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Stillaguamish River Watershed Fecal Coliform, Dissolved Oxygen, pH, Mercury, and Arsenic Total Maximum Daily Load Study

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Stillaguamish River Watershed Fecal Coliform, Dissolved Oxygen, pH, Arsenic, and Mercury Total Maximum Daily Load Study

by
Joe Joy

Washington State Department of Ecology
Environmental Assessment Program
Olympia, WA.

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Waterbody Numbers: (see Table 1)

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Table of Contents

Page

Appendices

List of Figures

List of Tables

Abstract

The Stillaguamish River basin has significant salmon habitat and recreational uses. The basin empties into Port Susan, a potential commercial shellfish harvest area.

The federal Clean Water Act 1998 303(d) listings for fecal coliform bacteria included the mainstem Stillaguamish River and its two major forks, several tributaries, and Port Susan. The listings for dissolved oxygen, pH, and arsenic were distributed in fewer tributary and mainstem reaches.

This technical assessment used water quality data collected during 2000 to 2002 by the Washington State Department of Ecology (Ecology), combined with data collected by local tribes, Ecology, and other agencies since the late 1980s. All of the 303(d) parameters mentioned above were addressed in the total maximum daily load (TMDL) assessment.

Many reaches of the Stillaguamish River, most tributaries, and Port Susan had seasonal fecal coliform problems. Freshwater fecal coliform load reductions recommended in the TMDL assessment should bring both freshwater reaches and Port Susan back into compliance with criteria.

Stormwater wasteload allocations were necessary for three NPDES stormwater permit jurisdictions. Load and wasteload allocations were developed for fecal coliform and biochemical oxygen demand.

Many tributaries experience seasonally low dissolved oxygen concentrations and low pH values. Groundwater and wetland inputs are partially responsible. Minimum dissolved oxygen targets were proposed after pollutants sources are removed. Pollutant load reductions should allow pH values to return to natural levels. A minimum dissolved oxygen target also was recommended for a reach of the Stillaguamish River where complex hyporheic exchange processes are thought to be occurring during extended low-flow conditions.

Arsenic concentrations are consistently elevated compared to EPA human-health criteria, but far below aquatic toxicity and drinking water standards. Mercury concentrations exceeded chronic toxicity criteria to protect aquatic life during events with elevated total suspended solids concentrations. Data suggest that both arsenic and mercury are from natural sources in the basin.

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Introduction

The Stillaguamish River basin includes portions of Snohomish and Skagit counties in Washington State (Figure 1). Several rivers and streams in the Stillaguamish River basin were on Washington State's 1996 and 1998 Section 303(d) list because of violations of one or more water quality criteria (Table 1).

In 2000, the Washington State Department of Ecology (Ecology) Water Quality Program selected the basin for a total maximum daily load (TMDL) assessment. Ecology's Environmental Assessment Program was asked to design and conduct the TMDL evaluation. Two TMDL projects emerged, based on personnel resources and analytical approaches for the 303(d)-listed parameters: (1) a temperature TMDL (Pelletier and Bilhimer, 2004), and (2) this TMDL evaluation of fecal coliform, dissolved oxygen, pH, arsenic, and mercury.

The TMDL analysis of listings for ammonia, lead, copper, and nickel in the Old Stillaguamish River (Table 1) was originally planned to be included in this evaluation (Joy, 2001). However, the Water Quality Program and the Environmental Assessment Program have decided to postpone those analyses until 2004 or later. The local Flood Control District has installed a tide gate mechanism in the channel to increase freshwater flow during the low-flow season of 2003. Also, the city of Stanwood will complete an upgrade of its wastewater treatment plant in 2004. Data collected after these projects are completed will provide a more realistic evaluation of the water quality conditions in the Old Stillaguamish River, and will allow a more accurate set of load and wasteload allocations.

Mercury was added to the list of possible pollutants in the basin, even though mercury was not on the 303(d) list. Local concern was generated by data presented in a report by the Puget Sound Water Quality Action Team (1998). Those data were collected by Ecology but also qualified as estimated values by Ecology (Joy, 2001). More recent mercury data were not available to make a proper water quality evaluation.

Section 303(d) of the federal Clean Water Act mandates that the state establish TMDLs for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991) for establishing TMDLs.

Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as cold water biota and drinking water supply, and criteria, usually numeric criteria, to achieve those uses. When a lake, river, or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the waterbody on a list of "impaired" waterbodies and to prepare an analysis called a TMDL.

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can

Table 1. Stillaguamish River basin (Water Resource Inventory Area 5) and Port Susan (WRIA 6) waterbodies on the 1998 Section 303(d) list for TMDL evaluations. Listing status in 1996 is also indicated for individual parameters.

Old ID No.	New ID No.	Name	Parameters	1996 303(d)
WA-05-1021	PA13UD	Deer Creek	Temperature	Yes
WA-05-1016	QJ28UC	Fish Creek	**Fecal Coliform**	Yes
	HD76OJ	Harvey Creek	**Fecal Coliform**	No
WA-05-1025	BH79GG	Higgins Creek	Temperature	Yes
	JU33JU	Jim Creek	**Fecal Coliform**	No
WA-05-1012	GH05SX	Jorgenson Slough (Church Creek)	**Fecal Coliform**	Yes
WA-05-1023	EX67XM	Little Deer Creek	Temperature	Yes
	IJ55EP	Lake Martha Creek	**Fecal Coliform**	No
	QE93BW	Old Stillaguamish River	**Fecal Coliform**, Ammonia, Lead, Copper, Nickel	No
WA-05-1018	VJ74AO	Pilchuck Creek	Temperature, **Dissolved Oxygen**	No
WA-PS-0020	390KRD	Port Susan	**Fecal Coliform**	Yes
WA-05-1015	OT80TY*	Portage Creek	**Fecal Coliform, Dissolved Oxygen,** Turbidity	Yes
WA-05-1010	QE93BW	Stillaguamish River	**Fecal Coliform**, Temperature, **Dissolved Oxygen, Arsenic**	Yes/Yes Yes/No
WA-05-1010	ZO73WL	Stillaguamish River (Hatt Slough)	**Fecal Coliform**, Temperature, **Dissolved Oxygen**	No/No Yes
WA-05-1020	WO38NV	N.F. Stillaguamish River	**Fecal Coliform**	Yes
WA-05-1020	XN66YN	N.F. Stillaguamish River	Temperature	Yes
WA-05-1050	SN06ZT	S.F. Stillaguamish River	**Fecal Coliform**, Temperature, **pH**, **Dissolved Oxygen**	Yes/Yes Yes/No
WA-05-9160	350KXA	Sunday Lake	Total Phosphorus, Total Nitrogen	No
	LU17DC	Unnamed Creek #0456	**Fecal Coliform**	No

* Includes the listings mistakenly assigned to OJ28UC, Fish Creek, and YF03BC, a branch of Portage Creek, but should have been entered as OT80TY, Portage Creek.

Bold - parameters are 303(d) listings addressed in this report.

be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources. If the pollutant comes from a discrete source (referred to as a point source) such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse sources (referred to as a nonpoint sources) such as general urban, residential, or farm runoff, the cumulative share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

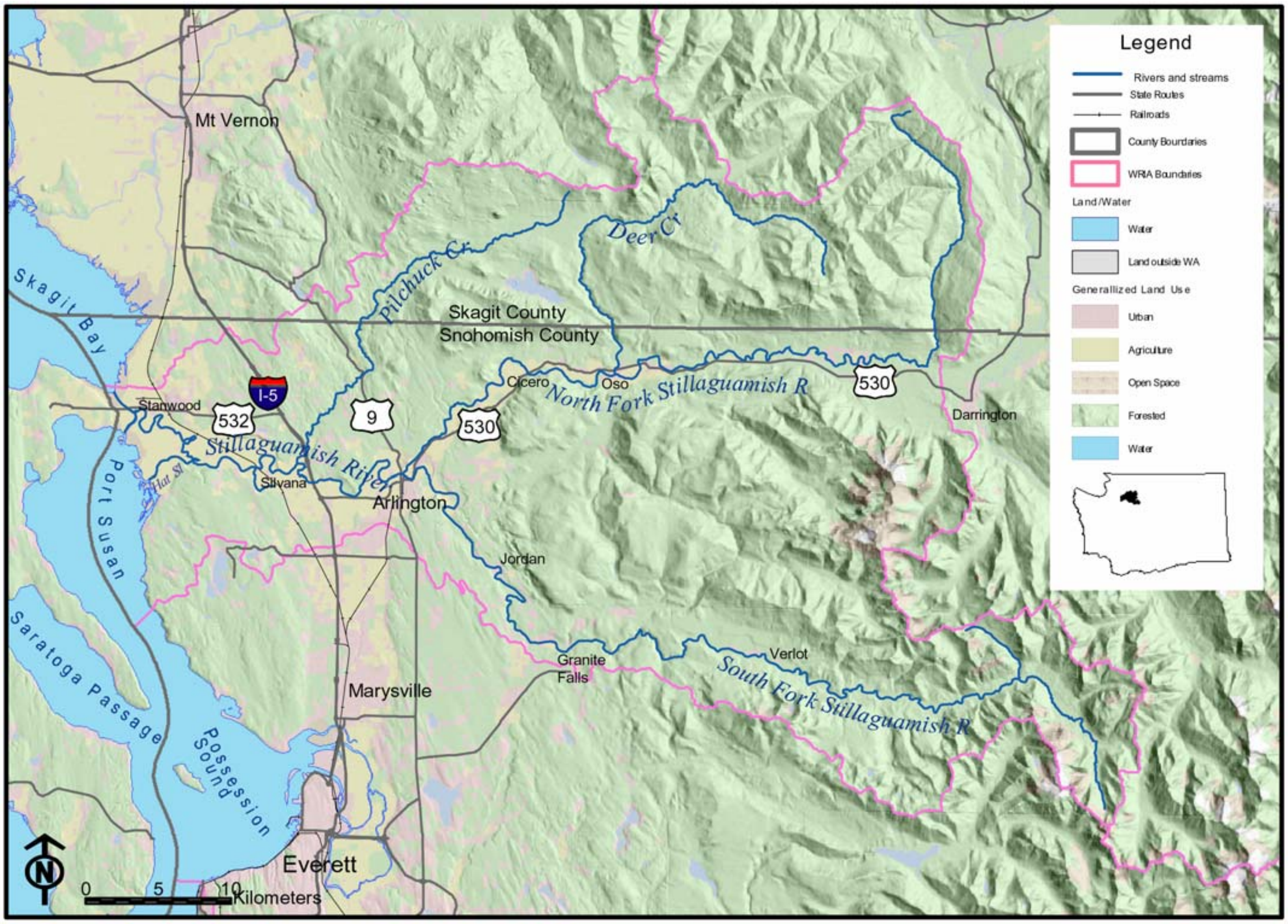

Figure 1. Generalized land cover in the study area.

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Background

Setting

The Stillaguamish River watershed covers 1770 km^2 and extends from sea level to 2,086 meters in elevation on Whitehorse Mountain in the Squire Creek drainage. It is the fifth largest tributary to Puget Sound. The Stillaguamish River has two major forks at river kilometer 28.6 (river mile 17.8); the North Fork drains 736 km^2, and the South Fork drains 660 km^2. Average annual precipitation in the watershed ranges from about 80 cm/year (about 30 inches/year) at lower elevations to about 380 cm/year (150 inches/year) at higher elevations (Figure 2) (Pess et al., 1999).

Headwater streams are typically steep (>0.2 m/m) and relatively small (bankfull width < 5 m, Pess et al., 1999). Channel slopes decrease dramatically (between 0.01 and 0.06 m/m) as streams traverse terraces carved into valley-filling glacial and alluvial deposits (Figure 3), and channels become larger as tributaries coalesce.

The geology of the Stillaguamish basin has been briefly described in the Salmon Habitat Limiting Factors Analysis (Washington Conservation Commission, 1999):

"The North Cascades include high grade Mid-Cretaceous to Paleocene melange rocks that dominate west of the Darrington Fault. East of the fault the dominant rock unit is the Darrington Phyllite, a metamorphic rock type that dominates the upper North Fork Stillaguamish. This rock is particularly prone to erosion, which is a major problem in this watershed. Crystalline rocks of the Oligocene Squire Creek stock form the south side of the North Fork and the north side of the upper South Fork Stillaguamish.

Glacial outwash from the Puget Lobe of the Cordilleran ice sheet forms the terraces in the forks and the topography of the lower watershed. Younger alluvial deposits are inset within the terraces in the wider portions of the valleys of the forks. The mainstem of the Stillaguamish flows through an alluvium-floored valley 1.5-3 km wide, inset within terraces of glacial outwash. The clay, silt and sand deposits of glacial and lake origin are the main source of the significant sediment production in the watershed (Perkins and Collins 1997). In the steeper sloped areas, these deposits are particularly prone to landslides, which are a significant problem for fisheries in this drainage."

Soils types vary widely but follow the patterns of the underlying geology. The valley soils over alluvial deposits tend to have low permeability; i.e., Hydrologic Group C and D soils predominate along the valley floors of the North Fork, lower South Fork, and along the mainstem and lower mainstem tributaries to Port Susan. More permeable Hydrologic Group A or B soils are found on the plateaus and hillsides.

The mountainous upper watershed contributing to the forks are primarily public forest lands (Figure 4). The U.S. Forest Service manages 697 km^2 (269 mi^2) within the Mount Baker-Snoqualmie National Forest, and the Washington State Department of Natural Resources (DNR) manages 210 km^2 (81 mi^2). Timber harvesting and recreational uses predominate. Only inactive and abandoned mines remain in once active metal mining areas near the headwaters of both forks (McKay, Jr., Norman, Shawver, and Teissere, 2001). Lower elevation forests (< 700m) are within the western hemlock zone (Franklin and Dyrness, 1973). Dominant conifer species in these forests are western hemlock, Douglas-fir, western red cedar, and Sitka spruce. Deciduous trees include red alder, black cottonwood, and bigleaf maple. Middle elevation forests (700-1300m) are in the silver fir zone, and higher elevations (> 1300m) are in the alpine fir zone.

Granite Falls (population est. 2,915) and Darrington (population est. 1,385) have growth management areas that influence some residential development in the upper basin along the valley floors (Figure 1). Other small residential, business, and agricultural properties are scattered the length of the valleys. The U.S. Department of Defense controls approximately 18.1 km^2 (7 mi^2) in the Jim Creek sub-basin of the South Fork. The Indian Ridge Corrections Center with its wastewater facility is also located in the Jim Creek sub-basin.

The South Fork enters a floodplain 6.4 km (4 miles) before the confluence with the North Fork. The mainstem at the confluence is at an elevation of 15.4 m (51 ft), and the gradient is fairly even to the mouth at Port Susan. Dikes are common along the length of the mainstem. The floodplain has visible evidence of historical meanders and sloughs.

Port Susan is bounded on the north and west by Camano Island. It is a shallow, poorly flushed bay that extends from South Pass at Stanwood to Port Gardner at Everett. Low-density residential and agriculture are the most common land uses around the bay. No commercial shellfish harvesting operations are currently permitted in Port Susan, but recreational harvesting occurs.

The primary riparian land use along the mainstem and lower reaches of the major forks is agriculture. The lower basin has diverse land uses, and most land is privately owned. Arlington (population est. 14,330) and Stanwood (population est. 4,190) have active urban growth areas. In 1995, Stienbarger (1995) estimated there were at least 909 commercial and non- commercial farms in the lower basin. Agriculture is still quite active in the lower basin, but conversions from agriculture to rural residential or non-commercial farm uses are becoming common along the Interstate 5 corridor. The DNR controls approximately 72.5 km^2 (28 mi^2) in the Pilchuck Creek sub-basin. Privately held forests are scattered throughout the upper reaches of other tributaries as well.

The Stillaguamish Tribe, Sauk-Suiattle Tribe, and Tulalip Tribes have cultural and economic interests in the Stillaguamish River basin. The Stillaguamish Tribe offices are located in Arlington, the Sauk-Suiattle Tribe offices are located in Darrington, and the Tulalip Tribes offices are located on the Tulalip Indian Reservation immediately south of the basin.

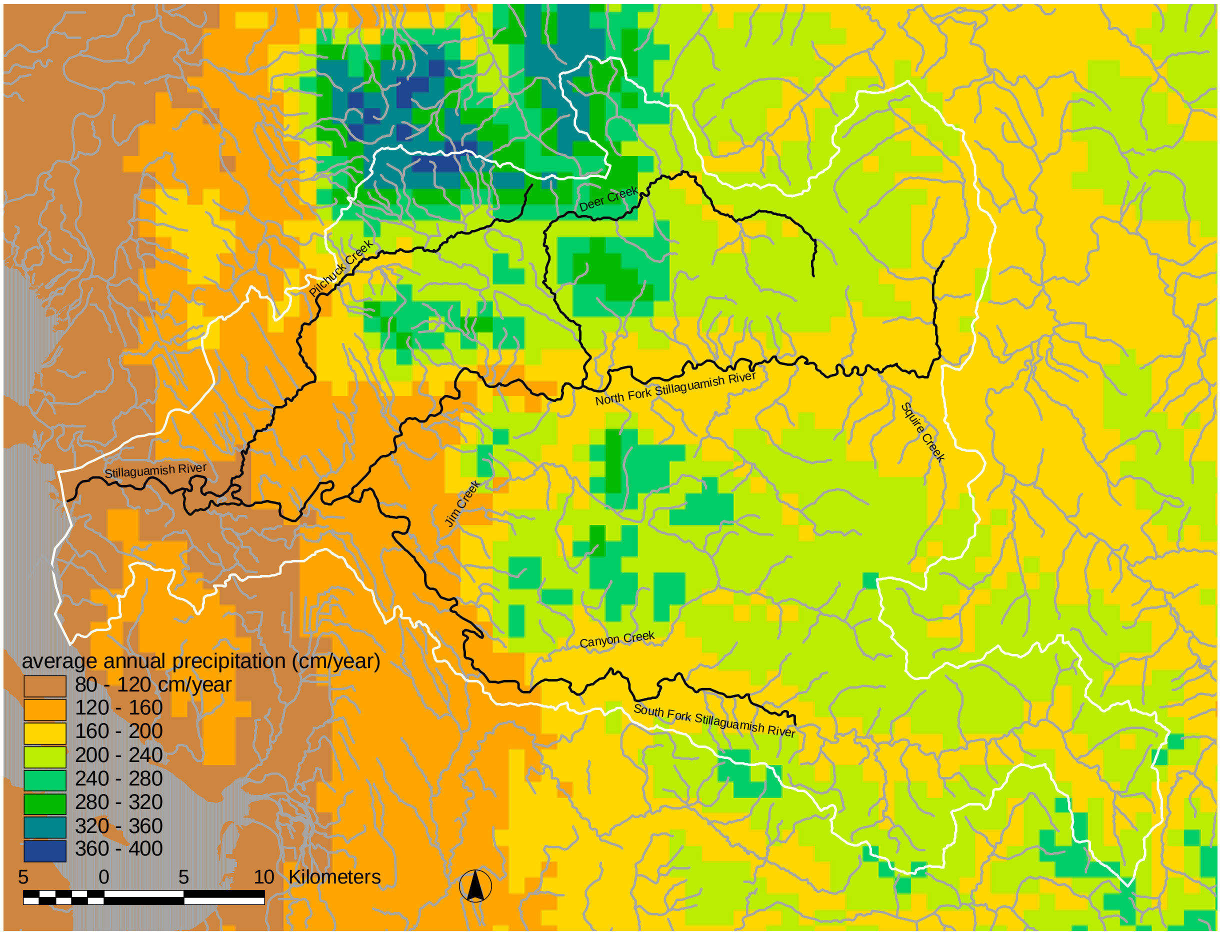

Figure 2. Annual average precipitation in the Stillaguamish River watershed (data from www.daymet.org).

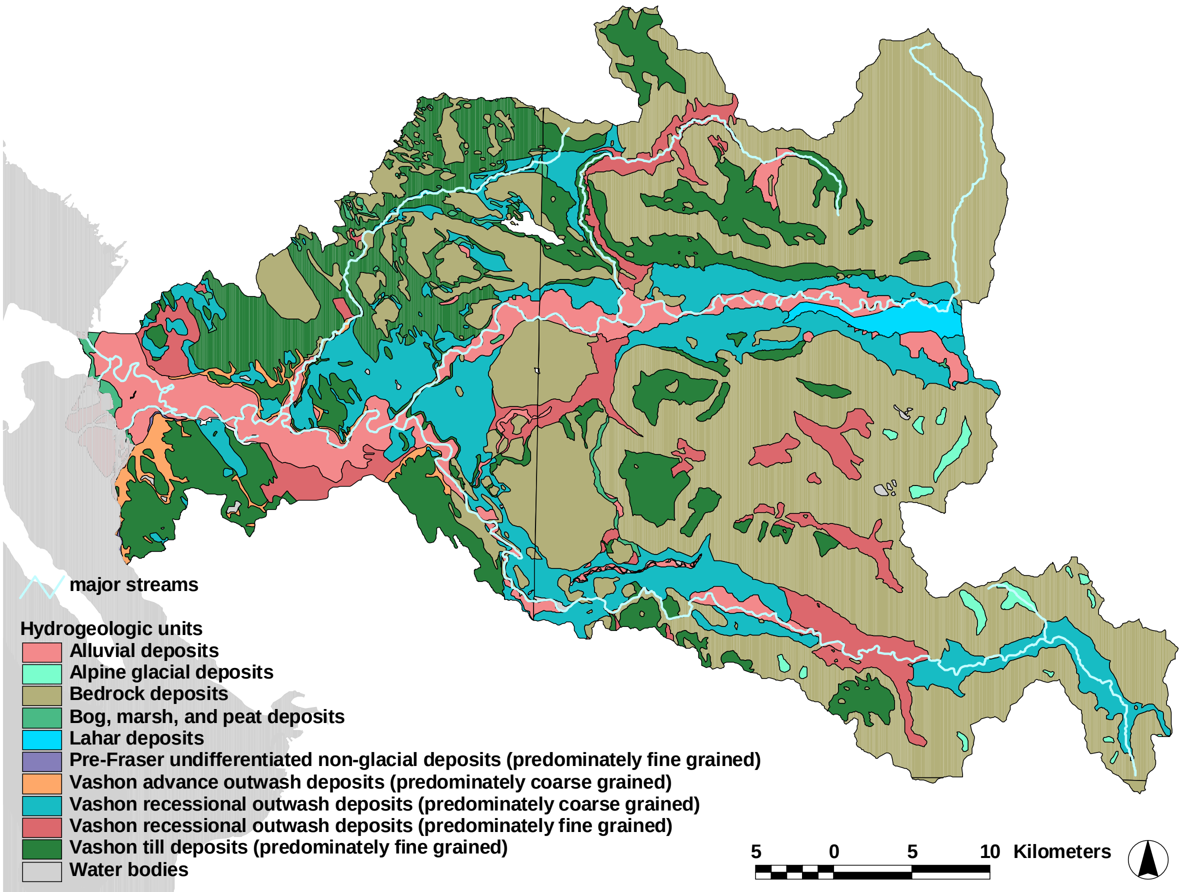

Figure 3. Surface hydrogeology of the Stillaguamish River watershed.

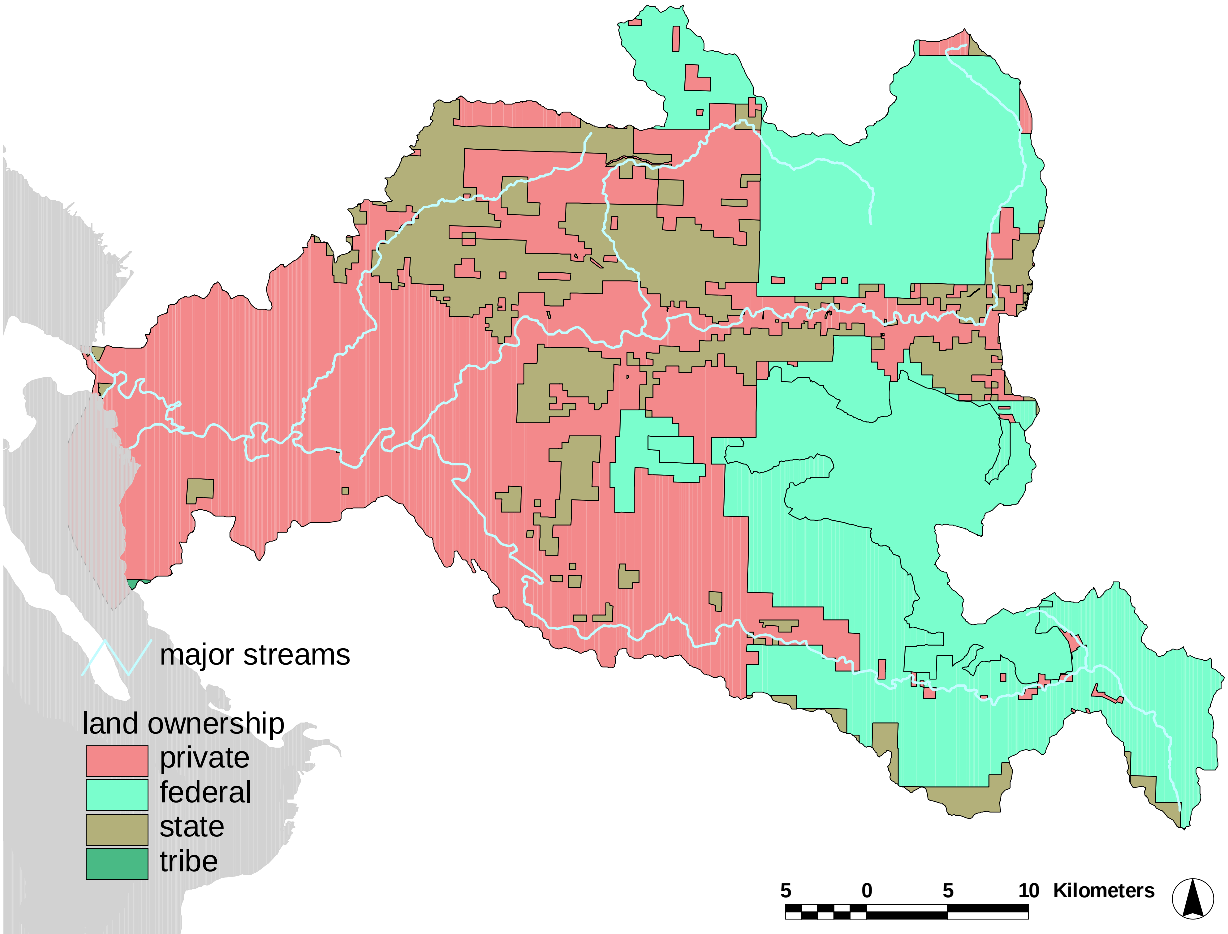

Figure 4. Land ownership in the Stillaguamish River watershed.

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At kilometer 4.4 (river mile 2.75) is another important hydrologic feature, a split between the Old Stillaguamish Channel and Hatt Slough. Most flow was redirected out of the Old Stillaguamish Channel by a series of major floods that released logjams more than 70 years ago. Hatt Slough provided a straight path to Port Susan for the floodwaters and now is the primary channel of the river. The Old Channel meanders for 12.9 km until it bifurcates at about river kilometer 2.4; South Pass transports about 80% of the flow to and from Port Susan; and West Pass carries the remaining flow to and from Skagit Bay.

During the dry season, the Old Channel is almost a tidal slough; namely, Church Creek, Miller Creek, and intermittent Stanwood Wastewater Treatment Plant (WWTP) effluent discharges are the only additional freshwater inflows to a small amount of Stillaguamish River inflow. During the wet season, water from the Stillaguamish River floods into this remnant channel and flushes it. With fewer flood events in the past couple of years, the remnant channel has experienced a build up of sediment and vegetation. As mentioned in the *Introduction*, the Flood Control District installed a tide gate to help entrain more freshwater in the Old Channel from the Stillaguamish River. In the summer of 2003, the District hopes that it will increase the flushing rate of the Old Channel and improve the water quality.

Both Hatt Slough and the Old Stillaguamish Channel via South Pass transport Stillaguamish River water to Port Susan. The Warm Beach area south of Hatt Slough and Camano Island to the west also contribute run-off through several small drainages to Port Susan, and they are considered part of the Stillaguamish water quality management area. Port Susan is a relatively shallow and poorly flushed bay. For several years, commercial shellfish harvesting has been restricted or prohibited in the bay by the Washington State Department of Health because of fecal coliform contamination in the water column. Port Susan currently is not classified since shellfish are no longer commercially harvested.

Flows

Ecology installed a network of flow gaging stations during 2001 as described in Pelletier and Bilhimer (2001) (Figure 5). The gages were placed in coordination with U.S. Geological Survey (USGS) and Snohomish County gage sites.

The USGS currently gages flows in the North Fork Stillaguamish River near Arlington (station 12167000) and in the South Fork Stillaguamish River near Granite Falls (station 12161000 - gage heights only). Some Ecology gage sites were placed at historical USGS sites to verify flow network relationships. Snohomish County also measures gage heights at several sites, but the discharge volume records for these sites have not been determined.

The USGS has historically gaged flows at several other stations in the watershed on an intermittent basis (Figure 5). Only one historical gaging station, the Stillaguamish River near Silvana, was established in the mainstem Stillaguamish River below the confluence of the forks. Continuous discharge data for the station (USGS #12167700) were only recorded over 15 months, but USGS and Ecology have kept rating curves current for instantaneous flow measurements. There are statistically strong correlations between flows at the long-term gages in the upper basin and the intermittent data collected at the Silvana gage site (Figure 6).

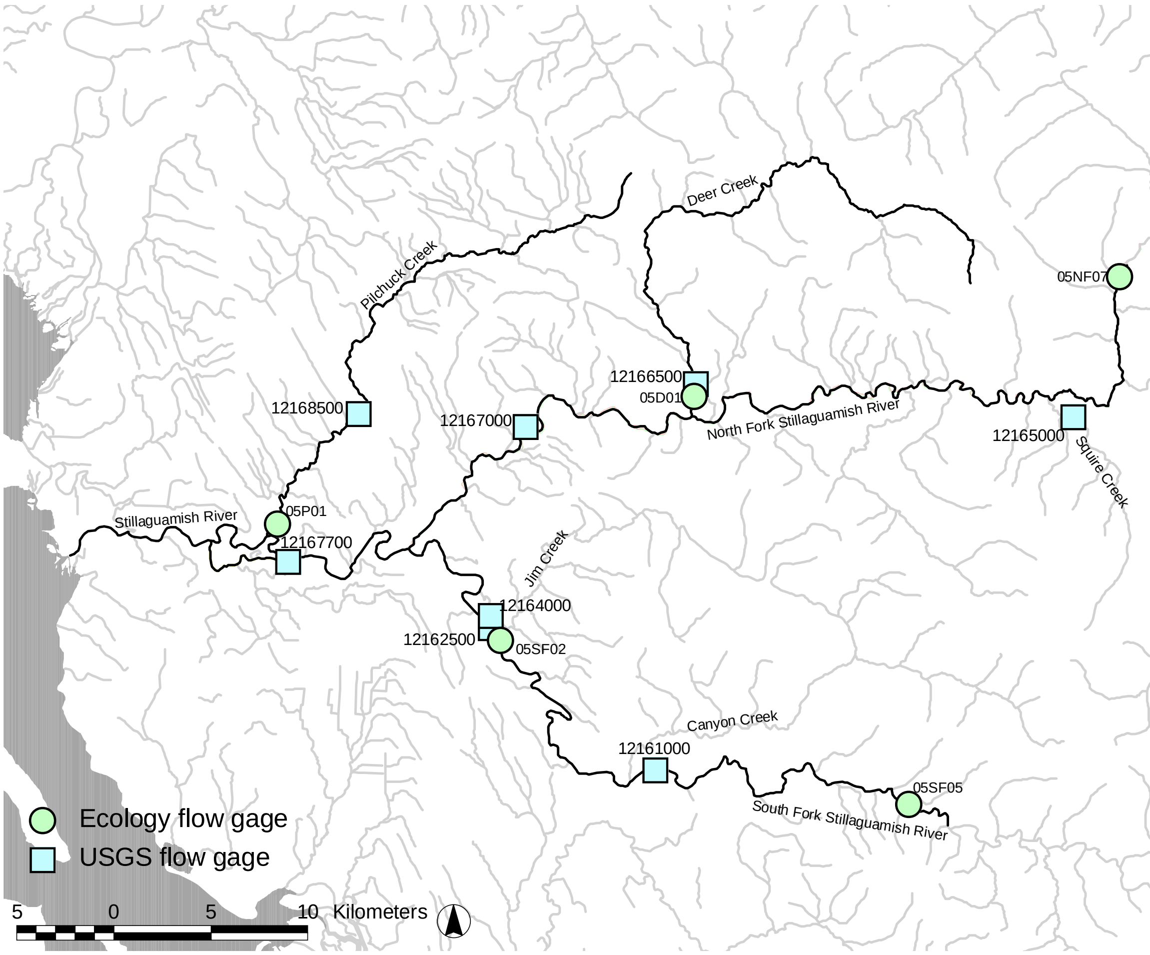

Figure 5. Flow gaging stations in the Stillaguamish River watershed.

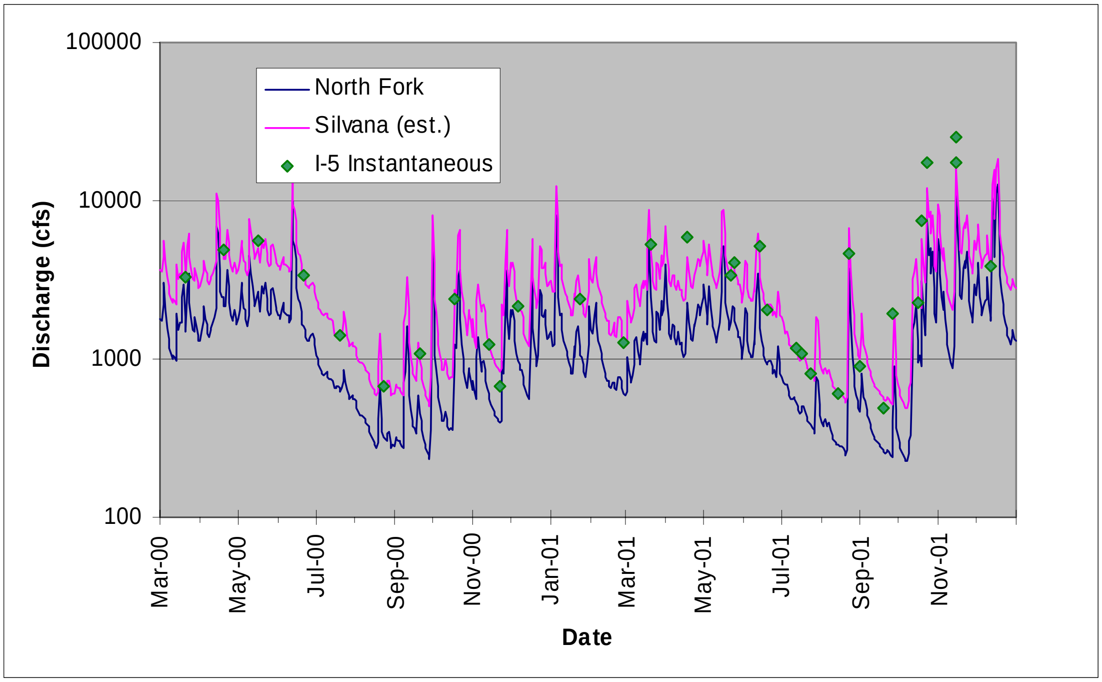

Figure 6. A daily mean discharge hydrograph for the Stillaguamish River near Silvana created from the discharge record at the North Fork Stillaguamish River near Arlington (USGS #12167000), compared to instantaneous measurements calculated from the wire-weight gage readings at Silvana in 2000 and 2001.

Flows in the Stillaguamish River respond to rainfall and snowmelt. There are no large storage or diversion structures in the basin. Small glaciers and snowfields at the highest elevations, and groundwater in the lower valleys supply water during the lowest flow periods. Approximately 75% of the annual precipitation falls between October and March (Washington Conservation Commission, 1999). Mean daily flows recorded for the two long-term USGS gage stations on the North and South forks show a similar monthly pattern (Table 2). Peak flows occur during short-term storms or rain-on-snow events. The lowest flows occur during late summer to early fall (August through October), before the fall rainstorms arrive. The annual 7-day, 10-year, low-flow statistics were estimated at USGS stations with greater than 10 years of flow data (Table 3).

Table 2. Mean daily discharge (in cfs) by month for two long-term USGS gage stations on the North Fork and South Fork Stillaguamish River.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Fork Stillaguamish 12167000	2,777	2,447	2,131	2,203	2,176	1,661	876	463	677	1,512	2,756	3,055
South Fork Stillaguamish 12161000	1,419	1,208	1,069	1,201	1,361	1,140	599	299	484	985	1,421	1,663

Table 3. Summary of the annual 7-day, 10-year (7Q10), low-flow statistics for USGS gaging stations in the Stillaguamish River basin.

Station	Station Name	Period	Drainage area (km2)	7Q10 low [(1)] cms (cfs)
12161000	South Fork Stillaguamish River near Granite Falls	1928 – 1980	308	2.237 (79)
12162500	South Fork Stillaguamish River above Jim Creek	1936 – 1957	515	3.427 (121)
12164000	Jim Creek near Arlington	1937 – 1957	120	0.193 (6.8)
12167000	North Fork Stillaguamish River near Arlington	1928 – 2001	679	4.956 (175)

[(1)] Calculated using Log Pearson III frequency factor or distribution-free methods (Aroner, 2002)

Tributaries in the lower valley respond to storm events and groundwater inflow. Residential development in some sub-basins may be creating ‘flashier’ hydrographic responses to storm events, and less extended seasonal storage from groundwater.

Water Withdrawals

Actual water withdrawals at any given time from streams in the Stillaguamish River watershed are not known, but information from the Water Rights Application Tracking database system (WRAT) was used as an indicator of the amounts of water that may be withdrawn. The water quantity potentially withdrawn from surface waters for consumptive use is about 2.2 cms from surface waters and 1.6 cms from groundwater (Table 4). Irrigation represents the majority of the consumptive withdrawal from surface waters.

Table 4. Summary of consumptive water rights in the Stillaguamish River watershed (Pelletier and Bilhimer, 2004).

Tributaries	Total of all water right flows	
	(cfs)	(cms)
Consumptive surface water withdrawals		
Alder Brook	4.06	0.115
Armstrong Creek	0.84	0.024
Bulson Creek	0.02	0.001
Canyon Creek	0.12	0.003
Edwards Creek	3.93	0.111
Fish Creek	3.68	0.104
French Creek	0.02	0.001
Hat Slough	15.52	0.439
Jim Creek	0.64	0.018
Lake Cavanaugh	0.05	0.001
Lake Creek	0.39	0.011
Lake Martha	0.01	0.0003
March Creek	1.23	0.035
Miller Creek	0.01	0.0003
NF Stillaguamish River	26.43	0.748
Pilchuck Creek	0.54	0.015
Port Susan	1.10	0.031
Portage Creek	1.33	0.038
SF Stillaguamish River	7.64	0.216
South Pass	1.00	0.028
South Slough	5.80	0.164
Stillaguamish River	0.30	0.009
Other	6.62	0.187
Total	81.27	2.300
Total consumptive groundwater withdrawals	56.40	1.600

Potential Pollutant Sources

There are several potential point and nonpoint sources in the basin that could contribute to the Stillaguamish basin Section 303(d) listings. Wastewater treatment plants (WWTPs) and dairies historically have been the focus of water quality actions in the lower basin and along the upper basin valleys to control bacteria, nutrients, and oxygen demand inputs. However, properties near Arlington and Stanwood are rapidly converting from agricultural to rural residential uses. Wastewater management practices and stormwater runoff issues in these areas of the basin have not necessarily meant a reduction of pollutant loads as much as a change in the delivery mechanisms and dispersal of pollutants sources.

Point sources are WWTPs with a distinct collection and discharge points where pollutants under permit can be monitored. Point sources in the Stillaguamish basin include the WWTPs at Arlington, Indian Ridge Correctional Facility, Warm Beach Christian Conference Center, Twin City Foods, and Stanwood. All have current National Pollutant Discharge Elimination System (NPDES) or State Waste Discharge permits. The operational units and permit limits for these facilities are described in Appendix A. All facilities are self-monitored and report to Ecology under current permit requirements. Most permits require effluent monitoring of pH, temperature, biochemical oxygen demand (BOD), total suspended solids, fecal coliform bacteria, and disinfection residuals. None of the facilities currently have permit limits on nutrient concentrations.

The WWTPs have been improving over the years to reduce bacteria, biochemical oxygen demand, and ammonia inputs into receiving waters. Increased housing densities and expanding utilities within the municipal service areas also have required the municipal WWTPs to increase their treatment capacities. Arlington WWTP completed an upgrade of its facility in 1998, and Stanwood will finish upgrading its facility in 2004. The Warm Beach Conference Center will finish upgrading its lagoon system by adding a wetland treatment unit in 2003. The Indian Ridge facility underwent a change in operational management in 2000. Twin City Foods in Stanwood has used an upgraded treatment lagoon and land application system for food processing waste, non-contact cooling water, and repack water since 1998.

Certain classes of stormwater systems are now considered point sources, although the contaminants are often released in an uncontrolled and dispersed manner. Snohomish County and the Washington State Department of Transportation (WSDOT) were required to implement a stormwater management program under Phase 1 of the NPDES and State Waste General Stormwater Permit process in 1995. Snohomish County has monitored and implemented improvements in several areas of the Stillaguamish basin with stormwater drainage and nonpoint runoff problems (Snohomish County, 2002). WSDOT and Snohomish County Public Works Department recognize that stormwater runoff from roads and adjacent properties have increasingly become a problem, especially along the Interstate 5 corridor. WSDOT has inventoried many highway stormwater drains located in Pilchuck Creek, Portage Creek, Church Creek, Harvey/Armstrong Creek, and North Fork Stillaguamish River sub-basins.

Stormwater quality and quantity from roadway runoff and uncontrolled runoff from land adjacent to ditches and drains have probably always been a problem for the county and municipal collection systems. More recently, it has been identified as a problem in areas of the county where new residential development has occurred and where non-commercial farms are located. Stormwater can be significant sources of fecal coliform bacteria, nutrients, metals, suspended solids, and oxygen demanding particles. Large and sudden quantities of stormwater runoff can disrupt natural hydrologic cycles and can ruin stream channel aquatic biota habitat.

Snohomish County and the Snohomish Conservation District have been working together to mitigate stormwater contaminant loads. For example, Glade Bekken, a small sub-basin near the mouth of the Stillaguamish River, was host to a number of watershed restoration projects in 1998 designed, in part, to repair stream habitat degraded by stormwater runoff and to reduce stormwater loads of fecal coliform, nitrate, and suspended solids (Thornburgh, 2001).

Arlington and Granite Falls are required under Phase 2 of the Municipal General Stormwater Permit process to complete plans and implement programs. Stormwater from the Arlington municipal area historically has been routed through several storm drains to the South Fork and mainstem Stillaguamish River, and to drainages in the Portage and March Creek sub-basins. Granite Falls is located mostly in the Pilchuck River sub-basin, but some stormwater may flow towards the South Fork Stillaguamish River.

Both quantity and quality effect of stormwater are issues for receiving water quality. Changes in land use may have affected seasonal flows in Portage Creek that have resulted in more serious and frequent flooding (Barlond, 2001). This is common in developing areas where impervious structures like homes and roads increase the amount of runoff to drains and streams. Arlington has made some improvements in its collection system and routing, and has worked with WSDOT in using wetlands for stormwater treatment and flood control in some areas (Blake, personal communication, 2002).

Nonpoint sources do not have easily identified and distinct locations where pollutants are discharged and can be monitored. Nonpoint sources are usually associated with land uses such as timber harvesting, construction, agricultural production, intensive recreational activities, and urban runoff. Many types of nonpoint sources are intermittent because they are generated by rainfall in sufficient amounts to produce runoff.

