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Lower Skagit River Total Maximum Daily Load Water Quality Study

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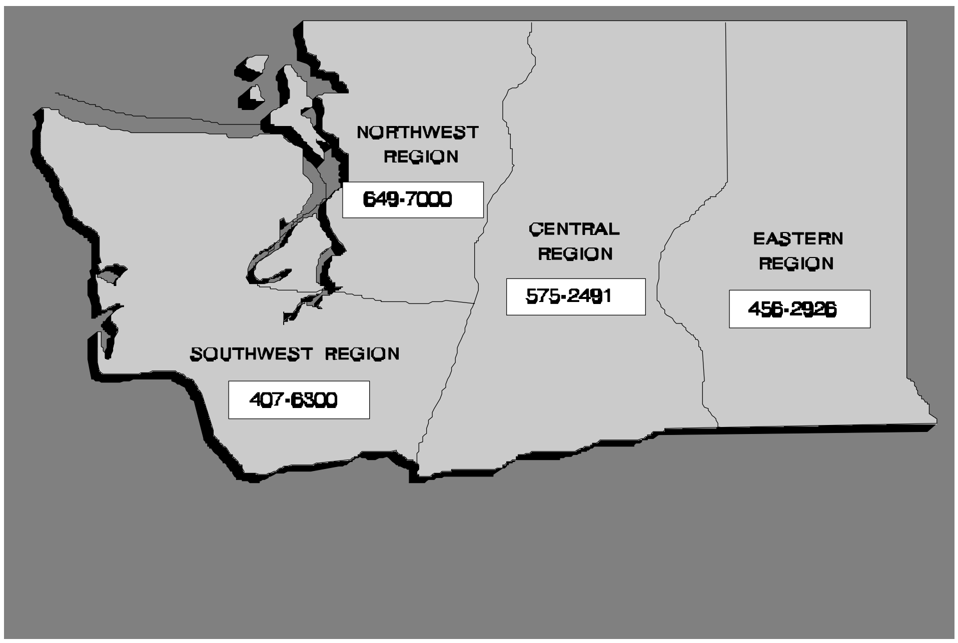

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Lower Skagit River Total Maximum Daily Load Water Quality Study

by
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List of Acronyms

Name	Definition
API	antecedant precipitation index
BOD_5	5-day biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
cfs	cubic feet per second
cfu	colony forming units
CSO	combined sewer overflow
CV	coefficient of variation
DO	dissolved oxygen
DS3	Datasonde 3®
FC	fecal coliform
ft	foot (feet)
LA	load allocation
mg/L	milligrams per liter
mL	milliliters
NH3-N	ammonia nitrogen
NPDES	National Pollutant Discharge Elimination System
NWRO	Northwest Regional Office
ppt	parts per thousand
PS	pump station
QAPP	quality assurance project plan
RM	river mile
SD	storm drain
TMDL	total maximum daily load
UBOD	ultimate biochemical oxygen demand
USGS	United States Geological Survey
WAC	Washington Administrative Code
WAS	Watershed Assessments Section
WLA	waste load allocation
WQS	water quality standards
WWTP	waste water treatment plant
%RSD	percent relative standard deviation

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Abstract

A water quality study was conducted in the lower Skagit River basin that included the mainstem downstream of Sedro-Woolley and the North and South Forks near Skagit Bay. This study focused on the effects of point and nonpoint pollutant loading on fecal coliform (FC) bacteria and dissolved oxygen (DO) levels in the lower Skagit River. Total Maximum Daily Loads (TMDLs) are proposed for FC bacteria, Carbonaceous Biochemical Oxygen Demand, and ammonia to protect the water quality standards for FC bacteria DO. During dry season low flow conditions, the DO water quality standards will be met if mass discharge from point sources remain below the recommended waste load allocations. Marine water quality standards for FC bacteria are expected to be met at the mouths of the North Fork and South Fork Skagit River if the following conditions are met: combined sewer overflow discharges are abated; point source discharges meet permit limitations; several major tributary nonpoint loading sources are reduced; and FC levels in the Skagit River above Sedro-Woolley are reduced to target levels which are more stringent than the Class AA standards. Meeting the long-term goal of all tributary water bodies complying with water quality standards will provide an additional margin of safety for the protection of Skagit Bay.

Summary and Recommendations

Dissolved Oxygen Analysis

- The critical location for low DO in the lower Skagit River was found to be in the South Fork near Conway.

- A CBOD and ammonia TMDL is proposed, in which the Skagit River has the capacity to assimilate current design levels of BOD_5 and ammonia nitrogen from permitted point source discharges without violation of the dissolved oxygen water quality standards.

- The proposed TMDL provides capacity for future levels of BOD_5 and ammonia nitrogen point source loading, provided that WLA limitations are met during the dry season critical low flow period (July through October). WLAs are proposed based on 2015 effluent flows; ammonia nitrogen concentrations of 10 mg/L or current levels (whichever is less); and BOD_5 concentrations of 20 mg/L.

- Effluent monitoring is recommended for ammonia nitrogen for all point sources. Ambient monitoring is recommended for DO in the South Fork Skagit River at the Conway bridge during neap high tide conditions.

Fecal Coliform Bacteria Analysis

- Current FC bacteria levels exceed Class A fresh water quality standards in many tributaries of the lower Skagit River, exceed Class AA standards in the Skagit River upstream of Sedro-Woolley, and very likely exceed the Class A marine standards at the mouths of the North and South Forks of the Skagit River.

- A FC bacteria TMDL is proposed in which Marine WQS will be protected in Skagit Bay at the mouth of the Skagit River if the following conditions are met: all permitted point sources meet their current permit limitations; Mount Vernon CSOs discharge no more than once per year; the Skagit River above Sedro-Woolley meets target values below the Class AA standards (6 cfu/100 mL geometric mean and less than 10% of values above 80 cfu/100 mL); Nookachamps, Carpenter, and Fisher Creeks meet freshwater standards; and loading sources at the Rexville pump station (Drainage District 15) and an unidentified source upstream of Kulshan Creek are significantly controlled.

- Meeting the long-term goal of all tributary surface waters meeting the Class A water quality standards will provide an additional margin of safety to the Skagit River and Skagit Bay. As resources allow, watershed plans and other nonpoint source control programs should be developed and fully implemented in watersheds, drainage districts, and other stormwater drainage areas that currently do not meet the standards.

- Long-term monitoring is necessary in the Skagit River (North and South Forks and above Sedro-Woolley) and in tributary waters to evaluate the FC bacteria TMDL.

Introduction

Study Area

The Skagit River basin has a drainage area of approximately 3,093 square miles, which includes its headwaters in British Columbia. It is the largest basin tributary to Puget Sound, and the largest basin in Washington outside the Columbia River. The study area for this project is the lower Skagit River, which is the lowland portion of the river downstream from the lower end of Skiyou Slough near Sedro-Woolley. Just before the Skagit drains into Skagit Bay, it splits into the North and South Forks which bound Fir Island. The Lower Skagit Study Area drains an area of about 200 square miles. Figure 1 presents a map of the study area.

The principal land uses in the study area are agriculture, forestry, and urban areas (Entranco, 1993). Both dairy farming and row cropping are widespread in the study area. The three main population centers are Mount Vernon, Burlington, and Sedro-Woolley. Much of the study area is diked and drained, and several pump stations discharge water from the drainage districts into the Skagit River.

The flows of the Skagit River and its tributaries exhibit a complex hydrology influenced by several sources. Summertime flows are maintained by ground water inflow in the tributary drainages, and are also strongly influenced by glacial outflow and snowmelt, which produce peak flows in early summer. Wintertime flows are dominated by the timing and amount of rainfall, with peak flows that may include snowmelt. Besides the natural flow regimes, three reservoirs on the upper Skagit River and two on the Baker River regulate flows on those rivers, which strongly affect the flows in the Lower Skagit River (Ebbesmeyer and Tangborn, 1995). The first reservoir was built in 1924, and all five reservoirs have been in operation since 1960.

Flows near the mouth of the Skagit River are gaged continuously at Skagit River near Mount Vernon (USGS, 1992). Mean daily flow is highest in June, with a second peak in December; lowest flows occur in September. The mean annual flow is 16,710 cubic feet per second (cfs). The 7Q10 low flow (7-day average flow with 10 year recurrence probability) is 4,730 cfs.

The North Fork, South Fork, and mainstem Skagit River are subject to tidal influence extending about 15 miles upstream to Mount Vernon. At high tide, flow is stopped and at times reversed in the North and South Forks. At low tide, measurements in September 1994 showed roughly one-third of river flow passing through the South Fork, and two-thirds in the North Fork.

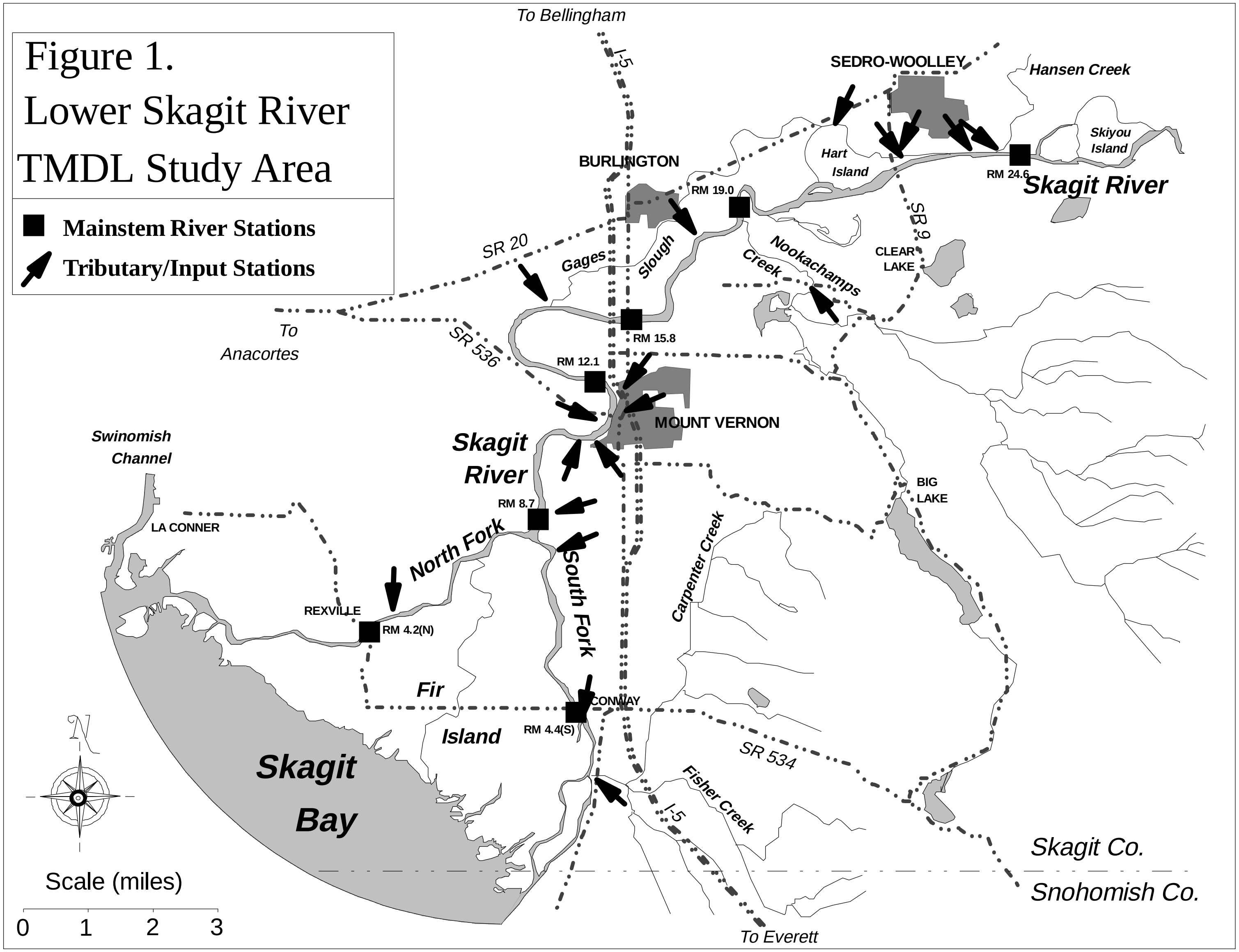
Figure 1.
Lower Skagit River
TMDL Study Area
Mainstem River Stations
Tributary/Input Stations
To Bellingham
I-5
SEDRO-WOOLLEY
Hansen Creek
Skiyou Island
Hart Island
RM 24.6
Skagit River
BURLINGTON
RM 19.0
SR 9
SR 20
Gages
Slough
Nookachamps
Creek
CLEAR LAKE
To Anacortes
SR 536
RM 15.8
RM 12.1
MOUNT VERNON
Swinomish Channel
Skagit River
RM 8.7
LA CONNER
North Fork
South Fork
BIG LAKE
Carpenter Creek
REXVILLE
RM 4.2(N)
Fir Island
CONWAY
RM 4.4(S)
SR 534
Skagit Bay
Fisher Creek
I-5
Skagit Co.
Snohomish Co.
Scale (miles)
0 1 2 3
To Everett

Three significant tributaries drain to the lower Skagit River: Hansen Creek, Nookachamps Creek, and Carpenter/Fisher Creeks. Several minor tributaries also drain to this stretch of the river. Stormwater drainage mostly reaches the river by pump stations (sometimes combined with gravity-flow pipes) managed by the City of Mount Vernon, Skagit County, or several drainage districts. In Sedro-Woolley several urban drains discharge directly to sloughs near the river. Contributions to the flow from direct ground water inflows on this stretch of the Skagit River appear to be insignificant (Larson, 1994).

Water Quality Standards

The Surface Water Quality Standards for the State of Washington are described in Chapter 173-201A WAC. The Skagit River and its tributaries in the study area are subject to Class A fresh water standards, with the exception of the upstream end of the study area (the Skagit River above Sedro-Woolley, at the lower end of Skiyou Slough), which is subject to Class AA standards.

Skagit Bay is Class A marine water, and the boundary between marine and freshwater standards occurs somewhere downstream of the bridges over the North and South Forks. The WQS regulations define the boundary as 1 part per thousand (ppt) salinity for the dissolved oxygen standard, and 10 ppt for the fecal coliform bacteria standard. A reconnaissance survey for this study made in September 1994 did not detect the presence of saline water at the two bridges at a higher high water tidal level, despite very high tide conditions with flow reversal.

Water Quality Standards for fecal coliform bacteria and dissolved oxygen are as follows:

<u>Class AA Freshwater:</u>

- Fecal coliform organism levels shall both not exceed a geometric mean value of 50 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.
- Dissolved oxygen shall exceed 9.5 mg/L

<u>Class A Freshwater:</u>

- Fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.
- Dissolved oxygen shall exceed 8.0 mg/L
- Class A Marine:
- Fecal coliform organism levels shall both not exceed a geometric mean value of 14 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 43 colonies/100 mL.
- Dissolved oxygen shall exceed 6.0 mg/L

Water bodies that do not meet the water quality standards despite the presence of technology-based pollutant controls are required by Section 303(d) of the Clean Water Act to be placed on a list of water-quality limited water bodies (Ecology, 1996). The following waterbodies in the study area were listed in 1996 for fecal coliform standard exceedance: Lower Skagit River, Carpenter Creek, Fisher Creek, North Fork Skagit River, Gages Slough, Nookachamps Creek, Hart Slough/Brickyard Creek, and Hansen Creek.

