Quality Assurance Project Plan

Henderson and Nisqually TMDL Study

by
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303(d) Listings Addressed in this Study:

Henderson Inlet (WA-13-0010) – Dissolved Oxygen, Fecal Coliform; Dobbs Creek (WA-13-1400) – Fecal Coliform, pH; Woodard Creek (WA-13-1600) – Dissolved Oxygen, Fecal Coliform, pH; Woodland Creek (WA-13-1500) – Dissolved Oxygen, Fecal Coliform; Meyer Creek (WA-13-0010) – Fecal Coliform, pH; Goose Creek (WA-13-0010) - Fecal Coliform; Nisqually Reach (WA-PS-0290) - Fecal Coliform; Nisqually River (WA-11-1010) - Fecal Coliform; McAllister Creek (WA-11-2000) - Dissolved Oxygen, Fecal Coliform; Ohop Creek (WA-11-1024) - Fecal Coliform; Red Salmon Creek (WA-PS-0290) - Fecal Coliform

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Abstract

Henderson Inlet, Nisqually Reach, and several streams in the Henderson and Nisqually basins are on the 1996 and 1998 303(d) list of impaired waterbodies due to violations of one or more water quality criteria. Both basins have tributaries that exceed the water quality standard for fecal coliform bacteria as well as some tributaries not meeting standards for pH, dissolved oxygen, or temperature.

EPA requires the states to set priorities for cleaning up 303(d) listed waters and to establish a Total Maximum Daily Load (TMDL) for each. A TMDL entails an analysis of how much of a pollutant load a waterbody can assimilate without violating water quality standards. This Quality Assurance (QA) Project Plan describes the technical study that will monitor levels of the above mentioned contaminants in the Henderson Inlet and Nisqually Reach basins and form the basis for a proposal to allocate contaminant loads to sources. The study will be conducted by Ecology's Environmental Assessment Program with assistance from Thurston County Environmental Health and Thurston Conservation District.

Introduction

Henderson Inlet, Nisqually Reach, and several streams in the Henderson and Nisqually basins (Figure 1) are on the 1996 and 1998 303(d) list of impaired waterbodies due to violations of one or more water quality criteria. Both basins have tributaries that exceed the water quality standard for fecal coliform bacteria as well as some tributaries not meeting standards for pH, dissolved oxygen, or temperature.

When a waterbody fails to meet water quality standards there is a federal requirement that the state and the United States Environmental protection Agency (EPA) establish TMDLs for all waterbodies not meeting water quality standards. Sometimes TMDLs are called Water Cleanup Plans. A TMDL includes the type, amount, and sources of water pollution in a waterbody; analysis of how much the pollution needs to be reduced or eliminated to achieve clean water; and strategies to control pollution. All TMDLs must be approved by EPA.

Ecology’s Water Quality Program selected the Henderson and Nisqually basins for TMDL assessments in 2002. The Environmental Assessment (EA) Program has been asked to design and conduct the TMDL evaluations for these basins. This Quality Assurance (QA) Project Plan summarizes historical data and findings for the basins and describes a TMDL evaluation project design. Due to differences in monitoring design, historical data, and geography, separate chapters are included in the QA Project Plan for each basin.

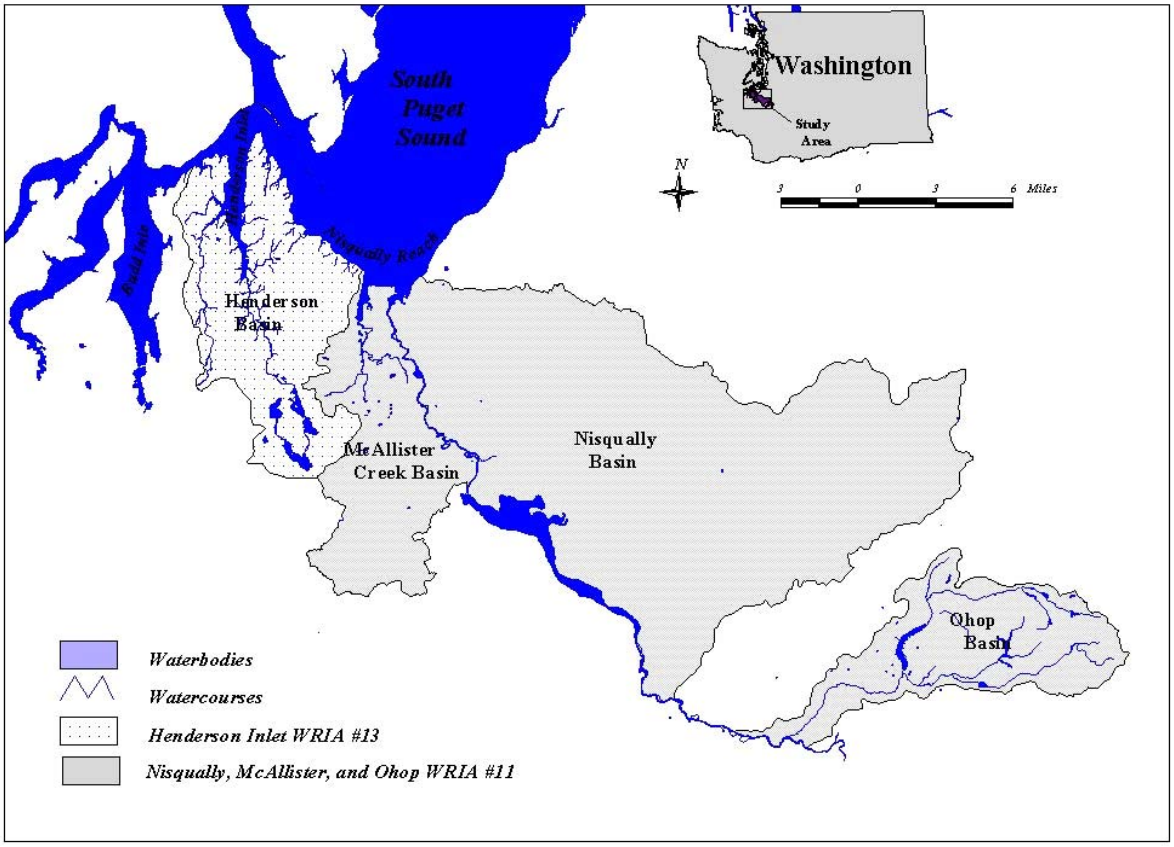


Figure 1. Study Area for the Henderson and Nisqually TMDL Study

Henderson Inlet and Tributaries

Introduction

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

This QA Project Plan describes a monitoring plan to develop a TMDL study for fecal coliform bacteria, dissolved oxygen, and pH. The temperature listings are addressed in a separate QA Plan (Zalewsky, 2002)

Table 1. Henderson Inlet and Tributaries that Do Not Meet Water Quality Standards

Waterbody	Parameter	Location	New ID #	Old ID #
Marine Water		Lat/Long		
Henderson Inlet	Dissolved Oxygen, Fecal Coliform	47.155, 122.835	390KRD	WA-13-0010
Henderson Inlet	Fecal Coliform	47.105, 122.825	390KRD	WA-13-0010
Freshwater		Township/Range/Section		
Dobbs Creek	Fecal Coliform, pH	19N 01W 28	No-ID	WA-13-1400
Sleepy Creek	Dissolved Oxygen, Fecal Coliform, pH	19N 02W 18	No-ID	WA-13-1700
Woodard Creek	Dissolved Oxygen, Fecal Coliform, pH	19N 01W 19	MJ83ZH	WA-13-1600
Woodland Creek	Dissolved Oxygen, Fecal Coliform, Temperature	18N 01W 16	JH31LN	WA-13-1500
Meyer (Snug) Creek	Fecal coliform bacteria, pH	19N 01W 20	No-ID	No-ID
Goose Creek	Fecal coliform bacteria	19N 01W 32	No-ID	No-ID

Project Description

Study Area

Henderson Inlet Basin
Henderson Inlet, located in Thurston County, is one of five inlets that form the southern terminus of Puget Sound. It is located between Budd Inlet on the west and Nisqually Reach on the east. The five-mile long inlet ranges from one-fourth to three-fourths miles in width, averaging about 25 feet in depth. A large portion of the lower inlet is exposed mudflats at low tide. Since the 1980s, commercial shellfish harvesting in the lower third of Henderson Inlet has been prohibited or restricted due to high fecal coliform bacteria levels in the water. Tidal elevations in this area (South Puget Sound) range from +16 to -4 feet from the 0 foot level (Cleland, 2000).

The 30,000 acre Henderson Inlet basin is the second largest basin in Water Resource Inventory Area (WRIA) 13 (Figure 1), Woodland and Woodard Creeks are the largest of the main tributaries to Henderson Inlet, draining 80% of the basin. The other major streams in the watershed, Dobbs Creek (East Creek), Meyer Creek (Snug Creek), and Sleepy Creek (Libby Creek), drain small areas of the Dickerson Point and Johnson Point peninsulas (Thurston County PHSS and WWM, 1995).

Woodland Creek
Woodland Creek, the largest creek draining to Henderson Inlet with an area of approximately 29.7 square miles (76.8 square kilometers), flows through northeast Olympia and central Lacey before emptying into Henderson Inlet (Figure 2). Four lakes connected by extensive wetlands form a horseshoe-shaped chain which makes up the headwaters of Woodland Creek. Hicks Lake flows into Pattison Lake and then Long Lake; all three lie between 152 and 157 feet above sea level (USGS, 1999).

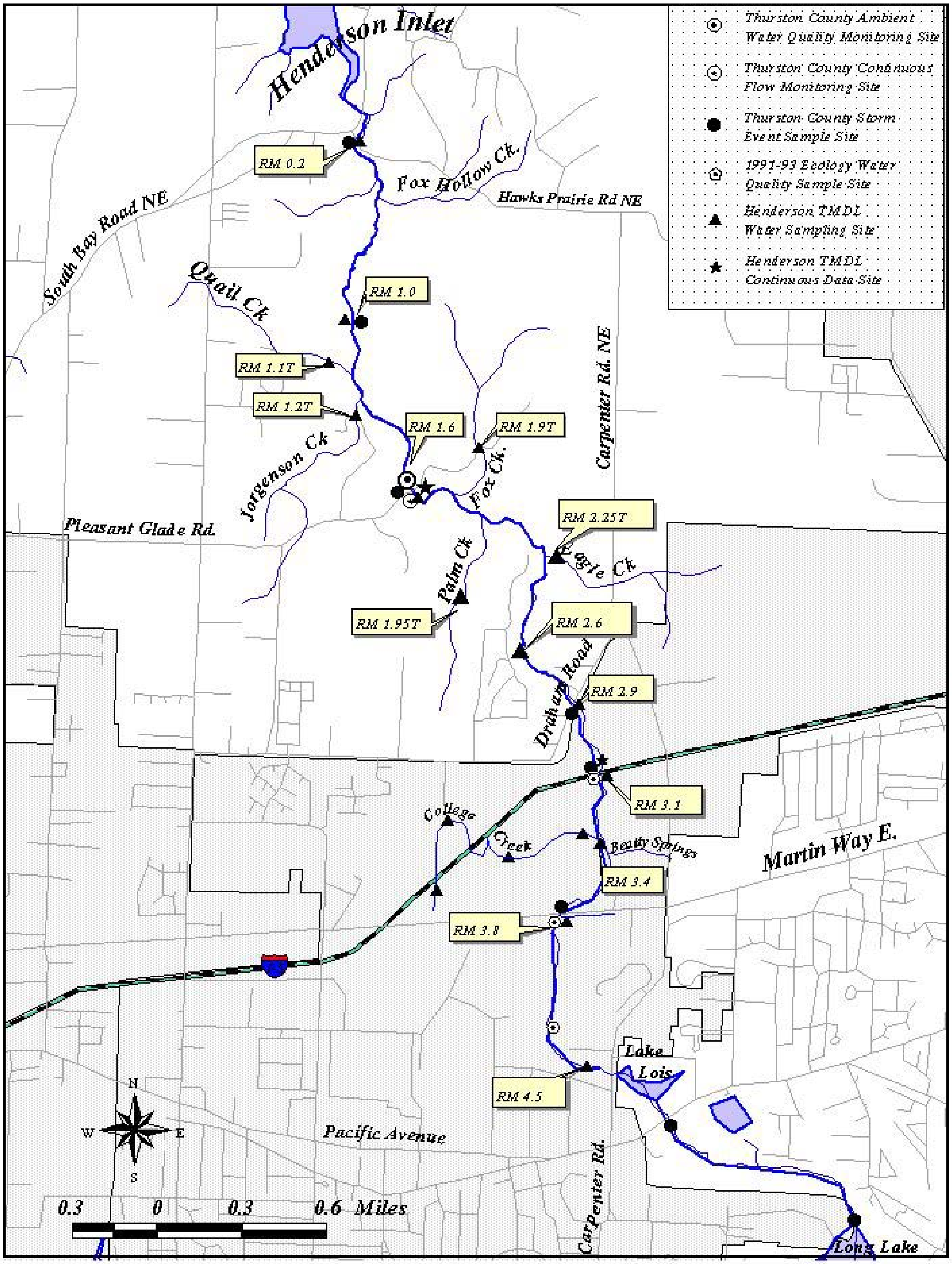


Figure 2. Woodland Creek Study Area

From Long Lake to Martin Way, Woodland Creek includes one mile of perennial stream to Lake Lois, which lies at a slightly lower elevation of about 145 feet above sea level. From Lake Lois, an intermittent channel, that often dries during the summer, flows through a narrow, steep-sided ravine through second-growth forest. Downstream of Martin Way, several springs provide perennial flow to lower Woodland Creek.

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

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

Woodard Creek
Woodard Creek, the second largest creek, is 7.5 miles in length and drains a basin of 5090 acres (Figure 3). Ground water feeds a large wetland at the headwaters of Woodard Creek just south of I-5 at the Pacific Avenue interchange. Industrial and commercial development on Fones Road surrounds the wetland at the creek's headwaters. Large portions of high density commercial areas in Lacey and Olympia, including the South Sound Mall and Olympia Square, drain into the wetland through the Fones Road ditch. The mouth of Woodard Creek is an estuarine wetland that is currently protected as a natural area by the Washington Department of Natural Resources.

Meyer Creek
Meyer Creek is approximately 1 mile in length (Thurston County PHSS and WWM, 1999). The headwaters of the creek originate in a wetland at Schinke Road and 56^{th} Avenue (Taylor, 1984). The creek flows northeast through pastureland and into Henderson Inlet at Snug Harbor approximately one mile south of Woodard Bay. Stream flows in 1984 averaged 0.19 cfs at the head to 0.46 cfs at the mouth (Taylor, 1984). Near the mouth of the creek, 1983-98 flows ranged from 0.002 - 7.44 cubic feet per second (cfs) with an average flow of 0.5 cfs. Primary land uses are rural, residential, and agricultural.

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

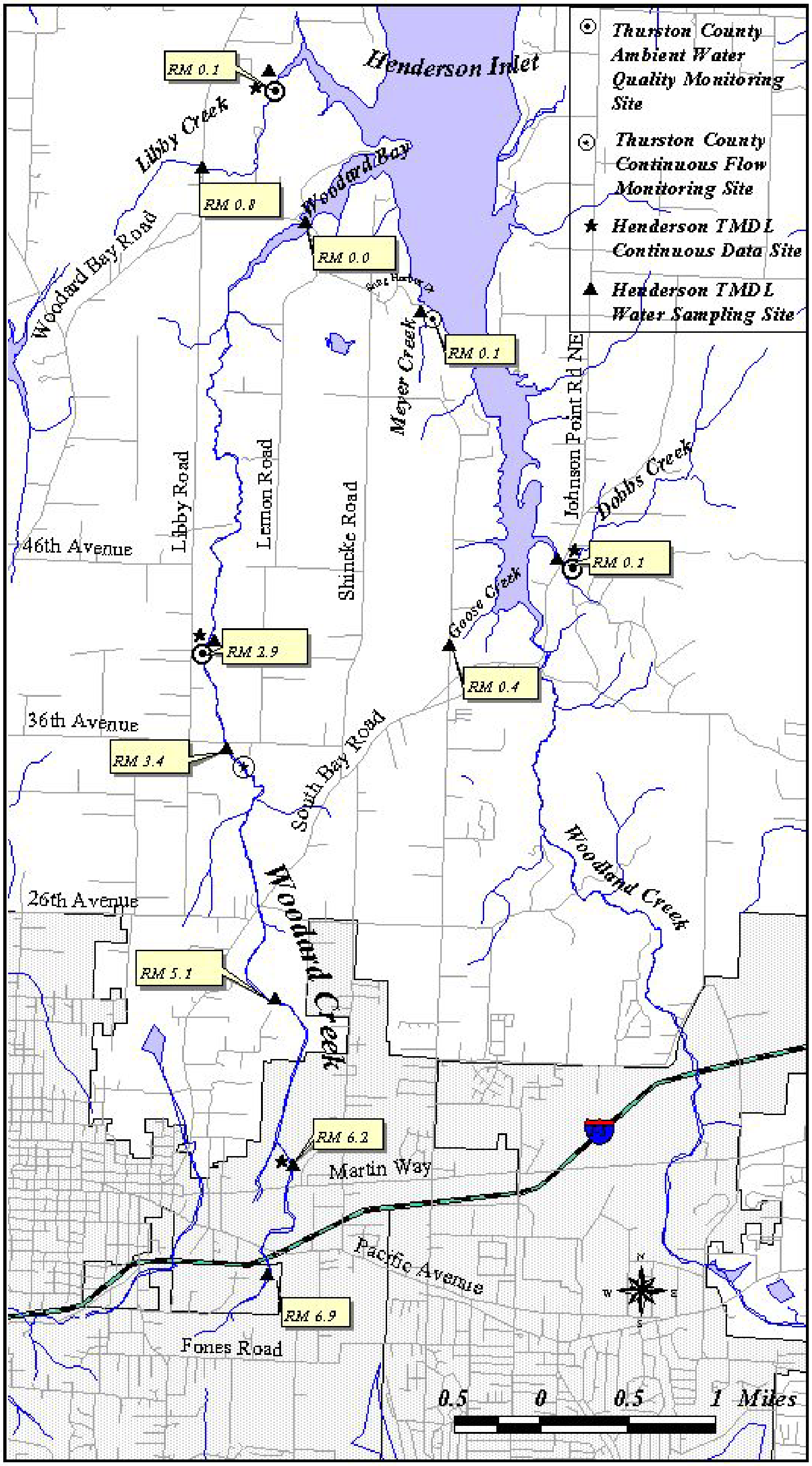


Figure 3. Woodard Creek Study Area

Dobbs Creek
Dobbs Creek is 1.5 miles in length and the primary land uses are rural, residential, and agricultural. The creek flows through wooded terrain as well as open pastures near the headwaters (Thurston County PHSS and WWM, 1999). Near the mouth of the creek, 1983-98 flows ranged from 0.3 to 16.2 cfs averaging 3.3 cfs (Thurston County PHSS and WWM, 2001). Coho and chum salmon use Dobbs Creek (Thurston County WWM, 1997).

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

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

Table 2. Salmon and Winter Steelhead Distribution for Henderson Inlet Streams

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

Henderson Inlet is one of Puget Sound's most productive shellfish harvesting areas. In 1986, more that 250,000 pounds of oysters were harvested. In 1984, the Washington State Department of Health (DOH) changed the classification of 180 acres of shellfish growing area in Henderson Inlet from Approved to Conditionally Approved, citing contamination from rural nonpoint sources. At that time, the designated area was closed to shellfish harvest for five days following a rainfall of greater than one inch in a 24-hour period. In 1985, 120 acres in the southern portion of the Conditionally Approved area was reclassified to Prohibited. In 1999, in response to declining water quality, DOH adjusted the criterion for the Conditionally Approved classification to the more restrictive 0.5" of rain in 24 hours. Based on the results of water samples collected between September 1996 and December 1999, DOH downgraded an additional eight acres of the Conditionally Approved area to Prohibited in November 2000 (Puget Sound Action Team, 2001). In 2001, an addition 300 acres of Approved shellfish growing area was downgraded to Conditional Approved (Figure 4).

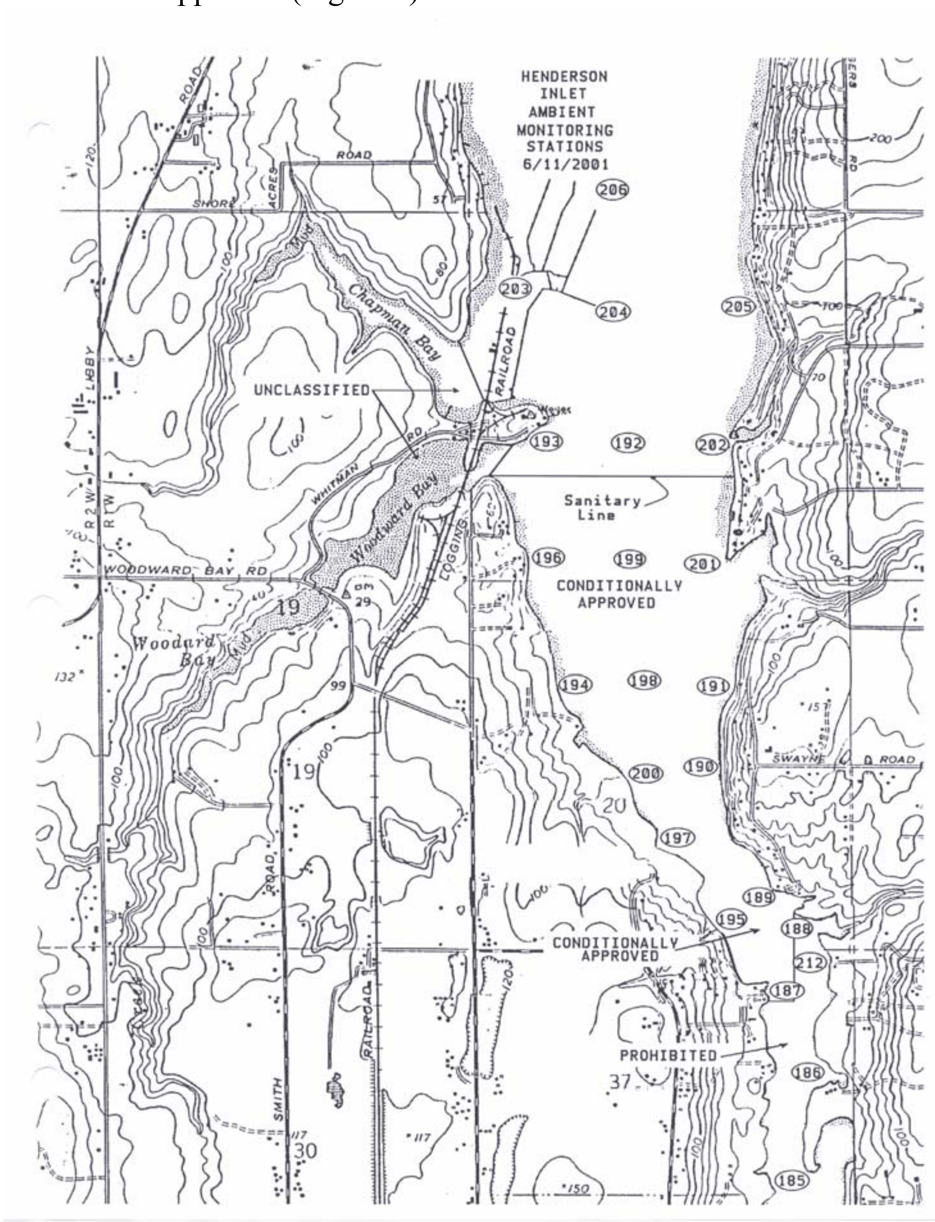


Figure 4. Washington State Department of Health Growing Area Classification and Sample Sites for Henderson Inlet

Geology (Henderson Inlet and Tributaries)
The Henderson Inlet watershed area is composed of glacially derived sediments overlying sedimentary rock. The area is located close to the southernmost extent of two glacial advances, the more recent Vashon and the earlier Salmon Springs advances. The geologic description for the study site is based on USGS (1998).

The most recent material deposited since the last glacial retreat is alluvium and deltaic deposits in the valley bottom of the Nisqually River. The uppermost glacial unit is the Vashon recessional outwash which is extensive over the study area.

A thick layer of Vashon till underlies the recessional outwash layer in most parts of the study area. This *hardpan* layer consists of poorly sorted sand, gravel, and boulders that are held in a mixture of silt and clay. Deposits of sand and gravel from melting along the edges of the Vashon glaciers make up the next oldest layer in the study area and are referred to as Vashon advance outwash.

Underlying the advance outwash lies a mostly fine-grained layer of clay and silt with smaller amounts of sand, gravel, peat, and wood referred to as the Kitsap Formation. The deepest glacial layer(s) lies below the Kitsap Formation and is composed of coarse sand and gravel and is referred to as the Salmon Springs (?) Drift and penultimate deposits (Lea, 1984).

Bedrock deposits in the study area are largely composed of sedimentary claystone, siltstone, and sandstone up to a depth of 1,800 feet below sea level (USGS, 1998 and Jones, 1996).

Hydrogeologic Units
The uppermost alluvium and recessional outwash units together are labeled Vashon recessional outwash (Qvr). This unit covers much of the study area except for occasional till-covered areas. Where present, this layer forms unconfined aquifers and drains into nearby creeks along topographic contours unless perched. The ten to fifty foot thick surficial aquifer is the source of major springs along Woodland Creek near Martin Way (USGS, 1999).

The Vashon till layer (Qvt) directly below the Qvr acts as a confining layer, preventing significant downward or upward percolation. This layer covers most of the study area and is sometimes at the surface. The Vashon advance outwash, Qva, is confined in most parts of the study area by low permeability layers above and below. The confining unit below Qva, including the Kitsap Formation and other low permeability materials, is referred to as Qf.

The deepest unconsolidated deposits in the study area, the Salmon Springs (?) Drift, penultimate deposits and similar materials, are referred to as the Qc unit. This unit is present in most of the study area and is highly used as a water source. Groundwater flow in the Qc aquifer underlying the Woodland Creek area is believed to flow easterly toward McAllister Springs rather than north along topographic contours (USGS, 1999). According to Beyerlein and Brascher (1994), most of the recharge occurring in the upper Woodland Creek basin flows to McAllister Creek or Puget Sound, completely skirting Woodland Creek.

Climate
The climate is typically maritime with cool, dry summers and mild, wet winters. Annual precipitation averages about 51 inches (Western Regional Climate Center http://www.wrcc.dri.edu/index.html). Winter precipitation typically consists of frequent, light-to-moderate intensity rainfall while summer storms produce short, moderate-to-high intensity rainfall. Winds are generally from the southwest and have a mean hourly speed of 6.5 mph. The average frost-free period is 150-200 days. Some snowfall, averaging between 10-15 inches per year in the basins, usually occurs between November and April (Thurston County WWM, 1995)

Project Objectives

Objectives of the proposed study are as follows:

- Determine maximum acceptable fecal coliform load and concentrations allowable at the mouths of tributaries to meet freshwater standards within the creek and marine water quality standards in Henderson Inlet.
- Determine the percent reductions necessary for bacteria sources to meet the above loading capacities for Woodland, Woodard, Dobbs, Meyer, and Sleepy Creeks.
- Identify the sources contributing to fecal coliform levels in Henderson Inlet. Determine the fecal coliform loads and concentrations necessary to meet marine water quality standards.
- Identify the contributors to low dissolved oxygen levels in Henderson Inlet. If low levels are due to anthropogenic sources, quantify the reductions in nutrient loading necessary to achieve marine dissolved oxygen standards in Henderson Inlet.
- Determine if low dissolved oxygen levels in Woodland, Woodard, and Sleepy Creeks and low pH levels in Dobbs, Sleepy, and Woodard Creeks are due to natural conditions; if not set load allocations for nutrients.

Sources of Pollution

Primary pollution sources include nonpoint sources such as contaminated stormwater, failing on-site systems, and animal waste (pet, agricultural, and wildlife). There is one Upland Fin-Fish General National Pollution Discharge Elimination System (NPDES) permit issued to the Nisqually Trout Farm to discharge to Woodland Creek.

Henderson Inlet Basin
Pollution sources of concern in the Henderson Inlet watershed are well documented in Thurston County's publication, *Bacteriological Contamination Source Identification* (Thurston County PHSS, 2002). The following is a summary of information from that document.

The watershed includes high-density commercial development as well as residential development with both municipal sewer service and on-site sewage systems. Fifty-five percent of the watershed is within the designated urban growth boundaries of the cities of Lacey and Olympia. Storm water from city and county road networks, as well as I-5, discharge into the two main Henderson Inlet tributaries. The city of Lacey has constructed regional stormwater treatment facilities for large storm sewer networks to mitigate pollutant loads from these systems into Woodland Creek; many stormwater outfalls continue to discharge untreated runoff. A few of the remaining large discharges to Woodland Creek include: I-5 runoff, College Street system, and the Tanglewilde at Martin Way system. Runoff from impervious surfaces that discharge to stream tributaries to Henderson Inlet may be a significant bacterial pollution source.

Septic system testing has been done for 27% of the systems located along the marine shoreline. Of those tested, 14 percent were found to be failing, with another 25% considered suspect. A residential subdivision in the Woodland Creek reach between RM 2.9 and 1.6 has been suspected of having failing on-site septic systems contributing to bacterial loading (Thurston County PHSS, 2002).

In addition to urban and residential development occurring within the Henderson watershed, large tracts of land are being converted to smaller, non-commercial farms, often with higher animal densities than the original farms. Poor farm management practices in these areas can result in manure-contaminated runoff reaching creeks and the inlet.

Water Quality Standards and Beneficial Uses

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

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]) are marine water Class AA (WAC 173-201A), which includes Henderson Inlet. Because Henderson Inlet tributaries discharge to Class AA waters, they are considered Class AA Waters. Characteristic uses for Class AA waterbodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation.

Numeric criteria for particular parameters are intended to protect designated uses. However, criteria are more stringent in AA waters such that the class shall markedly and uniformly exceed the requirements for all, or substantially all, uses.

The water quality standards are currently under revision. Changes have been suggested for dissolved oxygen and microbial pathogens' (currently represented by the fecal coliform group) numerical standards. The proposed standards apply to all waters used for primary contact recreation rather than distinguishing classes. Current and proposed standards are listed in Appendix A for each parameter of concern in the Henderson Inlet and tributaries.

Historical Information Review

Several organizations have performed hydrographic and water quality studies in areas affecting the freshwater and marine waters to Henderson Inlet.

Henderson Inlet Marine Data

Department of Health Shellfish Monitoring (Determan, 2001)
DOH monitors 20 stations in Henderson Inlet under its shellfish monitoring and classification program (Figure 5). For the most recently available reporting period (January 1999 – March 2000), one station was rated as bad (>43 MPN/100 ml) on all occasions.

