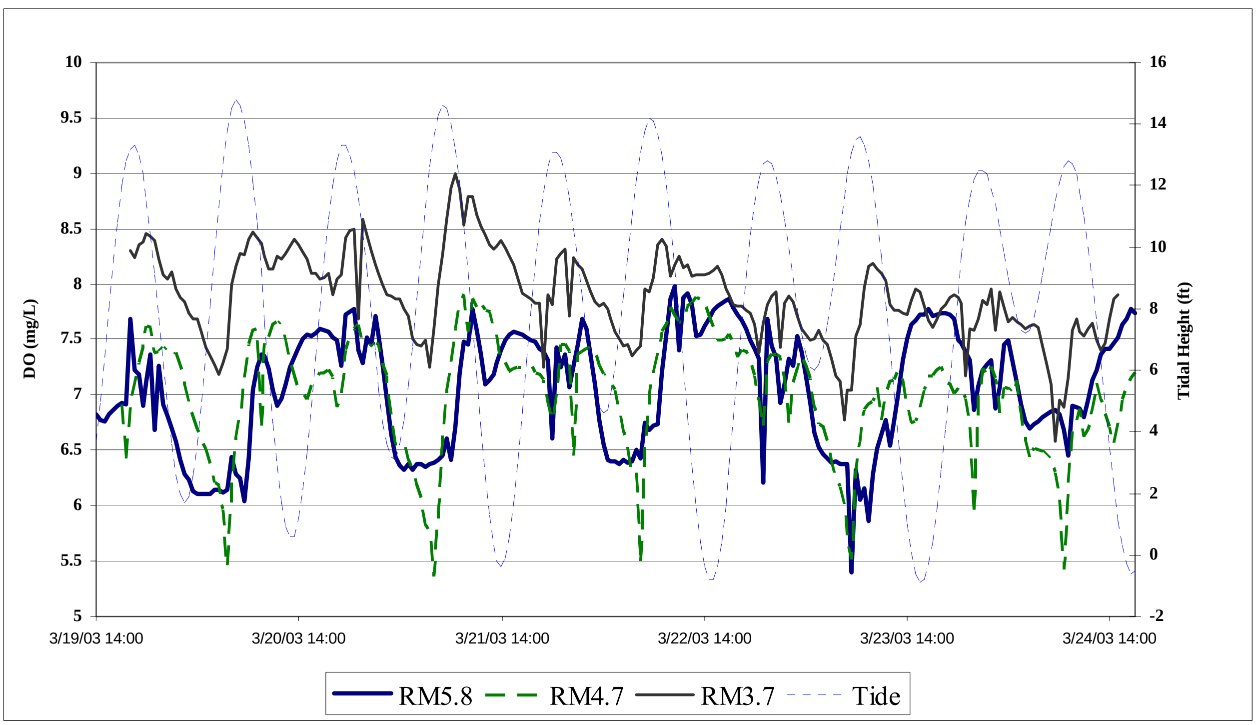

Figure 25. Continuous dissolved oxygen monitoring for McAllister Creek RM 5.8, 4.7, and 3.7, March 19 - 24, 2003.

Dissolved Oxygen Conditions in the Natural Environment

McAllister Creek is largely a groundwater fed system, and low dissolved oxygen levels in the groundwater contribute to low dissolved oxygen (DO) levels in the creek. The large upstream wetland and drainage from surrounding wet areas may contribute to already low levels of DO. Dissolved oxygen levels in wetland systems can vary seasonally, with very low DO levels in mid-summer and fall (1- 3 mg/L range) due to algae and plant decomposition after thriving during the spring and early summer. Microbes use oxygen when they aerobically decompose organic matter (Jackson Bottom Wetland Preserve, 2004).

McAllister Creek DO levels start out low, with the headwaters being fed by McAllister, Abbott, and Lodge springs. The mean DO value for McAllister Springs is about 4.9 mg/L (44% of saturation). The median DO for the wells and springs sampled in the USGS study near McAllister Springs was 4.9 mg/L, with a range of 0.10 to 9.3 mg/L. The median DO value from the three wells sampled in the current 2002-03 study was 7.3 mg/L (Appendix A).

Figures 19, 20, and 25 show that DO levels start out low at the wetland at RM 5.8. There are slight increases in DO levels downstream. The sites at RM 5.8 and 4.3 generally follow the same diurnal pattern, with greater swings in DO at RM 4.3. Dissolved oxygen at RM 3.8 is controlled largely by tidal fluctuation.

The low gradient in McAllister Creek and twice daily tidal shifts combine to form an environment that does not allow for significant reaeration. The creek has a total of 18 tide gates. Water flows out of the tide gates into the creek during low tide, but for most of the day water is contained behind a series of ditches where there is little or no water movement. The ditch system allows for little or no reaeration of water draining from the fields.

While lower DO levels are somewhat of a natural condition on McAllister Creek, excessive plant growth during the summer months may contribute to lower than natural DO levels downstream of RM 5.8. Figure 26 is a photo taken in August 2002 from the Steilacoom Road bridge (approximately RM 4.7) showing plant growth downstream of the bridge. Excessive nutrients may increase submerged plant growth in the summer months, creating low diel levels of DO and creating DO demand when plants decay (Cusimano and Ward, 1998). The addition of nutrients may have an effect on DO levels in the mainstem during the growing season, thus contributing to the already low values seen in the creek.