If water quality standards are not being met or are threatened by existing pollutant sources, then a Total Daily Maximum Load (TMDL) may be established to regulate acceptable pollutant loads, as required under Section 303(d) of the Federal Clean Water Act. The combined effects of various sources in the basin need to be evaluated as part of the TMDL technical study, to determine the best strategy to establish a TMDL and protect beneficial uses for the basin. The TMDL may be apportioned between point sources (waste load allocations or WLAs) if present, and nonpoint or background sources (load allocations or LAs). The allocations (WLAs and LAs) may be implemented through NPDES permits, state waste discharge permits, grant projects, watershed action plans, and other nonpoint source control activities.

Pollutant Sources

There are four permitted dischargers that discharge to the Lower Skagit River in the study area and have the potential to affect FC bacteria or DO. These are listed in Table 1. All four are NPDES permitted municipal wastewater treatment plants (WWTPs). The City of Mount Vernon also has several combined sewer overflows (CSOs) (Messman, *et al.*, 1994).

A number of potential nonpoint pollutant sources exist in the Lower Skagit River study area. Urban stormwater reaches the Skagit River through CSOs; city, county and drainage district pump stations; and direct stormwater discharges. Agricultural practices may be a source of nonpoint pollutants that reach the Skagit River through pump stations, tributary streams, or overland flow. Over 50,000 acres of the study area are farmland, and over 50 commercial dairy farms operate in the Lower Skagit River basin with a total of over 20,000 animals (Entranco, 1993). Failing or inadequate septic systems may also represent another potential pollutant source.

Table 1. Permitted Discharges in the Lower Skagit Study Area.

Facility	Discharge Location	Current Design Flow (cfs)	2015 Design Flow (cfs)
City of Sedro-Woolley	Skagit River	1.9	2.07
City of Burlington	Skagit River	2.0	5.05
City of Mount Vernon	Skagit River	4.0	5.7
Big Lake (Skagit Co. Sewer Dist. #2)	South Fork Skagit R	0.2	0.8

Problem Statement

There have been very few water quality studies done on the Skagit River until recently, probably due to its historically good quality and high flows (Entranco, 1991). However, a number of resources are showing signs of degradation, bringing attention to concerns about the water quality of the Skagit River.

Portions of the shellfish beds in Skagit Bay are classified as restricted or conditionally approved due to bacterial contamination, raising concerns that water quality problems in the Skagit River may be impacting the resources of the bay (WDOH, 1995). Limited data indicate high fecal coliform bacteria in the lower Skagit River may be contributing to problems in the Skagit Bay shellfish beds (Entranco, 1991).

Six species of anadromous salmon use the lower Skagit River for migration. Skagit fish runs have returned in reduced numbers in recent years, raising questions about the cause of that problem. The former state Department of Fisheries identified water quality as potential problems to the anadromous fishery (WDF, 1975). The water quality of tributaries and sloughs historically has been poor (Entranco, 1991). The heavy agricultural and urban use of the lower Skagit River basin raises concerns that discharges of pollutants may be contributing to fishery problems.

A major water quality study of the Lower Skagit River was conducted by Entranco (1993). That study examined the Lower Skagit River basin, and the water quality monitoring consisted of three elements: mainstem sampling including tributaries, wastewater treatment plants, drainage district pumps, and stormwater outfalls; four sloughs in the Delta; and multiple stations in the Nookachamps Creek system.

Preliminary data have identified a number of water quality problems. The standards for dissolved oxygen were exceeded in locations throughout the basin: in the mainstem, in the sloughs, and in the Nookachamps system. Dissolved oxygen in the mainstem was lowest during August and September low flows. However, the data from the Entranco study in 1992 showing DO below the water quality standards appear to be of poor quality, as indicated by the high variability and inconsistency of the data. On the other hand, flows in 1992 were extremely low, and the area has experienced rapid growth, so degradation of DO is possible. The issue is of importance because the salmon resource of the Skagit River has been in decline and DO problems would add to the stress on that resource.

Entranco (1993) also found that fecal coliform standards were exceeded in the North and South Forks, in the sloughs, and in the Nookachamps system. The high bacteria levels were attributed to dairy farms, urban runoff, and failing septic systems. These data add weight to concerns that Skagit River bacteria loading contributes to the contamination of shellfish beds in Skagit Bay. The Section 303(d) waters listed for FC bacteria in the lower Skagit River basin were all identified by the 1993 Entranco study.

In fall 1993 and winter 1994, a watershed needs assessment was conducted by the Department of Ecology (Ecology) for the water Quality Management Area that includes the lower Skagit River Basin (Messman *et al.*,1994). Ecology's Northwest Regional Office (NWRO) Water Quality Section proposed the lower Skagit River for a Total Maximum Daily Load (TMDL) water quality assessment study. Ecology's Water Quality Program requested that the Watershed Assessment Section (WAS) of the Environmental Investigations and Laboratory Services Program conduct the study.

Project Goals and Objectives

The Lower Skagit TMDL study area includes the lower mainstem and the North and South Forks of the Skagit River, from upstream of Sedro-Woolley downstream to the mouths of the Forks at Skagit Bay (Figure 1). Tributary inputs were evaluated as pollutant sources to the river, but tributary basins were not evaluated as a whole. Also, the sloughs that flow directly to Skagit Bay were not included in the study.

The parameters evaluated in this study were fecal coliform bacteria and dissolved oxygen . The goal of this study was to evaluate DO and bacteria levels in the lower Skagit River, compare them to the state Water Quality Standards (WQS), and propose an allocation approach to meet the WQS in the lower Skagit River study area.

To meet this goal, the major objectives of the study were as follows:

- Conduct dry season low flow water quality sampling investigations for calibration and verification of a dissolved oxygen model of the lower Skagit River.

- Develop a steady-state model of DO for the lower Skagit River to evaluate the capacity of the river to assimilate Carbonaceous Biochemical Oxygen Demand (CBOD) and ammonia loading from point and nonpoint sources and meet water quality criteria for dissolved oxygen.

- Use the steady state model of dissolved oxygen to determine the potential to violate water quality criteria in the lower Skagit River.

- Evaluate and recommend a TMDL strategy, possibly including WLAs for point sources and LAs for nonpoint and background sources for both CBOD and ammonia, to meet the water quality standards for DO.

- Conduct wet season water quality sampling investigations for fecal coliform bacteria.

- Develop a simple mass-balance and first order decay model to evaluate the relative levels of bacterial loading from sources along the lower Skagit River and the Forks.

- Use the mass balance model of bacteria to determine the potential of bacterial loading to violate water quality standards in the lower Skagit River and the Forks and in the marine waters of Skagit Bay at the mouths of the Forks.

- Evaluate and recommend a TMDL strategy, possibly including WLAs for point sources and LAs for nonpoint and background sources, to meet water quality standards for fecal coliform bacteria.

Water Quality Survey

Study Design

The design for this study was described in detail in the Quality Assurance Project Plan (QAPP) (Pickett, 1995). The field work for the study consisted of eight surveys during the wet season and two surveys in the dry season. Wet season surveys were conducted every two weeks from the last week of December 1994 to the first week of April 1995. Dry season surveys were conducted in mid-September and early October 1995.

The locations of sampling stations are shown in Figure 1. A detailed description of survey methods is provided in the Appendix. The analytical or instrument methods for the field and laboratory parameters are listed in Appendix Table A.1.

Field measurements included temperature, conductivity, and pH at all sites during all surveys, and DO during the dry season surveys. Also during dry season surveys, remote datalogging multi-parameter meters were deployed to measure those four field parameters hourly over 24 hours. Flows were measured at all tributaries where possible, and discharges from pumping outfall pipes were measured if the pipe was accessible and the pump running at the time of sampling.

Access to sampling stations varied widely, and sampling was conducted in open channels, through manholes, from pump station catwalks, off of bridges, and by boat. Samples and measurements were collected directly from the stream where possible, and indirectly by collecting sample water with a 3-gallon bucket where access for sampling directly into a bottle was not possible.

Data Quality

Methods

Laboratory analysis followed data quality objectives and quality control procedures as documented in the Manchester Environmental Laboratory User's Manual (MEL, 1994). Qualifiers have been included with the data reported to indicate data that did not meet the quality objectives. The target accuracy or reporting limits for the field and laboratory parameters are included in Appendix Table A.1.

Standardized field procedures were used that were designed to ensure data quality. Field sampling and measurement protocols followed those listed in the WAS protocols manual (Ecology, 1992). WWTP effluent sampling was conducted according to standard protocols for

Class II inspections (Glenn, 1994). Flow measurements were made with standard procedures (USBR, 1967). All field meters were calibrated and post-calibrated and have been maintained in accordance with the manufacturer’s instructions. All samples were stored on ice and delivered to Manchester Environmental Laboratory on the day following collection.

Field data quality was evaluated through the use of replicate and field verification sampling. A schedule of replicate sampling was established in the QAPP (Pickett, 1995). Field measurements taken with meters were verified through the use of sequential field measurements with alternate methods: conductivity with laboratory samples; temperature with mercury or alcohol thermometers; pH with standard solutions; and DO with measurements by Winkler iodide titration method. Data variability was assessed by calculating the coefficient of variation (CV, sometimes called the percent relative standard deviation, or %RSD) for the paired replicates or verification measurements. The bias of field data was assessed by calculating the residuals between field meter measurements and verification or post-calibration measurements.

Results

Pickett (1996) gives a detailed summary of the data Quality Assurance/Quality Control analysis. Data collected in the Lower Skagit TMDL study are usable subject to certain qualifications:

- Qualifiers were provided in the data tables that place conditions on the laboratory data.
- Data variability must be taken into consideration when interpreting results and applying data to other analyses.
- Data from certain locations may have been taken under unusual conditions. Some of these conditions are described below or in the Appendix. The unique circumstances of sampling must be taken into consideration in evaluating the data.

Data from the Skagit River and its tributary creeks (Hansen, Nookachamps, and Carpenter/Fisher Creeks) and some storm drain and pump station sources (Northern State Hospital Drain, Tributary at Riverfront Park, Brickyard Creek, and Gages Slough) were taken directly from flowing surface waters and should be representative of their quality. One exception is that during the December 1994 survey, the Skagit River was flooding and forcing water upstream in Nookachamps Creek, so it is uncertain whether this sample represents the river, the creek, or some mixture of both.

Data from certain storm drain and pump station sources (South Sedro-Woolley Storm Drain, Frontage Road Pump Station [Kulshan Creek], Division Street and Park Street CSOs, Britt Slough Pump Station) were collected some of the time from water flowing directly into the Skagit River, and at other times from water that was backed up, or flowing into or held in a wet well. These conditions were mostly controlled by the height of the river. As part of the data analysis, conditions at these locations were taken into consideration.

Other pump stations (Freeway Drive, Westside, Conway, and Rexville) were monitored solely from wet wells or drainage basins, and whether they were representative as inputs to the river would depend on whether inflows to the pump stations were causing active pumping to the river.

Survey Results

A summary of the data collected as part of this study was published in Pickett (1996). The data summary report includes complete tables of field measurements and laboratory analytical results. Data were also compared to the surface Water Quality Standards. Certain findings of the data summary report are relevant to the TMDL analysis:

- No Skagit River DO sample fell below 9 mg/L during the September and October surveys. All surface waters were in compliance with the Water Quality Standards for DO (except Kulshan Creek where one measurement fell below the Class A DO criterion). This is not consistent with the results in Entranco (1993), where low DO was found in the Skagit River at several locations.

- Hourly DO data collected by the Hydrolab® Datasonde 3® (DS3) found a drop in DO of about 1 mg/L at the higher high tide during the dry season surveys. This phenomenon is associated with stagnant conditions during a high neap tide, and is consistent with similar conditions found in the Snohomish River (Cusimano, 1995).

- During the summer surveys, the South Fork Skagit River showed slightly higher levels of ammonia nitrogen and bacteria as compared to the North Fork and upstream mainstem stations. The reason for this difference was unclear, but may have been related to the observed dip in DO.

- The Skagit River was below FC criteria, except during the December 1994 flood conditions when the Class AA criteria were exceeded at the upstream end of the study area.

- Surface waters that exceeded the FC criteria included Hansen Creek, Tributary at Riverfront Park, South Sedro-Woolley Storm Drain, Brickyard Creek, Nookachamps Creek, Kulshan Creek (Frontage Road Pump Station), and the Rexville Pump Station.

Dissolved Oxygen Analysis

Methods

To meet the study objective of analyzing dry season dissolved oxygen in the lower Skagit River, a computer modeling system was used that combined simplicity with the need to address the unique features of the Lower Skagit River. The characteristics of the study area that needed to be addressed included:

- The lower Skagit River divides into the North and South Forks and flows into Skagit Bay by these two separate channels. The division of flow between the forks is determined by hydraulic characteristics.

- During the dry season, most nonpoint sources are dry, and only the municipal point sources and several creeks discharge to the Skagit River.

- Velocities in the Skagit River are swift, and travel time through the study area appears to be less than one day.

- The City of Mount Vernon WWTP is close enough to the split of the North and South Forks that the discharge may not be fully mixed across the channel at the junction. This would allow a greater portion of the discharge's pollutant loading to enter the South Fork despite the larger portion of flow following the North Fork. Patterns of survey data found in the South Fork but not in the North Fork, such as the drop in DO at high tide and the elevated ammonia levels, provides evidence that this is occurring.

To determine whether a detailed analysis of ground water was necessary for the evaluation of Skagit River low flows, estimates were made of ground water inflows in the study area (Larson, 1994). The ground water contribution to the Skagit River was calculated to be less than 100 cfs, and probably closer to 10 cfs. This represents at most 2% of the total flow in the Skagit, and most likely is well below 1% of river flows. Ground water inputs were assumed to be negligible for the purposes of this study.

To develop the modeling system, system components were selected and calibrated to the September survey data. The system was then verified with the October survey data set. Goodness of fit was determined from paired modeled and observed results either by the difference between paired values or by calculating the CV of the pairs. Weather conditions and river and tributary input flows had changed considerably between the surveys, which was good for the purposes of testing the predictive abilities of the modeling system.

The following models were used as a modeling system to analyze DO in the lower Skagit River:

- The model HEC-RAS (USACOE, 1996) was used to determine flows, velocities, and channel depth and width in the study area. The U.S. Army Corps of Engineers supplied a HEC-2 input file for the lower Skagit River, which was modified for use with HEC-RAS for the study conditions. Using tidal heights for the nearest tidal station (La Conner, Washington) as the downstream boundary, the proportions of flow in the North and South Forks were varied until the river heights in each fork at the upstream junction were equal. That height was then used as the downstream boundary for calculations in the mainstem. The proportion of flow in each fork was determined under various conditions by this method. Model results were checked against field measurements.

- The model MULTI-SMP (LTI, 1992) was used to determine the effect of CBOD and ammonia nitrogen loading on dissolved oxygen levels in the Skagit River. MULTI-SMP is a relatively simple DO model that allows up to 10 discharges and stream segments. The model can be calibrated by adjusting segment-specific parameters: first-order decay rates for CBOD and ammonia; the reaeration rate; and sediment oxygen demand.