A significant source of nonpoint pollution in western Washington has historically been attributed to dairies and animal production facilities. A steady improvement in waste management and operational practices at these types of facilities over the past 25 years has reduced their pollutant loading in many basins. The Dairy Nutrient Management Act of 1998 required all dairies in the state to register and have certified nutrient management plans by December 31, 2003. Implementing and maintaining the management plans should reduce or eliminate pollutant loading from dairy operations.

The current inventory shows 21 active dairies in the Stillaguamish basin with approximately 5100 cows and 2000 heifers and calves (Ecology, 2003a). Most of the dairies are located in the lower valley floodplain, but a few are located along the valley of the North Fork, and clustered near Arlington in drainages to the South Fork. As of June 2003, eleven of these dairies have certified nutrient management plans. Only one dairy in the basin has a NPDES and State waste discharge general permit (WAG 01-3025B). It is located south of the Twin City Foods land application site between the Old Stillaguamish Channel and Hatt Slough.

There are fewer dairies in the basin now than in 1996. The 1996 dairy inventory listed 44 dairies with almost 8000 cows in the basin. By 1999 the number of active dairies in the basin was reduced to 31, with approximately 8000 cows and 3000 heifers and calves (Ecology, 2000). Now there are 21 active dairies. Two of the ten dairies that went out of business between 1999 and 2000 were in the South Fork sub-basin, and one was in the Pilchuck Creek sub-basin. The remaining eight were in the Portage Creek sub-basin and lower Stillaguamish floodplain between Arlington and Stanwood.

Between 1990 and 2000, Snohomish County's population increased by 30% (Washington State Office of Financial Management, 2003). Land use in the Stillaguamish River basin has changed as a result of that population growth. Properties are being converted from commercial agricultural and forestry uses to high and low density residential, non-commercial agriculture, and commercial/industrial uses.

These land use conversions may not necessarily result in reduced loading of contaminants traditionally associated with commercial agriculture, e.g., bacteria, nutrients, suspended solids, and pesticides. Rural residential areas, non-commercial agricultural interests, and commercial/industrial uses can generate greater loads of these same pollutants. Increased contaminant loading can be related to poor animal-keeping practices on smaller lots – anything from a pet horse or family cow to a boarding stable. These sources, along with poorly maintained and failing onsite septic systems, can be directly discharged into waterways.

Background concentrations of some contaminants in the basin complicate some aspects of the TMDL. Although inactive and abandoned mines could be potential sources of uncontrolled contamination, veins of arsenic and mercury-enriched bedrock in the headwater streams and aquifers of both forks may be responsible for some elevated concentrations of these metals. Riparian wetlands and groundwater seepage into small tributaries could be natural sources of lower dissolved oxygen concentrations during baseflow conditions. The diked flats used by Twin City Foods and the other farmlands in the lower Stillaguamish Valley provide an excellent wintering area for flocks of trumpeter swans, snow geese, and other waterfowl. The riparian areas, wetlands, sloughs, and tideflats of Port Susan provide an excellent habitat for seals and other wildlife, also a potential for significant seasonal bacteria loading.

Relatively narrow veins of metal ore in the Cascade Mountains, where headwater streams of the basin originate, are also rich with arsenic and mercury. Where tributaries and snowmelt cross these veins, contamination is possible. One potential anthropogenic source for arsenic and mercury contamination may be historical mining operations in the mountains along the veins. Huntting (1956) shows several historical mines in the South Fork and North Fork Stillaguamish River basins where arsenic and mercury were of secondary value. Metal mining was most active in the late 1800s until the 1920s. No active mines are located in the headwaters. The Washington State Department of Natural Resources, Ecology, the EPA, and other federal agencies are making an inventory and monitoring water quality in these inactive and abandoned mining areas (Norman, 2000; Raforth, Norman, and Johnson, 2002).

Another potential source of arsenic and mercury is groundwater. Elevated groundwater arsenic concentrations have been a well-known problem in the Granite Falls area where completed wells are in contact with the bedrock formations or bedrock-derived material (Snohomish County Health District and Washington State Department of Health, 1991). The elevated arsenic concentrations in groundwater are more widespread in Snohomish County than the Granite Falls area (Thomas, Wilkinson, and Embrey, 1997). Some wells in the Cascade foothills between Arlington and Granite Falls had elevated arsenic. Elevated mercury was detected in two of the wells north of Stanwood and another well in the North Fork valley. The sources of arsenic and mercury in these samples were not determined; sampling protocols and quality assurance were followed and acceptable.

Wildlife can contribute a significant load of bacteria, nutrients, and oxygen-demanding substances when they are found in large numbers. The first small flocks of snow geese arrive on the Skagit-Fraser estuaries in late September and build in numbers throughout October and early November. A small portion move on, and then the population is relatively stable until spring. This flock numbered about 41,100 during 1987-96 (WDFW, 2003). With other flocks of geese, swans, and ducks joining the snow geese, the populations of waterfowl wintering in the lower Stillaguamish waterways and adjacent fields are substantial. In Table 5, three to five years of Audubon bird counts and special inventories by the Washington Department of Fish and Wildlife in northeast Port Susan, Livingston Bay, and the lower Stillaguamish Delta were compiled and summarized by the Audubon Society (Cullinan, 2001).

Table 5. Bird population data for northeast Port Susan, Livingston Bay, and the Stillaguamish River delta (Cullinan, 2001).

Bird	Season Sited	Average Number	Maximum Number
Trumpeter Swan	Winter	51	139
Snow Goose	Winter	9,700	25,000
Ducks	Winter	4,040	6,864
Eagle	Winter	4	10
Merlin	Winter	1	3
Falcon	Winter	1	2
Shorebirds	Fall Migration	-	50,000
Shorebirds	Winter	24,175	31,050
Shorebirds	Spring Migration	34,350	50,000

About 300 harbor seals are residents of northern Port Susan. Their population has stabilized since 1993 or 1994 (Huber, personal communication, 2003). They haul-out on the tideflats in warmer months, pup in July and August, and stay around northern Port Susan throughout the year. In cooler months they spend most of their time in the water. Less is known about their dispersal within Port Susan during the winter months since they are in the water during the day, and lower tides (when they might move out of the water) occur at night.

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Applicable Water Quality Criteria

This report addresses impairments of characteristic uses caused by fecal coliform bacteria, dissolved oxygen, pH, arsenic, and mercury as pollutants. The characteristic uses designated by Washington State for protection in Stillaguamish River basin streams (Class AA and Class A) and for Port Susan (Class A) are as follows (Chapter 173-201A WAC):

"Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

- *(i) Water supply (domestic, industrial, agricultural).*
- *(ii) Stock watering.*
- *(iii) Fish and shellfish:*
  Salmonid migration, rearing, spawning, and harvesting.
  Other fish migration, rearing, spawning, and harvesting.
  Clam and mussel rearing, spawning, and harvesting.
  Crayfish rearing, spawning, and harvesting.
- *(iv) Wildlife habitat.*
- *(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).*
- *(vi) Commerce and navigation."*

Washington State has water quality criteria (Chapter 173-201A WAC) for fecal coliform bacteria, dissolved oxygen, pH, and metals to protect these characteristic uses (Table 6). Human-health criteria for arsenic and mercury are set by the EPA through the National Toxics Rule (40 CFR 131.36).

Ecology has adopted new criteria and standards for dissolved oxygen and bacteria indicators that are similar to the older criteria (Table 7). The new criteria cannot be implemented until they are approved by EPA. EPA's approval of the new standards may occur just as this TMDL is being finalized in 2004. Although there are few changes in the numeric criteria, the dissolved oxygen criteria would significantly change if major areas in the basin were classified as core salmon spawning and rearing instead of as non-core areas. Ecology is uncertain if EPA would hold approval and require a reassessment of the dissolved oxygen if classifications were changed. Post-TMDL assessments may be compared to the existing criteria and any new criteria that are adopted.

Other sections of Chapter 173-201A WAC are pertinent to the parameters in the Stillaguamish TMDL. Chapter 173-201A-070, a section on antidegradation, states that existing beneficial uses shall be maintained and protected, and no further degradation is allowed. The section goes on to state that:

"Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria."

Table 6. Current state water quality (Chapter 173-201A WAC) and National Toxics Rule (40 CFR 131.36) criteria used to determine if Stillaguamish River basin waters and Port Susan are supporting beneficial uses.

Criteria Category	Statistic	Criterion	Ancillary Data Required
Dissolved oxygen			
Class B Freshwater	Minimum	6.5 mg/L	
Class A Freshwater	Minimum	8.0 mg/L	
Class AA Freshwater	Minimum	9.5 mg/L	
Class A Marine	Minimum	6.0 mg/L	95% vertically avg. daily max. salinity > 1ppt
Fecal coliform			
Class A Freshwater	Geometric mean	100 cfu/100 mL	
	Not more than 10% of the samples exceed*	200 cfu/100 mL	
Class AA Freshwater	Geometric mean	50 cfu/100 mL	
	Not more than 10% of the samples exceed*	100 cfu/100 mL	
Class A Marine	Geometric mean	14 cfu/100 mL	Vertically averaged salinity ≥ 10 ppt
	Not more than 10% of the samples exceed*	43 cfu/100 mL	
FDA Shellfish harvesting	Geometric mean	14 MPN/100 mL	
	90th percentile value	43 MPN/100 mL	
pH			
Freshwater	Maximum	8.5	
	Minimum	6.5	
Marine	Maximum	7.0	
	Minimum	8.5	
Arsenic			
Freshwater Aquatic Toxicity	4-day average/3 years	150 ug/L	Dissolved arsenic (EPA, 1999 revision)
	1-hr average/3years	340 ug/L	Dissolved arsenic (EPA, 1999 revision)
Marine Aquatic Toxicity	4-day average/3 years	36 ug/L	21 ug/L to prevent non-lethal effects to diatoms
	1-hr average/3years	69 ug/L	95% vertically avg. daily max. salinity > 1ppt
Human Health **	Maximum	0.018 ug/L	Consumption of water and organisms
Human Health **	Maximum	0.14 ug/L	Consumption of organisms only
Mercury			
Freshwater Aquatic Toxicity	4-day average/3 years	0.012 ug/L	
	1-hr average/3years	2.1 ug/L	
Marine Aquatic Toxicity	4-day average/3 years	0.025 ug/L	95% vertically avg. daily max. salinity > 1ppt
	1-hr average/3years	1.8 ug/L	95% vertically avg. daily max. salinity > 1ppt
Human Health **	Maximum	0.14 ug/L	Consumption of water and organisms
Human Health**	Maximum	0.15 ug/L	Consumption of organisms only

* The 90th percentile is statistically similar to the criteria wording that states that not more than 10% of the samples used to calculate the geometric mean shall exceed the numerical criterion.

** National Toxics Rule human-health criteria: arsenic calculated at the suggested lifetime carcinogenic risk of 1:1,000,000.

Table 7. Proposed criteria changes that may be used in future assessments of the Stillaguamish River basin (Ecology, 2002).

Category	Statistic	Criterion	Beneficial use protected
Dissolved Oxygen			
Freshwater	One day minimum not exceeded more than once in 10 years	9.5 mg/L	Char areas, and salmon and trout spawning and core rearing and migration areas
	Same	8.0 mg/L	Salmon and trout spawning areas and non-core rearing and migration areas
	Same	6.5 mg/L	Salmon and trout rearing and migration only
Marine	One day minimum	7.0 mg/L	Extraordinary quality for aquatic life
	One day minimum	6.0 mg/L	Excellent quality for aquatic life
	One day minimum	5.0 mg/L	Good quality for aquatic life
	One day minimum	4.0 mg/L	Fair quality for aquatic life
Fecal Coliform			
Freshwater	Geometric Mean	50 cfu/100 mL	Extraordinary primary water contact recreation
	Not more than 10% of the samples exceed	100 cfu/100 mL	Extraordinary primary water contact recreation
	Geometric Mean	100 cfu/100 mL	Primary water contact recreation
	Not more than 10% of the samples exceed	200 cfu/100 mL	Primary water contact recreation
	Geometric Mean	200 cfu/100 mL	Secondary water contact recreation
	Not more than 10% of the samples exceed	400 cfu/100 mL	Secondary water contact recreation
Marine	Geometric Mean	14 cfu/100 mL	Primary contact recreation and shellfish harvesting
	Not more than 10% of the samples exceed	43 cfu/100 mL	Primary contact recreation and shellfish harvesting
Enterococci			
Marine	Geometric Mean	70 cfu/100 mL	Secondary contact recreation
	Not more than 10% of the samples exceed	208 cfu/100 mL	Secondary contact recreation

This is in recognition that non-anthropogenic sources like wetland and groundwater sources can influence local water quality conditions so that not all numeric criteria and standards are met at all times. In cases where dissolved oxygen concentrations are lower than the criteria due to natural conditions, Ecology TMDL policy (TMDL Workgroup, 1996) and the proposed state water quality criteria [Chapter 173-201A-200(1)(d)(i) WAC] allow up to 0.2 mg/L loss from cumulative anthropogenic sources.

Chapter 173-201A also contains a narrative criterion for each classification that states:

"Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department."

The narrative criteria statements acknowledge that measures of water quality other than those specifically addressed as numerical criteria can be used to measure compliance with the water quality standards. One example is that Washington State water quality standards do not have numeric nutrient criteria. The nutrients, nitrogen and phosphorus, are essential for plant growth and aquatic community health. However, when there is an overabundance of nutrients from point and nonpoint sources, aquatic plant growth can become over-stimulated, a process called cultural eutrophication. If natural reaeration processes cannot compensate for plant respiration and production in areas affected by eutrophication, then dissolved oxygen concentrations plunge at night and become supersaturated during the day. These diel swings can be harmful to macroinvertebrates and fish.

Fecal coliform criteria in marine waters are used to protect recreational uses and shellfish harvesting. The marine water criteria are similar for the two uses, but they are administered by two different state agencies in different ways.

- Washington State Department of Health (DOH) uses the fecal coliform criteria as one element of the shellfish harvest area certification process. According to DOH and Federal Drug Administration (FDA) regulations, fecal coliform samples can only be analyzed by the most probable number (MPN) method. To evaluate water quality compliance, DOH generates running geometric mean and 90th percentile statistics at each site from 30 consecutive samples. These statistics must consistently meet the FDA-mandated 14 MPN/100 mL and 43 MPN/100 mL criteria, respectively.

- Ecology uses samples analyzed by MPN or membrane filter (MF) methods. The Class A marine water criteria are applied to samples with salinities greater than 10 parts per thousand. There is no requirement for a minimum number of samples. Seasonal stratification of samples is required if compliance with the criteria can only be met when lower counts outside the season of concern are included in the sample set.

EPA has recommended nutrient criteria for rivers and streams to address cultural eutrophication (EPA, 2000). The criteria have been statistically derived for the Level III ecoregions of Puget Lowlands and North Cascades within aggregate Ecoregion II. The EPA recommends using the median 25th percentile of four season 25th percentiles of data collected from all stations within the Level III ecoregion. The 25th percentile was considered to be roughly comparative to the 75th percentile of reference station data until enough reference station data are analyzed (Table 8).

Table 8. Recommended EPA nutrient criteria for Level III ecoregions, Puget Sound and North Cascades, in aggregate Ecoregion II (EPA, 2000).

Parameter	Puget Lowland			North Cascades		
	Min	Max	25th percentile	Min	Max	25th percentile
Total Kjeldahl nitrogen (mg/L)	0.05	0.83	0.08	0.05	0.19	0.05
NO2+NO3 (mg/L)	0.01	3.7	0.26	0.01	0.22	0.03
Total nitrogen (mg/L) calculated	0.06	4.53	0.34	0.06	0.41	0.08
Total nitrogen (mg/L) reported	0.08	2.62	0.24	0.09	0.27	0.11
Total phosphorus (mg/L)	0.0025	0.330	0.0195	0.0025	0.042	0.003
Chlorophyll *a* (ug/L) – F	0.7	0.9	0.7	NA	NA	NA
Chlorophyll *a* (ug/L) – T	NA	NA	NA	0.55	0.76	0.55*

Total nitrogen – calculated = Total Kjeldahl nitrogen + NO2 + NO3
Chlorophyll *a* – F = Chlorophyll a by fluorometric method with acid correction
Chlorophyll *a* – T = Chlorophyll a, b, c by trichromatic method
* = based only on one season from samples collected from less than four rivers or streams.

The Stillaguamish River fecal coliform and dissolved oxygen TMDL incorporates measures other than "daily loads" to fulfill the requirements of Section 303(d). TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. This TMDL allocates other appropriate measures or "surrogate measures" as provided under EPA regulations [40 CFR 130.2(i)]. The "Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program" (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

"When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not."

The 303(d) listing in the mainstem Stillaguamish River for dissolved oxygen is based on the criteria in Table 6. The mechanism for the loss of dissolved oxygen in the river cannot be directly allocated to dissolved oxygen loads since it is caused by biological primary production and respiration processes (See *Technical Analysis:* Dissolved Oxygen, and *Loading Capacity:* Dissolved Oxygen in this report). Primary production is nutrient driven and not a function of biochemical oxygen demand (BOD), nitrogenous oxygen demand (NOD), or sediment oxygen demand (SOD). Therefore, although dissolved oxygen is the criteria to be met, the allocations will be to phosphorus and/or nitrogen loads.

In another case, fecal coliform compliance is measured by numeric criteria based on statistical attributes of counts at a site, i.e., both the geometric mean and "not more than 10% of the samples" at a site's fecal coliform population must meet the criteria. An allocation of fecal coliform count loads is awkward and does not adequately address the criteria compliance requirements under various hydrologic conditions at the site. For example, a high fecal coliform count out of compliance under low-flow conditions may have a lower load than a lower count within compliance under higher flow conditions. Instead of managing fecal coliform sources by defining an acceptable load, Ecology has used the Statistical Rollback Method (Ott, 1995) to manage the distribution of fecal coliform counts (See *Analytical Framework:* Fecal Coliform). The approach has proven successful in past bacteria TMDL assessments (Cusimano, 1997; Joy, 2000; and Sargeant, 2002).

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Water Quality and Resource Impairments

Beneficial Uses and Section 303(d) Listings

Several beneficial uses may not be meeting their full potential because of water quality impairments in the Stillaguamish River basin. The most important uses identified by local groups are salmon spawning and rearing, recreation, and shellfish harvesting. Chinook salmon were listed as a threatened species under the federal Endangered Species Act in 1999. Coho salmon are a candidate species. Commercial shellfish harvesting in Port Susan is prohibited because the area has not been assessed by the Washington State Department of Health since the mid-1980s.

The 1998 Section 303(d)-listed parameters for waterbodies in the basin are indicators that these uses are impaired (Table 9). Low dissolved oxygen and low pH can impair fish and aquatic life communities. Arsenic concentrations above human-health criteria can be a threat to human consumers of water, fish, and shellfish. High fecal coliform bacteria counts threaten primary and secondary recreational uses of the water and prevent shellfish harvesting.

Table 9. Washington State 1998 Section 303(d)-listed parameters for the Stillaguamish River basin and Port Susan that are addressed in the fecal coliform, dissolved oxygen, pH, and metals TMDL assessment.

Old WBID	New WBID	Name	Parameters
WA-05-1016	QJ28UC	Fish Creek	Fecal Coliform
	HD76OJ	Harvey Creek	Fecal Coliform
	JU33JU	Jim Creek	Fecal Coliform
WA-05-1012	GH05SX	Jorgenson Slough (Church Creek)	Fecal Coliform
	IJ55EP	Lake Martha Creek	Fecal Coliform
WA-05-1018	VJ74AO	Pilchuck Creek	Dissolved Oxygen
WA-PS-0020	390KRD	Port Susan	Fecal Coliform
WA-05-1015	OT80TY*	Portage Creek	Fecal Coliform, Dissolved Oxygen
WA-05-1010	QE93BW	Stillaguamish River	Fecal Coliform, Dissolved Oxygen, Arsenic
WA-05-1010	ZO73WL	Stillaguamish River (Hat Slough)	Fecal Coliform, Dissolved Oxygen
WA-05-1020	WO38NV	N.F. Stillaguamish River	Fecal Coliform
WA-05-1050	SN06ZT	S.F. Stillaguamish River	Fecal Coliform, pH, Dissolved Oxygen
	LU17DC	Unnamed Creek #0456	Fecal Coliform
WA-PS-0020	390KRD	Port Susan	Fecal Coliform

* Includes the listings mistakenly assigned to OJ28UC, Fish Creek, and YF03BC, a branch of Portage Creek, but should have been entered as OT80TY, Portage Creek.

Salmon use a variety of habitats in the Stillaguamish, the mainstem and major forks, large and small tributaries, beaver ponds, riparian wetlands and side channels, estuary sloughs, and salt marshes. Many of these habitats have been reduced severely from sedimentation of channels by natural landslides and from anthropogenic activities, e.g., diking and channelization, removal of riparian vegetation, and water quality degradation by land use activities (Washington Conservation Commission, 1999). Just under one-third (1432 km) of the total stream network is available habitat for anadromous fish (Washington Conservation Commission, 1999).

Salmon are present throughout the year in many parts of the basin. Table 10 shows the approximate timing of various life-stages of salmon species in the Stillaguamish (Washington Conservation Commission, 1999). Rearing of several species occurs throughout the year and in several types of habitats. Although the spawning period overlaps between species, salmon have specific spawning habitat requirements. For example, chinook salmon prefer the main channels of larger rivers while coho prefer smaller tributaries.

Table 10. General timing of life-stages of Stillaguamish basin salmon species (Washington Conservation Commission, 1999)

Species	Life Phase	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook	Upstream migration						xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx						
	Spawning								xxxxxxxxxxxxxxxxxxxxxxxx				
	Incubation	xxxxxxxxxxxxxxxx							xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration			xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
Coho	Upstream migration									xxxxxxxxxxxxxxxxxxxxxxxx			
	Spawning	xxxxxxxxxxxxxxxx									xxxxxxxxxxxxxxxxxxxxxxxx		
	Incubation	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									xxxxxxxxxxxxxxxxxxxxxxxx		
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration			xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
Pink	Upstream migration								xxxxxxxxxxxxx				
	Spawning								xxxxxxxxxxxxxxxxxxxxxxxx				
	Incubation	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx							xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
	Juvenile rearing			xxxxxxxxxxxxxxxxxxxxxxx									
	Smolt outmigration			xxxxxxxxxxxxxxxxxxxxxxx									
Chum	Upstream migration									xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
	Spawning	xxxx									xxxxxxxxxxxxxxxxxxxxxxxx		
	Incubation	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									xxxxxxxxxxxxxxxxxxxxxxxx		
	Juvenile rearing			xxxxxxxxxxxxxxxxxxxxxxxxxxx									
	Smolt outmigration			xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
Sockeye	Upstream migration							xxxxxxxxxxxxxxxxxxxxxxx					
	Spawning								xxxxxxxxxxxxxxxxxxxxxxxx				
	Incubation	xxxxxxxxxxxxxxxx								xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration			xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
Summer	Upstream migration				xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx								
Steelhead	Spawning		xxxxxxxxxxxxxxxxxxxxxxxxxxxx										
	Incubation		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx										
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration				xxxxxxxxxxxxxxxxxxxxxxx								
Winter	Upstream migration	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx										xxxxxxxxxxxxx	
Steelhead	Spawning			xxxxxxxxxxxxxxxxxxxxxxxxxxxx									
	Incubation			xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration				xxxxxxxxxxxxxxxxxxxxx								
Char	Upstream migration						xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx						
	Spawning									xxxxxxxxxxxxxxxxx			
	Incubation	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx								xxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration				xxxxxxxxxxxxxxxxxxxxxxx								
Sea-run	Upstream migration							xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					
Cutthroat	Spawning		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx										
	Incubation		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx										
	Juvenile rearing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx											
	Smolt outmigration				xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx								

Of the Section 303(d)-listed parameters in the Stillaguamish, dissolved oxygen, pH, and turbidity are the most likely to impair salmon health. Incubation is considered a particularly sensitive life-stage for salmon when adequate instream oxygen concentrations are essential to keep intergravel eggs aerated. Most of the salmon species, except for summer steelhead and char, spawn in areas that are on the Section 303(d) list for dissolved oxygen. Low pH (below 6.5) becomes a problem to salmon in any life stage when it makes metals and other pollutants more reactive and more toxic to the fish. Turbidity can reduce salmon spawning habitat when it indicates potential siltation of spawning and incubation areas. Elevated turbidities of long duration also can impair fish behavior and feeding, and can interfere with gill operation at particularly high turbidities.

Fisheries specialists have recommended many habitat and channel improvements to assist salmon recovery in the Stillaguamish basin (Stillaguamish Technical Advisory Group, 2000). Channel sedimentation, increased peak flows, extreme low flows, increased temperatures, and reduced dissolved oxygen were identified problems in the basin. The Salmon Habitat Limiting Factors Report (Washington Conservation Commission, 1999) for the Stillaguamish River basin noted that nonpoint sources of pollution such as agricultural practices, onsite sewage disposal, development and urban runoff, and forest practices were the major cause of water quality problems.

The Stillaguamish basin attracts many people for recreational opportunities. Salmon fishing is one obvious attraction to the river. Boating, riverside picnicking, and swimming occur all along the main forks and some tributaries. There are no designated swimming areas with lifeguards and bath houses. Full immersion swimming is probably limited to summer periods when air temperatures and water temperatures are highest. During the TMDL monitoring surveys, local swimming and wading areas were observed on the main branches of the river and on some tributaries, at most Washington Department of Fish and Wildlife (WDFW) access areas, public parks, and at some bridge crossings. Warm Beach Camp and Kayak Point Regional Park have boat launching areas on Port Susan, but no designated swimming areas are present.

Commercial shellfish harvesting in Port Susan was closed by the Washington State Department of Health (DOH) in 1986 due to bacterial contamination. The area became unclassified when no commercial interest was taken in the beds, and the DOH stopped monitoring water quality. Recreational access for shellfish collection is limited, and the WDFW has recreational harvest limits, but none of the beaches have been closed for sanitary considerations under the DOH recreational shellfish monitoring program (www.doh.wa.gov/ehp/sf/recshell.htm).

Water Quality Assessments Since 1998

The data used for the 1998 Section 303(d) listings were collected from 1988 to 1997 (Ecology, 2000). Some water quality improvements were in progress by 1997. For example, data collected from 1991 to 1994 and analyzed by the Tulalip Tribes (O'Neal, Nelson, and DeNeve, 2001) showed only a weak improving trend in fecal coliform counts in the mainstem. By the late 1990s, improvements were more evident. Joy and Glenn (2000), Klopfer (2000), Thornburgh and Williams (2001), and Joy (2001) reviewed and assessed various data sets collected from the 1980s through 1999. According to their assessments, water quality had significantly improved in many parts of the basin, but criteria were not being met in others. Among the findings were:

- Fecal coliform (FC) counts at the Stillaguamish River at Interstate 5 had declined significantly since 1977. A significant improving step-trend was evident for data collected from 1989 to 1993 compared to 1994 through 1999 data. FC data collected from 1995 through 1999 met both parts of the state water quality criteria.
- FC counts in Hatt Slough at Marine Drive had decreased from 1994 to 1999. However, there was still a downstream increase in FC bacteria from the mainstem Stillaguamish River at Arlington to Hatt Slough.
- Dissolved oxygen (DO) concentrations were 0.5 – 1.0 mg/L lower at Hatt Slough than at the Stillaguamish River at Arlington, but none of the concentrations had been below 8 mg/L from 1996 to 1999.
- The Earth Tech (1997) study below the Arlington WWTP demonstrated that diel DO concentrations dropped below 8 mg/L (7.2 mg/L) in a pool reach four miles below the outfall. Water quality sampling and QUAL2E modeling analyses were performed. Periphyton productivity and respiration were the suggested causes rather than effluent biochemical oxygen demand or nitrogenous oxygen demand concentrations.
- Church Creek FC counts continued to be elevated throughout the year, but especially during storm events.
- Glade Bekken, formerly Tributary 30, was monitored by Snohomish County during a watershed restoration project. FC counts had decreased in the creek, but did not meet criteria. DO concentrations have met the Class A criterion.
- Portage Creek continued to have low DO concentrations that do not meet the Class A criterion during low-flow periods, and elevated FC counts that do not meet criteria throughout the year.
- Pilchuck Creek DO concentrations have improved since 1995, and none of the concentrations through 1999 had been below 8 mg/L.
- FC data collected by Ecology from the South Fork Stillaguamish River at Arlington from 1995 through 1999 met both parts of the state water quality criteria.
- DO concentrations from the South Fork Stillaguamish River at Arlington have not been below 8 mg/L from 1995 through 1999, and no pH violations have been observed in the data since 1990.
- A 1995 step trend was evident that showed decreasing FC counts in the North Fork Stillaguamish River at Cicero. FC counts met Class A criteria.
- FC counts were in compliance with Class AA criteria in 1999 at both the North Fork at Darrington and at the South Fork at Granite Falls.
- The Stillaguamish Tribe has been sampling FC at several sites in northern Port Susan since summer 1998 (Klopfer, 2000). Most sites have shown slight improvements through 1999. Sites nearest to Hatt Slough were not meeting marine water DOH FC criteria. The sites south (Warm Beach Point and Kayak Point) and the sites to the northwest (North Port Susan and Peripheral Site 4) appeared to be within DOH FC criteria. The site near Warm Beach Slough has experienced the worst bacterial water quality of the sites monitored.

Fecal coliform counts and dissolved oxygen and ammonia concentrations in the basin have been improving in several areas. Some of these improvements may have coincided with the federal Dairy Buyout Program in the mid-1980s that reduced the number of cows in most Puget Sound basins. Many more of the improvements reported through the 1990s coincide with implementation of the Stillaguamish Watershed Plan and work implemented by the Stillaguamish Clean Water District.

In 1987, Ecology selected the Stillaguamish River basin as one of six "Early Action Watersheds" in the Puget Sound basin. As such, a watershed management committee was formed and received grant money to write the Stillaguamish Watershed Action Plan. The 1990 plan and accompanying technical supplement addressed the magnitude of various nonpoint sources of pollution and the actions needed to control and prevent problems from those sources.

The Stillaguamish Clean Water District Board, the Stillaguamish Implementation and Review Committee, and the Flood Control District continue to direct and fund implementation of the tasks stated in the action plan, and respond to newer concerns for salmon habitat restoration. Snohomish County Surface Water Management, Snohomish Conservation District, the Stillaguamish Tribe, the Tulalip Tribes, and other local groups have been working together to improve water quality by controlling and preventing nonpoint sources in the Stillaguamish basin and in Port Susan.

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Analytical Framework

The technical analysis of the data for this TMDL required the use of several mathematical procedures, mathematical models, and statistical equations. Some of the procedures and equations were used for all of the parameters examined; others were used only for specific parameters.

The following section describes the analytical processes used for each parameter and any accompanying assumptions needed for the procedures. The procedures used to establish critical conditions and to evaluate seasonal variability are also described. The procedures, assumptions, and rationale create the technical framework that supports the findings and conclusions in *Technical Analysis* and *Loading Capacity* sections of this report.

Fecal Coliform

The Stillaguamish River basin has a extensive data set on which to evaluate historical and current bacterial conditions, establish trends, and identify critical conditions:

- The fecal coliform (FC) data at enough key freshwater sites are from long-term (greater than 10 years) monitoring programs so that trends can be determined.
- The sampling at these sites has been monthly and random without bias to climatological or hydrological events.
- The basin is not under any manipulations from diversions or damming. Therefore, the distribution of FC counts should represent the major factors affecting FC counts at a particular site: source strength, dilution, die-off, and dispersion.
- The cumulative FC counts at most sites follow a lognormal distribution.

The attributes of this data set are ideal for using the Statistical Rollback Method (Ott, 1995). The method is used to determine if FC distribution statistics for individual sites meet the water quality criteria in the Stillaguamish River basin. The method has been successfully applied by Ecology in other FC bacteria TMDL evaluations (Cusimano and Giglio, 1995; Pelletier and Seiders, 2000; Coots, 2002).

Briefly, the geometric mean (approximately the median in a lognormal distribution) and 90^{th} percentile statistics are calculated and compared to the FC criteria. If one or both of the population statistics do not meet the criteria, then the whole distribution is “rolled-back” to match the more restrictive of the two criteria. The 90^{th} percentile criterion usually is the most restrictive. The new geometric mean and 90^{th} percentile statistics then becomes the “target” statistics for the site. (The term target is used to distinguish these estimated numbers from the actual water quality criteria.) The amount a distribution of FC counts is “rolled-back” from the original statistics to the most restrictive criterion, and target statistic is calculated as the percent of FC reduction required to meet the FC loading capacity. A detailed graphical example and interpretation is shown in Appendix B.

The rollback was applied to the most representative distribution after taking several analytical steps. Both step trends and monotonic trend analyses were performed on FC counts and discharge volumes to determine the most recent and stable data set, i.e. to ensure that high water and drought years are represented equally. Trend analyses, tests for seasonality, and statistical tests for lognormal distributions were performed using WQHYDRO, a statistical software package for environmental data analysis (Aroner, 2001). The geometric mean and 90th percentile statistics for various subsets of data were then calculated and compared to determine a critical season at each site, and to determine the target statistics.

Port Susan FC data were evaluated using the 30-day running average and 90th percentile statistical analysis required by the Food and Drug Administration for commercial shellfish harvest areas. The statistical formula for deriving the 90th percentile is shown in Appendix B. Data were also evaluated to determine if a seasonal component was evident. The FC count comparisons between sites on an event basis and location of sites relative to the mouths of the Stillaguamish River (Hatt Slough and South Pass) were investigated using regression analyses.

FC field data collected during the September 2000 synoptic survey were used to calibrate the QUAL2Kw model for the lower Stillaguamish River (Arlington to Hatt Slough). The model simulations of the September survey were helpful to:

- Characterize conditions of low dilution potential for FC point and nonpoint sources.
- Evaluate the relative impact of FC loading from monitored tributaries and point sources to the lower mainstem.
- Reveal residual loads from unidentified sources.
- Compare current FC loading from point, tributary, and nonpoint sources to simulations after recommended target FC reductions on those sources are achieved.

Pelletier and Bilhimer's (2004) QUAL2Kw model for the Stillaguamish Basin Temperature TMDL provided the channel and flow foundation on which to include additional parameters for analysis. A detailed discussion of how local channel morphology, basin hydrology, and climatological data were incorporated into the model is found in Pelletier's (2003) report. Bacteria counts were simulated in QUAL2Kw using the pathogen function (Chapra, 2001; Pelletier and Chapra, 2003). The model subjects bacteria input to die-off and settling. Die-off is a function of light exposure and a chosen temperature-dependent natural loss rate. The light's killing effectiveness is a function of the intensity of the sunlight, atmospheric factors like clouds and haze, and the clarity and depth of the water. Losses by settling depend on the settling velocity chosen and the depth and velocity of the water.

FC loading estimates from tributaries, point sources, and nonpoint sources were accomplished by first completing a flow balance for the lower mainstem. As part of the QUAL2Kw modeling, Pelletier and Bilhimer (2004) had calculated flow balances for the 2000-2002 TMDL study period. Flow balances were estimated from field measurements and gage data of flows made by Ecology and the USGS, and weighted by annual average precipitation according to the sub-watershed areas. A flow balance spreadsheet of the stream networks for the Stillaguamish River, South Fork Stillaguamish River, North Fork Stillaguamish River, Deer Creek, and Pilchuck

Creek was constructed to estimate surface water and groundwater inflows by interpolating between the gaging stations.

Since discharge records are lacking for the lower 17 kilometers of the Stillaguamish River and the Old Stillaguamish Channel, an assumption was made that on average 10% of the discharge in the Stillaguamish River is diverted to the Old Channel. Further assumptions were made that the Old Channel flow increases 2.5% from Church Creek and other drainage areas before half of the Old Channel is discharged through South Pass to Port Susan and the other half through West Pass to Skagit Bay.

FC loads from Hatt Slough and South Pass were estimated using an unbiased stratified ratio estimator equation from Thomann and Mueller (1987). The formula for the equation is shown in Appendix B. Annual, monthly, and seasonal FC loads were calculated from estimated discharge volumes at Interstate 5 and FC counts collected at Hatt Slough and South Pass by staff from Ecology, the Stillaguamish Tribe, and Snohomish County Surface Water Management.

FC loads from seals and birds were also estimated and compared to the Stillaguamish River loads. Seal FC loading estimates were based on average rates from Puget Sound studies (Calambokidis, McLaughlin, and Steiger, 1989) and from seal population estimates provided by the National Marine Fisheries Marine Mammal Program. Bird FC loads were estimated from Audubon bird counts in the Port Susan area (Cullinan, 2001), and from literature FC generation values for domesticated birds (ASAE, 1998).

FC loads in stormwater are generated from a variety of sources. Data collected over the past 40 years have suggested that these sources vary in intensity and are often generally associated with certain land uses. In the past few years, stormwater-generated pollutants have come under closer scrutiny by regulating authorities. Certain jurisdictions are now being held responsible for the quality and quantity of stormwater discharged by their systems under the federal Clean Water Act.

In 2002, a directive came from EPA requiring all TMDLs in jurisdictions with NPDES permits for stormwater systems to include the pollutant loads from those systems as wasteload allocations (Wayland and Hanlon, 2002). The directive came after sampling was completed for the Stillaguamish Basin TMDL, but Snohomish County and the Washington State Department of Transportation (WSDOT) have Phase I NPDES permits for their stormwater systems. Arlington and Granite Falls have submitted applications for stormwater permits under Phase II.

Data were not collected during the TMDL study to specifically characterize the stormwater from these NPDES permit sources. To comply with the EPA directive, stormwater FC loads from the five jurisdictions were estimated using the ‘Simple Method Model’ (Stormwater Center, 2004). The model requires the sub-basin drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. The land uses in each sub-basin were categorized as residential, commercial/industrial, agricultural, forest, and roadway. FC loads were calculated for each category to judge its relative importance to FC loading.

The model equations are presented in Appendix B. Data inputs were obtained from Geographic Information System covers depicting land use types, road densities, drainage areas, and annual precipitation volumes. Estimates of pollutant concentrations for various land use types were taken from literature sources (Stormwater Center, 2004; Novotny and Olem, 1994; National Stormwater Database, 2004; Embrey, 2001).

Snohomish County and WSDOT wasteload allocations were based on the contribution of each jurisdiction to the "Roadway" category. Conveyance of contaminants from adjacent land uses to the roadway ditches was not considered for this level of analysis. In contrast, municipal stormwater wasteload allocations were based on all land use categories within the urban boundary, not just the Roadway category. State highways through municipalities were subtracted from the municipal area and counted towards the WSDOT Roadway area.

Dissolved Oxygen

Most dissolved oxygen (DO) data collected in the Stillaguamish River basin have been from instantaneous daytime 'grab' measurements during daytime hours. Seven freshwater areas were on the 1998 303(d) list based on data collected in this way. Since minimum DO concentrations in productive systems often occur before dawn, it is difficult to interpret these data in terms of a state criterion stated as a minimum concentration that is consistently to be exceeded (Table 6). Trend analyses also become more difficult if the time of day when samples were collected shifted between blocks of years.

Taking multiple grab samples over the course of a day is one approach to estimate the diel range of DO concentrations. This can be very resource intensive in a large geographic area. Continuously recording DO probes deployed over a few days is another solution to the problem. This method was used at a limited number of sites because of the limited availability of the equipment.

Without extensive data, the relative contribution of natural and anthropogenic sources to areas with depressed DO conditions becomes difficult to assess. The low DO concentrations could be related to factors other than excessive instream productivity, e.g., riparian wetlands, stormwater discharges, and low DO groundwater input.

A multiple-step approach was taken to evaluate the instantaneous DO measurements collected at 36 freshwater sites. The lowest set of DO data at each site were referenced to season, time of collection, flow, and accompanying temperature, pH, and nutrient data. Field observations were also taken into account. Sites were then divided into two categories:

1. DO data from high productivity systems: DO measurements collected during the growing season and under lower flow conditions with accompanying pH values above 7, and nutrient concentrations seasonally influenced by excessive biomass production.
2. DO data from systems influenced by other factors: DO measurements collected throughout the year with accompanying pH values less than 7, and nutrient concentrations less seasonally variable.

Low DO concentrations from the first group were evaluated according to Ecology TMDL guidelines by adding a 0.5 mg/L safety factor to the water quality criterion (TMDL Workgroup, 1997). The criterion plus safety factor was compared to the lowest 10th percentile DO value reported over the most representative period of record. For example, the lowest allowable 10th percentile concentration for a Class A water would be 8.5 mg/L, as applied to the instantaneous measurements collected over the period of record. The rank 10th percentile value was calculated using the EXCEL® percentile formula (Appendix B). The safety factor allows for the likelihood that DO values recorded during daylight hours are higher than those existing before dawn because of instream productivity. The rank 10th percentile value was chosen to represent the average daily DO concentration during critical conditions for a particular site.

The second group of sites required more site-specific judgments about the ability of the waterbody to meet the criterion and beneficial uses. Fish habitat, soils, groundwater quality, and wetlands data were reviewed. At these sites, anthropogenic source loadings of biochemical oxygen demand (BOD) were estimated using the Simple Method Model (Stormwater Center, 2004) results based on land use types in the sub-basin, relative to potential natural sources of low DO water like groundwater or wetlands. Fecal coliform counts and other water quality data were considered for the pollutant loading assessments, so stormwater BOD wasteload allocations and background load allocations, as well as estimates of BOD load capacities, were based on the fecal reductions required to meet criteria.

Two point sources discharge to receiving waters identified as having potential DO limitations due to natural conditions; i.e., the DO minimum concentrations are naturally lower than the state DO criterion. Effluent from the Warm Beach Conference Center wastewater treatment plant (WWTP) currently discharges to Warm Beach Creek. Arlington WWTP discharges to the mainstem Stillaguamish River below the confluence of the North and South forks. As explained in the *Applicable Water Quality Criteria* section, anthropogenic source discharges are not allowed in areas that would further decrease DO concentrations more than 0.2 mg/L, so additional data analyses were conducted at these two sites.

NPDES permit limits for BOD loads and ammonia (for nitrogenous oxygen demand) were evaluated for direct oxygen loss potential from both WWTPs in the two receiving waters. Effluent total nitrogen and phosphorus concentrations were also assessed as part of the Arlington WWTP impact assessment. The Arlington WWTP assessment required detailed critical condition determinations and modeling.

Diel DO on the mainstem Stillaguamish River from the confluence of the North and South forks to Hatt Slough was evaluated to analyze the impact of Arlington WWTP effluent on downstream reaches of the river. The QUAL2Kw model (Chapra, 2000) as modified by Pelletier (Pelletier and Chapra, 2003) was calibrated to the mainstem DO conditions observed during the three-day October 2001 TMDL survey. This set of survey data contained:

- Nutrient and field parameter measurements at nine sites on the mainstem from the confluence of the forks to Hatt Slough, and sample analyses and field measurements from Arlington WWTP and four tributaries.
- Continuous DO, temperature, pH, and conductivity probe measurements taken at four sites in the reach (Figure 7).
- Periphyton biomass measurements at three sites.

Figure 7. Locations of four diel monitoring probes (broad crosses) in the Stillaguamish River from Arlington to Interstate 5 in September 2000 and October 2001. RKM = river kilometer

The August 1997 survey by Earth Tech (1997) was used for model verification. The data set was much more limited, but the survey was conducted during a low-flow event close to what would be considered critical conditions (See *Technical Analysis:* Dissolved Oxygen, Critical Conditions).

The diel DO output in QUAL2Kw is affected by DO saturation, reaeration, photosynthetic and respiration processes, and carbon and nitrogen oxidation. DO saturation is calculated from temperature and barometric pressure. Several reaeration formulas are available in the model that are automatically selected depending on depth and velocity ranges of a reach. Photosynthesis and respiration functions for periphyton, and heterotrophic bacteria respiration in the hyporheic zone were incorporated into this version of the model by Pelletier (Pelletier and Chapra, 2003). The modifications to the QUAL2Kw model are detailed in Appendix C.