Figure 26. Photograph of plant growth in McAllister Creek mainstem, taken from Steilacoom Road bridge just downstream of RM 4.7.

Nutrient Sampling

The U.S. Environmental Protection Agency (EPA) provided guidance for nutrient levels in rivers and streams in our region: Nutrient Ecoregion II, level III, the Puget Sound lowlands (EPA, 2000). Table 15 summarizes the EPA guidance recommendations for rivers and streams.

Table 15. EPA nutrient guidance for Ecoregion II, level III.

Parameter (mg/L)	Number of streams sampled	Reported Values		25^{th} percentiles based on all seasons data for the decade
		Minimum	Maximum	
Total Phosphorus	133	0.0025	0.33	0.02
Total Nitrogen	37	0.08	2.6	0.24
Nitrate+Nitrite-N	129	0.01	3.7	0.08

While the EPA guidance is useful, it is not meant to be representative of estuary conditions. Much of McAllister Creek is tidally influenced and receives a twice-daily influx of marine water.

In comparison to EPA nutrient values (Table 15), McAllister Creek mainstem nutrients were generally 50-100% higher than EPA 25th percentile values (Figure 27).

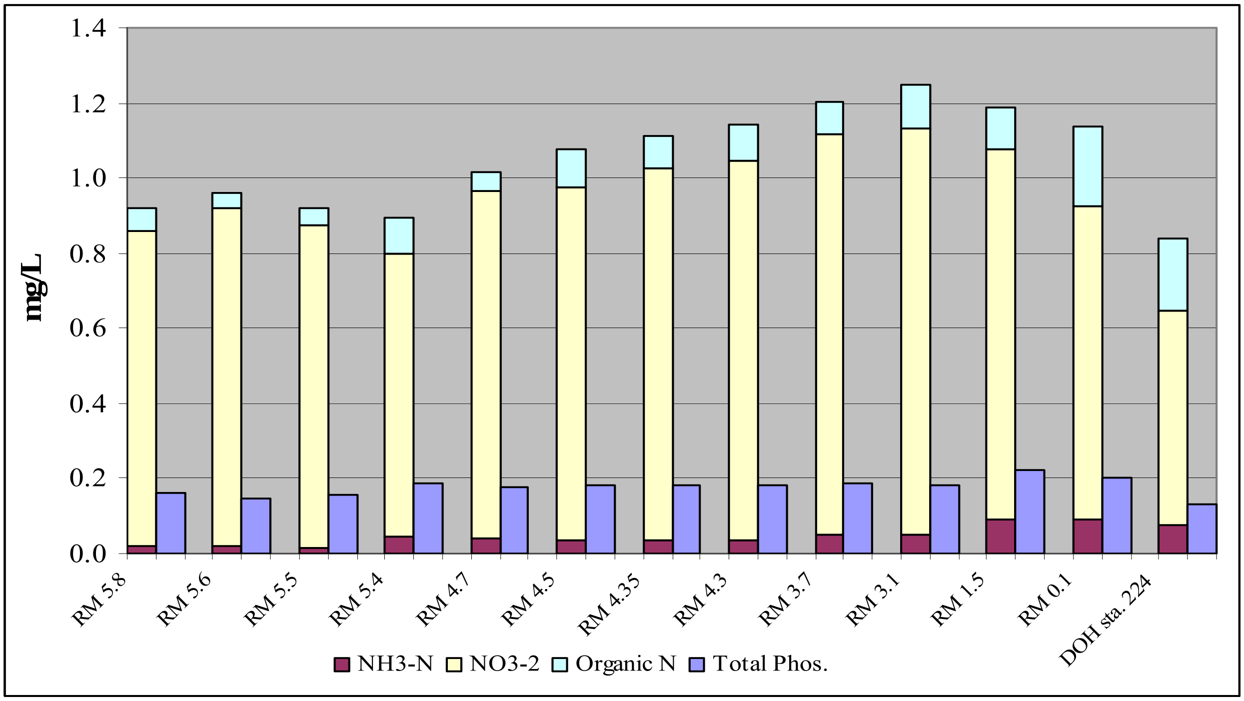

Figure 27. Nutrient levels for McAllister Creek mainstem sites.

Tributaries and tide gates also had high nitrogen and phosphorus levels, with some sites near the maximum reported values for nitrate+nitrite-N (Figures 28 and 29). Tide gate 11 (which includes Little McAllister Creek discharge), the tributary culvert near tide gate 11, the tributaries at RM 4.6, RM 4.4 (upstream and downstream), RM 4.34, RM 4.3, and Medicine Creek all had very high nitrate+nitrite-N values. All of these tributaries, with the exception of Medicine Creek, drain the west bank or west side of McAllister Creek (Figure 29). Groundwater flow near McAllister Creek is toward the creek from the west. Groundwater discharges to the western bank of the creek via seeps and springs.

Groundwater levels of nitrate+nitrite-N (NO2/3) were high, with the mean of three of the McAllister Creek area wells at 2.0 mg/L. The mean nitrate+nitrite-N concentration at McAllister Springs in the current 2002-2003 study, 1.2 mg/L, is somewhat lower than the two USGS values in 1988-89 (mean of 1.6 mg/L) but still elevated compared to surface levels. High groundwater levels of nitrogen are the biggest source of nitrogen loading to the creek.