- To evaluate the Mount Vernon WWTP discharge, the model CORMIX (Cornell University, 1995) was used. CORMIX is an “expert system” that analyzes the effluent plume from a discharge using a variety of computational methods for mixing characteristics, including first-order decay if appropriate. In this study CORMIX was used to determine the centerline concentration of ammonia or CBOD from the Mount Vernon WWTP discharge, the width of the plume, and through secondary calculations (Doneker, 1996), the flux-averaged and mid-channel pollutant concentrations.

For each analysis of the lower Skagit River for a given set of conditions, the modeling system used the following procedures:

1. For the appropriate Skagit River flow (from the USGS flow station at Mount Vernon), HEC-RAS was used to determine hydraulic characteristics and the flow in the South and North Forks. The downstream boundary condition was the mean tide at La Conner.

2. Because HEC-RAS uses a different number of segments for modeling than MULTI-SMP and CORMIX, the HEC-RAS results were averaged to match the different segmentation with a spreadsheet program. An average velocity for each model segment was calculated from the channel length and travel time. Average channel cross-section areas were calculated from velocity and flow. An average depth was calculated by assuming a rectangular channel cross-section with the same area and wetted perimeter as the measured channel from the HEC-RAS input file.

3. MULTI-SMP was run for the mainstem Skagit River in the study area using the average hydraulic values from HEC-RAS and observed values from the surveys. Values below detection were set at one-half the detection limit unless adjusted through calibration.

4. CORMIX was run for the Mount Vernon WWTP discharge from the outfall to the beginning of the forks. Model hydraulic inputs were derived from HEC-RAS results, as-built measurements of the outfall configuration, and survey results. For calibration and verification, observed midstream concentrations at the end of the mainstem were compared to a value calculated from the centerline model results using an equation based on the Gaussian distribution of the effluent plume:

   $C_n = C_U + \{ C_{CL} * \exp[-(n / b)^2] \}$, where:

   n = distance perpendicular from the plume centerline to midstream;

   C_n = Concentration at distance "n";

   C_U = Ambient concentration upstream of outfall;

   C_{CL} = Plume centerline concentration (CORMIX output); and

   b = Plume Gaussian "half-width" (CORMIX output).

5. MULTI-SMP was run for 24-hour average conditions in the South Fork Skagit River. Upstream DO was determined from the mainstem MULTI-SMP simulation with the Mount Vernon WWTP discharge included. Upstream ammonia nitrogen and 5-day CBOD (BOD_5) concentrations were determined from CORMIX results and the results of a mainstem MULTI-SMP simulation with no Mount Vernon WWTP discharge, calculated as follows:

   $C_{avg} = C_o + (C_{CL} / 1.4)$, where:

   C_{avg} = flux average concentration across the plume at the junction of the Forks; and

   C_o = river concentration with no Mount Vernon WWTP discharge at the junction of the Forks.

6. Since DO criteria do not provide a frequency of exceedance, the criteria must be met as a minimum value, not as an average. The modeling analysis was based on 24-hour and tidally averaged conditions. However, the datasonde results for both the September and October surveys showed a DO drop at high tide. To estimate critical minimum DO conditions, the maximum observed difference between average and minimum DO from datasonde data at the downstream end of the South Fork (1.2 mg/L) was subtracted from modeled DO results for that location. Since a dynamic model of the effect of tidal conditions on DO was beyond the scope of this study, and considering the difficulties of modeling dynamic tidal conditions with a steady-state model, this approach is the best available method to account for critical minimum DO conditions.

The models rely on ultimate CBOD (UBOD) values for their calculations, which are determined from BOD_5 concentrations and an UBOD:BOD_5 ratio. This ratio was calculated from laboratory analysis of effluent and instream samples with both the UBOD and BOD_5 methods. All BOD_5 values are used as carbonaceous, since ammonia nitrification is calculated separately.

Results

Calibration and Verification

The HEC-RAS model was checked against flows measured during surveys in the North and South Forks. Flow in the North Fork was measured on September 7, 1994, at 5,470 cfs, and predicted by HEC-RAS to be 5,365 cfs, which agrees reasonably well (less than a 2% difference). The flow measured on the South Fork on the same date was higher than modeling results, but the flow measurement is considered to be of poor quality, and the sum of measured North and South Fork flows was higher than USGS flows at Mount Vernon. A flow of 2,755 cfs was measured on the South Fork on August 22, 1995, and the HEC-RAS result for South Fork flow under similar conditions was 3175 cfs, which represents an error of about 15%.

Table 2 shows the input flows, concentrations, and loading for DO and ammonia, while Table 3 shows calibration and verification results for DO and ammonia. The modeling system was calibrated to observed conditions during the September 1995 survey. For the MULTI-SMP run on the mainstem Skagit River, the model was fairly insensitive to the model parameters. Because all observed ammonia values above the Mount Vernon discharge (river mile [RM] 19.0, 15.8, and 12.1) were below the reporting limit of 0.01 mg/L, the upstream boundary ammonia concentration was set at one-half the detection limit. Just above the North and South Forks at RM 8.7, CORMIX modeling results were used to predict a midstream concentration of ammonia to compare to the observed value. In the South Fork, MULTI-SMP was run for mean tide conditions and calibrated to 24-hour average survey results for DO and ammonia. An estimate of the minimum DO was also calculated. The CV values between model calibration and observed DO results were less than 4%, with absolute differences of 0.1 to 0.5 mg/L. Modeled results were less than 0.01 mg/L where observed ammonia results were below detection, and modeled and observed ammonia results above detection differed by no more than 0.002 mg/L.

The Lower Skagit DO model was verified using October 1995 survey conditions. The DO survey and model results matched well (CVs less than 2% at all stations). Ammonia modeling results at all stations were within 0.003 mg/L of observed values, or consistent with observed values at or below the 0.010 mg/L detection limit.

Table 2. Lower Skagit River TMDL Load Allocations

	Calibration (19 Sept 95)					Verification (2 Oct 95)				
	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)
Point Source WLA										
Sedro-Woolley WWTP	0.66	3	1.26	16.6	6.95	0.67	2	0.058	11.1	0.32
Burlington WWTP	1.06	6	23.2	53.1	205	1.37	4	21.2	45.6	242
Mt Vernon WWTP	2.45	13	26.7	265	545	4.41	12	23.3	441	856
Big Lake WWTP	0.08	4	1.00	2.6	0.66	0.09	5	1.03	3.8	0.79
Tributary LA										
Hansen Creek	(dry)					7.87	0.90	0.005	59.0	0.33
Nookachamps Creek	1.87	1.02	0.044	15.9	0.69	104.5	1.00	0.005	870	4.35
Kulshan Creek	(dry)					0.26	1.14	0.091	2.47	0.20
Upstream	4968	0.38	0.005	15731	207	7484	0.38	0.007	23699	437
WLA Total				338	758				502	1099
Tributary LA Total				15747	208				24631	441
GRAND TOTAL				16085	966				25132	1541
DO at critical location:				8.8	mg/L				9.1	mg/L
Difference from Criteria:				0.8	mg/L				1.1	mg/L
	Current Critical Conditions 2-yr Maximum Weekly Avg					**Current Critical Conditions Worst Case**				
	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)
Point Source WLA										
Sedro-Woolley WWTP	1.68	24	19.0	336	266	1.68	45	19.0	630	266
Burlington WWTP	1.6	17	29.0	227	387	1.6	45	29.0	600	387
Mt Vernon WWTP	4.0	36	26.7	1200	890	4.0	45	26.7	1500	890
Big Lake WWTP	0.20	17	1.10	28	1.8	0.20	45	1.10	75	1.8
Tributary LA										
Hansen Creek	(dry)					(dry)				
Nookachamps Creek	1.87	2.00	0.32	31.2	5.0	1.87	2.00	0.32	31.2	5.0
Kulshan Creek	(dry)					(dry)				
Upstream	3052	0.38	0.05	9663	1272	3052	0.38	0.05	9663	1272
WLA Total				1791	1545				2805	1545
Tributary LA Total				9695	1276				9695	1276
GRAND TOTAL				11486	2821				12500	2821
DO at critical location:				7.9	mg/L				7.9	mg/L
Difference from Criteria:				-0.1	mg/L				-0.1	mg/L
	2015 Critical Conditions Worst Case					**2015 Critical Conditions TMDL Alternative**				
	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)	Flow (MGD)	BOD5 (mg/L)	NH3-N (mg/L)	BOD5 (lb/d)	NH3-N (lb/d)
Point Source WLA										
Sedro-Woolley WWTP	2.07	45	19.0	776	328	2.07	20	10.0	345	173
Burlington WWTP	5.05	45	29.0	1894	1220	5.05	20	10.0	842	421
Mt Vernon WWTP	5.70	45	26.7	2138	1268	5.70	20	10.0	950	475
Big Lake WWTP	0.80	45	1.10	300	7.3	0.80	20	1.10	133	7.3
Tributary LA										
Hansen Creek	(dry)					(dry)				
Nookachamps Creek	1.87	2.00	0.32	31.2	5.0	1.87	2.00	0.32	31.2	5.0
Kulshan Creek	(dry)					(dry)				
Upstream	3052	0.38	0.05	9663	1272	3052	0.38	0.05	9663	1272
WLA Total				5108	2824				2270	1076
Tributary LA Total				9695	1276				9695	1276
GRAND TOTAL				14802	4100				11965	2352
DO at critical location:				7.8	mg/L				8.0	mg/L
Difference from Criteria:				-0.2	mg/L				0.0	mg/L

Table 3. Lower Skagit River DO Model Calibration and Verification										
	Calibration					Verification				
	DO			Ammonia-N		DO			Ammonia-N	
RM	Predict.	Observ.	CV	Predict.	Observ.	Predict.	Observ.	CV	Predict.	Observ.
Mainstem River Skagit										
19.0	10.3	10.2	0.9%	0.005	< 0.01	10.4	10.2	1.3%	0.007	0.01
15.8	10.3	9.8	3.8%	0.009	< 0.01	10.4	10.1	1.9%	0.01	≤ 0.01
12.1	10.2	10.3	0.5%	0.008	< 0.01	10.4	10.3	0.5%	0.009	< 0.01
8.7	10.2	10.3	0.9%	0.013	0.014	10.4	10.5	0.9%	0.013	0.012
South Fork Skagit River										
4.4										
24-hr avg	10.0	10.1	0.4%	0.023	0.025	10.3	10.2	0.8%	0.027	0.03
Minimum	8.8	9.3	3.6%			9.1	9.0	0.9%		

Critical Conditions

DO in the lower Skagit River was simulated for critical low flow conditions. HEC-RAS was run for the 7Q10 low flow of 4700 cfs. Critical conditions were assumed to occur during summer dry weather. Under these conditions, Nookachamps Creek would be the only nonpoint source actively discharging.

Three point source discharge flow situations were simulated for critical low-flow conditions. One model scenario was run with point source effluent flows at current design condition and BOD_5 concentrations set at the highest weekly average from a 2-year period (1995-96). Two scenarios were run at current and 2015 point source design flows, with BOD_5 concentrations for each point source discharge set to the weekly maximum BOD_5 permit limit. Design flows for 2015 were based on facilities growth planning (Shervey, 1996). Data from the 1992 water quality survey (Entranco, 1993) were reviewed, and the highest ammonia concentrations found in either 1992 or 1995 were used for point and nonpoint source inputs in the critical conditions runs.

Table 2 summarizes the input flows, concentrations, and loads for DO and ammonia used in the critical conditions analysis. Table 2 also shows the DO results at the downstream boundary in the South Fork Skagit River at the Conway Bridge, which is the critical location for low DO in the lower Skagit River. Dissolved oxygen levels at this location for the calibration and verification runs were 0.8 and 1.1 mg/L above the 8.0 mg/L criterion, respectively. At critical design loading and flow conditions, DO in the South Fork was predicted to be 9.1 mg/L as a 24-hour average and the minimum DO was estimated to be 7.9 mg/L, 0.1 mg/L below the criterion. For 2015 critical design conditions the minimum DO fell to 7.8 mg/L, 0.2 mg/L below the criterion.

As described earlier, the behavior of the effluent plume from the Mount Vernon WWTP results in a disproportionate split of loading between the North and South Forks of the Skagit River. Model results were used to develop estimates for this split. Under the calibration and verification model runs, about three-quarters of the loading from Mount Vernon was routed to the South Fork, as compared to only about one-third of mainstem flow. Under the critical conditions model runs about one-half of the Mount Vernon loading reaches the South Fork as compared to a lesser proportion of flow.

CBOD and Ammonia TMDL

A TMDL consists of allocations to point sources, nonpoint sources, and background. Reserves for future growth and for scientific uncertainty should be considered, but may be included in the allocations and through the use of conservative assumptions. Loading allocated for an existing permitted point source facility is termed a Wasteload Allocation (WLA), and any other allocation is termed a Load Allocation (LA).

TMDLs for CBOD and ammonia are proposed in the lower Skagit River for dry season critical low-flow conditions. The proposed BOD_5 and ammonia nitrogen TMDLs in the Lower Skagit River are shown in Table 2 and illustrated in Figure 2. The proposed TMDL can be summarized generally as follows:

- The TMDL applies from July through October of each year. The lowest flows and highest temperatures fall in these months.

- WLAs for BOD_5 and ammonia nitrogen will be provided to existing permitted dischargers calculated from 2015 projected flows; BOD_5 concentrations of 20 mg/L; and ammonia nitrogen concentrations of 1.1 mg/L for the Big Lake WWTP and 10 mg/L for the other three point sources.

- LAs will be provided at current concentrations to the Skagit River at the upstream boundary above Sedro-Woolley and to Nookachamps Creek. Hansen and Kulshan Creeks are expected to be dry during critical conditions.

- A reserve capacity for future growth of CBOD and ammonia loading is not specified. The loading capacity of the lower Skagit River is entirely allocated under the proposed TMDL. Growth of the point source discharges through 2015 is included in the WLAs.

- Scientific uncertainty is incorporated into the analysis through the use of reasonable conservative assumptions.