The model was set up to run critical conditions, and the results were compared to Class A criteria. The critical condition simulations included:

- River discharge set to the estimated lowest 7-day average flow with an annual 10-year recurrence interval (7Q10) volume assuming a stabilized channel and biological condition, i.e., no spates during the previous 30 days that would scour periphyton and heterotrophic bacteria biomass.
- Upstream temperature, pH, and nutrients set at seasonal 90th percentile values, and DO and alkalinity set at seasonal 10th percentile values.
- Arlington WWTP discharge rates and effluent characteristics set to dry season maximums for Phase 1 and Phase 2 expansions (Earth Tech, 1996).
- Benthal or groundwater oxygen demand, or hyporheic exchange active in pool reaches
- Periphyton biomass volumes set at highest levels observed in 2001.

Simulations with and without point sources and suspected nonpoint sources, and with modified headwater characteristics, were compared. The pollutant load capacity for the Stillaguamish River was determined for compliance with DO standards after evaluating the various simulations (see *Loading Capacity*).

pH

The pH measurements taken in the basin create the same difficulty as the dissolved oxygen measurements for comparison to the state criteria; i.e., the instantaneous measurements do not necessarily account for diel maximum and minimum values in productive systems. In addition, low pH values in the basin appear to occur during stormwater events or in certain hydrologic environments, while high pH may be related to biomass production during low-flow events. Only the South Fork Stillaguamish River was on the 303(d) list for pH violations (less than 6.5), but other potential candidates were documented after evaluating data from 27 sites for this assessment (See *Technical Analysis* and *Loading Capacity*).

Instantaneous pH measurements were assessed in a manner similar to the dissolved oxygen measurements. The pH data at all sites were reviewed in the context of other factors like season, time of collection, and dissolved oxygen and nutrient concentrations. In addition, monitoring site locations were inspected to determine if upstream wetlands and groundwater influences were possible. Sites were separated into two groups: 1) those with potential high or low pH criteria violations from excessive instream productivity, and 2) those with low pH values potentially related to other factors.

Although diel pH variability is not specifically addressed in the Ecology TMDL guidelines (TMDL Workgroup, 1997), the safety factor approach is reasonable for the first group of sites. In a biologically productive stream or river, the diel pH range can be determined by influences of instream respiration and productivity on the water carbonate buffering capacity. From the diel data that are available from the mainstem surveys, a safety factor of 0.2 standard units (s.u.) was chosen to cover the maximum diel range observed during TMDL surveys. The safety factor was applied to the 10th and 90th percentile pH for each site. The rank 10th and 90th percentile statistics were calculated using the EXCEL® percentile function (Appendix B). For example, sites located in Class A and Class AA waters in the first group with a rank 90th percentile pH value greater than 8.3, or a 10th percentile value less than 6.7 were considered threatened. Water quality standards for Class A and AA waters require pH values between 6.5 and 8.5 s.u. (Table 6).

In the Stillaguamish basin, depressed rather than elevated pH values were more common at several sites. These sites also had low pH values at mid-day rather than in the early morning. Therefore, the diel pH range is probably not a function of instream productivity as much as from groundwater input or decomposition processes from upstream wetlands. At these sites, potential anthropogenic sources of depressed pH are listed and their impact estimated after reviewing and evaluating fecal coliform, biochemical oxygen demand, and nutrient data. The impact is compared to a range of groundwater pH values (Thomas, Wilkinson, and Embrey, 1997) or other data from the area.

Arsenic and Mercury

Arsenic and mercury in the Stillaguamish River and two forks were assessed as concentrations and as loads based on six or more sampling events at four sites during the 2000-2002 TMDL study period (See *Technical Analysis:* Arsenic and Mercury). Additional arsenic data within the study period was also obtained for two sites in the basin from another Ecology study (Johnson, 2002). Concentrations of the two metals were compared to criteria (Table 6). Event arsenic and mercury loads were evaluated to identify potential sources. Discharge estimates for the load calculations were based on USGS gaging data and Pelletier's (2003) water balance work described earlier. The loads of both metals were compared to each other and to total suspended solids loads using regression analyses to evaluate correlations and transport mechanisms.

Seasonal Variation and Critical Conditions

Clean Water Act Section 303(d)(1) requires that TMDLs "be established at level necessary to implement the applicable water quality standards with seasonal variations". The current regulation also states that determination of "TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters" [40 CFR 130.7(c)(1)]. Finally, Section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The parameters and some geographic areas being evaluated in this Stillaguamish TMDL have different critical conditions and seasonal variations. The critical conditions for elevated fecal coliform counts and loads are different from the conditions when low dissolved oxygen concentrations are reported. In addition, the sources of fecal coliform contamination vary, so the critical condition for fecal coliform in the mainstem is different from the condition in some tributaries.

The data records were evaluated to identify critical conditions for each parameter at specific sites. For example, trend analyses, tests for seasonality, and statistical tests for lognormal distributions were performed using WQHYDRO, a statistical software package for environmental data analysis (Aroner, 2001). Regression analyses were performed to test if various pollutants of concern were correlated with each other, with discharge volumes, with total suspended solids, or with climatological events. To simplify implementation of the TMDL, an attempt is made to define the critical condition in common to as many sites as possible for a parameter like fecal coliform or dissolved oxygen without jeopardizing beneficial uses at any specific site in the basin.

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Technical Analysis

This *Technical Analysis* section describes and presents analyses of the most recent data to establish the current water quality conditions in the basin, especially in those areas and for those parameters on the 1998 303(d) list (Table 1). The hydrological and climatological characteristics are first described under which the recent water quality data were collected. Then the results of fecal coliform, dissolved oxygen, pH, and arsenic and mercury sample data are discussed using the methods previously described in the *Analytical Framework* section of this report. The critical conditions determining the loading capacities and TMDLs for each parameter are also described.

Data from several sources were combined to evaluate the current state of water quality in the Stillaguamish basin and Port Susan. Data from Ecology surveys conducted from 2000 to 2001 under the TMDL quality assurance project plan have been reviewed for their acceptability and published (Coffler, Gridley, and Joy, 2004). Quality assurance plans were in place for the 2000 to 2002 Snohomish County, Stillaguamish Tribe, and Ecology ambient monitoring programs. The collective database represents four types of monitoring to characterize different aspects of contaminant sources and transport mechanisms:

- Long-term data collection from the networks established over the past 30 years by Ecology, the Tulalip Tribes, the Stillaguamish Tribe, Snohomish County Surface Water Management, and the NPDES permit program
- Medium-flow and storm-event synoptic sampling in 2000 and 2001 (Figure 8).
- Enhanced monthly sampling in 2001 in Port Susan and key tributaries based on the Stillaguamish Tribe Port Susan and tributary network (Figure 9).
- Short-term weekly monitoring of informal recreational beaches in summer 2000 (bacteria only).

The location and some data analyses of the long-term network sites and recreational beach sites were previously described and discussed in pre-TMDL work (Joy and Glenn, 2000; Joy, 2001). Current data are defined as samples and measurements taken from June 2000 through June 2002.

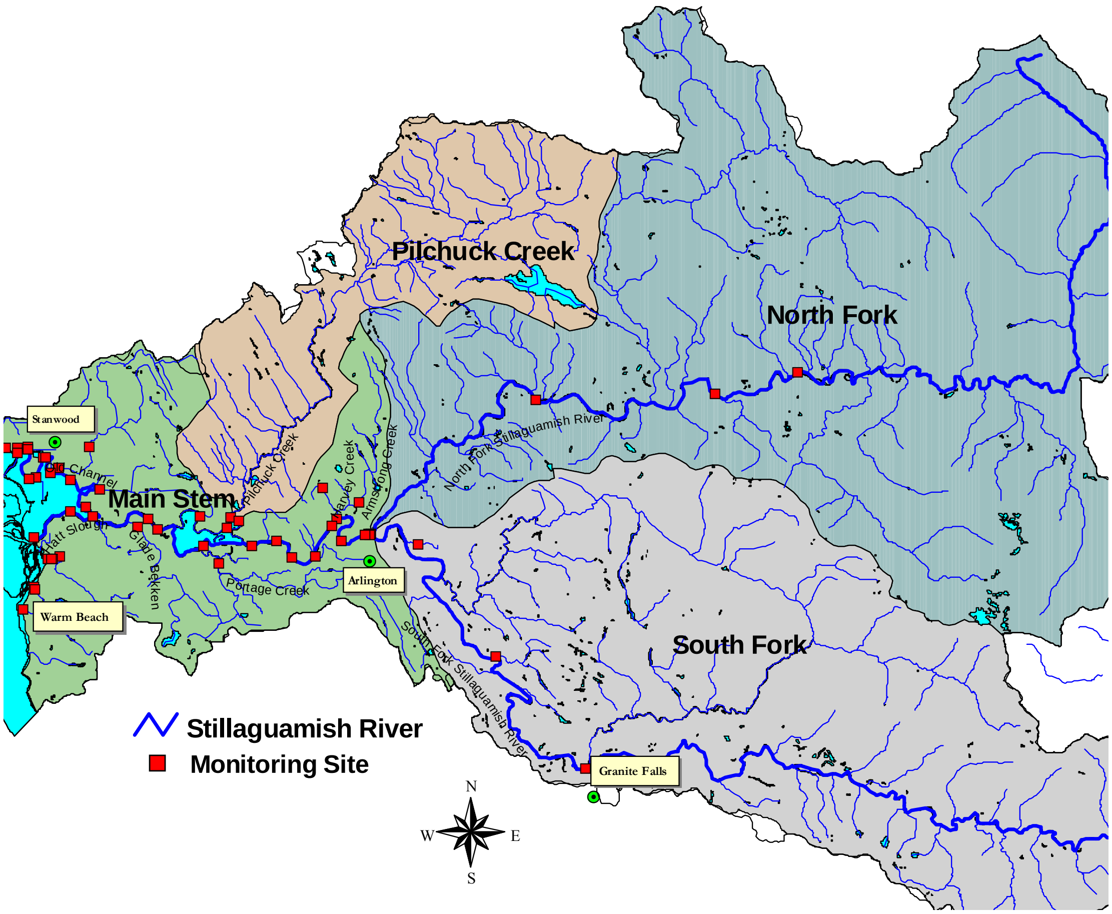


Figure 8. Water quality monitoring sites in the Stillaguamish River basin used by Ecology for storm-event and synoptic surveys.

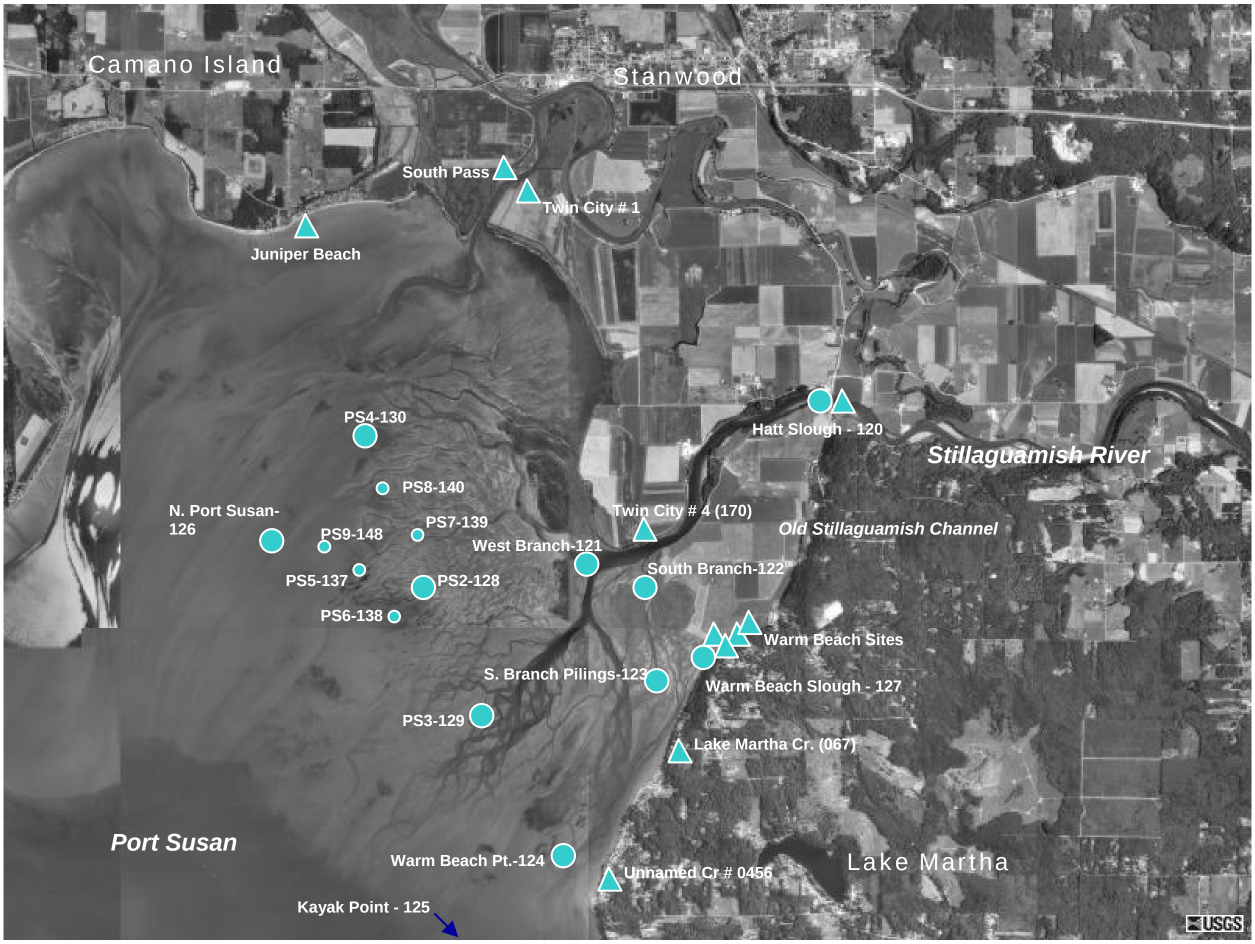


Figure 9. Fecal coliform monitoring sites located in and around northern Port Susan. Circles are sites monitored by the Stillaguamish Tribe; triangles are sites monitored by Ecology.

Flows and Rainfall

According to records from the Arlington Airport, the TMDL surveys took place during a wetter than normal summer season in 2001, and drier than normal fall season in 2000. Annual rainfall at Arlington was 39.55 inches in 2000, and 50.05 inches in 2001. The average rainfall over 40 years of complete records is 46.83 inches. The lowest annual rainfall, 30.3 inches, was recorded in 2002.

The 2001 water year (October 2000 through September 2001) was among the lowest on record for river discharge (Table 11). The lowest annual mean daily flow was 1123 cfs in 1930, and the highest was 2883 cfs in 1997. The months of October through May had lower than average monthly flows. The 90th percentile average daily peak flows for water year (WY) 2000 and WY 2001 are low compared to 3720 cfs for the period of record. The North Fork mean daily discharge exceeded 3720 cfs on only seven days in WY 2001, and on only 17 days through the 2000-2002 TMDL study period. In contrast, both annual 7-day average low-flows for 2000 and 2001 were higher than the period of record's 7-day average, 10-year, low-flow statistic (7Q10) of 175 cfs. The annual 7-day low-flow is the lowest mean value for any seven consecutive day period between October 1 and September 30.

Table 11. Flow statistics for the North Fork Stillaguamish River near Arlington (USGS 12167000) comparing period of record data to water years 2000 and 2001.

Period of record	Annual average cms (cfs)	7-day average low-flow cms (cfs)	90th percentile high-flow cms (cfs)
1928 – 2001	53.58 (1892)	4.96 (175)*	105.4 (3720)
Water year 2000	53.35 (1884)	7.96 (281)	99.4 (3510)
Water year 2001	33.22 (1173)	7.22 (255)	59.8 (2110)

* The 7-day, 10-year, low-flow statistic for the period of record

The discharge of the Stillaguamish River at the I-5 bridge was estimated from the North Fork Stillaguamish gage record using multiple regression techniques. The estimated annual daily average discharge at I-5 was 2433 cfs for WY 2001. The estimated 7-day average low flow in WY 2000 was 602 cfs, and in WY 2001 it was 547 cfs; both occurred in late September. The general response of river discharge to rainfall over the TMDL study period is shown in Figure 10.

One feature, a late-August storm in 2001, is quite prominent in the gage record. The storm dropped 0.65 inches over three days and increased the estimated mean daily discharge from 524 cfs prior to the storm, to 5895 cfs at the peak of runoff. The storm scoured the riverbed during the active benthic algae growing period, and sent a pulse of poor quality water into Port Susan.

A range of flow and climatological conditions were monitored. A mid-range flow synoptic survey was conducted on September 11-13, 2000. The mean daily discharge at I-5 was estimated at 2100 cfs on the first day after a total rainfall of 0.19 inches over the previous five days. The discharge at I-5 steadily dropped to 1010 cfs on the third day. A low-flow survey was conducted on October 2-4, 2001 with fairly stable, but slightly dropping, flows at I-5 of 590 cfs – 530 cfs. A late-spring storm event was monitored on June 12-13, 2001 with mean daily flows of 6280 cfs and 4210 cfs during a two-day cumulative rainfall of 1.27 inches. The 5-day antecedent precipitation measured 0.01 inches. A mid-fall storm was monitored on November 14-15, 2001 with a two-day cumulative rainfall of 0.64 inches, and a 5-day antecedent rainfall of 0.05 inches. Mean daily flows at I-5 were estimated at 19,020 cfs and 15,340 cfs.

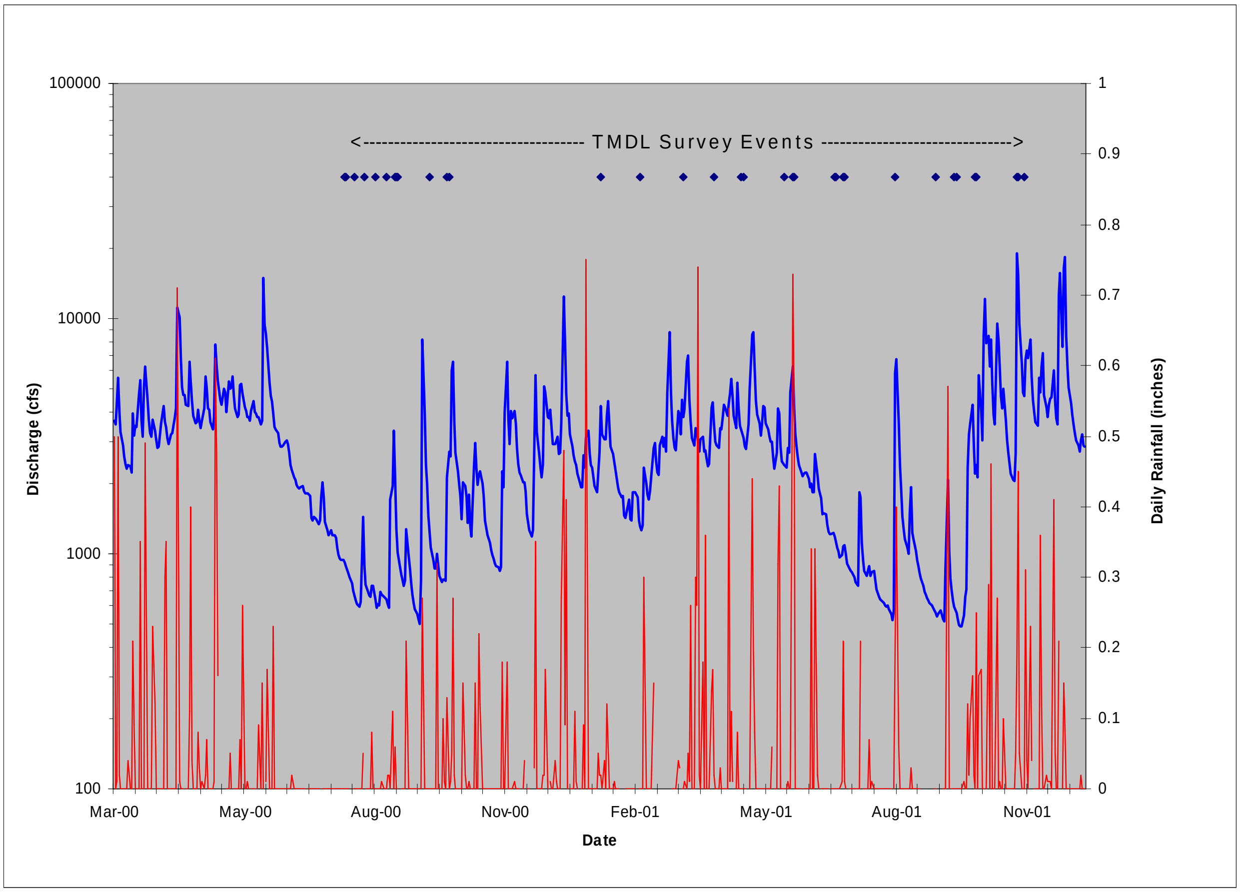


Figure 10. Estimated discharge record for the Stillaguamish River near Silvana (continuous line) and daily rainfall (vertical spikes) recorded at Arlington Airport during Ecology's TMDL surveys, July 2000 to November 2001.

Fecal Coliform

Current Conditions and Trends

Fecal coliform (FC) counts and loads in the 2000 – 2001 TMDL sampling period at some sites were more variable than in previous years. Data from the Stillaguamish River at Interstate 5 (I-5) are typical (Figure 11). FC data at I-5 collected in the 2001 water year, when most sampling took place, had a lower than usual median count and load, but a higher than usual 75^{th} percentile and maximum count. The wetter than normal summer and fall of 2001 and drier than normal fall of 2000, along with a low water year in 2001, probably exerted an influence on the increased variability in FC run-off, but resulted in a lower median FC load at I-5. Some of the apparent increases at other sites can be explained as database artifacts from more intensive monitoring activity, especially with the inclusion of storm-event data. However, FC count and load increases appeared to carry through to the 2002 water year at I-5 (Figure 11), when monitoring at other sites returned to routine sampling intervals.

Elevated FC counts in 2001 were responsible for interrupting improving trends at several sites. The Stillaguamish River at I-5, North Fork Stillaguamish River at Cicero, Pilchuck Creek, Stillaguamish River at Hatt Slough, Stillaguamish River below Arlington, South Fork Stillaguamish River at Arlington, and Armstrong Creek below the Hatchery had decreasing FC bacteria trends since the mid-1990s that were all negatively affected by poor bacterial water quality during the TMDL survey years. For example, data collected three to five years before and after 1998 at the South Fork Stillaguamish River at Arlington suggested there was a statistically significant decline in FC counts (Figure 12 – lower graph). There was no longer a statistically significant difference after including counts from 2001 (Figure 12 – upper graph).

Despite the increases in 2001 FC counts, water quality criteria were met most of the time at sites along the mainstem and forks. FC counts in the upper North and South forks continued to be well within FC criteria during all sampling surveys. The elevated FC counts observed in the 1990s at several sites along the upper North Fork that were responsible for the 303(d) listings of those reaches did not occur during the 2000-2002 TMDL study period. Some of the sources causing bacteria contamination may have been eliminated from those reaches. Usually water quality in the mainstem below the confluence of the forks was well within the Class A FC criteria. Elevated counts occurred only after significant storm events. The influence of these events will be discussed later in this report (see next section, Synoptic Surveys and Storm Events).

Several tributaries on the 1998 303(d) list for FC criteria violations continued to be out of compliance with standards based on the TMDL survey data. Trend analyses suggested that Fish Creek and Jim Creek had shown improvement over previous years, while Harvey Creek, Jorgenson Slough (Church Creek), Lake Martha Creek, Portage Creek, and Unnamed Creek had experienced no change or appeared to be worse. Of these smaller tributaries on the 303(d) list, only Jim Creek met FC criteria based on data collected in 2000 – 2001.

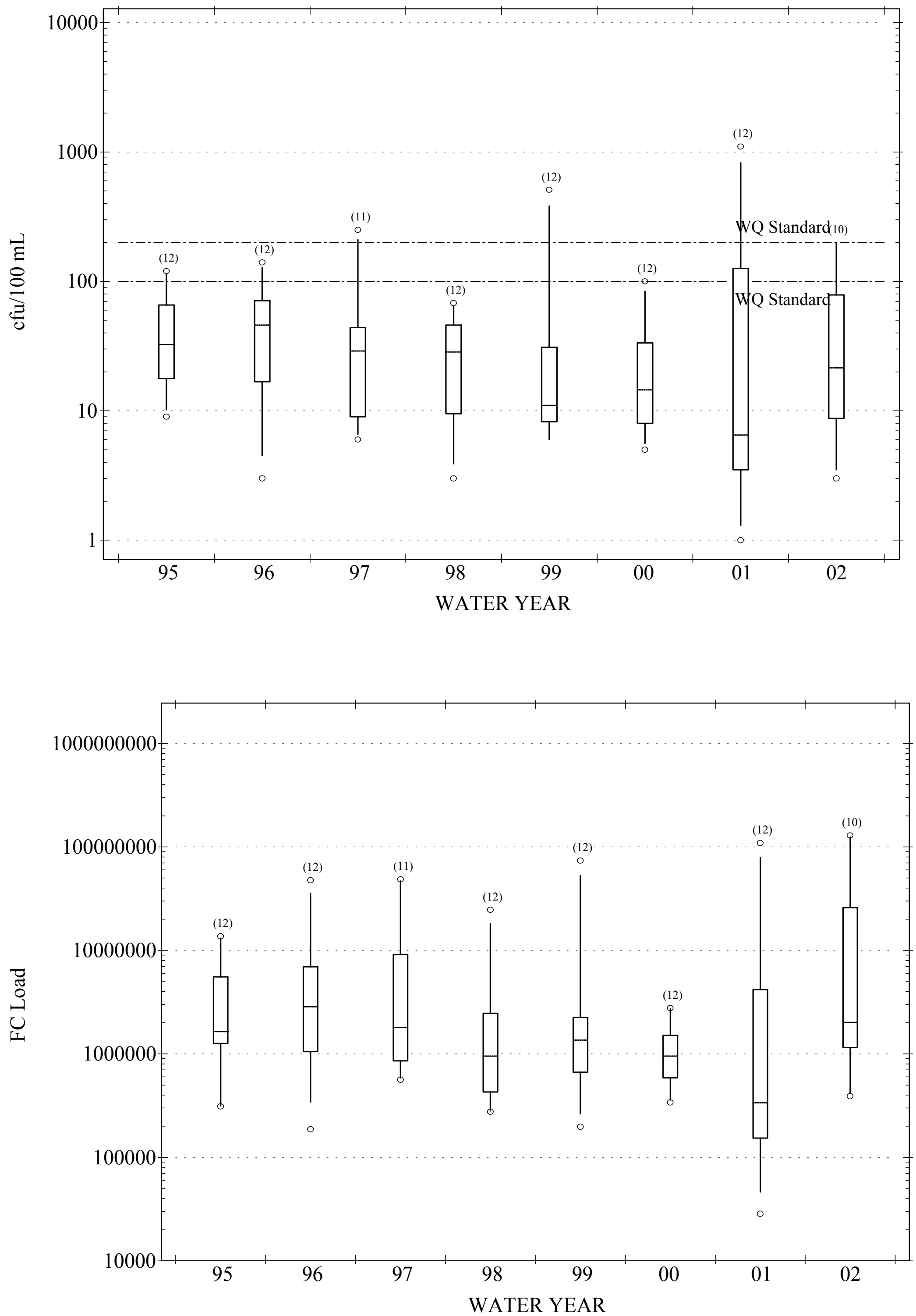
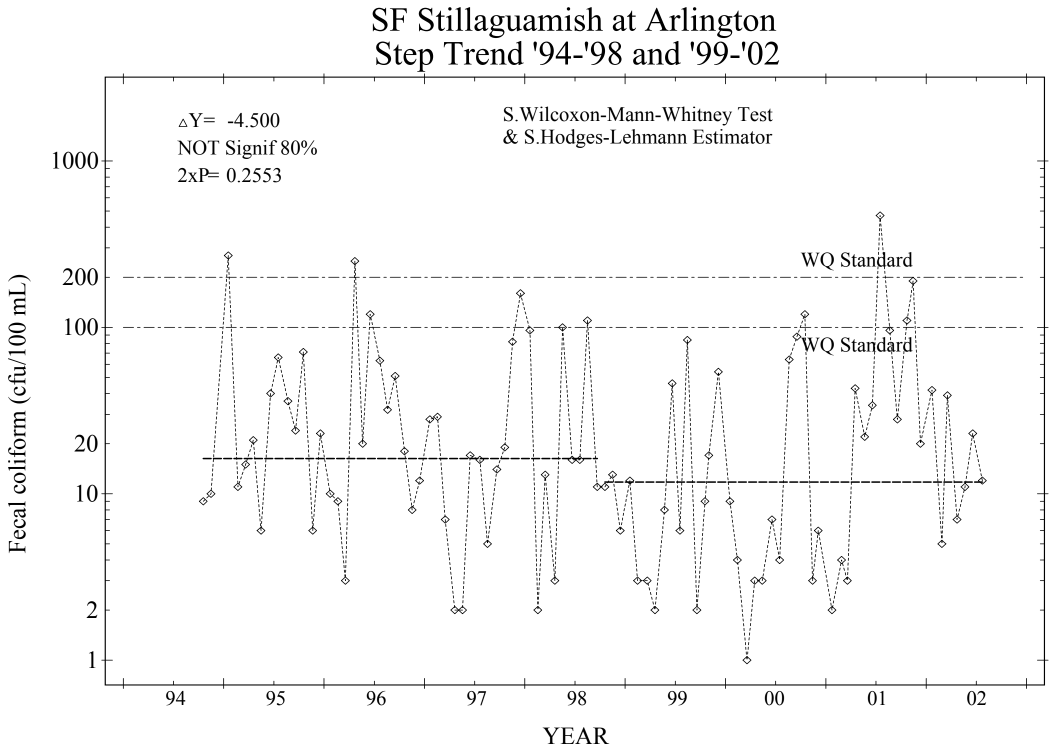


Figure 11. Fecal coliform count and estimated load (cfu/day x 10^6) statistics for monthly samples collected from the Stillaguamish River at Interstate 5 (Ecology Station 05A070) for water years 1995 to 2002. Class A FC criteria are indicated in the upper figure. The box-plot depicts the median, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles, and the range.



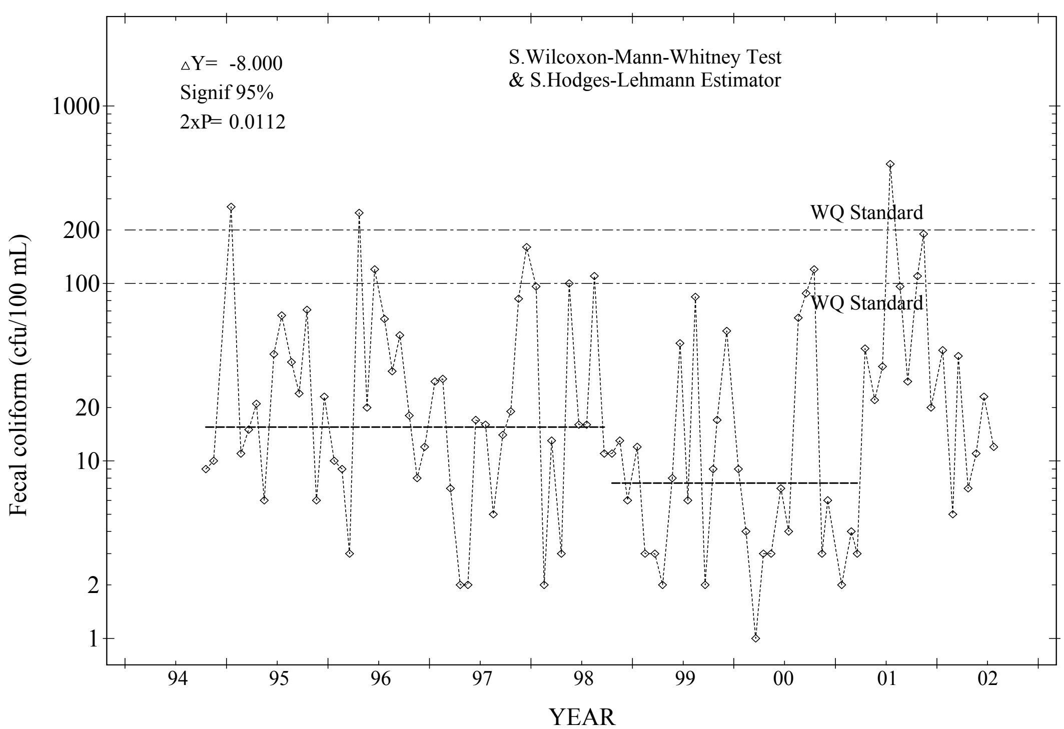


Figure 12. Two graphs of data from the South Fork Stillaguamish River that show the influence of the 2000-2001 monitoring year on Stillaguamish fecal coliform statistical trends (see text).

Other tributaries, not on the 303(d) list, were identified with FC criteria violations based on the TMDL data set. These included Glade Bekken, Miller Creek, Warm Beach Creek including the Pasture Drain and pond, Douglas Slough, Irvine Slough, Pilchuck Creek, March Creek, Kackman Creek, and several drains near Port Susan.

Port Susan Area

Port Susan was added to the TMDL study area in 2001 (Joy, 2001). Port Susan coliform data collected by the Stillaguamish Tribe exhibited an increase at sites in 2001 after showing improvements between 1998 and 2000. The Washington State Department of Health (DOH) Food Safety and Shellfish Programs uses 30-sample running geometric means and 90th percentile statistics to judge the suitability of bacteriological water quality in commercial shellfish harvest areas (Appendix B). The DOH only uses the most probable number (MPN) type of FC analysis to calculate the statistics (see *Applicable Water Quality Criteria*). These statistics appeared to be coming within the acceptable criteria (a geometric mean of 14 MPN/100 mL and a 90th percentile of 43 MPN/100 mL) at several sites early in 2000. By late 2001, PS-2, off the mouth of Hatt Slough (Figure 13), and many other sites were no longer approaching these criteria. The apparent trend was then recognized as part of a repeating seasonal pattern from fall storm-event loading.

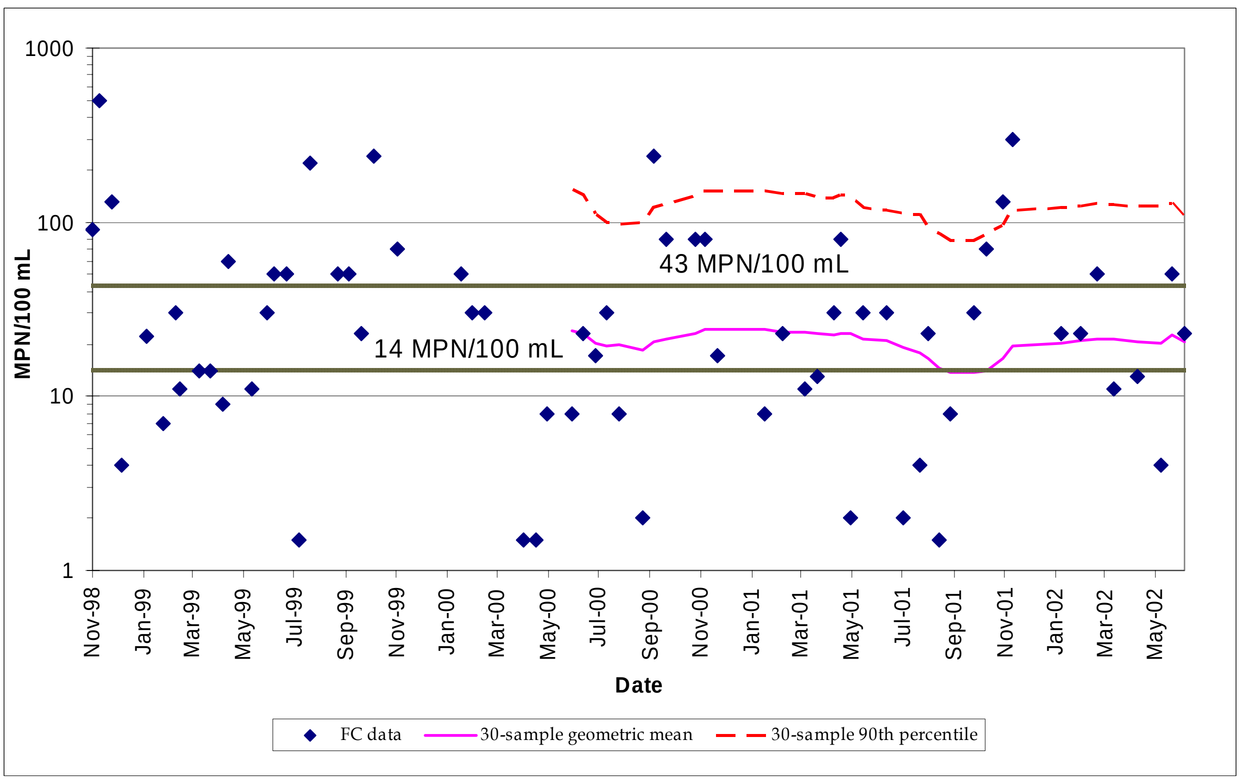


Figure 13. Fecal coliform sample results from site PS-2 of the Stillaguamish Tribe monitoring program in Port Susan. Commercial shellfish harvest criteria (14 MPN/100 mL geometric mean and 43 MPN/100 mL 90th percentile) used by the Washington State Department of Health are compared to the running 30-sample statistics.

Table 12 shows the summary statistical data from all 16 Port Susan sites monitored by the Stillaguamish Tribe. Four sites met the 30-sample criteria in June 2002 (based on samples collected since September 2000). The sites were all located more than 5.6 km (3.5 mi) out from the mouth of Hatt Slough (Figure 9): Kayak Point, Warm Beach Point, North Port Susan, and Peripheral Site #4 (PS-4). The statistics for sites PS-5 through PS-9 are based on fewer than ten samples, so they cannot be compared to the others. The South Branch Pilings site was very close to meeting the criteria, with a geometric mean of 12 MPN/100 mL and a 90^{th} percentile of 44 MPN/100 mL. It lies only 3.8 km (2.4 mi) away from Hatt Slough. All other sites close to Hatt Slough or near-shore discharge areas like Warm Beach Slough failed the criteria.

Table 12. Fecal coliform statistics calculated for 30 consecutive samples collected by the Stillaguamish Tribe prior to June 27, 2002 at 16 sites in Port Susan and Hatt Slough. Geometric mean and 90^{th} percentile are in MPN/100 mL.

Site Name	Hatt Slough	West Branch	South Branch	South Branch Pilings	West Branch Point	Kayak Point	North Port Susan	West Branch Slough
Site Number	120	121	122	123	124	125	126	127
Geometric Mean	15	27	24	12	6.1	4.2	3.3	28
90th percentile	64	98	102	44	31	20	12	100
30-sample status (6/27/02)		**Fail**	**Fail**	**Fail**	Pass	Pass	Pass	**Fail**

Site Name	PS-2	PS-3	PS-4	PS-5	PS-6	PS-7	PS-8	PS-9
Site Number	128	129	130	137	138	139	140	148
Geometric Mean	21	14	5.7	21	19	32	15	3.9
90th percentile	107	74	27	148	117	125	119	13
30-sample status (6/27/02)	**Fail**	**Fail**	Pass	*	*	*	*	*

* Insufficient data to determine status (n<10).

The Stillaguamish Tribe did not increase their sampling frequency or focus on storm events during the 2000-2002 TMDL study period. This provides further evidence that changes in data sampling intensity were not the primary cause of the increased FC counts recorded throughout the basin. In fact, the data strongly suggest that seasonal factors and increased basin run-off influenced bacteriological quality in the bay.

Correlation analysis was not successful in showing a consistent link between monthly or seasonal FC counts or loads from the Stillaguamish River (Hatt Slough and South Pass) and their respective counts at the Port Susan sites. However, FC counts in the bay appeared to respond to loading from the river; i.e., river loads and the monthly bay-wide median FC counts followed similar rising and falling patterns (Figure 14). Most apparent are the peak loading months of June and November that correspond to bay-wide FC count increases in response to more frequent storm events. The surprise August 2001 storm event that became part of the database also influenced the average August FC load.

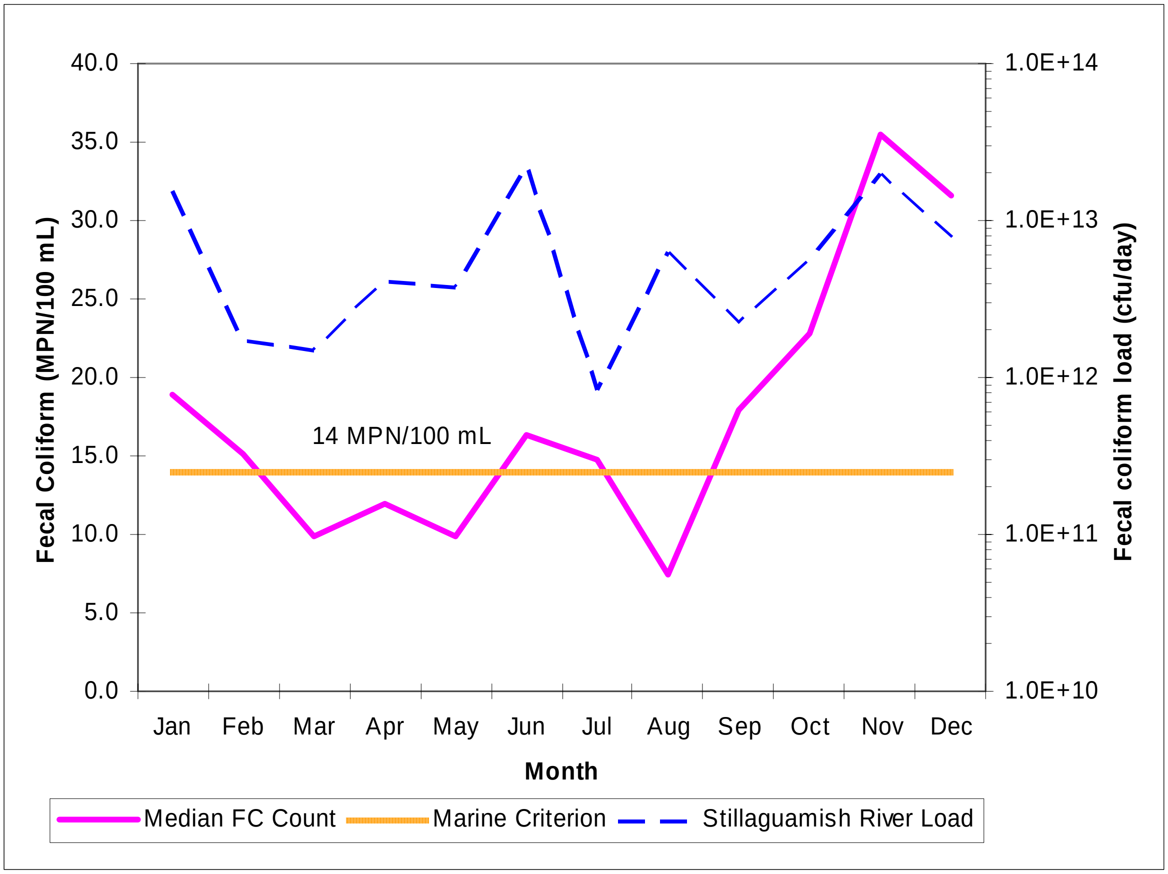


Figure 14. Monthly median fecal coliform (FC) counts from sites in Port Susan compared to estimated FC loads from the Stillaguamish River (Hatt Slough and South Pass) for 1998 -2002.

The FC loading months that affect water column FC counts in the bay appear to occur in the fall. Preliminary analyses showed that some failing sites in Table 12, such as PS-2 and PS-3, have seasonal FC counts (January - August) that produce geometric means and 90th percentiles within or nearly within the criteria. More data are necessary to confidently predict the seasonal FC loading effects on temporal FC counts in the bay.

The FC contributions of small drainages and the Stillaguamish River were compared. Samples were collected by Ecology from 12 sites along the northeastern shore of Port Susan as Stillaguamish Tribe researchers were collecting samples in the bay. FC samples were collected monthly from February to November 2001 from South Pass, Juniper Beach, Hatt Slough, and several small freshwater tributaries to Port Susan (Figure 9). These data are summarized in Table 13. Enterococci data also were collected and are summarized in Appendix D.