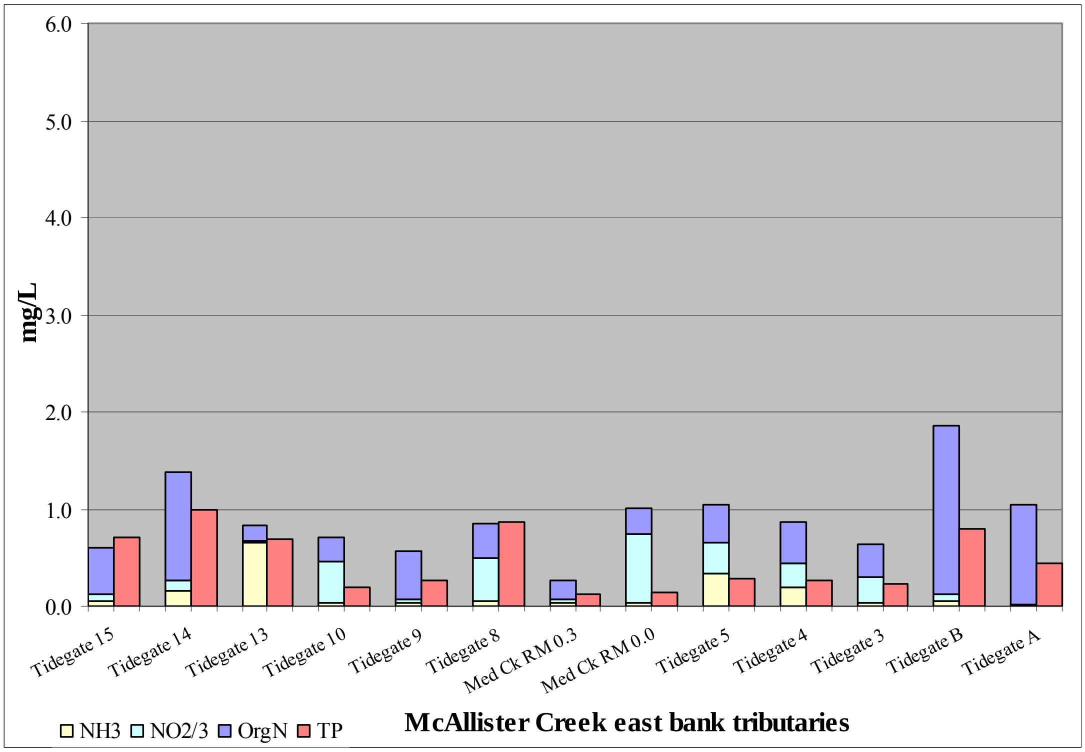

Figure 28. Nutrient levels for McAllister Creek east bank tributary sites.

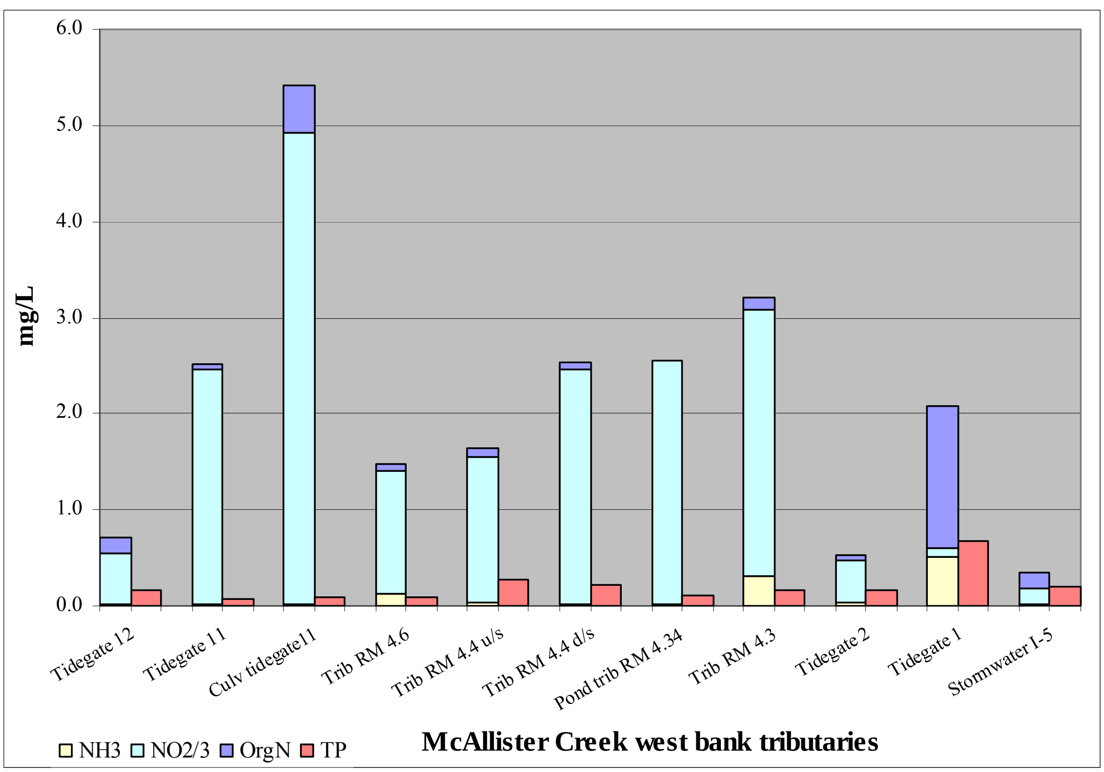

Figure 29. Nutrient levels for McAllister Creek west bank tributary sites.