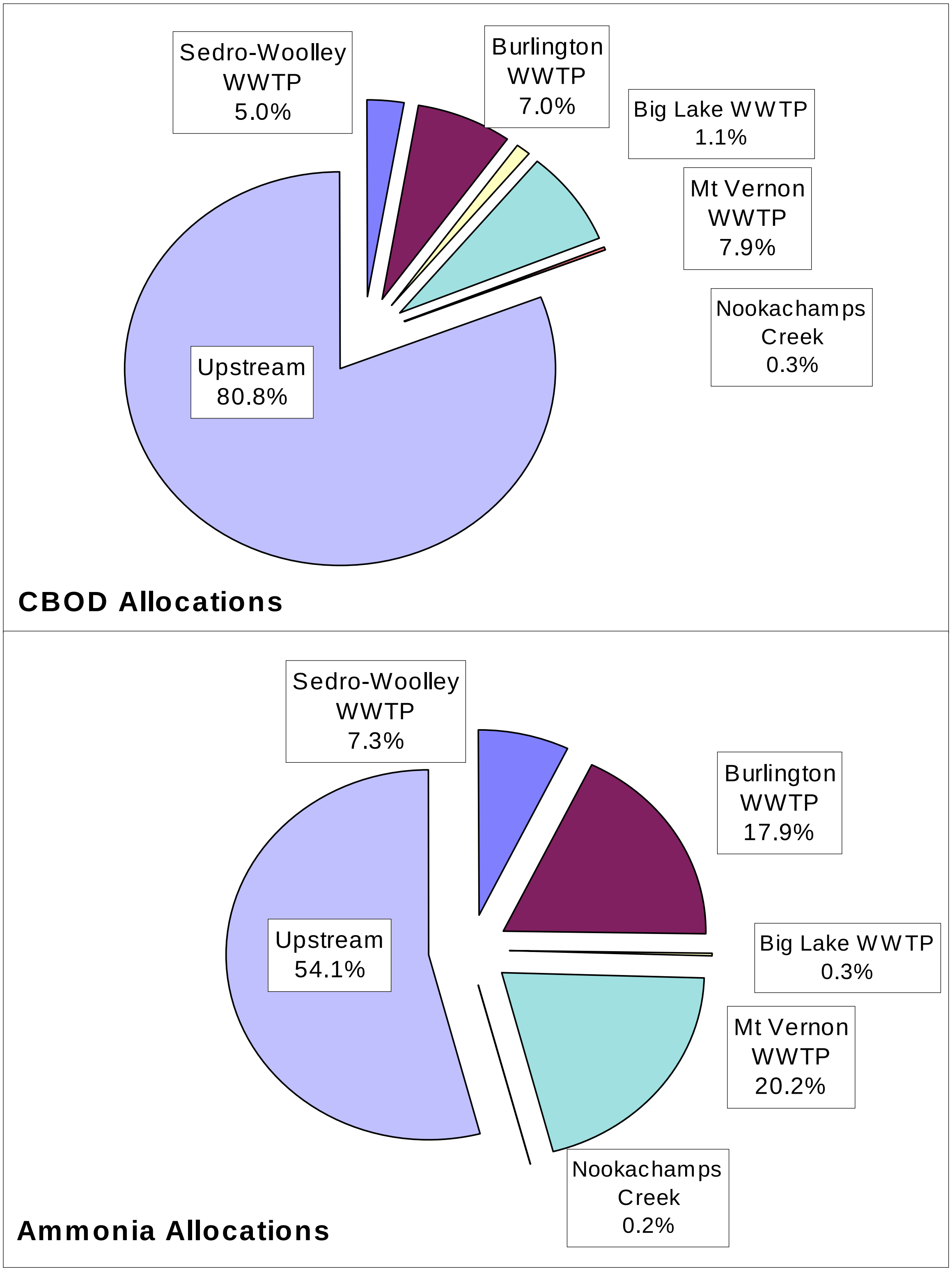

Figure 2. Lower Skagit TMDL CBOD and Ammonia Allocations (for 2015 Critical Conditions TMDL Alternative)

Implementation Considerations

Final TMDLs will only be established after the analysis of implementation alternatives with the involvement of dischargers and the public. There are a number of considerations that can be evaluated as part of the process to establish and implement a final TMDL:

- The TMDLs for ammonia nitrogen and BOD_5 depend only on maximum daily effluent loading. Therefore there is flexibility with the flows and concentrations that will meet the loading limits. TMDL limitations must be met in conjunction with technology-based CBOD limitations and toxicity-based ammonia limitations.

- For the point source discharges, 2015 design effluent flows were assumed that may be higher than actual dry season performance. The resultant loading levels are much higher than levels observed during the study. Even without reserve capacity for future growth, this suggests flexibility for accommodating increased wastewater flows from population growth.

- For each discharger there is a trade-off between ammonia and CBOD loading, and the WLAs reflect assumptions about achievable levels of these two parameters. The model is much more sensitive to ammonia than to CBOD, which means, for example that if the ammonia WLA is reduced by a small amount, then the CBOD WLA can be increased by a relatively larger amount. The final WLAs for ammonia nitrogen and BOD_5 must be determined through use of the model.

- The lower Skagit River is relatively insensitive to the location of the discharge, which could provide some flexibility for one discharge to increase its effluent loading if another discharge can reduce loading. This leaves open the possibility of creating a pollutant loading trading program for CBOD and ammonia as a means to find cost-effective solutions to the TMDL restrictions.

Fecal Coliform Bacteria Analysis

Methods

To evaluate the effect of fecal coliform loading sources on the Skagit River and Skagit Bay at the river's mouth, a steady-state mass-balance approach was used:

- FC marine standard target values were determined, which represented the FC bacteria levels in the river that would meet marine standards when the mixture of river and bay water reached 10 ppt salinity (Table 4).
- Methods were developed to predict runoff for ungaged tributaries using antecedent precipitation (Table 5). The flow balance was evaluated for each survey with a computer spreadsheet program (Table 6).
- Mass balances for FC bacteria were developed with a spreadsheet program (Table 7).
- A first-order decay process was applied to bacteria in the river, and the decay rate was determined by the best fit to observed data. The mass balances were adjusted to account for the decay rate, unmeasured loading sources, and for dynamic effects during the surveys (Table 8). The results of the adjusted mass balances were compared to the water quality standards (Table 9)
- TMDL mass balances were developed by reducing major loading sources until the FC levels in the river at the downstream boundaries (in the North and South Forks) met the marine standard target values (Tables 10 and 11).
- TMDL mass balances were developed that met the marine standards target values and also had all tributaries meeting fresh water standards (Tables 12 and 13).

Marine Standards Target Values

For the TMDL analysis, FC bacteria levels in the Skagit River were compared to the Class A and AA fresh water quality criteria. However, it is also important to evaluate the effect of bacteria in the Skagit River on Skagit Bay. For this purpose, an FC “marine standards target value” was developed, which was applied at the downstream boundary of the study area to protect marine FC standards in Skagit Bay at the mouth of the Skagit River. Table 4 shows the analysis used to develop the marine standards target values.

Table 4. Calculation of Fecal Coliform Marine Standards Target Values		
FC Marine Water Quality Standards		
(10 ppt Salinity or greater)		
Geometric Mean:	14 cfu/100 mL	
10% of Data	43 cfu/100 mL	
Salinity		
Skagit Bay:	23.8 ppt	(Median)
N & S Fork Skagit R:	0.037 ppt	
Percent Skagit River at 10 ppt Salinity		
	58.1 %	
FC Background Levels		
Skagit Bay:	0.5 cfu/100 mL	(Mean Background)
FC Marine Standards Target Values @ N & S Fork Bridges		
Geometric Mean:	24 cfu/100 mL	
10% of Data:	74 cfu/100 mL	

The WQS regulations establish Class A fecal coliform criteria for Skagit Bay of 14 cfu/100 mL (colony forming units per 100 milliliters) for the geometric mean and 43 cfu/100 mL for the upper 10% of the data used in calculating the geometric mean. Compliance with marine criteria is required at salinity levels of 10 parts per thousand (ppt) or greater. Using measured salinity levels in Skagit Bay and the Skagit River, the percentage of Skagit River water that would result in 10 ppt salinity was calculated. Then using the background FC levels found in Skagit Bay and the percentage of Skagit River at 10 ppt, target levels for bacteria in the Skagit River were derived from the marine water quality criteria. Marine standards target values are 24 cfu/100 mL to meet the geometric mean criterion and 74 cfu/100 mL to meet the 10% criterion.

Flow Balance

For each of the 10 surveys conducted, flow balances were developed. Direct measurements of flow were used for all survey stations where accurate data were collected. However, flow data were not collected or usable for some or all surveys at a number of stations. The gaps in the data are summarized as follows:

- Flows could not be directly measured at CSOs and stormwater pump stations.

- Flows were not measured at Hansen and Nookachamps Creeks during the survey of December 27-28, 1994 due to high river flows.

- Flows were not measured at Brickyard Creek, the South Sedro-Woolley storm drain, and the tributary at Riverfront Park during the October 3, 1995 survey because those sources were expected to be dry. However heavy rain during the days preceding the survey resulted in widespread stormwater runoff flows.

- Flows were measured at Carpenter/Fisher Creek during the wet season surveys, but the flows were not useful due to the tidal influence at this site. No flows were measured during the dry season surveys.

To address the gaps in flow data, several statistical methods were used to develop tools to predict runoff. A summary of the equations used for predicting inflows to the lower Skagit River is presented in Table 5.

For ungaged sources other than the CSOs, measured surface runoff was estimated by regression to the antecedent precipitation index (API). The API was proposed by Kohler and Linsley (1951) as a tool to estimate rainfall retention and release in natural watersheds. The API is a running sum of daily rainfall, calculated by adding each day's rainfall to a fraction ‘k’ of the previous day’s API. In this study API values were calculated with a ‘k’ value of 0.85 and the average of rainfall from two stations reported by the National Climatic Data Center (NCDC, 1995): “Mount Vernon 3 WNW” and “Sedro Woolley.” The choice of these parameters for calculating API was based on an evaluation of the goodness of fit of different regression equations for flow using various combinations of k and rainfall data from different locations.

Runoff was predicted from rainfall or API by using a regression model to develop a relationship between the parameters, with both the dependent and independent variables in units of depth (Ponce, 1989). The runoff for each watershed in units of depth was determined by dividing the discharge (in cfs) by the watershed area (in ft^2), and then converting the flow to inches per day. Linear and nonlinear regressions were evaluated to find the best fit for a relationship between the API and flow.

Good relationships were found for several of the tributaries using quadratic equations (of the form “ax^2+bx+c” or “ax^2+bx”, where a, b, and c are constants determined by best fit). Hansen and Nookachamps Creek had nearly identical relationships between API and flow in inches per day. Therefore, the data were pooled to develop an equation for both streams. Good relationships were also found for Brickyard Creek and for the stormwater channels near Sedro-Woolley.

Table 5. Predictive Equations used for Inputs to Lower Skagit River Flow Balance.	
Input Name	**Predictive Equation**
Hansen Creek Nookachamps Creek Britt Slough PS[1] Conway PS[1] Carpenter/Fisher Creeks[1] Rexville PS[1]	$Q_{w,t} = A_w[0.0656(API_t)^2 + 0.0743(API_t)]$
Tributary @ Riverfront Park South Sedro-Woolley SD[1]	$Q_{w,t} = A_w[0.0201(API_t)^2 + 0.0165(API_t)]$
Brickyard Creek	$Q_{w,t} = A_w[-0.0423(API_t)^2 + 0.181(API_t) - 0.0661]$, (when result is negative, $Q_{w,t} = 0.0$)
Mt. Vernon Freeway Dr PS	$Q_{w,t} = A_w[0.00104(API_t)^2 - 0.000205(API_t) + 0.0000758]$
Mt. Vernon Division St CSO	$Q_{w,t} = 1.51(P_t) + 0.211(P_{t-1})$
Mt. Vernon Westside PS	$Q_{w,t} = A_w[0.00334(API_t)^2 + 0.0000699(API_t) + 0.000394]$
Mt. Vernon Park St CSO	$Q_{w,t} = 2.719364373(P_t) + 1.351586383(P_{t-1})$
[1] Field data from these inputs not used as basis for predictive formula	$Q_{w,t}$ = Flow for watershed ‘w’ on day ‘t’. A_w = Surface area of watershed ‘w’. API_t = Antecedent Precipitation Index for day ‘t’. P_t = Daily precipitation for day ‘t’. P_{t-1} = Daily precipitation for previous day ‘t-1’.

Discharge flows from drainage district pump stations (Britt Slough, Rexville, and Conway) were not measured in this study (except for a few spot measurements). Direct measurement of daily flows would have required an extensive effort beyond the scope of this study. Indirect methods such as pump capacity curves or watershed models were also beyond the scope of this study. Therefore, since overestimating flow was the conservative approach for this analysis, the Hansen/Nookachamps flow equation, which produced the highest runoff for the observed API, was used to predict runoff for the ungaged pump stations. Also, because flow measurements for Carpenter and Fisher Creeks made in Fisher Slough near the South Fork Skagit were highly inaccurate due to tidal effects, the Hansen/Nookachamps flow equation was applied to this tributary as well.

For Mount Vernon stormwater runoff, monthly flows were available from the City of Mount Vernon (Enquist, 1996). Daily flows were predicted from the API and stormwater drainage areas (R.W. Beck, 1995) using linear and quadratic regressions, and summed to a monthly total. The quadratic regression gave the best fit to the monthly totals and was used in the mass balances.

For the CSOs, daily flows directly measured from December 1987 through August 1988 (City of Mount Vernon, 1994) were compared to the API and rainfall. A reasonably good fit was found for these sources using a bivariate linear regression of the daily flow to the daily rainfall and the previous day's rainfall.

Using measured and estimated flows, flow balances were developed for the 10 surveys using the USGS gaging station near Mount Vernon as the starting point. Inflows upstream of the Mount Vernon gage were subtracted and those downstream were added. The split in flow between the North and South Forks was estimated with HEC-RAS. (Note that the wet season surveys were conducted over two days, ending at the Mount Vernon gage on the first day and beginning at the same location on the second, which allows the flow and FC mass balances to be separately calculated for each day.)

Fecal Coliform Balance

Using the flow balances and observed fecal coliform bacteria results, mass balances for each of the 10 surveys were developed. First-order decay was used to model bacterial die-off. This approach has been used with success by other researchers (Thomann and Mueller, 1987; Mancini, 1978). The equation that predicts the bacteria concentration after a time period of duration t (C_t) as a function of the initial concentration (C_o) is of the form: $C_t = C_0 e^{(-Kt)}$. The rate coefficient K is temperature dependent, so the value of K at a temperature T (K_T) is predicted from the value of K at 20°C (K_{20}) with the equation: $K_T = K_{20}[\theta^{(T-20)}]$. A θ of 1.07 was used as recommended by Mancini (1978). The value of K_{20} for the FC analysis was determined from observed temperatures and the best fit of the mass balances to observed data from selected surveys with the fewest data gaps.

The mass balances using original data were adjusted by applying the decay rate. Time of travel values for the decay equations were determined from HEC-RAS results. After including FC decay, the 10 mass balances were then adjusted again to more closely match observed results in the Skagit River by estimating the FC levels of unmeasured sources and the distribution of loading between the North and South Forks. The adjustments made were based on an analysis of results, and are discussed in the Results section.

To evaluate compliance with the Water Quality Standards and for comparison with permit limits for FC, a geometric mean was calculated from the means of three consecutive wet season mass balances (resulting in six averaging periods of four weeks) and the two dry season mass balances, for a total of 7 averaging periods. For each input source or each calculation point in the river, the geometric mean and the highest value from each averaging period were compared to the applicable criteria. The geometric means from each averaging period were compared to either:

- the Class A geometric mean criteria;
- the Class AA geometric mean criteria;
- the marine standards geometric mean target value; or
- the monthly average permit limits.

The highest values from each averaging period was compared to either:

- the Class A 10% criteria;
- the Class AA 10% criteria;
- the marine standards 10% target value; or
- the weekly average permit limitation.

Fecal Coliform TMDL

TMDL mass balances were developed from the adjusted mass balances by reducing FC bacteria levels at the upstream boundary and in tributaries where necessary to meet TMDL objectives. This was accomplished by:

- Setting NPDES permitted point source loading to comply with permit limitations.
- Applying a percent change in loading to the data from each source (except CSOs). The percent change is applied equally to the 10 surveys for each source.

- Reducing CSO loading consistent with the Mount Vernon CSO reduction plan (City of Mount Vernon, 1994). This plan proposes restricting CSO discharges to one per year. Consistent with this restriction, all CSO discharges were set to zero except that, as a conservative assumption, the two surveys with the highest projected CSO discharges were retained. (The requirement for one discharge per year is based on statistical probability, so two discharges per year is possible. Also, the two discharges from the survey were in two different calendar years.)