Data at the 12 sites were highly variable, but a seasonal component was common in all data. Counts were lowest at all sites in February when all samples met FC criteria. On the other hand, counts were high at all sites during the August 2001 storm event when none met FC criteria. The two drains monitored from the Twin City Foods sprayfields had especially high counts in July and August. FC counts at the Warm Beach pump pond and three sites associated with it (Warm Beach Creek, Pasture drain, and Warm Beach WWTP outfall) gradually increased in

April and stayed elevated through November. Lake Martha Creek had low counts until August, and then had elevated counts the rest of the 2000-2002 study period. Counts from Unnamed Creek #0456 south of Lake Martha Creek were sporadic after March, and the creek bed was dry in July and September.

Table 13. Fecal coliform results from samples collected from freshwater and marine waters in and around northern Port Susan from February to November 2001.

Sites to and in Port Susan	Number of Samples	Fecal Coliform (cfu/100 mL)	
		Geometric Mean	90th Percentile*
Juniper Beach (Marine)	9	**15**	**92**
South Pass (Marine)	10	**29**	**125**
Twin City Foods Drain #1	9	**513**	**3780**
Twin City Foods Drain #4**	9	**149**	**1670**
Hatt Slough at Marine Dr.	10	30	197
Warm Beach Creek above outfall	10	46	**457**
Warm Beach WWTP outfall	9	53	**829**
Pasture Drain to Pump Pond	10	**182**	**1000**
Pond or discharge to Slough	10	**230**	**1130**
Lake Martha Creek at Soundview Dr.	10	82	**694**
Unnamed Creek #0456	7	**350**	**3640**
Class A Marine Water Criteria		14	43
Class A Freshwater Criteria		100	200

* The 90th percentile values are based on the FDA method assuming a lognormal distribution (Appendix B).

** Drain #4 never discharged surface water to Hatt Slough; the tide gate was always blocked with silt.

Bold values do not meet criteria.

The elevated bacteria counts in these small tributaries are potential sources of contamination to local recreational shellfish beds and to people enjoying beachside recreation, but their cumulative loading to Port Susan is minor compared to the Stillaguamish River. For example, the dike pond below Warm Beach Conference Center appears to influence Warm Beach Slough (site 127) results collected by the Stillaguamish Tribe (Table 12). The pond also discharges near other sources like Lake Martha Creek and Unnamed Creek. Together the three could pose a health risk at any time of the year because they are very accessible to people. Their influence on the FC counts at Warm Beach Point (site 124) and South Branch Pilings (site 123) farther out in Port Susan is less certain because these two sites were meeting or nearly meeting criteria (Table 12).

Discharge volumes measured in all of the tributaries were usually less than 0.03 cms (1 cfs) during the surveys, so daily loads were a minute fraction of those from Hatt Slough and South Pass. Some of the sites discharge only periodically through tide gates and by pumps, so their overall FC loading would be difficult to estimate. In one case, no surface water discharge to open water was observed; the tide gate between Hatt Slough and Twin City Drain #4 was sealed with silt the entire study period.

It appears that FC loads arriving from the Stillaguamish basin and small tributaries around the bay degrade bacteriological water quality. Some sources are active throughout the year, but Port Susan FC counts increase in June and again from September through December. This coincides with several possible sources of bacteria:

- Rainstorms and increased discharge from the Stillaguamish River usually occur in the spring and fall. FC loads from the drainage basin are carried farther into the bay with larger freshwater volumes.
- The river and surrounding areas may be carrying the 'first flush' of bacterial contaminants accumulated over the drier summer months.
- Large flocks of snow geese, other waterfowl, and shorebirds arrive in September on migrations or to winter along the lower reaches of the river in and around Port Susan. Spring migration brings large flocks of shorebirds.
- More severe winds arrive in the spring and autumn. Winds and wave action could resuspend contaminated sediment in the lower reaches of the river or estuary that was deposited earlier in the season.
- Flooding is not uncommon during these months. Agricultural and residential lands lying in the flooded areas can contribute FC loads from freshly manured fields, inundated septic systems, and other sources.

Synoptic and Storm-event Surveys

The synoptic and storm-event surveys demonstrated that FC densities in the river responded to changes in surrounding land use and to storm runoff. Synoptic sampling conducted during an average flow event characterized the change in bacterial quality along the Stillaguamish River during a period of low surface runoff in the basin. Although the storm events were not monitored synoptically, they provide useful information about the response of FC in the river to periods of rainfall and high surface runoff.

During the synoptic survey in September 2000, discharge in the river decreased over the three days. The estimated mean daily flow at the Interstate 5 (I-5) site dropped from 59.5 cms (2100 cfs) to 28.6 cms (1010 cfs). FC sample results in the mainstem on all three days were 100 cfu/100 mL or less, and samples taken from sites up both forks were below 40 cfu/100 mL. Portage Creek and Arlington WWTP had FC counts greater than 100 cfu/100 mL. The FC counts decreased at most mainstem sites over the three days. The estimated FC load at the I-5 site decreased by 75% between the first and third day.

After considering natural FC sample variability and a range of die-off rates, FC count increased in reaches that could not be attributed to tributary inputs. Significant and fairly consistent chloride and nutrient increases also occurred in reaches between Arlington and Armstrong Creek (km 27.7 to 24.7), on the North and South Branch below I-5, and between Silvana and Marine Drive (km 9.7 to 4.2) during the three days. Unidentified sources (e.g., unmonitored tributaries, drains, or nonpoint sources) along these reaches of the mainstem were suspected. The unidentified sources were simulated using the QUAL2Kw model by adding sources with a loading equivalent to one-third to four times the size of Portage Creek's FC load. The actual volume of these sources and their bacteria counts are not known; however, the simulation results with the sources in place fit field data better than without them (Figure 15).

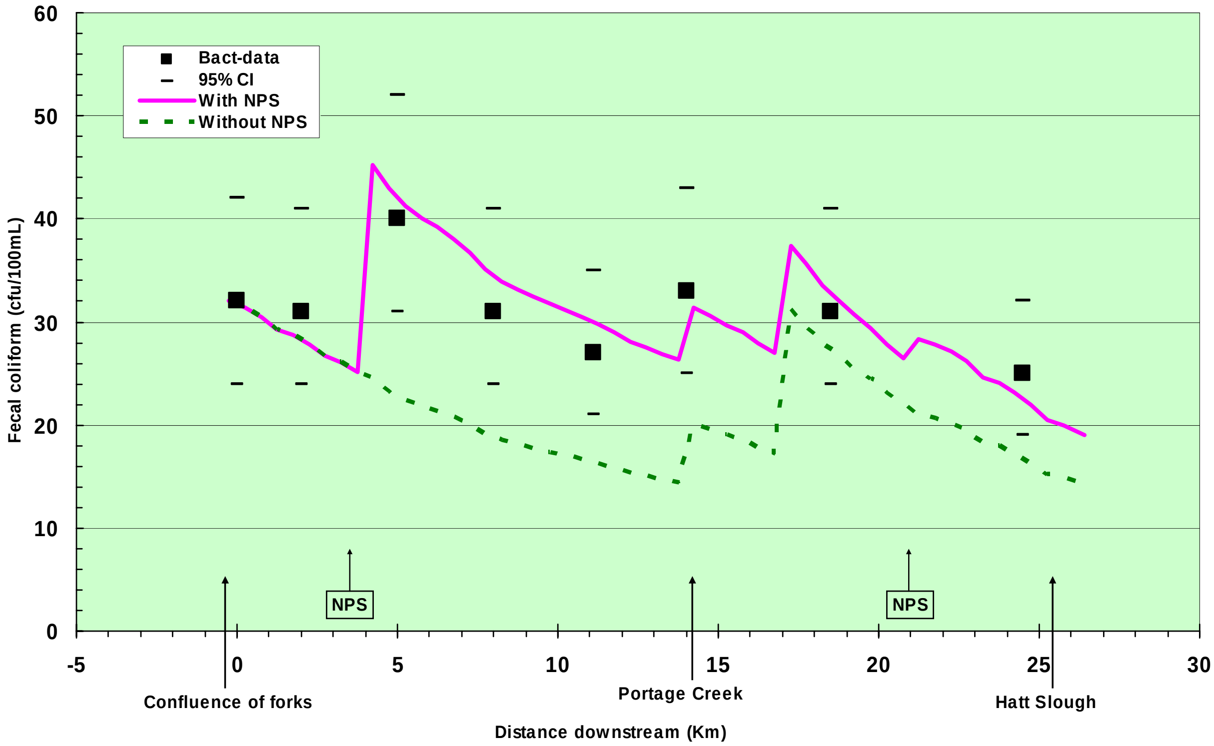


Figure 15. QUAL2Kw simulation results compared to fecal coliform data (with 95% confidence interval) collected from the lower Stillaguamish River on September 13, 2000. Unidentified source loads (NPS) at 4 km and 21 km were added to calibrate model with field data.

The survey under these conditions demonstrated that active sources of FC are present in the basin under average-flow conditions when transport from surface run-off is low. The FC loads from other unidentified sources may be present and increase the instream fecal counts. According to the model simulation results for the September 13th example, the unidentified sources increased FC loads at Hatt Slough by at about one third. The additional load degrades the water quality in the river and in Port Susan even though the FC counts were well within criteria.

FC results from the two 2-day, storm-event monitoring surveys demonstrated that areas of the Stillaguamish River basin still have significant sources of bacteria that cause water quality criteria violations and require controls. During each storm event, a third or more of the 42 samples collected from the mainstem, forks, tributaries, and point source sites had FC counts greater than 200 cfu/100 mL. Tributaries in the lower basin had the highest FC counts, and FC counts generally increased in the mainstem and forks from the upper basin to the mouth. Results from a representative set of sites are shown in Table 14.

Table 14. Fecal coliform results at selected sites in the Stillaguamish River basin for samples collected during two, 2-day storm-event surveys in 2001.

Site	June 12	June 13	November 14	November 15
	(cfu/100 mL)		(cfu/100 mL)	
South Fork below Granite Falls	92	17	28	22
Jim Creek at Jordan Road	320	150	160	20
South Fork at Twin Rivers	310	31	92	26
North Fork at C-Post Bridge	67	4	37	17
North Fork at Twin Rivers	240	43	Not accessible	40
Arlington WWTP	36	26	80	440
Stillaguamish River below Arlington	540	38	330	37
Armstrong Creek below Hatchery	2,800	75	200	170
March Creek	18,000	3,300	550	900
Stillaguamish River at Interstate 5	520	100	380	34
Portage Creek at 212th	6,300	770	350	1,600
Pilchuck Creek at Jackson Gulch	950	75	140	43
Stillaguamish River below Silvana	360	160	190	60
Glade Bekken at Terrace Road	52,000	2,500	360	310
Stillaguamish River at Hatt Slough	680	130	380	110

As might have been expected, the FC counts from the forested and less developed upper basin forks were much lower than from the more developed lower mainstem. Since the two forks comprise approximately 80% of the watershed area and deliver about 80% of the annual discharge, the bacterial quality of the water from the upper basin has a large influence on the lower mainstem. As observed in the historical data by Thornburgh and Williams (2001), FC counts in the lower basin generally increase downstream from Arlington to Hatt Slough.

Samples collected at sites located near the confluence of the forks (S. Fork at Twin Rivers and N. Fork at Twin Rivers) had higher FC counts than upstream sites (Table 14). FC counts at both Twin Rivers sites were greater than 200 cfu/100 mL on the first day of the June storm survey. FC counts at the sites in the upper reaches of the South Fork and North Fork were usually two to ten times less than counts at the Twin Rivers confluence. This increase in FC bacteria may be related to the increased development along the lower reaches of the forks, and up more developed tributaries like Jim Creek.

The samples collected on the first day of both storm events from nearly all of the mainstem sites downstream of the forks were greater than 200 cfu/100 mL. Most June FC counts were greater than 500 cfu/100 mL, and most November FC counts were greater than 300 cfu/100 mL (Table 14). The bacterial response in the two forks and the mainstem to these two storm events was of short duration; i.e., the FC counts returned to much lower levels on the second day of monitoring immediately after the peak flows had passed.

At least one FC sample collected from each of the six lower valley tributary sites and from the Arlington WWTP effluent had a count greater than 200 cfu/100 mL during the storm events (Table 14). All samples collected during the storm events from March Creek, Portage Creek, and Glade Bekken were greater than 200 cfu/100 mL. FC counts greater than 1000 cfu/100 mL were reported in samples from these three creeks, Armstrong Creek, and Kackman Creek. All five tributaries have reaches with potential residential, agricultural, and roadway stormwater sources of FC.

In contrast to the mainstem FC pattern, most tributary FC counts appeared to stay elevated for longer, or they experienced a lag in the peak FC count. For example, March Creek, Portage Creek, Kackman Creek, and Arlington WWTP had higher FC counts the second day of the November event, while mainstem FC counts had peaked the first day (Table 14). Pilchuck Creek, the largest tributary sub-basin in the lower basin, had a FC pattern similar to the mainstem and forks. Runoff from the large undeveloped areas in the Pilchuck and upper basin of the Stillaguamish River may provide water with low bacterial counts that can dilute the FC loads from more developed reaches and tributaries.

The effect of the FC loads from tributaries, point sources, and suspected nonpoint sources on the Stillaguamish River was difficult to assess. Sampling rapidly changing hydrographs in a large basin with several tributaries and few available staff resources prevented a synoptic monitoring approach during the storms. Estimates based on the few samples collected indicated that Portage Creek and Pilchuck Creek delivered the largest FC tributary loads to the lower basin. FC loading from the Arlington WWTP was minor compared to the tributary loads because the WWTP discharge volumes were much lower than the tributary volumes. FC loads from other nonpoint sources along the lower mainstem were suspected, but they could not be estimated because of variability in the mainstem.

Although the FC counts were much lower in November than in June, the estimated FC loads from the mainstem Stillaguamish River to Port Susan were much higher. During the June storm event, the Stillaguamish River at Interstate 5 (I-5) had an estimated mean daily flow of 7250 cfs. The FC count at I-5 was 520 cfu/100 mL, and at Hatt Slough it was 680 cfu/100 mL. During the November storm, the estimated flow at I-5 was 19,000 cfs. The FC counts at I-5 and at Hatt Slough were 380 cfu/100 mL A rough estimate would be that the November storm delivered about twice the FC load to Port Susan as the June storm on the first day. On the second day of the June storm, the FC load was about 13% of the first day's load to Port Susan. A similar estimate was made for the November storm where the FC load on the second day dropped to about 15% of the first day's load.

Freshwater Recreation Area Sampling

FC were sampled for weekly by Ecology for a five-week period in August and September 2000 at seven informal recreational bathing beaches. These data were presented earlier by Joy (2001), but are repeated here to demonstrate FC variability within a season and potential recreational use impacts. A statistical summary of the results of the TMDL freshwater beach survey is shown in Table 15. Enterococci data collected at the same time are summarized in Appendix D.

Table 15. Statistical summary of fecal coliform samples (n=5) collected weekly from seven informal recreational beach sites in the Stillaguamish River basin from August 7 to September 5, 2000.

Informal Recreational Beach Sites	Fecal Coliform (cfu/100 mL)		
	Geometric Mean	90th percentile*	Range
S.F. Stillaguamish at Jordan	34	63	18 – 55
S.F. Stillaguamish at Twin Rivers	34	112	10 – 130
N.F. Stillaguamish at Twin Rivers	19	49	9 – 61
N.F. Stillaguamish at Whitman Br.	3	11	1 – 10
Stillaguamish River at Marine Dr.	27	74	9 – 74
Pilchuck Creek at Jackson Gulch	86	**285**	40 – 280
Church Creek at Stanwood Park	**101**	197	57 - 190
Current State Class A Criteria	100	200	

* The 90th percentile values are based on the FDA method assuming a lognormal distribution (Appendix B).
Bold values do not meet current Washington State FC criteria.

Church Creek at Stanwood Park did not meet the geometric mean FC criterion, and the 90th percentile statistic was just under the 200 cfu/100 mL criterion. The Pilchuck Creek site FC densities did not meet the 90th percentile criterion. The other five sites met both parts of the FC criteria.

Church Creek appeared to be the most popular area, but not by swimmers. Children were often seen playing near or in the creek. Pilchuck Creek and the Twin Rivers Park beaches (the confluence of the North and South forks of the Stillaguamish River) were more likely to have swimmers. According to these data, Pilchuck Creek swimmers and children playing in Church Creek would probably be at a slightly greater health risk.

Critical Conditions and Loads

The analyses of the FC distributions show that the critical season for meeting Class A criteria in the major forks, lower mainstem, and most tributary sites occurs from May through November. However, FC loads and counts are most likely to become elevated during storm events throughout the year. Although primary contact recreation is not popular during storm events or during all of this critical period, Washington State FC criteria apply to primary and secondary recreation uses. Exposure to waterborne bacteria during secondary recreational uses can occur at any time of the year.

June and October through January appear to be the critical months for FC loading to Port Susan, resulting in fewer sites in the bay in compliance with DOH or Class A marine criteria (Figure 14). However, storm events can increase FC loading to Port Susan throughout the year. The available data support or suggest the following reasons for the critical season in fall:

- Median FC loads at the Stillaguamish River at I-5 increase from 3.2×10^{11} cfu/day in September to 4.5×10^{12} cfu/day October, and then often remain elevated through the next few months (Figure 16).

- A few more Port Susan monitoring sites meet Class A criteria, if only January - August data are used.
- The increasing frequency and intensity of storm events in the fall can dislodge and carry bacterial contaminants accumulated over the drier summer months.
- Large flocks of snow geese, shorebirds, and waterfowl stop or winter along the lower reaches of the river and in the estuary beginning in September. These birds could be the source of a significant seasonal FC load (Table 16).
- More severe winds arrive in the autumn. Winds and wave action resuspend bacteria-contaminated sediment in the lower reaches of the river or estuary that was deposited earlier in the season. Scouring action by increased river and tributary flows could also resuspend contaminated sediments previously delivered from upland areas.
- Flooding is not uncommon during these months. Agricultural and residential lands lying in the flooded areas can contribute FC loads from manured fields, septic systems, and other sources.

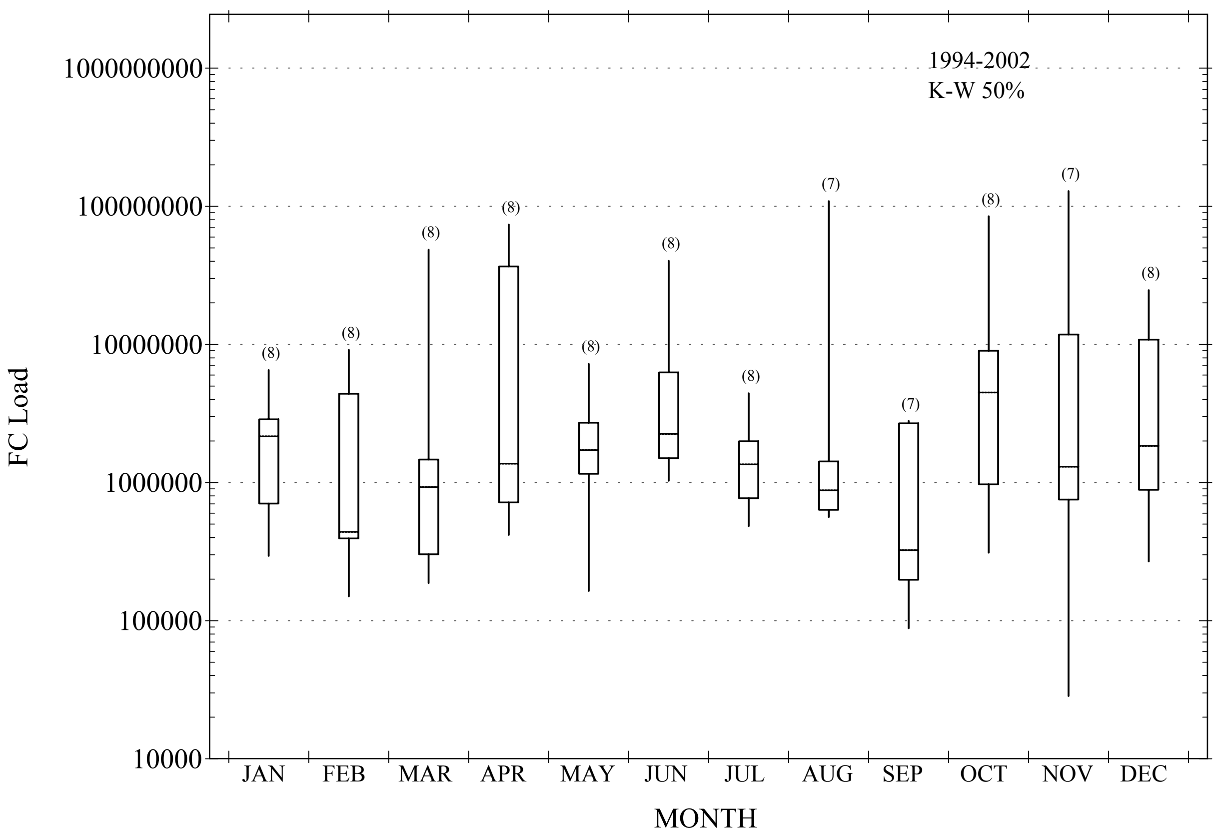


Figure 16. A box-plot summarizing monthly fecal coliform loads (cfu/day x 10^6) from data collected by Ecology at the Stillaguamish River at Interstate 5, #05A070, from 1994 to 2002. The box-plot depicts the median, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles, and the range.

Table 16. Bird population data for northeast Port Susan, Livingston Bay, and the Stillaguamish River delta (Cullinan, 2001), and estimates of the daily fecal coliform load.

Bird	Season Sighted	Average Population	Estimated FC Production (cfu/day) x 10^{12}	Maximum Population	Estimated FC Production (cfu/day) x 10^{12}
Trumpeter Swan	Winter	51	0.02	139	0.06
Snow Goose	Winter	9,700	3.9	25,000	10
Ducks	Winter	4,040	6.9	6,864	11.7
Shorebirds	Fall Migration	-	-	50,000	40
Shorebirds	Winter	24,175	20	31,050	25
Shorebirds	Spring Migration	34,350	25	50,000	40

The estimated average seasonal FC loads contributed from the Stillaguamish River (Hatt Slough and South Pass) to Port Susan during the 2000-2002 TMDL study period varied between 3.8 x 10^{12} cfu/day for July through September, and 1.4 x 10^{13} cfu/day for October through December. The November storm event discharged an average of 1.1 x 10^{14} cfu/day over two days, demonstrating the importance of FC loading from short-term events.

In Table 16, estimates of potential daily FC loads to Port Susan from wildfowl were calculated based on literature values for FC concentrations in fecal material and daily manure production from domestic ducks, geese, and chickens (ASAE, 1998). The daily or seasonal FC loadings from the various wildfowl to Port Susan depend on their accustomed habitat relative to water. For example, the geese and swans spend much of the time on fields and nearshore wetlands, so much of their FC loading would be through land delivery and runoff through drains and creeks. The shorebirds are more likely to spend more time on the tideflats, so FC loading would be a function of exposure of the feeding areas on tideflats and then tidal inundation. Ducks are probably the most pelagic of the species listed. Their FC loading would tend to be directly to the water column, although they might seek more protected sloughs during rougher weather.

The contribution of seal fecal material to FC concentrations in the water column is not well documented. The contribution seals make to FC loads in Puget Sound harbors and bays can vary greatly (Calambokidis, McLaughlin, and Steiger, 1989). Bacterial densities in seal fecal material (1.7 to 55 x 10^{9} cfu/day), dispersion of fecal wastes near haul-out areas, and flushing efficiency of the embayment can affect the FC loading from seals. If a seal produces 2.8 x 10^{10} cfu/day (average of the range quoted above), then 300 seals in Port Susan have the potential for contributing a daily fecal load of approximately 8.5 x 10^{12} cfu/day to the bay.

The loading from wildlife can be significant. If the average daily winter FC loading from seals and waterfowl were directly discharged to Port Susan, it would be more than the estimated daily average winter FC loading from the Stillaguamish River. Fortunately, only a fraction of the wildlife FC load is directly available to water since the wildlife are not in the water all of the time. Their seasonal impact on FC loading can still have an effect on areas of the bay. In an example from Massachusetts, researchers calculated that 67% of the annual FC load in Buttermilk Bay was from waterfowl; the loading was seasonal (December through March), but it was dispersed throughout the bay rather than concentrated in a single area (Weiskel, Howes, and Heufelder, 1996).

The increases in FC loading in the fall season from the Stillaguamish River and from wildlife are also accompanied by internal Port Susan sources. Estuarine mud often has higher counts of bacteria and viruses than overlying water (Thomann and Mueller, 1987). Many researchers also have found that bacteria and viruses survive for longer periods in the mud than in open water. There is also evidence that lower salinities can also release bacteria that are adsorbed to sediment (Erkenbrecher, 1981). Rougher weather and higher river flows in fall can resuspend contaminated sediments deposited at the mouth of the estuary during earlier periods. The lower salinities caused by increased freshwater input can also release more bacteria from the sediment into the water column. Estimating the FC loading from these sources would be difficult. The phenomenon is another potential source of loading to consider when assessing the water quality of Port Susan. Since resuspension is a possible source of FC loading in Port Susan, the loading from surrounding rivers and streams throughout the year is important to consider.

Summary of Fecal Coliform Results

FC counts at most sites monitored under more than one agency (Ecology, Stillaguamish Tribes, Snohomish County, and Water and Wastewater Services at Warm Beach) operating from June 2000 to June 2001 were combined to get a comprehensive picture for the 2000-2002 TMDL study period. The geometric mean and 90th percentile statistics calculated for FC at most lower basin mainstem and tributary sites did not meet the state FC criteria (Table 17). The final determination of criteria compliance will be made after an analysis of critical conditions for each site in the *Loading Capacity* section of this report.

According to the data collected during the TMDL study period, all sites located along the upper forks met Class A freshwater criteria, as did Hatt Slough at the Boat Launch. Mainstem sites located below Arlington, at I-5, and Hatt Slough at Marine Drive did not meet the 90th percentile criterion. Although some improvements were seen in several smaller tributaries, only samples from Jim Creek met both parts of the state criteria. Some of the creeks appear to have chronic FC sources. For example, data from Church Creek/Jorgenson Slough, Irvine Slough, Miller Creek, Portage Creek, Fish Creek, Glade Bekken, Kackman Creek, and Harvey Creek met neither the geometric mean nor the 90th percentile criteria. Data at other sites met the geometric mean criterion, but had episodic events with elevated FC counts more than 10% of the time, failing the second part of the state FC criteria.

The two Hatt Slough sites are only 230 meters apart, but the statistical results in Table 17 are quite different. The differences create some difficulties in characterizing the bacteriological quality of the reach. Several factors may contribute to the differences, including:
(1) two methods of analysis were used; the samples collected downstream at the Boat Launch were analyzed by MPN, and the upstream Marine Drive samples were analyzed by MF (see *Applicable Water Quality Criteria* for definitions of MPN and MF); (2) samples were collected at different times; and (3) the area is tidally influenced. The last factor may have caused a difference because the samples at the Boat Launch were usually taken at high ebb tide, and the samples upstream at Marine Drive were not.

Table 17. Statistical summaries of fecal coliform samples collected from sites in the Stillaguamish River basin during this TMDL daily load study (June 2000 to June 2002). Geometric mean and 90th percentile are in colony forming units/ 100 milliliters.

Site	Number of samples	Geometric mean	90^{th} percentile
Douglas Slough	42	44	**808**
Irvine Slough	13	**680**	**16,205**
Jorgenson Slough	27	**295**	**1,863**
Church Creek at Park	27	**104**	**435**
Miller Creek	17	**326**	**1,715**
Warm Beach Creek above WWTP	19	70	**578**
Agricultural Drain to Warm Beach	19	**121**	**572**
Warm Beach Dike Pond	19	**189**	**1025**
Lake Martha Creek	51	92	**1,008**
Hatt Slough at Marine Drive	56	41	**261**
Hatt Slough at Boat Launch	41	17	63
Glade Bekken	27	**171**	**1,558**
Pilchuck Creek	40	46	**312**
Portage Creek at 212^{th}	32	**236**	**2,032**
Portage Creek at 43^{rd}	19	**149**	**722**
Fish Creek	21	**206**	**4310**
Stillaguamish R. at Interstate 5	33	26	**223**
March Creek	7	**475**	**8,760**
Armstrong Creek at Mouth	4	46	**209**
Kackman Creek	10	**165**	**669**
Armstrong Creek at Hatchery	12	86	**667**
Harvey Creek at Grandview Road	6	**317**	**1527**
Stillaguamish R. below Arlington	12	48	**412**
Stillaguamish R. above Arlington	20	36	181
S.F. Stillaguamish at Arlington	35	27	156
Jim Creek at Mouth	12	55	190
Jim Creek at Whites Road	6	17	52
S.F. Stillaguamish at Granite Falls	30	6	40
N.F. Stillaguamish at Twin Rivers	9	33	116
N.F. Stillaguamish at Cicero	30	13	82
N.F. Stillaguamish at Whitman Br.	17	11	54
N.F. Stillaguamish at C-Post Br.	12	9	37
N.F. Stillaguamish at Darrington	25	8	47

* **Bold** values do not meet the fecal coliform criteria (Table 6)

Some of the summary statistics verify findings made during other TMDL tasks. For example, the synoptic survey indicated FC counts increased downstream in both forks, and also in some reaches from the confluence of the forks to Port Susan. Also, storm-event data demonstrated that runoff can seriously increase FC counts in waters throughout the basin, but the smaller tributaries are affected most severely. Finally, some sites like Pilchuck Creek occasionally experience FC counts above 200 cfu/100 mL during the summer recreational season, as well as during storm events throughout the year.

Port Susan water quality will depend on the freshwater sites coming into more consistent compliance with FC criteria. The Port Susan sites farther away from the mouth of Hatt Slough and South Pass were more likely to meet marine water criteria. The increased FC loading from the Stillaguamish basin during seasonal storm events, especially in the fall, have an effect on Port Susan FC counts. Additional FC loading from small tributaries around the bay, internal resuspension of bacteria-contaminated sediment, a resident seal population, and the arrival of large numbers of migratory waterfowl may increase bacteria counts in Port Susan.

The following conclusions and additional observations were reached from evaluating the FC density data collected in 2000 and 2002 relative to past data:

- The FC bacteria data sets for the upper South Fork, upper North Fork, and Hatt Slough at the boat launch meet freshwater Class A criteria (Table 17).
- More than 10% of the FC counts at sites just below the confluence of the forks, below Arlington, and at I-5 are greater than 200 cfu/100 mL. It is unlikely that Arlington WWTP effluent is a primary source of elevated FC in this area since its FC load is small. Data collected from sites above the outfall indicate a FC problem during storm runoff events.
- FC count reductions along the mainstem and in the two forks occurred after 1995 and 1996. Decreasing trends at many sites were interrupted by increased FC counts reported in 2001. This may suggest that improvements since 1996 have not consistently reduced FC counts in those areas.
- The elevated FC counts in Port Susan are usually associated with short pulse storm events during the spring and through the fall. The fall storms and increased discharge to Port Susan prevent many of the sites in the bay from complying with Class A marine water criteria.
- Only one of the tributaries evaluated in the basin met both parts of the state Class A FC criteria: Jim Creek. Only six sites on other tributaries had geometric mean counts below 100 cfu/100 mL: Pilchuck Creek at Jackson Gulch Road, the mouth of Armstrong Creek and below the hatchery, Lake Martha Creek, Warm Beach Creek, and Douglas Slough.
- Glade Bekken experienced a significant improvement in FC counts in 1999 to 2001 compared to 1996 to 1998. This may be a result of Snohomish Conservation District and Snohomish County Surface Water Management efforts upstream of Silvana Terrace Road.
- FC counts collected at Portage Creek at 212th, the last crossing before the confluence with the Stillaguamish River, appear to have increased significantly in 2001 and 2002. No trend was observed in the data from Portage Creek upstream at 43rd. A major tributary, Fish Creek, showed significant improvement in FC counts from 1997 to 2002 compared to 1994 to 1996. This suggests that a FC source is located between 212th and these upstream monitoring sites.

- FC counts in March Creek appear to increase greatly during storm events, but the data set is too small to totally characterize an annual pattern.
- Although geometric mean FC counts at the mouth of Armstrong Creek and below the hatchery met the Class A criteria, the counts upstream in Kackman Creek and Harvey Creek did not meet any part of the criteria.
- Unidentified sources may be increasing FC counts in the mainstem: between Arlington and Armstrong Creek, on the North Branch below I-5, and between Silvana and Marine Drive.
- Port Susan FC counts were decreasing in 1999, but they increased at many sites in 2000 to 2002. FC loads arriving from the Stillaguamish basin and small tributaries around the bay in September through December appear to degrade bacteriological water quality.
- Intermittent discharges from pump systems (Irvine Slough and Warm Beach Dike Pond) and drains with tide gates could be significant sources of local FC loading in the lower Stillaguamish River and in localized areas like Warm Beach Slough.

Dissolved Oxygen

Current Conditions and Trends

Most dissolved oxygen (DO) data collected in the Stillaguamish River basin have been from instantaneous daytime ‘grab’ measurements. The 303(d) listings for low DO were based on instantaneous measurements made in Pilchuck Creek and Portage Creek (both Class A), the South Fork above Granite Falls (Class AA), and the mainstem Stillaguamish River below Silvana and in Hatt Slough (Class A). The listings were based on samples collected in 1994-1996.

A diel study conducted below the Arlington WWTP by Earth Tech (1997) consultants found that DO concentrations at RKM 21.7 (RM 13.5) upstream of the Interstate 5 bridge dropped to 7.2 mg/L in the early morning, and rose to 11 mg/L in the late afternoon in August 1997. The consultants modeled the effluent biochemical oxygen demand (BOD) from the Arlington WWTP. The model demonstrated that effluent BOD and nitrogenous oxygen demand[1] had little effect on instream DO concentrations. They considered oxygen demand from periphyton biomass respiration the primary cause of low diel DO concentrations during a survey. Data from this study were not included in the 1998 303(d) database, so the reach was not listed.

Ecology, Snohomish County, and the Stillaguamish Tribe collected a combination of instantaneous and diel DO measurements in the basin during the 2000-2002 TMDL study period. Results from instantaneous measurements taken at 36 sites in the basin are summarized in Table 18. The sites were located along the North and South forks, the mainstem Stillaguamish River, several tributaries to the mainstem, and small drainages to Port Susan south of Hatt Slough.

[1] Nitrogenous oxygen demand is a term used to describe the biochemical oxidation of ammonia to nitrite and nitrate.

Table 18. A summary of dissolved oxygen concentrations from grab samples collected in the Stillaguamish River basin by Ecology, Snohomish County, and the Stillaguamish Tribe from June 2000 to June 2002.

Site	Number of Samples	Concentration Range (mg/L)	10th Percentile concentration
Twin City Foods Drain #4 (silted shut)	8	**1.2** – 18.8	**3.3**
Warm Beach Creek above WWTP outfall	7	**3.8** – 8.4	**3.9**
Pasture Drain to Pump Pond	6	**4.1** – 12.0	**4.7**
Pond or discharge to Warm Beach Slough	7	**3.0** – 9.1	**3.8**
Lake Martha Creek	10	8.8 – 12.1	9.4
Unnamed Creek #0456	7	8.6 – 11.8	8.7
Hatt Slough at Marine Drive	49	8.0 – 13.2	9.0
Stillaguamish River at Old Channel split	2	**5.7**, 10.1	-
Glade Bekken at Silvana Terrace Road	33	7.5 – 14.0*	9.5
Stillaguamish River below Silvana	7	9.8 – 13.2	9.9
Stillaguamish River (Cook or South Slough)	11	10.2 – 12.8	10.4
Stillaguamish River (North Channel) at Silvana	7	9.4 – 12.9	9.6
Pilchuck Creek at Jackson Gulch Road	37	**7.6** – 13.6	8.5
Portage Creek at 212th	32	**5.1** – 12.2	**5.5**
Portage Creek at 15th	10	**3.7 – 7.2**	**4.2**
Portage Creek at 43rd	25	**6.4** – 11.4	**6.8**
Krueger Creek at Burns Road	5	8.4 – 11.6	9.5
Portage Creek at Highway 9	10	8.8 – 11.6	9.3
Prairie Creek at 69th and 204th	9	9.7 – 14.2	10.4
Fish Creek	24	9.2 – 14.0	9.8
Stillaguamish River at Interstate 5	37	9.1 – 14.4	9.7
March Creek at 220th NE	6	**4.8** – 8.0	**4.8**
Armstrong Creek at Mouth	3	9.5 – 10.3	9.7
Kackman Creek at 252nd	6	**6.6** – 9.0	**7.0**
Armstrong Creek at Hatchery	6	9.3 – 11.6	9.5
Harvey Creek at Grandview Road	9	9.8 – 11.8	10.0
Stillaguamish River above Arlington	32	8.9 – 13.4	9.9
S.F. Stillaguamish at Arlington	38	9.5 – 14.6	9.9
Jim Creek at Mouth	4	10.4 – 12.5	10.7
S.F. Stillaguamish at Jordan Walkway	9	10.0 – 12.5	10.1
S.F. Stillaguamish at Granite Falls (Class AA)	28	10.0 – 14.3	10.7
N.F. Stillaguamish at Twin Rivers	10	9.8 – 11.6	10.3
N.F. Stillaguamish at Cicero	32	10.1 – 14.3	10.8
N.F. Stillaguamish at Whitman bridge	9	10.8 – 11.6	11.0
N.F. Stillaguamish at C-Post bridge	4	10.7 – 13.0	10.8
N.F. Stillaguamish at Darrington	25	10.8 – 14.0	11.2

Bold values do not meet the dissolved oxygen criteria.
* Glade Bekken had only a single violation of the criteria, so it does not meet the 303(d) listing policy (see text).

The data summarized in Table 18 do not include all of the data collected during the 2000-2002 TMDL study period. DO data from the Old Stillaguamish Channel and its tributaries will be discussed in a future report. Several mainstem sites were only monitored a few times. Data at these sites were not summarized because they were all well within the DO criterion, and they are available in the Data Summary Report (Coffler, Gridley, and Joy, 2004). Data obtained from continuously recording DO probes will be discussed later in this report (*Dissolved Oxygen in the Stillaguamish River below Arlington).*

Based on the combined data, 11 sites did not meet the Class A criterion of 8 mg/L (Table 18). The lowest DO concentrations at all sites were reported from measurements made during the months of May through October. Applying a 0.5 mg/L safety factor to the 10th percentile concentration to account for diel, minimum DO concentrations did not identify any additional sites (see *Analytical Framework* for explanation). All but one of the sites are located on tributaries or drains to the lower Stillaguamish River or to Port Susan:

- Twin City Foods Drain #4
- Warm Beach Creek above the Warm Beach WWTP outfall
- Pasture Drain and Pond (2 sites) to Warm Beach Slough
- Pilchuck Creek
- Portage Creek (3 sites)
- March Creek
- Kackman Creek
- Stillaguamish River at the Old Channel Split

All appear to have fecal coliform contamination problems as well, according to the statistical summaries in Table 17.

Past monitoring data have been used to place the lower Stillaguamish River on the 1998 303(d) list. During low-flow periods, the lower Stillaguamish River from around RKM 4.8 (RM 3) to Hatt Slough can experience short-term depressed DO concentrations. Some of the reaches below the Marine Drive bridge may be influenced by low-DO marine water from Port Susan (Klopfer, 2000). Upstream of the bridge, the unusually low DO concentrations at midday are caused by deoxygenated water from the Old Stillaguamish Channel flowing back into the main river channel. This was observed during the September 13, 2000 synoptic survey (Coffler, Gridley, and Joy, 2004). The DO concentration near the bifurcation point of the two channels (Site #05TMS3) was 5.72 mg/L. DO concentrations in the Old Stillaguamish Channel have been as low as 2.6 mg/L at the Norman Road bridge (Site #05TOC4), and five-day BOD concentrations of 3 - 5 mg/L were recorded (Coffler, Gridley, and Joy, 2004).

The Stillaguamish River reach affected is limited to the right side of the main channel and is dependent on the following factors:

- The tidal volume and tidal stage timing differences in the Old Channel and Hatt Slough.
- The oxygen depletion in the upper reaches of the Old Stillaguamish Channel.
- The direction, dilution, and dispersion characteristics of the Stillaguamish River.

In late 2002, a tide gate was installed in the Old Stillaguamish Channel to operate during the low–flow season starting in 2003 (SIRC, 2002). The gate is designed so that water is allowed to pass from the Stillaguamish River to the Old Stillaguamish Channel, but not in the reverse direction. If the tide gate works as designed, low DO water will not reach the mainstem and Hatt Slough from the Old Channel. The low DO concentration problem in the Old Stillaguamish Channel and the effectiveness of the tide gate will be addressed in a future report.

Glade Bekken had a single DO measurement below 8 mg/L in May 2001, but the 10th percentile value of the data set was well above the 8.5 mg/L concentration of concern. Past studies by Snohomish County have not found DO violations along the mainstem of the creek (Thornburgh, 2001). The 303(d) listing policy for Ecology requires violations from instantaneous data to occur at least three times (Ecology, 2002). Therefore, Glade Bekken should be monitored more intensively in the future, but should not be considered for a load capacity analysis at this time.

Pilchuck Creek was on the 1998 303(d) list for DO based on data collected by Snohomish County prior to 1995. Pilchuck Creek had three excursions below 8 mg/L within the current monitoring period (2000 – 2002), the first since 1994 – 1995 when it was listed. Two excursions below the criterion in Pilchuck Creek were on consecutive days in August 2000 (7.89 and 7.9 mg/L), and the third was in May 2001 (7.56 mg/L). The August values were at 80% saturation. The May concentration was at 69% saturation. The rank 10th percentile DO concentration for Pilchuck Creek is 8.5 mg/L based on instantaneous samples collected by Snohomish County and Ecology, just at the concentration recommended to account for diel minima within the DO criterion. No other water quality parameters were out of compliance with criteria during the three events that would help to identify the source(s) of the low DO concentrations.

Pilchuck Creek data, collected since 1994, showed an improving DO trend in Pilchuck Creek until it was interrupted in 2000. Temperature data continue to show a significant cooling trend. Temperature is often a controlling factor for DO concentrations because lower water temperatures will increase DO solubility. In some cases, lower temperatures can also indicate the influence of local groundwater infiltration.

The Pilchuck monitoring site at Jackson Gulch bridge is located in a floodplain, near the confluence with the Stillaguamish River, and downstream of Interstate 5. During the low-flow season, the monitoring site on Pilchuck Creek is a large, slow pool. The pool could be a source of sediment oxygen demand or heterotrophic bacteria activity in a hyporheic exchange zone (see *Dissolved Oxygen in the Stillaguamish River below Arlington*). The oxygen demand could be from a mix of autochthonous (generated within the stream) and allochthonous (delivered to the stream) materials. Wetland areas and groundwater could also contribute water with naturally low oxygen concentrations.

Oxygen-demanding wastes could come from upstream from anthropogenic and natural sources. Reaches immediately upstream of the sampling site drain forested lands, with scatterings of wetlands, agriculture, and residential areas. All of these land uses have sources of organic material that can be delivered to the creek and can contribute to oxygen demand. Manure from livestock operations has historically been a source of excessive oxygen-demanding pollutants in the basin. The four dairies listed in 1996 in the Pilchuck Creek sub-basin are no longer active, but there are non-commercial farms and equestrian centers in the lower watershed (Thornburgh and Williams, 2001). A Washington State Department of Transportation (WSDOT) map shows several stormwater outfalls to Pilchuck Creek from Interstate 5 and the Jackson Gulch interchange upstream of the sampling site. Stormwater from several arterial county roads, including Jackson Gulch Road, also enter the creek or its tributaries.