The nutrients of primary importance for algal development and growth are phosphorus and nitrogen. The ratio of nitrogen to phosphorus is generally accepted as an indicator of which nutrient is more limiting to algal growth. An analysis of limiting nutrients for algal growth are described in Appendix J. The McAllister Creek mainstem had an abundance of both nitrogen and phosphorus available for algal growth. Tributaries and tide gates discharging from the east bank were generally nitrogen-limited, while tributaries from the west bank were phosphorus-limited. It is likely that the most limiting factor for plant growth in lower McAllister Creek is the toxic effect of saltwater on freshwater plants.

Load Capacity and Natural Conditions

McAllister Creek has naturally low levels of dissolved oxygen. The abundance of nutrients present in the creek likely contributes to increased submerged plant growth in the summer months, creating low diel levels of dissolved oxygen and creating oxygen demand when plants decay. To determine if nutrients could be contributing to excessive plant growth in the creek, a mass balance was performed using nutrient concentrations and loading at McAllister RM 5.8 as the natural or background condition. As mentioned earlier, McAllister Creek RM 5.8 is at the downstream end of a large wetland complex that is not diked or drained as is the creek downstream. Results of the mass balance are presented in Appendix J. Both total phosphorus and nitrogen inputs occurred above natural background levels seen at RM 5.8. While some nitrogen and phosphorus inputs are natural, some are clearly from anthropogenic sources.

High groundwater levels of nitrate+nitrite-N are the primary source of nitrogen to McAllister Creek. Groundwater nitrate+nitrite-N levels vary, with lows of 1.2 mg/L seen at McAllister Springs to highs of 3-3.5 mg/L seen at a spring flowing to the trout farm near RM 4.3. Pre-development groundwater data for nitrogen are not available, so it is difficult to determine if these nitrogen levels are natural or due to impacts from anthropogenic sources.

Phosphorus is greatly affected by sediment oxygen levels. When oxygen levels drop, dissolved phosphorus can be released into the sediment pore waters where it is free to diffuse into the overlying water (Appendix J). Lower dissolved oxygen levels found in some of the ditches behind tide gates could contribute to higher phosphorus levels.

Human and animal wastes contain substantial amounts of phosphorus and nitrogen (Chapra, 1997). In areas where high bacteria levels are seen, there are associated releases of nutrients.

No load or wasteload allocations will be given in this report for dissolved oxygen or nutrients due to the difficulty in differentiating between natural and anthropogenic sources of nutrients. Recommendations for nutrient controls are included in this report. As per the Washington State Water Quality Standards, dissolved oxygen levels at McAllister RM 5.8 represent natural water quality conditions and shall constitute the dissolved oxygen water quality criteria for McAllister Creek.

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 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 simple mass-balance calculations for Red Salmon Creek and subsequent derivation of target values in freshwater assume no fecal coliform die-off. Mass-balance calculations for fecal coliform from Red Salmon Creek also disregarded die-off and dilution in the marine waters.

- To be conservative, when determining reduction rates due to dilution and die-off for the lower reaches of McAllister Creek (RM 4.3 to 0.1), reductions in tide gates and tributaries along this reach were not factored in when calculating target bacteria concentrations at McAllister RM 3.7 and 0.1.

- Low dissolved oxygen levels are largely a natural condition, but to be conservative, recommendations are included for nutrient reductions as well as for investigating the sources of high nitrate+nitrite-N levels in groundwater.

TMDL Schedule and Monitoring

Schedule

The TMDL process allows an iterative approach to improving water quality when nonpoint sources predominate. However, the Department of Ecology (Ecology) is responsible for achieving compliance within a reasonable schedule. The compliance targets are calculated using the best available data, but the interpretation of the data is 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 action 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 Nisqually Shellfish Protection District Stakeholder Group, the Nisqually River Council, and other local initiatives. The Stakeholder Group makes bacteria clean-up recommendations to the Thurston County Commissioners for the Nisqually 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:

Nisqually River and Reach

- DOH stations
- Nisqually River at RM 3.4
- Sequalitchew Creek at mouth

Ohop Creek

- Ohop Lake at outlet
- Lynch Creek at RM 6.2T
- Ditch at Peterson Road (RM 2.2T)
- Ohop Creek at RM 3.3
- Ohop Creek at mouth (RM 0.1)

Red Salmon Creek

- Unnamed tributary to Red Salmon (RM 1.3T)
- Red Salmon at Mounts Road (RM 1.4)

McAllister Creek

- DOH stations
- Little McAllister Creek near mouth
- Medicine Creek near mouth
- McAllister Creek at Steilacoom Road (RM 4.7)
- McAllister Creek upstream of Martin Way (RM 3.7)
- McAllister Creek downstream of Interstate-5 (RM 3.1)
- Tide gates after best management practices are in place

Dissolved Oxygen

Dissolved oxygen monitoring should be included at the following sites:

McAllister Creek

- Nisqually Trout Farm #1
- McAllister Creek at RM 5.8
- McAllister Creek at Steilacoom Road (RM 4.7)

Monitoring Schedule

A complete evaluation of the TMDL follow-up monitoring data should be conducted in 2009, after five years of data have been collected. Within five years, the bay should meet *Extraordinary* marine standards, the river should meet the TMDL bacteria target, and the ditches should meet *Extraordinary* freshwater standards for fecal coliform bacteria.