A TMDL mass balance was developed in which calculated values at the downstream boundaries of the North and South Forks of the Skagit River met FC target levels by reducing the most significant bacteria sources (those that had the greatest impact on Skagit River bacteria levels). A second TMDL mass balance was evaluated in which CSOs and unidentified sources were abated, and all other bacteria sources were reduced to meet the water quality standards.

To determine how tributary FC load reductions affected Skagit River FC levels and where load reductions would produce the greatest benefit to the river, the sensitivity of the mass balance model was analyzed. The flow balance for October was used, because the balance was calculated for a single day with no break at Mount Vernon. Each tributary was assigned the highest FC concentration found during the 10 surveys. Then each tributary was reduced by either 50% or 90%, and the response to the river at the downstream boundaries to each tributary's reduction was observed.

Results

Fecal Coliform Balance

The flow balances developed for the 10 surveys are shown in Table 6. The lower Skagit River fecal coliform mass balances developed from the flow balances and observed fecal coliform bacteria results are shown in Table 7.

To determine a FC decay rate (K_{20}), different rate values were selected and used in the FC mass balances until a best fit was found between predicted and observed. The nine surveys in January through April were used for finding K_{20} since these had the best flow and load measurements and the fewest data gaps. Several different methods were tried to calculate a best fit, and most gave values of K_{20} that were either zero or much higher than literature values (EPA, 1985; Mancini, 1978). A method was found to evaluate the best fit that gave a reasonable result: residuals were calculated between observed data and predicted data from the mass balances, and the arithmetic mean of the residuals was calculated, with the goal of finding an average residual of 0.0 cfu/100 mL. The K_{20} determined in this fashion and used in this study was 0.048 hr^{-1}. This value falls within the range of literature values (EPA, 1985), and is slightly higher than the value for K_{20} of 0.033 hr^{-1} suggested by Mancini (1978).

The distribution of residuals for the FC mass balance were evaluated using original data. The greatest errors are found for the North and South Forks, and for the October 1995 survey. The Forks are complicated by tidal effects and the differential split of loading into the two branches (as described above for DO). In the October survey, bacteria were not measured in many of the inflow sources.

To better predict FC values in the lower Skagit River, adjustments were made to the inputs in the mass balances. The adjusted mass balance is shown in Table 8. The following changes were made to the mass balances:

- For the December 28 balance, upstream concentrations at Mount Vernon were adjusted upward. Due to flood conditions, concentrations appear to have been dropping rapidly at Mount Vernon on the 28th, and the observed values in the Forks likely represented higher levels from earlier conditions.

- Bacteria levels measured on February 8 in the North Fork were much higher than the levels predicted by the mass balance (in contrast to a good prediction in the South Fork). This suggests a significant source of bacterial loading somewhere in the North Fork. This loading source was estimated with a new input.

In both the September and October 1995 surveys, observed values in the Skagit River indicated a significant source of bacterial loading between RM 15.8 (the Mount Vernon USGS gaging station at the Old Highway 99 bridge) and RM 12.1 (upstream of Kulshan Creek). This loading source was estimated with a new input.

- FC values for inputs not sampled during the October survey were estimated by using the maximum values for each unmeasured input from the other nine surveys, and then adjusting input values downward to match observed values in the river.

As evidenced by survey results and the DO analysis described above, a greater proportion of the sources in the Mount Vernon area on the left bank (perhaps as far upstream as Kulshan Creek) are transported to the South Fork as compared to the split in flow. However, an analysis of all discharges to determine the split of their loading between the Forks would be fairly complex and was not attempted. Instead, the mass balances were adjusted by splitting the loading at the Forks at a different proportion than for flow, so that predicted results matched observed values in the Forks. The adjusted FC mass balances were then compared to the Water Quality Standards, NPDES permit limitations, and marine standards target values at the downstream boundaries of the study. Table 9 shows the results of the analysis, which used the methodology described above in "Compliance with Standards and Limitations". This analysis gave the following results:

- During the first 4 weeks of the study the upstream boundary exceeded Class AA standards, many of the surface water tributaries exceeded Class A standards, and the marine standard target values were exceeded in the North Fork.

Table 6. Lower Skagit River Flow Balance

(All flows in cfs)

		27-28 Dec 94		10-11 Jan 95		24-25 Jan 95		7-8 Feb 95		21-22 Feb 95	
Station Name	RM	Input	River	Input	River	Input	River	Input	River	Input	River
Skagit R above Sedro-Woolley	24.6		38460		15993		15534		25096		46268
Hansen Creek	24.3	64.6	38524	23.2	16017	16.8	15550	5.7	25102	121.2	46389
Northern St. Hospital SD	24.2	0.0	38524	0.0	16017	0.0	15550	0.0	25102	0.0	46389
Tributary @ Riverfront Park	23.6	0.0	38524	0.0	16017	0.0	15550	0.0	25102	0.9	46390
South Sedro-Woolley SD	22.9	0.0	38524	0.1	16017	0.0	15550	0.3	25102	0.7	46391
Sedro-Woolley WWTP	22.8	1.4	38526	0.9	16018	0.7	15551	1.0	25103	1.7	46393
Brickyard Creek	21.1	20.8	38547	0.4	16018	0.4	15551	1.7	25105	18.2	46411
Skagit R abv Nookachamps Ck	19.0		38547		16018		15551		25105		46411
Nookachamps Creek	18.8	451	38997	180	16198	146	15698	193	25298	886	47297
Burlington WWTP	18.1	2.7	39000	2.1	16200	2.1	15700	2.2	25300	3.2	47300
Skagit R at Mt. Vernon (Day 1)	15.8		39000		16200		15700		25300		47300
Skagit R at Mt. Vernon (Day 2)	15.8		55700		18200		15100		23500		39200
Gages Slough PS	14.6	0.0	55700	0.0	18200	0.0	15100	0.0	23500	0.0	39200
Skagit R above Division St.	12.1		55700		18200		15100		23500		39200
Frontage Rd PS/Kulshan Ck	11.9	4.7	55705	1.1	18201	0.3	15100	0.4	23500	1.8	39202
Freeway Dr PS	11.9	0.02	55705	0.00	18201	0.00	15100	0.00	23500	0.03	39202
Division St CSO	11.4	0.07	55705	0.03	18201	0.00	15100	0.00	23500	0.00	39202
Westside PS	11.0	0.12	55705	0.02	18201	0.01	15100	0.03	23500	0.19	39202
Park St CSO	10.9	0.43	55705	0.20	18201	0.00	15100	0.01	23500	0.01	39202
Mt. Vernon WWTP	10.7	7.7	55713	5.2	18206	4.2	15105	5.1	23506	7.4	39209
Skagit River above N/S Forks	8.7		55713		18206		15105		23506		39209
Britt Slough PS	8.3	5.3	55718	1.0	18208	0.5	15105	1.4	23507	7.9	39217
South Fork			21658		6392		5256		8377		14595
Big Lake WWTP	7.8	0.1	21658	0.1	6392	0.2	5256	0.1	8377	0.1	14595
South Fork Skagit R at Conway	4.3		21658		6392		5256		8377		14595
Conway PS	4.4	53.1	21711	10.5	6403	5.3	5261	14.2	8392	79.4	14674
Carpenter/Fisher Creeks	3.1	218	21929	43.0	6446	21.7	5283	58.4	8450	326	15000
North Fork			34060		11816		9849		15130		24623
Rexville PS	4.2	97.3	34158	19.2	11835	9.7	9859	26.0	15156	146	24768
North Fork Skagit R at Rexville	4.1		34158		11835		9859		15156		24768

Table 6, continued

(All flows in cfs)

Station Name	RM	7-8 Mar 95 Input	7-8 Mar 95 River	21-22 Mar 95 Input	21-22 Mar 95 River	4-5 Apr 95 Input	4-5 Apr 95 River	19 Sept 95 Input	19 Sept 95 River	3 Oct 95 Input	3 Oct 95 River
Skagit R above Sedro-Woolley	24.6		17098		20998		14336		7694		11406
Hansen Creek	24.3	19.5	17117	34.4	21033	27.4	14364	0.0	7694	12.2	11418
Northern St. Hospital SD	24.2	0.0	17117	0.0	21033	0.0	14364	0.0	7694	0.0	11418
Tributary @ Riverfront Park	23.6	0.0	17117	0.0	21033	0.0	14364	0.0	7694	0.9	11419
South Sedro-Woolley SD	22.9	0.5	17118	0.3	21033	5.7	14369	0.0	7694	2.3	11421
Sedro-Woolley WWTP	22.8	0.8	17119	1.1	21034	0.9	14370	1.0	7695	1.0	11422
Brickyard Creek	21.1	1.4	17120	3.6	21038	3.4	14374	0.0	7695	14.6	11437
Skagit R abv Nookachamps Ck	19.0		17120		21038		14374		7695		11437
Nookachamps Creek	18.8	78.0	17198	360	21398	124	14498	2.9	7698	162	11599
Burlington WWTP	18.1	2.0	17200	2.3	21400	2.0	14500	1.6	7700	1.4	11600
Skagit R at Mt. Vernon (Day 1)	15.8		17200		21400		14500		7700		11600
Skagit R at Mt. Vernon (Day 2)	15.8		17100		20900		15000				
Gages Slough PS	14.6	0.5	17101	0.7	20901	0.6	15001	0.0	7700	0.0	11600
Skagit R above Division St.	12.1		17101		20901		15001		7700		11600
Frontage Rd PS/Kulshan Ck	11.9	0.3	17101	0.5	20901	0.6	15001	0.0	7700	0.4	11600
Freeway Dr PS	11.9	0.00	17101	0.01	20901	0.01	15001	0.00	7700	0.02	11600
Division St CSO	11.4	0.06	17101	0.03	20901	0.16	15001	0.00	7700	0.40	11601
Westside PS	11.0	0.02	17101	0.03	20901	0.04	15001	0.00	7700	0.10	11601
Park St CSO	10.9	0.11	17101	0.05	20901	0.81	15002	0.00	7700	1.58	11602
Mt. Vernon WWTP	10.7	4.3	17105	5.3	20907	6.1	15008	3.8	7704	6.8	11609
Skagit River above N/S Forks	8.7		17105		20907		15008		7704		11609
Britt Slough PS	8.3	1.0	17106	1.9	20908	2.3	15011	0.1	7704	4.9	11614
South Fork			5986		7397		5222		2623		4000
Big Lake WWTP	7.8	0.1	5987	0.1	7397	0.1	5222	0.1	2623	0.1	4001
South Fork Skagit R at Conway	4.3		5987		7397		5222		2623		4001
Conway PS	4.4	10.0	5997	19.0	7416	23.1	5245	0.0	2623	48.7	4049
Carpenter/Fisher Creeks	3.1	41.3	6038	77.9	7494	94.8	5339	3.7	2623	200	4049
North Fork			11120		13512		9789		5081		7614
Rexville PS	4.2	18.4	11138	34.8	13546	42.3	9831	1.7	5082	89.2	7703
North Fork Skagit R at Rexville	4.1		11138		13546		9831		5082		7703

Table 7. Fecal Coliform Mass Balance - Original Data

(In = Input Values; O = Observed Values; B = Mass Balance Results)

		27-28 Dec 94 (cfu/100mL)			10-11 Jan 95 (cfu/100mL)			24-25 Jan 95 (cfu/100mL)			7-8 Feb 95 (cfu/100mL)			21-22 Feb 95 (cfu/100mL)		
			River			River			River			River			River	
Station Name	RM	In	O	B	In	O	B	In	O	B	In	O	B	In	O	B
Skagit R above Sedro-Woolley	24.6		154	154		5	5		1	1		1	1		24	24
Hansen Creek	24.3	130		154	50		5	52		1	32		1	46		24
Northern St. Hospital SD	24.2	0		154	0		5	0		1	0		1	0		24
Tributary @ Riverfront Park	23.6	670		153	58		5	0		1	124		1	46		24
South Sedro-Woolley SD	22.9	9995		152	10342		5	77		1	38		1	309		23
Sedro-Woolley WWTP	22.8	19		152	6		5	203		1	39		1	97		23
Brickyard Creek	21.1	2020		151	637		5	11		1	34		1	464		23
Skagit R abv Nookachamps Ck	19.0			149			5			1			1			23
Nookachamps Creek	18.8			147	130		6	29		2	190		3	240		27
Burlington WWTP	18.1	8		146	3		6	1		2	125		3	1		27
Skagit R at Mt. Vernon (Day 1)	15.8		139	144		9	6		1	2		1	3		31	27
Skagit R at Mt. Vernon (Day 2)	15.8		60	60		5	5		1	1		1	1		37	37
Gages Slough PS	14.6			59	0		5	0		1	0		1	24		37
Skagit R above Division St.	12.1			58			5			1			1			36
Frontage Rd PS/Kulshan Ck	11.9	470		58	807		5	34		1	61		1	218		36
Freeway Dr PS	11.9	147		58	610		5	8		1	230		1	164		36
Division St CSO	11.4	209762		58	144914		5	481871		1			1	60498		36
Westside PS	11.0	315		58	708		5	278		1	9322		1	1844		36
Park St CSO	10.9	14866		58	8944		5	3541		1	4343		1	80975		36
Mt. Vernon WWTP	10.7	185		58	54		5	1		1	3		1	24		36
Skagit River above N/S Forks	8.7			58			5			1			1			36
Britt Slough PS	8.3	23		58	100		5	50		1	33		1	12		35
South Fork				58			5			1			1			35
Big Lake WWTP	7.8	33		58	1		5	1		1	1		1	2		35
South Fork Skagit R at Conway	4.3		71	56		8	5		3	1		3	1		26	34
Conway PS	4.4	107		57	1		5	2		1	1		1	100		35
Carpenter/Fisher Creeks	3.1	107		57	73		5	13		1	42		2	101		36
North Fork				58			5			1			1			35
Rexville PS	4.2	2398		63	134		5	9		1	140		2	309		36
North Fork Skagit R at Rexville	4.1		78	63		7	5		1	1		29	5		31	36

Table 7, continued

(In = Input Values; O = Observed Values; B = Mass Balance Results)