Two reaches of Portage Creek were on the 1998 303(d) list (Table 1). Portage Creek has a long history of low DO concentrations in its lower reaches during the daylight hours. The low DO concentration can occur from May through November (Figure 17). Data collected at sites from 1989 to 1995 in these lower reaches caused the 1998 303(d) listings.

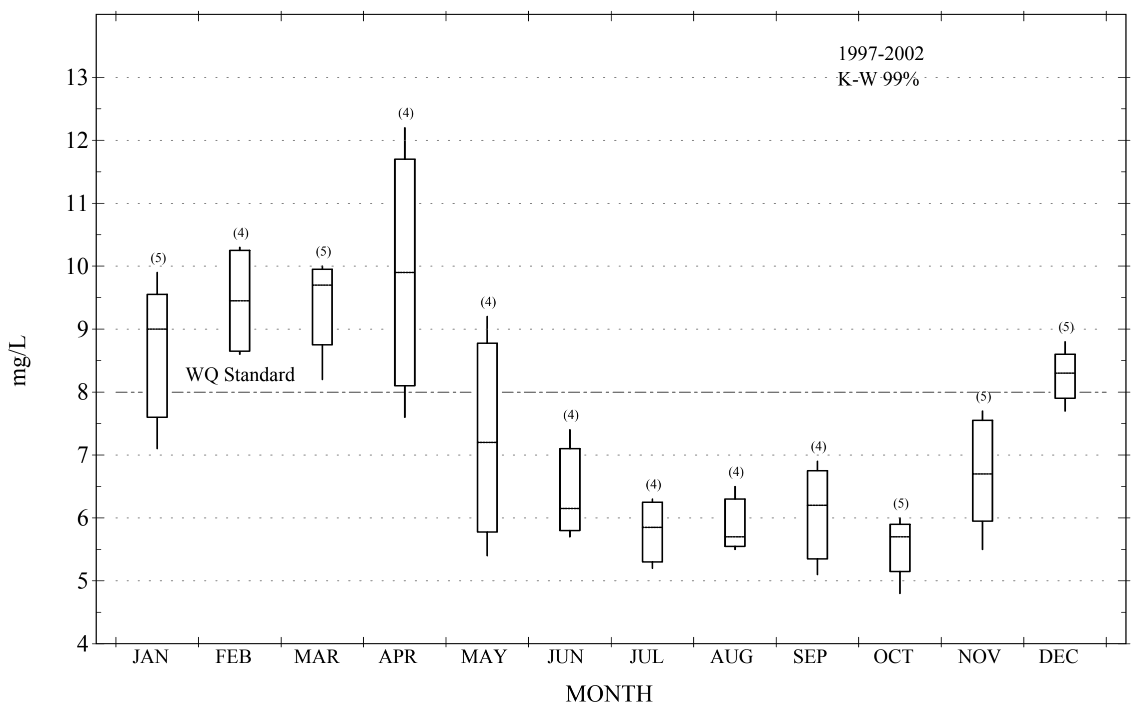


Figure 17. A box-plot of monthly dissolved oxygen measurements collected at Portage Creek at 212th NE by the Snohomish County Surface Water Management Program from October 1997 to April 2002. The monthly range of measurements is compared to the 8 mg/L Class A criterion. The box-plot depicts the median, 10th, 25th, 75th, and 90th percentiles, and the range.

Instantaneous DO measurements made at sites in upper Portage Creek, Prairie Creek, and Fish Creek met the Class A criterion (Table 18). Of the seven sites in the Portage Creek sub-basin, three had DO measurements out of compliance with criteria. All three are located on slow winding reaches of Portage Creek after it drops from the plateau to the Stillaguamish River floodplain – the same reaches on the 303(d) list.

Taken together, all DO data collected from 1994 to 2002 at the two lowest sites at 43rd and 212th appear to show significant improvement. However, a part of the improvement may be the result of a shift to collecting samples later in the day that occurred since 1998. Since DO concentrations tend to increase over the day, measurements taken before noon will usually be lower than those taken in the afternoon. Closer investigation showed that some improvement in morning DO concentrations was observed in the database. All DO concentrations at 212th measured before noon in May through November since 1998 were over 5 mg/L; prior to 1998, 66% were below 5 mg/L. A similar pattern of improvement was seen at 43rd where DO concentrations measured before noon since 1998 were an average of 0.8 mg/L higher, and at Fish Creek where concentrations were an average of 1.2 mg/L higher.

The trend is not good when data are examined seasonally. For example, DO concentrations taken at 212th from May through November since 1998 have shown a statistically significant decreasing trend, similar to the increasing fecal coliform and decreasing temperature trends at the same site. The results may suggest that surface flows are decreasing and that groundwater is becoming a greater portion of the surface flows during these months. Less water may be available to handle pollutant loads. Unfortunately, surface discharge data have not been collected in the sub-basin to further analyze this theory and determine if there has been decreasing summer flows.

The low DO concentrations and elevated fecal coliform counts do not appear to be correlated, but they suggest that pollutant sources are still active in the sub-basin. Land use in the Portage Creek sub-basin has been changing. Only one of the seven dairies present in 1996 remains active in the lower sub-basin. Residential, non-commercial farm, and commercial developments have been increasing on the eastern plateau in and around Arlington. Prairie Creek and upper Portage Creek receive stormwater through several outfalls that drain the developed areas served by Arlington. Also, WSDOT geographic information system coverages (www.wsdot.wa.gov) show several stormwater outfalls to Portage Creek from Interstate 5 and Highway 9. The Fish Creek watershed on the plateau to the west has also seen increased non-commercial farm and residential development activity.

Portage Creek, March Creek, Twin City Foods Drain #4, Kackman Creek, and the Warm Beach Creek set of sites appeared to have chronic DO problems. The 10th percentile DO concentrations are well below 8 mg/L. All of these creeks and drains are slow-moving and shallow during the low-flow period. All sites are located downstream of areas that are wetlands or have hydric soils – potentially influenced by low-DO groundwater and anaerobic subsurface water derived from riparian wetlands. However, all also have elevated fecal coliform counts (Table 17) and elevated nutrient concentrations that may indicate sources of oxygen-demanding wastes are present. Manured fields and animal access areas had been sources of contaminants to Portage Creek in a 1988 – 89 study (Plotnikoff, 1991). Stormwater runoff from Arlington, WSDOT, or Snohomish County systems may also be a source of oxygen-demanding pollutants in some of these creeks.

Warm Beach Creek has similar origins and hydrology to Lake Martha Creek and Unnamed Creek #0456 that did not exhibit low DO concentrations. However, the creek has several potential sources of oxygen-demanding pollutants just upstream of the WWTP. The horse stables and duck pond located on Warm Beach Creek could be sources of manure upstream of the WWTP outfall. The Snohomish Conservation District has been working with the Warm Beach Conference Center to better manage the wastes at the horse stables.

The Dike Pond to Warm Beach Slough receives water from the Pasture Drain, effluent from the Conference Center WWTP, and Warm Beach Creek. The WWTP discharges an average of 10 lbs/day of BOD to the creek, sometimes with very little or no dilution. The Pasture Drain connects to a network of drains to the north. The low DO concentrations in the Pasture Drain could be groundwater or nonpoint sources related to agricultural and residential activities. The pond retention time is highly variable, and algal respiration, duckweed, and oxygen-demanding wastes settled to the bottom probably contribute to reduced water column DO concentrations. Salinities in the Pasture Drain and Dike Pond may indicate saltwater inundation. Water density differences in the Dike Pond could reduce mixing and aeration.

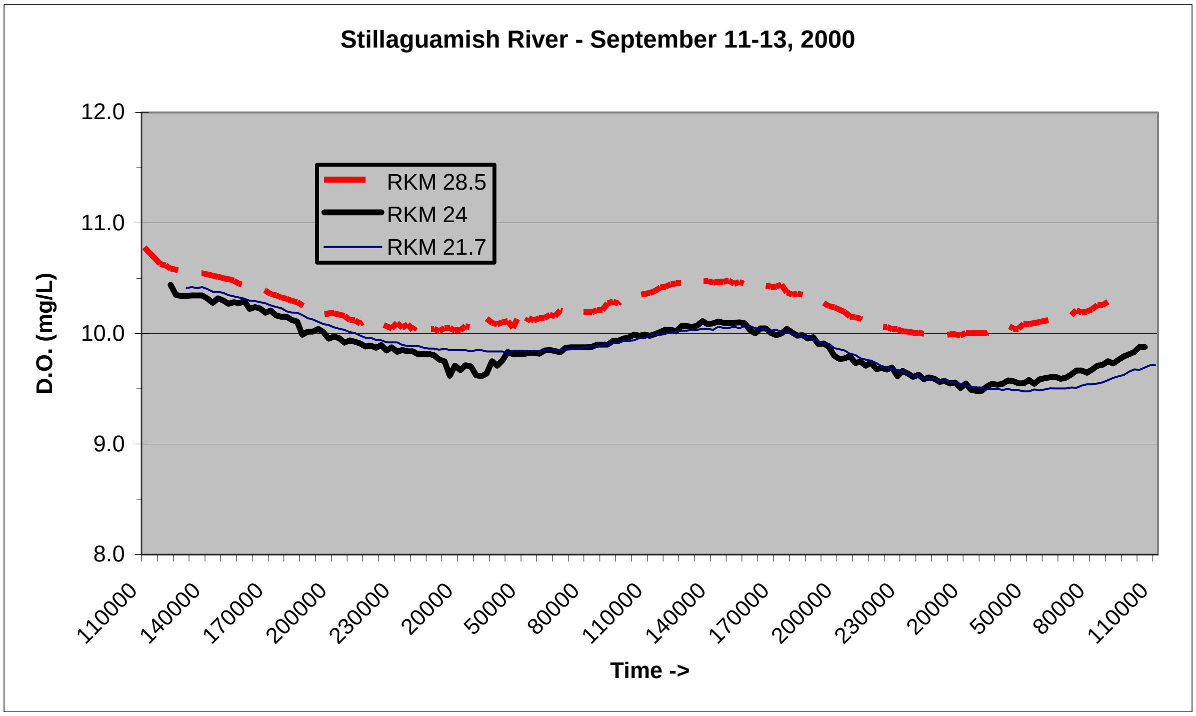
Coho salmon and winter steelhead use Portage Creek and Kackman Creek; coho also use March Creek (WCC, 1999). Tide gates may prevent fish from entering Twin City Foods Drain #4 and the Warm Beach Creek system, and they are not shown as supporting salmon (WCC, 1999). Coho spawning and egg incubation occurs from October through May, so the most serious periods of depressed DO concentrations may be avoided. Winter steelhead spawning and incubation span November through July, so the late incubation period would be most critical for attaining adequate DO in these streams. Juvenile salmon using the streams as rearing habitat over the year could require refuge elsewhere if DO concentrations drop for extended periods below 5 mg/L.

Monitoring data collected along the two main forks in the upper basin met the Class AA and Class A criteria (Table 18). The South Fork Stillaguamish at Granite Falls reach was on the 303(d) list in 1998. The Stillaguamish Tribe data set for the North Fork Stillaguamish near Darrington recorded a low DO measurement prior to 1996, but a single event is not frequent enough to qualify for the 303(d) list. The site on the South Fork at Granite Falls in Class AA waters met the criterion of 9.5 mg/L, as did the site on the North Fork at Darrington just downstream of Class AA waters. The estimated 10^{th} percentile DO concentrations also meet the concentration recommended to account for diel minimums within the DO criterion (Table 18).

Dissolved Oxygen in the Stillaguamish River below Arlington

The mainstem Stillaguamish River reaches between the confluence of the forks at Arlington and Interstate 5 (Figure 7) that were identified as having pre-dawn DO concentrations less than 8 mg/L in the Earth Tech (1997) study were investigated during this TMDL study. Continuously recording probes were deployed in September 2000 and October 2001 to record DO, temperature, pH, and conductivity over 48-hour periods. The probes were not deployed in August 2000 or 2001 (usually the peak autotrophic growth period) because of mid-summer spates (short-duration, high-flow events) and equipment scheduling difficulties.

Two very different DO conditions were recorded (Figure 18). Where September 2000 DO conditions below Arlington were well within the Class A criterion, the October 2001 survey had similar DO conditions to the Earth Tech (1997) August 1997 survey (Figure 18 and Table 19).



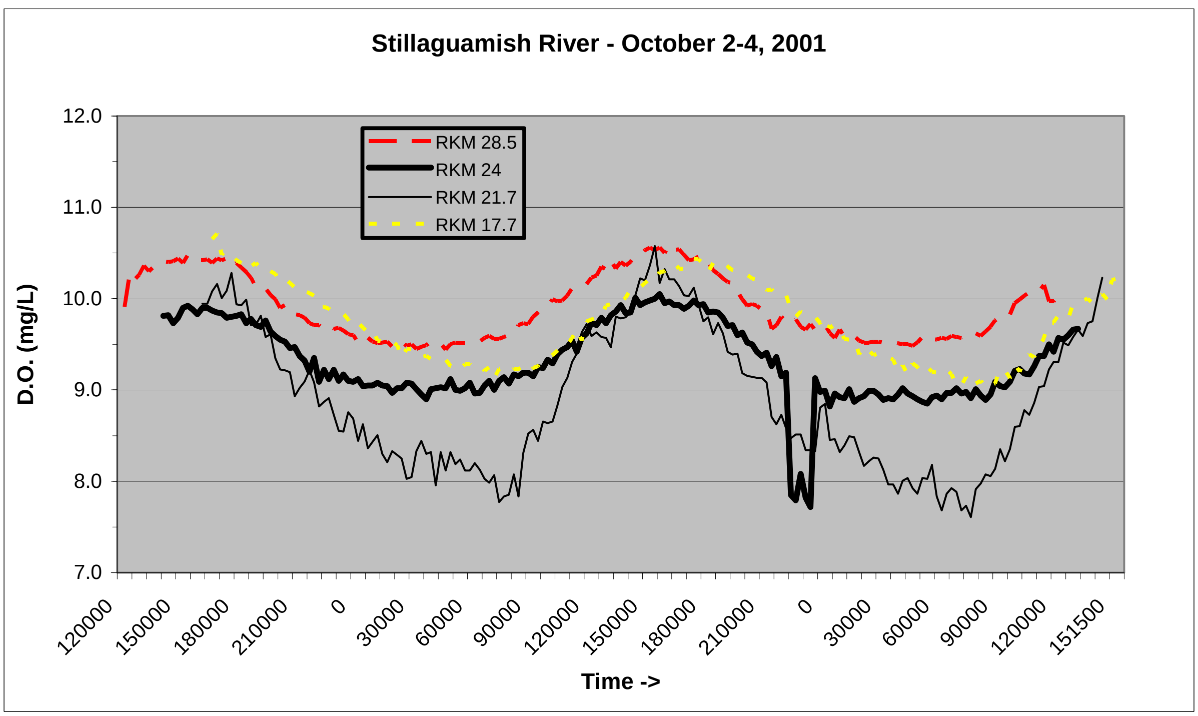


Figure 18. Diel dissolved oxygen (DO) data recorded by probes deployed in the Stillaguamish River between Arlington and Interstate 5. Site locations are shown in Figure 7.

Table 19. Comparison of key characteristics during three diel dissolved oxygen (DO) surveys on the Stillaguamish River below Arlington.

Parameter	August 1997	September 2000	October 2001
River Discharge (cfs/cms)	325 / 9.2	2100 / 59.5	605 / 17.2
Water Temp. range (°C) at RKM 21.7	17.3 – 20.4	11.6 – 14.2	11.3 – 14.1
Photoperiod (hrs)	14.2	12.8	11.5
DO range (mg/L) at RKM 21.7	7.3 – 11.0	9.4 – 10.1	7.9 – 10.6

cfs = cubic feet per second; cms = cubic meters per second

The October 2001 survey confirmed that the pool reach at RKM 21.7 (RM 13) downstream of the Arlington WWTP outfall experiences a wide diel DO range, with minimum DO concentrations below the 8 mg/L Class A criterion in the early morning hours. The minimum DO in 2001 was only 7.9 mg/L compared to 7.3 mg/L in 1997, but the diel DO range in 2001 was far greater than the upstream and downstream ranges. The cause of the sudden, short-term DO loss at the site upstream below Armstrong Creek (RKM 24) around midnight in 2001 is thought to be a malfunction of the meter or a temporary interference with the probe. However, monitoring the reach for similar responses may be warranted in future studies.

Water temperatures were lower and there were fewer hours of daylight during the October 2001 survey than the September 2000 survey. These factors would be expected to impede periphyton growth and respiration rates in October. What may have been more important for the DO diel range in the pool at RKM 21.7 was that hydrologic conditions were similar in August 1997 and October 2001. The discharge volumes in the Stillaguamish River were below 28.32 cms (1000 cfs) during those surveys compared to over 56.6 cms (2000 cfs) during the September 2000 survey (Table 19). The channel from Armstrong Creek to the Interstate 5 (I-5) bridge was characterized as a series of four slow pools connected by small riffle areas during the two lower flow surveys. In both cases, these flow conditions had been stable for more than a week, and probably more favorable for supporting periphyton growth.

Periphyton biomass was not measured directly in August 1997 and September 2000, but photographs in the Earth Tech (1997) report show verdant periphyton growth at several key sites. The average periphyton biomass (as chlorophyll *a*) at RKM 19.3 (RM 12) during the October 2001 survey was estimated at 260 mg/m^2. Some researchers consider biomass concentrations greater than 100-200 mg/m^2 to be at nuisance levels (Biggs, 2000; Welch and Dodds, 2000). In contrast, a 94.2 cms (3326 cfs) spate had probably scoured away a large portion of the periphyton biomass two days prior to the September 2000 diel survey.

The DO concentrations in the Stillaguamish River are susceptible to the influence of seasonal non-filamentous periphyton and filamentous algal growth because ideal light, nutrient, substrate, and water velocity and depth are present. During the summer and fall low-flow period, the river channel is wide, shallow, and has a range of velocities ideal for both filamentous and non-filamentous algal growth. The substrate is stable, most commonly having rocks that are cobble-sized or greater. Adequate light is present because most of the low-flow channel is not shaded, and the turbidity values are minimal in July through September.

Nutrients are supplied from natural watershed sources by recycling processes within the river system and from anthropogenic sources. The dissolved forms of nutrients are more available for autotrophic algae and periphyton use. Phosphorus appears to be the limiting nutrient for periphyton growth based on nitrogen-to-phosphorus (N/P) ratios and QUAL2Kw model simulations. Ratios greater than 10:1 generally indicate phosphorus is the limiting nutrient for algal biomass growth, and under 10:1 indicates nitrogen limitation.

The monthly median N/P ratios as dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (SRP) in the South Fork Stillaguamish River (Ecology Station 05A090) was 38:1 to 143:1 (Ecology, 2002). In the North Fork Stillaguamish River (05B070) the range of ratios has been 22:1 to 119:1. At Interstate 5 (05A070), the monthly median ratios of 39:1 to 149:1 are greater than 20 throughout the year, and similar to the South Fork ratios.

Total phosphorus loading into the upper mainstem reaches is important because bacteria can mineralize some of the bound phosphorus into more usable forms by autotrophs. Total phosphorus concentrations and loads appear to have been increasing since 1980 according to trend analyses of data collected by Snohomish County Surface Water Management above Arlington (MSAR) and by Ecology at I-5 (05A070), South Fork at Arlington (05A090), South Fork at Granite Falls (05A110), and the North Fork at Cicero (05B090) (Figure 19). The total phosphorus loads at North Fork at Cicero, South Fork at Arlington, and at I-5 have increased without concomitant increases in discharge volumes. Some caution is necessary in interpreting phosphorus trend data because the analytical detection limits for phosphorus have changed over the past decade.

Arlington WWTP, several tributaries, and nonpoint sources discharge additional phosphorus to the river between the confluence of the forks and Interstate 5. Arlington WWTP effluent is the major contributor of phosphorus, especially as SRP, into the reach during the low-flow season. Based on the few TMDL synoptic surveys during the summer and fall:

- 56% to 78% of the total phosphorus load comes from upstream
- 15% to 33% comes from the Arlington WWTP
- 1.5% to 2% comes from Armstrong Creek
- 0.2% comes from March Creek
- 1.6% to 14% comes from unidentified nonpoint sources or instream sources

Given the ideal conditions for periphyton growth in the Stillaguamish River, very little phosphorus and nitrogen is needed to stimulate periphyton growth to nuisance levels if low flows are stable for more than a week. For example, the average periphyton biomass measured as chlorophyll *a* in July 2001 was 88 mg/m^2 at the confluence of the two forks at RKM 28.5 (RM 18) above the Arlington WWTP outfall. The concentration of SRP in the water column then was less than 5 ug/L (~ 25 lbs/day), total phosphorus was 12 ug/L (75 lbs/day), and DIN, primarily as nitrate, was 72 ug/L (451 lbs/day). The total phosphorus and nitrate concentrations are higher than the North Cascades Ecoregion reference levels, but lower than the Puget Lowland Ecoregion levels suggested by EPA in Table 8.

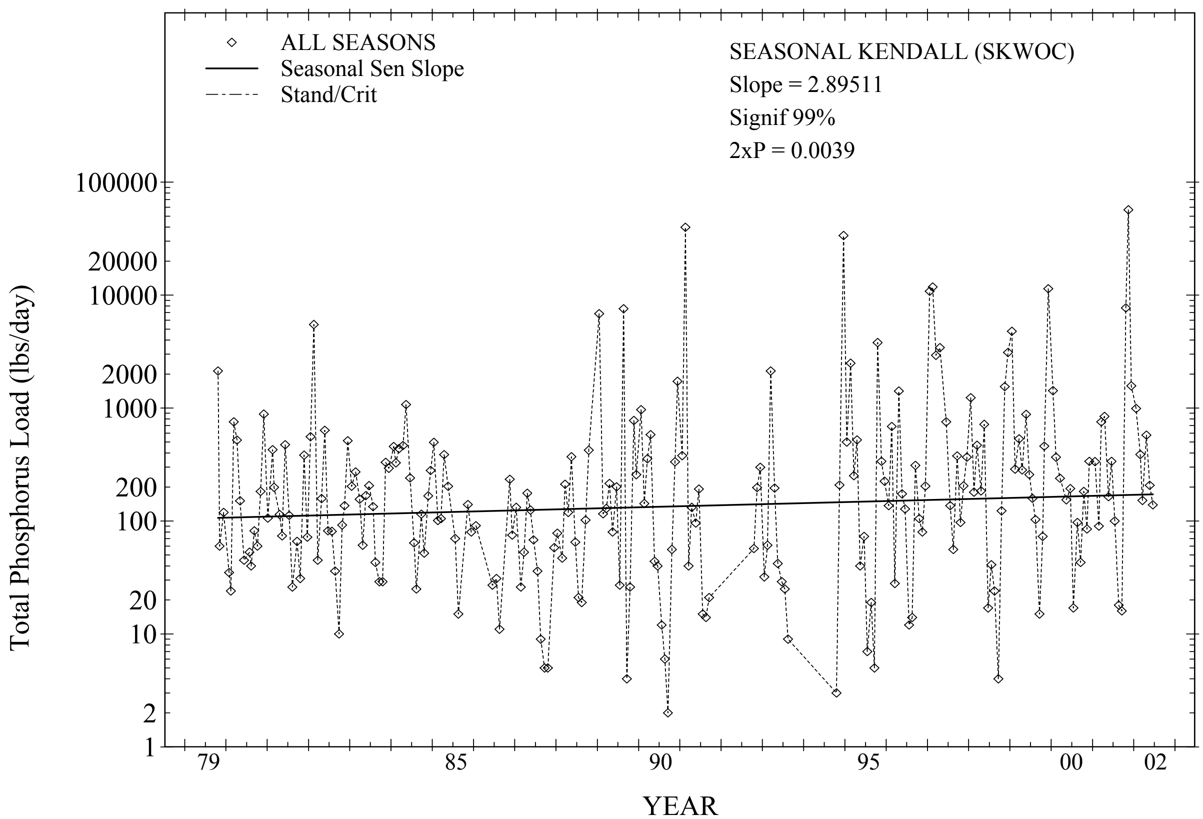


Figure 19. A graph of the increasing total phosphorus load recorded at the South Fork Stillaguamish River at Arlington from 1979 to 2002 (Ecology site #05A090).

Arlington WWTP phosphorus input was estimated to be about 2 mg/L SRP (13 lbs/day) and 2.3 mg/L DIN (15.4 lbs/day) during the same survey. The average periphyton biomass measured downstream at RKM 19.3 (RM 12) was 151 mg/m^2. The nutrients in the water column also increased: the SRP concentration was 5 ug/L, total phosphorus was 17 ug/L, and DIN was 91 ug/L. The increases in periphyton biomass and the water column nutrient increases were greater than would have been expected from Arlington WWTP effluent, Armstrong Creek, and March Creek.

Comparing data analysis and QUAL2Kw model simulations to field observations, it appeared that the low DO and increased nutrient conditions in the mainstem Stillaguamish pools were affected by more complex processes than periphyton biomass production and respiration. QUAL2Kw simulations suggested that periphyton growth and biomass influence a part of the diel DO range. However, to match the full range of the field data, an additional oxygen demand from another process in the model was necessary. Earth Tech (1997) had found it necessary to add a sediment oxygen demand factor to make their QUAL2E model simulations match their field data. Groundwater input, sediment oxygen demand, decaying periphytic materials, or respiration by heterotrophic bacteria in the saturated gravel bed material below or along the river channel are possible sources of additional oxygen demand and nutrients.

Some of the channel and valley features of this reach of the Stillaguamish River suggest that the interaction between surface water and water in the channel bed may be occurring. The processes within the channel bed, called hyporheic processes, have been identified in other parts of the Stillaguamish River (Vervier and Naiman, 1992) and in many rivers like it with channels of coarse alluvial materials (Naegeli and Uehlinger, 1997; Uehlinger, 2000). The hyporheic zone features heterotrophic bacteria communities capable of using oxygen to decompose organic materials, much like a trickling filter in a WWTP. As the bacteria breakdown the organic material, they release nitrogen and phosphorus in the dissolved inorganic form.

QUAL2Kw simulations of the DO data collected in 1997 (Earth Tech, 1997) were run with and without the hyporheic functions (Figure 20). When the hyporheic function was added to the QUAL2Kw model (Pelletier and Bilhimer, 2004) in the reaches between the first pool at RKM 25 and Interstate 5, the DO, pH, and mineralized nutrient simulations fit the field data much better. As a verification test, simulations of the October 2001 field data responded in a similar way. Several adjustments to respiration, productivity, and hyporheic exchange rates different from the 1997 values were necessary to match the water column data that suggested these model functions were site and time specific.

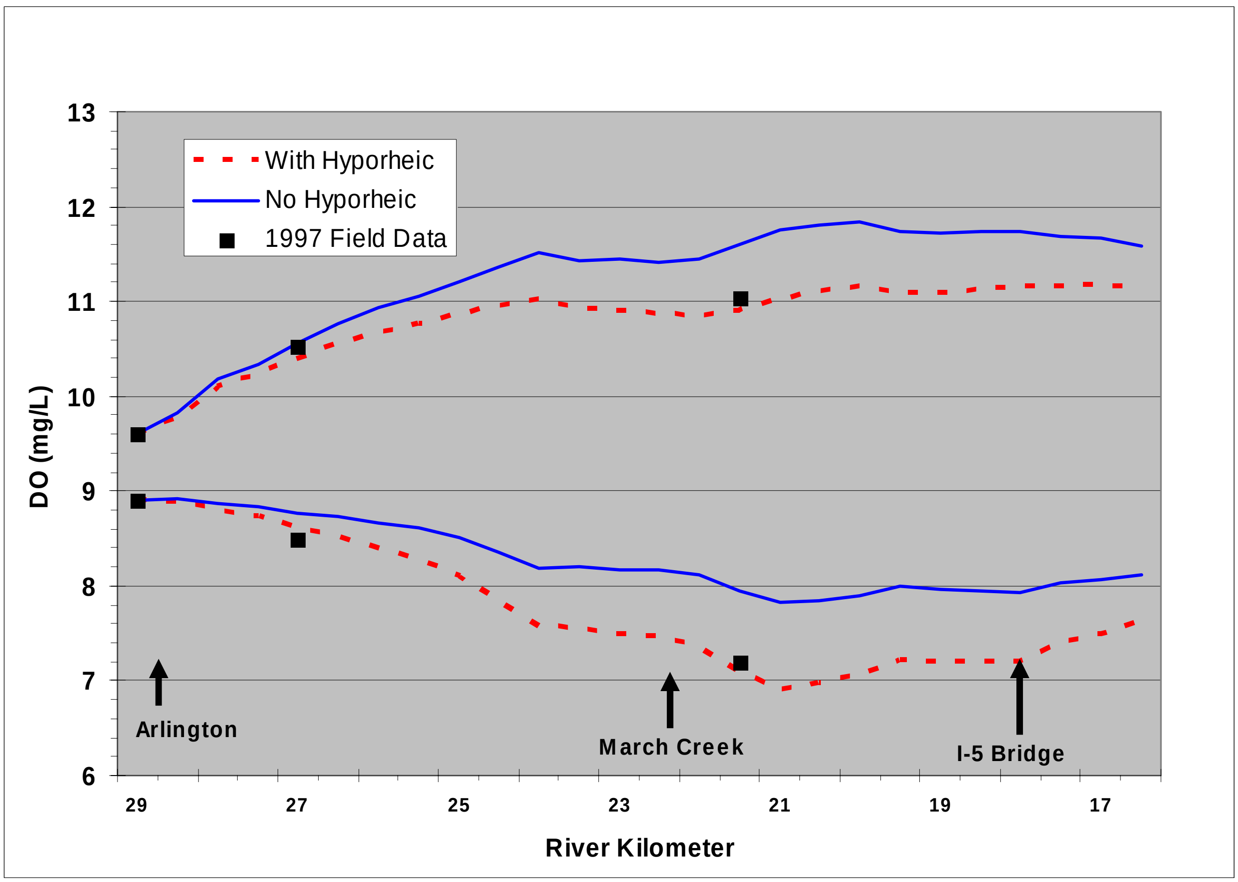


Figure 20. QUAL2Kw simulations of maximum and minimum dissolved oxygen (DO) profiles in the mainstem Stillaguamish River compared to diel DO data collected by Earth Tech in August 1997. The effect of simulating hyporheic respiration in QUAL2Kw is demonstrated in the dashed lines.

The potential influence of the hyporheic zone to water quality and stream ecology in certain systems has just recently been brought out of academics into applied research (Jones and Mulholland, 2000). Unfortunately, the quantities of surface water and groundwater entering the hyporheic zone were not measured in the Stillaguamish River study, and the exact locations of where water enters and exits are not known. The rates of bacterial growth and respiration rates and nutrient mineralization rates were not measured either. Although the hyporheic model does address some questions about the data, there are many uncertainties concerning the heterotrophic bacteria functions, and there may be other valid explanations for the processes observed in the Stillaguamish.

The October 2001 diel monitoring results indicate the DO criterion violation may be limited to the one pool since DO concentrations in the next pool downstream at RKM 17.7 (RM 11) were significantly above 8 mg/L. However, a more extensive area may be affected under critical conditions such as experienced during a 7-day, 10-year, low-flow event. Although the DO concentrations are not critically low (less than 5 mg/L) in the pool reach at RKM 21.7 (RM 13.5) during any of the surveys, they may pose an impediment to aquatic life during critical conditions. The riffle and glide reaches upstream and downstream of the pool are essential spawning areas for pink and chinook salmon (WCC, 1999). Low DO concentrations have not been documented in these reaches. The area is also a rearing area for most of the salmon species present in the basin.

Critical Conditions

DO critical conditions generally occurred during the summer and fall low-flow season, although the mechanisms for the DO decline differed by site. The mainstem critical condition for low DO concentrations occurs during a stable low-flow, with both biomass growth and benthal demand mechanisms in place. Tributary sites experience depressed DO concentrations as discharge volumes decline in the summer and fall. Higher water temperatures that might lower oxygen solubility have not occurred at these sites when low DO concentrations have been recorded.

In the mainstem Stillaguamish River at RKM 21.7, the largest diel ranges accompanied by DO minima below 8 mg/L seem to occur when the following situations coincide:

- Abundant nutrients are available in the water column
- Discharge decreases for a week or more below 28.32 cms (1000 cfs) so retention time through pools increases
- Water clarity increases allowing increased periphyton growth
- Periphyton biomass is not interrupted or scoured away or disrupted by spates, e.g., large storm events
- Groundwater inputs, or chemical and gas exchanges from hyporheic and heterotrophic bacteria respiration processes, interact with water in pool reaches

The TMDL capacity of the mainstem to maintain adequate DO concentrations was evaluated at the lowest 7-day average flow with an annual 10-year recurrence interval (7Q10): approximately 9.38 cms (330 cfs) at the confluence of the forks. The annual 7Q10 statistic for the Stillaguamish River is slightly lower than the seasonal 7Q10 (10.30 cms) used in the temperature

TMDL (Pelletier and Bilhimer, 2004) because the annual 7Q10 usually occurs sometime from August through October when temperatures may not be at their peak. Under 7Q10 flow conditions, the critical reaches of river between Arlington and Interstate 5 are step-pools with hydrological properties that generate the greatest diel DO range. By coincidence, the Earth Tech (1997) DO monitoring survey in August 1997 was conducted during 7Q10 stream conditions (9.29 cms).

The months with the annual 7Q10 flow statistic are appropriate for mainstem DO evaluation for other reasons as well:

- August through October are critical for some salmon using the mainstem for migration, spawning, and egg incubation
- Periphyton biomass would be still capable of higher growth and decay rates with adequate light and nutrient levels
- Reaction rates for biological decomposition would also be higher than average
- Lower DO saturation would be present from higher river temperatures relative to winter months

The TMDL guidelines state that all accessory parameters and point source loads need to be adjusted to critical conditions as well (TMDL Workgroup, 1997). Headwater temperature, DO, and chemical inputs are set at the appropriate highest or lowest 10^{th} percentile value. Point source loads of BOD, total suspended solids, and ammonia are set to the weekly maxima allowed under the permit. The modeling inputs for the Stillaguamish River at the confluence of the North and South forks, for Arlington WWTP effluent, and for the tributaries used in the DO critical condition model simulation are listed in Table 20. The alkalinity of the headwaters is also a sensitive parameter in the model. A value of 25 mg/L as $CaCO_3$ was selected (from a range of 25 to 35 mg/L) after determining that it was the minimum concentration observed at Ecology site 05A070 (at Interstate 5) under low-flow conditions.

Table 20. Headwater, point source, and tributary input values used to evaluate Stillaguamish River dissolved oxygen in the QUAL2Kw model simulations under critical low-flow conditions.

Name	DO mg/L	Temp ° C	Flow cms	BOD_5 mg/L	NH3-N mg/L	NO3-N mg/L	SRP mg/L	TP mg/L
Headwater at RKM 28.5	8.5 – 9.6	18 – 22	9.382	2	0.001	0.066	0.005	0.030
Arlington WWTP	3.0 – 6.0	13 – 20	0.088 (0.131)*	45	1	2	3	3.2
Nonpoint Source	4.0 – 5.0	16 – 20	0.050	35	0.1	5.0	0.5	1.0
Armstrong Creek	9.0 – 10.5	12 – 14	0.139	4	0.005	0.77	0.017	0.049
Nonpoint Source	4.0 – 5.0	16 - 20	0.020	35	0.5	1.0	0.1	0.6
March Creek	4.0 – 5.0	13 – 18	0.016	4	0.010	0.100	0.009	0.050
Portage Creek	5.0 – 8.0	13 -15	0.234	6	0.005	0.665	0.030	0.078
Pilchuck Creek	7.9 - 10	15 – 22	0.200	2	0.005	0.550	0.005	0.023
Glade Bekken	10 – 11	13 – 18	0.027	3	0.005	0.400	0.045	0.093

* Phase 2 Arlington WWTP discharge volume

Critical DO conditions at several tributary sites did not appear to be affected by biomass production. Depressed tributary DO concentrations may be aggravated by effects from benthal demand, oxygen-demanding pollutants from point and nonpoint sources, or inputs from groundwater or wetlands with low DO concentrations during low-flow periods. Seasonal low flows appeared to contribute to the severity of the DO problems in some creeks.

Summary of Dissolved Oxygen Results

DO measurements during the 2000-2002 TMDL study period reveal that there are a few reaches in some waterbodies in the Stillaguamish River basin that experience DO minima below 8 mg/L. Most of these reaches are located in smaller tributaries or drains in the lower Stillaguamish River floodplain. Data from two mainstem reaches of the Stillaguamish River also did not meet criteria. Low DO measurements are more prevalent in the summer/fall low-flow period. DO concentrations at several sites appeared to have improved since 1994.

Although the South Fork Stillaguamish River above Granite Falls was previously listed on the 1998 303(d) list, it appears to have been meeting Class AA (minimum of 9.5 mg/L) criteria since 1995. Data from 12 waterbody reaches did not meet the DO criterion for Class A waters (minimum of 8.0 mg/L). Portage Creek and the lower Stillaguamish River (RM 3) were on the 1998 303(d) list. The 12 sites are:

- Twin City Foods Drain #4
- Warm Beach Creek above the Warm Beach WWTP outfall
- Agricultural Pasture Drain to Warm Beach Dike Pond
- Warm Beach Dike Pond to Warm Beach Slough
- Pilchuck Creek at Jackson Gulch Road
- Portage Creek at 212th NE
- Portage Creek at 15th NE
- Portage Creek at 43rd NE
- March Creek from mouth to 220th NE
- Kackman Creek at 252nd NE
- Stillaguamish River at RKM 21.7 (RM 13.5)
- Stillaguamish River at the bifurcation with the Old Stillaguamish Channel at RKM 4.8 (RM 3)

The lowest DO oxygen concentrations at all sites were reported from measurements made during the months of May through October. Several of the sites with low DO were measured in small streams with slow-moving reaches located in the floodplain. In addition to possible anthropogenic sources of oxygen demand, low-DO groundwater, wetlands drainage, and hyporheic zone processes may naturally depress instream DO concentrations below 8 mg/L during the low-flow period.

It is likely that DO concentrations around Stillaguamish River RKM 4.8 (RM 3) occasionally fall below the Class A criterion because the Old Stillaguamish River Channel reverses flow and discharges low-DO water back into the main channel during some tidal cycles under low-flow conditions. DO conditions in the reach may improve if a tide gate installed on the Old Stillaguamish Channel prevents the reverse flow into the Stillaguamish River.

The situation at RKM 21.7 (RM 13.5) of the Stillaguamish River is more complex and involves periphyton growth and hyporheic respiration or some other mechanism. The DO minima below 8 mg/L have been recorded in one pool reach after low-flow conditions have been maintained for more than a week. The Arlington WWTP, upper basin inputs, tributaries, and other potential sources of nutrients and BOD upstream of the reach may aggravate the DO depression.

pH

Current Conditions and Trends

The South Fork Stillaguamish River was the only waterbody in the basin on the 1998 303(d) list as pH-impaired. The listing was based on two Ecology instantaneous measurements in the South Fork at Arlington recorded in 1987 and 1991 (Ecology, 2000). The pH values were lower than the 6.5 standard units (s.u.) Class A criterion (6.4 s.u. on both occasions). The pH measurements taken at the site have not fallen below 6.5 s.u. since 1991 (Figure 21).

One reason for the apparent improvement may be that the monitoring time changed in 1993 from the morning to the afternoon. As with dissolved oxygen, pH values tend to increase in the afternoon and decrease at night in response to aquatic production and respiration. However, the data still meet the criterion after applying a 0.2 s.u. safety factor to the 10th percentile statistic to account for estimating maximum pH values based on instantaneous measurements (see *Analytical Framework*). Another reason may be that an event or instream condition was monitored that has not occurred during any monitoring run since. For example, a source of stormwater upstream of the site may have been eliminated. And finally, pH is not easily measured in low-conductivity water. Low-ionic buffers and better liquid-filled probes were not used by Ecology until the mid-1990s when quality control measures became stricter. Since these changes, there is higher confidence in the accuracy of the pH measurements.

Ecology and Snohomish County collected a combination of instantaneous and diel pH measurements throughout the basin during the 2000-2002 TMDL study period. The Stillaguamish Tribe stopped measuring pH at its sites in 1999 (Klopfer, 2000). Most of the pH measurements were taken throughout the Stillaguamish River basin in the same manner as the dissolved oxygen measurements. These instantaneous measurements exhibit the same limitations for interpretation as the dissolved oxygen measurements; i.e., the diel minima and maxima in productive systems usually occur very early in the morning and late in the afternoon or early evening.

A summary of data for 27 sites is presented in Table 21. The calculated 90th and 10th percentile values are listed in the table as well. As previously explained, the percentile values are used to apply a 0.2 s.u. safety factor to estimate the maximum diel range in highly productive systems.

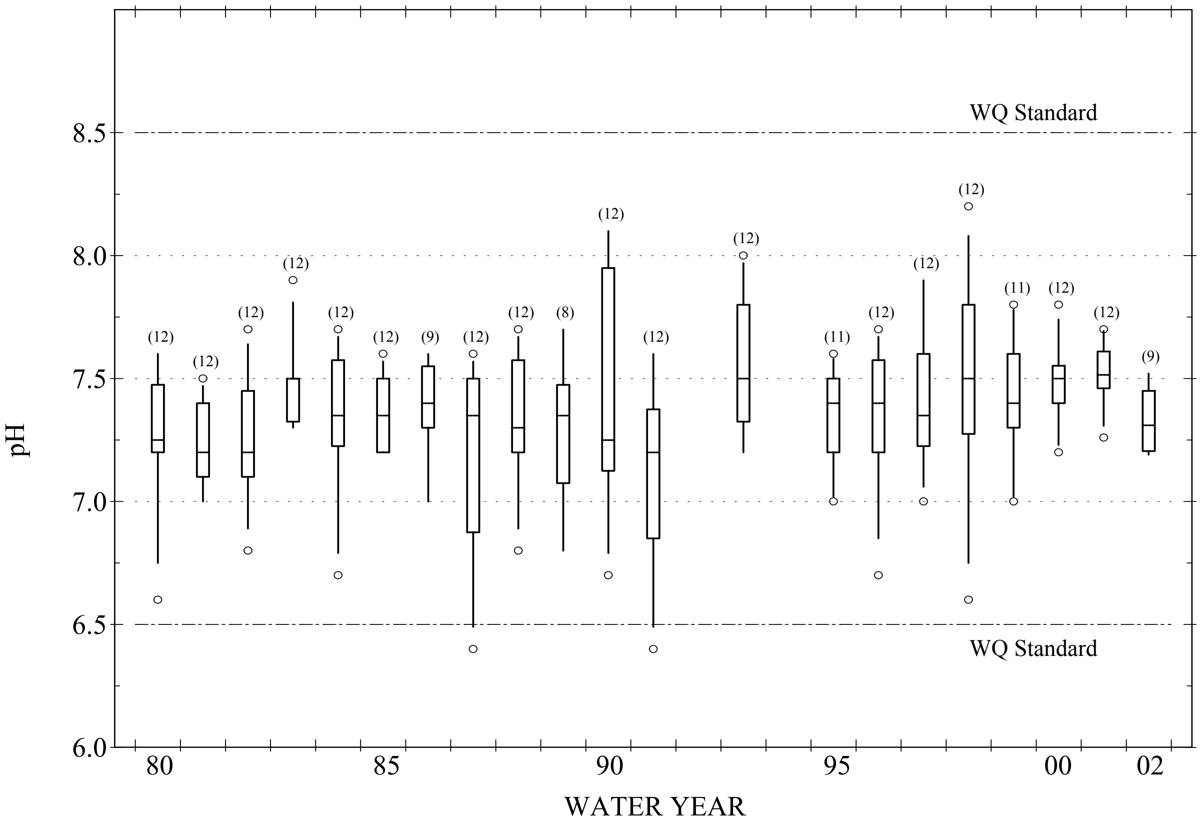


Figure 21. Monthly pH statistics from the South Fork Stillaguamish River at Arlington (Ecology 05A090) from 1980 to 2000 shown as a box-plot. Class A pH criteria are shown. The box-plot depicts the median, 10th, 25th, 75th, and 90th percentiles, and the range. The number of samples used for each box is in the parenthesis above the box.