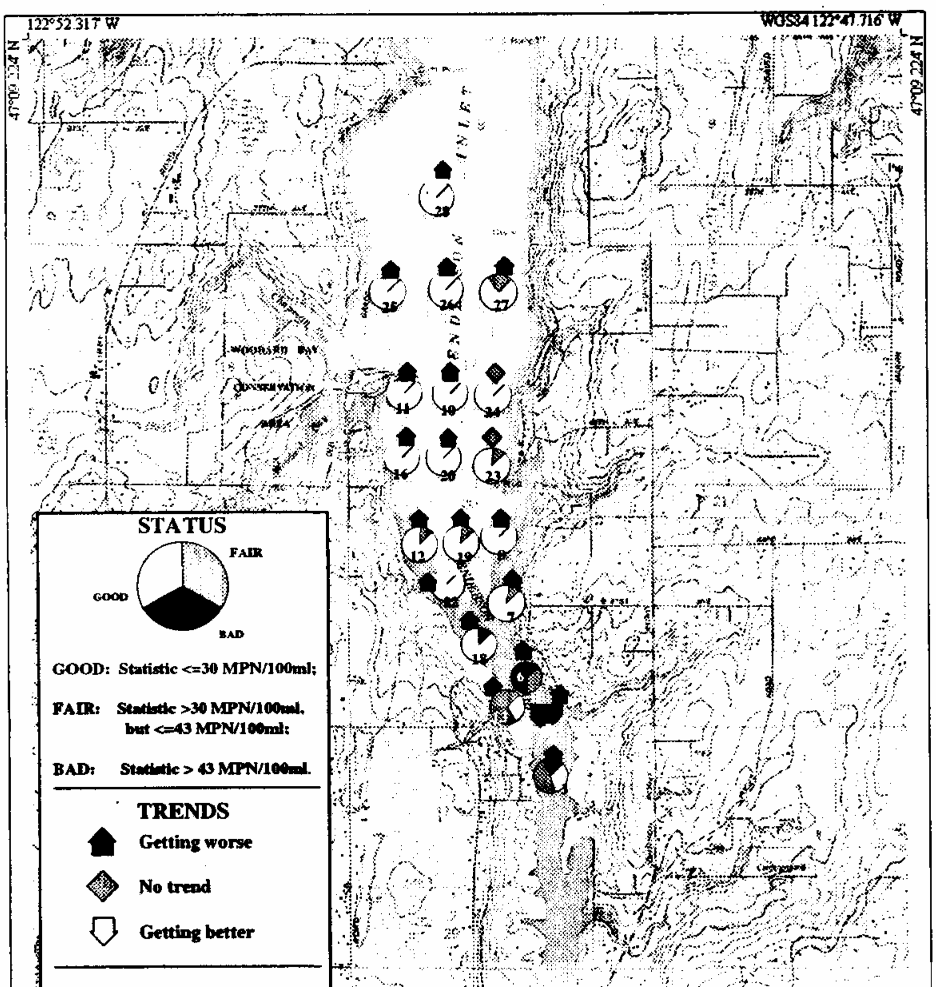
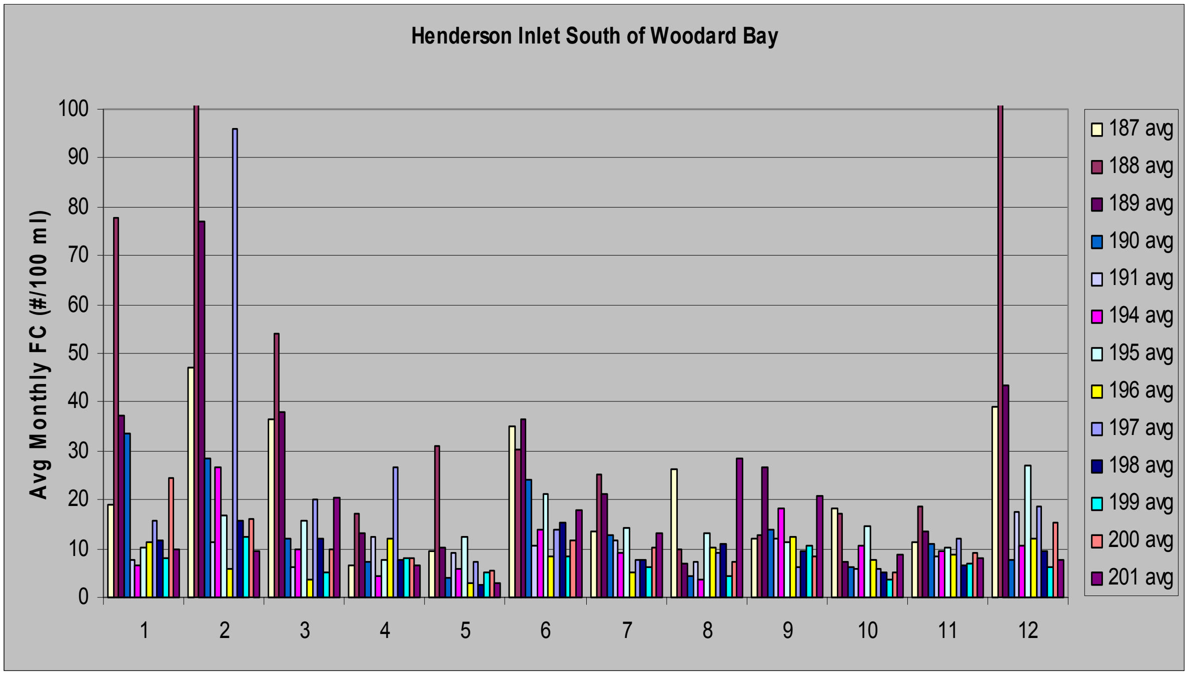


Figure 5. (DOH - 4) Henderson Inlet Bacteria Status and Trends, Based on 90th Percentiles. Status Applies to Period January 1999 through March 2000 while Trends Apply to the Entire Period of Record, 1988 through March 2000 (Determan, 2001)

Eighteen stations indicate a worsening trend over the period of record. Samples are analyzed with the multiple tube fermentation (MPN) procedure using A-1 broth (Method 9221 E; APHA et al., 1998).

Average monthly fecal coliform concentrations tend to show higher winter levels and lower summer levels (Figure 6). The stations in the southern part of the inlet exhibit higher concentrations than those located near the mouth (figure 7). DOH provided historical data in electronic format (including the station number, concentration, and tidal condition) for the present analysis. When fecal coliform concentrations were averaged for all stations and all times collected during an ebb tide, the average concentration (19.6 MPN/100 ml) was higher than that for all stations at all times sampled during a flood tide (13.8 MPN/100 ml). Average ebb tide fecal coliform exceeds average flood tide fecal coliform for all but six stations (191, 195, 196, 201, 205, and 211). On average, ebb tide fecal coliform concentrations are over 150% of the flood tide concentrations.

(A)



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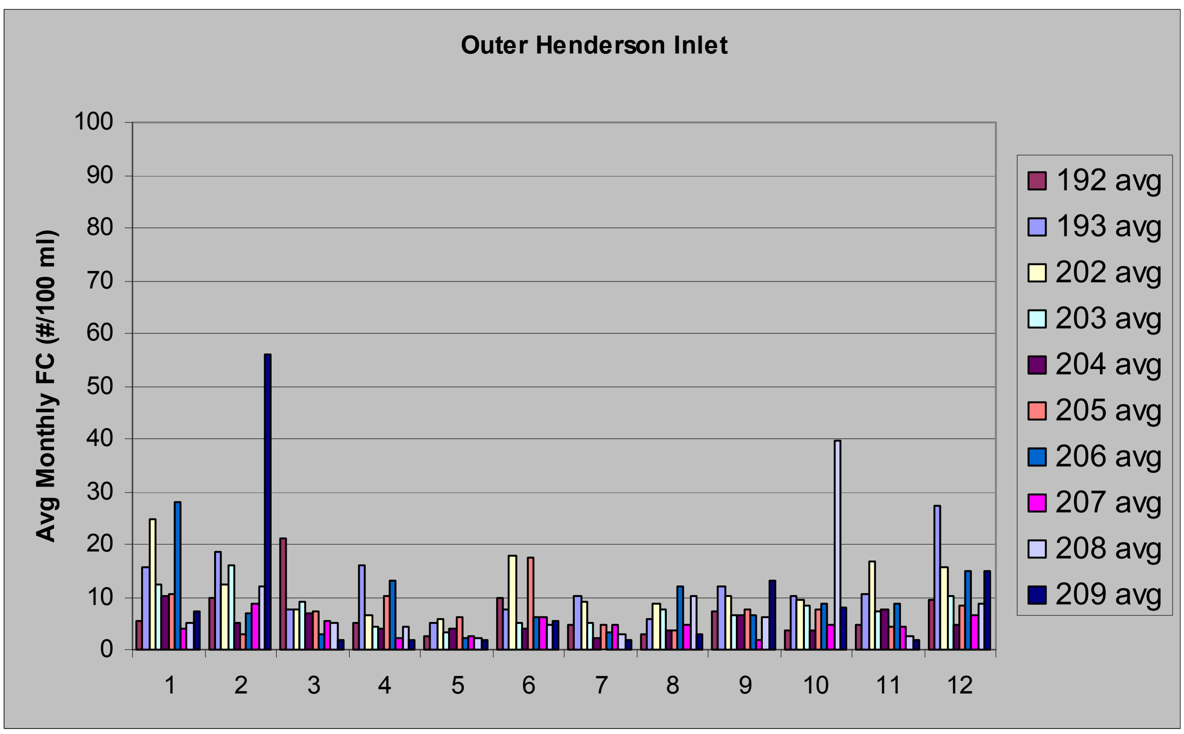

Figure 6. Average Fecal Coliform Concentration by Month South (A) and North (B) of Woodard Bay

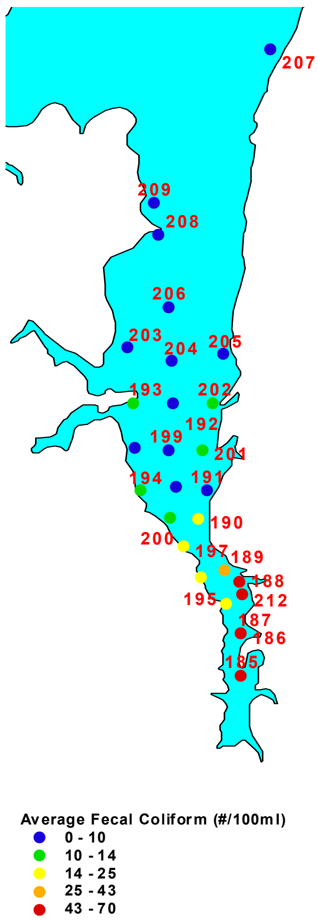

Figure 7. Spatial Distribution of Average Fecal Coliform Levels in Henderson Inlet

Thurston County Public Health, Environmental Health Division and UW Bacteriological Contamination Source Identification for Henderson Inlet (Thurston County PHSS, 2002)
From February 2000 through May 2001, Thurston County conducted water, sediment, and shellfish meat sampling in Henderson Inlet to determine the sources of bacterial contamination. Dr. Samadpour at the University of Washington used genetic fingerprinting of *Escherichia coli* colonies to determine possible sources of bacteria contamination. The focus study area was southern Henderson Inlet near the DOH marine monitoring station that was downgraded to Prohibited in October 2000. Sample sites included Woodland Creek, Swayne Creeks, and the recently downgraded marine station (188) on Henderson Inlet.

Overall, 27 source types of fecal pollution were identified. Eighty-six percent of the samples were matched to known sources. Swayne creeks source types tended to be more rural in nature such as birds, deer, canines, and rodents. Woodland Creek reflected more urban source types such as humans and dogs. A variety of sources were found at the marine station with avian, unknown sources, and human being the most predominant source types. Avian, human, canine, and unknown source types were the most frequently found source types and were found during more than half the water sampling events.

DOH and Thurston County Environmental Health Program Hydrographic Study (Thurston County PHSS, 2002, Appendix A)

Washington State Department of Health and Thurston County Environmental Health conducted hydrographic studies from December 1999 through February 2000 near historical station 5 (station 188 on Figure 4) (Thurston County PHSS, 2002, Appendix A). Analysis of DOH marine water quality indicates fecal coliform levels are higher during ebb tide than flood tide, following rainfall events, during southerly winds, and greater than or equal to two hours after the start of ebb tide; however, several high concentrations occurred when rainfall greater than 0.5 inches during the previous 24 hours. The study concluded that Woodland Creek waters travel from the urbanized area to historical station 5 (station 188) within two hours for a typical ebb tide. In the December 9, 1999 ebb tide release, surface floats and drogues remained near DOH historical station 5 (station 188) throughout the day. Releases to the south, at mid-ebb tide, passed over or near historical station 5 and indicated a gyre formed. The December 13, 1999, release targeted Woodland Creek flow paths. Surface floats moved faster than drogues, but all tracers moved in the direction of the thalweg, or deepest part, of Henderson Inlet toward historical station 5 but away from historical station 3 (station 187). Travel times were on the order of two hours from Woodland Creek to historical station 5. Releases south of the cove reached the shore, confirming the existence of the gyre and long residence times. The study noted three septic system failures on the west shore, 400 yards south of historical station 3. A grab sample from water entering the inlet prior to the fall 1998 repair had a fecal coliform concentration of 215,000/100 ml. Samples collected during moderate ebb tide exchanges and collected greater than two hours after high tide (i.e., the start of the ebb tide) tended to have elevated concentrations at historical station 5 when compared with samples collected during large tidal exchange events, within two hours of the start of the ebb tide, winds from the south, and rainfall.

Thurston County, Washington, Net Shore-Drift (Schwartz and Hatfield, 1982)

Field observations of net shore-drift indicators, including fining of materials and accumulations on woody debris or groins, were used to identify drift cells and the net direction of sediment transport. Drift cells define near-shore areas of influence based on the sources and sinks of material transported alongshore. The larger the drift cell, the larger the geographic area of influence. Drift cells develop due to local wind-generated waves combined with local bathymetry and geomorphology. The southern portion and western shore of Henderson Inlet do not exhibit significant near-shore drift; this is likely due to the low wave energy and fine sediments. However, the eastern shore includes multiple cells, as shown in Figure 8, with generally southward net transport south of Swayne Road and northward transport north of Chapman Bay. Material appears to accumulate in the bay near 68th Avenue and at the spit north of 68th Avenue.

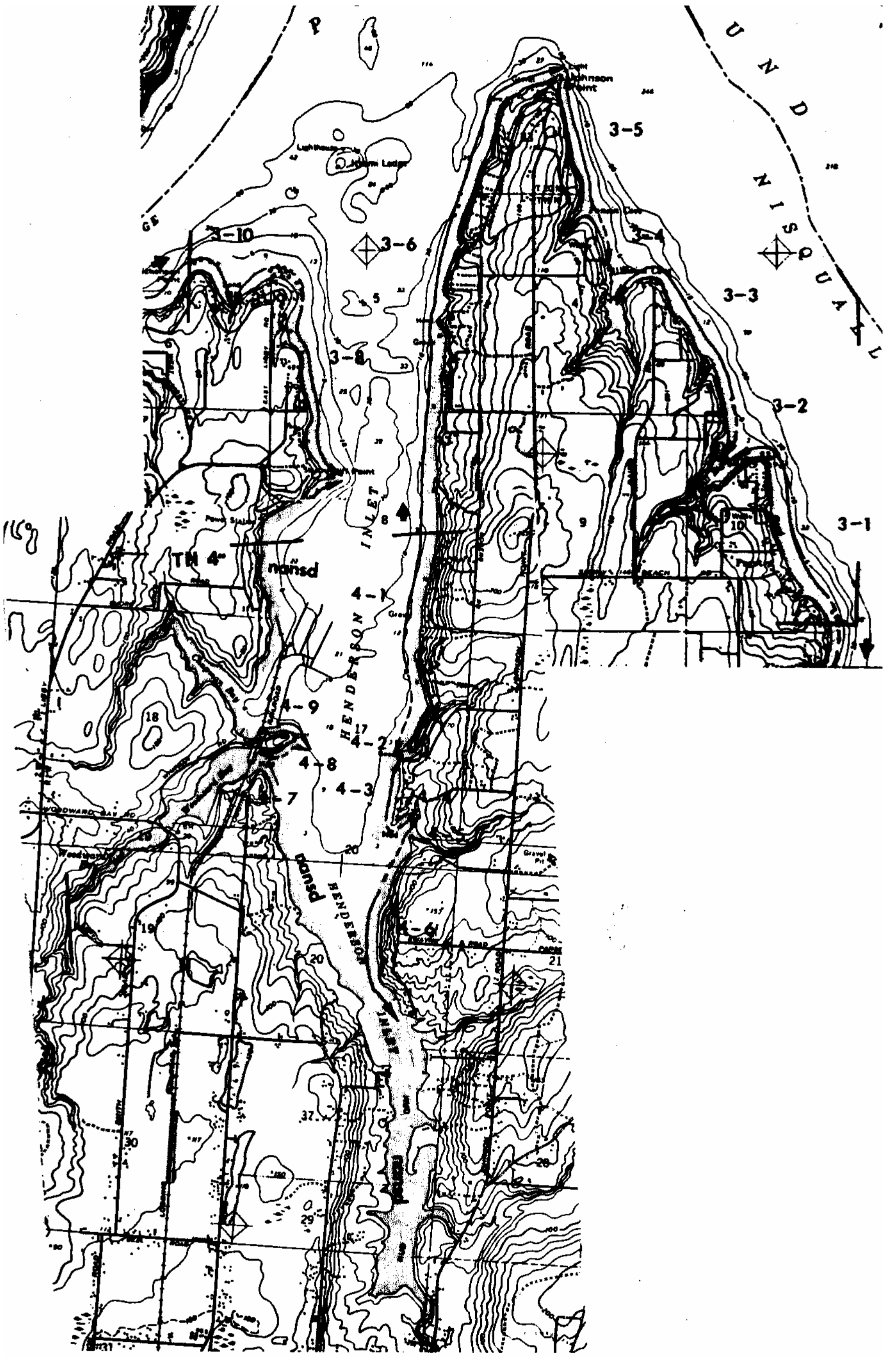

Figure 8. (Drift 3) Net shore drift in Henderson Inlet, from Schwartz and Hatfield (1982). Map Identifies Drift Cells, Direction of Nearshore Sediment Transport, and Areas of No Appreciable Net Shore Drift (nansd)

Washington State Department of Ecology Ambient Monitoring (Newton et al., 1994; Newton, 1998)

The Washington State Department of Ecology monitors a location off Cliff Point (HND001) as part of its rotating Puget Sound stations. Parameters measured at discrete depths and dates are summarized in Table 3. In addition, staff record profiles of temperature, salinity, density, dissolved oxygen, light transmission, and pH at 0.5-m increments. On November 3, 1992 and November 16, 1995, dissolved oxygen did not meet the water quality standards, prompting the 303(d) listing. Figure 9 illustrates the dissolved oxygen profile on these dates. Late fall appears to be the critical period for dissolved oxygen in Henderson Inlet.

Table 3. Department of Ecology Ambient Marine Water Quality Monitoring Data

Dates	Parameters
10/5/92	Temperature
11/3/92	Salinity
12/1/92	Density
1/11/93	Dissolved Oxygen
2/8/93	pH
3/3/93	Transmissivity
4/12/93	Secchi depth
5/17/93	Fecal Coliform
6/7/93	Chlorophyll a
7/12/93	Pheopigment
8/9/93	Nitrate (dissolved)
9/7/93	Ammonium
11/16/95	Orthophosphate
2/26/96	Nitrite+Nitrate
3/20/96	Total Ammonia
4/30/96	
5/29/96	
6/17/96	
8/12/96	
9/16/96	

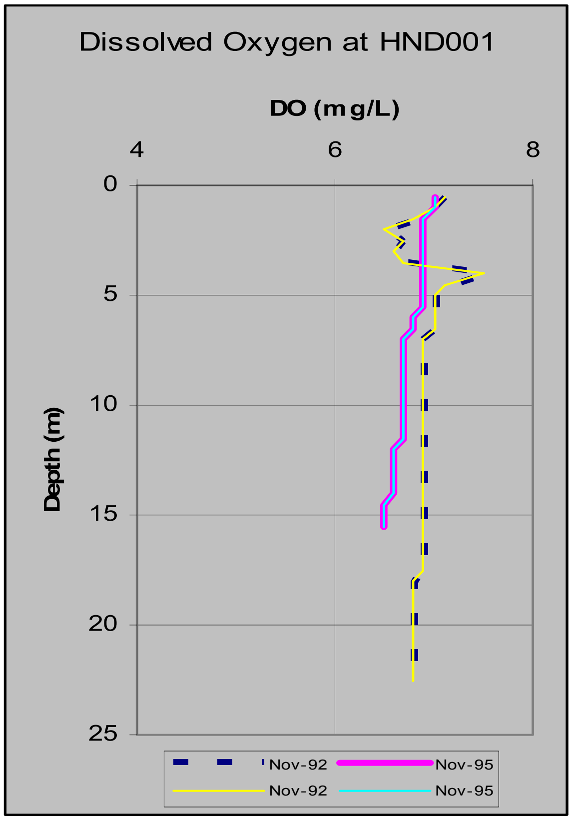

Figure 9. Historical Dissolved Oxygen Profiles in Henderson Inlet

Circulation and Flushing in South Puget Sound (URS Company, 1986)
The study included Henderson Inlet. Previous estimates of flushing rates were based on the ratio of inlet volume to tidal volume, assuming no reflux. The net transport for Henderson Inlet was based on a water and salt balance. Table 4 summarizes flushing estimates.

Table 4. Flushing Estimates Based on Tidal Prism and Water/Salt Balance

Parameter	**UW (1971) and Duxbury et al. (1972)**	**URS Company (1986)**
Total Volume at MHW	0.55 x 10^8 m^3	
Total Volume at MLLW	0.31 x 10^8 m^3	
Intertidal Volume	0.24 x 10^8 m^3	
Intertidal Volume/MHW Volume	44%	
Flushing Rate	2.3 tidal cycles = 1.2 days	(calculated 6.4 days)
Net Transport	0.5 x 10^3 m^3/s	0.1

Thurston County Public Health and Social Services Department, Environmental Health Program (Davis, Personal Communication, 2002)
Thurston County Environmental Health mapped the septic systems tested along Henderson Inlet. The areas tested were representative of the entire shoreline of the inlet, and the 13% failure rate should be representative.

Thurston County Initial Assessment, Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1995)
The plan reviews several studies that indicate that urban storm water runoff in Woodland and Woodard Creeks contributes the greatest bacterial loads to Henderson Inlet. The studies also mention that poorly maintained septic systems discharge effluent directly into Henderson Inlet.

Henderson Inlet Watershed Freshwater Data

Woodland Creek Segment Monitoring draft data collected by Thurston County (Davis, Personal Communication)
From April 2001 to March 2002 Thurston County staff conducted storm event monitoring for fecal coliform at several sites along Woodland Creek. The focus of the monitoring was identifying areas of fecal coliform input. The county will produce a report on findings in December 2002.

Seven storm events were sampled; the results are presented in Figures10a and 10b. Not all sites were sampled during all storm events. None of the sites sampled met Class AA freshwater standards for fecal coliform. For the first four sample events (Figure 10a), increases in fecal coliform loading were seen between Martin Way at RM 3.8 and Draham Road at RM 2.9 and between RM 2.9 and Pleasant Glade Road at RM 1.6. An additional sample site was included at I-5, RM 3.1 for the next few sample events (Figure 10b) and increases in loading were seen between RM 3.1 and 1.6.

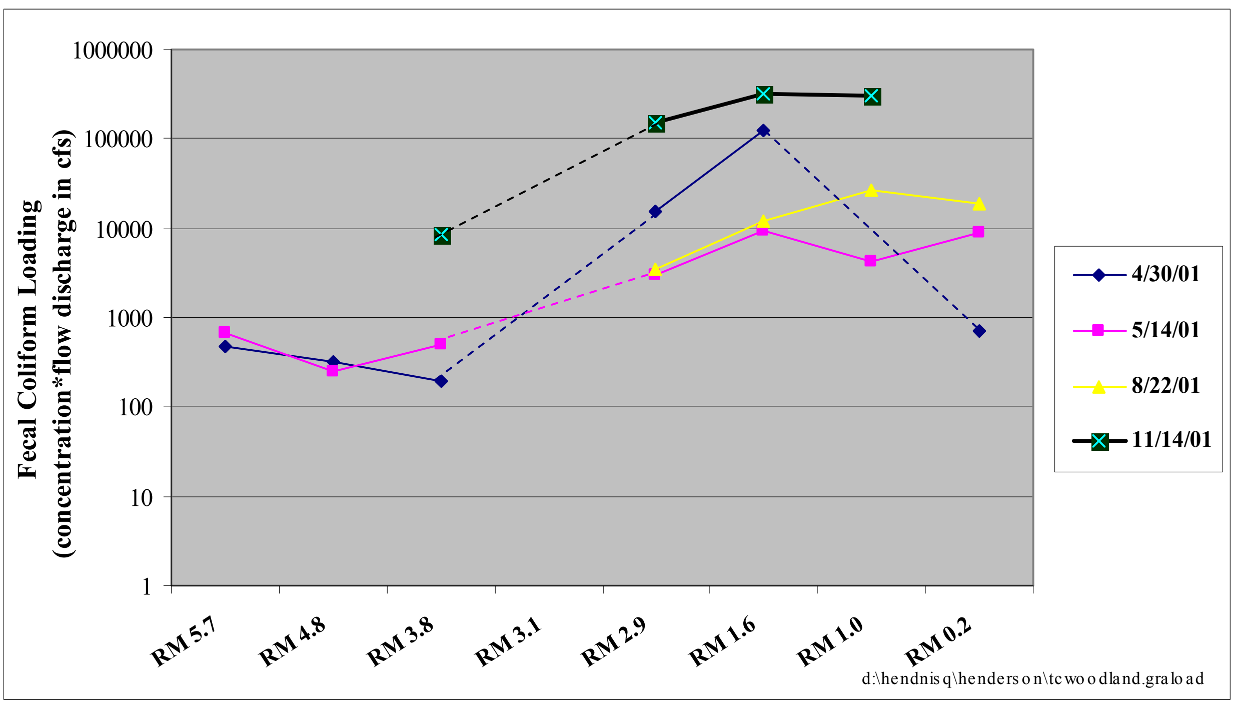

Figure 10a. April - November Storm Event Monitoring on Woodland Creek

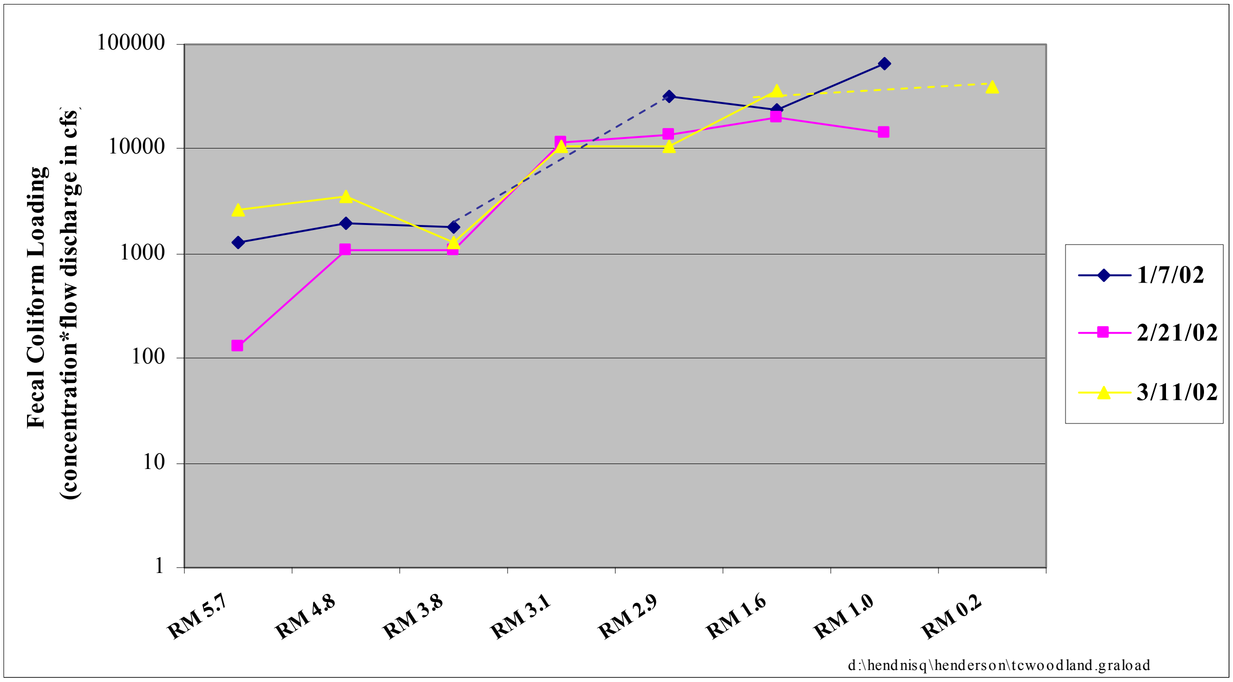

Figure 10b. January - March 2002 Storm Event Monitoring on Woodland Creek

Thurston County Initial Assessment, Henderson Inlet Watershed (Clingman, 2001)
Thurston County summarized watershed conditions from a range of sources. The benthic index of biological integrity (B-IBI) is low for Woodland Creek (22, 24) and moderate for Woodard Creek (32, 36) (Thurston County PHSS and WWM, 2000). Residential, industrial, and agricultural water use relies on groundwater. In addition, McAllister Springs serves the city of Olympia as well as 3,000 residents in the Tanglewilde PUD service area. The city of Lacey derives part of its water supply from wells in the Meadows subdivision.

Thurston County Initial Assessment, Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County Department of Water and Waste Management, 1995)
The drainage plan was developed to "correct existing problems in the basin and prevent future problems from occurring." The plan recommends several actions to reduce flooding, improve water quality, improve fish habitat, and reduce storm flows throughout the Woodland and Woodard Creek watersheds. The plan includes a thorough basin characterization of hydrology, geology, and wildlife, drawing from several previous surveys and studies.

Large organic debris has been removed from residential areas (Johnson and Caldwell, 1992). Woodland Creek substrate includes much sand, but the study could not determine whether this is a natural condition or due to soil erosion from increased runoff. A spring-fed tributary at RM3.3 provides most of the baseflow in the summer, with the area between Lake Lois and the tributary going dry during summer and fall. Salmonids (chum, coho, and chinook salmon) spawn in the spring-fed tributary and downstream, although Department of Fisheries staff noted some spawning as far as RM5.0. Coho salmon populations have decreased in Woodland Creek since 1956 (Baranski, 1991). Woodard Creek salmonids primarily spawn downstream of RM3.5.

Removal of riparian vegetation was noted along Woodland and Woodard Creeks, which increases erosion and reduces shade. Impervious areas have reduced infiltration and groundwater recharge, which the study indicates has contributed to the seasonal drying of some reaches of the creeks. In addition, the plan maps particular problem areas along Woodland and Woodard Creeks that include flooding, water quality, and fish habitat degradation concerns.

The plan summarizes the results of several studies that found that "agricultural practices, septic systems, and stormwater discharges contributed most of the contamination to the basins' water resources."

Thurston County modified HSPF models of Woodland and Woodard Creeks, initially developed by Aquaterra Consultants (Beyerlein and Brascher, 1994), to provide a tool for the hydrologic analyses. The calibration period used was October 1988 through September 1990. The Woodland Creek watershed was divided into 18 subbasins and Woodard Creek watershed into seven subbasins. Precipitation from Olympia Airport was used to estimate precipitation for each watershed. The model was used to estimate past and future conditions to understand the range of modifications that have occurred or could occur in the systems. Native vegetation types were assumed for the entire watersheds; however, the present drainage network was used even though it reflects some human modifications to flow conveyance structures. Two goals were used to drive future conditions: no increase in peak stream flows and a decrease in peak flows, compared with present conditions.

Analysis of Existing Fish Habitat in a Portion of Woodland Creek, Thurston County, Washington (Johnson and Caldwell, 1992)

The 1991 survey includes the reach from Draham Road downstream to Pleasant Glade Road, then a mix of residential and open space. Field teams identified existing fish habitat, quantified habitats at different flows, and evaluated the effectiveness of proposed storm water management plants on habitat. The study found a variety of fast-water and slow-water habitats, but channel complexity is lower in residential areas than open space areas. The habitat survey is included as Appendix H in Thurston County Department of Water and Waste Management (1995). The report quotes other reports in indicating that "80-90% of the precipitation falling on the upper Woodland Creek basin flows to McAllister Creek or Puget Sound without entering Woodland Creek." The report also summarizes water budgets developed by Entranco (1977) for Hicks, Pattison, and Long Lakes. Hicks and Pattison lakes are dominated by groundwater inputs and outputs, while 18% of the input and 40% of the output from Long Lake involve groundwater. The report also references anecdotal reference to a time when Woodland Creek flowed perennially, but no data were available to verify. Wells in the surface (Qva) aquifer, which may be hydraulically connected to Woodland Creek, draw approximately 0.6 cfs, which constitutes 7% of the minimum flow in Woodland Creek and 3% of the mean stream flow if all withdrawals impact surface water. Beatty Springs receives discharge from the lower Qvr aquifers. Well withdrawals are less than 0.1 cfs up gradient of the stream from the Qvr aquifer and 0.11 cfs from the surface Qva aquifer. The sum represents 5% of the summer flow at the springs.

Groundwater Contributions to Stream Flow (Pitz and Sinclair, 1999)
An analysis of surface discharge records by the Department of Ecology identifies 96% of the total mean annual stream flow at Pleasant Glade is from groundwater.

Historical Woodland Creek Discharge Data (USGS, 1949-1969 and 1988-1990)

USGS maintained daily flow records at Pleasant Glade Road from 1949 to 1969 (USGS station 12081000), presented in Figure 11.