Conclusions and Recommendations

Nisqually River and Nisqually Reach

Conclusions

Historically, the Washington State Department of Health (DOH) found water quality violations near the mouth of the Nisqually River. No flow monitoring, and only minor nutrient monitoring, have occurred within the 55-square-mile watershed.

While the Nisqually River and McAllister Creek have been monitored regularly, no extensive monitoring has occurred on Sequalitchew Creek. Given the proximity of the Sequalitchew Creek mouth to the Nisqually Flats, high bacteria levels in the creek could significantly influence water quality within the shellfish beds, as indicated by the DOH monitoring stations.

Recommendations

- Begin regular monitoring of Sequalitchew Creek for fecal coliform bacteria; coordinate this work with the town of Dupont and the Fort Lewis Military Reservation.
- Test septic systems east of the Nisqually Flats and near Hoffman Hill. Any future developments should be subject to intensive septic design review.
- The Nisqually River and Nisqually Reach should be reclassified from the current Category 5 on the 303(d) list to Category 1, *Meets Tested Standards.*

Ohop Creek

Conclusions

Ohop Creek upstream of Ohop Lake met water quality standards for fecal coliform bacteria. Just below the lake, Ohop Creek RM 6.0 did not meet water quality standards during the wet or dry season. Stormwater from the city of Eatonville drains to Lynch Creek. This could be the cause of higher wet-season bacteria levels in Lynch Creek and at Ohop Creek RM 6.0.

Recommendations

- Stormwater sources on Lynch Creek should be investigated.
- Dry season sources of bacteria should be investigated upstream from the outlet of Ohop Lake to RM 3.3.
- While bacteria levels improve from Ohop Creek RM 3.3 to the mouth, agricultural sources should be investigated along the ditch that parallels Ohop Creek downstream of RM 3.3.

Red Salmon

Conclusions

Livestock grazing occurs in the areas that drain to the lower portions of Red Salmon Creek and Wash Creek.

Recommendations

- Livestock should be excluded from waterways and wet areas year-round.
- On-site sewage treatment systems adjacent to Wash Creek should be investigated.

McAllister Creek

Fecal Coliform Bacteria

Conclusions

McAllister Creek RM 5.8 to 5.4

Increases in bacteria concentrations occurred between RM 5.8 and 5.4. McAllister Creek RM 5.8 met fecal coliform standards, and there were no known anthropogenic sources upstream. The McAllister Springs facility located at the headwaters of the creek is fenced with a grassy lawn adjacent to the creek. It is possible the open grassy area adjacent to the creek could attract geese.

Possible inputs in this reach include sources between tide gates 13-15. Tide gate 15 met fecal coliform standards and had the highest dissolved oxygen levels of the three tide gates. Tide gate 13 had the highest bacterial concentrations and loading and the lowest dissolved oxygen levels.

McAllister Creek RM 5.4 to 4.7

Possible bacterial sources between McAllister Creek RM 5.4 and 4.7 included tide gates 9-12, and a culvert discharge near tide gate 11. Little McAllister Creek flows out of tide gate 11 and is the source of the majority of bacterial input from tide gate 11. This tide gate had the highest dissolved oxygen levels of the tide gates, again due to well-aerated flow from Little McAllister Creek. Both tide gate 11 and the culvert drain near tide gate 11 had very high nitrate+nitrite-N levels.

Little McAllister Creek drains the Meadows subdivision. Thurston County bacterial source tracking (BST) (Thurston County, 2004) results showed that when fecal coliform levels are greater than 50 col/100mL, the most frequently found sources are human, avian, and canine, in that order.

Tide gate 9 had the second highest bacterial loading and very low dissolved oxygen levels; this area is a high priority for agricultural best management practices (BMPs). Agricultural BMPs also are needed for areas drained by tide gate 10 which also had low dissolved oxygen levels.

The west bank culvert near tide gate 11 had high bacterial levels at times and had the highest concentrations of nitrate+nitrite-N. This culvert drains a wet area and possibly receives drainage from the upland bluff area or from a groundwater seep. While very little flow discharges from this area, high nitrogen levels at this site may contribute to plant growth in the creek and to low dissolved oxygen levels.

McAllister Creek RM 4.7 to 4.5

This reach includes residential housing served by on-site sewage treatment systems along the west bank and agricultural areas along the east bank. There was a noticeable increase in bacteria levels in this reach. While slightly elevated levels of bacteria were found occasionally in some tributaries or seeps sampled on the west bank, no area stood out. Tributaries along this bank had high nitrate+nitrite-N levels. Dissolved oxygen levels increased slightly in this reach, meeting marine standards at RM 4.5.