The pH data collected by Ecology and Snohomish County monitoring programs suggest low pH may be a problem at several sites in the basin. Sites reporting pH measurements below 6.5 s.u., or 10th percentile values below 6.7 s.u., were:

- Stillaguamish River above Arlington below the confluence of the North and South forks
- Kackman Creek
- Pilchuck Creek at Jackson Gulch
- March Creek
- South Fork Stillaguamish River at Granite Falls

The Stillaguamish Tribe monitoring program also had reported low pH values at Pilchuck Creek, Portage Creek, the South Fork Stillaguamish River at Jordan bridge, the North Fork Stillaguamish at Whitman bridge, and at Swede Haven bridge prior to 1996. None of the sites had had pH values under 6.5 s.u. from 1996 to 1999. The tribal program stopped measuring pH at some of the sites in 1999 (Klopfer, personal communication, 2002).

Table 21. Summary of instantaneous pH measurements made in the Stillaguamish River basin by Ecology, Snohomish County, and the Stillaguamish Tribe from June 2000 to June 2002.

Site	Number of Samples	Concentration Range (standard units)	10th and 90th Percentile
Church Creek at Park	30	7.0 – 7.9	7.1 7.8
Hatt Slough at Marine Drive	43	6.5 – 7.8	6.9 7.5
Glade Bekken at Silvana Terrace Road	32	6.8 – 7.9	7.1 7.6
Pilchuck Creek at Jackson Gulch Road	38	6.5 – 8.1	**6.6** 7.5
Portage Creek at 212th	33	6.6 – 7.6	6.8 7.3
Portage Creek at 43rd	25	7.0 – 7.5	7.1 7.4
Fish Creek	24	6.6 – 7.8	6.8 7.6
Stillaguamish River at Interstate 5	38	6.9 – 7.8	7.1 7.7
March Creek at 220th NE	6	6.5 – 7.2	**6.5** 7.2
Armstrong Creek at Mouth	3	7.4 – 7.5	7.4 7.5
Kackman Creek at 252nd	6	**6.2** -7.6	**6.3** 7.2
Armstrong Creek at Hatchery	6	6.8 – 7.7	6.9 7.5
Stillaguamish River above Arlington	32	**6.4** – 7.7	6.9 7.6
S.F. Stillaguamish at Arlington	42	7.0 – 8.4	7.1 7.8
Jim Creek at Mouth	4	6.9 – 7.4	7.0 7.3
S.F. Stillaguamish at Jordan Walkway	12	6.6 – 8.1	6.9 7.9
S.F. Stillaguamish at Granite Falls	30	**6.4** – 8.1	7.1 7.8
N.F. Stillaguamish at Twin Rivers	13	6.9 – 8.2	7.0 7.9
N.F. Stillaguamish at Cicero	33	7.0 – 8.2	7.0 7.8
N.F. Stillaguamish at Whitman bridge	10	6.9 – 8.3	6.9 **8.3**
N.F. Stillaguamish at C-Post bridge	5	6.9 – 7.6	6.9 7.4
N.F. Stillaguamish at Darrington	25	7.0 – 8.0	7.3 7.6

The low pH value of 6.4 s.u. recorded by Ecology at the South Fork Stillaguamish below Granite Falls occurred on the first day of monitoring during the November 2001 storm event monitored during this TMDL. The next day of the storm event the pH was 7.05 s.u. Stormwater from Granite Falls could be of some concern here. However, since only one pH violation of criterion was detected in the reach (including Ecology site 05A110), it does not qualify under the 303(d) listing criteria (Ecology, 2002). Additional monitoring should be considered during storm events, but actions through a TMDL are not warranted at this time.

High pH values, over 8.5 s.u., were not reported at any site during the 2000-2002 TMDL study period, although pH values above 8.0 were recorded at several sites on the North and South forks. The 90th percentile pH value for the North Fork at Whitman bridge of 8.3 s.u. was at the safety factor for productive systems. The high pH values were recorded on three consecutive weeks in August 2000 during the TMDL recreation beach bacteria survey (Coffler, Gridley, and Joy, 2004). The samples were all collected in the late morning or early afternoon, whereas pH maxima usually occur in the late afternoon or early evening.

The low buffering capacity (low alkalinity) of the system could make it susceptible to swings in pH over acceptable levels. In past years, the Stillaguamish Tribe documented high pH values in the North Fork and other sites in the basin (Klopfer, 2000). Periodically during summer low-flow conditions, Ecology site 05B070, the North Fork Stillaguamish River at Cicero, has recorded pH values greater than 8.5 s.u. along with supersaturated dissolved oxygen concentrations in 1997 and 1999 (Ecology, 2003a).

The channel and hydrological characteristics of the North Fork are as ideal as the mainstem for periphyton growth. Total phosphorus concentrations on the North Fork have not shown significant increases since 1994, but they may have increased since the 1980s; the data quality from the earlier period is not high. However, an increase in periphyton biomass production stimulated by nutrients in a poorly-buffered system could cause seasonal episodes of the elevated pH levels. As the periphyton grow, they use carbon and shift the carbonate balance from acidic to basic pH values. During respiration processes at night, the shift is back from basic to acidic pH values.

The lowest pH values at most sites throughout the basin usually occurred in November through April. Senescing organic matter washing through or into the stream and river channels could create declining pH as bacteria decompose the organic material; western Washington rainwater (median pH ~ 5.3) could be another source. Some of the low pH values (5.2 – 6.3 s.u.) recorded by the Stillaguamish Tribe throughout the basin in 1994 and 1995 were measured during storm events (Klopfer, 2000).

The low pH values reported by Snohomish County at the Stillaguamish River above Arlington occurred during storm events. Low pH values were more common at this site from 1999 to 2000 (Snohomish County, 2002). The 10th percentile value for 49 pH data collected from 1999 to 2002 is 6.6. Random sampling that include more storm events in one year, changes in upstream water quality, or changes in measuring technique can influence the data and statistics. Arlington and Washington Department of Transportation (WSDOT) have stormwater outfalls upstream of the site on the South Fork. The site qualifies for the 303(d) list and will have allocations based on stormwater contributions.

The pH values recorded at a few tributary sites (Pilchuck, Kackman, March) are low enough to require closer scrutiny. As mentioned in the dissolved oxygen discussion, Pilchuck Creek and March Creek have Snohomish County and WSDOT stormwater outfalls upstream of the monitoring sites. The low pH values have been recorded during winter months of the year when organic decomposition processes rather than instream productivity may be active.

It is uncertain how much local wetlands, groundwater input, and hydric soils contribute to the low pH values, and how much can be attributed to waste inputs. At all, except Pilchuck Creek, elevated fecal coliform counts and nutrient concentrations accompanied the low pH. Groundwater pH values in the areas of interest have ranges of 6.0 to 8.6 s.u., depending upon the aquifer source. For example, water to the Portage Creek basin that runs through the Vashon recessional outwash aquifer has a median pH value of 6.2 s.u. (Thomas, Wilkinson, and Embrey, 1997).

A majority of pH values measured at Kackman Creek have been below 6.5 s.u. Stillaguamish Tribe pH monitoring data from 1996 to 1999 and six of Ecology's 2000- 2001 TMDL surveys suggested low pH values are common at the site. The TMDL monitoring occurred during or shortly after storm events, but discharge volumes were less than 0.14 cms (5 cfs). The

Stillaguamish Tribe monitoring reported that low pH values occurred during November through May. Kackman Creek also experiences chronic low dissolved oxygen concentrations during storm events and summer low-flow periods; fecal coliform counts seem to be related to storm events. Groundwater with low pH would be a source during a dry winter season in Kackman Creek. Upstream wetlands, agricultural sources, and stormwater could also be sources in wetter periods.

Critical Conditions

The critical hydrologic and biological conditions for high pH in Stillaguamish freshwater systems would occur during the same season as for low dissolved oxygen (August to October). The potential for elevated pH at some sites in the Stillaguamish basin would most likely be a result of biomass production during low flow during the growing season. Nutrients, light, and substrate are limiting factors for periphyton growth and its effect on pH. The alkalinity and carbon cycling of the waterbody is another controlling factor for pH. The North Fork Stillaguamish at Whitman bridge was the only site reporting a potential high pH problem, but ambient monitoring data suggests there may be pH problems downstream to Cicero during low-flow conditions.

Low pH values in parts of the basin occurred during the winter, especially during storm events but also during low-flow periods. The critical conditions causing a depressed pH response may be from an influx of low pH water and oxygen-demanding substances of natural or anthropogenic origin. Anthropogenic and natural sources can contribute during low-flow conditions or during storm events.

Summary of pH Results

The pH-limited 303(d)-listed site, South Fork Stillaguamish River at Arlington, has met criteria since 1991 according to Ecology monthly monitoring data and data collected during the TMDL monitoring surveys. Two sites have had unacceptable pH measurements below the 6.5 s.u. criterion:

- Stillaguamish River above Arlington had low pH values associated with storm events.
- Kackman Creek at 252nd had low pH at all times of the year. Natural and anthropogenic sources may be contributing to the low values.

A 0.2 s.u. safety value is applied to the 10th and 90th percentile pH statistics to estimate diel minima and maxima caused by instream productivity or other factors. The statistics at three sites did not meet the safety value categories:

- The North Fork Stillaguamish from Whitman bridge to Cicero may have maximum pH values greater than 8.5 s.u. from biomass productivity.
- March Creek may have low pH values resulting from stormwater runoff, wetland drainage, groundwater, and nonpoint source pollutants.
- Pilchuck Creek may have low pH values from stormwater runoff, decomposing materials delivered to the waterbodies from nonpoint sources, or instream decomposition processes.

Storm events in November through April are associated with lower pH values in the river and several streams in the basin. Low-pH rainwater, subsurface flow through hydric soils and wetlands, and surface stormwater pollutants are possible sources of the decreased pH. The impact of stormwater and nonpoint sources need to be identified and controlled.

Arsenic and Mercury

Current Conditions - Arsenic

The 1998 303(d) listing for arsenic in the Stillaguamish River was initially from data in the Ecology database that was coded improperly; no detectable concentrations of arsenic were reported at the Stillaguamish River at Interstate 5 (Ecology 05A070) between 1991 and 1996. Recently, better methods have been developed to analyze arsenic in natural waters. Using these low-detection limit methods, Johnson (2002) demonstrated that arsenic is commonly detected in Washington State rivers at concentrations less than those causing acute or chronic aquatic toxicity, but greater than the human-health criteria based on a 1:1,000,000 carcinogenic risk.

Ecology sampled several sites in the Stillaguamish River basin for total recoverable and dissolved arsenic in 2000 and 2001. The sampling focused on the North and South forks near their confluence and the mainstem at I-5 and at Marine Drive (Table 22). In addition, Arlington WWTP effluent was sampled three times, and Portage Creek was sampled once.

Table 22. Total recoverable (TR As) and dissolved (Diss. As) arsenic concentrations and total suspended solids (TSS) concentrations collected from sites on the Stillaguamish River during Ecology's TMDL surveys.

Date	North Fork Stillaguamish River*			South Fork Stillaguamish River at Confluence			Stillaguamish River at Interstate 5			Hatt Slough at Marine Drive		
	TR As ug/L	Diss. As ug/L	TSS mg/L	TR As. ug/L	Diss. As ug/L	TSS mg/L	TR As. ug/L	Diss. As ug/L	TSS mg/L	TR As. ug/L	Diss. As ug/L	TSS mg/L
10/5/00	-	-	-	0.5 U	0.5 U	14	-	-	-	0.5 U	0.5 U	4
1/31/01	1.1	0.38	31	4.1	0.5	335	2.4	0.8	187	2.7	0.95	164
5/8/01	0.43	0.4	5	0.44	0.39	10	0.6	0.37	9	0.47	0.41	9
6/12/01	1.02	0.42	78	3.27	0.55	524	1.4	0.44	203	0.82	0.45	40
7/12/01	0.75	0.78	2	0.68	0.63	9	0.67	0.67	4	0.65	0.65	2
10/3/01	0.96	0.91	12	0.84	0.8	-	0.88	0.81	6	-	-	-
10/16/01	0.7	0.65	5	0.61	0.53	18	0.67	0.56	15	0.66	0.55	11

* Samples were collected at confluence on 6/12 and 10/3; all others were collected at the Cicero monitoring site.
U = not detected at the concentration listed
ug/L = microgram/liter
mg/L = milligram/liter

The values in the table are total recoverable and dissolved arsenic. Organic and inorganic arsenic were not speciated in the samples. The dissolved fraction of arsenic was about 80% to 100% of the total recoverable fraction except during storm events with higher total suspended sediment (TSS) concentration, e.g., on 1/31/01 and 6/12/01 when dissolved arsenic was 15% - 60% of the total fraction. As observed elsewhere in the state, none of the concentrations exceed the aquatic toxicity criteria in Table 6. However, all the data are in violation of the National Toxics Rule (40 CFR 131.36) (NTR) human-health criteria.

Total recoverable arsenic concentrations were generally higher in the South Fork than in the North Fork Stillaguamish, but no significant difference was observed between dissolved arsenic concentrations from the two forks. Arsenic concentrations remained unchanged down the mainstem Stillaguamish River between I-5 and Marine Drive. Arlington WWTP effluent total recoverable arsenic was consistently around 0.85 ug/L (range 0.83 – 0.91 ug/L), similar to average concentrations in the North and South forks. Portage Creek, sampled during the June 2001 storm event had a total arsenic concentration of 2.73 ug/L, similar to the concentration of arsenic sample collected from the South Fork on that day (Table 22).

Two other independent monitoring studies with data pertinent to arsenic in the Stillaguamish basin were conducted during the TMDL evaluation period. Johnson (2002) sampled and evaluated water column concentrations of arsenic from several sites in Washington. Among those rivers sampled were the North Fork Stillaguamish near Darrington and the Stillaguamish River at Silvana (Table 23).

Table 23. Total recoverable arsenic (TR As), total suspended solids (TSS), and flow data at two sites in the Stillaguamish River basin (Johnson, 2002).

NF Stillaguamish near Darrington (05B110)				Stillaguamish River at Silvana (05A070)			
Date	TR As (ug/L)	TSS (mg/L)	Flow (cfs)	Date	TSS (mg/L)	TR As (ug/L)	Flow (cfs)
7/17/01	0.75	0.5	72	7/17/01	9	0.41	1090
8/21/01	0.68	0.5	41	8/22/01	279	2.65	4278
9/18/01	0.69	1	41	9/19/01	2	0.93	488
10/23/01	1	201	1549	10/23/01	588	1.6	17215
11/14/01	1.5	284	6909	11/14/01	1290	2.48	26322
12/11/01	0.27	2	405	12/11/01	56	0.99	3893
1/22/02	0.23	2	-	1/22/02	47	0.88	3808
2/27/02	2.03	16	706	2/27/02	27	0.7	5281
3/19/02	0.3	2	366	3/19/02	15	0.57	3551
4/23/02	0.22	4	597	4/22/02	59	0.78	3422
5/22/02	0.21	3	706	5/22/02	11	0.41	7674
6/19/02	0.19	6	533	6/19/02	11	0.37	6774

Johnson's (2002) arsenic concentrations at the Stillaguamish River at Interstate 5 (Silvana) are similar to those detected during the TMDL surveys. Just as in the TMDL surveys, the arsenic concentrations in Johnson's samples increased during storm events and as TSS increased. Based on the concentrations found in rivers in Washington State and in other background sources like rainwater, Johnson concluded that typical river concentrations of arsenic would not meet the NTR human-health criteria. He recommended that most of the Section 303(d) listings for arsenic be removed, and that future listings should clearly define an anthropogenic source.

Abandoned and inactive mines in the upper basin may be of some concern as a potential source of arsenic contamination. Raforth, Norman, and Johnson (2002) sampled Glacier Creek above and below an abandon mine in the Monte Cristo District. The mine is not located in the South Fork Stillaguamish River sub-basin, but it is just over the ridge in the South Fork Sauk River. The concentrations of total recoverable arsenic in Glacier Creek above and below the waste rock dump area were greater than 0.3 ug/L. Loading analysis revealed that the concentration coming from a combination of the waste rock dump area and two tributaries was approximately 11 – 12 ug/L arsenic. Stream sediment samples also were enriched upstream and downstream of the waste rock dump when compared to quality guidelines (Raforth, Norman, and Johnson, 2002).

Groundwater is another potential source of arsenic in the Stillaguamish basin. The median total arsenic concentration for 295 groundwater samples collected in the western part of Snohomish County by USGS in 1993 and 1994 was 2 ug/L (Thomas, Wilkinson, and Embrey, 1997). Fifty-two wells, representing all seven geohydrologic units, had total arsenic concentrations greater than 10 ug/L. Five samples exceeded the EPA drinking water standard for arsenic of 50 ug/L. All five were taken from wells located between Granite Falls and Arlington.

Based on the five TMDL monitoring events with data from all four sites, the average arsenic load delivered from the two forks accounted for approximately 80% of the average arsenic load calculated for Marine Drive. This was similar to the percentage of discharge delivered from the upper basins. Grouping results from all TMDL sites, TSS concentrations appeared to be correlated with total recoverable arsenic concentrations even though most of the arsenic was in the dissolved form at low TSS concentrations (Figure 22). The strong correlation between TSS and arsenic at the grouped sites suggest that source materials of arsenic and TSS are probably the same.

Arsenic concentrations above the human-health criteria appear to be in all compartments of the Stillaguamish basin hydrology. The arsenic loading estimates, groundwater testing, and the arsenic and TSS analyses indicate that source materials of arsenic are the same throughout the basin. The limited number of available data suggests that no arsenic enrichment takes place between these upper and lower basin sites. Enrichment from abandoned and inactive mines in the upper basin was not detected. The South Fork Stillaguamish River had slightly higher concentrations of arsenic than the North Fork, and there were more mines in the South Fork sub-basin with yields of arsenic (Huntting, 1956). However, groundwater concentrations from wells in the South Fork basin were higher than other areas (Thomas, Wilkinson, and Embrey, 1997).

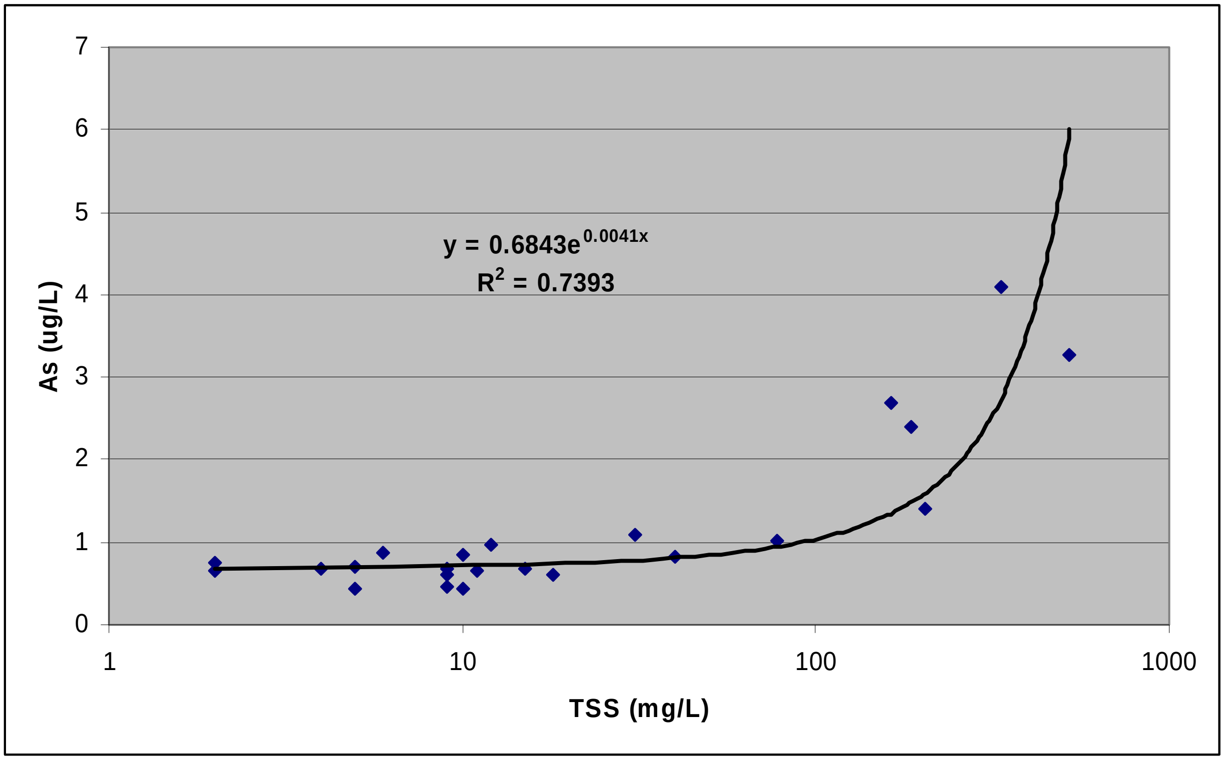


Figure 22. Correlation between water column total suspended solids (TSS) concentrations and total recoverable (TR) arsenic concentrations from samples collected at sites in the Stillaguamish River basin: North Fork Stillaguamish at Cicero and Twin Rivers, South Fork Stillaguamish at the mouth, Stillaguamish River at Interstate 5 (I-5), and Hatt Slough at Marine Drive.

Current Conditions - Mercury

Mercury was investigated because two samples collected at the Stillaguamish River at I-5 (Ecology 05A070) in 1995 had concentrations greater than the freshwater aquatic chronic toxicity criterion of 0.012 ug/L. Both samples had accompanying TSS and turbidity values that were elevated, and river flows were greater than 141.6 cms (5000 cfs). One of the mercury results did not meet quality assurance criteria, so no 303(d) listing for mercury was made based on these samples.

During the TMDL surveys, samples were collected for total mercury at the same times and sites as arsenic. The total mercury results are shown in Table 24. Most results met aquatic toxicity and human-health criteria. However, samples collected at most sites during storm events on 1/31/01 and 6/12/01 did not meet the 0.012 ug/L freshwater chronic toxicity criterion. The criterion is a four-day average, so it is unknown if the criterion was actually violated during the two events.

Table 24. Total recoverable mercury concentrations (ug/L) collected from sites on the Stillaguamish River during Ecology's TMDL surveys. (Total suspended solids concentrations associated with these samples are shown in Table 22.)

Date	North Fork Stillaguamish River *		South Fork Stillaguamish River at Confluence		Stillaguamish River at Interstate 5		Stillaguamish River at Marine Drive (Hatt Slough)	
10/5/00	-		0.0021		-		0.002	U
1/31/01	0.0063		**0.0261**	J	**0.0217**	J	**0.0216**	J
5/8/01	0.0034		0.0029		0.003		0.0046	
6/12/01	**0.016**		**0.0497**		**0.019**		0.01	
7/12/01	0.002	U	0.0025		0.0026		0.0036	
10/3/01	0.0032		0.0029		0.0043			
10/16/01	0.0054		0.0059		0.0064		0.0076	

* Samples were collected at confluence on 6/12 and 10/3; all others were collected at the Cicero monitoring site.
U = not detected at the concentration listed.
J = estimated concentration
Bold values exceed the freshwater aquatic chronic toxicity criterion of 0.012 ug/L.

Mercury appeared to be correlated with arsenic and TSS. Mercury concentrations were highly correlated with arsenic concentrations at Hatt Slough, I-5, and the South Fork (Figure 23). The North Fork correlation was not as strong. The correlation between mercury and TSS suggests that suspended sediment may be the source of the mercury (Figure 24). Mercury increased with increased TSS and increasing discharge volumes during storm events.

Based on the five monitoring events with data from all four sites, the average mercury load delivered from the two forks accounted for approximately 50% of the average mercury load calculated for Marine Drive. This was different from the arsenic loading analyses. The results might suggest that a higher proportion of mercury was generated in the lower basin than in the upper basin based on drainage area, but the source of mercury is unknown. The data were not consistent in showing if the gain in mercury occurred between Arlington and I-5, or between I-5 and Hatt Slough. However, the key to controlling mercury concentrations does appear to be controlling TSS concentrations.

Mercury samples were collected from Arlington WWTP effluent and Portage Creek during the 2000-2002 TMDL study period. The three Arlington WWTP effluent samples analyzed for mercury had concentrations from 0.0034 to 0.0096 ug/L. These concentrations are similar to the average concentrations in the North and South forks of the Stillaguamish (Table 24). The mercury sample collected from the effluent on June 12 was 0.0034 ug/L, far lower than the river mercury concentrations at that time. Portage Creek was sampled during the June 2001 storm event. The mercury concentration of 0.018 ug/L was similar to the mainstem Stillaguamish River at I-5 during that event. Both were greater than the 0.012 ug/L aquatic toxicity criterion and contained high TSS concentrations.

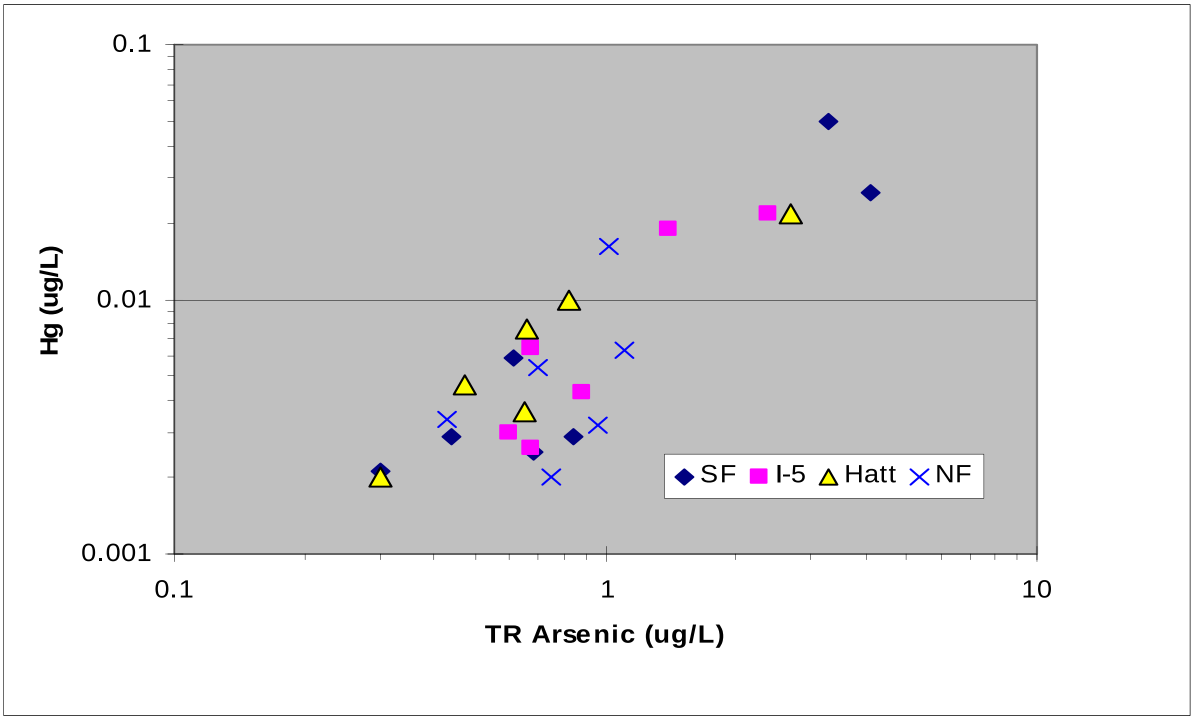


Figure 23. Correlations between total recoverable arsenic (TR Arsenic) and mercury (Hg) in whole water samples from four sites in the Stillaguamish River basin: North Fork Stillaguamish at Cicero and Twin Rivers (NF, r^2=0.23), South Fork Stillaguamish at the mouth (SF, r^2=0.73), Stillaguamish River at Interstate 5 (I-5, r^2=0.89), and Hatt Slough at Marine Drive (Hatt, r^2=0.93).

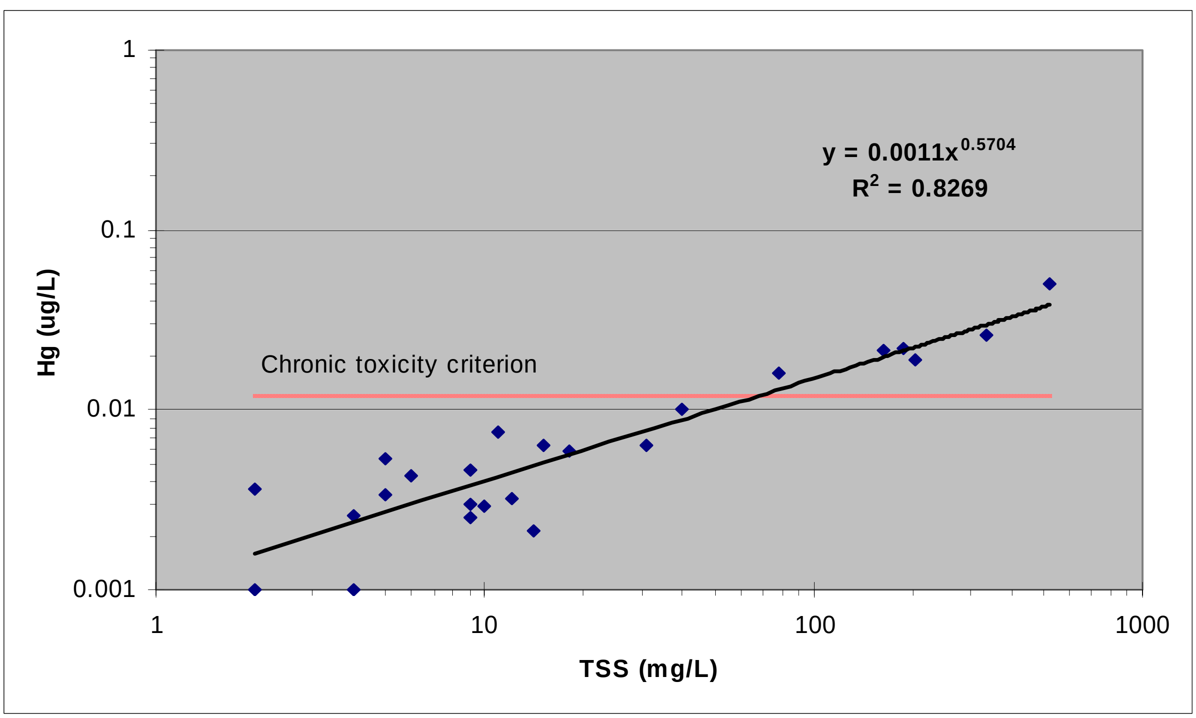


Figure 24. Relationship between total suspended solids (TSS) and mercury (Hg) concentrations for samples collected in the Stillaguamish River basin. The 0.012 ug/L chronic aquatic toxicity criterion for mercury is shown.

Mercury was also collected quarterly in 2002 by Ecology's monitoring program at the North Fork Stillaguamish near Darrington (05B110). One of four samples did not meet the freshwater chronic toxicity criterion (Table 25).

Table 25. Quarterly mercury, total suspended solids, and discharge data collected in 2002 from Ecology site 05B110, North Fork Stillaguamish River near Darrington.

Date	Mercury (ug/L)	TSS (mg/L)	Discharge (cfs)
02/27/02	0.015	16	706
04/23/02	0.0048	4	597
06/19/02	0.0032	6	533
08/21/02	0.0020	1	111

Mercury concentrations were elevated in the February sample during a moderate flow event, five days after a storm (USGS records for North Fork Stillaguamish near Arlington). The TSS concentration of 16 mg/L was in the upper quartile of monthly measurements taken near Darrington since 1992.

The sources of mercury in the upper watershed are similar to those for arsenic, and are found in several compartments of the basin hydrology. Abandoned and inactive mines in the upper basin may be of some concern as a potential source of contamination. The concentration of total mercury in Glacier Creek (in the Sauk River basin) above the waste rock dump area was 0.0042 ug/L during a high-flow condition, and less than the detection limit of 0.002 ug/L during a low-flow condition (Raforth, Norman, and Johnson, 2002). The downstream concentrations increased to 0.0058 ug/L during the high-flow event; no mercury was detected during the low-flow condition.

Loading analysis of the Glacier Creek data revealed that the concentration coming from a combination of the waste rock dump area and two tributaries was approximately 0.006 ug/L mercury. Stream sediment samples also were enriched upstream, but not downstream, of the waste rock dump when compared to quality guidelines (Raforth, Norman, and Johnson, 2002).

Another potential basin-wide source of mercury is rainwater. Rainwater samples collected in Washington by the National Atmospheric Deposition Program in 2001 contained an average concentration of 0.006 ug/L mercury. This concentration is higher than many of the values in Table 24.

Groundwater is another potential source of mercury in the Stillaguamish basin. Mercury concentrations (0.2 - 1.2 ug/L) were detected by USGS in three wells in the Stillaguamish basin at a reporting limit of 0.1 ug/L (Thomas, Wilkinson, and Embrey, 1997). The EPA drinking water limit for mercury is 2 ug/L. Two of the samples were from wells near Stanwood; the other was from a well in the North Fork Stillaguamish River basin. The source of mercury in these samples was not discerned.

Fish collected in Port Susan have shown detectable, but not elevated, mercury tissue burdens (West, O'Neill, Lippert, and Quinnell, 2001). Mercury was detected in all three English sole collected in Port Susan. Concentrations were 0.06 to 0.07 mg/Kg, far below the 1.0 mg/Kg action level for mercury.

Critical Conditions – Arsenic and Mercury

Total recoverable arsenic and mercury concentrations were highest during high-flow conditions accompanying elevated suspended solids concentrations. Arsenic and mercury loads were highly correlated with TSS loads. Arsenic concentrations are consistently greater than the EPA human-health criteria, so no condition is more critical than another to meet these criteria. Reducing TSS may reduce arsenic concentrations, but not to levels below the criteria. Mercury concentrations only exceeded the freshwater chronic toxicity criterion during storm events. Therefore, storm events producing high TSS over more than four days would be a critical condition for mercury loading and chronic criteria violations.

Summary of Arsenic and Mercury Results

Arsenic concentrations in the Stillaguamish River basin are typical for Washington State waters, i.e., they are high enough to violate human-health criteria based on carcinogenic risk, but are far below levels harmful to aquatic organisms. Water column arsenic appears to be in the dissolved form except when elevated TSS concentrations are present. There is a high correlation between arsenic loads and TSS loads at all sites. The regressions and loading comparisons appeared to show that there was no arsenic enrichment in the lower basin, and that arsenic was distributed evenly throughout the basin. The contributions of abandoned and inactive mining areas and groundwater are not known.

Mercury concentrations in the Stillaguamish basin were below criteria except during two storm events. It is unknown if mercury concentrations exceed the chronic toxicity criteria for aquatic life over four consecutive days. Most storm events in the basin are of a shorter duration. Mercury loads are highly correlated with TSS loads throughout the basin. Mercury concentrations are also highly correlated with arsenic concentrations at lower basin sites. According to loading estimates, the lower basin contributed approximately half of the mercury load calculated at Hatt Slough. Low-level mercury concentrations are found in rainwater. The contributions of abandoned and inactive mining areas and groundwater are not known.

Loading Capacity

Fecal Coliform

The fecal coliform bacteria (FC) loading capacities of waters within the Stillaguamish River basin and surrounding northern Port Susan are determined by protecting the most critical beneficial uses in those waters. The loading capacities are directly related to the bacteria distribution represented by the acceptable geometric mean and 90th percentile counts stated in the criteria. The following uses were considered the most critical uses for protection for various types of water of the basin:

- Protecting recreational bathing provides the most restrictive criteria for the rivers and streams in the upper Stillaguamish basin. The loading capacities are represented as Class A or AA freshwater criteria.
- Small freshwater streams discharging directly to Port Susan must meet the freshwater recreational bathing criteria, but they also must not result in violation of more restrictive Class A marine water criteria to protect recreation use or shellfish harvesting. The loading capacities for these sites are better represented by freshwater Class AA criteria to reduce actual mass loading of FC to Port Susan beaches during critical periods.
- Port Susan sites must meet state Class A marine water criteria and Washington State Department of Health (DOH) commercial shellfish harvest criteria; the latter criteria are usually more stringent. The loading capacities of Port Susan sites are the FC population distribution characteristics compared to criteria based on the 30-sample DOH method.

Seasonal analysis of data ensured that the loading capacities at each site are focused on critical FC loading and transport mechanisms. The loading capacity of each site was evaluated by using the statistical analyses described earlier. The 90th percentile was the most restrictive statistic at all sites not meeting criteria. Using the Statistical Rollback Method described earlier, FC geometric mean targets were calculated for sites not meeting the FC criteria. In theory, if the geometric mean target is met, then only 10% of a sample set should exceed the applicable FC criterion, e.g., 200 cfu/100 mL for Class A freshwater, or 43 MPN/100 mL for Class A marine water.

Only six of 22 freshwater sites currently meet their loading capacities and both parts of the FC criteria under all conditions examined and for the most stable period of record (Table 26). All are located in the upper basin, and are highlighted in the table. The status of some sites is different from what was in Table 17 because of critical condition factors.

The Stillaguamish River at Interstate 5, and the South Fork and the North Fork Stillaguamish River at Twin Rivers, met FC criteria on the first round of statistical analyses. However, all three sites showed signs of excessive FC loading from unidentified sources during storm events in 2001-2002. The lower reaches of the two forks could be responding to increased development near Arlington. The QUAL2Kw model simulations, storm-event data, and synoptic survey data also suggest there are FC loads from unidentified sources along reaches between Arlington and

Port Susan. These could be from agricultural or residential uses adjacent to the river or along small drainages leading to the river.

Table 26. Fecal coliform statistical summaries for freshwater monitoring sites along the mainstem Stillaguamish River and major forks and tributaries. Geometric mean and 90th percentile counts are cfu/100 mL.

Site	WQ Class*	Number of Data	Period of Record	Critical Period	Geometric Mean	90th percentile	Target Capacity Geometric Mean
Hatt Slough at Marine Drive	FW – A	46	1998 - 2002	Jun - Dec	56	313	36
Stillaguamish River at I-5	FW – A	21	2000 - 2002	Jun - Nov	54	417	26
Stillaguamish below Arlington	FW – A	25	1996 - 2002	May - Nov	52	357	29
Stillaguamish above Arlington	FW – A	54	1994 - 2002	May - Nov	50	260	39
SF Stillaguamish at Arlington	FW – A	17	2001 - 2002		43	216	40
SF Stillaguamish at Granite Falls	FW – AA	25	1996 - 2002	Jun - Sep	10	62	-
NF Stillaguamish at Twin Rivers	FW – A	9	2000 – 2001		32	232	28
NF Stillaguamish at Cicero	FW – A	31	1996 - 2002	Jul - Nov	14	177	-
NF Stillaguamish at Whitman Br.	FW – A	41	1997 - 2002		18	92	-
NF Stillaguamish at C-Post Br.	FW – A	28	1997 - 2002		9	69	-
NF Stillaguamish near Darrington	FW – A	34	1992 - 2002	Jun - Sep	14	96	-
Glade Bekken	FW – A	27	1999 - 2001	May - Nov	225	2,450	18
Pilchuck Creek	FW – A	65	1996 - 2001	May - Dec	51	272	38
Portage Creek at 212th	FW – A	126	1994 - 2001		147	1,170	25
Portage Creek at 43rd	FW – A	90	1994 - 2001		146	650	45
Fish Creek	FW – A	29	1997 - 2002	Dec - Jun	169	1,070	32
March Creek	FW – A	7	2000 - 2001		475	8,760	10
Armstrong Creek at Mouth	FW – A	19	1997 - 2001		60	280	43
Armstrong Creek below Hatchery	FW – A	37	1996 - 2002		67	583	23
Kackman Creek at 252nd	FW – A	20	1998 - 2002		104	630	33
Harvey Creek at Grandview Road	FW – A	22	1996 - 2002	Mar - Sep	158	830	38
Jim Creek at Jordan Road	FW – A	28	1996 - 2002		55	320	34
Jim Creek at Whites Road	FW – A	18	1998 - 2002		22	75	-

* FW – A = Freshwater Class A; FW – AA = Freshwater Class AA
Bolded names meet fecal coliform loading capacity by meeting state criteria.

The Old Stillaguamish River Channel that splits from the mainstem before Hatt Slough will be the subject of a more comprehensive TMDL evaluation in the future. However, none of the data from the nine tributary monitoring sites in this part of the basin met FC criteria, so preliminary FC loading capacities with target criteria were calculated (Table 27). Freshwater Class A FC criteria were used to calculate the loading capacities in all cases, since none of the sites directly discharge to beaches where shellfish harvesting or beach recreation occurs. Several of the sites had limited data and will need further monitoring to better characterize their current FC loading. At several of these sites, the target geometric mean counts required to meet the loading capacities are quite low because FC counts were the highest observed in the basin.

Table 27. Fecal coliform critical condition summaries for tributaries to the Old Stillaguamish Channel near Stanwood. Geometric mean and 90th percentile counts are cfu/100 mL.

Site	WQ Class*	Number of Data	Period of Record	Geometric Mean	90th percentile	Target Capacity Geometric Mean
Douglas Slough	FW – A	70	1999 - 2002	40	620	13
Irvine Slough	FW – A	13	2000 - 2001	730	16,500	7
Jorgenson Slough	FW – A	31	1994 - 2001	320	1,580	42
Church Creek at Park	FW – A	97	1994 - 2001	147	770	38
Miller Creek at Miller Road	FW – A	21	2000 - 2002	311	2,350	28
Twin City Foods Drain #1	FW – A	17	2001	406	3,550	24
Twin City Foods Drain #2	FW – A	5	2001	285	23,100	3
Twin City Foods Drain #3	FW – A	4	2001	1180	9,550	24
Twin City Foods Drain #5	FW – A	6	2001	545	4,743	22

* FW – A = Freshwater Class A

The several small freshwater tributaries discharging directly to Port Susan require more stringent criteria than Class A because their influence on the bacteriological quality of local recreational shellfish beds needs to be minimized. Therefore, their FC loading capacities should be Class AA: a geometric mean of 50 cfu/100 mL, and a 90th percentile count of less than 100 cfu/100 mL (Table 28). The following three tributaries are recommended to be given targets to comply with a loading capacity based on Class AA freshwater criteria: Unnamed Creek #0456, Lake Martha Creek, and Warm Beach Dike Pond. Loading capacities for the two sites upstream of the Warm Beach Dike Pond – the Agricultural Drain and Warm Beach Creek – were calculated using Class AA criteria as well.

Table 28. Fecal coliform critical condition summaries for West Pass, South Pass, and several small tributaries to Port Susan. Geometric mean and 90th percentile counts are cfu/100 mL.

Site	WQ Class*	Number of Data	Period of Record	Critical Period	Geometric Mean	90th percentile	Target Capacity Geometric Mean
West Pass of Old Stillaguamish	MW - A	17	2000 - 2001		85	1,250	3
South Pass of Old Stillaguamish	MW - A	26	2000 - 2001		42	150	11
Twin City Foods Drain #4	FW - A	9	2001		149	1,670	18
Warm Beach Creek above WWTP	FW - AA	10	2001 - 2002	Jun - Nov	253	543	47
Agricultural Drain to Warm Beach	FW - AA	12	2001 - 2002	May - Nov	120	900	13
Warm Beach Dike Pond	FW - AA	12	2001 - 2002	May - Nov	172	1,300	14
Warm Beach Slough	MW - A	75	1998 - 2002		29	118	10
Lake Martha Creek	FW - AA	58	1996 - 2002	May - Oct	288	1,220	23
Unnamed Creek # 0456	FW - AA	7	2001		350	3,600	11

* MW - A = Marine Water Class A; FW - A = Freshwater Class A; FW - AA = Freshwater Class AA;

The critical period for FC counts in Hatt Slough at Marine Drive occurred from June through December (Table 26). The data collected by Ecology and Snohomish County at the Marine Drive site consistently exhibited freshwater conditions. The target loading capacity is based on Class A freshwater criteria. South Pass is another FC loading source to northern Port Susan from the Stillaguamish basin. It usually qualified as a marine site based on salinity, even though the highest FC counts were recorded during low salinity storm flows. The FC target capacity was set to meet the Class A marine water standards (Table 28). West Pass to Skagit Bay was treated in the same manner.