Thurston County maintained a stream gage on Woodland Creek at Pleasant Road from February 1988 to 1996. The Woodland Creek gauge was damaged in 1996 and was recently re-established in August 2002. A summary of stream flow data for Woodland Creek at Pleasant Glade Road is presented in Appendix B, Table 1. A continuous flow station was also maintained on Woodland Creek at Martin Way from March 1988 to June 1994 and Thurston County currently maintains a continuous flow gauge on Woodland Creek at 36th Avenue.

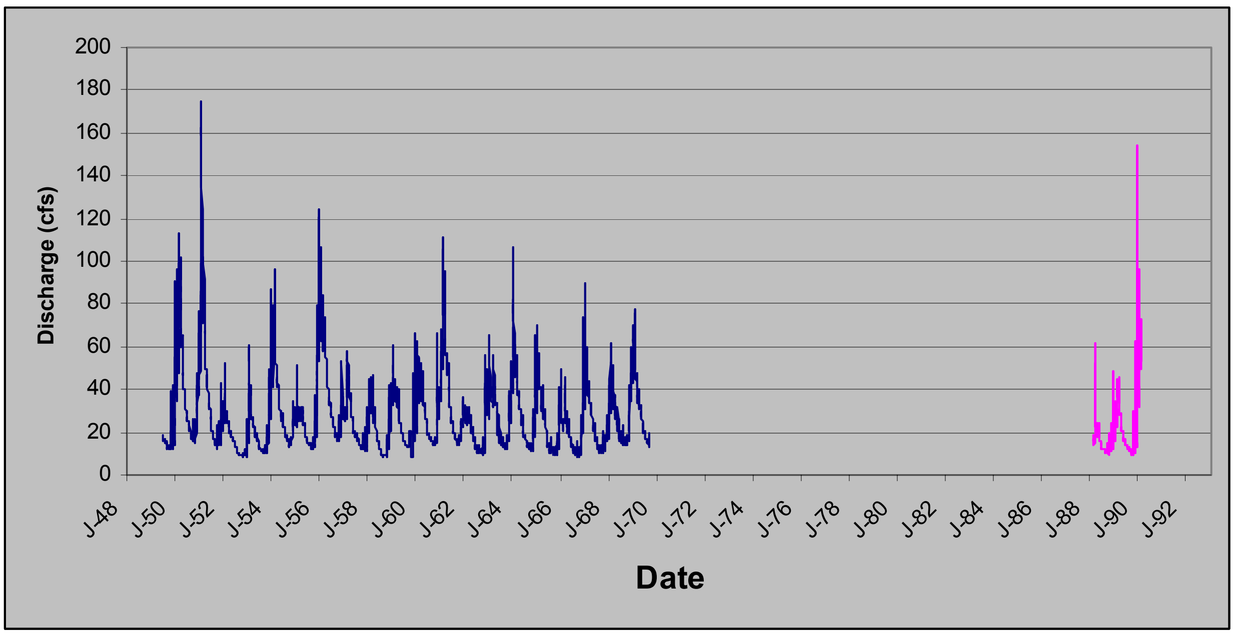

Figure 11. Woodard Creek Continuous Streamflow Monitored at Pleasant Glade Road

Conceptual Model and Numerical Simulation of the Groundwater Flow System in the Unconsolidated Sediments of Thurston County, Washington (Drost et al., 1999)
USGS applied MODFLOW to the study area, which includes Henderson Inlet and McAllister Creek, to evaluate potential effects of increasing withdrawals on springs and surface waters. Seepage studies on Woodland Creek indicate 6.6 cfs at Pleasant Glade Road is from springs.

Hydrology and Quality of Ground Water in Northern Thurston County, Washington (Drost et al., 1998)
The USGS - Thurston County Department of Health study objectives included determining the extent of the system and describing groundwater quality in the area. Table 5 summarizes groundwater quality for the Vashon recessional outwash (Qvr), Vashon advance outwash (Qva),

and sea level aquifers (Qc). Dissolved oxygen levels were generally low ranging from 3.3 to 6.7 mg/L.

Table 5. Median Groundwater Concentrations of Various Parameters by Aquifer System

	Uplands lower aquifer (Qvr)	**Uplands surface aquifer (Qva)**	**Sea Level aquifer (Qc)**
Discharge location	McAllister Springs, Abbot Springs, Beatty Springs (Nisqually Trout Farm)	Woodland Creek	McAllister and Abbott springs, Nisqually valley flood plain sediments
Dissolved oxygen	6.7 mg/L	5.7 mg/L	3.3 mg/L
pH	6.7	6.8	7.2
Specific conductance	129 umhos	124 umhos	144 umhos
Nitrate	1.7 mg/L	0.78 mg/L	0.34 mg/L
Iron	7 ug/L	14 ug/L	20 ug/L

Thurston County Discharge and Water Resources Monitoring Reports 1993-1998 Water Year. Thurston County Storm and Surface Water Program 1994-1999.
Thurston County has monitored for several water quality parameters on Sleepy, Dobbs, Meyer, Goose, Woodland, and Woodard Creeks. Parameters of interest include: pH, temperature, dissolved oxygen, fecal coliform, and stream flow. The monitoring period varies depending on the site with data available from 1988 to the present. Thurston County water quality data can be found at: http://www.geodata.org/swater. Thurston County data results for the TMDL parameters of interest are included below. Appendix C contains summaries of pertinent water quality parameters for each creek.

Dobbs Creek data collection occurred between December 1987 through August 1998. Geometric mean fecal coliform bacteria levels were highest during the summer months, with most months not meeting the water quality standard. In looking at yearly fecal coliform data, 1987-88 were the only years to meet water quality standards, with bacteria levels increasing since then (Figure 12). There were some low pH levels seen during the wet season--December through March.

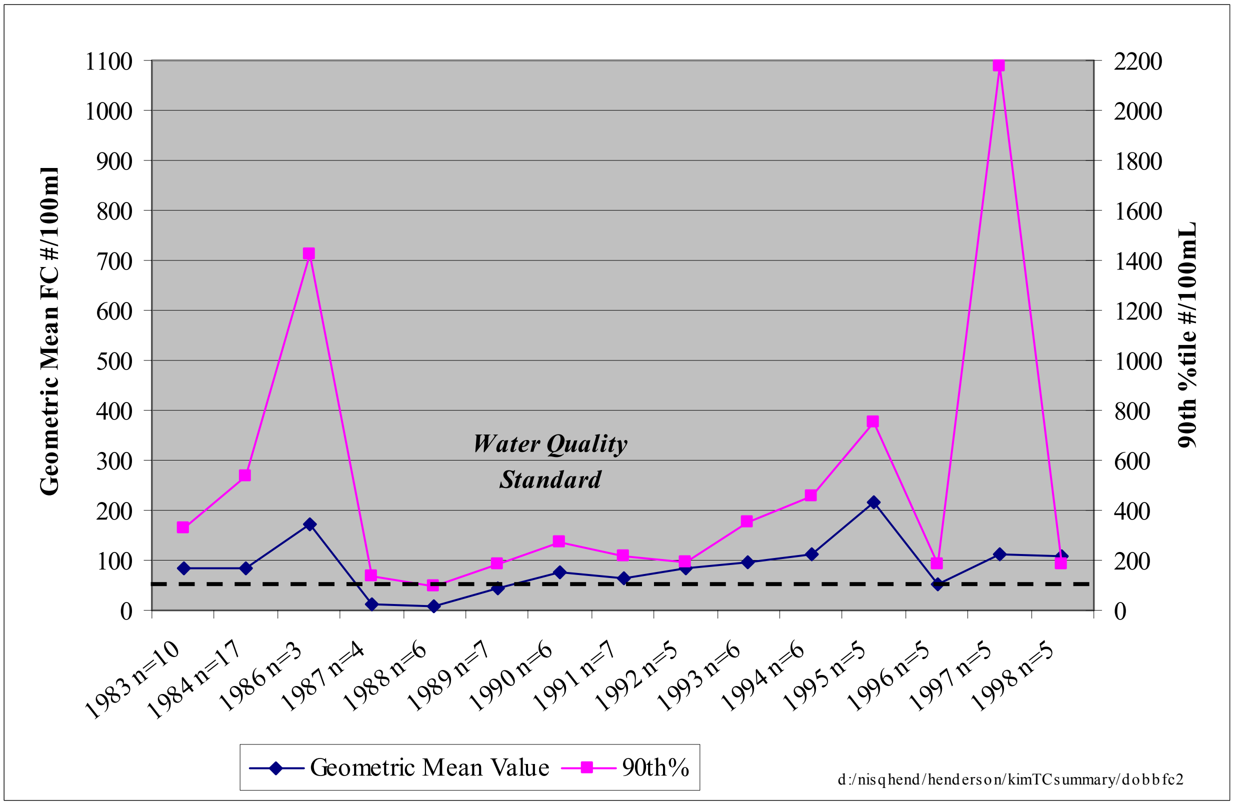

Figure 12. 1983-1998 Dobbs Creek Geometric Mean and 90th Percentile Fecal Coliform

Sleepy Creek data collection occurred between December 1987 through August 1998. Dissolved oxygen results show problems occur mostly during the low flow periods of July through September; however, no data are available for June (Appendix C, Table 2). Minor excursions to the pH standard are generally seen during the winter months. No pattern in fecal coliform is seen with high levels occurring during the high and low flow periods.

Meyer Creek was sampled between August 1983 through September 1998. A summary of pH and fecal coliform results are presented in Appendix C, Table 3. No distinct pattern is seen in fecal coliform levels over the years. Higher levels of bacteria are seen in the summer months but this may be an artifact of different sample sizes. Lower pH levels tend to occur during the wet season from November through March.

Goose Creek was sampled from August 1983 - July 1984. A summary of fecal coliform levels and flow are presented in Appendix C, Table 4. Flow levels are low in this creek (under one cubic foot per second (cfs) for most of the year) and there is no pattern seen in fecal coliform levels.

Woodard Creek sampling started in June 1986 and continues to be part of the Thurston County ambient monitoring program. A summary of water quality data for fecal coliform, dissolved oxygen, pH, and flow is presented for June 1986 - August 2001 in Appendix C, Table 5. The highest levels of bacteria for the site on Woodard Creek were seen from June through October.

From 1987 - 2001 geometric mean fecal coliform levels ranged from 22-85 cfu/100mL (Figure 13). The pH values were lower from November through March and dissolved oxygen values were lowest during the summer season, July through September.

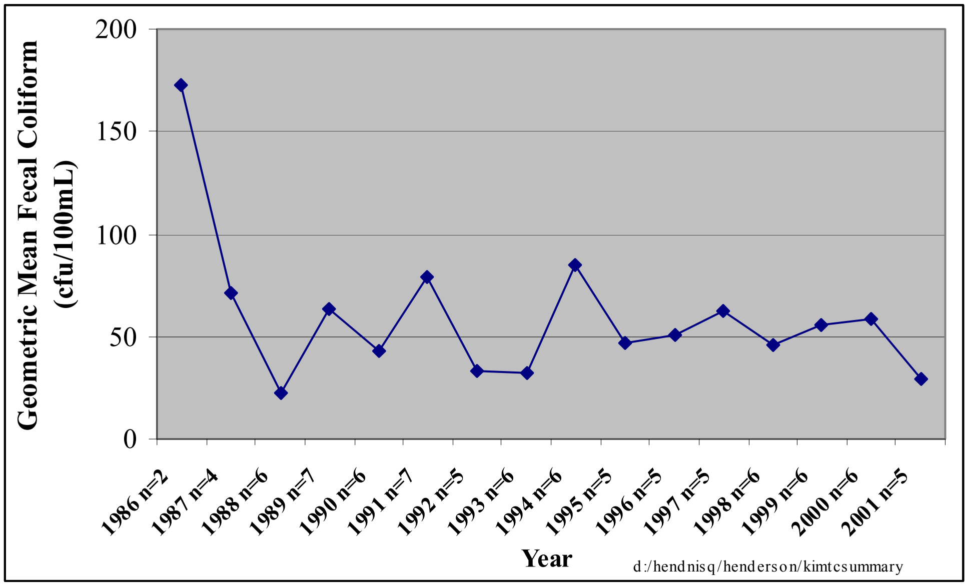

Figure 13. Woodard Creek Geometric Mean Fecal Coliform 1986-2001

Woodland Creek sampling started in August 1983 and continues to be part of the Thurston County Ambient Monitoring Program. A summary of water quality data for fecal coliform, dissolved oxygen, and flow is presented for August 1983-August 2001 in Appendix C, Table 6. Monthly mean fecal coliform concentrations and loads are presented in Figure 14. The figures show no yearly trend in fecal coliform levels. Monthly data show higher fecal coliform concentrations during the low flow months. Fecal coliform loading levels appear to be fairly constant with some higher averages in June and October. This maybe be due to the low number of samples (n=2) available for analysis for these months. No yearly trend is seen in annual fecal coliform concentrations from 1983-2001 (Figure 15).

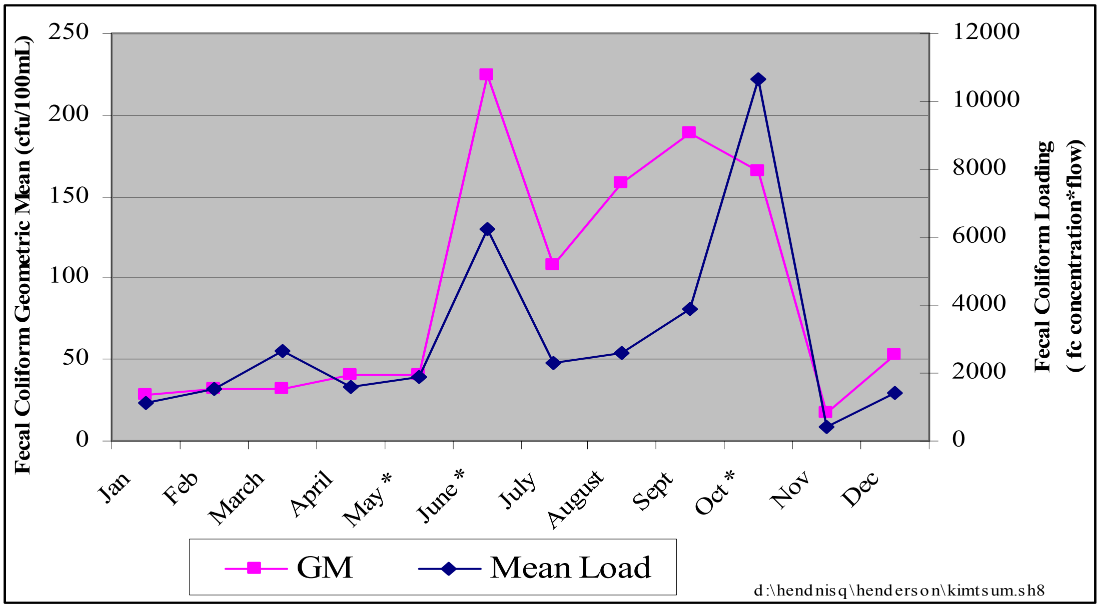

Figure 14. Woodland Creek Monthly Fecal Coliform Geometric Mean and Loading 1983-2001

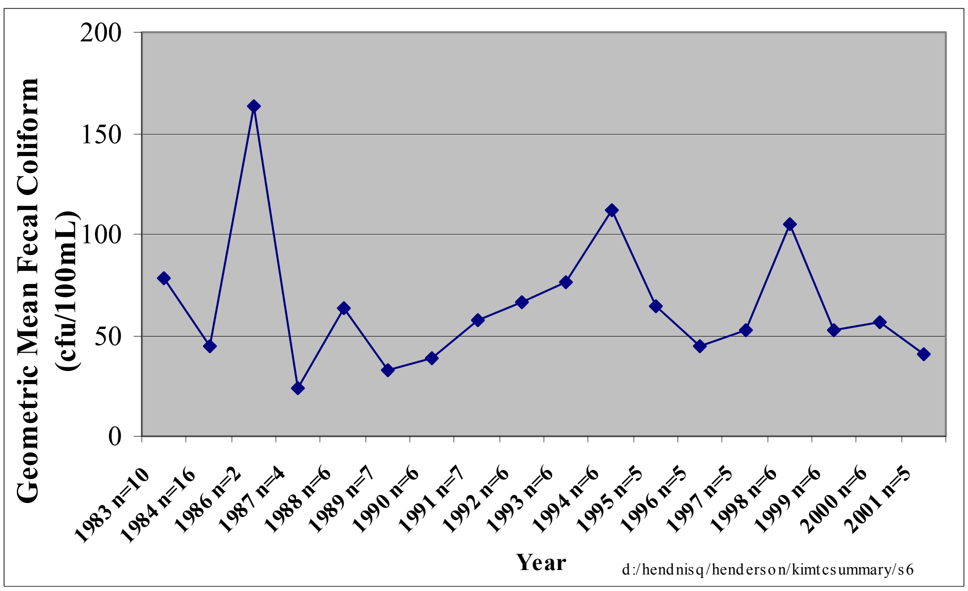

Figure 15. Woodland Creek Yearly Fecal Coliform Geometric Mean 1983-2001

Dissolved oxygen data shows no monthly trend with lower levels also found during the winter months.

City of Lacey Water Quality Data from Ambient Monitoring and Stream Team Volunteers (Julie Rector, City of Lacey, 2002)

City of Lacey staff and Stream Team volunteers collected water samples for a variety of parameters on Woodland Creek and tributaries. A summary of pertinent water quality results is included in Appendix D. Lacey staff conducted storm event monitoring from January - October of 2001 on Woodland Creek and some tributaries for several parameters. Fecal coliform levels were high during storm event sampling.

Washington State Department of Ecology, Woodland Creek Water Quality Assessment (Patterson and Dickes, 1994)
Four sites along the mainstem of Woodland Creek (RM 3.1, 3.7, 3.8, and 4.2) were monitored before and during construction of the new Ecology Headquarters Building from January 1991 through July1993. The primary objective was to assess water quality impacts resulting from runoff from construction activities. Water quality monitoring included monthly temperature, pH, dissolved oxygen, fecal coliform, and stream flow measurements.

During portions of the study period, Woodland Creek was dry between stations RM 4.2 and RM 3.7. During this same time period, station RM 3.1 was always flowing. The average difference in discharge between station RM 3.7 and downstream station RM 3.1 during the study period was +9.6 cfs, with a minimum increase of 4.0 cfs and a maximum increase of 18.0 cfs. Groundwater inflow likely accounts for the increases in measured discharge as evidenced by the 4.8° C average decrease in surface water temperatures (May-September) between the two stations (Zalewsky, 2002).

Monitoring results showed that a city of Lacey storm drain was found to be a primary loading source for fecal coliform excursions and increased total suspended solids during storm events.

Lake Lois, located approximately 0.5 miles upstream of RM 4.2, is the last in a series of lakes that make up the headwaters of Woodland Creek. Natural conditions (intermittent and low flows) were the primary reason for water quality in Woodland Creek occasionally not meeting the water quality standards for temperature, dissolved oxygen, pH, and characteristic uses (fish migration) (Patterson and Dickes, 1994).

Figures 16 and 17 present fecal coliform concentration and loading information, respectively, for 1991 - 93. Results show higher concentrations of fecal coliform during periods of low flow at RM 4.2, but lower loading during this period. The biggest increase in loading is between Woodland Creek RM 3.8 and 3.1; this reach also has increasing flows.

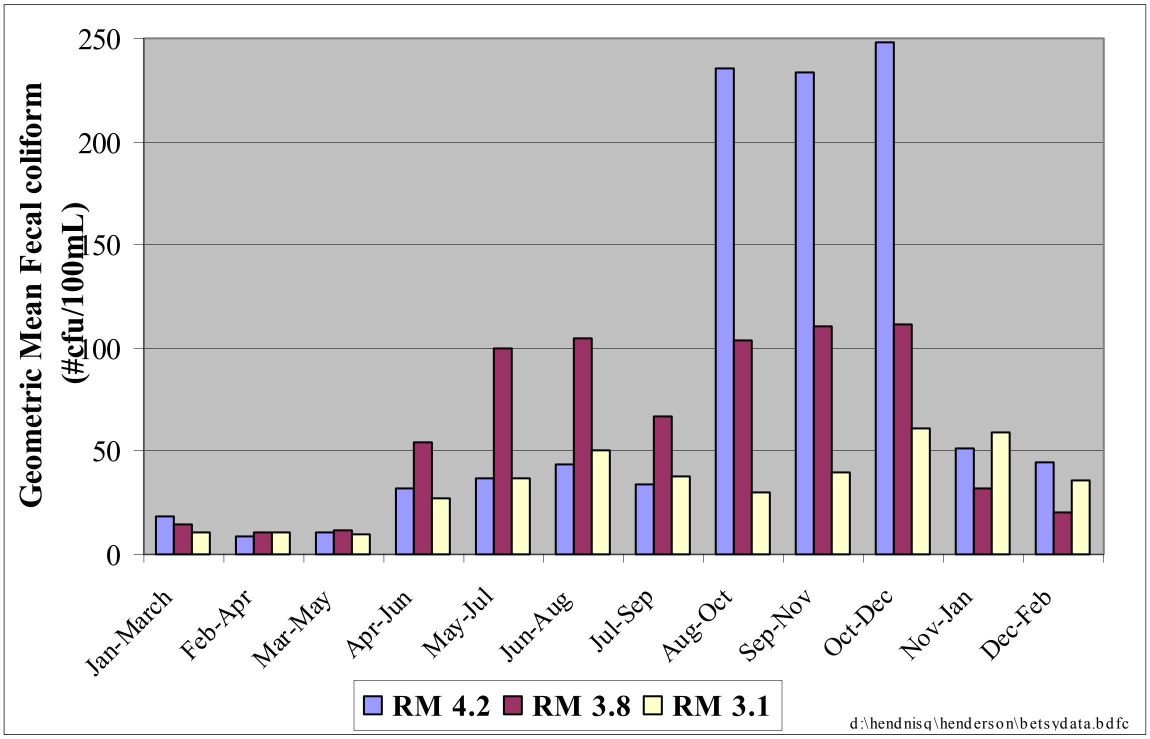

Figure 16. 1991-93 Woodland Creek Fecal Coliform Three Month Geometric Mean

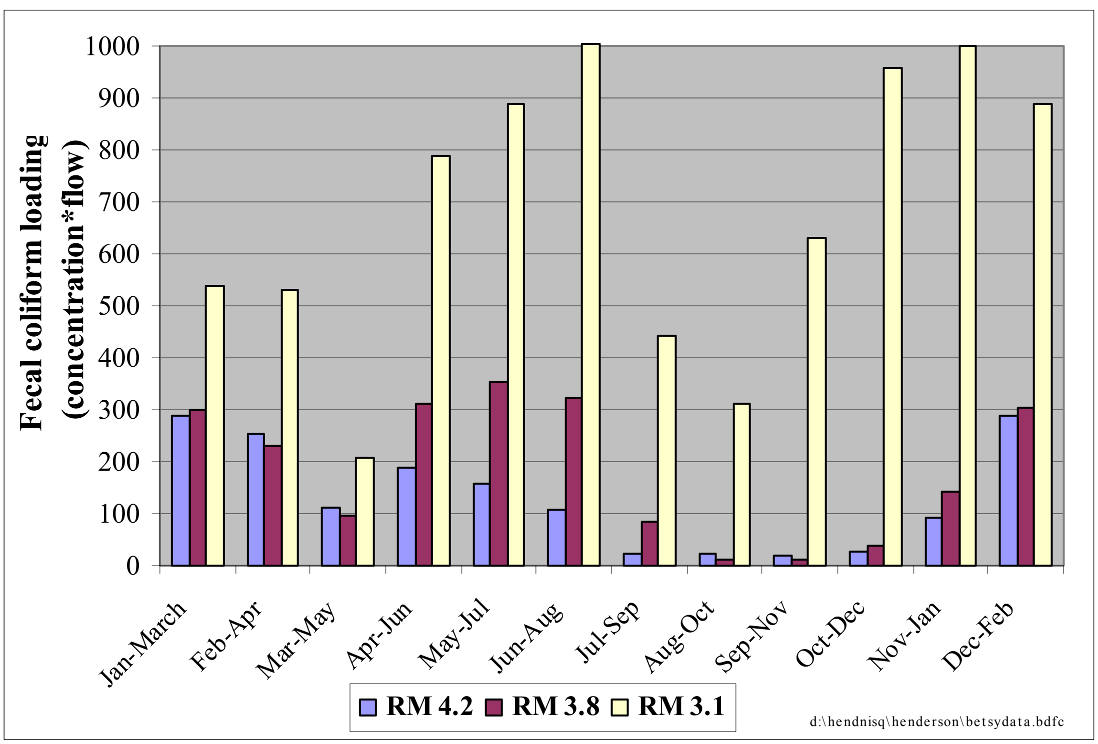

Figure 17. 1991-93 Woodland Creek Fecal Coliform Loading

A review of dissolved oxygen levels at three sites is presented in Table 6. Year-round low dissolved oxygen levels are seen at RM 3.1 with yearly average dissolved oxygen saturation at 70%. At RM 3.8, dissolved oxygen levels are the best with a yearly average of 96% saturation. At RM 4.2, low dissolved oxygen levels are seen from May - September with yearly average saturation values at 87%. Table X shows a pattern of increasing dissolved oxygen levels between RM 4.2 and 3.8, and then a decrease seen between RM 3.8 and 3.1.

Table 6. Woodard Creek Sites Monthly Dissolved Oxygen Values and Percent Saturation

Woodard Creek Site	Month	Number of Samples	Average Dissolved Oxygen (mg/L)	Minimum Dissolved Oxygen (mg/L)	Average Percent Saturation
RM 4.2	Jan	2	11.5	11.3	93%
RM 3.8	Jan	2	12.4	12.0	100%
RM 3.1	Jan	3	8.6	7.8	73%
RM 4.2	Feb	3	11.1	10.4	91%
RM 3.8	Feb	3	11.6	11.1	95%
RM 3.1	Feb	3	8.8	7.8	76%
RM 4.2	March	3	9.6	7.1	81%
RM 3.8	March	2	11.2	11.0	96%
RM 3.1	March	3	8.8	7.8	76%
RM 4.2	April	3	10.2	9.5	94%
RM 3.8	April	3	10.7	9.9	97%
RM 3.1	April	3	8.6	8.0	77%
RM 4.2	May	3	9.2	8.6	91%
RM 3.8	May	3	9.6	9.3	95%
RM 3.1	May	2	7.8	7.7	72%
RM 4.2	June	3	8.2	7.6	86%
RM 3.8	June	3	9.3	8.8	97%
RM 3.1	June	2	7.6	7.1	71%
RM 4.2	July	2	7.8	7.2	82%
RM 3.8	July	2	8.5	8.3	89%
RM 3.1	July	3	7.1	6.8	66%
RM 4.2	August	1		7.8	89%
RM 3.8	August	1		9.1	102%
RM 3.1	August	2	6.7	6.4	62%
RM 4.2	Sept	1		8.2	86%
RM 3.8	Sept	1		9.4	96%
RM 3.1	Sept	2	6.9	6.7	63%
RM 4.2	Oct	1		8.8	n/a
RM 3.8	Oct	1		10.1	n/a
RM 3.1	Oct	2	6.8	6.5	58%
RM 4.2	Nov	2	8.3	7.0	73%
RM 3.8	Nov	1		10.6	93%
RM 3.1	Nov	2	7.1	7.0	63%
RM 4.2	Dec	2	11.1	10.8	86%
RM 3.8	Dec	1		12.2	94%
RM 3.1	Dec	2	8.2	8.1	68%

Woodland and Woodard Creek Basins, Stormwater Quality Survey (Davis and Coots, 1989)

Seven Olympia and Lacey storm sewer systems which discharge to Woodland and Woodard Creeks were sampled to characterize stormwater quality under typical flow and rainfall conditions.

The median fecal coliform value for the stormwater samples was 4207 cfu/100mL, and 100% of the samples exceeded 100 cfu/100mL. Fecal coliform analysis was also performed on sediment samples. Samples from four creek sites and the stormwater sites all had counts at or above 1300 cuf/100grams.

Regional Planning Efforts

Henderson Inlet Watershed Management Action Plan (Henderson Inlet Watershed Committee, 1989)
The above plan attributed most of the Henderson Inlet contamination sources to storm water, agricultural practices, and on-site septic systems tributary to five streams: Woodland, Woodard, Sleepy, Meyer, and Dobbs. The plan notes that bacteria concentrations increase during the winter and spring. Thurston County Health Department, in conjunction with the Washington State Department of Social and Health Services, Shellfish Section, monitored Henderson Inlet water quality from 1981 to 1985, during which time inlet fecal coliform concentrations increased.

Response Strategy for Shellfish Growing Area Downgrades in Henderson Inlet and the Nisqually Reach (Puget Sound Action Team, 2001)
This shellfish closure response strategy was developed in response to shellfish growing area downgrades in Henderson Inlet and Nisqually Reach. The strategy describes actions to improve water quality in these areas and reverse the downgrades. For each action a responsible entity, timetable, and funding resources, both available and needed are designated. Actions include identifying and controlling agricultural, stormwater, and on-site sewage system sources of pollution.

Nisqually Reach and Tributaries

Introduction

Nisqually Reach and River and McAllister and Ohop Creeks are on the 303(d) list of water-bodies that do not meet water quality standards for a water quality parameter. In addition, review of historic 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 7 lists the water bodies in the Nisqually Reach and basin that are on the 303(d) list or do not meet water quality standards and the water quality parameters of concern for each waterbody.

Table 7. Nisqually Basin Waterbodies on the 303(d) List or Not Meeting Water Quality Standards

Waterbody	Parameter	Location	New ID #	Old ID #
WRIA 11 Marine Water		Lat/Long		
Nisqually Reach	Fecal coliform bacteria	47.115, 122.695	390KRD	WA-PS-0290
WRIA 11 Freshwater		Township/Range/Section		
Nisqually River	Fecal coliform bacteria	18N 01E 08	OE72JI	WA-11-1010
McAllister Creek	Fecal coliform bacteria, dissolved oxygen	18N 01E 37	LD26OX	WA-11-2000
McAllister Creek	Fecal coliform bacteria, dissolved oxygen	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 19N 01E 09	No-ID	No-ID

Project Description

Study Area

Nisqually Reach
The Nisqually Reach is the area where the Nisqually Delta and deeper waters of Puget Sound meet and includes those waters inside a line from Johnson Point to Gordon Point, Anderson Island, Ketron Island, and Drayton and Balch passages. The Nisqually Delta, formed by the Nisqually River, consists of broad mudflats and salt marsh. Two smaller creeks flow into Nisqually Reach in WRIA 11, McAllister and Red Salmon Creeks.

Nisqually River
The Nisqually basin covers 761 square miles within the greater Puget Sound watershed (Watershed Professionals Network, 2002) (Figure 1). 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 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. In addition, a site on the lower Nisqually River, at river mile (RM) 3.4, will be sampled to verify improvements in bacteria levels.

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 18). The average annual discharge is 67 cfs and the basin covers 44 square miles. The principle 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 hobby 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 hobby farms in the lower mile. The town of Eatonville's stormwater collection system discharges into Lynch Creek. Twenty-Five Mile Creek flows from commercial owned timberlands through an area of hobby farms and a recently abandoned clay mining operation before joining Ohop Creek at RM 9.9 (Kerwin, 1999).