Tide gate 8 is near the upstream end of this reach. While tide gate 8 had higher bacteria concentrations, very little flow discharged from this tide gate. Often water behind the tide gate is stagnant. While high concentrations are sometimes seen at tide gate 8, loading from this area is likely quite low. It is possible that downstream pollution sources could influence this reach, especially Medicine Creek.

McAllister Creek RM 4.5 to 4.3

Bacterial sources in this reach include Medicine Creek and various groundwater seeps. Bacterial concentrations did not increase in this reach, likely due to dilution from numerous groundwater sources in this area. Medicine Creek, a tributary in this reach, was sampled upstream at RM 0.3 and at the mouth. The upstream Medicine Creek site met water quality standards but the mouth site did not. In addition, nitrate+nitrite-N increased in this reach. Therefore, there is a source of bacteria and nitrogen input between RM 0.3 and the mouth.

McAllister Creek RM 4.3 to 3.7

This reach must meet the freshwater fecal coliform standard, and the station at McAllister RM 3.7 must meet the marine standard. Bacterial levels drop in this reach due to marine water influence and dilution by marine water and groundwater.

Possible sources in this area include discharge from tide gates 3-5. Bacteria levels in these tide gates have improved since historical levels, but none of the tide gates met water quality standards for fecal coliform. Tide gate 5 and 4 are the highest priorities for agricultural BMPs; both of these sites also had the lower dissolved oxygen levels. Tide gate 3 bacteria levels are improving and near meeting fecal coliform standards. All three sites tend to have higher bacteria levels during the dry summer period.

Nisqually Trout Farm #1 is located at the end of a remnant channel of McAllister Creek at approximately RM 4.1 on the west bank. The trout farm could have an impact on McAllister Creek dissolved oxygen levels due to nutrients in the fish food.

McAllister Creek RM 3.7 to 3.1

Increases in bacteria levels were seen in this reach. Located in this reach is a large commercial development including a recreational vehicle (RV) park, stormwater discharge from Interstate-5 (I-5), and tide gates 1 and 2. Tide gate 1 drains the RV park area and often has high bacteria concentrations, but there is very little water in the ditch behind this tide gate and it is often stagnant.

Thurston County tested both stormwater from Martin Way and I-5 for possible sources (Thurston County, 2004). Seven out of 16 isolates tested at this site were unknown (not in the source library). Birds were the most frequently seen, followed by rodents and canines.

On September 22, 2004, field staff walked the dike trail path which extends for approximately 500 feet on either side of the entrance to the RV Park. Staff counted 63 piles of what appeared to be dog feces along the dike trail which is adjacent to McAllister Creek. This path is used for fishing access to McAllister Creek and for exercising pets.

McAllister Creek RM 3.1 to RM 0.1

Bacteria levels drop in this reach due to dilution and the effects of marine water. Tide gates A and B in this reach either meet or are close to meeting marine water quality standards.

Department of Health Stations 234 and 224

Thurston County conducted BST analysis at two DOH stations: at the mouth of McAllister Creek and near Luhr Beach. At the mouth of the creek, avian sources were seen most frequently, then rodent, unknown, canine, and human, in that order. Other sources were not seen as frequently. For the station near Luhr Beach, avian was the most frequently seen source, then canine, rodent, unknown, bovine, and human, in that order (Thurston County, 2004).

During this 2002-03 TMDL study, Thurston County also sampled drainage from the Luhr Beach residential area near DOH station 224. A drainage system, including underground stormwater pipes and roadside ditches, serves the neighborhood. Bacteria levels at the Luhr Beach site were very high, with a geometric mean of 1,264 col/100 mL and a 90^{th} percentile of 35,800 col/100 mL. Sources identified in the Thurston County study were similar to those seen at the Luhr Beach marine station, with frequency of sources in order being avian, canine, human, and unknown (Thurston County, 2004).

McAllister Creek RM 5.8 to 3.1

A potential source of bacteria along this entire reach is fisherman during salmon runs on the creek. The only bathroom facilities available are in the commercial area near I-5. Fisherman often access McAllister Creek via the Steilacoom Road bridge at RM 4.7, and no bathroom facilities are available in this area.

Recommendations

Recommendations for fecal coliform in McAllister Creek are detailed below. Priority areas are based on estimated fecal coliform loading as well as bacteria concentrations described in Table 13.

- Investigate possible bacterial sources in the Meadows subdivision that drain to Little McAllister Creek and support improvements to the Meadows subdivision stormwater system (Thurston County, 2004).
- Continue to work with the Luhr Beach neighborhood for solutions to high bacteria levels, including on-site sewage treatment system surveys and pet waste education.
- Limit animal access to ditches and waterways that drain to tide gates and to McAllister Creek, with priority areas as tide gates 9, 13, 12, 4, and 5 (in that order).
- Re-vegetate along the McAllister Creek riparian area, with the first priority being the McAllister Springs area, to discourage congregation of wildlife along the creek bank.
- Install a pet waste station along the McAllister Creek dike path near the RV Park.
- Install portable toilets during the fishing season at creek access points (Steilacoom Road and Martin Way).
- Inspect on-site sewage treatment systems in residential areas between McAllister RM 4.7 and 4.5, and between Medicine Creek RM 0.3 and mouth.