The current upstream cumulative FC loads to Hatt Slough were estimated and compared to estimated FC loads if the TMDL targets in Table 26 were met. The estimates were based on average daily loads derived from critical seasonal flows and the current and target geometric mean statistics. A natural die-off factor was not included in the calculations. The estimates suggest that if the targets are attained, the FC loads at Marine Drive will be reduced by 75%, quite adequate for meeting the 36% reduction required to meet Class A criteria at that site. The analysis also suggests that meeting the targets for the North and South forks, and mainstem targets below Arlington and at the Interstate 5 bridge, will be essential to reduce the FC loads by 75%. The cumulative tributary FC load reductions will account for 20% of the overall load reduction. The other 55% will be from other reductions along the mainstem.

Another simple estimate was made of the average daily FC loads to Port Susan for the months of June through December (Table 29). Hatt Slough, South Pass, Warm Beach drainages, and wildlife sources were included in the estimate to consider a rough order of magnitude comparison between sources. The estimates of the wildlife loads have a large margin of error but demonstrate their potential importance as a background source. The estimates suggest an overall FC load reduction to Port Susan of 37%, and a 77% reduction from freshwater sources.

Table 29. Estimated average daily fecal coliform loads to Port Susan from various sources for the months of June through December. Load estimates are shown for 2000 – 2002, current period, and for a time in the future when fecal coliform TMDL targets are met.

	Current Loading (cfu/day)	Post-TMDL Loading (cfu/day)
Hatt Slough	12×10^{12}	2.9×10^{12}
South Pass	1×10^{12}	0.2×10^{12}
Warm Beach Drainages	0.2×10^{12}	0.01×10^{12}
Birds	5.2×10^{12}	5.2×10^{12}
Seals	8.5×10^{12}	8.5×10^{12}
Total	27×10^{12}	17×10^{12}

cfu = coliform-forming units per day.

Data collected by the Stillaguamish Tribe in Hatt Slough at the boat launch approximately 0.5 kilometers downstream from Marine Drive yielded a 30-day sample geometric mean of 15 MPN/100 mL (Table 30). Farther downstream were the South and West branches with geometric mean densities higher than in Hatt Slough. The sites on the two branches were given target capacity geometric mean FC densities based on the DOH 30-sample criteria to reduce loading between the Stillaguamish Tribe Hatt Slough site and Port Susan.

Some Port Susan sites were not meeting DOH 30-sample criteria for commercial harvest areas. The statistics for the last 30 samples are shown in Table 30. They are not significantly different from the statistics derived from the whole set of samples collected by the Stillaguamish Tribe since 1998. The loading capacities for Port Susan sites were calculated by using the Statistical Rollback Method so that the criteria of a 90th percentile of 43 MPN/100 mL and a geometric mean of 14 MPN/100 mL will be met:

- The loading capacities represented by the geometric mean targets are generally around 10 MPN/100 mL to meet the 90th percentile criterion of 43 MPN/100 mL.
- Kayak Point, Warm Beach Point, and North Port Susan meet criteria.
- The number of samples for PS-5 through PS-9 and Juniper Beach are inadequate for a 30-sample calculation.
- The FC reductions required for Port Susan sites vary from 2% to 60%.

Table 30. Fecal coliform target geometric means calculated from statistics derived for 30 consecutive samples collected by the Stillaguamish Tribe prior to June 27, 2002 at 16 sites in Port Susan and the Stillaguamish River estuary. Geometric mean and 90th percentile counts are MPN/100 mL.

Site Name	Hatt Slough	West Branch	South Branch	SB Pilings	WB Slough	PS-2	PS-7**	PS-6**
Site Number	120	121	122	123	127	128	139	138
Geometric Mean	15	27	24	12	28	21	32	19
90th percentile	64	98	102	44	100	107	125	117
Target Capacity Geometric Mean	NR*	12	11	11	12	8	11	7

Site Name	PS-3	PS-5**	PS-8**	PS-4	PS-9**	WB Point	Kayak Point	NP Susan	Juniper Beach**
Site Number	129	137	140	130	148	124	125	126	-
Geometric Mean	14	21	15	5.7	3.9	6.1	4.2	3.3	15
90th percentile	74	148	119	27	13	31	20	12	65
Target Capacity Geometric Mean	8	6	6	NR	NR	NR	NR	NR	10

* NR = none required

** Less than 30 samples available to calculate statistics.

SB = South Branch; WB = Warm Beach; PS = Port Susan

A 77% reduction in freshwater FC loads to Port Susan is estimated if FC loading capacities are met in the Stillaguamish River, its tributaries, and the Warm Beach drainages. The freshwater FC loads are the likely cause of criteria violations in Port Susan since seals and birds are present in winter and spring when criteria in the bay are often met. Estimated FC reductions required for sites in Hatt Slough, the Stillaguamish River estuary, and Port Susan are close to 60% in Hatt Slough and are as low as 2% in the estuary. The level of freshwater FC load reduction should allow sites in Port Susan to meet water quality criteria for shellfish harvesting.

Dissolved Oxygen

The dissolved oxygen (DO) loading capacities of waters within the Stillaguamish River basin are determined by protecting the most critical beneficial uses in those waters. The loading capacities are directly related to the minimum DO concentration stated in the criteria, or to natural conditions as defined in Chapter 173-201A-070 WAC. Salmonid spawning is considered the most critical beneficial use in the Stillaguamish River basin requiring adequate oxygen concentrations. Salmonid rearing and migration, and life support for other fish and aquatic communities, require less stringent oxygen concentrations.

Twelve reaches in the basin were identified as not meeting the Class A water quality criterion of 8 mg/L. Two reaches are on the mainstem Stillaguamish River, and the other ten are on tributaries to the Stillaguamish River or to Port Susan. Two reaches on the 1998 303(d) list – South Fork Stillaguamish at Granite Falls (Class AA at 9.5 mg/L) and an upper Portage Creek at Highway 9 (Class A) – were found not to have DO impairments. This TMDL evaluation will recommend that these last two waterbody segments be taken off of the 303(d) list.

Three sites will be required to meet the minimum Class A DO criteria of 8 mg/L.

- The Stillaguamish River above Hatt Slough has experienced low DO in the past because deoxygenated water from the Old Stillaguamish Channel has flowed back into the main river channel. A tide gate installed in 2003 should prevent the problem from occurring in the future and keep minimum freshwater DO concentrations above 8 mg/L. Incoming marine water may occasionally lower DO concentrations in Hatt Slough to 6.5 mg/L.
- Warm Beach Creek above the WWTP outfall has several likely upstream sources of BOD, ammonia, and oxygen-demand. Although insufficient flow volumes may be a significant factor for making DO measurements in the summer, any flowing water in the creek should be free of oxygen-demanding contaminants so that the 8.0 mg/L Class A criterion will be met.
- DO concentrations measured at Pilchuck Creek at Jackson Gulch Road have been infrequently below 8 mg/L. Removing or reducing documented nonpoint and stormwater sources upstream of the site should bring DO back into compliance.

Two ‘natural condition’ issues concerning the DO results have made it difficult to evaluate minimum potential concentrations at the other nine sites:

- The floodplain reaches of some tributaries to the lower Stillaguamish River and ditches through diked lands have naturally low DO from surrounding wetlands and valley groundwater inputs. Several of the reaches also exhibit low pH (near 6.5) and cool water temperatures that also indicate wetland or groundwater inputs. However, nonpoint sources also may contribute to some of the low DO conditions in these tributaries. Fecal coliform criteria are not met in these reaches, but low DO concentrations and elevated FC counts are not strongly correlated at any of the monitoring sites.
- The seasonally low DO conditions in the Stillaguamish River between Arlington and I-5 appear to be dominated by some sort of benthic demand. QUAL2Kw model results suggest that areas of hyporheic exchange are causing DO depressions in one or two pools in the reach. These processes are difficult to model, and the DO loss due to natural conditions may be more significant than that caused by upstream source nutrient and BOD inputs.

At most of these sites, an estimate of the best potential minimum DO concentration is necessary because DO is suspected of being naturally lower than the Class A criterion of 8 mg/L. The estimated minimum concentrations are listed in Table 31. The concentrations were based on best professional judgment after considering natural and anthropogenic inputs. More detailed data and the removal of nonpoint sources of pollutants will be required before the natural DO minima for these systems can be fully determined.

Table 31. Dissolved oxygen minimum concentrations estimated for reaches in the Stillaguamish River basin based on considerations of local natural and pollutant sources. The load capacities as BOD_5 are estimated from reductions of nonpoint sources.

Site	Waterbody ID Number	Concentration Range (mg/L)	Potential Minimum DO at Critical Period (mg/L)	Load Capacity BOD_5 (lbs/day)
Twin City Foods Drain #4	-	1.2 – 18.8	6.5	-
Warm Beach Creek above WWTP Outfall	SH96KX	3.8 – 8.4	8	20
Pasture Drain to Pump Pond	SH96KX	4.1 – 12.0	6.5	10
Pond or Discharge to Warm Beach Slough	SH96KX	3.0 – 9.1	6.5	30
Pilchuck Creek at Jackson Gulch Road	VJ74AO	7.6 – 13.6	8	890
Portage Creek at 212th	OT80TY	5.1 – 12.2	6.5	300
Portage Creek at 15th	OT80TY	3.7 – 7.2	6.5	280
Portage Creek at 43rd	OT80TY	6.4 – 11.4	7	250
March Creek at 220th NE	WI88QF	4.8 – 8.0	6.5	30
Kackman Creek at 252nd	XB43NX	6.6 – 9.0	7	10
Stillaguamish River below Arlington	QE93BW	7.3 – 14.1	7	-
Stillaguamish River above Hatt Slough	QE93BW	5.7 – 13.2	8	-

An estimate of oxygen demand from anthropogenic sources is required to estimate the best potential minimum DO concentration. In this analysis, the presence of elevated fecal coliform bacteria and nutrients was assumed to come from the same anthropogenic sources as excess oxygen demand. All of the tributaries in Table 31 require fecal coliform reductions. These reductions were used as relative gages of BOD reduction.

The Simple Method model (Stormwater Center, 2004) that calculates runoff pollutant loads from various land uses was used to estimate current BOD_5 loading. The model estimates of current loads were checked against loads generated from mean flow statistics and the few available BOD_5 sample data, and were found to be similar in magnitude. The loading capacities were estimated by applying reductions based on the fecal coliform loading capacities[2] (Tables 26, 27, 28, and 30). The loading capacities yield average BOD_5 concentrations around 1 mg/L compared to 1.5 to 3 mg/L BOD_5 estimated for current conditions. The loading capacity for Twin City Foods Drain #4 could not be estimated because the drainage area was not known, and water in the drain was never running.

[2] A 75% reduction in BOD_5 for March Creek was assumed, rather than the 98% reduction recommendation for fecal coliform.

The targets in Table 31 were set no lower than the Class B 6.5 mg/L minimum DO concentration in Washington State Chapter 173-201A WAC to protect fish and aquatic life, and salmonid life stages other than embryo and larval development. Portage Creek, March Creek, and Kackman Creek have been identified as coho salmon or winter steelhead habitat (WCC, 1999). All of the monitoring sites on these creeks are located in large, slow pools or in grass-choked channels that would not be considered good spawning habitat.

The target DO concentrations may be adequate for salmon egg development and for fry survival and growth. The adequacy of DO concentrations for egg development and fry viability is dependent on sediment porosity and the velocity of the water reaching the egg or fry (Warren, 1971). The Class A criterion of 8 mg/L will provide more than adequate DO through coho and steelhead redds in most, but not all, cases,. However, egg and fry can survive and thrive at lower water column DO concentrations (greater than 5 mg/L) if redds are placed in porous gravels and water velocities that allow good circulation of DO and nutrients (Warren, 1971).

Coho spawning and egg incubation occurs from October through May, so the most serious periods of minimum DO concentrations may be avoided. Winter steelhead spawning and egg incubation in Portage Creek and Kackman Creek span November to July, so the late incubation period would be most critical for attaining adequate DO in spawning areas of these streams.

Investigating the quality and location of spawning areas in these creeks was beyond the scope of this TMDL evaluation. The relationships between DO concentrations and salmon egg and fry survival at this level of detail have not been made. More complete assessments will be required to ensure that DO is not a habitat-limiting factor in spawning areas.

An attempt was made to determine the loading capacities of phosphorus, BOD, ammonia, and nitrogen for the Stillaguamish River between Arlington and Interstate 5. The QUAL2Kw model (Chapra and Pelletier, 2003) was used to simulate the effects of carbon, nitrogen, and phosphorus loads on DO under low-flow critical conditions (Table 20). Heterotrophic bacteria and periphyton growth, and hyporheic exchange functions used to simulate conditions recorded in August 1997 and October 2001, were included. The input values and coefficients used in the model are available in Appendix C.

The nutrient and BOD loads from Arlington WWTP and nonpoint sources were varied successively to compare their effects on DO changes in downstream reaches. These were compared to the minimum DO concentrations under simulated natural conditions (no anthropogenic inputs). Headwater nutrient loads were also varied in the set of simulations. The results of these simulations are summarized in Table 32. An example of two DO profiles is shown in Figure 25.

Table 32. Summary of QUAL2Kw simulations of Arlington WWTP input and Stillaguamish River minimum dissolved oxygen (DO) responses during critical low-flow conditions.

	Model Simulations	Arlington WWTP effluent				Downstream Response
		BOD_5	SRP	NH3	NO3	Minimum DO
		mg/L	mg/L	mg/L	mg/L	mg/L
1	1997 Arlington Loading (0.024 cms)	10.8	2.6	0.8	9.7	6.5
2	2001 Arlington Loading (0.052 cms)	8	3.5	0.6	2	6.4
3	Arlington Phase I permit (0.088 cms)	45	3.0	1.0	2	6.3
4	Arlington Phase II permit (0.131 cms)	45	3.0	1.0	2	6.2
5	Arlington Phase I - BOD modified	10	3.0	1.0	2	6.4
6	Option 5 + SRP modified	10	1.0	1.0	2	6.4
7	Arlington Phase I – no SRP	10	0	1.0	2	6.5
8	No Arlington WWTP but NPS present	0	0	0	0	6.6
9	Arlington Phase I but no NPS present	10	1.0	1.0	2	6.7
10	No Arlington WWTP or direct NPS	0	0	0	0	6.9
11	10 + Headwaters nutrient reductions *	0	0	0	0	7.2
12	11 + Arlington Phase I modified	10	1.0	1.0	2	7.0
13	12 + NPS present	10	1.0	1.0	2	6.7

* Nutrients reduced to North Cascades Ecoregion reference concentrations (Table 8)
NPS - Unidentified nonpoint source loads

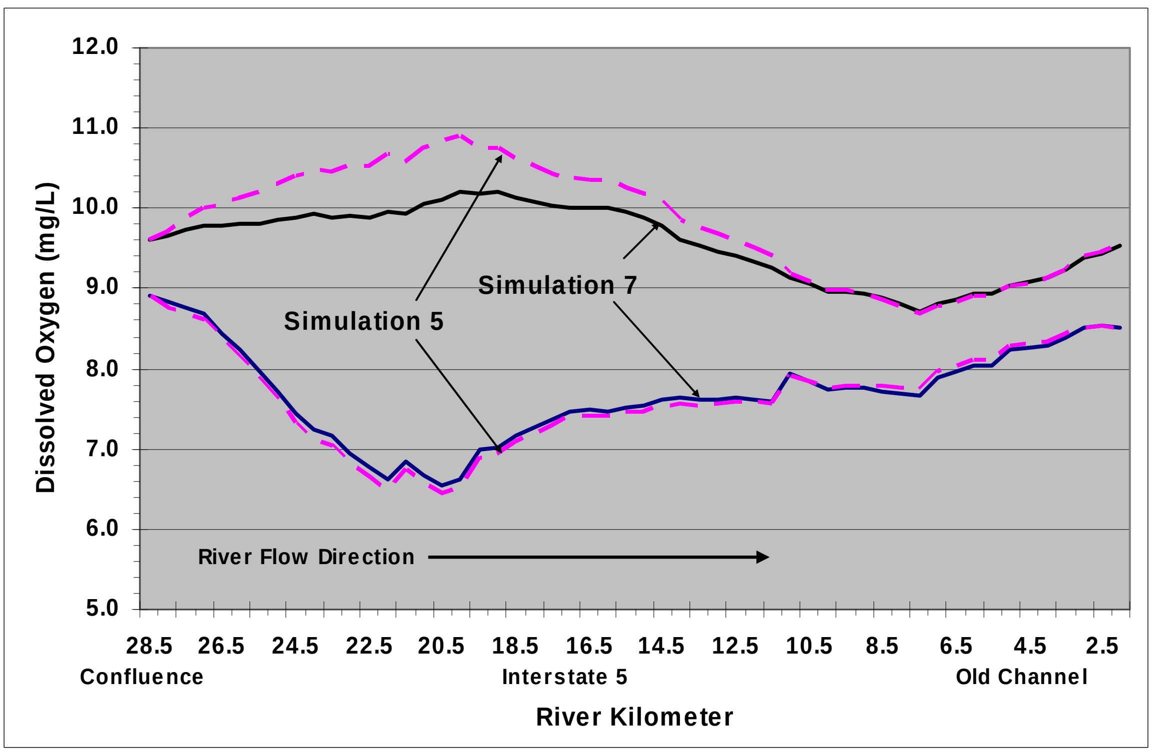


Figure 25. Two QUAL2Kw model simulations showing the range of diel dissolved oxygen concentrations in the Stillaguamish River from the confluence of the forks to Port Susan. Simulation 5 and 7 conditions are described in Table 32.

In all simulations, the minimum DO concentration located around RKM 20 was far lower than any DO observed in the 1997 and 2001 field surveys. For example, the 6.5 mg/L DO minimum in the August 1997 loading scenario (Simulation 1) is nearly 1 mg/L lower than what was observed in the field at that time. Slightly higher water temperatures and headwater concentrations of nutrients required for the critical conditions settings may have caused the difference. However, even natural background (Simulations 10 and 11) results, with anthropogenic (point and nonpoint) sources of phosphorus and carbon absent as natural conditions, were 0.8 and 1.2 mg/L below the Class A DO criterion. The scenarios with anthropogenic sources (Simulations 1- 9, 12, 13) result in DO concentrations 0.2 – 0.7 mg/L lower than the natural background scenarios.

The simulation results suggest that the instream processes, represented in QUAL2Kw by periphyton biomass growth and the heterotrophic bacteria growth in the hyporheic zone, may be the dominant factors controlling minimum DO concentrations during low-flow conditions. How periphyton and heterotrophic bacteria biomass are affected by the combination of carbon, ammonia, nitrogen, and phosphorus loads cannot be confidently determined at this time. The instream processes are too biologically and physically dynamic.

Extrapolating a single model calibration of these processes to critical conditions and calculating loading capacities for BOD, phosphorus, and nitrogen is not technically defensible at this time. For example, the DO results in the model are very sensitive to both the initial biomass and growth rates of periphyton and heterotrophic bacteria, and their placement along the reach. Since the model is only quasi-dynamic, the initial periphyton biomass had to be set near the value measured when the greatest DO range was measured, and the growth rates had to be calibrated to field data.

Heterotrophic bacteria initial biomass and rate values were added by trial-and-error calibration. Biggs (2000) showed that the number of days for biomass accrual had more of an effect than nutrient concentrations on maximum chlorophyll *a* biomass, but both were important factors. The same is possibly true for the heterotrophic communities as well. Since changes in the accumulation rates of periphyton biomass and heterotrophic bacteria biomass have not been quantified for the Stillaguamish system, the initial biomass of these populations at the onset of critical conditions is uncertain.

As stated earlier, when the Washington State DO standard cannot be met under natural conditions, the natural condition becomes the DO criterion (Chapter 173-201A-070 WAC). It is Ecology's policy that effluents cannot cause more than a 0.2 mg/L loss of DO in areas where natural conditions are lower than standards (TMDL Workgroup, 1996). The results in Table 32 suggest that Arlington WWTP effluent and nonpoint sources in the reach may reduce DO by 0.2 mg/L or greater. The survey data and research literature suggest that carbon and phosphorus loading to the reach stimulates periphyton growth. However, the margin of error in the simulations is too great to determine if 0.2 mg/L is a significant additional loss compared to background because of the complex biological processes in the reach.

The QUAL2Kw model predicted a potential minimum DO concentration at RKM 21.7 (RM 13.5) in the Stillaguamish River between Arlington and the Interstate 5 bridge of 6.9 to 7.2 mg/L under critical conditions (Simulations 10 and 11, Table 32). Therefore, a minimum

DO concentration of 7 mg/L should be attainable under critical conditions if upstream, nonpoint source, and point source nutrient inputs are managed and controlled. DO concentrations below 7.3 mg/L have not been detected outside of the single pool area, so the spatial extent of the 7 mg/L minimum would be very limited. As described previously in the tributary DO discussion, salmon spawning and rearing area and other beneficial uses in the reach should be protected at this minimum DO target.

pH

As with dissolved oxygen, the contaminant loading capacities for waterbodies with pH criteria violations vary by cause. The Stillaguamish basin waterbodies with pH values higher than the 8.5 criterion probably have excessive aquatic biomass with high productivity. Nutrient loading is controlled to reduce biomass in these cases and to lower diel pH maxima. In waterbodies with pH values lower than the 6.5 criterion, the causes could be from several natural or anthropogenic causes. Anthropogenic loading of low pH water or organic contaminants that increase decomposition processes needs to be reduced to increase pH to natural conditions.

The areas in the Stillaguamish basin with low pH criterion violations are observed either seasonally or during storm events. The ability of these waterbodies to meet the pH criterion once anthropogenic sources of oxygen demand or low pH water are reduced is not known. The loading capacities cannot be calculated. The following sites should be reassessed to determine natural seasonal or event-based pH conditions once the anthropogenic sources of oxygen-demand or low pH stormwater are reduced or eliminated as fecal coliform and dissolved oxygen loading capacities are met:

- Stillaguamish River above Arlington at the confluence of the North and South forks
- Pilchuck Creek
- Kackman Creek
- March Creek

The North Fork Stillaguamish River at Whitman bridge to Cicero bridge (NFRKM 28.3 to NFRKM 15.2) was the only location where seasonal episodes of pH maxima over criteria are recorded. The TMDL data collected did not specifically find pH values over the 8.5 s.u. criterion, but historical data at Cicero and frequency of data near 8.5 s.u. are strong indications that this does occur. Nutrients increases since 1995 are not apparent from data in this reach, but some increases may have occurred since the 1980s.

The nutrient loading capacity for the North Fork Stillaguamish was not explored in depth because the problem in the area was not previously identified on the 303(d) list. However, trend analyses on data collected at Ecology 05B070, North Fork Stillaguamish at Cicero, suggests a significant increasing trend in total phosphorus loads at the site since 1980 (Figure 26). According to Ecology monthly monitoring data, phosphorus loads have not increased upstream at the site near Darrington (05B110), and pH there has been well within criteria. Sources of phosphorus between 05B110 (RKMNF 48.3) and Cicero bridge (RKMNF 15.2), starting above Whitman bridge (RKMNF 28.3), have not been specifically identified. Potential nonpoint sources of phosphorus include residential, highway, and agricultural runoff.

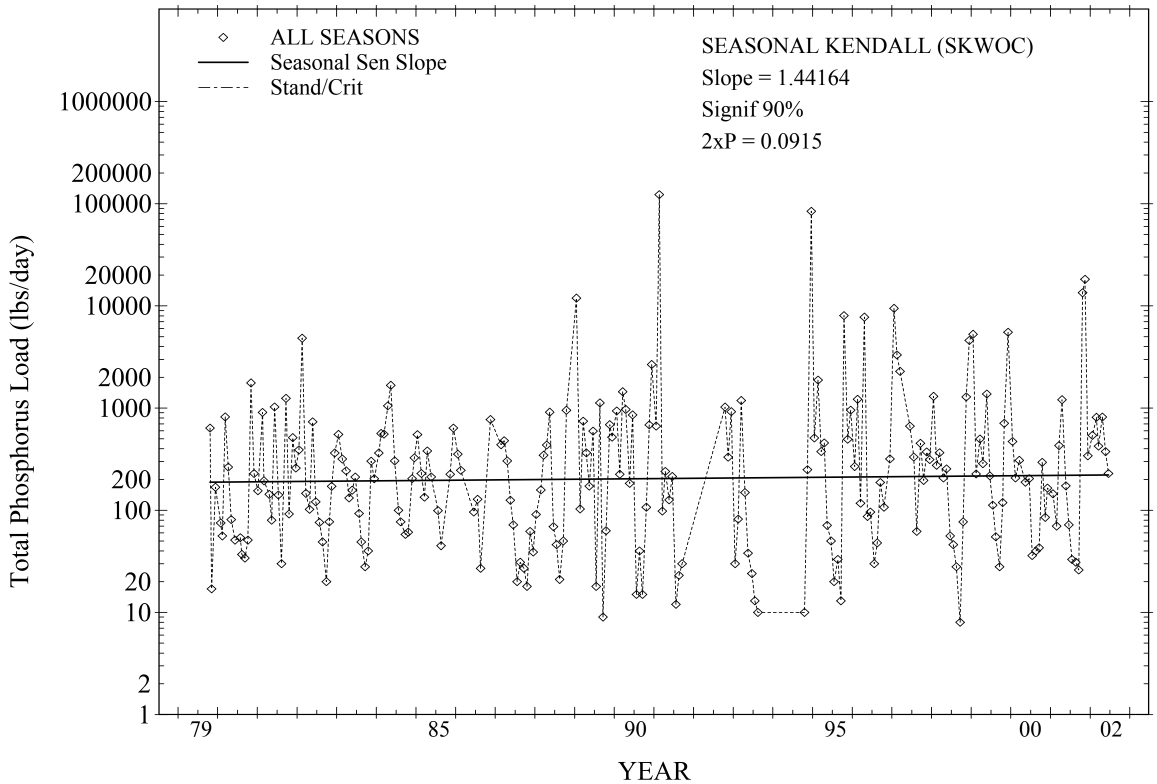


Figure 26. Total phosphorus load trend in monthly data collected by Ecology at the North Fork Stillaguamish River (Station 05B070) from 1979 to 2002.

Reducing the total phosphorus load may improve the July through September low-flow pH conditions by decreasing the biomass responsible for the elevated pH values. Bringing the median seasonal total phosphorus concentration to 0.01 mg/L will be equal to the 1987 to 1995 seasonal average. The 0.01 mg/L total phosphorus value is between the Puget Sound and North Cascades summer reference values of 0.017 and 0.0025 mg/L, respectively (EPA, 2000). This represents a seasonal total phosphorus loading capacity of 21 lbs/day.

Arsenic and Mercury

Arsenic is available from natural geologic sources in the basin, and no loading capacity calculation is necessary or possible. Arsenic concentrations are consistently above the 0.14 ug/L EPA human-health criteria based on a 1:1,000,000 carcinogenic risk. Arsenic concentrations in the Stillaguamish River are far below aquatic toxicity criteria. No evidence of anthropogenic sources of arsenic was uncovered in the data analysis. This TMDL evaluation recommends that arsenic be removed from the 303(d) list for the Stillaguamish River.

Mercury is also available from natural geologic sources in the Stillaguamish River basin. Mercury concentrations throughout the basin may periodically exceed the 0.012 ug/L chronic aquatic toxicity criterion. The mercury criterion is a four-day average concentration that is not to be exceeded more than once every three years. Samples were not collected over four-day periods to measure exact compliance with the criterion.

Mercury concentrations collected near the mouths of the North and South forks, and two sites in the mainstem Stillaguamish River, were correlated with total suspended solids (TSS) concentrations. Reducing TSS, especially TSS mobilized during storm events, would reduce mercury transport and availability. The correlation between TSS and mercury concentrations is shown in Figure 27.

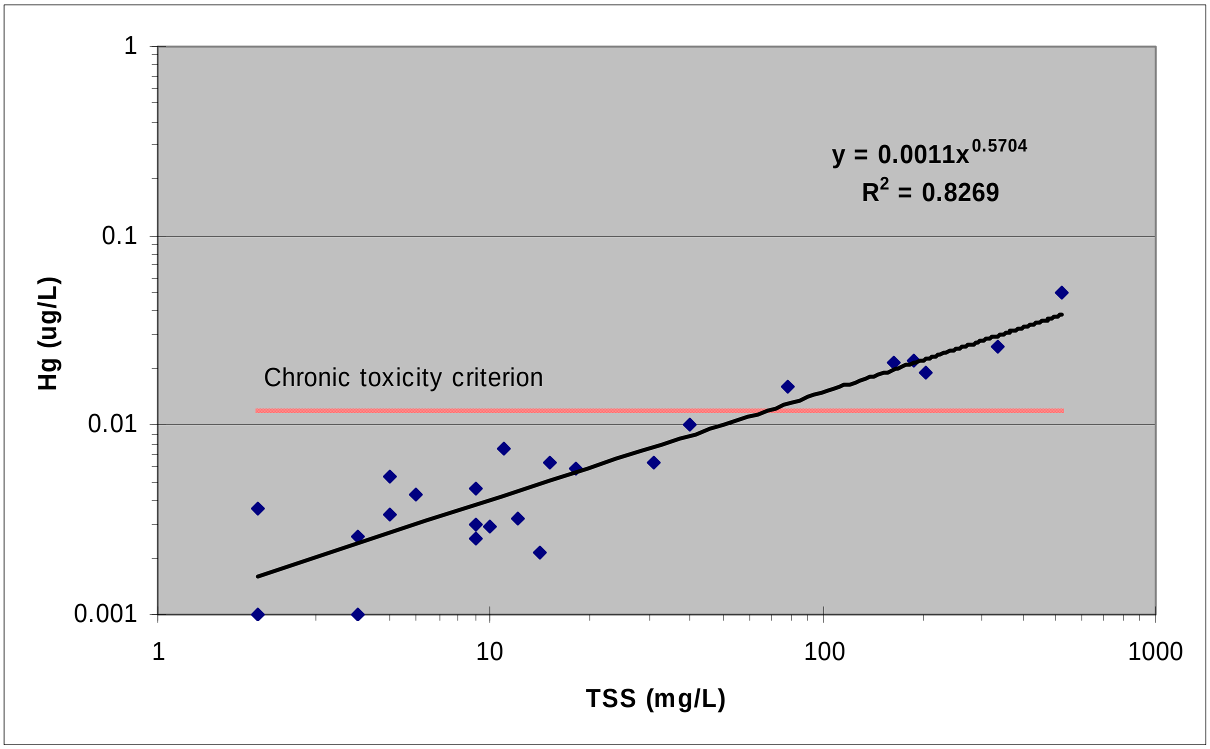


Figure 27. Relationship between total suspended solids (TSS) and mercury (Hg) in samples collected by Ecology from two sites on the Stillaguamish River, two sites on the lower North Fork Stillaguamish River, and at the mouth of the South Fork Stillaguamish River. The EPA 0.012 ug/L chronic aquatic toxicity criterion is also shown.

A target TSS concentration to limit mercury concentrations greater than the aquatic toxicity criterion could be based on the regression equation relating TSS in mg/L to mercury in ug/L:

$$\text{Mercury} = 0.0011 \times \text{TSS}^{0.5704}$$

An average four-day TSS concentration of 65 mg/L would limit the mercury concentration to 0.012 ug/L. The TSS concentrations are not well correlated with discharge at any of the sites. Sudden increases in runoff generally create increases in TSS. The TSS concentrations in the lower portion of the two forks and in the mainstem Stillaguamish River often peak much greater than 65 mg/L during storm events, but usually drop rapidly over the next couple of days.

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Wasteload and Load Allocations

It is a task of the total maximum daily load evaluation to recommend wasteload allocations and load allocations. The wasteload allocations are derived for point sources with NPDES or state waste permits, and load allocations are derived for nonpoint sources. Together the allocations must meet the load capacity for each waterbody.

Fecal Coliform

The TMDL evaluation has demonstrated that fecal coliform (FC) bacteria criteria violations are prevalent throughout the lower Stillaguamish River basin, especially during storm events. The waterbodies in Table 33 were on the 1998 Section 303(d) list for impairments due to excessive FC bacteria. All 12 waterbodies still require FC reductions to meet criteria. The table lists the total FC reduction required for each waterbody to meet the appropriate FC criteria. The FC bacteria reductions are based on the roll-back determinations in Tables 26 - 29. Most of the tributaries require more than a 70% FC reduction to meet criteria. Mainstem and major branches require less than a 70% FC reductions.

Table 33. Stillaguamish River basin and Port Susan tributaries listed in Section 303(d) in 1998. Fecal coliform reductions necessary to meet Washington State water quality criteria are shown. The status of the waterbody on the 1996 303(d) is also shown.

Old WBID	New WBID	Name	Fecal Coliform Reductions	1996 303(d)
WA-05-1016	QJ28UC	Fish Creek	81%	Yes
	HD76OJ	Harvey Creek	76%	No
	JU33JU	Jim Creek at Mouth	38%	No
WA-05-1012	GH05SX	Jorgenson Slough (Church Creek)	87%	Yes
	IJ55EP	Lake Martha Creek	92%	No
WA-PS-0020	390KRD	Port Susan	61%	Yes
WA-05-1015	OT80TY*	Portage Creek at 212th NE	83%	Yes
WA-05-1010	QE93BW	Stillaguamish River at I-5	52%	Yes
WA-05-1010	ZO73WL	Stillaguamish River at Marine Drive	36%	No
WA-05-1020	WO38NV	N.F. Stillaguamish River (at mouth)	14%	Yes
WA-05-1050	SN06ZT	S.F. Stillaguamish River (at mouth)	7%	Yes
	LU17DC	Unnamed Creek #0456	97%	No

* Includes the listings mistakenly assigned to OJ28UC, Fish Creek, and YF03BC, a branch of Portage Creek, but should have been entered as OT80TY, Portage Creek.

This TMDL evaluation identified 23 additional tributaries or tributary reaches, drains, and sloughs that do not meet the FC criteria. Waterbodies in Table 34 were not on the 1998 Section 303(d) list for FC bacteria, but require FC reductions to meet state criteria and fully support beneficial uses. Most of the waterbodies in Table 34 require FC reductions greater than 70%. A few of the waterbodies in Table 34 were on the 1998 303(d) list for dissolved oxygen, pH, or temperature. Others have been known to local groups as potential problems for several years, but have not been included in the 305(b) statewide assessment.

Table 34. Additional Stillaguamish River basin and Port Susan tributaries not listed in Section 303(d) in 1998. Fecal coliform reductions necessary to meet Washington State water quality criteria are shown.

Name	Water Quality Classification	Fecal Coliform Reductions
Glade Bekken	FW - A	92%
Pilchuck Creek	FW - A	26%
March Creek	FW - A	98%
Armstrong Creek at Mouth	FW - A	29%
Armstrong Creek below Hatchery	FW - A	66%
Kackman Creek	FW - A	68%
West Pass of Old Stillaguamish	FW/MW - A	97%
South Pass of Old Stillaguamish	FW/MW - A	75%
Douglas Slough	FW/MW - A	68%
Irvine Slough	FW/MW - A	99%
Church Creek at Park	FW - A	74%
Miller Creek at Miller Road	FW - A	91%
Twin City Foods Drain #1	FW/MW - A	94%
Twin City Foods Drain #2	FW/MW - A	99%
Twin City Foods Drain #3	FW/MW - A	98%
Twin City Foods Drain #4	FW/MW - A	88%
Twin City Foods Drain #5	FW/MW - A	96%
Warm Beach Creek above WWTP	FW - AA	81%
Agricultural Drain to Warm Beach	FW - AA	89%
Warm Beach Dike Pond	FW - AA	92%
Warm Beach Slough	MW - A	64%

Ten of the waterbodies in Table 34, and Jorgenson Slough (Church Creek) in Table 33, are tributaries to, or located in, the Old Stillaguamish Channel sub-basin. As stated earlier in this report, a more complete analysis of the Old Stillaguamish Channel will be conducted at a later date when the effects of the new tide gate and Stanwood Wastewater Treatment Plant (WWTP) can be evaluated. The FC load reductions for the 11 waterbodies listed in the tables are accurate and can be considered general load allocations. Implementation of nonpoint source controls should not be delayed in these sub-basins.

The major source of FC contamination in most of the waterbodies in Tables 32 and 33 is nonpoint runoff from mixed land uses. The TMDL evaluation did not identify the FC load associated with specific properties or land uses for these waterbodies. Therefore, most of the required reductions are load allocations to general nonpoint sources.

However, the EPA now requires wasteload allocations for all NPDES stormwater permit holders (Wayland and Hanlon, 2002). Since Snohomish County and the Washington State Department of Transportation are Phase 1 Stormwater NPDES permit holders, most of the load reductions in Tables 32 and 33 require at least one WLA for stormwater. Arlington and Granite Falls Phase 2 stormwater permit applicants are also jurisdictions that may require stormwater wasteload allocations for some waterbodies in Tables 32 and 33.

Wasteload allocation estimates for Snohomish County and the WSDOT in Table 35 are calculated on roadway areas, and Arlington wasteload allocations are estimated from all land uses within the city limits (see *Analytical Framework*).

Table 35. Fecal coliform (FC) wasteload allocations for stormwater discharge permit holders, Snohomish County and the Washington State Department of Transportation, as well as a stormwater permit applicant, the City of Arlington.

Waterbody	NPDES Permit Holder	Estimated Portion of FC Load (%)	Wasteload Allocations (cfu/day)
Fish Creek	Snohomish County	5%	5.35×10^{8}
Harvey Creek at Grandview	Snohomish County	1.2%	6.59×10^{7}
Jim Creek at Mouth	Snohomish County	1.6%	4.34×10^{9}
Portage Creek at 212th	Snohomish County	2.9%	1.92×10^{9}
	WSDOT	1.8%	1.18×10^{9}
Portage Creek at 43rd	Arlington	39%	4.44×10^{10}
Lake Martha Creek	Snohomish County	8.8%	--
Unnamed #0456	Snohomish County	6.9%	--
Glade Bekken	Snohomish County	6.5%	1.30×10^{8}
Pilchuck Creek	Snohomish County	2.5%	8.54×10^{9}
	WSDOT	16.5%	5.57×10^{10}
March Creek	Snohomish County	0.4%	7.15×10^{6}
	WSDOT	1.2%	2.42×10^{7}
	Arlington	19%	3.71×10^{8}
Armstrong Creek at Mouth	Snohomish County	2.3%	1.63×10^{9}
	WSDOT	1.2%	8.04×10^{8}
Kackman Creek at 252nd	Snohomish County	3.6%	1.71×10^{8}
Warm Beach Dike Pond	Snohomish County	4.3%	--
North Fork Stillaguamish at Mouth	Snohomish County	2.1%	3.0×10^{10}
	WSDOT	1.5%	2.1×10^{10}
South Fork Stillaguamish at Mouth	Snohomish County	2.9%	6.07×10^{10}
	Arlington	5.6%	1.16×10^{11}

The Arlington WWTP, Indian Ridge WWTP, and Warm Beach Conference Center WWTP discharge to waterbodies requiring FC load reductions: Stillaguamish River above Arlington, Jim Creek, and Warm Beach Creek, respectively (Tables 32 and 33). The FC wasteload allocations for the treatment plants are based on calculations using upstream FC counts, the mixing zone characteristics at the outfall, and the FC loading capacity of the receiving water. The current NPDES permits for these facilities have FC limits (Appendix A), but because of the TMDL, some of the limits require modification.

In most cases, the compliance point for FC is at the edge of the chronic mixing zone boundary (Bailey, 2002). Indian Ridge WWTP can meet the downstream FC target on Jim Creek under current permit limits of 100 cfu/100 mL (Table 36). However, since the FC water quality above the Arlington WWTP and Warm Beach Conference Center WWTP do not meet FC criteria in their respective receiving waters, the effluent from these facilities cannot increase the FC concentration or load. Therefore, adjustments to the FC limits in their NPDES permits are necessary (Table 36). These concentration limits must be met at the end of the outfall.

Table 36. Fecal coliform limits recommended for three wastewater treatment plants with NPDES permits and wasteload allocations (WLA) to comply with the Stillaguamish River basin TMDL.

Facility Name	Current FC Permit cfu/100 mL	Proposed Permit cfu/100 mL	WLA cfu/day
Indian Ridge Corrections Center WWTP	100	100	8.0×10^8
Arlington WWTP	200 / 400	39 / 128	3.0×10^9
Warm Beach Conference Center WWTP*	200 / 400	47 / 100	1.3×10^8
Warm Beach Conference Center WWTP**	-	11 / 26	3.1×10^7

* Assuming discharge to Warm Beach Creek at current maximum monthly flow of 0.075 MGD, and the discharge is allowed under special considerations.
** Assuming discharge to Hatt Slough near the South Branch with maximum monthly flow of 0.075 MGD.

Warm Beach WWTP effluent quality has improved according to 2002 monitoring reports (Ecology, 2003a) and additional data from the facility manager (Wynn, 2002) for 2002. The Warm Beach WWTP facility has added a wetlands treatment system that should further reduce the effluent FC and the variability from this source. The outfall location for the improved facility has not yet been determined. If the outfall remains in Warm Beach Creek, the effluent would be required to meet the TMDL target concentrations at the end of the outfall because the channel is dry during some summer periods. Municipal effluent discharges under 0.5 million gallons per day (MGD) are allowed to intermittent low-land streams if the effluent quality can meet Class A water quality criteria (Bailey, 2002). It is uncertain how this applies to TMDL modified intermittent streams. If the Warm Beach WWTP outfall is moved to Hatt Slough near South Branch, Table 36 shows the FC permit limits would be more restrictive than in Warm Beach Creek. This is because of the geometric mean target for the South Branch reach is 11 cfu/100 mL (Table 30).

Dissolved Oxygen

Loading capacity analyses were conducted for nine reaches representing five tributaries in the Stillaguamish River basin (Table 31). Minimum DO concentrations were set to improve water quality in the tributaries, but also to acknowledge that in some cases natural DO conditions may be below the 8 mg/L Class A criterion. Wasteload allocations for point sources with NPDES permits, and load allocations for nonpoint sources, were calculated for the five tributaries where appropriate (Table 37).

Snohomish County and the Washington State Department of Transportation (WSDOT) are Phase I Stormwater NPDES and State General Permit holders in the five tributaries. The City of Arlington is a Phase 2 Stormwater Permit applicant. The Simple Method Model (Stormwater Center, 2004) was used to estimate the BOD_5 wasteload allocations for the permit holders, as it was for the fecal coliform stormwater permit wasteload allocations.

Load allocations were estimated for background and nonpoint contributions of BOD_5. Background loads were estimated by minimizing BOD concentrations (e.g., 1 - 3 mg/L) delivered from various land uses in the Simple Method Model. The nonpoint source load allocations then became the difference between the load capacity and the sum of the background and wasteload allocations (Table 37).

Table 37. Estimates of the BOD_5 loading capacities, load allocations (LA), and wasteload allocations (WLA) for six sites in the Stillaguamish River basin to meet the TMDL dissolved oxygen target.

Waterbody	Load Capacity BOD_5 (lbs /day)	Background LA BOD_5 (lbs /day)	Nonpoint LA BOD_5 (lbs /day)	NPDES Permit Holder	WLA BOD_5 (lbs /day)	Target DO (mg/L)
Portage Creek at 212th	300	210	70	Snohomish County	12	6.5
				WSDOT	8	
Portage Creek at 43rd	250	100	8	Arlington	142	7
Pilchuck Creek	890	350	330	Snohomish County	27	8
				WSDOT	179	
March Creek	30	10	20	Snohomish County	0.02	6.5
				WSDOT	0.06	
				Arlington	0.7	
Kackman Creek at 252nd	10	5	4	Snohomish County	0.6	7
Warm Beach Creek & Dike Pond	30	20	8	Snohomish County	1.4	8
				Warm Beach WWTP	0	

The Warm Beach facility has recently completed an upgrade. If the plant remains in Warm Beach Creek, its effluent characteristics must meet water quality criteria and show no measurable effect downstream in the Dike Pond. During some periods of the summer, Warm Beach Creek has no flow upstream of the Warm Beach Conference Center WWTP, so the effluent is not diluted. In such cases, Ecology policy states that the water quality standard must be met at the end of the outfall (Bailey, 2002). When Warm Beach Creek is flowing, it does not meet the Class A criterion. Since no further degradation is permitted downstream, the BOD wasteload allocation must be zero, unless the facility can show that its effluent BOD and DO concentrations do not cause further degradation

Specific load allocations and wasteload allocations for sources along the two reaches of the mainstem Stillaguamish River identified with DO problems cannot be calculated. The impact of the Old Stillaguamish River Channel on the Stillaguamish varies with tide phase, flow volumes and dispersion, and the water quality characteristics of the two bodies of water. Sources of nitrogen, phosphorus, and carbon affecting DO in the reach of the Stillaguamish River from Arlington to the Interstate 5 (I-5) bridge were modeled using QUAL2Kw (Table 32). The results were not accurate enough for the complexity of the problem.