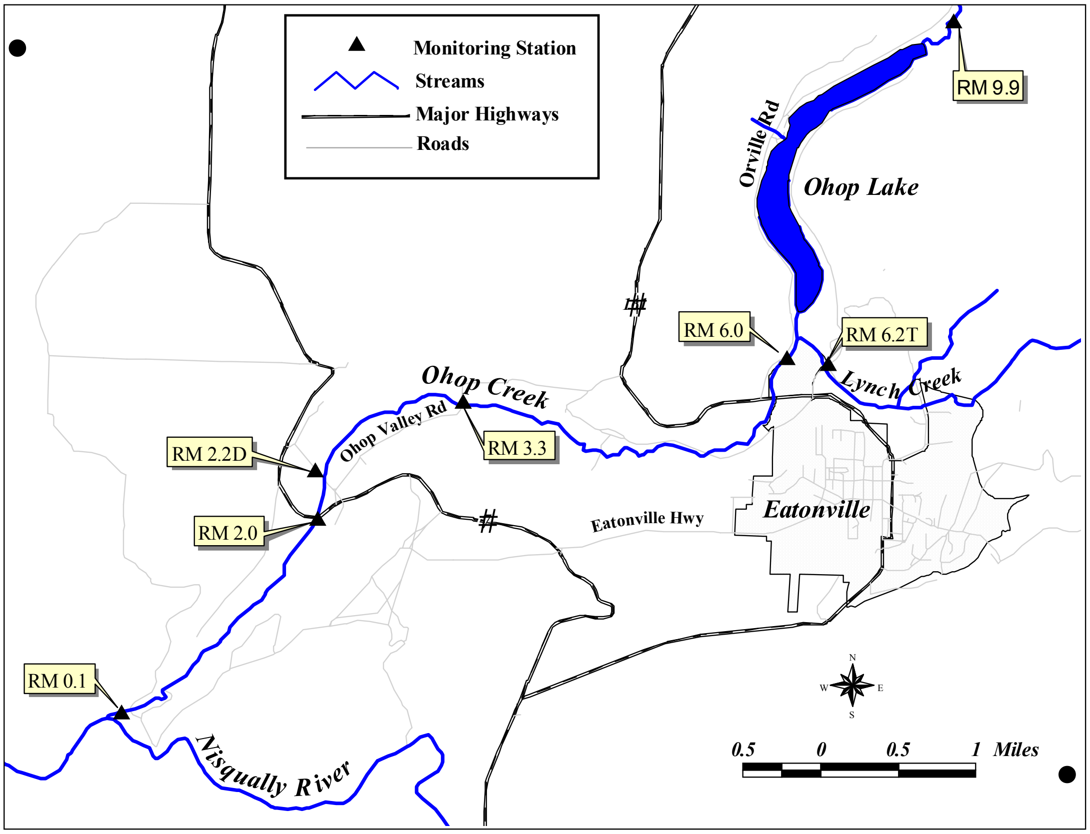

Figure 18. Ohop Creek Study Area

McAllister Creek

McAllister Creek (Figure 19) 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 ' 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 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 5' at RM 4.3. Little McAllister Creek enters McAllister Creek in this stretch at RM 5.3 through two tide gates. 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, the creek has been routed through a drainage ditch to McAllister Creek. Just upstream of Steilacoom Road is the McAllister Creek Fish Hatchery run by Washington State Department of Fish & Wildlife (WDFW). Due to budget constraints, this hatchery closed operations in June 2002.

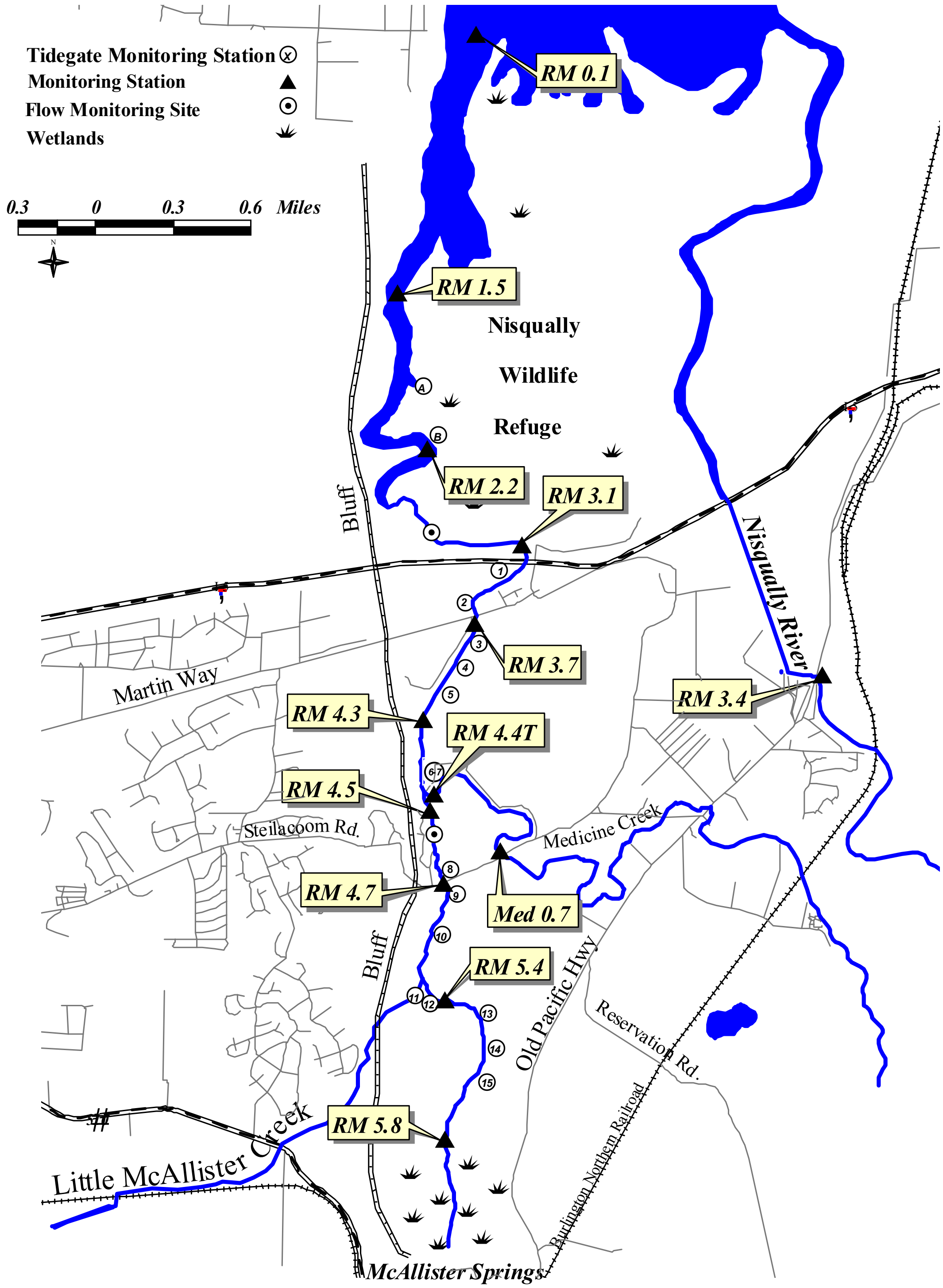

Figure 19. McAllister Creek Study Area

Below Steilacoom Road is the only residential development adjacent to the creek, located along its west side between RM 4.7 and 4.3. 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 the creek at RM 4.1. 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. There is almost no canopy cover currently and the channel is narrow, weed-choked, and frequently dry above the Steilacoom Road crossing (Thurston County WWM, 1994).

At RM 3.65 McAllister Creek enters a diversion channel under Martin Way, then flows into a newer diversion channel under I-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.

At RM 2.4, after leaving the artificial channel, the creek flows through the 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, 1994). Two tidegates discharge to the creek in this reach, draining water from the Nisqually Wildlife Refuge.

Two times a day, 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 tidegates and extensive diking in order for lands lying to the east of the creek to be drained for agricultural use (Wiley and Walter, 1996). The location of the major tide gates is included in Figure 19.

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, 1994). USGS maintained a continuous recording gauging station near McAllister Springs from 1951 to 1964 (Thurston County WWM, 1994), averaging 24 cfs and an intermittent gage at Steilacoom Road from 1941 to 1949, where flow ranged from 48 to 132 cfs. Department of Fisheries staff recorded instantaneous flows near the McAllister Creek hatchery in 1984 and 1985; however, flows were lower than usual, likely due to a drought.

Red Salmon Creek

Red Salmon Creek is a small independent tributary on the eastern edge of the Nisqually Delta. The creek originates from a series of diffuse springs and seeps in wetlands north of I-5. From its origin, the creek flows westerly, through an area of low density residential houses, hobby 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).

Fisheries Resource
The Lower Nisqually River serves as a transport corridor for all the anadromous 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. Coho, chinook, and pink salmon, along with steelhead and coastal cutthroat, use Ohop Creek.

McAllister Creek supports natural runs of chinook, coho, chum, steelhead and anadromous (sea-run) cutthroat while Red Salmon Creek supports natural runs of coho, chum, steelhead, and sea-run cutthroat.

In 1992, DOH reclassified 1000 acres of commercial shellfish growing areas in the Nisqually Reach from Approved to Conditional 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 of 2000, DOH reclassified about 74 acres at the east end of the area from Conditionally Approved to Restricted (Department of Health, 2002). In 2002, DOH upgraded 960 acres from Conditionally Approved and Restricted to Approved. 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 commercial shellfish growing area currently remain Restricted and are located west of the mouth of McAllister Creek. Also, recreational shellfish beds, located in the mouth of McAllister Cree, continue to be unsafe for consumption (Thurston County, 2002).

Geology and Hydrogeology
The study area is composed of glacially derived sediments overlying Tertiary sedimentary rock. The area is located close to the southernmost extent of the two glacial advances, the more recent Vashon and the earlier Salmon Springs advances. The geologic description for the study site is based on USGS (1998). This study describes groundwater resources in Thurston County and is based on earlier published interpretations.

The unconsolidated material in the study area can be divided into six units. The most recent material is alluvial and deltaic sand deposited in the bottom of the Nisqually Valley and major water courses. The uppermost glacial unit in the study area is the Vashon recessional outwash made up of sand and gravel. The recessional outwash covers much of the study area and where saturated forms unconfined or perched aquifers. A thick layer of Vashon till underlies the recessional outwash in most areas and surfaces on the Johnson Point peninsula. This "hardpan" layer consists of poorly sorted sand, gravel, and boulders that are held in a mixture of silt and clay. The till forms a confining layer preventing upward flow from the underlying Vashon advance outwash aquifer, except in the McAllister Springs corridor. The Vashon outwash consists of gravel in a matrix of sand and is a major water source. The underlying silt and clay layer referred to as the Kitsap Formation forms a second confining layer. Underlying the Kitsap Formation is a second major aquifer, Salmon Springs sea level aquifer. This aquifer is used extensively and is composed of coarse sand and gravel. Similar to the Vashon advance outwash aquifer, the sea level aquifer is confined in most places except at the McAllister Springs area where it merges with the advance outwash to form a single connected aquifer system referred to in PGG (2000) as the McAllister Gravel Aquifer.

Hydrogeologic Units

The alluvium and recessional outwash units together are labeled Vashon recessional outwash (Qvr). This unit covers much of the study area, except for the northern part of the McAllister Creek corridor and occasional till-covered areas. Where present, this layer forms unconfined aquifers and drains into nearby creeks along topographic contours unless perched.

The Vashon till layer (Qvt) directly below the Qvr acts as a confining layer, preventing appreciable downward or upward percolation. This layer covers most of the study area and is sometimes at the surface. However it is not found in the McAllister Creek corridor. The thickness of the till varies and is generally 20 to 60 feet.

The Vashon advance outwash, Qva, is confined in most parts of the study area by low permeability layers above and below (Qvt and Qf) except near McAllister Springs where no overlying till layer exists.

The unit below the Qva, including the Kitsap Formation and other low permeability materials, are referred to as Qf. The northern part of the Nisqually River delta is mapped as Qf by USGS (1998), although the deposits are much younger than the Kitsap Formation. This unit serves as an effective confining layer.

The deepest unconsolidated deposits in the study area, the Salmon Springs (?) Drift, penultimate deposits, and similar materials are referred to as the Qc unit. This unit is present in most of the study area and is highly used as a water source. The Qc is usually confined except at the McAllister Springs area where it merges with the Qva to form a single connected aquifer system referred to in PGG (2000) as the McAllister Gravel Aquifer.

PGG (2000) refers to the Qc as the sea level aquifer system and found that the aquifer provides flow to McAllister Creek via McAllister Springs as well as many small springs along the edge of the Nisqually Valley where overlying layers are absent. In addition, upward flow occurs from the Qc to floodplain sediments on the valley floor.

Climate

The climate is typically maritime with cool dry summers and mild wet winters. Annual precipitation averages about 51 inches (Western Regional Climate Center http://www.wrcc.dri.edu/index.html). Winter precipitation typically consists of frequent, light-to-moderate intensity rainfall while summer storms produce short, moderate-to-high intensity rainfall. Winds are generally from the southwest and have a mean hourly speed of 6.5 mph. The average frost-free period is 150-200 days. Some snowfall, averaging between 10-15 inches per year in the basins usually occurs between November and April (Thurston County WWM, 1995)

Tidal Exchange

Tidal elevations range from +16 to -4 ft MSL (Cleland, 2000) in South Puget Sound.

Project Objectives

Objectives of the proposed study by area are as follows:

Nisqually Reach

- Determine maximum acceptable fecal coliform loads and concentrations allowable at the mouths of tributaries to meet freshwater standards within the creek or marine water quality standards in Nisqually Reach. Set target levels for fecal coliform bacteria concentrations.

Nisqually River and Ohop Creek

- Verify that the improved fecal coliform levels for Nisqually River and Ohop Creek meet Class A freshwater standards for fecal coliform and can be taken off the 303(d) list.

Red Salmon Creek

- Determine if Red Salmon Creek meets Class AA freshwater quality standards for fecal coliform bacteria. Set fecal coliform TMDL target levels if fecal coliform bacteria levels do not meet water quality standards.

McAllister Creek

- Determine the percent reductions necessary for bacteria sources to meet the fecal coliform target levels set for McAllister Creek.
- Determine locations of bacterial pollution sources.
- Determine if the lower dissolved oxygen levels in McAllister Creek are due to natural conditions

Sources of Pollution

Primary pollution sources include nonpoint sources such as contaminated stormwater, failing on-site systems, and animal waste (pet, agricultural, and wildlife). In the study area, there are no National Pollution Discharge Elimination System (NPDES) permitted discharges at this time. A Washington State Fish & Wildlife fish hatchery, located at Steilacoom Road on McAllister Creek, closed operations in June 2002 due to budget constraints. The Fort Lewis Solo Point waste water treatment plant discharges northeast of the Nisqually Reach portion of the study area.

McAllister Creek Basin
Potential sources of low dissolved oxygen in the upland reaches of McAllister Creek include an extensive wetland system fed largely by groundwater. Agricultural operations from RM 5.7 to 3.7 include cattle operations and vegetable farms. Tidegates drain agricultural land and are possible pollution sources. A 2002 study of McAllister Creek found high bacteria counts in many of the tide gates (Dickes). Animal keeping operations can contribute bacteria and excess nutrients such as nitrogen and phosphorus to water. Excess nutrients can cause increased algal and macrophyte growth which in turn depletes oxygen levels in the water through respiration and decomposition.

The only residential development on the creek is located between RM 4.7 and 4.5 on the west side. Commercial development is limited to a stream section near I-5 along Martin Way. Drainage from these sites is intercepted before it reaches McAllister Creek by a drainage canal that runs parallel to the creek in this section. This drainage canal discharges to the USFW Nisqually Wildlife Refuge. However, drainage from the RV park, located on the north side of the creek, drains to McAllister creek. None of the basin is sewered, so residential and commercial wastewater treatment occurs through on-site sewage treatment systems.

Red Salmon Creek Basin
A 1996 study (Whiley and Walter) found that potential sources of bacterial contamination in this small basin were on-site sewage treatment systems and a beef cattle operation. The report recommended that Pierce County Environmental Health inspect on-site systems in the area and that Pierce Conservation District contact the landowner of the beef cattle operation to provide technical assistance.

Ohop Creek Basin
A 1997 study (Whiley and Walter) found that water quality of lower Ohop Creek is affected by the outflow from Ohop Lake. The eutrophic lake is the source of a majority of total phosphorus and ammonia to the lower creek. Release of organic material from the lake in the form of phytoplankton is likely the reason for the lower dissolved oxygen observed in the lower reach. Lower Ohop Creek is affected by Eatonville's residential and urban land uses because the major discharge point of the city's stormwater is Lynch Creek, Ohop's major tributary below the lake. Currently Ohop valley is almost exclusively in agricultural use, hay production and animal grazing. Historically, the valley had numerous dairy operations. However, the last two dairies closed in 1996 (Whiley and Walter, 1998).

Water Quality Standards and Beneficial Uses

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

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 marine water Class AA (WAC 173-201A). This includes Nisqually Reach. Nisqually River from the mouth to Alder Dam (RM 44.2) is Freshwater Class A. The other tributaries to Nisqually Reach are not specifically classified in the water quality standards. Because the Nisqually Reach tributaries discharge to Class AA waters, they are considered Class AA waters. Characteristic uses for Class A and AA waterbodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation.

Numeric criteria for particular parameters are intended to protect designated uses. However, criteria are more stringent in AA waters such that the class shall markedly and uniformly exceed the requirements for all or substantially all uses. The water quality standards are currently under revision. Changes have been suggested for dissolved oxygen and microbial pathogens (currently represented by the fecal coliform group) numerical standards. The proposed standards apply to all waters used for primary contact recreation rather than distinguishing classes. Current and proposed standards are listed in Appendix A for each parameter of concern in the study area.

Historical Information Review

Several organizations have performed hydrographic and water quality studies in areas affecting the freshwater and marine waters tributary to the Nisqually Reach.

Nisqually Reach Marine Data

Department of Health Shellfish Monitoring (Determan, 2001)

Department of Health monitors 28 stations in the Nisqually Reach under its shellfish monitoring and classification program (Figure 20). For the most recently available reporting period (January 1999 – March 2000), four stations were rated as bad (>43 MPN/100 ml) on all occasions: two near the mouth of McAllister Creek and Luhr Beach and two near the mouth of the Nisqually River. Eleven stations indicate a worsening trend over the period of record. Samples are analyzed with the multiple tube fermentation (MPN) procedure using A-1 broth (Method 9221 E; APHA et al., 1998).

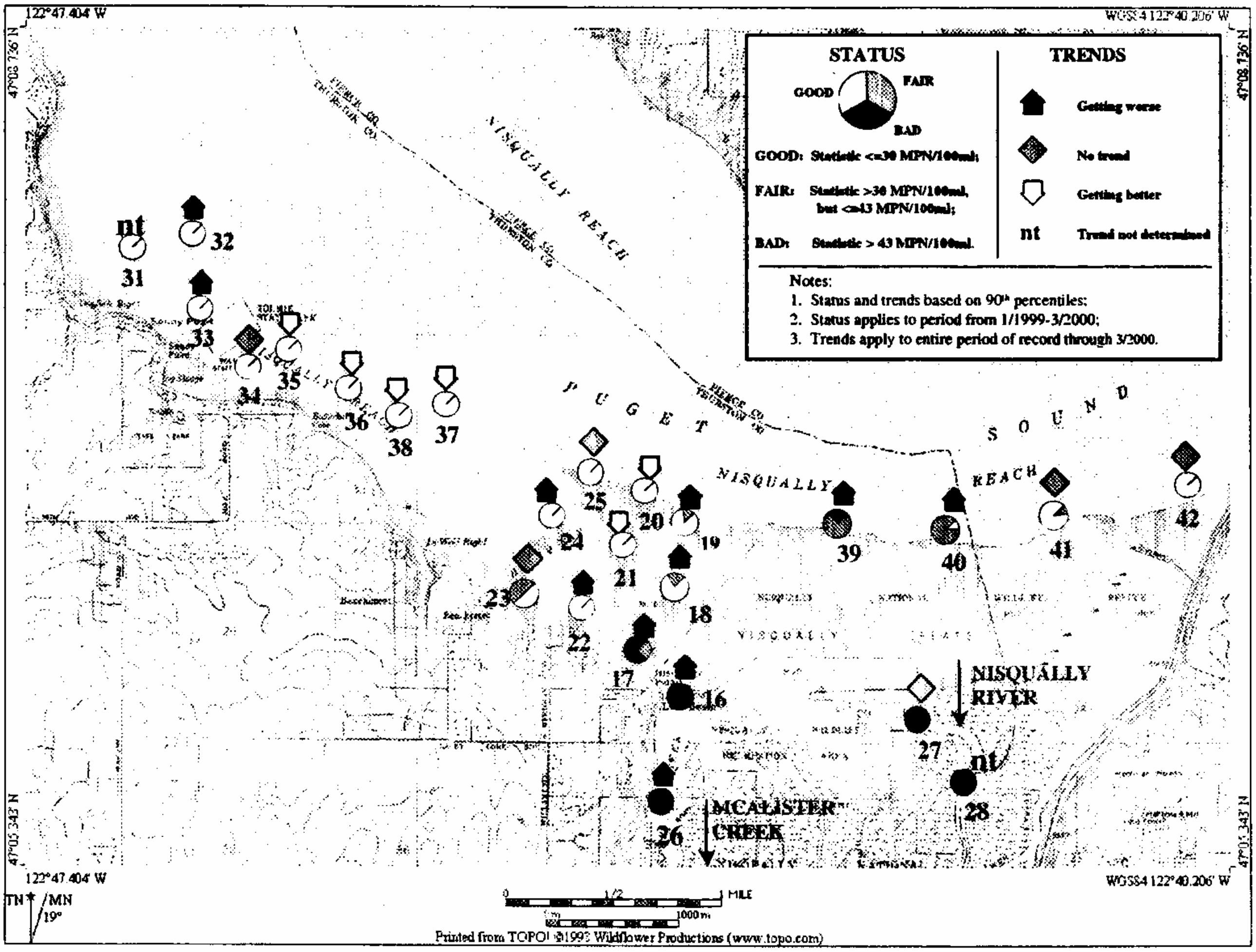

Figure 20. Nisqually Reach Bacteria Trends (Determan, 2001)

The Department of Health collected fecal coliform data between February 1988 and December 2001. Average monthly fecal coliform concentrations show a strong seasonal pattern (Figure 21) across the entire growing area. The McAllister Creek/Luhr Beach area tends to have higher concentrations and Tolmie/Beachcrest tends to have lower concentrations than elsewhere. Average fecal coliform levels for all stations and all time periods are greater during flood tide (19.0 MPN/100 ml) than ebb tide (10.6 MPN/100 ml). Figure 22 illustrates the impact of tide condition for stations near McAllister Creek.

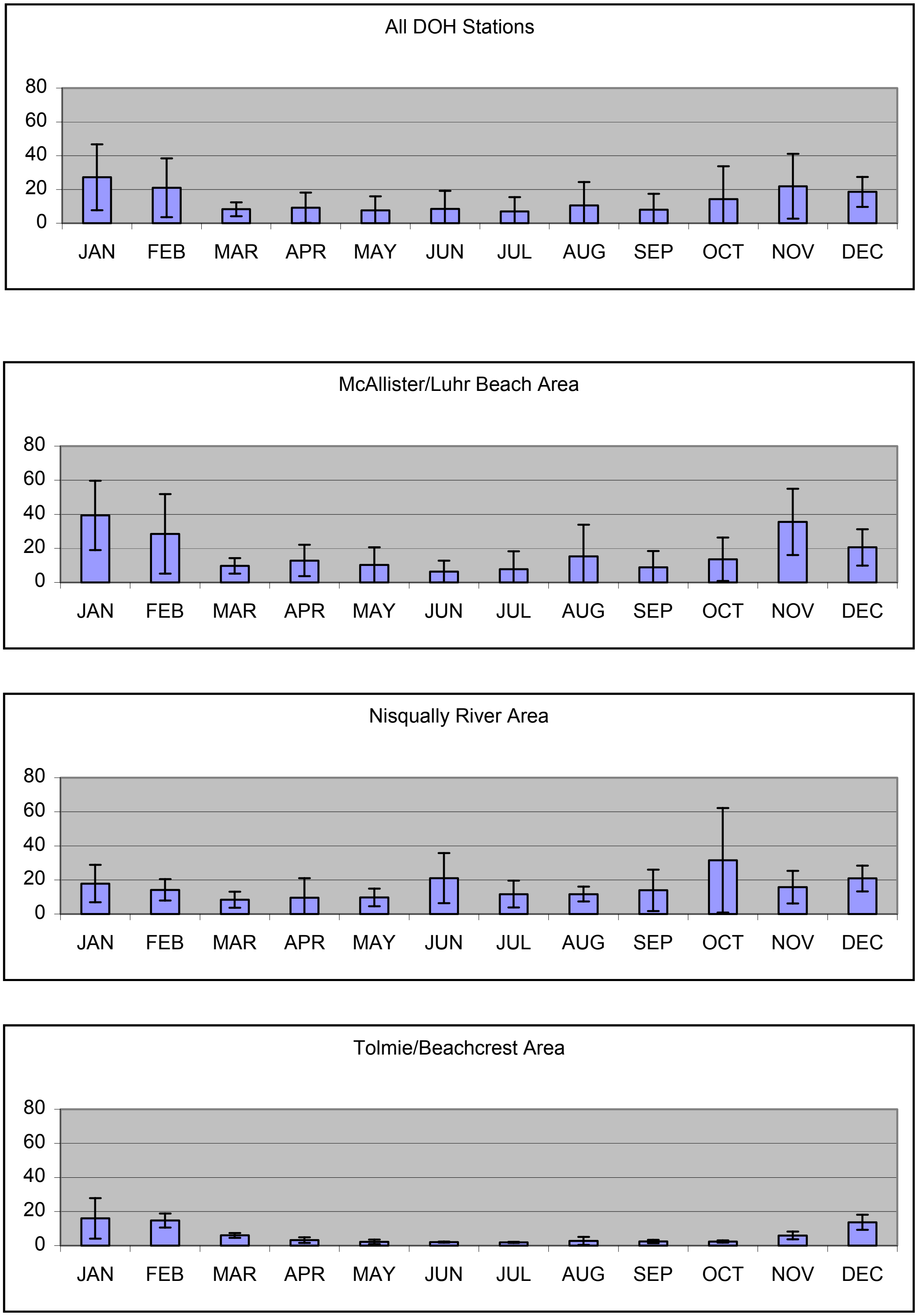

Figure 21. Average Fecal Coliform Concentration by Month for Three Regions in the Nisqually Area. (Error Bars Represent One Standard Deviation)

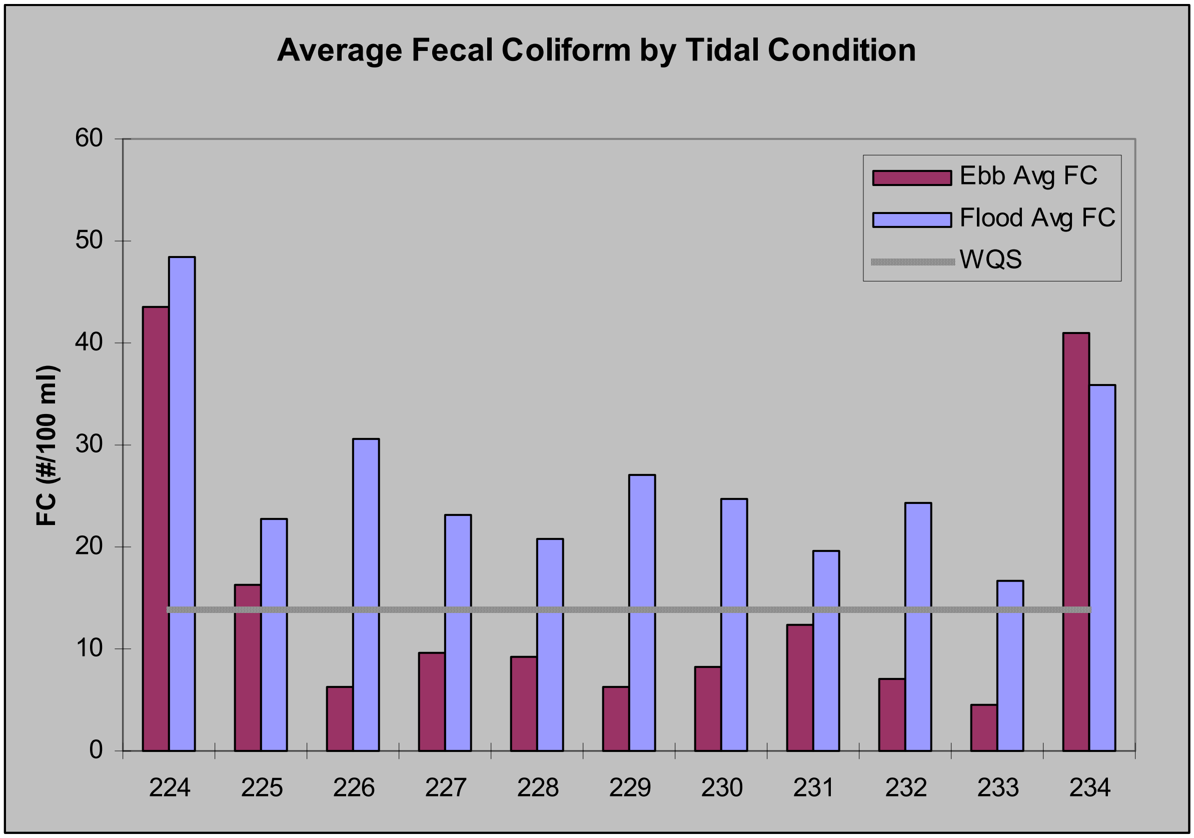

Figure 22. Nisqually Reach Average Fecal Coliform Concentration by Tidal Condition

Washington State Department of Health, Office of Shellfish Programs, Sanitary Survey of the Nisqually Reach Conditionally Approved Commercial Shellfish Growing Area (Cleland, 2000)

Department of Health surveyed tributary water quality and conducted hydrographic analyses near McAllister Creek. The study concluded that stations near McAllister Creek do not meet water quality standards and McAllister Creek adversely impacts the growing areas. DOH conducted a shoreline survey in June 1993. The survey identified several dairy farms in the McAllister Creek area and birds in the Nisqually National Wildlife Refuge (up to 5000 waterfowl) as potential contributors. Neither the Beachcrest moorage area nor seals were believed to be contributors. In the 1997 Thurston County Public Health survey, 78% of the shoreline septic systems were evaluated, and 45 systems were identified as failing or suspect and subsequently repaired.

Nisqually Indian Tribe Fecal Coliform Source Investigation in the Nisqually Reach Watershed (Whiley and Walter, 1996)
Five beach stations from Tolmie State Park to Hogum Bay periodically exhibited elevated fecal coliform concentrations, attributed to failing septic systems. Concentrations increased during storms as compared to dry weather. Peak concentrations ranged from 110/100 ml at Butterball Cove to 7998/100 ml at Hogum Bay. Whiley and Walter found that McAllister Creek "provides the most continuous source of fecal coliform bacteria to the marine waters of the Nisqually Reach," and should be targeted for future actions.

DOH Hydrographic Studies (Meriweather, 1999)
DOH staff conducted a drogue study of three areas (McAllister Creek mouth, historical station 24 [station 232], and historical station 23 [station 231]) in the Nisqually Reach Conditionally Approved area during flood tide conditions. Historically, stations 18 through 25 (226 through 233) had higher concentrations during flood tides and low salinities. Staff released deep drogues (four-foot depths), shallow drogues (one-foot depths), grapefruit (two to three inches), and rhodamine dye and observed flotsam paths. From the McAllister Creek mouth drop (near station 234), the grapefruit traveled 1000 feet north in 37 minutes (about 0.5 ft/sec) while the shallow drogues remained within 150 yards of the release location; deep drogues did not travel significantly. All tracers released at historical station 24 [station 232] traveled to the northwest. Grapefruit traveled 1200 feet in 12 minutes (1.7 fps), deep drogues traveled 3400 feet in 44 minutes (0.55 fps), and shallow drogues traveled 6300 feet in 52 minutes (1.0 fps). A subset of tracers (one deep drogue, one shallow drogue, three grapefruit) released from historical station [station 231] traveled northwest and then north. The deep drogue traveled 0.3 fps while the shallow drogue traveled 0.4 fps. The grapefruit traveled through the area more quickly and could not be located.

Fort Lewis Wastewater Outfall Circulation and Water Quality (URS Consultants, 1988)
The study summarized drogue studies and water quality surrounding the outfall at Solo Point. During flood tides, drogues moved to the southwest but then began circulating clockwise. During the spring flood tide deployment, drogues moved 0 to 35 cm/s (10 to 15 cm/s median) to the southwest.

Thurston County, Washington, Net Shore-Drift (Schwartz and Hatfield, 1982)
Field observations of net shore-drift indicators, including fining of materials and accumulations on woody debris or groins, were used to identify drift cells and the net direction of sediment transport. Drift cells develop due to local wind-generated waves combined with local bathymetry and geomorphology. The study reported no significant nearshore drift in and around the Nisqually Flats (Figure 23). However, a zone of divergence was noted at Nisqually Head with a southerly-trending cell in the McAllister Creek estuary and a northwesterly-trending cell toward Hogum Bay. A southeasterly trending cell occurs from Butterball Cove, across DeWolf Bight, to Hogum Bay. Big Slough appears to accumulate materials from the east and from Sandy Point.