Station Name	RM	7-8 Mar 95 (cfu/100mL)			21-22 Mar 95 (cfu/100mL)			4-5 Apr 95 (cfu/100mL)			19 Sept 95 (cfu/100mL)			3 Oct 95 (cfu/100mL)		
			River			River			River			River			River	
		In	O	B	In	O	B	In	O	B	In	O	B	In	O	B
Skagit R above Sedro-Woolley	24.6		1	1		2	2		1	1		3	3		39	39
Hansen Creek	24.3	13		1	31		2	2592		6	0		3	2078		41
Northern St. Hospital SD	24.2	0		1	13		2	0		6	0		3			41
Tributary @ Riverfront Park	23.6	46		1	379		2	0		6	0		3			41
South Sedro-Woolley SD	22.9	1889		1	554		2	195		6	0		3			40
Sedro-Woolley WWTP	22.8	103		1	13491		3	36742		9	481		3	123		40
Brickyard Creek	21.1	29		1	510		3	841		9	0		3			39
Skagit R abv Nookachamps Ck	19.0			1			3			9		4	3		42	38
Nookachamps Creek	18.8	17		1	119		4	256		11	94		3	1056		53
Burlington WWTP	18.1	2		1	5		4	50		11	25		3	7		52
Skagit R at Mt. Vernon (Day 1)	15.8		1	1		4	4		5	10		3	3		79	50
Skagit R at Mt. Vernon (Day 2)	15.8		2	2		2	2		5	5						
Gages Slough PS	14.6	1		2	76		2	32		5			32			84
Skagit R above Division St.	12.1			2			2			5		32	30		117	80
Frontage Rd PS/Kulshan Ck	11.9	36		2	190		2	2400		5	1997		30	1265		80
Freeway Dr PS	11.9	61		2	35		2	2398		5			30			80
Division St CSO	11.4			2			2	0		5			29			79
Westside PS	11.0	474		2	2398		2	2337		5			29			78
Park St CSO	10.9	1918		2	2198		2	259230		19			29			78
Mt. Vernon WWTP	10.7	4		2	2		2	46		19	2307		30	2863		79
Skagit River above N/S Forks	8.7			2			2			18		24	27		96	76
Britt Slough PS	8.3	33		2	120		2	90		18			27			75
South Fork				2			2			18			27			75
Big Lake WWTP	7.8	3		2	1		2	1		18	16		26	27		74
South Fork Skagit R at Conway	4.3		3	2		4	2		4	17		44	21		147	65
Conway PS	4.4	1		2	10		2	36		17			21			64
Carpenter/Fisher Creeks	3.1	160		3	205		4	309		22			21			64
North Fork				2			2			18			27			75
Rexville PS	4.2	11		2	47		2	1		17			21			65
North Fork Skagit R at Rexville	4.1		3	2		5	2		4	17		22	37		101	65

Table 8. Fecal Coliform Mass Balance - Adjusted Data

(In = Input Values; O = Observed Values; B = Mass Balance Results)

		27-28 Dec 94 (cfu/100mL)			10-11 Jan 95 (cfu/100mL)			24-25 Jan 95 (cfu/100mL)			7-8 Feb 95 (cfu/100mL)			21-22 Feb 95 (cfu/100mL)		
			River			River			River			River			River	
Station Name	RM	In	O	B	In	O	B	In	O	B	In	O	B	In	O	B
Skagit R above Sedro-Woolley	24.6		154	154		5	5		1	1		1	1		24	24
Hansen Creek	24.3	130		154	50		5	52		1	32		1	46		24
Northern St. Hospital SD	24.2	0		154	0		5	0		1	0		1	0		24
Tributary @ Riverfront Park	23.6	670		153	58		5	0		1	124		1	46		24
South Sedro-Woolley SD	22.9	9995		152	10342		5	77		1	38		1	309		23
Sedro-Woolley WWTP	22.8	19		152	6		5	203		1	39		1	97		23
Brickyard Creek	21.1	2020		151	637		5	11		1	34		1	464		23
Skagit R abv Nookachamps Ck	19.0			149			5			1			1			23
Nookachamps Creek	18.8	0		147	130		6	29		2	190		3	240		27
Burlington WWTP	18.1	8		146	3		6	1		2	125		3	1		27
Skagit R at Mt. Vernon (Day 1)	15.8		139	144		9	6		1	2		1	3		31	27
Skagit R at Mt. Vernon (Day 2)	15.8		60	75		5	5		1	1		1	1		37	37
Gages Slough PS	14.6	0		74	0		5	0		1	0		1	24		37
Possible Unidentified Source	14.6															
Skagit R above Division St.	12.1			73			5			1			1			36
Frontage Rd PS/Kulshan Ck	11.9	470		73	807		5	34		1	61		1	218		36
Freeway Dr PS	11.9	147		73	610		5	8		1	230		1	164		36
Division St CSO	11.4	209762		73	144914		5	481871		1	100000		1	60498		36
Westside PS	11.0	315		73	708		5	278		1	9322		1	1844		36
Park St CSO	10.9	14866		73	8944		5	3541		1	4343		1	80975		36
Mt. Vernon WWTP	10.7	185		73	54		5	1		1	3		1	24		36
Skagit River above N/S Forks	8.7			73			5			1			1			36
Britt Slough PS	8.3	23		73	100		5	50		1	33		1	12		35
South Fork				73			5			1			1			35
Big Lake WWTP	7.8	33		72	1		5	1		1	1		1	2		35
South Fork Skagit R at Conway	4.3		71	71		8	5		3	1		3	1		26	34
Conway PS	4.4	107		71	1		5	2		1	1		1	100		35
Carpenter/Fisher Creeks	3.1	107		71	73		5	13		1	42		2	101		36
North Fork				73			5			1			1			35
Rexville PS	4.2	2398		78	134		5	9		1	140		2	309		36
Possible Unidentified Source	4.2										(??)		28			
North Fork Skagit R at Rexville	4.1		78	78		7	5		1	1		29	28		31	36

Table 8, continued

(In = Input Values; O = Observed Values; B = Mass Balance Results)

		7-8 Mar 95 (cfu/100mL)			21-22 Mar 95 (cfu/100mL)			4-5 Apr 95 (cfu/100mL)			19-Sep-95 (cfu/100mL)			3-Oct-95 (cfu/100mL)		
			River			River			River			River			River	
Station Name	RM	In	O	B	In	O	B	In	O	B	In	O	B	In	O	B
Skagit R above Sedro-Woolley	24.6		1	1		2	2		1	1		3	3		39	39
Hansen Creek	24.3	13		1	31		2	2592		6	0		3	2078		41
Northern St. Hospital SD	24.2	0		1	13		2	0		6	0		3	13		41
Tributary @ Riverfront Park	23.6	46		1	379		2	0		6	0		3	670		41
South Sedro-Woolley SD	22.9	1889		1	554		2	195		6	0		3	10342		42
Sedro-Woolley WWTP	22.8	103		1	13491		3	36742		9	481		3	123		42
Brickyard Creek	21.1	29		1	510		3	841		9	0		3	2020		44
Skagit R abv Nookachamps Ck	19.0			1			3			9		4	3		42	43
Nookachamps Creek	18.8	17		1	119		4	256		11	94		3	2852		82
Burlington WWTP	18.1	2		1	5		4	50		11	25		3	7		81
Skagit R at Mt. Vernon (Day 1)	15.8		1	1		4	4		5	10		3	3		79	78
Skagit R at Mt. Vernon (Day 2)	15.8		2	2		2	2		5	5						
Gages Slough PS	14.6	1		2	76		2	32		5			3			76
Possible Unidentified Source	14.6										(??)		32	(??)		111
Skagit R above Division St.	12.1			2			2			5		32	30		117	106
Frontage Rd PS/Kulshan Ck	11.9	36		2	190		2	2400		5	1997		30	1265		106
Freeway Dr PS	11.9	61		2	35		2	2398		5			30	2398		106
Division St CSO	11.4	100000		2	100000		2	1		5			29	481871		121
Westside PS	11.0	474		2	2398		2	2337		5			29	9322		120
Park St CSO	10.9	1918		2	2198		2	259230		19			29	259230		155
Mt. Vernon WWTP	10.7	4		2	2		2	46		19	2307		30	2863		156
Skagit River above N/S Forks	8.7			2			2			18		24	27		96	149
Britt Slough PS	8.3	33		2	120		2	90		18			27	100		148
South Fork				2			2			18			39			172
Big Lake WWTP	7.8	3		2	1		2	1		18	16		39	27		170
South Fork Skagit R at Conway	4.3		3	2		4	2		4	17		29	30		147	149
Conway PS	4.4	1		2	10		2	36		17			30	107		148
Carpenter/Fisher Creeks	3.1	160		3	205		4	309		22			30	309		163
North Fork				2			2			18			20			135
Rexville PS	4.2	11		2	47		2	1		17	0		16	100		118
Possible Unidentified Source	4.2															
North Fork Skagit R at Rexville	4.1		3	2		5	2		4	17		22	16		101	118

Table 9. Compliance with Standards - Adjusted Mass Balance

(bold values exceed targets)

		Monthly Geometric Means							
Station Name	RM	12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	***Target Value***
Skagit R above Sedro-Woolley	24.6	10	2	4	3	4	1	11	*50*
Hansen Creek	24.3	70	44	42	27	27	**102**		*100*
Northern St. Hospital SD	24.2								*100*
Tributary @ Riverfront Park	23.6				64	93			*100*
South Sedro-Woolley SD	22.9	**1997**	**313**	97	**282**	**687**	**589**		*100*
Sedro-Woolley WWTP	22.8	28	36	92	73	**513**	**3707**	**243**	*200*
Brickyard Creek	21.1	**242**	62	56	77	**189**	**231**		*100*
Skagit R abv Nookachamps Ck	19.0	10	2	3	3	4	3	11	*100*
Nookachamps Creek	18.8	61	89	**110**	92	78	80	**517**	*100*
Burlington WWTP	18.1	3	7	5	7	2	8	13	*200*
Skagit R at Mt. Vernon (Day 1)	15.8	11	3	5	4	5	4	15	*100*
Skagit R at Mt. Vernon (Day 2)	15.8	8	2	4	5	5	3		*100*
Gages Slough PS	14.6					12	13		*100*
Skagit R above Division St.	12.1	8	2	4	5	5	3	56	*100*
Frontage Rd PS/Kulshan Ck	11.9	**234**	**119**	77	79	**115**	**255**	**1590**	*100*
Freeway Dr PS	11.9	90	**104**	67	132	71	**173**		*100*
Division St CSO	11.4	**244675**	**191138**	**142853**	**84576**	**84576**			*100*
Westside PS	11.0	**396**	**1225**	**1685**	**2012**	**1279**	**1385**		*100*
Park St CSO	10.9	**7780**	**5162**	**10759**	**8770**	**6989**	**10301**		*100*
Mt. Vernon WWTP	10.7	22	5	4	6	6	7	**2570**	*200*
Skagit River above N/S Forks	8.7	8	2	4	5	5	4	64	*100*
Britt Slough PS	8.3	49	55	27	23	36	71		*100*
South Fork		8	2	4	5	5	4	82	*100*
Big Lake WWTP	7.8	4	1	1	2	2	2	21	*200*
South Fork Skagit R at Conway	4.3	7	2	4	4	5	4	**67**	*24*
Conway PS	4.4	6	1	6	5	10	7		*100*
Carpenter/Fisher Creeks	3.1	47	34	38	88	**149**	**216**		*100*
South Fork Skagit R blw Conway	3.1	8	2	4	6	8	7	**71**	*24*
North Fork		8	2	4	5	5	4	52	*100*
Rexville PS	4.2	**143**	55	73	78	54	9		*100*
North Fork Skagit R at Rexville	4.1	8	6	11	13	5	4	**44**	*24*

Table 9, continued

Station Name	RM	10th Percentile of Monthly Values 12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	***Target Value***
Skagit R above Sedro-Woolley	24.6	**154**	5	24	24	24	2	39	*100*
Hansen Creek	24.3	130	52	52	46	46	**2592**	**2078**	*200*
Northern St. Hospital SD	24.2	0	0	0	0	13	13		*200*
Tributary @ Riverfront Park	23.6	**670**	124	124	124	**379**	**379**		*200*
South Sedro-Woolley SD	22.9	**10342**	**10342**	**309**	**1889**	**1889**	**1889**		*200*
Sedro-Woolley WWTP	22.8	203	203	203	103	**13491**	**36742**	**481**	*400*
Brickyard Creek	21.1	**2020**	**637**	**464**	**464**	**510**	**841**		*200*
Skagit R abv Nookachamps Ck	19.0	149	5	23	23	23	9	43	*200*
Nookachamps Creek	18.8	130	190	**240**	**240**	**240**	**256**	**2852**	*200*
Burlington WWTP	18.1	8	125	125	125	5	50	25	*400*
Skagit R at Mt. Vernon (Day 1)	15.8	144	6	27	27	27	10	78	*200*
Skagit R at Mt. Vernon (Day 2)	15.8	75	5	37	37	37	5	0	*200*
Gages Slough PS	14.6	0	0	24	24	76	76		*200*
Skagit R above Division St.	12.1	73	5	36	36	36	5	106	*200*
Frontage Rd PS/Kulshan Ck	11.9	**807**	**807**	**218**	**218**	**218**	**2400**	**1997**	*200*
Freeway Dr PS	11.9	**610**	**610**	**230**	**230**	164	**2398**		*200*
Division St CSO	11.4	**481871**	**481871**	**481871**	**100000**	**100000**	**100000**		*200*
Westside PS	11.0	**708**	**9322**	**9322**	**9322**	**2398**	**2398**		*200*
Park St CSO	10.9	**14866**	**8944**	**80975**	**80975**	**80975**	**259230**		*200*
Mt. Vernon WWTP	10.7	185	54	24	24	24	46	**2863**	*400*
Skagit River above N/S Forks	8.7	73	5	36	36	36	18	149	*200*
Britt Slough PS	8.3	100	100	50	33	120	120		*200*
South Fork		73	5	35	35	35	18	172	*200*
Big Lake WWTP	7.8	33	1	2	3	3	3	27	*400*
South Fork Skagit R at Conway	4.3	71	5	34	34	34	17	**149**	*74*
Conway PS	4.4	107	2	100	100	100	36		*200*
Carpenter/Fisher Creeks	3.1	107	73	101	160	**205**	**309**		*200*
South Fork Skagit R blw Conway	3.1	71	5	36	36	36	22	**163**	*74*
North Fork		73	5	35	35	35	18	135	*200*
Rexville PS	4.2	**2398**	140	**309**	**309**	**309**	47		*200*
North Fork Skagit R at Rexville	4.1	**78**	28	36	36	36	17	**118**	*74*

During the rest of the winter and spring months some of the surface water tributaries exceeded Class A standards, but the Skagit River met Water Quality Standards and the North and South Forks met the marine standards target levels.

- During the September/October sampling period many of the surface water tributaries exceeded Class A standards, and both the North and South Forks exceeded the marine standards target levels.

Fecal Coliform TMDL

To develop a TMDL for FC in the Skagit River, mass balances were developed with the load reductions needed to comply with the marine standards at the mouth of the river by meeting the marine standards target values at the downstream boundary of the study area. Table 10 shows the TMDL mass balances for meeting marine standards, and Table 11 shows how these mass balances comply with the WQS and marine standards target values.

To develop TMDL mass balances for meeting marine standards, the following changes were made to the adjusted mass balances:

- After point sources were set to be in compliance with permit limitations, loading was then increased to reflect projected growth for the year 2015 (Shervey, 1996). The percent increase is shown in the third column of Table 10.

- All CSO discharges were set to zero except for two surveys with the highest projected CSO discharges (as described in Methods).

- FC loading levels for selected tributary sources were reduced. Each tributary was reduced by a flat percentage that changed all survey results equally. The sources selected were those with the greatest impact on FC concentrations at the river's mouth: the upstream boundary, Nookachamps Creek, the unidentified source at RM 14.6, Carpenter/Fisher Creeks, and the Rexville pump station (see Implementation Considerations below). FC concentration in the two creeks were reduced to meet surface water quality criteria, and the other sources were reduced to the level necessary to meet the marine standards target values. The percentage reductions applied are shown in Table 10.

The WQS regulation requires that all surface waters of the state meet the water quality standards, except were Ecology has authorized a mixing zone or modification. Therefore, the Ecology’s long-term goal is to ensure the attainment of standards in all waters. TMDL mass balances were developed based on all tributary and upstream surface waters complying with fresh water quality criteria. Tables 12 and 13 show the TMDL mass balances and compliance with standards, respectively, for the scenario where the standards are met at all locations.