The load allocation of water with low DO concentrations from the Old Stillaguamish River Channel to the mainstem Stillaguamish River is zero. If the newly-installed tide gate at the bifurcation point does not eliminate the flow of deoxygenated water from the Old Stillaguamish Channel, then a new load allocation will be determined when the dissolved oxygen TMDL is completed for the Old Channel.

Loading capacity analyses of the Stillaguamish River between Arlington and the I-5 bridge concluded that loading under natural conditions could not be calculated at this time using the QUAL2Kw model. The analyses also showed that although they could not be accurately quantified, low-flow period loads of nutrients and BOD from the upper basin, Arlington WWTP, unidentified nonpoint sources, Armstrong Creek, and March Creek have an effect on the DO concentrations in the reach (Table 32). A target minimum DO concentration of 7 mg/L was recommended to protect beneficial uses in the reach and to stimulate management plans and activities limiting anthropogenic inputs of carbon, nitrogen, and phosphorus.

Nutrient (carbon, nitrogen, and phosphorus) loads affecting the reach will require closer management to minimize DO losses in the river and to meet the 7 mg/L target during the critical season. For example, Arlington WWTP effluent appears to have an effect on downstream DO concentrations and stimulates periphyton biomass production. The current NPDES permit for the Arlington WWTP five-day BOD load has technology-based limits, and nitrogen and phosphorus loads are not addressed. If seasonal permit limits were ‘performance-based’ to better reflect the effluent BOD_5 quality since the 1998 upgrade (less than 10 mg/L) and if nitrogen and phosphorus monitoring and treatment planning were written into the permit, then better management alternatives for the effluent treatment and disposal could be developed when natural conditions in the river are better defined.

Phosphorus loading in both the lower North Fork and the South Fork Stillaguamish has increased according to trend analyses performed on the Ecology monthly monitoring data. The QUAL2Kw model simulations also suggested that nonpoint and tributary sources in the reach can be significant during low-flow periods. The DO target may not be met until nutrient loads from these sources are reduced or excluded. Phosphorus reductions are also recommended to decrease pH maxima in the North Fork Stillaguamish River. The Clean Water District’s nonpoint management plans and implementation activities should direct resources at the phosphorus loading problem in this area.

pH

The following sites should be reassessed to determine natural seasonal or event-based pH conditions once the anthropogenic sources of oxygen-demand or low pH stormwater are reduced or eliminated as fecal coliform and dissolved oxygen loading capacities are met:

- Stillaguamish River above Arlington at the confluence of the North and South forks
- Pilchuck Creek
- Kackman Creek
- March Creek

Meeting conditions for natural conditions may be indirectly attained when targets for fecal coliform or dissolved oxygen are met. Stormwater wasteload allocations and nonpoint load allocations have already been set in the three tributaries to meet loading capacities for dissolved oxygen and fecal coliform (Tables 35 and 37). The fecal coliform loading reductions for the mouths of the South Fork and North Fork Stillaguamish River, and their accompanying stormwater wasteload allocations, should be sufficient to bring pH values into compliance at the confluence of the forks above Arlington during storm events (Tables 33 and 35). Since the potential sources of low pH from decomposition of organic materials are similar to those that may contain fecal bacteria and oxygen-demand, the reductions in place should help attain the best potential pH values. Wetland drainage and groundwater inputs should be included as part of the determination of natural conditions in the tributaries, as should seasonal instream organic material cycling processes.

The North Fork Stillaguamish River at Whitman bridge to Cicero bridge (NFRKM 28.3 to NFRKM 15.2) is affected by elevated pH values. Reducing the total phosphorus load may improve the July through September low-flow pH conditions by decreasing the periphyton biomass responsible for the elevated pH values. Bringing the median seasonal total phosphorus concentration to 0.01 mg/L and reducing the median seasonal load from 41 lbs/day to 20 lbs/day will be equal to the 1987 to 1995 seasonal average. The load is allocated to background (6 lbs/day) and nonpoint sources (14 lbs/day).

Arsenic and Mercury

Arsenic and mercury in the basin are from natural sources without enrichment from anthropogenic sources. The metals are highly associated with suspended solids. Both the South Fork and North Fork have documented natural erosion areas with total suspended solids (TSS) loads that have created sedimentation problems in downstream channel reaches (WCC, 1999). Continued work reducing the TSS loading from these areas and basin-wide would help decrease arsenic and mercury loading. No amount of reduction would allow arsenic concentration to meet EPA human-health criteria. Therefore, all loads for arsenic and mercury are allocated to background.

To better manage incidental mercury from sediment, a target TSS concentration to limit mercury concentrations greater than the aquatic toxicity criterion could be based on the regression equation relating TSS in mg/L to mercury in ug/L:

$$\text{Mercury} = 0.0011 \times \text{TSS}^{0.5704}$$

An average four-day TSS concentration of 65 mg/L would limit the mercury concentration to 0.012 ug/L. The TSS concentrations are not well correlated with discharge at any of the sites. Sudden increases in runoff generally create increases in TSS. A TSS loading capacity was not developed.

Based on very few samples collected from the North Fork Stillaguamish near Darrington (n=4), the TSS surrogate concentration of 65 mg/L would not be appropriate there. Based on a linear correlation ($r^2 = 0.93$) for the four data points, a TSS concentration of 13 mg/L for the North Fork near Darrington would limit mercury to 0.012 ug/L. A four-day average TSS concentration of less than 13 mg/L at these sites should result in mercury concentrations within the chronic toxicity criterion.

Margin of Safety

This TMDL evaluation requires a list of implicit and explicit expressions margins of safety (MOS) used to determine the loading capacity, load allocations, and wasteload allocations. The MOS magnitude varies with the confidence in the data available and the analytical tools used. The MOS is the means by which the analysis accounts for the uncertainty about the relationship between pollutant loads and the receiving water quality (EPA, 2001). To protect beneficial uses to the fullest extent, a conservative approach must be taken so that an error in load allocations and wasteload allocations does not cause impairment of the waterbody. The following are conservative assumptions that implicitly or explicitly contribute to an MOS:

- The statistical rollback method was applied to fecal coliform data from the most critical season, and the resultant target geometric means are more stringent than the Washington State criterion of 100 cfu/100 mL. This is an explicit assumption for the MOS.
- Since the variability in fecal coliform counts during the critical season when storm-event data are included is usually quite high, the targets are more restrictive. This is especially true at sites with fewer than 20 data. These factors are implicit contributions to the MOS.
- The fecal coliform loading capacities and target geometric means for the North Fork Stillaguamish River at Twin Rivers and the Stillaguamish River at Interstate 5 were conservatively calculated to include the loading from unidentified sources located along upstream reaches. These are implicit contributions to the MOS.
- The fecal coliform loading capacities and target geometric means for three small tributaries that discharge directly to Port Susan are based on more restrictive Class AA freshwater criteria rather than Class A criteria. This is an explicit contribution to the MOS.
- The cumulative freshwater fecal coliform loads to Port Susan during the critical season will be reduced by 77% under the TMDL targets, even if instream die-off is not considered. Port Susan sites require fecal coliform reductions of 2% - 60%. The difference is an explicit MOS.
- The treatment plant wasteload allocations for fecal coliform do not consider dilution in a mixing zone during a 7-day, 10-yr (7Q10), low-flow event at full permit capacity. This is an explicit MOS.
- The targets for minimum dissolved oxygen concentrations in areas considered to have natural sources of low dissolved oxygen are set to be protective of supporting most phases of the salmon life cycle under the worst habitat conditions. Therefore, sites located in areas with better habitat and water movement should have all phases of the life cycle protected. This is an implicit MOS.
- The stormwater model assumes that 90% of the rainfall creates runoff, and the concentrations of fecal coliform and BOD are in the upper range of mean values in technical literature. In western Washington, the low intensity of many rain events does not deliver runoff.

Therefore, higher fecal coliform and BOD loads are predicted by the model than are actually delivered. The wasteload allocations and load allocations based on these model results are probably more restrictive. This is an implicit assumption for the MOS.

- Some of the sites recommended for pH TMDL-related activities were identified by applying a 0.2 standard unit (s.u.) safety factor to the 10^{th} and 90^{th} percentile statistics. The application of the safety factor is an explicit addition to the margin of safety.

Recommendations for Follow-up Monitoring

Monitoring is an important component for assessing the progress or success of implementation measures based on the total maximum daily load (TMDL) recommendations. Post-implementation monitoring is required in the TMDL process to ensure that water quality standards are being attained and that implementation measures are effective. If water quality standards are not met after the TMDL has been established, then adjustments to the load and wasteload allocations may be required, or implementation activities may require modification.

Successful TMDL evaluations require several types of monitoring data. Water quality, aquatic resources, land use, and implementation activity data are needed to evaluate the progress of the TMDL. The details of the location, type, and timing of data collection will be discussed and approved in the detailed implementation plan in relation to a TMDL compliance schedule.

Following are general recommendations for monitoring, based on experiences gained developing this report:

- Tributary, mainstem, and Port Susan compliance with fecal coliform standards and reduction goals should be measured at the sites where data were used to generate the reduction goals. Storm-event data should be included but not over-represented in the record.

- Intensive monitoring to identify sources and problem reaches are very helpful, but data used in those investigations should not be blended with routine monitoring data to determine the overall progress of TMDL-related activities.

- Port Susan fecal coliform data should continue to be collected using the FDA commercial shellfish harvesting protocols.

- Dissolved oxygen data should be collected over day and night cycles during critical periods at sites identified as not meeting standards. If multiple samples are not possible, then samples should be collected early in the morning close to sunrise to catch minimum concentrations.

- Reaches upstream of dissolved oxygen, pH, and fecal coliform monitoring sites should be characterized for groundwater, wetland, stormwater, and nonpoint source inputs. Reaches upstream and downstream of monitoring sites should have salmon and general aquatic habitat assessments.

- Salmon productivity and habitat-limiting factors in Portage, March, Pilchuck, and Kackman creeks, as well as Glade Bekken sub-basin, need documentation.

- Mainstem Stillaguamish River primary productivity response and hyporheic exchange rate changes related to seasonal low flows require more spatial and temporal definition. The relationships of these physical and biological changes to dissolved oxygen, pH, and nutrients need better understanding.

- Nonpoint sources active during dry or runoff conditions along the mainstem Stillaguamish River and its two major forks need to be identified and removed.

- Stormwater conveyance infrastructures and stormwater quantity and quality need better characterization to establish more accurate stormwater load and wasteload allocations.

- The changes in land use and the measures used to reduce the impact of land uses on water quality should be inventoried, evaluated, and tracked.

- Wastewater treatment plants should include phosphorus and nitrogen monitoring of effluent and receiving waters, especially during critical conditions.

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Appendices

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Appendix A

Point Source Descriptions and NPDES Permit Limits

Arlington Wastewater Treatment Plant

The Arlington WWTP treatment plant discharges effluent to the Stillaguamish River just below the confluence of the North and South forks at RKM 28.6 (RM 17.8). The treatment processes include a mechanical screen and a vortex type grit chamber, biological treatment in sequencing batch reactors (SBRs), a flow equalization basin, and an ultraviolet (UV) disinfection system.

Arlington WWTP effluent quality must meet secondary municipal treatment standards as specified in its NPDES permit (Table A1). The permit also requires monitoring of pH, fecal coliform bacteria, biochemical oxygen demand, total suspended solids, and discharge volume. Effluent monitoring of inorganic nitrogen, phosphorus, and metals is not required under the permit. However, Arlington does some independent monitoring to check unit processes in the facility (Randolph, personal communication, 2000).

Table A1. Arlington NPDES permit limits.

Parameter	Limit
pH	Shall be within the range of 6 to 9 standard units.
Fecal Coliform Bacteria	Monthly Geometric Mean = 200 organisms/100 mL Weekly Geometric Mean = 400 organisms/100 mL
BOD_5 (concentration)	Average Monthly Limit is the most stringent of the following: - 30 mg/L - may not exceed fifteen percent (15%) of the average influent concentration Average Weekly Limit = 45 mg/L
Total Suspended Solids (concentration)	Average Monthly Limit is the most stringent of the following: - 30 mg/L - may not exceed fifteen percent (15%) of the average influent concentration Average Weekly Limit = 45 mg/L

Parameter	Design Quantity
Monthly average flow (max. month)	2.0 MGD
BOD_5 influent loading (max. month)	4,600 lbs/day
TSS influent loading (max. month)	3,100 lbs/day

Indian Ridge Corrections Center Wastewater Facility

Indian Ridge Corrections Center is a small facility formerly operated by the Washington State Department of Social and Health Services, but now operated by Snohomish County. The facility discharges effluent to Jim Creek approximately 4.8 kilometers (3 miles) above the confluence with the South Fork Stillaguamish River. The treatment process at the facility has operated since 1997, and it includes preliminary treatment through a mechanical fine screen, biological treatment in SBRs followed by ultraviolet (UV) disinfection system. The old facility was a package activated sludge WWTP.

Table A2. Indian Ridge Corrections Center NPDES permit limits

Parameter	Effluent Limitations[a]: Outfall # 1	
	Average Monthly	Average Weekly
Biochemical Oxygen Demand[b] (5 day)	30 mg/L, 6 lbs/day	45 mg/L, 8 lbs/day
Total Suspended Solids[b]	30 mg/L, 6 lbs/day	45 mg/L, 8 lbs/day
Fecal Coliform Bacteria	100/100 mL	--------
pH	Daily minimum is equal to or greater than 6, and the daily maximum is less than or equal to 9.	

[a]The average monthly and weekly effluent limitations are based on the arithmetic mean of the samples taken with the exception of fecal coliform, which is based on the geometric mean.

[b]The average monthly effluent concentration for BOD5 and Total Suspended Solids shall not exceed 30 mg/L or 15 percent of the respective monthly average influent concentrations, whichever is more stringent.

Parameter	Design Quantity
Monthly average flow (max. month)	21,000 gpd
BOD_5 influent loading (max. month)	61 lbs/day

Warm Beach Conference Center Wastewater Treatment Plant

The Warm Beach Christian Camp and Conference Center are located on a bluff north of the unincorporated community of Warm Beach, overlooking Port Susan. The Camp was developed in the late 1950s. The Center accommodates groups throughout the year, but peak attendance is in summer. The Center is planning to enlarge its facilities, so it is increasing its wastewater treatment capacity.

The existing WWTP at the camp consists of biological treatment in two aerated lagoon cells followed by disinfection with calcium hypochlorite solution. The secondarily treated wastewater is discharged with subsurface drainage intercepted from around the lagoons to an unnamed stream tributary. NPDES permit limits are based on conventional technology for lagoon effluent (Table A3).

The tributary with treated effluent flows to a pond that also receives drainage water from low-lying lands to the north of the facility. Water from the pond is intermittently discharged to a slough leading to Port Susan via a pump and culvert through the dike. The tributary and pond are not on the Section 303(d) list. Part of Port Susan is on the list because of data collected from 1989 to 1991 (Paulsen et al., 1991) near the slough at Warm Beach The slough is located approximately 1.2 km (0.75 miles) south of Hatt Slough.

The Center is just completing construction of a managed wetland treatment system to further treat effluent from the lagoons. The system has specific hydraulic and biological treatment areas to reduce various nutrients and bacteria. The NPDES permit limits for the new plant will be more stringent than for the current facility. The location of the outfall from the wetland has not been determined as of February 2003. Potential locations include the slough currently used and a channel from Hatt Slough.

Table A3. Warm Beach Conference Center NPDES permit limits, interim and final.

Parameter	Interim Effluent Limitations[a]: Outfall # 1	
	Average Monthly	Average Weekly
Biochemical Oxygen Demand[b] (5 day) (BOD_5)	30 mg/L, 19 lbs/day	45 mg/L, 29 lbs/day
Total Suspended Solids (TSS)	75 mg/L, 47 lbs/day	112 mg/L, 70 lbs/day
Fecal Coliform Bacteria	200/100 mL	400/100 mL
pH[c]	Daily minimum is equal to or greater than 6, and the daily maximum is less than or equal to 9.	
Parameter	Average Monthly	Maximum Daily
Total Residual Chlorine[d,f]	---------	2.0 mg/L

Parameter	Final Effluent Limitations[a]: Outfall # 1	
	Average Monthly	Average Weekly
Biochemical Oxygen Demand[b] (5 day) (BOD_5)	30 mg/L, 19 lbs/day	45 mg/L, 29 lbs/day
Total Suspended Solids (TSS)	75 mg/L, 47 lbs/day	112 mg/L, 70 lbs/day
pH[c]	Daily minimum is equal to or greater than 6, and the daily maximum is less than or equal to 9.	
Fecal Coliform Bacteria	100/100 mL	See footnote [e] below
Total Residual Chlorine[f]	8 ug/L	19 ug/L
Total Ammonia (NH3-N)	1.8 mg/L	3.5 mg/L
Parameter	Average Monthly	Minimum Daily
Dissolved Oxygen	---------	8.0 mg/L

[a]Interim effluent limitations were effective until April 30, 2003. Final effluent limitations became effective on May 1, 2003. See condition S8. “Compliance Schedule”.

The average monthly and weekly effluent limitations are based on the arithmetic mean of the samples taken, with the exception of fecal coliform which is based on the geometric mean.

[b]The average monthly effluent concentration for BOD_5 shall not exceed 30 mg/L or 15 percent of the monthly average influent concentration, whichever is more stringent.

[c]Indicates the range of permitted values. When pH is continuously monitored, excursions between 5.0 and 6.0, or 9.0 and 10.0, shall not be considered violations provided no single excursion exceeds 60 minutes in length, and total excursions do not exceed 7 hours and 30 minutes per month. Any excursions below 5.0 and above 10.0 are violations if such values are attributable to inorganic chemical addition to the treatment process or to industrial contribution(s). The instantaneous maximum and minimum pH shall be reported monthly.

[d]Total residual chlorine shall be maintained which is sufficient to attain the interim fecal coliform limits specified above. Chlorine concentrations in excess of that necessary to reliably achieve the limits shall be avoided.

[e]No more than 10 percent of all samples obtained for calculating the monthly geometric mean value shall exceed 200 colonies/100 mL.

[f]The maximum daily value for total residual chlorine is the maximum of the daily values during a calendar month. The daily value is defined as the arithmetic mean of the sample measurements taken during a calendar day.

The average monthly value for total residual chlorine is the arithmetic mean of the daily values during a calendar month.

Twin City Foods Wastewater Treatment Plant

Twin City Foods, located in Stanwood, pipes its process water, repack water, and vegetable unloading area drainage water to an 8.5 million gallon capacity lagoon located on reclaimed agricultural land between the Old Stillaguamish Channel and Hatt Slough. Solids in the process water are screened-out at the plant for animal feed. Under the most recent permit, some winter repack water is discharged to the Stanwood WWTP, but that will discontinue when Stanwood upgrades its system. Sanitary wastewater also is routed to Stanwood.

The Twin City Foods lagoon water is distributed by pumps and pipes to seven spray guns for land application to about 600 acres. Dairy manure is also applied to about 300 acres of the same application areas from a separate lagoon. The lagoon effluent application rate is agronomically determined for nitrogen uptake to protect groundwater and surface water quality.

The area is surrounded by dikes. Many of the fields are underlain with drainage tile at a depth of three feet to 18 inches that drain to the deep ditches. The deep ditch network empties to the Old Stillaguamish Channel and Port Susan at several tide gates. Surface monitoring sites are located at a few of these tide gates.

Table A4. Twin City Foods State Waste Discharge permit limits

Parameter	Limit
Flow	Lagoon: 2.49 MGD maximum Stanwood WWTP: 0.075 MGD maximum (300 gpm instantaneous peak) and 0.060 MGD weekly average Fields: 19 inches/acre/year
pH	Lagoon: between 6.5 and 8.5 standard units. Stanwood WWTP: between 5 and 11 standard units
Nitrogen	Fields: 100 lbs/acre/year
BOD_5	Stanwood WWTP: 125 lbs/day average, 150 lbs/day maximum

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Appendix B

Equations for Statistical Analyses

Statistical Theory of Rollback

The statistical rollback method proposed by Ott (1995) describes a way to use a numeric distribution of a water quality parameter to estimate the distribution after abatement processes are applied to sources. The method relies on basic dispersion and dilution assumptions and their effect on the distribution of a chemical or a bacterial population at a monitoring site downstream from a source. It then provides a statistical estimate of the new population after a chosen reduction factor is applied to the existing pollutant source. In the case of the TMDL, compliance with the most restrictive of the dual fecal coliform criteria will determine the reduction factor needed.

As with many water quality parameters, fecal coliform (FC) counts collected over time at an individual site usually follows a lognormal distribution. That is, over the course of a year's sampling period, most of the counts are low, but a few are much higher. When monthly FC data are plotted on a logarithmic-probability graph (the open diamonds in Figure B-1), they appear to form nearly a straight line.

The 50th percentile, an estimate of the geometric mean, and the 90th percentile, a representation of the level over which 10% of the samples lie, can be located along a line plotted from an equation estimating the original monthly FC data distribution. In the graphical example, these numbers are 75 cfu/100 mL and 383 cfu/100 mL, respectively. Using the statistical rollback method, the 90th percentile value is then reduced to 200 cfu/100 mL (Class A 90th percentile criterion), since 75 cfu/100 mL meets the Class A geometric mean criterion. The new distribution is plotted parallel to the original. The estimate of the geometric mean for this new distribution, located at the 50th percentile, is 39 cfu/100 mL. The result is a geometric mean target of a sample distribution that would likely have less than 10% of its samples over 200 cfu/100 mL. A 48% FC reduction is required from combined sources to meet this target distribution from the simple calculation: (383 - 200) / 383 = 0.477 * 100 = 48%.

The following is a brief summary of the major theorems and corollaries for the Statistical Theory of Rollback (STR) from *Environmental Statistics and Data Analysis* by Ott (1995).

1. If Q = the concentration of a contaminant at a source, and D = the dilution-diffusion factor, and X = the concentration of the contaminant at the monitoring site, then X = Q*D.
2. Successive random dilution and diffusion of a contaminant Q in the environment often result in a lognormal distribution of the contaminant X at a distant monitoring site.
3. The coefficient of variation (CV) of Q is the same before and after applying a "rollback"; i.e., the CV in the post-control state will be the same as the CV in the pre-control state. The rollback factor = r, a reduction factor expressed as a decimal (a 70% reduction would be a

rollback factor of 0.3). The random variable Q represents a pre-control source output state and rQ represents the post-control state.

4. If D remains consistent in the pre-control and post-control states (long-term hydrological and climatic conditions remain unchanged), then CV(Q)*CV(D)=CV(X), and CV(X) will be the same before and after the rollback is applied.
5. If X is multiplied by the rollback factor r, then the variance in the post-control state will be multiplied by r^2, and the post-control standard deviation will be multiplied by r.
6. If X is multiplied by the rollback factor r, the quantiles of the concentration distribution will be scaled geometrically.
7. If any random variable is multiplied by a factor r, then its expected value and standard deviation also will be multiplied by r, and its CV will be unchanged. (Ott uses "expected value" for the mean.)

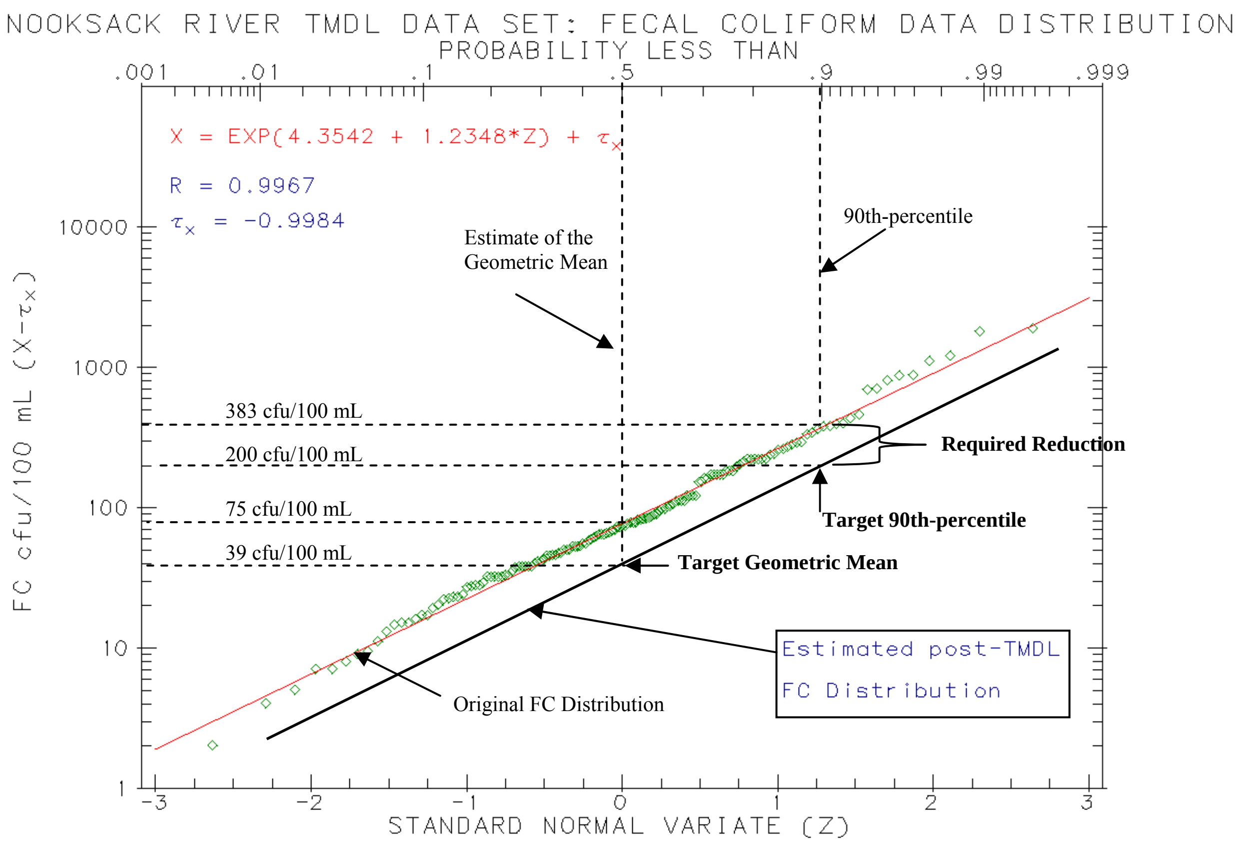

Figure B-1. Graphical demonstration of the statistical rollback method (Ott, 1995) used to calculate the fecal coliform TMDL target on the lower Nooksack River.

Statistical Formula for Deriving Percentile Values

The 90th percentile value for a population can be derived in a couple of ways. The set of FC counts collected at a site were subjected to a statistically-based formula used by the federal Food and Drug Administration to evaluate growing areas for shellfish sanitation. The National Shellfish Sanitation Program Model Ordinance (USFDA, 2000) states:

The estimated 90th percentile shall be calculated by:

(a) Calculating the arithmetic mean and standard deviation of the sample result logarithms (base 10);

(b) Multiplying the standard deviation in (a) by 1.28;

(c) Adding the product from (b) to the arithmetic mean;

(d) Taking the antilog (base 10) of the results in (c) to get the estimated 90th percentile; and

(e) The most probable number (MPN) values that signify the upper or lower range of sensitivity of the MPN tests in the 90th percentile calculation shall be increased or decreased by one significant number.

The 90th percentile derived using this formula assumes a lognormal distribution of the FC data. The variability in the data is expressed by the standard deviation, and with some data sets it is possible to calculate a 90th percentile greater than any of the measured data.

The 10th and 90th percentile values for pH and dissolved oxygen were calculated using the EXCEL® spreadsheet based on the rank order of the data set. The 10th percentile of a data set containing n data is estimated as at the k^{th} ordered datum:

$$k = ((n - 1)*0.1) + 1$$

Likewise, the 90th percentile is calculated:

$$k = ((n - 1)*0.9) + 1$$

For example, given a simple data set of 10 datum in the following rank order:

6.94, 7.05, 7.07, 7.09, 7.3, 7.32, 7.42, 7.45, 7.52, 7.63

the 10th percentile is located at ((10 – 1)*0.1) + 1 = 1.9. Between rank 1 (6.94) and rank 2 (7.05), the 10th percentile is estimated as 7.04. The 90th percentile is located at ((10 – 1)*0.9) + 1 = 9.1. Between rank 9 (7.52) and rank 10 (7.63), the 90th percentile is estimated as 7.53.

Beales Ratio Equation

Beales ratio estimator from *Principles of Surface Water Quality Modeling and Control* by Thomann and Mueller (1987) provides a mass loading rate estimate of a pollutant. The formula for the unbiased stratified ratio estimator is used when continuous flow data are available for sites with less frequent pollutant sample data. The average load is then:

$$\overline{W}_p = \overline{Q}_p \cdot \frac{\overline{W}_c}{\overline{Q}_c} \cdot \left[\frac{1 + \left(1/n \right) \cdot \left(S_{QW} / \left(\overline{Q}_c \overline{W}_c \right) \right)}{1 + \left(1/n \right) \cdot \left(S_Q^2 / \overline{Q}_c^2 \right)} \right]$$

where,
$\overline{W}_p$ is the estimated average load for the period,
p is the period,
$\overline{Q}_p$ is the mean flow for the period,
$\overline{W}_c$ is the mean daily loading for the days on which pollutant samples were collected,
$\overline{Q}_c$ is the mean daily flow for days when samples were collected,
n is the number of days when pollutant samples were collected.

The Simple Method to Calculate Urban Stormwater Loads

L = Annual load in lbs
R = Annual runoff in inches
C = Pollutant concentration in mg/L
A = Area in acres
0.226 = unit conversion factor

L = 0.226 * R * C * A

L = Annual load in billions of colonies
C = Bacteria concentration in #/100 mL
1.03 E-3 = unit conversion factor

L = 1.03 E-3 * R * C * A

R = P * Pj * Rv

P = Annual rainfall in inches
Pj = Fraction of annual rainfall events that produce runoff (assumed 90%, although not necessarily true for western Washington storm intensities)

Rv = Runoff coefficient

Rv = 0.05 + 0.9Ia

Ia = Percent impervious cover

Table B1. Mean concentration estimates and percent imperviousness for various land uses.

Land use type	Fecal coliform	Total phosphorus	BOD_5	Impervious cover
	(cfu/100mL)	(mg/L)	(mg/L)	(%)
Roadway	890	0.26	10	80
Residential	2000	0.26	13	40
Commercial/Urban	980	0.21	15	87
Forest	100	0.10	1	20
Agriculture	3000	0.35	15	30

Table B2. Land use assumptions for individual sub-basins as percentages.

Sub-basin	Roadway	Residential	Commercial	Forest	Agriculture
Glade Bekken	2%	11%	0.4%	72%	16%
Pilchuck Creek	4%	2%	0.4%	80%	2%
Portage Creek at 43rd	13%	35%	10%	24%	13%
Fish Creek	2%	15%	3%	70%	10%
Portage Creek at 212th	8%	26%	6%	39%	23%
Armstrong Creek	1%	6%	1%	77%	13%
Harvey Creek at Grandview	0.3%	0.1%	0%	99.6%	0%
Kackman Creek at 252nd	1%	8%	0%	69%	13%
March Creek	3%	15%	5%	0%	78%
Lower S.F. Stillaguamish	2%	19%	2%	44%	32%
Lower N.F. Stillaguamish	0.7%	1.5%	0.5%	85%	12%
Lake Martha Creek	2.2%	18.5%	0.1%	73%	0%
Unnamed Creek #0456	1.6%	17%	0%	82%	0%
Warm Beach Dike Pond	1.4%	6.2%	0.4%	76%	16%

Areas

Glade Bekken (2000 acres)
Pilchuck (48,768 acres)
Portage at 43rd (5550 acres)
Fish (4813 acres)
Portage at 212th (13,696)
Armstrong (7145 acres)
Harvey (600 acres)
March (800 acres)
Lower South Fork (15,617 acres)
Lower North Fork (30,567 acres)
Martha (1350 acres)
Unnamed (900 acres)
Warm Beach (2590 acres)

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Appendix C

QUAL2Kw Input Parameters and Coefficients

Sample:

QUAL2Kw
Stream Water Quality Model
Mainstem Stillaguamish (10/3/2001)
Water Column Rates

Parameter	Value	Units
Inorganic suspended solids		
Settling velocity	1	m/d
Stoichiometry		
Carbon	70	mgC
Nitrogen	10	mgN
Phosphorus	1	mgP
Dry weight	100	mgD
Chlorophyll	3	mgA
Oxygen		
Reaeration model	Internal excluding wind	
Temp Corr (Reaeration)	1.024	
O2 for Carbon oxidation	2.67	gO2/gC
O2 for NH4 Nitrification	4.57	gO2/gN
Oxygen inhib C oxidation model	Michael-Ment	
Oxygen inhib C parameter	0.5	mgO2/L
Oxygen inhib nitrification model	Michael-Ment	
Oxygen inhib nitrification parameter	0.5	mgO2/L
Oxygen enhance denitrification model	Michael-Ment	
Oxygen enhance denitrification parameter	0.5	mgO2/L
Slow C		
Hydrolysis rate	0.5	/d
Temp Corr	1.047	
Fast C		
Oxidation rate	4	/d
Temp Corr	1.047	
Organic N		
Hydrolysis	2	/d
Temp Corr	1.07	
Ammonium		
Nitrification	4	/d
Temp Corr	1.07	
Nitrate		
Denitrification	1	/d
Temp Corr	1.07	
Sed Denitrification Transfer Coeff	0	m/d
Temp Corr	1.07	
Organic P		
Hydrolysis	2	/d
Temp Corr	1.07	
Floating plants (phytoplankton)		
Max Growth	2	/d
Temp Corr	1.07	
Basal Respiration	0.1	/d
Temp Corr	1.07	
Death	0.1	/d
Temp Corr	1.07	
Nitr Half Sat Constant	15	ugN/L
Phos Half Sat Constant	3	ugP/L

Light Model	Half Saturation	
Light Constant	35	langleys/d
Ammonia preference	60	ugN/L
Settling velocity	0.1	m/d
Stationary fixed plants (periphyton/macrophytes)		
Growth kinetics model	Zero order	
Light model	Half Saturation	
POM (detritus)		
Hydrolysis	0.5	/d
Temp Corr	1.07	
Settling Velocity	0.6	m/d
Half-saturation constants for CO2 or HCO3- limitation of photosynthesis (moles/liter)		
half-saturation for floating plants (phytoplankton)	0.0E+00	moles/L
HCO3- used by phytoplankton	Yes	
half-saturation for stationary plants (periphyton/macrophytes)	0.0E+00	moles/L
HCO3- used by periphyton/macrophytes	Yes	
Pathogen indicator bacteria (e.g. fecal coliform or E. coli)		
Base mortality at 20 deg C	0.8	/d
Temp Corr	1.07	
Settling Velocity	1	m/d
alpha constant for light mortality	1	/d per ly/hr
Stationary heterotrophic bacteria in the hyporheic sediment zone		
Simulate water quality in the hyporheic zone	Yes	
Growth kinetics model for stationary heterotrophic bacteria	First order	
Oxygen inhib of growth and respiration of heterotrophic bacteria	Michael-Ment	

Input of system ID		
River Name	Mainstem Stillaguamish	
Month	10	
Day	3	
Year	2001	
Time zone in hours relative to GMT/UTC	-8	hours
Daylight savings time	Yes	
pCO2	375	ppm
Input of time step and simulation variables		
User calc step	2.8125	minutes
Number of days for simulation	10	days
Number of time steps per dynamic output interval	128	
Water quality variables for simulation	All state variables	
Output from the last model run		
Julian day	276	days
Program determined calc step	2.8125	minutes
Time of sunrise	7:11 AM	
Time of solar noon	12:58 PM	
Time of sunset	6:43 PM	
Photoperiod	11.53	hours

Headwater and downstream boundary data:

Constant characteristics				
Location	0	km		
Headwater latitude	48.204	deg (positive N)		
	0	min (positive N)		
	0	sec (positive N)		
Headwater longitude	-122.126	deg (negative W)		
	0	min (negative W)		
	0	sec (negative W)		
Elevation	14.2	m		
Flow	17.1260	m^3/s		
Bottom width	51.800	m		
Side slope (left bank)	0.000	m/m		
Side slope (right bank)	0.000	m/m		
Channel slope	0.0024	m/m		
Manning n	0.045			
Alpha-Velocity				
Beta-Velocity				
Alpha-Depth				
Beta-Depth				
Prescribed dispersion		m^2/s		
Prescribed downstream boundary?	No			
Hourly upstream conditions:			12:00 AM	1:00 AM
Temperature		C	12.37	12.16
Conductivity		umho/cm	73.80	73.80
Inorganic Solids		mgD/L	6.00	6.00
Dissolved Oxygen		mg/L	9.32	9.25
Slow C		mgC/L	0.10	0.10
Fast C		mgC/L	1.00	1.00
Norg		ugN/L	85.00	85.00
NH4-N		ugN/L	53.00	53.00
NO3-N		ugN/L	177.00	177.00
Porg		ugP/L	5.90	5.90
Soluble Reactive Phosphorus		ugP/L	7.10	7.10
Phyto		ugA/L	1.30	1.30
POM		mgD/L	1.00	1.00
Alkalinity		mgCaCO3/L	37.20	37.20
pH		s.u.	7.52	7.51
Pathogen Indicator		cfu/100mL	1.00	1.00

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Appendix D

Enterococci Data

Fecal coliform and enterococci samples were collected monthly from February to November 2001 at 12 sites, mainly small freshwater tributaries to Port Susan. These data are summarized in Table D1. The two indicators were positively correlated (r^2=0.452) after lognormal transformations; South Pass counts had the best correlation (r^2=0.726). Some sites would not have passed the enterococci criteria while meeting the fecal coliform criteria, and some other sites showed the opposite tendency. Data pairs at individual site were highly variable, but a seasonal component was common in all data. Counts for both indicator counts were somewhat low at most sites from February to May, but then dramatically increased after May at all sites except South Pass and Juniper Beach. Counts for both indicators were especially high at all sites during the August 22nd storm event.

Table D1. Fecal coliform and enterococci results from samples collected from freshwater and marine waters in and around northern Port Susan.

Sites to and in Port Susan	Fecal Coliform (cfu/100 mL)		Enterococci (cfu/100 mL)	
	Geometric mean	90th percentile	Geometric mean	90th percentile
Juniper Beach (Marine)	**15**	**65**	10	87
South Pass (Marine)	**29**	**95**	28	142
Twin City Foods Drain #1	**513**	**1740**	**79**	**4180**
Twin City Foods Drain #4*	**149**	**1840**	30	92
Hatt Slough at Marine Drive	30	117	**57**	**211**
Warm Beach Creek above outfall	46	**251**	**425**	**6110**
Warm Beach WWTP outfall	53	**832**	**58**	**2240**
Pasture Drain to Pump Pond	**182**	**1068**	**259**	**1150**
Pond or Discharge to Slough	**230**	**656**	**388**	**2470**
Lake Martha Creek at Soundview Drive	82	**596**	**296**	**3580**
Unnamed Creek #0456	**350**	**2840**	**1125**	**5800**
Marine Criteria**	14	43	70	208
Freshwater Criteria**	100	200	33	151

* Drain never discharged to Hatt Slough – tide gate was always blocked with silt.
** Fecal coliform Washington State Class A criteria; enterococci EPA freshwater guidelines and proposed Washington State marine secondary contact criteria.
Bold – Values exceed criteria.

A wide range of FC-to-enterococci ratios was observed. The significance of the FC-to-enterococci ratios is uncertain at this time, although the sudden change in ratio could suggest a change in bacteria source or in indicator bacteria survivability. Most all sites had a mixed set of ratios, but 12% of all the ratios for all sites were above 4. A ratio greater than 4 can indicate human sources of fecal contamination if the source material is less than 24 hours old.

One interesting observation was a dramatic change in the ratios at the two drains from the Twin City Foods fields (TCF#1 and TCF#4). The ratios for TCF#1 were over 4 from February through July, and dropped below 4 from August through October. The opposite occurred at TCF#4. The Twin City Foods fields are used for land application of the food processing wastewater. As noted earlier, dairy manure was also added to the holding lagoon in the past, but that practice had stopped by 2000. The fields also play host to large flocks of swans and snow geese from September through February, but they appeared to be on all fields and not in selected areas. Other wildlife (and two farmhouses near TCF#4) are present along the drains throughout the year.

Weekly fecal coliform and enterococci bacteria were sampled by Ecology for a five-week period in August 2000 at seven informal recreational bathing beaches. At the time of the sampling design (Joy, 2001), enterococci was being proposed as the freshwater and marine bacteria indicator replacement for fecal coliform in the state water quality standards (Ecology, 1998). A statistical summary of the results of the TMDL freshwater beach survey is shown in Table D2.

Church Creek at Stanwood Park did not meet most of the fecal coliform or enterococci criteria (Table D2). The August 21 sample collected from the South Fork Stillaguamish River at Twin Rivers Park had an elevated density of enterococci that sent the 90^{th} percentile value near the criterion for that site. The Pilchuck Creek site fecal coliform densities did not meet the 90^{th} percentile criterion, but enterococci densities met criteria. Bathers were observed at both of these sites. The other four sites met all of the bacteriological criteria.

Table D2. Statistical summary of bacteria indicator samples (n=5) collected weekly from seven informal recreational beach sites in the Stillaguamish River basin, August 7 to September 5, 2000.

Informal Recreational Beach Sites	Fecal Coliform (cfu/100 mL)		Enterococci (cfu/100 mL)	
	Geometric mean	90th percentile	Geometric mean	90th percentile
S.F. Stillaguamish at Jordan	34	63	20	42
S.F. Stillaguamish at Twin Rivers	34	112	18	85
N.F. Stillaguamish at Twin Rivers	19	49	8	20
N.F. Stillaguamish at Whitman Br.	3	11	6	22
Stillaguamish River at Marine Dr.	27	74	9	27
Pilchuck Creek at Jackson Gulch	86	**285**	10	31
Church Creek at Stanwood Park	**101**	197	**89**	**368**
Current and Proposed Criteria	100	200	33	89

Bold values exceed current Washington State fecal coliform or EPA enterococci guidelines for a moderately used, full-body contact recreation beach.

There was some weekly variability at some stations between counts of fecal coliform and enterococci. There appeared to be some overall positive correlation between log-transformed fecal coliform and enterococci densities in the basin (r^2=0.309). However, site-specific correlations between the two indicators in these data sets varied widely. For example, Pilchuck Creek (r^2=0.807) and South Fork Stillaguamish at Twin Rivers Park (r^2=0.908) had positive and significant correlations. Church Creek (r^2=0.294) had a negative and significant correlation. But the data from three sites were not correlated. Therefore, fecal coliform counts would not necessarily be a good predictor of future enterococci results if the freshwater criteria should change.

Again, the significance of the FC-to-enterococci ratio is not very reliable unless the source materials are fresh, but the rations may be useful to future investigators. Few of the ratios from these samples were greater than 4, except at Pilchuck Creek. All Pilchuck Creek ratios were greater than 4 which might indicate human sources of contamination. Only 4 samples had ratios less than 0.7: two at the North Fork Stillaguamish River at Whitman bridge, and one each at Church Creek and the South Fork Stillaguamish River at Jordan bridge. These samples may have been contaminated from animal sources.