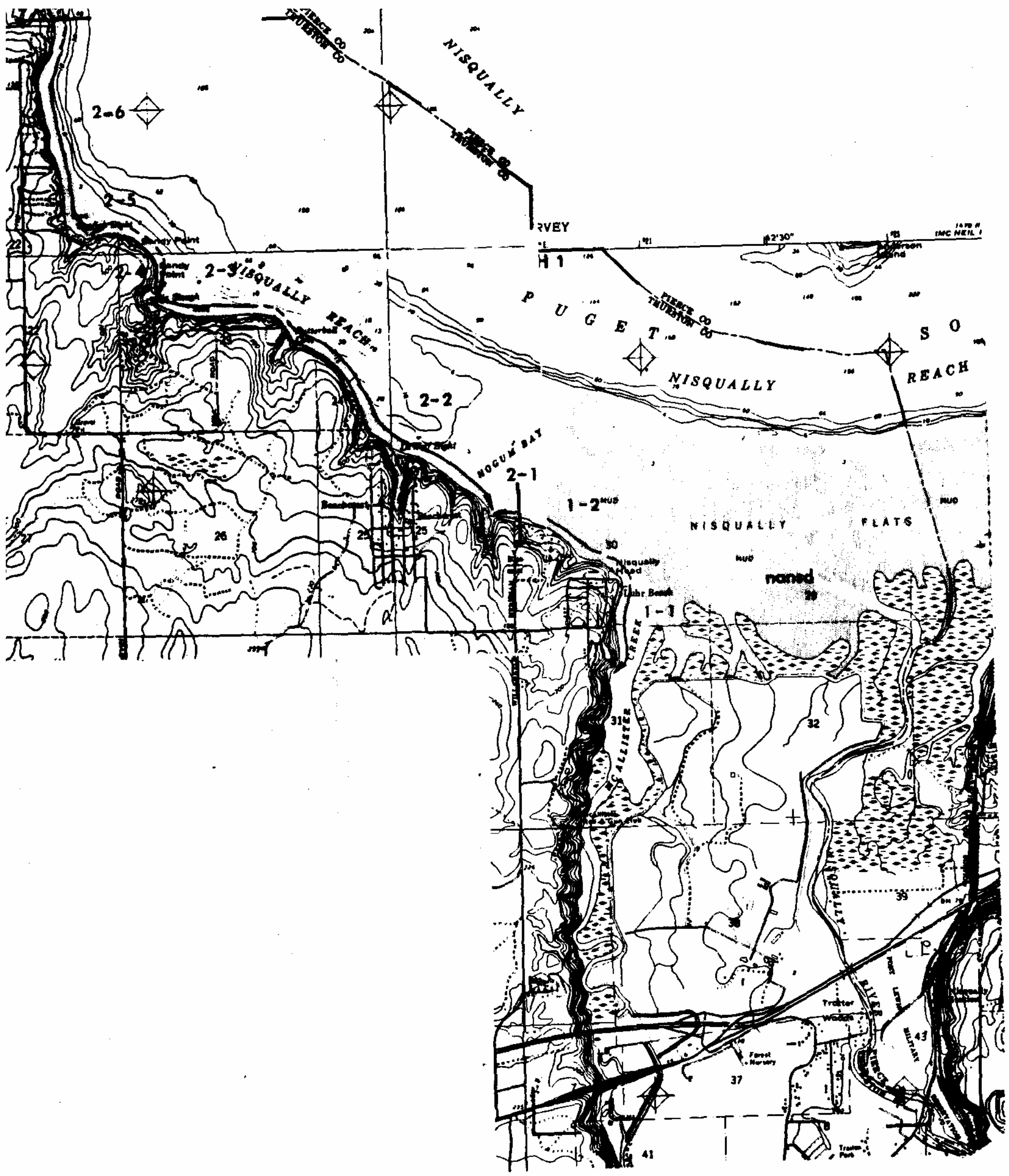

Figure 23. Net Shore Drift West of Nisqually Flats, from Schwartz and Hatfield (1982). Map Identifies Drift Cells, Direction of Nearshore Sediment Transport, and Areas of No Appreciable Net Shore Drift (nansd)

Pierce County, Washington, Net Shore-Drift (Schwartz and Harp, 1982)
The Pierce County study includes the coastline to the northeast of the Nisqually River. The region exhibits a net northward drift through Cormorant Passage (Figure 24) interrupted by the Foss Tug jetty located south of Sequalitchew Creek and a small southerly-flowing cell between Solo Point and Tatsolo Point.

Figure 24. Net Shore Drift East of Nisqually Flats, from Schwartz and Harp (1982). Map Identifies Drift Cells, Direction of Nearshore Sediment Transport, and Areas of No Appreciable Net Shore Drift (nansd).

Washington State Department of Ecology Ambient Monitoring
The Washington State Department of Ecology has monitored station NSQ002 off of Devils Head in the Nisqually Reach as a part of the core program since October 1996. Data include monthly discrete samples analyzed for fecal coliform, chlorophyll a, pheopigment, nitrate, ammonium, orthophosphate, and silicate as well as monthly profiles of temperature, salinity, dissolved oxygen, pH, and light transmission. No surface grabs analyzed for fecal coliform bacteria have been greater than one colony forming unit (cfu)/100 ml.

Department of Health (Lennartson, 2002)
The Luhr Beach Nature Center septic system has been dye tested twice, but no evidence of failure was found.

Department of Fisheries and Wildlife (Michael, 2002)
WDFW previously operated a fish hatchery on McAllister Creek. WDFW noted tidal conditions that occur about one week each year reduce flushing near the hatchery such that dissolved oxygen decreases and salinity increases. WDFW staff have anecdotally noted that the McAllister Creek channel has filled upstream of Interstate 5.

Nisqually Reach Watershed Freshwater Data

Washington State Department of Ecology McAllister Creek Monitoring (Dickes, 2002)
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 Department of Health. Results indicate high concentrations of bacteria, nutrients, and sediment enter the mainstem from tributaries as well as the discharges from the agricultural tidegates 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 inches of rain. Table 8 compares fecal coliform data to the freshwater quality standards.

Table 8. Comparison of McAllister Creek Fecal Coliform Levels with the Class AA Freshwater Standard (Data from Dickes, 2002)

Site	Number of Samples	Geometric Mean	Number of Samples >100 cfu/100 mL	Meets Standards
McAllister Ck. RM 6.3	3	2	0 of 3	Yes
McAllister Ck. RM5.8	5	14	0 of 5	Yes
McAllister Ck. RM 5.4	5	17	0 of 5	Yes
McAllister Ck. RM 5.3	4	11	0 of 4	Yes
McAllister Ck. RM 4.7	5	31	1 of 5	Not enough data
McAllister Ck. RM 4.5	3	16	0 of 3	Yes
Medicine Ck. RM 4.4T	4	199	4 of 4	NO
McAllister Ck. RM 4.2	5	49	1 of 5	Not enough data
McAllister Ck. RM 4.1	2	159	2 of 2	NO
McAllister Ck. RM 3.7	7	83	3 of 7	NO
McAllister Ck. RM 3.4	6	79	2 of 6	NO
McAllister Ck. RM 3.3	3	21	0 of 3	Yes
McAllister Ck. RM 3.1	7	105	3 of 7	NO
Tidegates (TG) and Storm Drains (upstream to downstream)				
TG15	3	38	1 of 3	Not enough data
TG14	1	n/a	0 of 1	Not enough data
TG13	4	38	1 of 4	Not enough data
TG12	4	39	2 of 4	NO
TG11(front)	4	35	1 of 4	Not enough data
TG11(back)	3	36	0 of 3	Yes
TG10	4	192	1 of 4	Not enough data
TG9	5	350	3 of 5	NO
TG8	1	n/a	1 of 1	*
TG5	7	970	5 of 7	NO
TG4	5	2265	5 of 5	NO
MC33 stormwater discharge upstream Marin Way	2	2182	2 of 2	NO
MC31stormwater discharge under I-5	5	29	3 of 5	NO

Fecal coliform problems were especially apparent downstream of McAllister RM 4.5, with high concentrations of bacteria from Medicine Creek, RM 4.4T. (Figure 25).

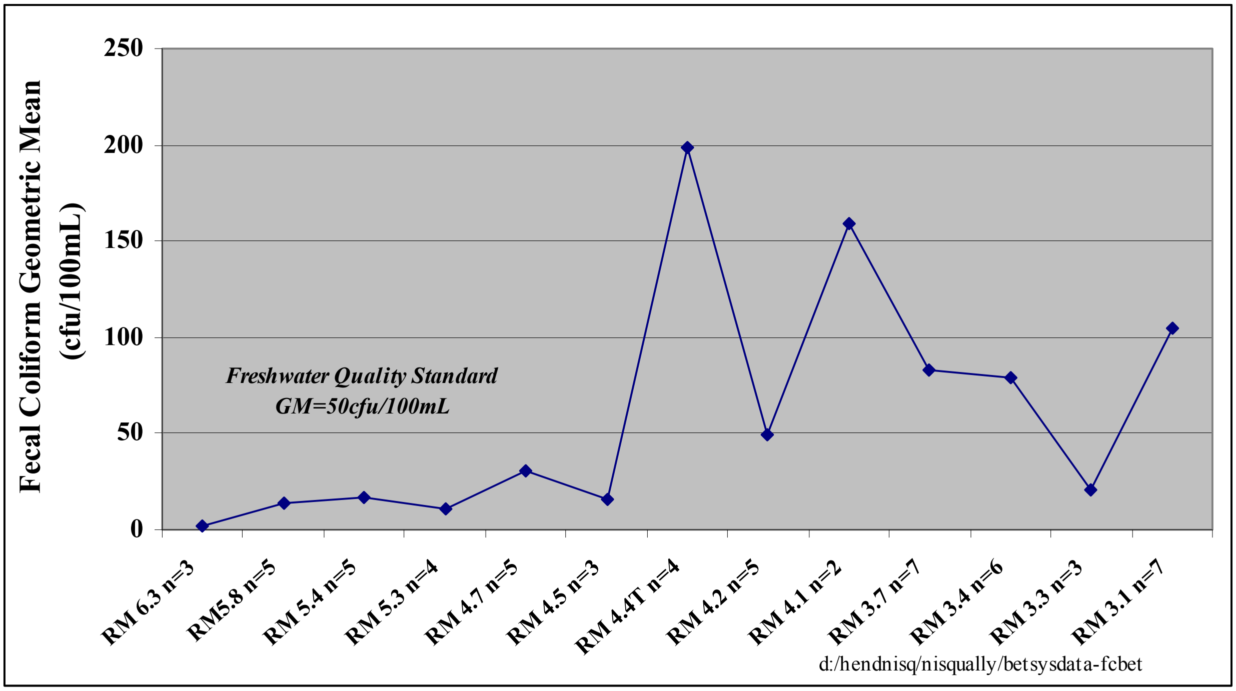

Figure 25. March - June 2001 McAllister Creek Fecal Coliform Levels (Data from Dickes, 2002).

Nisqually/McAllister/Red Salmon Water quality data from Department of Health (Department of Health Shellfish Programs, 2002)

The Department of Health Shellfish Programs has been collecting additional freshwater data at several sites in the Nisqually basin along with their routine marine data collection. Fecal coliform data was collected at McAllister Creek RM 4.7 and 3.4, Nisqually River at approximately RM 2.9 and 1.5, Red Salmon Creek, and Luhr Beach. Table 9 contains a summary of the water quality results from these sites.

Table 9. Summary of DOH Fecal Coliform Results for Tributaries to Nisqually Reach

Site	Sample Dates	n	Geometric Mean	90th Percentile	Standard	Meets Standards
Luhr Beach	2/8/00-4/3/02	25	54	511	Marine AA	NO
McAllister Ck. RM3.4	9/3/98-4/3/02	39	29	156	Marine AA*	NO
McAllister Ck. RM4.7	11/3/98-4/3/02	38	22	100	Freshwater AA	Yes
Nisqually RM 1.5	11/3/98-4/3/02	35	8	43	Freshwater A**	Yes
Nisqually RM 2.9	11/3/98-4/3/02	33	10	49	Freshwater A	Yes
Red Salmon Ck.	4/16/01-4/3/02	13	56	151	Freshwater AA**	NO

* Salinity measurements obtained during sampling indicate marine standards apply.
** Salinity measurements obtained during sampling indicate freshwater standards apply.

A two-tailed paired t-test ($\alpha = 0.05$) was used to compare upstream and downstream fecal coliform results for two sites on the Nisqually RM 1.5 and 2.9 (n= 31) and two sites on McAllister Creek RM 3.4 and 4.7 (n=37). The upstream and downstream fecal coliform concentrations were not significantly different for the McAllister Creek sites or the Nisqually River sites.

Nisqually River fecal coliform levels are excellent, meeting the more stringent marine standard at RM 1.5. Red Salmon and McAllister Creeks did not meet fecal coliform standards. McAllister Creek had lower levels of fecal coliform at RM 4.7 than downstream at RM 3.4, though not statistically significant. The highest levels of fecal coliform were seen at the Luhr Beach marine site. Salinity levels at Luhr Beach ranged from 20-30 parts per thousand (ppt). The Department of Health will continue sampling these sites during the TMDL study.

Nisqually Indian Tribe, The Review and Analysis of Water Quality for the Nisqually River, and the Major Lakes of the Nisqually Basin (Whiley and Walter, 2000)
This report compiles historical water quality data for the Nisqually River and major drainages in the Nisqually basin. Information on basin hydrology and water quality is included in the report.

McAllister Creek Seepage Inflow Study (Pacific Groundwater Group, 2000)
The purpose of the study was to identify the sources and quantify the rates of groundwater inflow to McAllister Creek from the two aquifers based on spring and stream discharge measurements as well as historical estimates. The upland aquifer occurs in Vashon recessional and advance outwash sediments (Qvr and Qva). The sea-level aquifer system includes two distinct formations, the Salmon Springs drift (Qc) aquifer and McAllister gravel aquifer, connected hydraulically. Figure 26 summarizes the incremental inflows for August 2000, which was found to represent long-term average conditions based on historical information. In summary, the uplands aquifer system supplies about 12.9 cfs to seeps along the bluff west of McAllister Creek, including Little McAllister Creek, while the sea-level aquifer discharges about 56.5 cfs to McAllister Springs, Abbot Springs, Medicine Creek, and through valley-floor sediments. The study states that “local groundwater recharge to the floodplain sediments … is of minor importance during the drier summer months.”

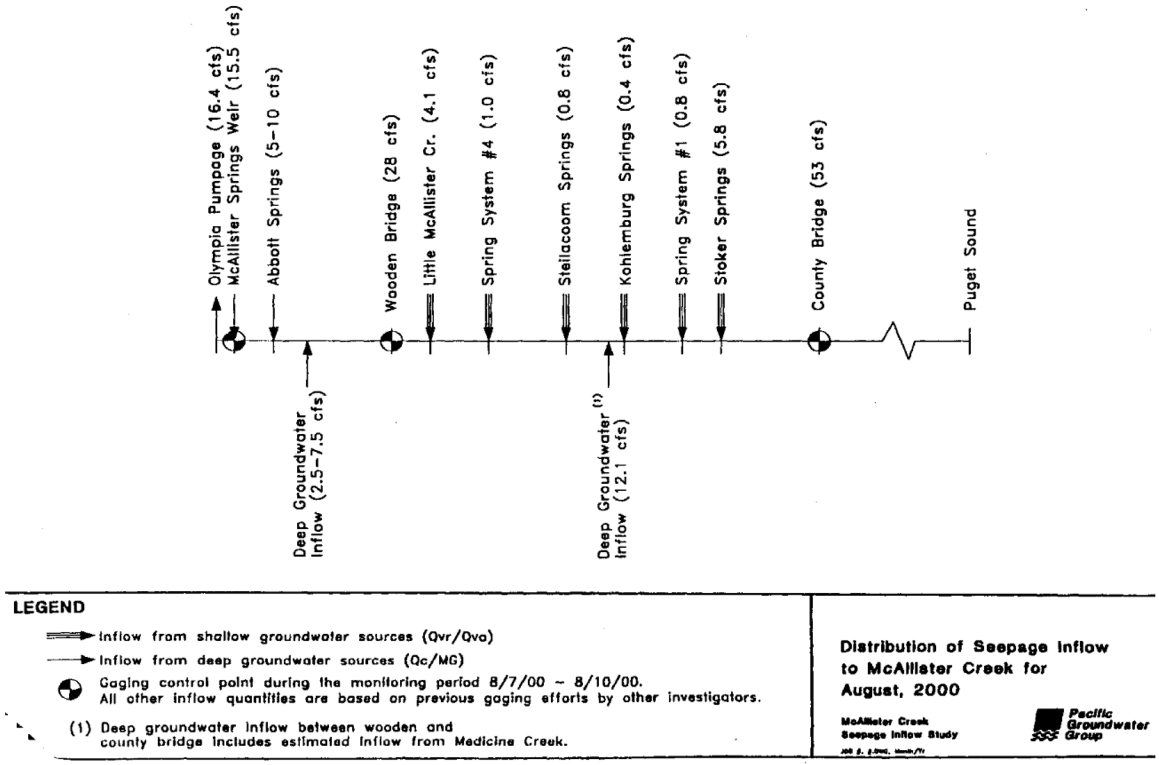

Figure 26. Distribution of Seepage Inflow to McAllister Creek for August 2000

Nisqually Indian Tribe Analysis of Fecal Coliform Concentrations in the NisquallyRiver Drainage (Whiley and Walter, 1998)
This fecal coliform bacteria study included Nisqually River and major tributaries such as Mashel River, Ohop, Tanwax, Yelm, Muck Creeks, and McAllister Creek. Study objectives included determining whether specific reaches of the Nisqually River have significantly higher fecal coliform concentrations, and to evaluate the role of McAllister Creek and the Nisqually river on bacterial levels in the Nisqually Reach shellfish growing area. Monitoring for fecal coliform occurred at 15 stations from June 1995 - April 1997.

Study results for the Nisqually River indicate that while significant increases in fecal coliform concentrations were observed for the lower 22 miles of the river, those increases were well within the Washington State Water Quality Standard. The trend in fecal coliform for the lower river indicates that concentrations have decreased over the past 19 years from a median level of 33 cfu/100mL to a present median of 10 cfu/100 mL. The study concluded that continued inclusion of the Nisqually River on the 303(d) list is not recommended based on fecal coliform concentrations observed during the study and the historic trend in concentrations in the lower river. The study also confirmed previous findings that McAllister Creek appears to be a chronic source of fecal coliform positively affecting concentrations over the shellfish growing areas of the Nisqually Reach, while the Nisqually River appears to have limited influence.

For Ohop Creek the study found the lowest concentrations of fecal coliform were observed during the wet season when median fecal coliform levels were 25 cfu/100mL, while increases in bacteria occurred during storm-events. Even higher levels were observed during the dry season, May to October, with median fecal coliform concentrations of 145 cfu/100mL.

Nisqually Indian Tribe Identification of Pollution Sources Impacting Salmon Habitat in the Mashel River and Ohop Creek Drainages (Whiley and Walter, 1997).
This study focused on Ohop Creek and Mashel River tributaries to the Nisqually River. The purpose of the study was to identify sources potentially limiting salmon spawning and rearing habitat within the two drainages. Seven stations in the Ohop Creek basin were sampled from August 1993 - April 1995 for water quality parameters such as flow, temperature, dissolved oxygen, pH, total suspended solids, total phosphorus, nitrite-nitrate, total ammonia, and fecal coliform. The study results showed that greater fecal coliform levels were generally present at the lower Ohop Creek sites, below RM 6.0, 3.3, 2.0, and the mouth. During the study, the lower Ohop Creek stations received drainage from two dairy farms since closed. At Ohop Creek, a significant difference was found for the dry season samples. The dry season was the period found to have the highest coliform levels at the lower stations. Additional data was collected for the mouth of Ohop Creek RM 0.1 from June 1995 - April 1997. The median fecal coliform level of the more recent dry season water samples was 120 cfu/100 mL as opposed to the study median of 270 cfu/100mL, a significant improvement in fecal coliform levels. The likely reason for the improvement is that the last two remaining dairy farms within the Ohop valley closed operations between the 1993-94 sample period and 1995. No significant difference was determined for either the wet season or storm event data sets.

Nisqually Indian Tribe Investigation of Fecal Coliform Sources within Drainage to the Nisqually Reach (Whiley and Walter, 1996)
In June 1992 - November 1995, the tribe conducted fecal coliform monitoring within the lower reaches of the major drainages to the Nisqually Reach including the Nisqually River, McAllister Creek, Red Salmon Creek, and five upland drainages along the shoreline from Luhr Beach to Tolmie State Park. The study objectives were to determine the major sources of fecal coliform bacteria to the Nisqually Reach from upland drainage areas and to establish a base of information from which the success of future remedial actions could be judged. An additional study objective was to collect baseline water quality data on McAllister Creek.

Results showed that McAllister Creek provides 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. Figure 27 presents the geometric mean and 90th percentile for each site. After McAllister RM 5.4, the geometric mean remains fairly constant; this is likely due to tidal changes that affect the creek (Whiley and Walter, 1996). The report found that other factors (beside the identified sources) that may influence fecal coliform concentrations within McAllister Creek were the combined effect of alterations made to the creek channel, tidal influences, and reductions in base flow.

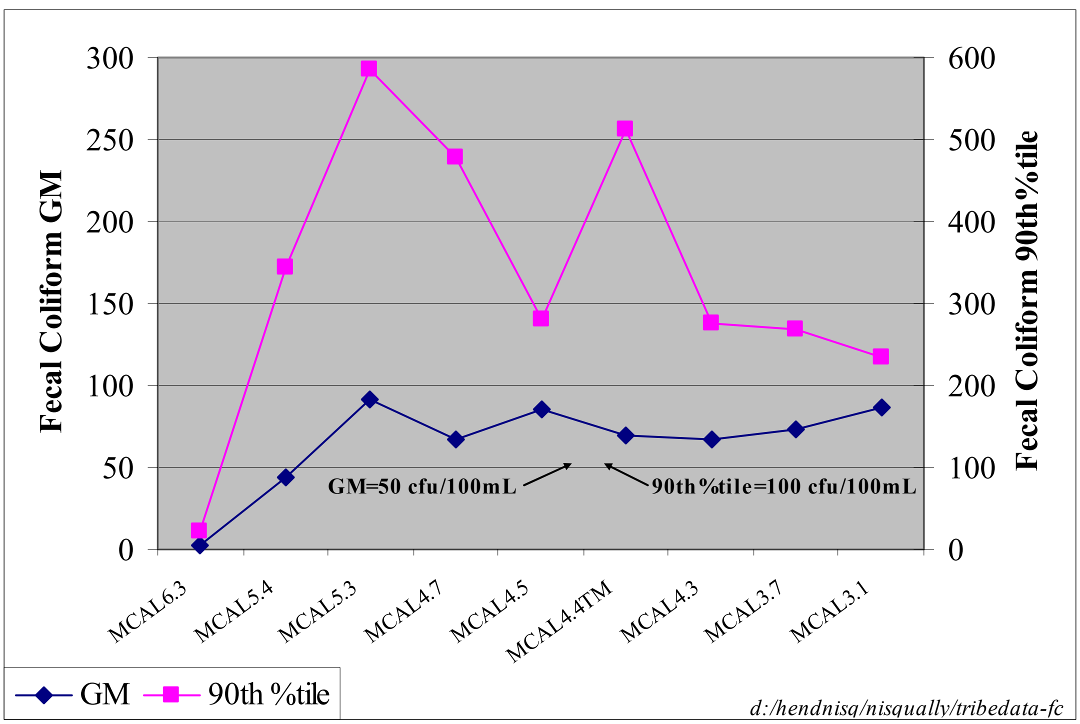

Figure 27. 1993-95 McAllister Creek Fecal Coliform Levels (Data from Whiley and Walter, 1996)
The report also concluded that Red Salmon Creek posed a lower threat to the shellfish beds, but fecal coliform levels in the creek were chronically elevated. Red Salmon Creek did not meet Class AA freshwater quality standards for fecal coliform (Figure 28.)

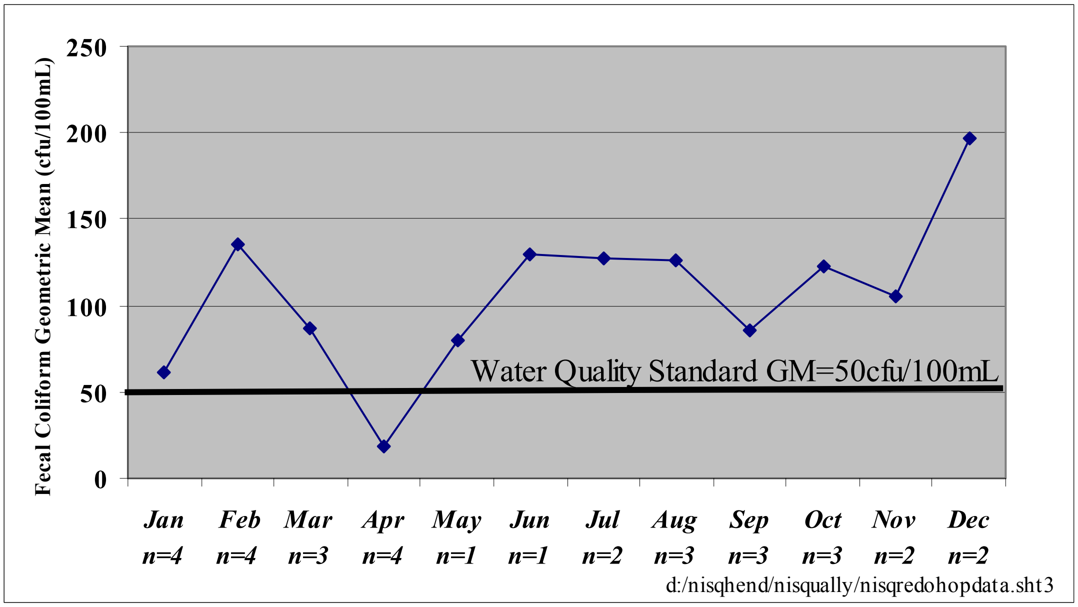

Figure 28. 1993-1995 Red Salmon Creek Fecal Coliform Levels (Data from Whiley and Walter, 1996)

Thurston County Environmental Health Ambient Monitoring Data 1993-99

Thurston County monitored several parameters on McAllister Creek at I-5 from 1993 through 1998 including dissolved oxygen, conductivity, and fecal coliform. Conductivity levels obtained during the study ranged from 187-33960 umhos with a 95th percentile conductivity of 17,700 umhos, equivalent to salinity greater than 10 ppt. Thus, the marine AA water quality standards apply to this station. Table 10 provides a summary of the dissolved oxygen and fecal coliform data the county collected.

Table 10. Summary of Thurston County Dissolved Oxygen and Fecal Coliform Data 1993-1998

Year	n	Fecal Coliform GM	Fecal Coliform Median	Fecal Coliform Range	Dissolved Oxygen Mean	Dissolved Oxygen Range
1993	7	148	100	11-7500	8.7	7.0-10.9
1994	6	47	50	30-90	7.1	3.4-8.4
1995	6	114	77.5	55-500	8.0	7.3-8.7
1996	6	72	55	30-340	8.0	6.7-8.8
1997	6	40	27.5	20-110	8.0	6.6-9.1
1998	5	63	110	15-130	8.3	7.5-9.3

This site met marine dissolved oxygen levels in 1995, but did not meet marine dissolved oxygen levels for any other year sampled (Figure 29). Fecal coliform levels did not meet marine standard for any year sampled and did not meet the freshwater standard for most years either.

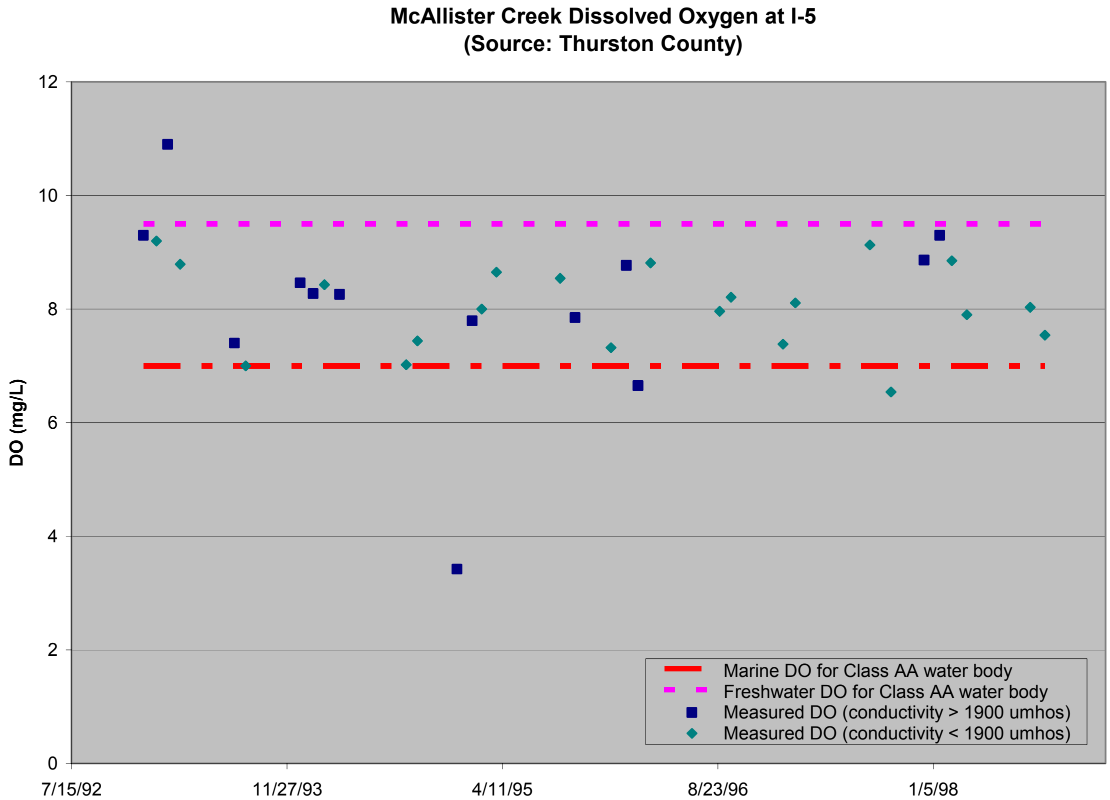

Figure 29. McAllister Creek Dissolved Oxygen Levels at Interstate-5

Washington State Department of Ecology River and Stream Ambient Monitoring Reports (Department of Ecology 1990-2002)

Department of Ecology's Ambient Monitoring Program conducts monthly monitoring for several parameters at Nisqually RM 3.4. Data from 1990 through the present is available. The station at Nisqually RM 3.4 was 303(d) listed based on two points of ambient monitoring data from 1992 and 1993.

Figure 30 presents the Ambient Monitoring fecal coliform data from October 1992 through June 2002. Since April 1993, there have been no reported fecal coliform values > 200 cfu/100mL. Fecal coliform levels at this site are extremely low, easily meeting the required Class A freshwater fecal coliform standard. Most years this site meets the stringent Class AA marine standard for fecal coliform.

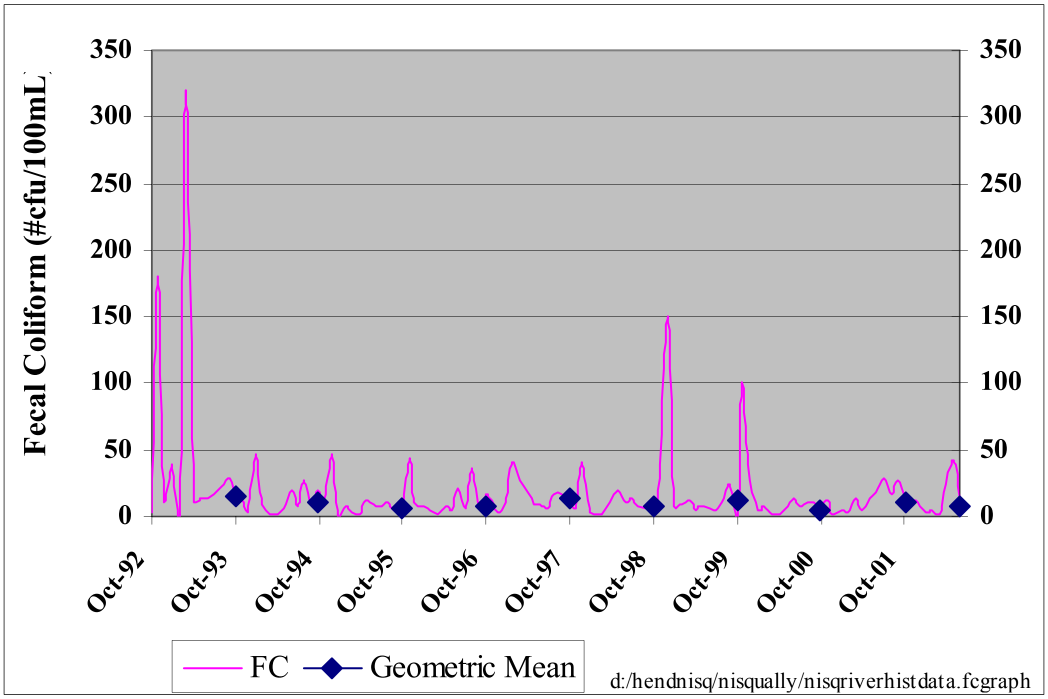

Figure 30. Nisqually RM 3.4 Fecal Coliform Data October 1992 - June 2002

McAllister/Eaton Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1994)

The study area for this plan extended beyond the surface water drainage divide for McAllister Creek, since the McAllister basin aquifer system receives infiltrated stormwater from the Woodland Creek watershed as well as the Fort Lewis potholes, St. Clair potholes, and Lake St. Clair/Eaton Creek drainage; the latter basins have no surface water outlet.