Dissolved Oxygen

Conclusions

While low dissolved oxygen levels in McAllister Creek are largely a natural condition, high nutrient levels may exacerbate the already low dissolved oxygen levels.

High nitrogen concentrations in McAllister Creek are likely from groundwater feeding into the creek in the form of nitrate+nitrite-N and from several of the west bank tributaries. Many of the west bank tributaries are groundwater fed. Additional nutrient sources include animal and human waste inputs which also contribute fecal coliform bacteria. Application of fertilizers to residential lawns and agricultural land also may contribute nutrients.

McAllister Creek had low dissolved oxygen levels due to natural conditions in the creek. It is not possible to quantify the extent that anthropogenic sources contribute to the low dissolved oxygen levels.

Recommendations

While load allocations for nutrients are not feasible, recommendations for actions to improve dissolved oxygen levels in McAllister Creek are listed below:

- Investigate possible widespread changes in groundwater nitrate concentrations in the McAllister Creek basin.
- Investigate possible anthropogenic sources of nitrogen to groundwater along the west bank of McAllister Creek, including inputs from on-site sewage treatment systems and fertilizer use.
- Apply fertilizers at agronomic rates, with no-application buffer zones adjacent to waterways.
- Implement measures to control bacterial sources as a means of controlling both nutrient and bacterial sources to the creek.
- Use dissolved oxygen levels at McAllister Creek RM 5.8 as freshwater dissolved oxygen criteria for McAllister Creek.

Temperature and pH

Conclusions

Higher temperatures detected in the lower reaches of McAllister Creek are likely due to natural conditions. Many of the tributaries and tide gates that flow into McAllister Creek did not meet temperature standards. This TMDL study did not attempt to address temperature issues for McAllister Creek.

Recommendations

- Tributaries and tide gates that do not meet temperature criteria should be placed on the 303(d) list for temperature.
- A TMDL for temperature should include the tributary impacts to McAllister Creek.
- McAllister Creek should not be placed on the 303(d) list for temperature.
- McAllister Creek should not be placed on the 303(d) list for pH, since slightly lower pH values are due to natural conditions.

References

Adams, Angela. 2004. Personal communication via e-mail. King County Department of Natural Resources, Seattle, WA.

Albertson, S.L., K. Erickson, J.A. Newton, G. Pelletier, R.A. Reynolds, and M.L. Roberts. 2002. South Puget Sound Area Water Quality Study, Phase 1. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-021. http://www.ecy.wa.gov/biblio/0203021.html

APHA, AWWA, and WEF. 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, American Water Works Association, and Water Environment Federation. United Book Press, Inc. Baltimore, MD.

Aroner, E. 2001. WQHYDRO, Water Quality/Hydrology Graphics/Analysis System. PO Box 18149, Portland, OR. earoner@earthlink.net.

Carroll, J. and G. Pelletier. 1991. Diagnostic Study of Lake Sawyer, King County, Washington. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA. Publication No. 91-e05.

Chapra, Steve. 1997. Surface Water Quality Modeling. Lecture 28: The Eutrophication Problem and Nutrients. McGraw Hill, USA.

Cleland, Bill. 2000. Sanitary Survey of the Nisqually Reach Conditionally Approved Commercial Shellfish Growing Area. Washington State Department of Health, Office of Shellfish Programs, Olympia, WA.

Cusimano, C. and W. Ward. 1998. Rocky Ford Creek TMDL Study. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 98-326.

Determan, Tim. 2001. Status and Trends in Fecal Coliform Pollution in Puget Sound, Year 2000. Washington State Department of Health, Office of Food Safety and Shellfish Programs, Olympia, WA.

Determan, Tim. 2004. Personal communication via e-mail. Washington State Department of Health, Office of Food Safety and Shellfish Programs, Olympia, WA.

Dickes, Betsy. 2002. McAllister Creek Water Quality Survey for Fecal Coliform Bacteria, Total Suspended Solids, Turbidity, and Nutrients. Water Quality Program, Washington State Department of Ecology, Olympia, WA. Publication No. 02-10-017. http://www.ecy.wa.gov/biblio/0210017.html

Drost, B.W., D.M. Ely, and W.E. Lum, II. 1999. Conceptual model and numerical simulation of the ground-water-flow system in the unconsolidated sediments of Thurston County, Washington. U.S. Geological Survey Water-Resources Investigations Report 99-4165, 254 p.

Drost, B.W., G.L. Turney, N.P. Dion, and M.A. Jones. 1998. Hydrology and quality of ground water in Northern Thurston County, Washington. U.S. Geological Survey Water-Resources Investigation Report 92-4109, 230 p. + 5 plates.

EPA. 2000. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Nutrient Ecoregion II. Office of Water, U.S. Environmental Protection Agency, Washington, D.C.
Publication No. EPA 822-B-00-015.

Hetherington, Dick. 2004. Personal communication via e-mail. EPA NPDES Permits Unit, Seattle, WA.

Hruby, Tom. 2004. Personal communication. Shorelands and Environmental Assistance Program, Wetlands Section, Washington State Department of Ecology, Olympia, WA.

Jackson Bottom Wetland Preserve. 2004. Gene Pool Water Quality, Hillsboro, OR. http://www.jacksonbottom.org.