To develop these mass balances, the following changes were made to the previous TMDL mass balances:

- All surface water tributary FC concentrations met the Class A Water Quality Standards. Where necessary, tributary concentrations were reduced by a flat percentage that changed all survey results equally. The percentage reduction required is shown in Table 12.

- All possible unidentified sources found in the surveys were reduced to zero.

Table 13 shows that if all surface water inflows tributary to the Skagit River were to meet freshwater standards, an additional margin of safety is provided for compliance with marine standards at the river's mouth.

In summary, a TMDL for FC in the lower Skagit River is recommended that will protect fresh water quality standards in the Skagit River and its North and South Forks, and marine water quality standards at the river's mouth. The allocations for the TMDL are as follows:

Wasteload Allocations:

- All NPDES permitted dischargers meet technology-based permit limitations.

- CSOs are abated to meet goal of no more than one discharge per year.

Load Allocations:

- FC bacteria in the Skagit River upstream of Sedro-Woolley must meet target levels that are lower than Class AA water quality standards. Target values for this location that will protect the marine standards at the river's mouth are: 6 cfu/100 mL as a geometric mean, with no more than 10% of the samples used to calculate the mean exceeding 80 cfu/100 mL.

- Nookachamps, Carpenter, and Fisher Creeks must meet the Class A Water Quality Standards.

Table 10. TMDL Fecal Coliform Mass Balance - Marine Standards Met at Mouth

(In = Input Values; B = River Mass Balance Results)
(All values FC bacteria in cfu/100mL)

Station Name	RM	Percent Change	27-28 Dec In	27-28 Dec B	10-11 Jan In	10-11 Jan B	24-25 Jan In	24-25 Jan B	7-8 Feb In	7-8 Feb B	21-22 Feb In	21-22 Feb B
Skagit R above Sedro-Woolley	24.6	-48.0%		80		2		1		1		12
Hansen Creek	24.3	0.0%	130	80	50	3	52	1	32	1	46	12
Northern St. Hospital SD	24.2	0.0%	0	80	0	2	0	1	0	1	0	12
Tributary @ Riverfront Park	23.6	0.0%	670	80	58	2	0	1	124	1	46	12
South Sedro-Woolley SD	22.9	0.0%	9995	79	10342	3	77	1	38	1	309	12
Sedro-Woolley WWTP	22.8	8.9%	19	79	6	3	203	1	39	1	97	12
Brickyard Creek	21.1	0.0%	2020	79	637	3	11	1	34	1	464	12
Skagit R abv Nookachamps Ck	19.0			78		2		1		1		12
Nookachamps Creek	18.8	-93.0%	0	77	9	3	2	1	13	1	17	12
Burlington WWTP	18.1	152.5%	8	77	3	3	1	1	125	1	1	12
Skagit R at Mt. Vernon (Day 1)	15.8			75		2		1		1		12
Skagit R at Mt. Vernon (Day 2)	15.8			75		5		1		1		37
Gages Slough PS	14.6	0.0%	0	74	0	5	0	1	0	1	24	37
Possible Unidentified Source	14.6	-67.0%										
Skagit R above Division St.	12.1			73		5		1		1		36
Frontage Rd PS/Kulshan Ck	11.9	0.0%	470	73	807	5	34	1	61	1	218	36
Freeway Dr PS	11.9	0.0%	147	73	610	5	8	1	230	1	164	36
Division St CSO	11.4		209762	73		5		1		1	60498	36
Westside PS	11.0	0.0%	315	73	708	5	278	1	9322	1	1844	36
Park St CSO	10.9		14866	73		5		1		1	80975	36
Mt. Vernon WWTP	10.7	42.5%	185	73	54	5	1	1	3	1	24	36
Skagit River above N/S Forks	8.7			73		5		1		1		36
Britt Slough PS	8.3	0.0%	23	73	100	5	50	1	33	1	12	35
South Fork				73		5		1		1		35
Big Lake WWTP	7.8	300.0%	33	72	1	5	1	1	1	1	2	35
South Fork Skagit R at Conway	4.3			71		4		1		1		34
Conway PS	4.4	0.0%	107	71	1	4	2	1	1	1	100	35
Carpenter/Fisher Creeks	3.1	-54.0%	49	71	33	5	6	1	20	1	46	35
North Fork				73		5		1		1		35
Rexville PS	4.2	-50.0%	1199	74	67	5	5	1	70	1	155	35
Possible Unidentified Source	4.2	0.00%										
North Fork Skagit R at Rexville	4.1			74		5		1		28		35

Table 10, continued

Station Name	RM	7-8 Mar In	7-8 Mar B	21-22 Mar In	21-22 Mar B	4-5 Apr In	4-5 Apr B	19 Sept In	19 Sept B	3 Oct In	3 Oct B
		(In = Input Values; B = River Mass Balance Results) (All values FC bacteria in cfu/100mL)									
Skagit R above Sedro-Woolley	24.6		1		1		1		2		20
Hansen Creek	24.3	13	1	31	1	2592	6	0	2	2078	23
Northern St. Hospital SD	24.2	0	1	13	1	0	6	0	2	13	23
Tributary @ Riverfront Park	23.6	46	1	379	1	0	6	0	2	670	22
South Sedro-Woolley SD	22.9	1889	1	554	1	195	6	0	2	10342	24
Sedro-Woolley WWTP	22.8	103	1	250	1	300	6	100	2	400	24
Brickyard Creek	21.1	29	1	510	1	841	6	0	2	2020	26
Skagit R abv Nookachamps Ck	19.0		1		1		6		2		26
Nookachamps Creek	18.8	1	1	8	1	18	6	7	2	200	28
Burlington WWTP	18.1	2	1	5	1	50	6	100	2	400	28
Skagit R at Mt. Vernon (Day 1)	15.8		1		1		6		1		26
Skagit R at Mt. Vernon (Day 2)	15.8		2		2		5				
Gages Slough PS	14.6	1	2	76	2	32	5	0	1	0	26
Possible Unidentified Source	14.6								11		37
Skagit R above Division St.	12.1		2		2		5		10		36
Frontage Rd PS/Kulshan Ck	11.9	36	2	190	2	2400	5	1997	10	1265	36
Freeway Dr PS	11.9	61	2	35	2	2398	5	0	10	2398	36
Division St CSO	11.4		2		2		5		10		35
Westside PS	11.0	474	2	2398	2	2337	5	0	10	9322	35
Park St CSO	10.9		2		2		5		10		35
Mt. Vernon WWTP	10.7	4	2	2	2	46	5	100	10	400	35
Skagit River above N/S Forks	8.7		2		2		5		9		34
Britt Slough PS	8.3	33	2	120	2	90	5	0	9	100	33
South Fork			2		2		5		13		58
Big Lake WWTP	7.8	3	2	1	2	1	5	100	13	400	57
South Fork Skagit R at Conway	4.3		2		2		4		10		50
Conway PS	4.4	1	2	10	2	36	5	0	10	107	51
Carpenter/Fisher Creeks	3.1	73	2	94	3	142	7	0	10	142	58
North Fork			2		2		5		7		20
Rexville PS	4.2	6	2	23	2	1	4	0	5	50	18
Possible Unidentified Source	4.2										
North Fork Skagit R at Rexville	4.1		2		2		4		5		18

Table 11. Compliance with Fecal Coliform Standards - Marine Standards Met at Mouth

		Monthly Geometric Means							
Station Name	RM	12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	***Target Value***
Skagit R above Sedro-Woolley	24.6	5	1	2	2	2	1	6	*50*
Hansen Creek	24.3	70	44	42	27	27	102		*100*
Northern St. Hospital SD	24.2								*100*
Tributary @ Riverfront Park	23.6				64	93			*100*
South Sedro-Woolley SD	22.9	1997	313	97	282	687	589		*100*
Sedro-Woolley WWTP	22.8	28	36	92	73	136	198	200	*200*
Brickyard Creek	21.1	242	62	56	77	189	231		*100*
Skagit R abv Nookachamps Ck	19.0	5	1	2	2	2	2	6	*100*
Nookachamps Creek	18.8	4	6	8	6	5	6	36	*100*
Burlington WWTP	18.1	3	7	5	7	2	8	200	*200*
Skagit R at Mt. Vernon (Day 1)	15.8	5	1	2	2	2	2	6	*100*
Skagit R at Mt. Vernon (Day 2)	15.8	8	2	4	5	5	3		*100*
Gages Slough PS	14.6					12	13		*100*
Skagit R above Division St.	12.1	8	2	4	5	5	3	19	*100*
Frontage Rd PS/Kulshan Ck	11.9	234	119	77	79	115	255	1590	*100*
Freeway Dr PS	11.9	90	104	67	132	71	173		*100*
Division St CSO	11.4								*100*
Westside PS	11.0	396	1225	1685	2012	1279	1385		*100*
Park St CSO	10.9								*100*
Mt. Vernon WWTP	10.7	22	5	4	6	6	7	200	*200*
Skagit River above N/S Forks	8.7	8	2	4	4	5	3	18	*100*
Britt Slough PS	8.3	49	55	27	23	36	71		*100*
									100
South Fork		8	2	4	4	5	3	28	*100*
Big Lake WWTP	7.8	4	1	1	2	2	2	200	*200*
South Fork Skagit R at Conway	4.3	7	2	4	4	5	2	23	*24*
Conway PS	4.4	6	1	6	5	10	7		*100*
Carpenter/Fisher Creeks	3.1	21	16	18	40	68	100		*100*
South Fork Skagit R blw Conway	3.1	7	2	4	5	6	4	24	*24*
									100
North Fork		8	2	4	4	5	3	12	*100*
Rexville PS	4.2	71	28	36	39	27	4		*100*
North Fork Skagit R at Rexville	4.1	7	5	11	12	5	2	10	*24*

Table 11, continued

Station Name	RM	10th Percentile of Monthly Values 12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	***Target Value***
Skagit R above Sedro-Woolley	24.6	80	2	12	12	12	1	20	*100*
Hansen Creek	24.3	130	52	52	46	46	2592	2078	*200*
Northern St. Hospital SD	24.2	0	0	0	0	13	13	13	*200*
Tributary @ Riverfront Park	23.6	670	124	124	124	379	379	670	*200*
South Sedro-Woolley SD	22.9	10342	10342	309	1889	1889	1889	10342	*200*
Sedro-Woolley WWTP	22.8	203	203	203	103	250	300	400	*400*
Brickyard Creek	21.1	2020	637	464	464	510	841	2020	*200*
Skagit R abv Nookachamps Ck	19.0	78	2	12	12	12	6	26	*200*
Nookachamps Creek	18.8	9	13	17	17	17	18	200	*200*
Burlington WWTP	18.1	8	125	125	125	5	50	400	*400*
Skagit R at Mt. Vernon (Day 1)	15.8	75	2	12	12	12	6	26	*200*
Skagit R at Mt. Vernon (Day 2)	15.8	75	5	37	37	37	5		*200*
Gages Slough PS	14.6	0	0	24	24	76	76	0	*200*
Skagit R above Division St.	12.1	73	5	36	36	36	5	36	*200*
Frontage Rd PS/Kulshan Ck	11.9	807	807	218	218	218	2400	1997	*200*
Freeway Dr PS	11.9	610	610	230	230	164	2398	2398	*200*
Division St CSO	11.4								*200*
Westside PS	11.0	708	9322	9322	9322	2398	2398	9322	*200*
Park St CSO	10.9								*200*
Mt. Vernon WWTP	10.7	185	54	24	24	24	46	400	*400*
Skagit River above N/S Forks	8.7	73	5	36	36	36	5	34	*200*
Britt Slough PS	8.3	100	100	50	33	120	120	100	*200*
									200
South Fork		73	5	35	35	35	5	58	*200*
Big Lake WWTP	7.8	33	1	2	3	3	3	400	*400*
South Fork Skagit R at Conway	4.3	71	4	34	34	34	4	50	*74*
Conway PS	4.4	107	2	100	100	100	36	107	*200*
Carpenter/Fisher Creeks	3.1	49	33	46	73	94	142	142	*200*
South Fork Skagit R blw Conway	3.1	71	5	35	35	35	7	58	*74*
									200
North Fork		73	5	35	35	35	5	20	*200*
Rexville PS	4.2	1199	70	155	155	155	23	50	*200*
North Fork Skagit R at Rexville	4.1	74	28	35	35	35	4	18	*74*

Table 12. TMDL Fecal Coliform Mass Balance, Standards Met at All Locations

(In = Input Values; B = River Mass Balance Results)
(All values FC bacteria in cfu/100mL)

Station Name	RM	Percent Change	27-28 Dec In	27-28 Dec B	10-11 Jan In	10-11 Jan B	24-25 Jan In	24-25 Jan B	7-8 Feb In	7-8 Feb B	21-22 Feb In	21-22 Feb B
Skagit R above Sedro-Woolley	24.6	-48.0%		80		2		1		1		12
Hansen Creek	24.3	-92.3%	10	80	4	2	4	1	2	1	4	12
Northern St. Hospital SD	24.2	0.0%	0	80	0	2	0	1	0	1	0	12
Tributary @ Riverfront Park	23.6	-70.1%	200	79	17	2	0	1	37	1	14	12
South Sedro-Woolley SD	22.9	-98.1%	193	79	200	2	1	1	1	1	6	12
Sedro-Woolley WWTP	22.8	8.9%	19	79	6	2	203	1	39	1	97	12
Brickyard Creek	21.1	-90.1%	200	78	63	2	1	1	3	1	46	12
Skagit R abv Nookachamps Ck	19.0			77		2		1		1		12
Nookachamps Creek	18.8	-93.0%	0	76	9	2	2	1	13	1	17	12
Burlington WWTP	18.1	152.5%	8	75	3	2	1	1	125	1	1	12
Skagit R at Mt. Vernon (Day 1)	15.8			74		2		1		1		12
Skagit R at Mt. Vernon (Day 2)	15.8			75		5		1		1		37
Gages Slough PS	14.6	0.0%	0	74	0	5	0	1	0	1	24	37
Possible Unidentified Source	14.6	-100.0%										
Skagit R above Division St.	12.1			73		5		1		1		36
Frontage Rd PS/Kulshan Ck	11.9	-93.7%	30	73	51	5	2	1	4	1	14	36
Freeway Dr PS	11.9	-91.7%	12	73	51	5	1	1	19	1	14	36
Division St CSO	11.4		209762	73		5		1		1	60498	36
Westside PS	11.0	-97.9%	7	73	15	5	6	1	200	1	40	36
Park St CSO	10.9		14866	73		5		1		1	80975	36
Mt. Vernon WWTP	10.7	42.5%	185	73	54	5	1	1	3	1	24	36
Skagit River above N/S Forks	8.7			73		5		1		1		36
Britt Slough PS	8.3	0.0%	23	73	100	5	50	1	33	1	12	35
South Fork				73		5		1		1		35
Big Lake WWTP	7.8	300.0%	33	72	1	5	1	1	1	1	2	35
South Fork Skagit R at Conway	4.3			71		4		1		1		34
Conway PS	4.4	0.0%	107	71	1	4	2	1	1	1	100	35
Carpenter/Fisher Creeks	3.1	-54.0%	49	71	33	5	6	1	20	1	46	35
North Fork				73		5		1		1		35
Rexville PS	4.2	-91.6%	200	71	11	4	1	1	12	1	26	34
Possible Unidentified Source	4.2	-100.00%										
North Fork Skagit R at Rexville	4.1			71		4		1		1		34