The surface waterbody, McAllister Creek, originates at 6.7 feet MSL at McAllister Springs, where 20-40% of the flow originates from Lake St. Clair. The plan distinguishes five reaches, with the characteristics summarized in Table 11.

Table 11. McAllister Creek Reach Characteristics

Reach	1	2	3	4	5
Start RM	6.3 (McAllister Springs)	5.6	4.3 (Steilacoom Rd)	3.65 (Martin Way)	2.4 (natural channel below I-5)
End RM	5.6	4.3 (Steilacoom Rd)	3.65 (Martin Way)	2.4 (natural channel below I-5)	(estuary)
Tributaries	Abbott Springs (7-10 cfs) Lodge Springs (6 cfs)	Little McAllister Creek, Medicine Creek, seeps, agricultural ditches/tide gates			
Gradient	Extremely low	Low	Increasing		
Land use	Forested wetland	Agriculture	Residential (to RM4.1); undeveloped forest	Transportation	Undeveloped
Riparian cover	Good (shrub)	Low	Good in undeveloped forest; removed in residential area	Very little	Salt marsh wetlands
Temperature variation	Low	High			
Substrate	Gravels, sand, peat, muck	Peat, muck	Gravels		Silt and muck
Habitat	Good (pools, springs, side channels, fallen trees)	Uniform (no riffles or large organic debris)	Good from RM4.1 to RM3.65 (riparian wetlands and canopy cover)		
Tidal amplitude	3-4 ft	5 ft			
Bank condition	Good	Poor (dikes)		Poor (riprap)	Right bank poor (dikes)
General description				Diversion channel	

The city of Olympia monitors water quality at the springs. Temperatures range from 10 to 11°C, with fecal coliform concentrations of 1/100 ml; however, dissolved oxygen falls below 9.5 mg/L.

Medicine Creek had been a significant salmon stream, but the creek is highly disturbed and has been altered extensively including removal of riparian vegetation, decreased flows, and diking. Little McAllister Creek originates from springs along the bluff, cascading down the bluffs through logjams that block fish passage. Riparian cover is good. A ditch draining wetlands south of Pacific Avenue has increased the length of the creek and the surface runoff, which has incised the ditch.

Lake St. Clair covers 261 acres and is nearly 100 feet deep. The lake level has fluctuated between 66.25 and 69.75 ft above sea level. Volunteer monitoring indicates a strong thermal gradient and near-zero bottom dissolved oxygen levels. Eaton Creek originates in a spring-wetland complex and flows 3.25 miles to Lake St. Clair. Groundwater modeling indicates the area contributing to the springs extends east to Pattison and Long Lakes and south to include Eaton Creek and Raymond Ditch.

More than half the wetlands that occurred historically at the McAllister/Nisqually delta have been destroyed (Burg, 1984). Remnant marshes are estuarine emergent wetlands.

Regional Planning Efforts

Nisqually River Level 1 Watershed Assessment, WRIA 11 (Watershed Professionals Network Envirovision GeoEngineers, 2002)
The Level 1 watershed assessment for WRIA 11 provides an assessment of water availability and quality, as well as information on fish and wildlife habitat. The document provides an overview of the basin geology, soils, precipitation, and land use, information on water quantity, stream flow, groundwater inputs, and instream flows as well as summaries of water quality data and fish habitat information. Recommendations are made regarding data gaps and information needed to improve the understanding of water supply needs, instream flows, and water quality.

Response Strategy for Shellfish Growing Area Downgrades in Henderson Inlet and the Nisqually Reach (Puget Sound Action Team et al., 2001)
This shellfish closure response strategy was developed in response to shellfish growing area downgrades in Henderson Inlet and Nisqually Reach. The strategy describes actions to improve water quality in these areas and reverse the downgrades. For each action, a responsible entity, timetable, and funding resource (both available and needed) are designated. Actions include identifying and controlling agricultural, stormwater, and on-site sewage system sources of pollution.

Project Organization

The roles and responsibilities of Ecology staff are as follows:

- ***Debby Sargeant*** *(Project Manager for the TMDL Technical Study, Environmental Assessment Program, Water Quality Studies Unit)*: Responsible for overall project management. Defines project objectives, scope, and study design. Responsible for writing the project QA Project Plan and final report. Manages data collection program. Writes TMDL technical study report.

- ***Mindy Roberts*** *(Marine Modeler, Environmental Assessment Program, Water Quality Studies Unit)*: Defines study design for the marine components. Responsible for writing the marine components of the QA Project Plan and final report, and conducting the marine TMDL analysis.

- ***Jeannette Barreca*** *(Project Manager for the Overall TMDL Project, Water Quality Program, Southwest Regional Office)*: Acts as point of contact between Ecology technical study staff and interested parties and coordinates information exchange and meetings. Supports, reviews, and comments on QA Project Plans and technical reports. Leads implementation planning and preparation of TMDL document for submittal to EPA.

- ***Kelly Susewind*** *(Section Supervisor, Water Quality Program, Southwest Regional Office)*: Responsible for approval of TMDL submittal to EPA.

- ***Will Kendra*** *(Section Manager, Environmental Assessment Program, Watershed Ecology Section)*: Responsible for approval of project QA Project Plan and final TMDL report.

- ***Karol Erickson*** *(Unit Supervisor, Environmental Assessment Program, Water Quality Studies Unit)*: Reviews project QA Project Plan, final TMDL report, and technical study budget.

- ***Barbara Carey*** *(Environmental Assessment Program, Nonpoint Studies Unit)*: Responsible for groundwater sampling including study design, data analysis, and reporting findings.

- ***Stuart Magoon*** *(Ecology Manchester Laboratory Director, Environmental Assessment Program)*: Provides laboratory staff and resources, sample processing, analytical results, laboratory contract services, and QA/QC data. Reviews sections of the QA Project Plan relating to laboratory analysis.

- ***Chuck Springer*** *(Environmental Assessment Program, Stream Hydrology Unit)*: Responsible for the deployment and maintenance of continuous flow loggers and staff gauges. Responsible for producing records of hourly flow data at select sites for the study period.

- ***Cliff Kirchmer*** *(Quality Assurance Officer, Environmental Assessment Program)*: Reviews QA Project Plan and all Ecology quality assurance programs. Provides technical assistance on QA/QC issues during the implementation and assessment of the project.

- ***Sue Davis*** *(Project Lead for Thurston County Public Health and Social Services, Environmental Health Division)*: Coordinates Thurston County monitoring assistance and county lead for technical issues and assistance.

- ***Julie Rector*** *(City Contact for City of Lacey Cooperative Monitoring)*: City lead for technical issues and assistance.

- ***Kirk Robinson*** *(Project Lead for Thurston Conservation District)*: Provides monitoring assistance for McAllister Creek and lead for technical issues and assistance.

- ***George Walter*** (*Contact for Nisqually Tribe Cooperative)*: Tribal technical lead for water quality issues.

Quality Objectives

The measurement quality objectives are presented in Table 12. The laboratory's data quality objectives and quality control procedures are documented in the Manchester Environmental Laboratory (MEL) Lab Users Manual (MEL, 2000) and the MEL Quality Assurance Manual (MEL, 2001).

Table 12. Measurement Quality Objectives for Field and Laboratory Determinations.

Analysis	Accuracy % deviation from true value	Precision Relative Standard Deviation	Bias % deviation from true value	Lower Reporting Limits Concentration units
Field Measurements				
Velocity*	± 2% of reading +0.05 f/s 0.1 f/s	0.1 f/s	N/A	0.05 f/s
pH[1]	0.2 s.u.	0.05 s.u.	0.10 s.u.	N/A
Water Temperature[1]	± 0.2°C			1°C to 50°C
Dissolved Oxygen	15	5% RSD*	5	0.1 mg/L to 15 mg/L
Specific Conductivity	10	<10% RSD*	5	1 umhos/cm
Laboratory Analyses				
Fecal Coliform (MF)	N/A	25% RSD[2]*	N/A	1 cfu/100 mL
Escherichia Coli (MF)	N/A	25% RSD[2]*	N/A	1 cfu/100 mL
Biochemical oxygen demand	N/A	25% RSD*	N/A	2 mg/L
Turbidity	20	10% RSD*	N/A	1 NTU
Total Persulfate Nitrogen	30	10% RSD*	10	0.025 ppm
Ammonia Nitrogen	25	10% RSD*	5	0.010 ppm
Nitrate & Nitrite Nitrogen	25	10% RSD*	5	0.010 ppm
Orthophosphate P	25	10% RSD*	5	0.003 ppm
Total Phosphorus	25	10% RSD*	5	0.010 ppm

[1] As units of measurement, not percentages
[2] Logtransformed data
* Values listed are targets for maximum acceptable error.

Accuracy includes both precision and bias. Precision is a measure of data scatter due to random error, while bias is a measure of differences between a parameter value and the true value due to systematic errors. Precision can be quantified using a number of parameters, including relative percent difference (RPD)[1], standard deviation (s)[2], pooled standard deviation (s_p)[3], or percent relative standard deviation (%RSD)[4]. For paired results, %RSD = RPD/√2. The %RSD will be used to assess data quality, as listed in the table. Since random error affects the determination of bias, bias qualification is very difficult. Adherence with established protocols will eliminate most sources of bias (Lombard et al, 2001).

Experience at the Department of Ecology has shown that duplicate field thermometer readings consistently show a high level of precision, rarely varying by more than 0.2°C. Therefore, replicate field thermometer readings were not deemed to be necessary and will not be taken.

Henderson Study Design

General Approach

The TMDL study will require field data collection and a closer analysis of historical data. Synoptic field surveys during the critical periods will examine fecal coliform bacteria, dissolved oxygen, and pH issues in Henderson Inlet basin. The critical period for fecal coliform is during rainfall events; for pH the critical period is the wet season from November through March. The critical period for dissolved oxygen occurs during the summer months with low values at some sites during the winter months as well. Field surveys will be focused on storm event sampling during the wet season and some dry season monitoring to address dissolved oxygen issues. Continuous monitoring and groundwater monitoring will be conducted to answer specific questions regarding dissolved oxygen and pH. For Goose and Meyer Creeks, monitoring will be conducted to determine if these sites are still impaired for fecal coliform bacteria.

Ecology will coordinate freshwater modeling efforts with Thurston County's HSPF efforts to the extent possible. HSPF is a linked watershed and waterbody model that can simulate simple one-dimensional stream transport and transformation of various water quality constituents, including bacteria. For example, we may be able to build water quality components onto the water quantity components currently under development through the 2514 process.

Point and nonpoint source loads of bacteria can be routed through the Woodland Creek stream network under varying hydrologic conditions, evaluating transport and fate of the bacteria at the mouth of Woodland Creek. Existing data will be used to quantify loads by stream reach and/or to compare with model results. An alternative approach, should the HSPF model not meet the needs of the current project, is to route the differential loads downstream and compile a simple mass balance using exponential decay to account for settling and die-off.

A simple spreadsheet model will be developed for Henderson Inlet. The model will be used to evaluate the effect of dilution and travel time on fecal coliform concentrations in the inlet based on marine, shoreline, and tributary sources of bacteria. Direct marine sources of bacteria from wildlife will be estimated from available wildlife surveys and literature reviews of loading rates. Shoreline sources (e.g., septic systems) will be estimated from previous studies of septic system failure rates applied to the number of septic systems near the inlet. Tributary point sources will be estimated using a combination of in-stream data, hydrologic modeling of larger tributaries, and data analysis. Thurston County and Ecology data will be used directly or as model input to estimate the loads reaching Henderson Inlet from the mouths of Woodland and Woodard Creeks. Additional smaller tributaries have bacteria data that may be sufficient to estimate loads. Contributions from unmonitored locations will be estimated using monitoring data from areas with similar land uses; the land area without monitoring data is small relative to the overall Henderson Inlet watershed area.

Marine Monitoring for Henderson Inlet

Previous data (Determan, 2001) indicate a longitudinal variation in fecal coliform levels in Henderson Inlet, with the highest levels in the southern part of the inlet, as shown in Figure 7. In general, stations south of 61st Avenue exceed a fecal coliform concentration of 14/100 ml, while those stations north do not. DOH data (Melvin, 2002) indicate a tendency toward higher concentrations in the winter, during ebb tides, during southerly winds, and greater than or equal to two hours after the start of ebb tide, as described under Historical Information Review.

Henderson Inlet Time of Travel and Flow Paths

Time of travel provides an indication of the area of influence of bacteria sources as well as residence time. As travel time and distance traveled increase, greater die-off and dilution can occur. Previous hydrographic surveys (Thurston County PHSS, 2002, Appendix A) found that Woodland Creek waters travel to the vicinity of DOH historical station 5 (station 188) within two hours on a typical ebb tide. We will conduct a similar but supplemental survey, coupled with fecal coliform grabs from Woodland Creek and water column profiles along Henderson Inlet. The coupled time of travel and fecal coliform samples will provide information regarding fecal coliform transport and die-off not available in the currently available data.

Three ebb-tide events will be targeted in the southern and central parts of the inlet, two during winter conditions (November through April) and one during summer conditions (July through September). Typical or strong tidal exchange events will be monitored to estimate faster travel times, preferably under calm conditions or southerly winds. On each occasion, at least 50 surface drogues (oranges or grapefruits) will be released at several shore locations, as described in Table 13, and positions monitored by boat over the tidal cycle. Figure 31 shows freshwater and marine water monitoring stations. Grabs from Woodland Creek and Woodard Creek will be collected two to five times per event, beginning several hours before release of the drogues, and discharge will be measured at the mouths or estimated from upstream continuous gaging where available to characterize the incoming load of bacteria over the tidal cycle. Fecal coliform grab samples will be collected and flows estimated for Dobbs Creek, Meyer Creek, Swayne Creeks, and Libby/Sleepy Creek two to five times during the tidal cycle under study. In addition, surface grabs will be collected and analyzed for fecal coliform bacteria and profiles (temperature, salinity, conductivity, dissolved oxygen) recorded along a longitudinal gradient in Henderson Inlet[5].

Table 13. Release Locations for Henderson Inlet Time of Travel Studies

Release Location	Distance along center of inlet from Woodland Creek mouth	Tidal Condition
Mouth of Woodland Creek	0 ft	High slack tide
Mouth of Woodard Creek	13,500 ft	High slack tide
Optional Locations		
Mouth of Dobbs Creek	1,800 ft	One hour after high slack tide
Near DOH station 188 (Swayne Creeks)	6,500 ft	Two hours after high slack tide
Mouth of Meyer Creek	9,000 ft	
Mouth of Libby Creek	15,000 ft	

[5] Chapman Bay is closed to boaters year round, and Woodard Bay is closed from Labor Day to April 1 to reduce impacts on waterfowl in the Woodard Bay Natural Resource Conservation Area, managed by the Department of Natural Resources. Ecology has received permission to access Woodard and Chapman Bays by canoe or kayak with previous notification to Leslie Durham, regional lands manager for DNR.

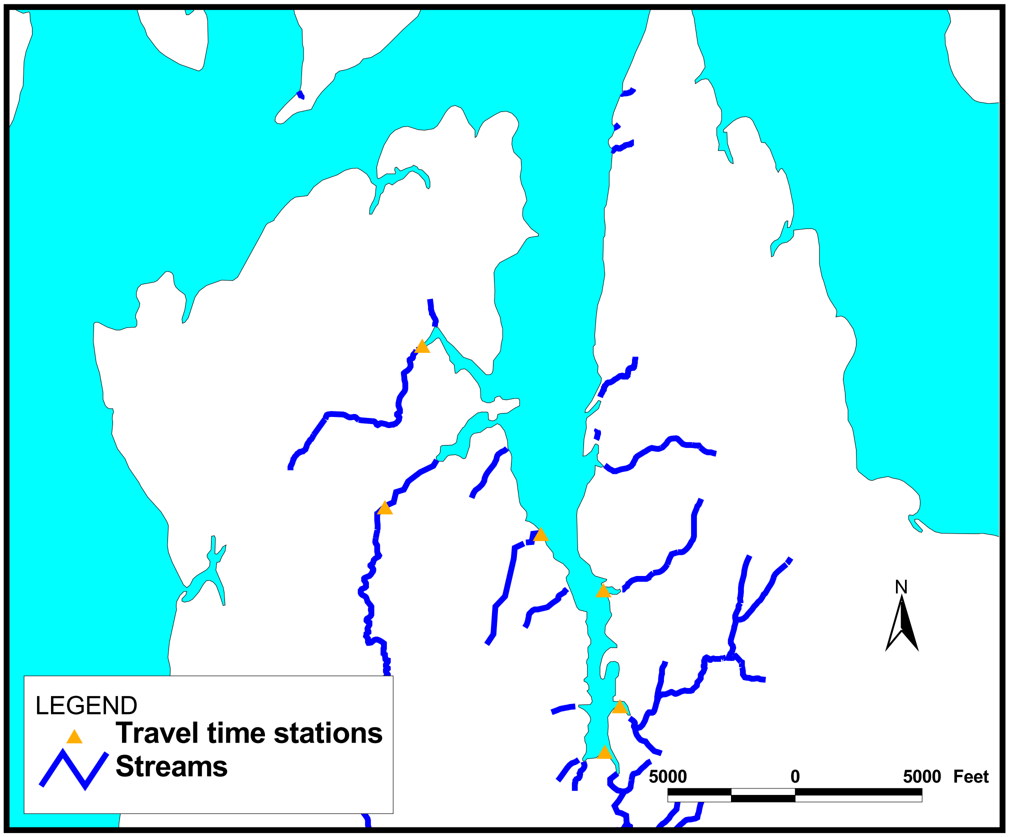

Figure 31. Monitoring Stations for Henderson Inlet Time of Travel Studies

In Situ Fecal Coliform Decay

Fecal coliform bacteria are lost from the water column via several physical, chemical and biological mechanisms, including death, settling, and predation. Ambient factors contributing to death of the organism include temperature, solar radiation, and salinity. Mancini (1978) developed a model of fecal coliform bacteria die-off, based on a literature review that indicates high temperature and light increase die-off rates. Shorter light wavelengths (<370 nm; Mancini, 1978), which are attenuated in the upper water column, appear to be responsible for most of the lethal effects. Thus, die-off rate will vary with depth. Also, as the percent of sea water increases, the bacteria die off faster (Hanes and Savage, 1971), due to osmotic pressure as well as other components of sea water. These various factors are combined into a bacterial decay function often represented as first-order decay:

$$C = C_o e^{-kt}$$

where C is the concentration at any time, t; C_o is the initial concentration; and k is a die-off rate, which may vary with temperature (T) and percent seawater (Mancini, 1978):

$$k = [\ 0.8 + 0.006\ (\%\text{sea water})\ ] * 1.07^{(T-20)}$$

Literature values of k range from 0.3/day to 3.0/day for fresh and seawater, with reasonable k(T=20°C) of 0.8/day for freshwater and 1.4/day for seawater.

We will conduct in situ die-off studies to identify appropriate site-specific die-off rates. The experiments will use enclosed chambers with minimal light attenuation (such as glass, acrylic, or other plastic) that thermo-regulate with the ambient environment yet confine bacteria-sized particles (Easton, 2000). These chambers will be filled with surface and mid-column ambient Henderson Inlet water, spiked with either bird or dog feces, and suspended from a pier near the surface and at mid-column. Duplicate chambers will be used for each treatment. Chambers will be installed and the first sub-sample collected in the morning. Morning and afternoon sub-samples will be collected on Day 1 (t=0, t=0.25 days) and Day 2 (t=1 and 1.25 days), then morning samples only on and after Day 3 (t=2 days) until the curve is defined. Depending on the in situ die-off characteristics, four to six samples collected over two to four days will be necessary to develop the curves. The experiment will be repeated in winter and summer conditions.

Wildlife Bacteria Contributions

Waterfowl and marine mammals excrete wastes directly into freshwater and marine water bodies. Gulls void an average of 20g of fecal matter per day (Gould and Fletcher, 1978; Nixon and Oviatt, 1973), with 5.3 x 10^6 fecal coliform per gram of feces (wet weight), and a range 2.7 to 37 x 10^6 fecal coliform per gram of feces (Gould and Fletcher, 1978). Therefore, each gull contributes on the order of 10^7 fecal coliform per day. Contributions from other wildlife, domestic animals, and humans are summarized in Table 14. We will estimate wildlife bacterial contributions using literature values for daily fecal production or concentrations and any available wildlife counts. The primary wildlife area appears to be the Woodard Bay Natural Resource Conservation Area, used by both seabirds and seals.

Table 14. Fecal Coliform Contributions by Species

Species	FC density (10^6 fc/g-feces)	Fecal rates (g-feces/day)	FC loads (10^6/day)	Reference
Humans	13.0		2,000	Metcalf and Eddy, 1991
Wildlife				
Seagull	5.3 (2.7 to 37)	20	100 (54 to 740)	Gould and Fletcher, 1978; Nixon and Oviatt, 1973
Duck	33.0		11,000	Mara, 1974; Metcalf and Eddy, 1991
Canada goose				
Seal	190		66,500	Calambokidis et al., 1989
Domestic Animals				
Dog				
Cow	0.23		5,400	Metcalf and Eddy, 1991
Chicken	1.3		240	Metcalf and Eddy, 1991
Pig	3.3		8,900	Metcalf and Eddy, 1991
Turkey	0.29		130	Metcalf and Eddy, 1991

The Black Hills Audubon Society performs the annual Christmas bird count in the region, although published numbers combine bird counts from Woodard Bay with portions of the

Nisqually Reach, Budd Inlet, and Eld Inlet. Bird use generally peaks at this time, and counts represent maximum usage.

A study conducted in the East Bay of Budd Inlet from September 1993 to May 1994 documented species and counts. Figure 32 illustrates the seasonal pattern of bird usage, with highest levels from November to March.

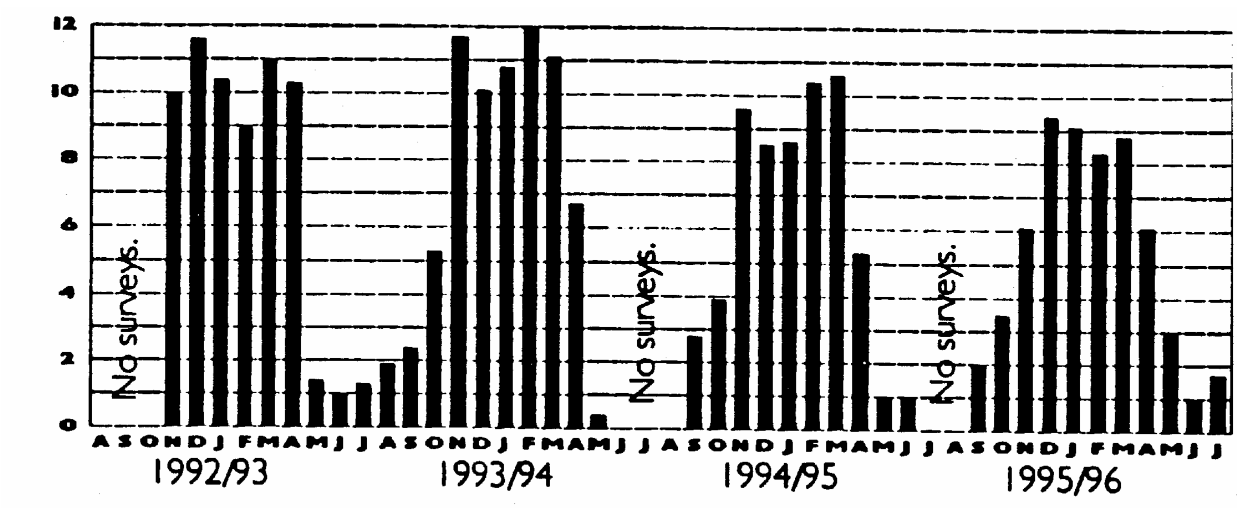

Figure 32. Budd Inlet Bird Counts from September 1993 - May 1994

In addition, the Washington Department of Fish and Wildlife has performed seal counts since 1993 (Lambourn, 2002), while earlier counts were conducted by John Calambokidis. Woodard Bay appears to be the only significant seal haul-out area within Henderson Inlet. Peak usage occurs during the pupping, molting, and mating season, typically from the last week of June to mid-November. Peak numbers have been reasonably constant at 400 to 500 animals from 1993 through 2000, although DFW staff noted a significant decrease in peak usage (under 300 animals) since summer 2001 which coincides with a decrease in the number of logs available as winter storms detach logs from the rafts; the remaining animals are believed to have moved to other locations outside of Henderson Inlet. At other times of year, seal numbers are approximately half; however, DFW has focused surveys on periods of peak usage. DFW staff found minimal variation in the number of seals hauled out with tidal cycle, a typical pattern at nearby regional haul outs.

Domestic Animal Bacteria Contributions

Domestic animal contributions are summarized in Table 14. In general, loads from domestic animals are included in tributary loads to Henderson Inlet.

Sediment Resuspension

Bacteria may be harbored in freshwater and/or marine sediments and subsequently re-released to the water column as a result of storm scour in streams and/or waves and currents impacting tidal mudflats. In general, fecal coliform bacteria require environmental conditions present in the gut of warm-blooded mammals to reproduce. Most studies indicate that bacteria deposited in sediments of streams and estuaries do not reproduce. However, these bacteria can survive for longer periods within sediments than in the overlying water column (Burton et al., 1987; Gerba and McLeod, 1976). Survival rates of bacteria in sediment may be longer than 30 days compared with several days in the water column (Sherer et al., 1992).

A recent study found that wind waves played a minor role in resuspension of bacteria in Dungeness Bay (Rensel and Smayda, 2001). Paired marine water samples were collected before and after the water column was agitated via prop wash. While turbidity increased, fecal coliform concentrations did not increase following agitation; concentrations decreased, possibly due to dilution with underlying waters. One location, which smelled strongly of fecal material, exhibited an increase in water column fecal coliform concentrations; however, initial water column concentrations were also high. In another study of a reservoir in Massachusetts (CDM, 1995), no evidence was found to support a concern that convection currents associated with fall turnover contributed to significant increases in water column fecal coliform concentrations. Weiskel et al. (1996) found that resuspension of bacteria from subtidal sediments was small compared with other sources to a shallow estuary in Massachusetts; the study compared water column concentrations before and after disturbing the bottom sediments. McDonald et al. (1982) identified freshwater sediment scour and bacterial resuspension as the source of increases in fecal coliform concentrations following pulsed releases from upstream impoundments.

A laboratory study conducted by personnel from the Bremerton-Kitsap County Health Department concluded that fecal coliform were reproducing in the sediments (Struck, 1988); however, this finding has not been supported in other studies. Gibbs et al. (1997) reported increased concentrations of fecal coliform and *Salmonellae* following land application of composted biosolids as compared with the initial concentrations, which they attribute to an increase in moisture content to that required for reproduction. In a Michigan study, fecal coliform and fecal streptococci were found to persist in high concentrations in storm drain sediments during warm, dry weather periods; that study also found some evidence of reproduction (Marino and Gannon, 1991).

While sediments may harbor bacteria that may be resuspended under certain conditions, the sediments generally are not the original source of bacteria. Therefore, as actual bacteria sources are controlled, bacteria resuspension from sediments should attenuate. Thus, bacteria held in the sediments will be treated as internal storage and not as a distinct source.

Henderson Inlet Ambient Dissolved Oxygen Levels

We will record profiles of dissolved oxygen throughout Henderson Inlet in fall 2003. Historical data indicate minimum DO levels in the hypolimnion occur in late fall. One event, lasting up to two days, will be conducted.

Henderson Watershed Freshwater Monitoring

Monitoring for Henderson Inlet tributaries will include Woodland, Woodard, Sleepy (Libby), Meyer (Snug), Dobbs, and Goose Creek. Sampling sites for Woodland Creek are presented in figure 2, and all other sites in the Henderson basin are shown in Figure 3.

Synoptic Surveys

Synoptic field surveys will include three to four low flow events from June through September in 2003; and up to six to eight storm events during the wet season from mid-November through April 2002-03. A storm event is defined as 0.30" of rain in the previous 24 hours. Both Henderson Inlet and many of the tributary streams of interest have higher fecal coliform levels during storm events. Field and laboratory parameters for each site and season are shown in Table 15.

Sampling for each survey will be conducted in one day by two teams of two from the Department of Ecology and Thurston County. Instantaneous stream flow measurements or gauge reading will be obtained at each site to determine flow. Samples will be taken as grab samples from a single location for all sites. For monitoring stations influenced by tide, sampling will occur at the lowest tide possible during the day.

Table 15. Field and Laboratory Monitoring Parameters and Sample Times for Each Station

Sample Site	RM	Site Code	FC/E-coli Storm Event	FC/E-coli Low Flow	Nutrients Storm Event	Nutrients Low Flow	Dissolved O_2 Storm Event	Dissolved O_2 Low Flow	Temp, pH, Salinity, or Cond.
Woodland Creek (fc, DO)									
At Hawks Prairie Road	0.2	WL0.2	X	X		X		X	All events
At Hollywood Drive	1.0	WL1.0	X	X					All events
Quail Creek	1.1T	WL1.1T	X	X					All events
Jorgenson Creek	1.3T	WL1.3T	X	X					All events
At Pleasant Glade Road	1.6	WL1.6	X	X		X	X	X	All events
Fox Creek	1.9T	WL1.9T	X	X					All events
Palm Creek	1.95 T	WL195T	X	X*					All events
Eagle Creek	2.25 T	WL225T	X	X					All events
21st Court NE	2.6	WL2.6	X	X					All events
At Draham Road	2.9	WL2.9	X	X					All events
D/S of Interstate-5	3.1	WL3.1	X	X		X	X	X	All events
College Creek at RM 3.4T									
At Mouth	0.0	CC0.0	X	X					All events
Behind Top Foods	0.2	CC0.2	X	X*					All events
At Century Court	0.4	CC0.4	X						All events
At Bike Path U/S I-5	0.6	CC0.6	X						All events
U/S of College Creek	3.4	WL3.4	X	X		X	X	X	All events
Trib U/S from College Creek	3.4	WL3.4SP	X	X					All events
U/S of Martin Way	3.8	WL3.8	X	X*		X	X	X	All events
Stormwater RB Martin Way (Tanglewilde)	3.8T	WL3.8T	X						All events
Just D/S Lake Lois	4.5	WL4.5	X	X*		X		X	All events
Woodard Creek (fc,DO,pH)									
At Woodard Bay Rd.	0.0	WD0.0	X	X		X	X	X	All events
Off of Libby Rd.	2.9	WD2.9	X	X		X	X	X	All events
At 36th Ave.	3.4	WD3.4	X	X		X	X	X	All events
At Lindell Rd.	5.1	WD5.1	X	X		X	X	X	All events
At Ensign Rd.	6.2	WD6.2	X	X		X	X	X	All events
At Bike Path Pacific Ave.	6.9	WD6.9	X	X		X	X	X	All events
Sleepy Creek (fc,DO)									
Near mouth	0.1	SL0.1	X	X		X		X	All events
At Libby Road	0.8	SL0.8	X	X*		X		X	All events
Dobbs Creek (fc,pH)									
At Johnson Point Rd.	0.1	DB0.1	X	X					All events
Meyer Creek (fc,pH)									
At Snug Harbor Dr. NE	0.1	MY0.1	X	X					All events
Goose Creek (fc)									
At Sleater-Kinney Road	0.4	GO0.4	X	X*					All events

* For some sites low flow sampling may not be possible due to no flow at these sites during the dry season.