Joy, Joe. 2000. Lower Nooksack River Basin Bacteria Total Maximum Daily Load Evaluation. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-006. http://www.ecy.wa.gov/biblio/0003006.html

Kendra, Will. 1989. Quality and Fate of Fish Hatchery Effluents During the Summer Low Flow Season. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 89-17. http://www.ecy.wa.gov/biblio/8917.html

Kerwin, John. 1999. Salmon and Steelhead Habitat Limiting Factors, Water Resource Inventory Area 11. Washington State Conservation Commission, Olympia, WA.

Lee, G.F. and A. Jones-Lee. 1998. Determination of Nutrient Limiting Maximum Algal Biomass in Waterbodies, Report G. Fred Lee & Associates, El Macero, CA.

Manchester Environmental Laboratory. 2000. Lab User's Manual, Fifth Edition. Environmental Assessment Program, Washington State Department of Ecology, Manchester, WA.

Mann, Laurie. 2004. Personal communication via e-mail. Washington TMDL Program Manager. Region 10, U.S. Environmental Protection Agency.

Microsoft Corporation. 2001. Microsoft Excel 2002 (10.3207.2625). Copyright © 1985 – 2001.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands, Third Edition. John Wiley & Sons, Inc, New York, NY.

Momohara, Dean. 2005. Personal communication. Manchester Environmental Laboratory, Environmental Assessment Program, Washington State Department of Ecology, Manchester, WA. January.

Nautical Software Incorporated. 1993-1995. Tides and Currents for Windows, Version 2.1.

Ott, W. 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

Pacific Groundwater Group. 1998. McAllister Springs Wellfield-Phase II supplemental analysis of pumping effects and proposed mitigation for the City of Olympia. September.

Pacific Groundwater Group. 2000. City of Lacey McAllister Creek Seepage Inflow Study. Prepared for the City of Lacey by Pacific Groundwater Group, October 25, 2000. 10 p.

Roberts, Mindy. 2003. South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-021. http://www.ecy.wa.gov/biblio/0303021.html

Sargeant, D. 2002. Dungeness River and Matriotti Creek Fecal Coliform Bacteria Total Maximum Daily Load Study. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-014. http://www.ecy.wa.gov/biblio/0203014.html

Sargeant, D. 2004. Personal communication with Barbara Carey. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. January.

Sargeant, D., M. Roberts, and B. Carey. 2003. Quality Assurance Project Plan: Henderson and Nisqually TMDL Study. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-100. 103 p.+ appendices. http://www.ecy.wa.gov/biblio/0303100.html

Schwartz, M.L. and D.M. Hatfield. 1982. Thurston County, Washington, Net Shore-Drift. Report prepared for the Washington State Department of Ecology by Coastal Consultants, Inc., Bellingham, WA.

Thurston County Department of Water and Waste Management. 1993. McAllister/Eaton Creek Comprehensive Drainage Basin Plan. Storm and Surface Water Program, Olympia, WA.

Thurston County Public Health and Social Services. 2002. Bacteriological Contamination Source Identification, Henderson Inlet, 1999-2001. Final Report. University of Washington and Thurston County Public Health, Environmental Health Division.

Thurston County Public Health and Social Services. 2004. Nisqually Reach Pollution Source Identification Task 5: DNA Typing Analysis. Clean Water Act Section 319 Nonpoint Source Fund, Grant Number: G0200281. Thurston County Public Health and Social Services Department, Environmental Health Division, Olympia, WA.

URS Consultants. 1988. An Oceanographic Study of the Fort Lewis (Solo Point) Wastewater Outfall. Report submitted to Weyerhaeuser Company.

URS Consultants and Evans-Hamilton, Inc. 1986. Circulation and Flushing in Southern Puget Sound. Report submitted to Washington State Department of Ecology.

Washington State Department of Health. 2004. 2003 Annual Inventory: Commercial & Recreational Shellfish Areas of Washington State. Office of Food Safety and Shellfish Programs, Washington State Department of Health, Olympia, WA.

Watershed Professionals Network. 2002. Nisqually River Level I Watershed Assessment (WRIA 11) prepared for Nisqually Watershed Planning Group. Watershed Professionals Network, Envirovision GeoEngineers, Bellingham, WA.

Wetzel, R.G. 1983. Limnology. Second Edition. Saunders College Publishing, Philadelphia, PA. 767 p.

Whiley, Anthony J. and George F. Walter. 1996. Investigation of Fecal Coliform Sources within Drainage to the Nisqually Reach. Nisqually Indian Tribe, Water Quality Program, Olympia, WA. Technical Report Number 2.

Whiley, Anthony J. and George F. Walter. 1997. Identification of Pollution Sources Impacting Salmon Habitat in the Mashel River and Ohop Creek Drainages. Nisqually Indian Tribe, Water Quality Program, Olympia, WA. Technical Report Number 3.

Whiley, Anthony J., G. Walter, and T. Connor. 1994. Water Quality Investigations of the Lower Nisqually Basin 1991-1993. CCWF Grant # TAX 90187. Nisqually Indian Tribe, Natural Resources Department, Olympia, WA.

The Appendices are available at http://www.ecy.wa.gov/biblio/0503002app.html

They are linked on the web summary page.