Continuous Monitoring for Dissolved Oxygen and pH

Tributaries on the 303(d) list for dissolved oxygen (DO) include Woodland Creek between RM 4.2-3.1; Woodard Creek at RM 2.9 to the mouth, Sleepy Creek at RM 0.2, and Dobbs Creek at RM 0.1. For most sites, lower dissolved oxygen levels are seen primarily in the summer or low flow season. At Woodland Creek RM 3.1 dissolved oxygen levels are depressed year round.

To further examine dissolved oxygen issues, three to four days of continuous monitoring will be conducted each month from July through September in 2003 during the low flow season at the sites described in Table 16. For Woodland Creek at RM 3.1, continuous DO monitoring will occur year round. Dissolved oxygen measurements will also be obtained during all low-flow season synoptic surveys.

Tributaries on the 303(d) list for pH include: Woodard, Sleepy, Dobbs, and Meyer Creeks. Low pH occurs primarily during the wet season from November - March. To further examine pH issues, 3-4 days of continuous pH monitoring will be included during December and March (Table 16). In addition, pH readings will be obtained during all synoptic surveys.

Table 16. Continuous Monitoring for pH and Dissolved Oxygen

Sample Site	River Mile	Continuous pH monitoring	Continuous Dissolved Oxygen monitoring
Woodland Creek			
Woodland Ck at Pleasant Glade Road	1.6	No sampling	Low flow
Woodland Ck at I-5	3.1	No sampling	Low flow
Woodland Ck at I-5	3.4	No sampling	Low flow and Wet Season
Woodland Ck at Martin Way	3.8	No sampling	Grab samples for DO (low flow)
Woodland Ck Downstream Lake Lois	4.5	No sampling	Grab samples for DO (low flow)
Woodard Creek			
Woodard Ck off of Libby Rd.	2.9	December and March	Low flow
Woodard Ck at Ensign Rd.	6.2	December and March	Low flow
Henderson Tributaries			
Libby Creek near mouth	0.1	December and March	Low flow
Dobbs Creek at Johnson Point Rd.	0.1	December and March	Low flow
Meyer Creek at Snug Harbor Dr. NE	0.1	December and March	No sampling
Goose Creek at Sleater-Kinney Road	0.4	No sampling	No sampling

Stream Flow

Staff gauges will be installed at selected sites. During the field surveys, flows will be measured at selected stations or staff gauge readings will be recorded. A flow rating curve will be developed for sites with a staff gauge.

Thurston County currently operates a continuous flow gauging station on Woodard Creek at 36th Avenue. The county is planning to reinstall their permanent continuous flow station on Woodland Creek at Pleasant Glade Road during the summer of 2002.

Ecology will install one continuous flow gauging station on Woodland Creek at RM 3.1, south of I-5. Flow estimates will be determined by the Environmental Monitoring and Trends Section, Stream Hydrology Unit. Estimation of discharge and instantaneous flow measurement will follow the Stream Hydrology Unit protocols manual (Ecology, 1999). Flows will be calculated from continuous stage height records and rating curves developed prior to and during the project. Stage height will be measured by pressure transducer and recorded on data loggers every 15 minutes. All station data loggers will have data downloaded every two weeks for the first two months and monthly after that. If during the study continuous, flow monitoring proves impractical, flows will be estimated by regression analysis of instantaneous measurements of gauged versus un-gauged sites and by estimates of watershed runoff using hydrographic methods.

Groundwater Sampling

Groundwater discharge to Woodland Creek between RM 3.8-3.1 will be assessed to determine groundwater impacts to surface water; numerous springs occur in this reach. A total of two to three wells and major springs will be sampled. The wells may be private, public water supply, or monitoring wells. The wells will be sampled once in fall 2002 and once in winter 2003 to determine seasonal effects. Wells selected for monitoring will be located using an electronic global positioning system (GPS) and on 1/24k quad maps for subsequent analysis and plotting via Arcview GIS software.

The following criteria will be used to select the domestic wells that will be sampled near McAllister and Woodland Creeks:

1) A well drillers report (well log) must be available for the well.
2) The well should be completed within the upper-most aquifer that is commonly used for domestic water supply within the area.
3) The well must be easily accessed for water level and water quality sampling
4) The current well owner must grant access to the well.
5) The well should not have a water treatment device (such as a water softener or iron treatment system) or a large storage tank that cannot be bypassed during well purging and sampling.

Field analyses for groundwater samples will include temperature, pH, electrical conductivity, and dissolved oxygen. Samples will be collected for laboratory analysis for ammonia-N, nitrate+nitrite-N, total persulfate N, total phosphate, and soluble reactive phosphate.

Travel Time Estimates

Travel time, the movement of water from point to point in the stream, will be estimated during low and moderate flows for stretches of Woodard and Woodland Creeks. Time of travel for Woodard Creek between RM 6.2 - 5.1, and RM 3.4 - 2.9 will be measured once during the low flow period and during the wet season. For Woodland Creek a time of travel study for three reaches during low flow will occur at the reach between Lake Lois outfall and RM 3.8, the reach below Martin Way and I-5, and one of the lower reaches.

A tracer (either salt or dye) will be slug injected at the upstream location in the stream, and a conductivity meter or fluorometer will be used to measure the concentration of tracer downstream. A plot of concentration against time defines the passage of the tracer cloud at each sampling site. Time of travel is measured by observing the time required for movement of the tracer cloud between sampling sites. In addition, the data can be used to determine dispersion characteristics of the stream.

Nisqually Study Design

General Approach

The TMDL study will require field data collection and a closer analysis of historical data. Synoptic field surveys during the critical period, low tide conditions will examine the fecal coliform bacteria and dissolved oxygen issues for McAllister Creek. For Ohop Creek, Red Salmon Creek, and the Nisqually River, monitoring will be conducted to determine if these sites are still impaired for fecal coliform bacteria.

We will evaluate McAllister Creek water quality using a combination of data analysis and simple spreadsheet models. For example, we will estimate fecal coliform loads using current and historical monitoring data, then use a simple spreadsheet model coupled with the time of travel data to estimate the concentration of bacteria at downstream and marine stations to the Luhr Beach area (i.e., in an area of predominantly one-dimensional transport) during ebb tide conditions.

Continuous monitoring and groundwater monitoring for dissolved oxygen will be conducted to determine if lower dissolved oxygen levels in McAllister Creek are due to natural conditions. Nutrient sampling will be conducted to determine if excess nutrients are contributing to lower dissolved oxygen levels. If bacteria levels are reduced, it is assumed that a decrease in nutrient levels will also be seen.

Marine Monitoring for Nisqually Reach

Extent of McAllister Creek Marine Waterbody Designation

WAC 173-201A-060 describes the application of freshwater or marine water quality standards on the basis of salinity. Where 95% of the vertically averaged daily maximum salinity levels are less than one part per thousand, the freshwater standards apply. For fecal coliform, the marine water quality standard (14/100 ml) applies where salinity is 10 parts per thousand or greater. The historical Thurston County data at I-5 have a 95th percentile conductivity of 17,700 micromhos, equivalent to a salinity greater than 10 ppt. Therefore, the marine fecal coliform and dissolved oxygen standards apply at that point. The city of Olympia drinking water quality monitoring verifies that McAllister Springs is a fresh waterbody. However, no historical conductivity information exists between these locations.

To determine the upstream extent of the marine waterbody designation on McAllister Creek, we will survey salinity and conductivity profiles at multiple locations during high tide conditions.

Nisqually Reach Time of Travel and Flow Paths

Time of travel provides an indication of the area of influence of bacteria sources as well as a residence time to estimate oxygen drawdown resulting from low water exchange. Marine fecal coliform concentrations show spatial and temporal variations, with highest levels occurring in the winter near the mouth of McAllister Creek (Figures 21 and 22). As travel time increases, fecal coliform die-off decreases resulting in highest potential concentrations with other factors remaining equal. A DOH analysis also found that higher marine fecal coliform levels tend to occur during flood tide compared with ebb tide conditions. Therefore, multiple studies will be conducted to determine the area of influence of potential bacteria sources to the Nisqually Reach and residence time during low tidal exchange periods in McAllister Creek.

McAllister Creek Travel Time and Flow Paths

To determine the fastest travel time between locations on McAllister Creek and the nearby estuary, surface tracer releases will be conducted longitudinally at six locations, described in Table 17.

Table 17. Release Locations for McAllister Creek Time of Travel Studies

Release Location	Access	Collect Location	Distance
Tide Gate #15 (near RM 5.6)	Small boat/ downstream of McAllister Springs	Steilacoom Rd	4,800 ft
Steilacoom Rd (near RM 4.7)	Small boat or foot	Medicine Creek	2,500 ft
Medicine Creek confluence (near RM 4.4)	Boat/downstream of log jam	Tide Gate #1	5,100 ft
Tide Gate #1 (near RM 3.7)	Boat or foot/near Martin Way	McAllister Estuary #1	7,300 ft
McAllister Estuary #1	Boat/downstream of bends where channel opens	McAllister Estuary #2	5,300 ft
McAllister Estuary #2	Boat/near Levee Rd	Luhr Beach	4,500 ft

At each drop location, 50-100 surface tracers (either oranges or grapefruit) will be released. A downstream observer will record the time to travel the specified distance and will remove the tracers. To expedite the studies, grapefruit and oranges may be dropped simultaneously at adjacent stations. After a reasonable time, any materials remaining on the margins will be removed by a sweep boat. Drops will occur after high slack tide where the tidal exchange expected by the following low tide is as large as possible. Wind conditions at the estuary will be recorded. Two events will be monitored: one in the summer/fall warm season and one in the winter/spring cool season. Surface grabs, collected at the time of release and two to five times during the study, will be analyzed for fecal coliform. Profiles of temperature, salinity, conductivity, and dissolved oxygen will be recorded on a longitudinal track from McAllister Creek to Luhr Beach.

Flow Paths and Travel Time near Luhr Beach

Previous drogue studies found a northwest trajectory of surface layers around Nisqually Head during a strong winter flood tide (Meriweather, 1999). The net nearshore drift splits at Nisqually Head (Schwartz and Hatfield, 1982), with a net southward drift south of Luhr Beach. However, drift typically reverses during alternating tidal conditions and northward drift can occur. We will investigate flow paths from McAllister Creek during flood tide and from the shore northwest of Luhr Beach during ebb tide conditions. Table 18 summarizes the surface tracer release locations and conditions.

Table 18. Release Locations for Luhr Beach Time of Travel Studies

Release Location	Tidal Condition	Shoreline Distance to Station 225	Travel Time at 0.5 ft/s (hrs)	Travel Time at 1.0 ft/s (hrs)
Luhr Beach	Flood,1 hr prior to peak velocity	2,000 ft	1.1	0.6
Headland near Willamette/Meridian Rd	Ebb, 1 hr prior to peak velocity	1,500 ft	0.8	0.4
Bay at DeWolf Bight/Beachcrest	Ebb,2 hrs prior to peak velocity	5,000 ft	2.8	1.4
Headland northwest of Butterball Cove	Ebb, 2.5 hrs prior to peak velocity	9,500 ft	5.3	2.6
Big Slough/Tolmie State Park	Ebb, 3 hrs prior to peak velocity	13,000 ft	7.2	3.6

At least 50 surface tracers will be released within 100 feet of the shoreline, alternating between oranges and grapefruit at adjacent stations. Surface grabs collected at the time of release will be analyzed for fecal coliform. Qualitative drift direction will be identified for each release. Distance and time of travel will be estimated by establishing GPS waypoints near the center of the surface tracers or any identifiable tracers. The study will target high ebb tide velocities during tidal conditions of large exchange to determine fastest likely travel times and largest distances during a single tidal cycle. Two events will be monitored, one during summer/fall and one during winter/spring.

Flow Paths and Travel Time Northeast of Nisqually Flats

Previous studies (URS Consultants, 1988) have evaluated circulation characteristics around the Fort Lewis wastewater outfall near Solo Point. Surface and deep drogues moved to the southwest during flood tides and often circulated clockwise to the north beyond Cormorant Passage. We will investigate large-scale circulation patterns using the EFDC hydrodynamic model developed for the South Puget Sound Area Water Quality Study (Albertson et al., 2002) including a hypothetical tracer study from the Fort Lewis wastewater outfall to evaluate flow paths and travel time to the Nisqually flats. If the model runs indicate the Solo Point/Tatsolo Point region significantly affects the Nisqually flats, we will conduct additional surface tracer studies. Table 19 lists potential release locations and conditions. Two events will be monitored, if necessary, using the procedures described above.

Table 19. Potential Release Locations Northeast of Nisqually Mudflats

Release Location	Tidal Condition	Shoreline Distance to Station 248	Travel Time at 0.5 ft/s (hrs)	Travel Time at 1.0 ft/s (hrs)
Mouth of Sequalitchew Creek	Flood, 1 hr before peak velocity	2,500 ft	1.4	0.7
Cliffs near 47.1255°N, -122.6590°W	Flood, 2 hrs before peak velocity	6,000 ft	3.3	1.7
Tatsolo Point	Flood, 3 hrs before peak velocity	11,000 ft	6.1	3.1
Outfall location between Solo and Tatsolo Points	Flood, 3.5 hrs before peak velocity	13,000 ft	7.2	3.6

Residence Time During Low Tidal Exchange

Slow flushing rates could contribute to low dissolved oxygen conditions, particularly in areas where the oxygen demand is high. Historical data, which were the basis for the 303(d) listing, show DO does not meet marine water quality standards at I-5. In addition, McAllister Springs does not meet freshwater dissolved oxygen standards.

We will identify critical tidal periods where exchange over the cycle is minimal. We will use surface tracers (oranges and grapefruit) to estimate travel time and travel distance by water masses at two locations: near I-5, where the original listing occurred and near Steilacoom Road, representative of more freshwater conditions. During the release, we will monitor temperature, salinity, conductivity, and dissolved oxygen profiles to further identify water masses. One event will be monitored.

Nisqually Watershed Freshwater Monitoring

Synoptic Surveys

McAllister Creek
The McAllister Creek TMDL study will require some field data collection and a closer analysis of historical data. Nine synoptic field surveys will be conducted to examine the fecal coliform bacteria and dissolved oxygen issues. Surveys will be conducted seven times during the November - April period and twice during the low flow months (July and August). Synoptic surveys will be conducted when the least amount of tidal influence occurs. Three teams from Department of Ecology, Thurston County, and Thurston Conservation District will conduct the sampling. One team will sample upper McAllister Creek and Medicine Creek with kayaks, another boat team will sample lower McAllister Creek from RM 4.3 to Luhr Beach, conservation district staff will sample select tidegates via land. Sample sites and field and laboratory

parameters for each team are described in Appendix E. All samples will be run by Ecology Manchester Environmental Laboratory.

For McAllister Creek field measurements for dissolved oxygen, conductivity, and temperature profiles will be obtained at each sample site to evaluate stratification. If stratification occurs, fecal bacteria samples will be obtained from surface and at depth.

To further examine fecal coliform issues hourly tidal cycle, sampling will be conducted over a 12-hour period at RM 4.7 and 3.7. Tidal cycle sampling will be conducted twice during the study to look at differing tidal cycles.

Ohop Creek, Red Salmon Creek, and Nisqually River
Sampling for Ohop Creek, Red Salmon Creek and the Nisqually River will be conducted to determine whether each area should be de-listed or to set TMDL targets for bacteria on each waterbody. Synoptic field sampling will be conducted monthly at the sites described in Table 20.

Sampling for each survey will be conducted in one day by a team from the Department of Ecology. Samples will be taken as grab samples from a single location for all sites. For monitoring stations influenced by tide, sampling will occur at the lowest tide possible during the day.

Table 20. Field and Laboratory Monitoring Parameters for Each Station

Sample Site	RM	Fecal Coliform/ E-col bacteria	Stream flow
Red Salmon Creek listed for fecal coliform			
Red Salmon Creek east tributary		Monthly	Monthly
Red Salmon Creek west tributary		Monthly	Monthly
Nisqually River listed for fecal coliform			
Nisqually River at Military Road		Monthly	No
Ohop Creek listed for fecal coliform			
Ohop Ck (mouth)	0.1	Monthly	Monthly
Ohop Ck at Hwy 7	2.0	Monthly	No
Ohop ditch at Peterson Road	2.2 D	Monthly	No
Ohop Ck at Ohop Valley Road	3.3	Monthly	No
Ohop Ck downstream Lynch Ck	6.0	Monthly	No
Lynch Creek	6.2T	Monthly	Monthly
Ohop Ck	9.9	Monthly	No

Continuous Monitoring for Dissolved Oxygen

McAllister Creek
To further examine dissolved oxygen on McAllister Creek three to four days of continuous monitoring will be conducted in December 2002, March, July, and August 2003 at three sites on McAllister Creek, RM 3.7, 4.7, and 5.8

Stream Flow

McAllister Creek

Ecology will install one continuous flow gauging station on McAllister Creek at Steilacoom Road. Flow estimates will be determined by the Environmental Monitoring and Trends Section, Stream Hydrology Unit. Estimation of discharge and instantaneous flow measurement will follow the Stream Hydrology Unit protocols manual (Ecology, 1999). Flows will be calculated from continuous stage height records and rating curves developed prior to and during the project. Stage height will be measured by pressure transducer and recorded on data loggers every 15 minutes. All station data loggers will have data downloaded every two weeks for the first two months and monthly after that. If (during the study) continuous flow monitoring proves impractical, flows will be estimated by regression analysis of instantaneous measurements of gauged versus un-gauged sites and by estimates of watershed runoff using hydrographic methods.

Ohop Creek, Red Salmon Creek and Nisqually River

Staff gauges will be installed at selected sites. During the field surveys, flows will be measured at selected stations or staff gauge readings will be recorded. A flow rating curve will be developed for sites with a staff gauge.

The United States Geological Survey (USGS) maintains a series of gauging stations on the mainstem Nisqually River including their most downstream station at McKenna, RM 21.8. In addition, a gauging station is located on Ohop Creek just downstream of Ohop Lake at RM 6.1.

Groundwater Sampling

Groundwater discharge to McAllister Creek will be characterized to access groundwater impacts to surface water; numerous springs occur along the entire creek length. A total of two to three wells will be sampled. The wells may be private, public water supply, or monitoring wells. The wells will be sampled once in fall 2002 and once in winter 2003 to determine seasonal effects. Wells selected for monitoring will be field located on 1/24k quad maps for subsequent analysis and plotting via Arcview GIS software. The criteria used to select wells to be sampled is described in the section on Henderson Freshwater Monitoring, Groundwater Sampling.

Field analyses for groundwater samples will include temperature, pH, electrical conductivity, and dissolved oxygen. Samples will be collected for laboratory analysis for ammonia-N, nitrate+nitrite-N, total persulfate N, total phosphate, and soluble reactive phosphate.

Travel Time Estimates

Travel time studies are described in the Nisqually Reach Marine Monitoring section.

Analytical and Sampling Procedures

Flows

Stream discharge information will be obtained at critical sampling locations to provide loading information. Ecology's stream hydrology unit installed a continuous recording gauge on Woodland Creek south of I-5. Thurston County currently has a continuous recording gauge on Woodard Creek at 36th Avenue and on Woodland Creek at Pleasant Road.

Ecology's continuous gauging stations' flows will be determined by the Environmental Monitoring and Trends Section Stream Hydrology Unit (SHU). Estimation of discharge and instantaneous flow measurement will follow the SHU protocols manual (Ecology, 1999). Flows will be calculated from continuous stage height records and rating curves developed prior to and during the project. Stage height will be measured by pressure transducer and recorded by a data logger every 15 minutes. All data loggers will be downloaded monthly.
Staff gages will be installed at other selected sites. During the field surveys, flows will be measured at selected stations and/or staff gauge readings will be recorded. A flow rating curve will be developed for sites with a staff gauge.

Flows on McAllister Creeks are difficult to obtain due to creek depth and tidal influence. Ecology will install a continuous recording station at Steilacoom Road if property access can be obtained.

Field Procedures

Field sampling and measurement protocols will follow those listed in the Watershed Assessment Section protocols manual (Ecology, 1993). Field measurements at all sampling stations will include conductivity, dissolved oxygen, pH and temperature. All meters will be pre- and post-calibrated in accordance with the manufacturer's instructions. Pre- and post-checks with standards will evaluate field measurement accuracy. A minimum of ten percent of all dissolved oxygen measurements will be checked by a Winkler titration.

Grab samples will be collected directly into pre-cleaned containers supplied by Mel and described in MEL (2000) except ortho-phosphorus which will be collected in a syringe and filtered into a pre-cleaned container. The syringe will be rinsed with ambient water at each sampling site three times before filtering. Analytical methods, sample containers, volumes, preservation and hold time are listed in Table 21. Samples for laboratory analysis will be stored on ice and delivered to MEL within 24 hours of collection.

Ground-water levels will be measured at each of the study wells prior to sampling. Water level measurements will be made using a calibrated electric well probe or steel tape in accordance with standard USGS methodology (Stallman, 1983).

For ground water sampling, a flow-thorough sampling cell will be used to ensure a consistent purging and sampling procedure. Wells will be purged at a rate of approximately three gallons per minute, the maximum flow rate for the sampling cell. Groundwater temperature, electrical conductivity, pH, and dissolved oxygen concentrations will be measured at three minute intervals during well purging. Laboratory samples will be obtained when a minimum of three casing volumes of water have been purged from the well and all field parameters have stabilized. Stabilization has occurred when there is less than a five percent difference, between successive three-minute measures, for all parameters.

Table 21. Summary of Laboratory Measurements and Methods

Parameter	Bottle	Preservative	Holding Time	EPA Method	Detection Limit
Biochemical Oxygen Demand (BOD)	1 gallon cubitainer	Cool to 4ºC	48 hours	405.1	2 mg/L
Conductivity	500 mL poly	Cool to 4ºC	28 days	120.2	1 μmhos/cm
Ammonia	125 mL clear poly	H_2SO_4 to pH < 2, Cool to 4ºC	28 days	350.1	0.010 ppm
Nitrate/Nitrite	125 mL clear poly	H_2SO_4 to pH < 2, Cool to 4ºC	28 days	353.2	0.010 ppm
Nitrogen – Total Persulfate	125 mL clear poly	H_2SO_4 to pH < 2, Cool to 4ºC	28 days	SM4500[1]	0.025 ppm
Orthophosphorus	125 mL amber poly	Cool to 4ºC	48 hours	356.3	0.003 ppm
Phosphorus, total	125 mL clear poly	H_2SO_4 to pH < 2, Cool to 4ºC	28 days	SM4500-PI	0.010 ppm
Turbidity	500 mL poly	Cool to 4ºC	48 hours	180.1	1 NTU
Fecal Coliform	250 mL glass/poly autoclaved	Cool to 4ºC	30 hours	SM MF 9222D	1 cfu
E Coli	250 mL glass/poly autoclaved	Cool to 4ºC	30 hours	9221 F [EC MUG]	1 cfu

[1] SM indicates Standard Methods rather than EPA method.

Sampling for McAllister Creek will be conducted using kayaks. The Environmental Assessment Program Safety Manual does not describe monitoring procedures from a kayak. Procedures for sampling from a kayak are described in Appendix F.

Laboratory Procedures

Laboratory analyses of chemical parameters of interest listed in Table 21 will be performed in accordance with MEL protocols (2000). Nutrient analysis will include inorganic (nitrate/nitrite nitrogen, ammonia nitrogen), total (persulfate) forms of nitrogen, orthophosphate, and total phosphorus. According to the MEL manual (2000), the required reporting limits for laboratory data in Table 21 should be attainable through the analytical methods listed in the table. The MEL laboratory staff will consult the project manager if any changes in procedures over the course of the project are recommended, or if matrix difficulties are encountered.

The project manager will follow normal procedures for notification and scheduling. If laboratory sample load capacities are in doubt, rescheduling of individual surveys may be negotiated. Storm-event surveys will require close communication with the laboratory to ensure microbiological media and other laboratory resources are available.

Primary productivity is determined using Standard Methods 10300D-4 (2), the free-water diurnal curve method. Reaeration rates applied to the curve method will be estimated from channel depth and water velocity characteristics during the period when dissolved oxygen measurements are recorded.

Quality Control Procedures

Total variation for field sampling and analytical variation will be assessed by collecting replicate samples in addition to lab duplicates and comparing those data to data quality objectives. Replicate samples will be collected at a rate of 10% of all samples. Bacteria samples tend to have a high % RSD compared to other water quality analyses. Total variation for field sampling and laboratory analysis of bacteria samples will be assessed by collecting duplicates for approximately 20% of samples. Ten percent of the filtered orthophosphorus samples sent to the lab will be filter blanks to ensure filter and container quality. In addition, field blanks and total phosphorus standards will be submitted with routine samples to the laboratory to determine the presence of bias in analytical methods.

All samples will be analyzed at MEL. The laboratory's data quality objectives and quality control procedures are documented in the MEL Lab Users Manual (MEL, 2000) and the MEL Quality Assurance Manual (MEL, 2001). MEL will follow standard quality control procedures (MEL, 2000). The results of the laboratory quality control (QC) sample analyses should be used to determine if the measurement quality objectives stated in Table 12 have been met. The laboratory QC data including check standards, replicates, spiked samples, and blanks will be reviewed to determine if the measurement data quality objectives have been met.

Field sampling and measurements will follow quality control protocols described in WAS (1993). Standard USGS protocols for groundwater level data collection will be followed throughout this study (Stallman, 1983). The equipment used to measure groundwater levels (electric tape or steel tape) will be inspected prior to use to verify that it is working properly. Steel tapes will be checked for bends or twists that might result in inaccurate readings. Electric tapes will be checked to confirm they have fresh batteries and will be calibrated with a steel tape of known accuracy prior to initial use. Water levels will be measured to the nearest 0.01 foot, with two successive measurements being made at each well. The difference between measurements should not exceed 0.01 feet.

All meters used to measure water quality field parameters (water temperature, electrical conductivity, pH, and dissolved oxygen concentration) will be checked and calibrated as appropriate against known standards at the start of each sampling day. Meter calibration will be done in accordance with the manufacturer directions. Field duplicate samples will be used to assess the variability in laboratory sample analyses. Blind duplicate samples, comprising approximately 10 percent of total samples, will be submitted to the laboratory during each sampling event.

Data Analysis and Use

Data reduction, review, and reporting will follow the procedures outlined in MEL's Lab Users Manual (MEL, 2000). Laboratory staff will be responsible for internal quality control validation, and for proper data transfer and reporting data to the project manager via the Laboratory Information Management System (LIMS).

All water quality data will be entered from LIMS into Ecology's Environmental Information Management (EIM) system. Data will be verified and a random 25% of the data entries will be independently reviewed for errors. If errors are detected, another 25% will be reviewed until no errors are detected.

The project manager or principal investigator will validate the quality of the data received from the laboratory and collected in the field in reference to the measurement quality objectives (MQOs) described in Table 19. The review ill be performed on a quarterly basis. Adjustments to field or laboratory procedure or the measurement quality objectives may be necessary after such a review. Clients and QA Project Plan signature parties will be notified of major changes. Data that does not meet MQOs may be approved for use by the project manager but this data will be qualified appropriately.

Elevated fecal coliform densities (>200 cfu/100mL) will be reported to the SWRO in accordance with the official notification procedure. All other data will be made available to the SWRO for disbursement after quality control and EIM are completed.

Data analysis will include evaluation of data distribution characteristics and, if necessary, appropriate distribution of transformations. Estimation of univariate statistical parameters and graphical presentation of the data (box plots, time series, regressions) will be made using SYSTAT/SYGRAPH8 (SPSS, 1997) and EXCEL (Microsoft, 2001) software.

A statistical model will be used to estimate daily, seasonal, and annual bacteria loading. The Statistical Theory of Rollback from Ott (1995) will be applied to the estimated distributions of bacteria to establish distribution statistics that meet the water quality criteria (i.e. geometric mean and 90th percentile).

Ecology will coordinate freshwater modeling efforts with Thurston County's HSPF efforts to the extent possible. HSPF is a linked watershed and water body model that can simulate simple one-dimensional stream transport and transformation of various water quality constituents, including bacteria. For example, we may be able to build water quality components onto the water quantity components currently under development through the 2514 process. Point and nonpoint source loads of bacteria can be routed through the Woodland Creek stream network under varying hydrologic conditions, evaluating transport and fate of the bacteria at the mouth of Woodland Creek. Existing data will be used to quantify loads by stream reach and/or to compare with model results. An alternative approach, should the HSPF model not meet the needs of the current project, is to route the differential loads downstream and compile a simple mass balance using exponential decay to account for settling and die-off.

A simple spreadsheet model will be developed for Henderson Inlet. The model will be used to evaluate the effect of dilution and travel time on fecal coliform concentrations in the inlet based on marine, shoreline, and tributary sources of bacteria. Direct marine sources of bacteria from wildlife will be estimated from available wildlife surveys and literature reviews of loading rates. Shoreline sources (e.g., septic systems) will be estimated from previous studies of septic system failure rates applied to the number of septic systems near the inlet. Tributary point sources will be estimated using a combination of instream data, hydrologic modeling of larger tributaries, and data analysis. Thurston County and Ecology data will be used directly or as model input to estimate the loads reaching Henderson Inlet from the mouths of Woodland and Woodard Creeks. Additional smaller tributaries have bacteria data that may be sufficient to estimate loads. Contributions from unmonitored locations will be estimated using monitoring data from areas with similar land uses; the land area without monitoring data is small relative to the overall Henderson Inlet watershed area.

We will evaluate McAllister Creek water quality using a combination of data analysis and simple spreadsheet models. For example, we will estimate fecal coliform loads using current and historical monitoring data, then use a simple spreadsheet model coupled with the time of travel data to estimate the concentration of bacteria at downstream and marine stations to the Luhr Beach area (i.e., in an area of predominantly one-dimensional transport) during ebb tide conditions.

Reporting, Schedule, and Budget

The proposed schedule for this TMDL project is as follows:

Reconnaissance Survey Sampling for Dissolved Oxygen	Summer 2002
Submit Initial QA Project Plan for Review (Internal and External)	September 6, 2002
Revised QA Project Plan Approval	November 11, 2002
TMDL Survey Sampling	November 2002 - September 2003
Data Review and Analysis	April 30, 2004
Draft Final Report - Supervisor Review	June 15, 2004
Draft Final Report - Client Review	September 1, 2004
External Review	October 15, 2004
EIM Data Entry	March 30, 2004
Final Report	December 30, 2004

A detailed laboratory budget for monitoring is presented in Appendix G; total laboratory budget for the project is $69,567. The budget for the freshwater monitoring is $58,867 and marine monitoring is $10,700. Additional costs of groundwater monitoring and gage installation by the Stream Hydrology Unit have not been calculated.

References

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 Department of Ecology, Publication Number 02-03-021.

APHA, AWWA, and WEF. 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. United Book Press, Inc. Baltimore, Maryland.

Baranski, C. 1991. Letter to Phillip Jensen Dated February 21, 1991. Washington Department of Fisheries, Olympia, Washington.

Beyerlein, D. and J. Brascher. 1994. Woodland and Woodard Creek HSPF Calibration for Thurston County, Washington. Report Prepared for Thurston County.

Burg, M. 1984. Habitat Change in the Nisqually River Delta, Puget Sound, Washington. Master's Thesis, University of Washington, Seattle, Washington.

Burton, G. Allen, Jr., Douglas Gunnison, and Guy R. Lanza. 1987. Survival of Pathogenic Bacteria in Various Freshwater Sediments. Applied and Environmental Microbiology 53:633-638.

Calambokidis, J., B. McLaughlin, and G. Steiger. 1989. Bacterial Contamination Related to Harbor Seals in Puget Sound, Washington. Report to Jefferson County and the Washington Department of Ecology in Cooperation with the Washington Department of Social and Health Services. 74 pp.

Camp Dresser and McKee, Inc. 1995. Wachusett Reservoir Water Quality: Interim Assessment. Prepared for Massachusetts Water Resources Authority.

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

Clingman, Tom. 2001. WRIA 13 Initial Assessment, Henderson Inlet Watershed. Thurston County Water and Waste Management, Revised Draft.

Davis, Susan and Randy Coots. 1989. Woodland and Woodard Creek Basins, Stormwater Quality Survey. Report Prepared for Thurston County Public Works Department, City of Lacey and City of Olympia.

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.

Dickes, Betsy. 2002. McAllister Creek Water Quality Survey for Fecal Coliform Bacteria, Total Suspended Solids, Turbidity, and Nutrients. Washington State Department of Ecology, Water Quality Program, Publication Number 02-10-017.

Duxbury, A. C. 1983. Two Letters to Mr. Robert Monn at the Washington State Department of Ecology, Dated January 24, 1983 and February 4, 1983.

Easton, John H. 2000. The Development of Pathogen Fate and Transport Parameters for Use in Assessing Health Risks Associated with Sewage Contamination. Ph.D. Thesis, University of Alabama, Birmingham.

Ecology. 1993. Field Sampling and Measurement Protocols for the Watershed Assessments Section - Draft. Environmental Assessment Program, Washington State Department of Ecology. Olympia, Washington.

Ecology. 1999. Determination of Instantaneous Flow Measurements on Rivers and Streams. Stream Hydrology Unit, Environmental Assessment Program, Washington State Department of Ecology. Olympia, Washington.

Entranco. 1977. Thurston County Lakes Restoration Environmental Description.

Gerba, Charles P. and John S. McLeod. 1976. Effect of Sediments on the Survival of Escherichia Coli in Marine Waters. Applied and Environmental Microbiology, 32(1):114-120.

Gibbs, R. A., C. J. Hu, G. E. Ho, and I. Unkovich. 1997. Regrowth of Faecal Coliforms and Salmonellae in Stored Biosolids and Soil Amended with Biosolids. Water Science and Technology 35(11-12):269-275.

Gould, D. J. and M. R. Fletcher. 1978. Gull Droppings and Their Effects on Water Quality. Water Research, 13:665-672.

Hanes, N. B. and H. P. Savage. 1971. Toxicity of Sea Water to Coliform Bacteria. Journal of the Water Pollution Control Foundation, 43(5):854.

Haring, D. and J. Konovsky. 1999. *Washington State Conservation Commission Salmon Habitat Limiting Factors Final Report Water Resource Inventory Area 13*. Washington State Conservation Commission, Olympia, Washington.

Henderson Inlet Watershed Action Plan. January 1989.

Johnson, A. W. and J. E. Caldwell. 1992. Analysis of Existing Fish Habitat in a Portion of Woodland Creek, Thurston County, Washington. Prepared by Aquatic Resource Consultants and J. E. Caldwell & Associates for Thurston County Public Works, Olympia, Washington.

Jones, 1996. Thickness of Unconsolidated Deposits in the Puget Sound Lowland, Washington and British Columbia: U.S. Geological Survey Water Resources Investigations Report 94-4133, 1pl., scale 1:500,000.

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

Lambourn, Dyanna. 2002. Personal Communication with Mindy Roberts via Telephone. Washington Department of Fish and Wildlife.

Lea, P. D., 1984. Pleistocene Glaciation at the Southern Margin of the Puget Lobe, Western Washington: Seattle, Washington, University of Washington, Master of Science Thesis, 96 p.

Lennartson, Don. 2002. Personal Communication. Verbal Report at Henderson/Nisqually Data Sharing Meeting Held January 9, 2002, at Department of Ecology.

Lombard, S. and C. J. Kirchmer. 2001. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Environmental Assessment Program, Washington State Department of Ecology. Manchester, Washington.

Mancini, J. L. 1978. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. Journal of the Water Pollution Control Federation 50:2477-2484.

Mara, D. D. 1974. Bacteriology for Sanitary Engineers, Churchill Livingston, Edinburgh.

Marino, Robert P. and John J. Gannon. 1991. Survival of Fecal Coliforms and Fecal Streptococci in Storm Drain Dediment. Water Research 25(9):1089-1098.

McDonald, A., D. Kay, and A. Jenkins. 1982. Generation of Fecal and Total Coliform Surges by Stream Flow Manipulation in the Absence of Normal Hydrometeorological Stimuli. Applied and Environmental Microbiology, 44:292-300.

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

MEL. 2001. The Quality Assurance Manual for the Washington State Department of Ecology Manchester Environmental Laboratory. Environmental Assessment Program, Washington State Department of Ecology. Manchester, Washington.

Melvin, Don. 2002. Washington Department of Health. Personal Communication Via E-mail with Debby Sargeant, Washington Department of Ecology.

Meriwether, Frank. 1999. Hydrographic Study of Nisqually Reach Conditionally Approved Area. Memorandum to Nisqually Reach Growing Area Files, May 5, 1999. Department of Health, Office of Shellfish Programs.

Metcalf & Eddy. 1991. Wastewater Engineering. Third Edition. McGraw-Hill, Inc., New York.

Michael, Hal. 2002. Personal Communication. Verbal Report at Henderson/Nisqually Data Sharing Meeting Held January 9, 2002, at Department of Ecology.

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

Newton, Jan, et al. 1994. Marine Water Column Ambient Monitoring Program 1993. Washington State Department of Ecology, Publication #94-210, Lacey, Washington.

Newton, Jan. 1998. Washington State Marine Water Quality in 1996 and 1997. WDOE Publication #98-338.

Nixon, S. W. and C. A. Oviatt. 1973. Ecology of a New England Salt Marsh. Ecological Monographs 43:463-498.

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

Pacific Groundwater Group. 2000. McAllister Creek Seepage Inflow Study. Prepared for City of Lacey.

Patterson, Barbara R. and Betsy Dickes. 1994. Woodland Creek Water Quality Assessment Final Report, Ecology Building Project. WDOE Publication #94-62.

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

Pitz, C. and K. Sinclair. 1999. Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Water Supply Bulletin Number 60. WDOE Publication #99-327.

Puget Sound Action Team. 2001. *Response Strategy for Shellfish Growing Area Downgrades in Henderson Inlet and the Nisqually Reach*. Puget Sound Action Team, Lacey, Washington.

Rector, Julie 2002. Memorandum to Debby Sargeant Dated September 26, 2002. City of Lacey, Lacey, Washington.

Rensel, J., E. Jack, and Thomas J. Smayda. 2001. Dungeness Bay Bathymetry, Circulation, and Fecal Coliform Studies. Prepared for Jamestown S'Klallam Tribe.

Schwartz, M. L. and B. D. Harp. 1982. Pierce County, Washington, Net Shore-Drift. Report Prepared for the Washington State Department of Ecology by Coastal Consultants, Inc., Bellingham, Washington.

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, Washington.

Sherer, B. M. J. R. Miner, J. A. Moore, and J. C. Buckhouse. 1992. Indicator Bacteria Survival in Stream Sediments. Journal of Environmental Quality, 21:591-595.

SPSS, 1997. SYSTAT Version 7.0.1 SYSTAT, Inc., July, 1997.

Stallman, R. W., 1983. Aquifer-Test Design, Observation, and Data Analysis. Techniques of Water-Resources Investigations of the USGS, Book 3, Chapter B1. 26 p.

Struck, Philip H. 1988. The Relationship Between Sediment and Fecal Coliform Levels in a Puget Sound Estuary. Journal of Environmental Health 50(7):403-407.

Taylor, Marilou. 1984. Final Document. The Henderson/Eld Inlet Water Quality Study. Thurston County Human Services Department, Environmental Health Division, EPA 205(j) Grant, Thurston County, Olympia, Washington.

Thurston County. 2002. Thurston County Shellfish Protection for Henderson Inlet and Nisqually Reach, Background Nisqually Reach (Updated August 6, 2002). Olympia, Washington. Internet address: http://www.co.thurston.wa.us/shellfish/background.htm. Accessed September 24, 2002.

Thurston County Department of Water and Waste Management. 1994. McAllister/Eaton Creek Comprehensive Drainage Basin Plan. Storm and Surface Water Program, Olympia, Washington.

Thurston County Department of Water and Waste Management. 1995. Woodland and Woodard Creek Comprehensive Drainage Basin Plan. Storm and Surface Water Program, Olympia, Washington.

Thurston County Department of Water and Waste Management. 1997. Henderson Inlet Drainage Management System Final Report, CCWF Grant Project TAX90209, Thurston County, Olympia, Washington.

Thurston County Public Health and Social Services and Water and Waste Management Departments. 1997. Thurston County Water Resources Monitoring Report: 1995-1996 Water Year.

Thurston County Public Health and Social Services and Water and Waste Management Departments. 1998. Thurston County Water Resources Monitoring Report: 1996-1997 Water Year.

Thurston County Public Health and Social Services and Water and Waste Management Departments. 1999. Thurston County Water Resources Monitoring Report: 1997-1998 Water Year.

Thurston County Public Health and Social Services and Water and Waste Management Departments. 2000. Thurston County Water Resources Monitoring Report: 1998-1999 Water Year.

Thurston County Public Health and Social Services and Water and Waste Management Departments. 2001. Historic Water Quality Data Provided in Electronic Form by Thurston County Water Resources: 1988-2001 Water Years.

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

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

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

USGS, 1998. Hydrology and Quality of Ground Water in Northern Thurston County, Washington. Water Resources Investigations Report 92-9104 (Revised), 230 p. + 5 plates.

USGS, 1999. Conceptual Model and Numerical Simulation of the Ground-Water-Flow System in the Unconsolidated Sediments of Thurston County, Washington. Water Resources Investigations Report 99-4165, 254 p.

University of Washington. 1971. Puget Sound and Approaches Seasonal Variations of Oceanographic Parameters in its Near Surface Saters. Department of Oceanography. Washington Sea Grant Report Contract Number RD-NE4.

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

Weiskel, Peter K., Brian L. Howes, and George R. Heufelder. 1196. Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology, 30(6):1872-1881.

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

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, 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, Nisqually Natural Resources Water Quality Program, Technical Report Number 3.

Whiley, Anthony J. and George F. Walter. 1998. Analysis of Fecal Coliform Concentrations in the Nisqually River Drainage. Nisqually Indian Tribe, Nisqually Natural Resources Water Quality Program, Technical Report Number 5.

Whiley, Anthony J. and George F. Walter. 2000. Review and Analysis of Water Quality for the Nisqually River and the Major Lakes of the Nisqually Basin. Nisqually Indian Tribe, Water Quality Program, Technical Report Number 6.

Zalewsky, Brian. 2002. *Woodland Creek Temperature Total Maximum Daily Load Quality Assurance Project Plan*. Washington State Department of Ecology, Environmental Assessment Program, Olympia, Washington.

Appendices

Appendix A. Water Quality Standards of Concern

Brackish Waters

It is important to note that in brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria is based on vertically averaged salinity. The freshwater criteria is applied at any point where ninety-five percent of the vertically averaged daily maximum salinity values are less than or equal to one part per thousand. Marine criteria shall apply at all other locations except that the marine criteria applies for dissolved oxygen when the salinity is ≥ 1 parts per thousand (ppt) and fecal coliform bacteria when the salinity is ≥ 10 parts per thousand (ppt). Because the standard is written in terms of the daily maximum salinity values, much of McAllister Creek is likely classified as a marine water body for dissolved oxygen and fecal coliform bacteria.

Dissolved Oxygen

1. Current Criteria
   - For Class A Freshwaters: *dissolved oxygen shall exceed 8.0 mg/L.*
   - For Class AA Freshwaters: *dissolved oxygen shall exceed 9.5 mg/L.*
   - For Class AA Marine Waters: *dissolved oxygen shall exceed 7.0 mg/L. When natural conditions such as upwelling occur, causing the dissolved oxygen to be depressed near or below 7.0 mg/L, natural dissolved oxygen levels may be degraded by up to 0.2 mg/L by human-caused activities.*

2. Proposed Criteria
   - Salmonid Spawning and Incubation Protection**:** *To protect the incubation period for salmonids, human-caused conditions and activities are not to cause average daily minimum dissolved oxygen levels in the water column to fall below 10.5 mg/l, with no single daily minimum during this period falling below 8.0 mg/l.*
   - Salmonid Rearing Protection***:*** *In waters used by salmonids for life-stages other than incubation, or during times of the year that incubation is not occurring, human-caused conditions and activities are not to cause average daily minimum dissolved oxygen levels in the water column to fall below 8.5 mg/l, with no single daily minimum during this period falling below 7.0 mg/l.*
   - Non-Salmonid Rearing and Migration Protection**:** *In waters containing solely nonsalmonid species, human caused conditions and activities are not to cause average daily minimum dissolved oxygen levels in the water column to fall below 7.0 mg/l year-round, with no single daily minimum during this period falling below 6.0 mg/l. The two average periods, June 1 - September 30 and October 1 - May31, are to be used to calculate compliance with the rearing criteria in waters that are not used for spawning.*

Fecal Coliform Bacteria

1. Current Criteria
   - For Class A Freshwaters: *"...fecal coliform organism levels shall both not exceed a geometric mean[1] value of 100 colonies/100mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL."*
   - For Class AA Freshwaters: "*…fecal coliform organism levels shall both not exceed a geometric mean value of 50 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 100 colonies/100 mL."*
   - For Class AA Marine Waters: "*…fecal coliform organism levels shall both not exceed a geometric mean value of 14 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 43 colonies/100 mL."*

2. Proposed Criteria: *The current preferred alternative is to change the indicator organism from the fecal coliform group to the Escherichi coli (E. coli) for freshwater. E. coli, an enteric bacterium, is the most common member of the fecal coliform group, a sub-group of total coliform that grows mainly in the intestines of warm-blooded animals. For marine water where shellfish harvesting occurs, the marine fecal coliform standard will not be changed. In areas with no shellfish harvesting concerns, Enterococci is the proposed indicator.*

pH

1. Current Criteria
   - For Class A Freshwaters: *pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.5 units.*
   - For Class AA Freshwaters: *pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.2 units.*
   - For Class AA Marine Waters*: pH shall be within the range of 7.0 to 8.5 with a human-caused variation within the above range of less than 0.2 units.*

2. New Criteria Are Not Proposed For pH

WAC173-201A-060(2) summarizes estuarine water quality standards:

"In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria shall be applied on the basis of vertically averaged salinity. The freshwater criteria shall be applied at any point where ninety-five percent of the vertically averaged daily maximum salinity values are less than or equal to one part per thousand. Marine criteria shall apply at all other locations; except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater."

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[1] The geometric mean is calculated as the n^{th} root of the product of n numbers

Appendix B. Thurston County Continuous Flow Discharge Data

Table B1. Average Monthly Flow Discharge Woodland Creek at Pleasant Glade Road

Month	1988	1989	1990	1991	1992	1993	1994	1995	1996
Jan		18.82	43.52	37.27	27.77	17.20	13.63	25.32	56.78
Feb	15.05	21.00	59.30	43.30	38.10	15.16	16.58	41.72	50.70
March	19.16	34.42	45.51	47.14	31.87	16.67	20.80	43.53	
April	28.26	31.75	33.16	62.07		23.71	15.98	30.31	
May	20.36	21.38	26.82	37.17	18.21	22.77	14.31	22.74	
June	17.58	16.71	24.70	27.86	14.94	21.59	13.75	17.30	
July	12.91	14.34	17.24	21.06	13.52	16.06	12.69	16.11	
Aug	11.60	12.68	14.27	18.20	12.31	14.36	11.58	15.35	
Sept	10.84	11.50	13.66	16.17	11.82	13.11	11.59	13.17	
Oct	10.15	10.39	19.11	15.00	11.10	13.96	10.67	15.57	
Nov	14.53	12.88	29.38	19.31	13.58	14.20	12.75	26.01	
Dec	14.11	15.96	41.10	22.07	13.84	13.51	28.12	43.94	

Table B2. Average Monthly Flow Discharge Woodland Creek at Martin Way

Month	1988	1989	1990	1991	1992	1993	1994
Jan	January		1.59	11.38	17.03	7.10	0.05
Feb	February		3.16	25.38	18.94	13.47	0.24
March	March	1.65	9.42	21.23	20.31	10.86	0.33
April	April	6.73	10.21	15.87	25.34	9.34	3.40
May	May	3.76	4.80	12.46	19.04	4.89	3.55
June	June	1.78	1.67	10.37	13.09	0.82	1.77
July	July	nd	0.34	3.93	7.27	0.26	nd
Aug	August	nd	nd	nd	5.00	0.02	nd
Sept	September	nd	nd	nd	3.01	0.00	nd
Oct	October	nd	nd	nd	1.22	0.01	nd
Nov	November	0.46	0.78	7.67	2.66	0.06	nd
Dec	December	0.40	0.47	17.22	6.59	0.00	nd

nd: no data available for this time period.

Appendix C. Summary of Thurston County Water Resources Ambient Monitoring Data

Table C1. Dobbs Creek Monthly Water Quality Data Summary August 1983 - September 1998

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	No. of Samples pH	Average pH	Range pH
January	5.66	14	55	10-1600	11	7.2	6.5-7.5
February	3.86	11	34	5-130	8	6.9	6.2-7.5
March	5.63	12	71	5-1600	10	6.7	6.0-7.5
April	5.70	4	98	33-240	1	6.7	6.7
May	1.74	2	40	33-49			
June	1.28	3	217	79-1000			
July	0.83	10	104	30-305	7	7.2	6.8-7.9
August	0.77	12	104	20-385	8	7.6	7.0-8.6
September	0.79	6	75	23-160	4	7.7	7.5-7.8
October	0.96	2	40	33-49			
November	2.34	5	91	49-140	3	7.3	7.2-7.3
December	4.27	13	154	25-4300	10	6.8	6.2-7.6

Table C2. Sleepy Creek Monthly Water Quality Data Summary August 1983 - September 1998

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	No. of Samples D.O.	Average Dissolved Oxygen mg/L	Minimum Dissolved Oxygen mg/L	Average Temp °C
January	4.08	11	44	5-180	11	13.2	12.0	4.5
February	1.77	8	23	5-60	8	12.6	9.8	4.6
March	2.64	9	47	5-1430	9	11.7	10.3	7.1
April	13.54	2	108	93-125				
July	0.06	7	100	25-355	7	9.1	7.0	13.5
August	0.05	9	187	25-2450	9	8.5	7.5	15.0
September	0.02	3	77	35-160	3	8.9	8.5	13.7
November	0.52	3	124	20-600	3	11.4	10.7	7.1
December	15.39	11	167	15-2750	10	11.9	6.2	6.3

Table C3. Meyer Creek Monthly Water Quality Data Summary August 1983 - September 1998

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	No. of Samples pH	Average pH	Range pH
January	0.67	12	12	2-70	11	7.3	6.6-7.7
February	0.30	10	24	3-565	8	7.2	6.4-7.7
March	0.66	12	72	15-2400	10	6.8	5.5-7.7
April	0.99	3	210	79-470	1		7.0
June		1		1000			
July	0.14	7	258	75-1995	7	7.1	6.3-7.7
August	0.11	12	290	88-760	8	7.7	6.9-8.1
September	0.10	6	141	5-1300	4	7.7	7.6-7.8
October	0.15	2	108	49-240			
November	0.25	5	16	10-33	3	6.8	6.2-7.5
December	1.16	13	58	8-6900	10	6.9	6.4-7.7

Table C4. Goose Creek Monthly Water Quality Data Summary August 1983 - July 1984

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL
January	3.69	3	90	14-1600
February	1.40	3	34	15-79
March	1.64	2	69	2-2400
April	0.28	3	99	25-350
June	0.25	2	79	79
July	0.12	2	759	240-2400
August	0.06	3	151	110-240
September	0.01	2	53	22-130
October	0.13	2	26	5-140
November	0.07	2	3	2-5
December	0.52	2	174	33-920

Table C5. Woodard Creek Monthly Water Quality Data Summary June 1986-August 2001

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	No. of Samples pH	Aver. pH	Range pH	No. of Samples D.O.	Average Dissolved Oxygen mg/L	Minimum Dissolved Oxygen mg/L	Aver. Temp °C
January	32.72	17	28	2-125	14	7.0	5.7-7.8	14	12.1	10.3	5.3
February	30.96	14	32	5-85	11	7.1	5.8-7.8	11	11.7	10.2	6.0
March	36.76	15	32	5-540	13	6.8	5.4-7.5	13	11.0	9.4	8.7
April	36.52	4	41	30-49	1		7.2	1	12.2	12.2	9.4
May	48.44	2	40	33-49							
June	35.60	3	225	79-410							12.1
July	15.89	13	108	23-455	10	7.3	6.4-7.7	10	9.9	6.8	13.1
August	13.56	14	158	12-540	10	7.6	7-7.8	11	9.8	9.2	13.5
September	15.63	7	188	95-805	5	7.5	7.2-7.7	5	9.9	9.2	12.8
October	13.35	2	165	17-1600							
November	17.91	5	18	2-45	3	7.1	6.4-7.5	3	10.8	9.0	7.4
December	23.58	17	52	5-300	13	6.9	6.2-7.6	14	11.5	10.0	6.9

Table C6. Woodland Creek Monthly Water Quality Data Summary August 1983-2001

Month	Average Flow cfs	No. of Samples (FC)	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	No. of Samples D.O.	Average Dissolved Oxygen mg/L	Minimum Dissolved Oxygen mg/L	Average Temp °C
January	32.72	17	28	2-125	14	11.4	10.6	7.3
February	30.96	14	32	5-85	11	11.0	8.9	7.7
March	36.76	15	32	5-540	13	11.1	9.9	9.0
April	36.52	4	41	30-49	1	12.8	12.8	10.7
May	48.44	2	40	33-49				11.6
June	35.60	3	225	79-410				12.5
July	15.89	13	108	23-455	10	9.9	6.2	12.7
August	13.56	14	158	12-540	11	10.1	8.6	12.2
September	15.63	7	188	95-805	5	9.9	9.7	11.8
October	13.35	2	165	17-1600				10.0
November	17.91	5	18	2-45	3	10.9	9.7	8.6
December	23.58	17	52	5-300	14	11.2	9.2	8.1

Appendix D. City of Lacey Historical Water Quality Monitoring Data

Table D1. Summary of City of Lacey Water Quality Monitoring Data

Site	Time period	Data Collection	Fecal Coliform GM	Fecal Coliform Range	Mean Dissolved Oxygen	Dissolved Oxygen Range
Eagle Ck. at Carpenter Rd.	11/00-12/01	Lacey staff	6 (n=9)	1-196	9.6 (n=9)	8.2-12.1
Woodland Ck. at * Draham Rd.	11/00-12/01	Lacey staff	18 (n=13)	3-200	8.1 (n=14)	7.4-9.4
Woodland Ck. at Draham Rd.	7/93-10/01	Stream Team	23 (n=22)	0-240		
Woodland Ck. at I-5	7/93-5/00	Stream Team	26 (n=9)	8-65		
Woodland Ck. at Abbot Raphael Hall	1/94-2/01	Stream Team	19 (n=7)	7-800		
Woodland Ck. below Lake Lois	7/93-5/01	Stream Team	32 (n=8)	3-200		
Woodland Ck. at Pacific Ave.	7/93-11/95	Stream Team	32 (n=5)	14-108		
Woodland Ck. at Long's Pond ditch	7/93-5/01	Stream Team	22 (n=7)	8-70		
Woodland Ck. at Long Lk. Outfall	1/94-2/01	Stream Team	20 (n=16)	4-150		

* Average flow during this sampling period was 10.2 cfs, with a range of 4.1-22.4 cfs.

Table D2. Lacey Staff Conducted Storm Event Monitoring from January - October of 2001 on Woodland Creek and Some Tributaries for Several Parameters. Pertinent Results are Presented in D2

Site	Fecal Coliform GM cfu/100mL	Fecal Coliform Range cfu/100mL	Mean Dissolved Oxygen mg/L	Dissolved Oxygen Range mg/L	Mean Flow cfs	Flow Range cfs
7th Avenue Outfall, below Lake Lois	4490 (n=6)	540-1900	8.7 (n=4)	7.9-9.8	0.65	0.01-2.90
College ditch at bike path	6466 (n=3)	2200-12800	8.3 (n=3)	7.8-8.9	1.06	0.32-1.84
Woodland Ck. At Draham Rd.	456 (n=5)	68-2100	6.9 (n=3)	6.5-7.5	7.31	5.64-9.18

Table D3. Thurston County Woodland Creek Stream Segment Monitoring of Storm Events April 2001-March 2002

Date	Previous 12 Hour Rainfall	Parameter	Long Lake Outlet	Pacific Avenue	Martin Way	Downstream Interstate-5	Draham Road	Pleasant Glade	Hollywoods	Mouth (Hawks Prairie)
			RM 5.8	RM 5.0	RM 3.8	RM 3.1	RM 2.9	RM 1.6	RM 1.0	RM 0.2
4/30/01	0.60	FC	88	68	235		1080	5200		3450
		Flow	5.4	4.6	0.84		14	24.3		24.3
		Load*	475.2	312.8	197.4		15120	126360		83835
5/14/01	0.41	FC	163	80	6350		317	575	263	565
		Flow	4.1	3.1	0.08		9.5	16.2	16.1	16
		Load*	668.3	248	508		3011.5	9315	4234.3	9040
8/22/01	0.75	FC					380	880	1500	1050
		Flow	dry	dry	dry		9.3	13.9	17.6	17.6
		Load*					3534	12232	26400	18480
11/14/01	3.06	FC			780		1325	2050	1900	
		Flow	dry	dry	10.7		113	159	159	
		Load*			8346		149725	325950	302100	
1/7/02	1.28	FC	50	93	83		385	233	644	
		Flow	25.5	21.3	21.6		83.6	101	101	
		Load*	1275	1980.9	1792.8		32186	23533	65044	
2/21/02	1.04	FC	5	45	58	285	270	305	215	
		Flow	25.6	23.8	18.3	40.4	51.5	65.5	66	
		Load*	128	1071	1061	11514	13905	19978	14190	
3/11/02	1.10	FC	105	150	70	210	170	428		460
		Flow	24.6	23.8	18.1	50.6	62.8	85.4		85
		Load*	2583	3570	1267	10626	10676	36551.2		39100

*Load estimates were obtained by multiplying fecal coliform concentrations (#cfu/100mL) x flow discharge (cfs).

Appendix E. Field and Laboratory Monitoring Parameters and Sample Times for each Station

Sample Site	RM	Site Code	FC/E-coli November 2002 - August 2003	Nutrients * April, July, August 2003	Field Measurements DO, Cond, Temp.		Flow Discharge if Possible
					Profiles	Mid-Channel	
Upper McAllister Creek by Kayak (Water and Land Sampling)							
McAllister D/S of wetlands	5.8	MC5.8	X	X	X		
TG-15 if possible		TG15W	X	X		X	X
TG-14 if possible		TG14W	X	X		X	X
TG-13 if possible		TG13W	X	X		X	X
U/S of Little McAllister Creek	5.4	MC5.4	X	X	X		
TG-11 (Litt McAL)		TG11W	X	X		X	X
Culvert at TG-11		TG11C	X			X	X
TG-10 if possible		TG10W	X	X		X	X
TG-9 by land		TG9L	X	X		X	X
McAllister Ck at Steilacoom Rd.	4.7	MC4.7	X	X	X		
TG-8 by land		TG8L	X	X		X	X
McAllister Ck below residential area	4.5	MC4.5	X	X	X		X
Lower McAllister Creek by Boat							
Upstream of blue bridge	4.3	MC4.3	X	X	X		
Stormwater discharge U/S from Martin Way		SW2W	X	X		X	X
Upstream of Martin Way	3.7	MC3.7	X	X	X		
Storm drain under I-5		SW1W	X	X		X	X
TG-1 if possible		TG1W	X	X		X	X
Downstream of I-5	3.1	MC3.1	X	X	X		
Upstream of TG-B	2.2	MC2.2	X	X	X		
Downstream of TG-A	1.5	MC1.5	X	X	X		
McAllister near mouth	0.1	MC0.1	X	X	X		
Luhr Beach		DOH224	X			X	
Thurston CD Samples by Land							
TG-15 by land		TG15L	X	X		X	
TG-14 by land		TG14L	X	X		X	
TG-13 by land		TG13L	X	X		X	
TG-12 by land		TG12L	X	X		X	
TG-10 by land		TG10L	X	X		X	
TG-9 by land		TG9L	X	X		X	
TG-5 by land		TG5L	X	X		X	
TG-4 by land		TG4L	X	X		X	
Thurston County Samples by Land							
Medicine Creek		MED0.1	X	X		X	X
TG-3		TG3L	X	X		X	X
TG-2		TG2L	X	X		X	X
TG-1		TG1L	X	X		X	X
TG-B		TGBL	X	X		X	X
TG-A be done by land)		TGAL	X	X		X	X

**** BOD at select tidegates during these months***

Appendix F. Operating Kayaks for Field Work

Purpose

To ensure that kayaks owned or leased by Ecology are operated according to Ecology policy *Operating Ecology Boats* (page 87, 88) and/or boat manufacturer's specification in order to prevent personal injury and loss/damage to expensive field sampling equipment.

Application

For EA staff operating kayaks owned or leased by Ecology. Kayaks will only be used if all other sampling options have been exhausted and supervisor and safety committee permission has been obtained.

Requirements

1. EA kayak operators must comply with all provisions of the *EA Boating Plan* (page 85, 86) and Ecology policy *Operating Ecology Boats* (page 87, 88) by briefing the crew on all safety-related items on board the boat.
2. Check weather and tidal conditions or flow discharge conditions before launching.
3. Life jacket should be worn at all times when in the kayak.
4. A minimum of two staff are needed for field work using a kayak.
5. The type of kayak used for sampling should be very stable, with good primary stability.
6. Each kayak should be equipped with the following safety items: bailing device such as a manually operated bilge bump, flotation bags, a paddle float, and a dry bag containing a cell phone or radio, flares, and a first aid kit.
7. If stability is a concern while sampling, two kayaks should raft side by side with a paddle placed over the fore deck of both boats, one kayaker holds both boats in the side by side position using the paddle while the other kayaker conducts the sampling.
8. Personnel operating kayaks should have a minimum of 100 hours experience in kayak operation.

Appendix G. Laboratory Budget for Henderson Nisqually TMDL Project

Laboratory costs include 50% discount for Manchester Lab.

Table G1. Henderson Inlet and Nisqually Reach Marine Monitoring Budget

Laboratory Costs for Fecal Coliform (Marine Monitoring)
Henderson Inlet and Nisqually Reach

Program	Events	Samples Per Event	Samples	Unit Cost	Total Cost
Henderson Inlet Marine Monitoring					
Henderson Inlet Time of Travel and Flow Paths	3	42	126	$20	$2,520
Tributary Sampling	3	12	36	$20	$720
Henderson Inlet Surface Grabs	3	30	90	$20	$1,800
In Situ Fecal Coliform Die-Off	2	24	48	$20	$960
Subtotal			174		$3,480
Nisqually Reach Marine Monitoring					
McAllister Creek Time of Travel and Flow Paths	2	36	72	$20	$1,440
Flow Paths and Travel Time Near Luhr Beach	2	35	70	$20	$1,400
Flow Paths and Travel Time Northeast of Nisqually Flats	2	36	72	$20	$1,440
Sequalitchew Creek	2	6	12	$20	$240
Marine Monitoring	2	30	60	$20	$1,200
Subtotal			214		$4,280
Additional Monitoring (As Needed)			50	$20	$1,000
Replicates (15%)			97		$1,940
Total			535		**$10,700**

Table G2. Henderson Inlet and Nisqually Reach Tributaries Freshwater Monitoring Budget

	Events	Samples per Event	Number of Samples	Unit Cost	Total Cost
Henderson Tributaries					
Fecal Coliform/E-coli (Nutrient Agar MUG)	12	37-38 including 20% duplicates	447	$35	$15,645
Nutrients	4	15-16 including 10% duplicates	62	$68	$ 4,216
Conductivity/Salinity	12	3	36	$10	$ 360
Henderson Subtotal					$ 20,221
Nisqually Tributaries					
McAllister Creek					
Fecal Coliform/E-coli (Nutrient Agar MUG)	10	42 including 20% duplicates	420	$35	$14,700
Nutrients	3	38-39	115	$68	$ 7,820
BOD5	3	22	66	$46	$ 3,036
Conductivity/Salinity	10	3-4	35	$10	$ 350
McAllister Subtotal					$29,406
Ohop, Red Salmon Creeks, and Nisqually River					
Fecal Coliform/E-coli (Nutrient Agar MUG)	10	42 including 20% duplicates	420	$35	$14,700
Ohop/Red Salmon/Nisqually Subtotal	14	12	168	$55	$ 9,240
TOTAL					**$58,867**

Total budget for fresh and marine water sampling for Henderson and Nisqually TMDL study is $ 69,567. This does not include groundwater monitoring costs or the services of Ecology's stream hydrology unit.