Table 12, continued

Station Name	RM	7-8 Mar In	7-8 Mar B	21-22 Mar In	21-22 Mar B	4-5 Apr In	4-5 Apr B	19 Sept In	19 Sept B	3 Oct In	3 Oct B
		(In = Input Values; B = River Mass Balance Results) (All values FC bacteria in cfu/100mL)									
Skagit R above Sedro-Woolley	24.6		1		1		1		2		20
Hansen Creek	24.3	1	1	2	1	200	1	0	2	160	20
Northern St. Hospital SD	24.2	0	1	13	1	0	1	0	2	13	20
Tributary @ Riverfront Park	23.6	14	1	113	1	0	1	0	2	200	20
South Sedro-Woolley SD	22.9	36	1	11	1	4	1	0	2	200	20
Sedro-Woolley WWTP	22.8	103	1	250	1	300	1	100	2	400	20
Brickyard Creek	21.1	3	1	51	1	83	1	0	2	200	20
Skagit R abv Nookachamps Ck	19.0		1		1		1		2		19
Nookachamps Creek	18.8	1	1	8	1	18	1	7	2	200	22
Burlington WWTP	18.1	2	1	5	1	50	1	100	2	400	22
Skagit R at Mt. Vernon (Day 1)	15.8		1		1		1		1		21
Skagit R at Mt. Vernon (Day 2)	15.8		2		2		5				
Gages Slough PS	14.6	1	2	76	2	32	5	0	1	0	20
Possible Unidentified Source	14.6								1		20
Skagit R above Division St.	12.1		2		2		5		1		19
Frontage Rd PS/Kulshan Ck	11.9	2	2	12	2	151	5	126	1	80	19
Freeway Dr PS	11.9	5	2	3	2	200	5	0	1	200	19
Division St CSO	11.4		2		2		5		1		19
Westside PS	11.0	10	2	52	2	50	5	0	1	200	19
Park St CSO	10.9		2		2		5		1		19
Mt. Vernon WWTP	10.7	4	2	2	2	46	5	100	1	400	19
Skagit River above N/S Forks	8.7		2		2		5		1		18
Britt Slough PS	8.3	33	2	120	2	90	5	0	1	100	18
South Fork			2		2		5		2		32
Big Lake WWTP	7.8	3	2	1	2	1	5	100	2	400	31
South Fork Skagit R at Conway	4.3		2		2		4		1		27
Conway PS	4.4	1	2	10	2	36	4	0	1	107	28
Carpenter/Fisher Creeks	3.1	73	2	94	3	142	7	0	1	142	35
North Fork			2		2		5		1		11
Rexville PS	4.2	1	2	4	2	0	4	0	1	8	10
Possible Unidentified Source	4.2										
North Fork Skagit R at Rexville	4.1		2		2		4		1		10

Table 13. Compliance with Fecal Coliform Standards, Standards Met at All Locations

Station Name	RM	Monthly Geometric Means 12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	*Target Value*
Skagit R above Sedro-Woolley	24.6	5	1	2	2	2	1	6	*50*
Hansen Creek	24.3	5	3	3	2	2	8		*100*
Northern St. Hospital SD	24.2								*100*
Tributary @ Riverfront Park	23.6				19	28			*100*
South Sedro-Woolley SD	22.9	39	6	2	5	13	11		*100*
Sedro-Woolley WWTP	22.8	28	36	92	73	136	198	200	*200*
Brickyard Creek	21.1	24	6	6	8	19	23		*100*
Skagit R abv Nookachamps Ck	19.0	5	1	2	2	2	1	6	*100*
Nookachamps Creek	18.8	4	6	8	6	5	6	36	*100*
Burlington WWTP	18.1	3	7	5	7	2	8	200	*200*
Skagit R at Mt. Vernon (Day 1)	15.8	5	1	2	2	2	1	6	*100*
Skagit R at Mt. Vernon (Day 2)	15.8	8	2	4	5	5	3		*100*
Gages Slough PS	14.6					12	13		*100*
Skagit R above Division St.	12.1	8	2	4	5	5	3	5	*100*
Frontage Rd PS/Kulshan Ck	11.9	15	7	5	5	7	16	100	*100*
Freeway Dr PS	11.9	7	9	6	11	6	14		*100*
Division St CSO	11.4								*100*
Westside PS	11.0	9	26	36	43	28	30		*100*
Park St CSO	10.9								*100*
Mt. Vernon WWTP	10.7	22	5	4	6	6	7	200	*200*
Skagit River above N/S Forks	8.7	8	2	4	4	5	3	5	*100*
Britt Slough PS	8.3	49	55	27	23	36	71		*100*
									100
South Fork		8	2	4	4	5	3	8	*100*
Big Lake WWTP	7.8	4	1	1	2	2	2	200	*200*
South Fork Skagit R at Conway	4.3	7	2	4	4	5	2	6	*24*
Conway PS	4.4	6	1	6	5	10	7		*100*
Carpenter/Fisher Creeks	3.1	21	16	18	40	68	100		*100*
South Fork Skagit R blw Conway	3.1	7	2	4	5	6	3	7	*24*
									100
North Fork		8	2	4	4	5	3	3	*100*
Rexville PS	4.2	12	5	6	7	5	1		*100*
North Fork Skagit R at Rexville	4.1	7	2	4	4	5	2	3	*24*

Table 13, continued

Station Name	RM	12/27/94 -1/25/95	1/11/95 -2/8/95	1/25/95 -2/22/95	2/8/95 -3/8/95	2/22/95 -3/22/95	3/8/95 -4/5/95	9/19/95 -10/3/95	*Target Value*
		10th Percentile of Monthly Values							
Skagit R above Sedro-Woolley	24.6	80	2	12	12	12	1	20	*100*
Hansen Creek	24.3	10	4	4	4	4	200	160	*200*
Northern St. Hospital SD	24.2	0	0	0	0	13	13		*200*
Tributary @ Riverfront Park	23.6	200	37	37	37	113	113		*200*
South Sedro-Woolley SD	22.9	200	200	6	36	36	36		*200*
Sedro-Woolley WWTP	22.8	203	203	203	103	250	300	400	*400*
Brickyard Creek	21.1	200	63	46	46	51	83		*200*
Skagit R abv Nookachamps Ck	19.0	77	2	12	12	12	1	19	*200*
Nookachamps Creek	18.8	9	13	17	17	17	18	200	*200*
Burlington WWTP	18.1	8	125	125	125	5	50	400	*400*
Skagit R at Mt. Vernon (Day 1)	15.8	74	2	12	12	12	1	21	*200*
Skagit R at Mt. Vernon (Day 2)	15.8	75	5	37	37	37	5		*200*
Gages Slough PS	14.6	0	0	24	24	76	76		*200*
Skagit R above Division St.	12.1	73	5	36	36	36	5	19	*200*
Frontage Rd PS/Kulshan Ck	11.9	51	51	14	14	14	151	126	*200*
Freeway Dr PS	11.9	51	51	19	19	14	200		*200*
Division St CSO	11.4								*200*
Westside PS	11.0	15	200	200	200	52	52		*200*
Park St CSO	10.9								*200*
Mt. Vernon WWTP	10.7	185	54	24	24	24	46	400	*400*
Skagit River above N/S Forks	8.7	73	5	36	36	36	5	18	*200*
Britt Slough PS	8.3	100	100	50	33	120	120		*200*
									200
South Fork		73	5	35	35	35	5	32	*200*
Big Lake WWTP	7.8	33	1	2	3	3	3	400	*400*
South Fork Skagit R at Conway	4.3	71	4	34	34	34	4	27	*74*
Conway PS	4.4	107	2	100	100	100	36		*200*
Carpenter/Fisher Creeks	3.1	49	33	46	73	94	142		*200*
South Fork Skagit R blw Conway	3.1	71	5	35	35	35	7	35	*74*
									200
North Fork		73	5	35	35	35	5	11	*200*
Rexville PS	4.2	200	12	26	26	26	4		*200*
North Fork Skagit R at Rexville	4.1	71	4	34	34	34	4	10	*74*

- Loading from the Rexville pump station (Drainage District 15) and the unidentified source upstream of Kulshan Creek must be significantly reduced (by 50% and 67% respectively).

- As a long-term goal, all surface waters should meet water quality standards, and all other unidentified sources found during the survey should be eliminated or brought under appropriate regulatory standards.

Future Growth: Future growth of WWTP loading has been factored into the WLAs through the year 2015. Future growth, as it impacts nonpoint source loading, must comply with LAs.

Margin of Safety: A margin of safety to account for scientific uncertainty has been included in several ways:

- Conservative assumptions were used where possible.

- The use of a 30-day averaging period rather than a longer period with the geometric mean and 10% criteria when evaluating the FC standards reduces the possibility of masking noncompliance periods.

- The long-term goal that all tributary sources meet Class A standards helps account for the possibility that some sources have been underestimated, and generates TMDL mass balances results at the downstream boundaries that are lower than the marine standards target values.

- Fecal coliform decay rates usually increase in marine waters, so bacteria levels at the mouth of the Skagit River are likely slightly lower than predicted in this analysis.

Implementation Considerations

To evaluate the relative effects of load reductions from different sources, a sensitivity analysis was conducted. The maximum concentration found in each source was applied to conditions during the October survey, each source was reduced individually by 50 and 90 percent, and the effect on FC concentrations at the downstream boundaries observed. Table 14 shows the results of this analysis.

The sensitivity analysis reveals several important factors to be considered in implementation:

- Only seven sources had a major impact on FC concentrations at the river's mouth (greater than 3% reduction of river concentration due to a 90% reduction in the loading source).

- Reductions in WWTP FC loading below permit levels had virtually no effect on the river's concentration.

- Many of the nonpoint FC loading sources had virtually no effect on the river's concentrations.

This table provides a guideline for implementation, with the sources prioritized for action roughly as follows:

1. CSO abatement is the single most important action needed to improve Skagit River water quality and protect Skagit Bay from FC bacteria contamination.

2. Nookachamps Creek's Watershed Action Plan and related implementation activities should be reviewed to determine if they are adequate to ensure that the creek will comply with the WQS. The Plan should be revised, if necessary, and fully implemented.

3. The unidentified source on the Skagit River upstream of Kulshan Creek should be investigated and, if appropriate, controls implemented to eliminate the source or bring it within applicable standards.

4. Carpenter and Fisher Creeks should have Watershed Plans developed and implemented so that the creeks attain water quality standards.

5. A Watershed Plan or equivalent should be developed for Drainage District 15, to improve FC levels in the discharge from the Rexville pump station.

6. Review of over 20 years of ambient data from the Skagit River at Mount Vernon suggests that the upstream target value of 80 cfu/100 mL is exceeded about 10% of the time, which is consistent with the results of this study. Conditions in the upper Skagit River basin should be investigated to determine the sources of these high fecal coliform values and whether human-caused nonpoint sources exist that require additional controls, so that upstream target values are met.

7. As resources allow, other tributaries and urban stormwater sources should be evaluated for nonpoint source controls with the long-term goal that these water bodies meet Class A FC standards.

8. Although the Britt Slough and Conway pump stations and the Gages Slough discharge met the WQS during this study, the sources should be monitored for long-term compliance, and appropriate actions taken if they begin to exceed the standards.

Table 14. Fecal Coliform Reductions in N and S Forks Due to Reductions in Loading

50% Load Reduction of each Source

No.	SAMPLING STATIONS	S Fork Skagit R cfu/100mL	S Fork Skagit R % Change	N Fork Skagit R cfu/100mL	N Fork Skagit R % Change
1	Skagit R above Sedro-Woolley	277	-23.38%	120	-19.99%
2	Rexville PS	362	0.00%	137	-9.23%
3	Park St CSO	337	-6.86%	142	-5.86%
4	Nookachamps Creek	338	-6.63%	142	-5.67%
5	Unidentified Source (RM 14.6)	339	-6.36%	142	-5.44%
6	Division St CSO	351	-3.18%	146	-2.72%
7	Carpenter/Fisher Creeks	354	-2.11%	150	0.00%
8	Brickyard Creek	361	-0.41%	150	-0.35%
9	Hansen Creek	361	-0.42%	150	-0.36%
10	South Sedro-Woolley SD	361	-0.32%	150	-0.27%
11	Conway PS	361	-0.18%	150	0.00%
12	Mt. Vernon STP	362	-0.07%	150	-0.06%
13	Burlington STP	362	-0.02%	150	-0.02%
14	Westside PS	362	-0.02%	150	-0.01%
15	Britt Slough PS	362	-0.02%	150	0.00%
16	Tributary @ Riverfront Park	362	-0.01%	150	-0.01%
17	Frontage Rd PS/Kulshan Ck	362	-0.01%	150	-0.01%
18	Big Lake STP	362	-0.01%	150	0.00%
19	Sedro-Woolley STP	362	-0.01%	150	-0.01%
20	Freeway Dr PS	362	0.00%	150	0.00%
21	Gages Slough PS	362	0.00%	150	0.00%
22	Northern St. Hospital SD	362	0.00%	150	0.00%
	Baseline (no reductions)	362		150	

90% Load Reduction of each Source

No.	SAMPLING STATIONS	S Fork Skagit R cfu/100mL	S Fork Skagit R % Change	N Fork Skagit R cfu/100mL	N Fork Skagit R % Change
1	Skagit R above Sedro-Woolley	210	-42.09%	96	-35.98%
2	Rexville PS	362	0.00%	125	-16.62%
3	Park St CSO	317	-12.34%	135	-10.55%
4	Nookachamps Creek	319	-11.93%	135	-10.20%
5	Unidentified Source (RM 14.6)	321	-11.45%	136	-9.79%
6	Division St CSO	341	-5.73%	143	-4.89%
7	Carpenter/Fisher Creeks	348	-3.80%	150	0.00%
8	Brickyard Creek	359	-0.74%	149	-0.63%
9	Hansen Creek	359	-0.76%	149	-0.65%
10	South Sedro-Woolley SD	360	-0.57%	150	-0.49%
11	Conway PS	361	-0.32%	150	0.00%
12	Mt. Vernon STP	362	-0.12%	150	-0.10%
13	Burlington STP	362	-0.04%	150	-0.03%
14	Westside PS	362	-0.03%	150	-0.02%
15	Britt Slough PS	362	-0.03%	150	0.00%
16	Tributary @ Riverfront Park	362	-0.01%	150	-0.01%
17	Frontage Rd PS/Kulshan Ck	362	-0.02%	150	-0.02%
18	Sedro-Woolley STP	362	-0.01%	150	-0.01%
19	Big Lake STP	362	-0.01%	150	0.00%
20	Freeway Dr PS	362	0.00%	150	0.00%
21	Gages Slough PS	362	0.00%	150	0.00%
22	Northern St. Hospital SD	362	0.00%	150	0.00%
	Baseline (no reductions)	362		150	

TMDL Monitoring

Long-term monitoring will be important to ensure compliance with the requirements of the Lower Skagit River DO and FC TMDLs. Ecology conducts long-term monthly ambient monitoring in the Skagit River near Mount Vernon. This is a valuable long-term record, but additional monitoring is needed for TMDL assessment, because the ambient monitoring station is upstream of the critical locations in the river as well as many of the loading sources. For TMDL monitoring, the following elements should be considered:

- Ammonia nitrogen in WWTP discharges should be monitored for compliance with WLAs during the July through October TMDL period at all plants where this parameter is not currently monitored.

- DO in the South Fork Skagit River should be monitored at the Conway bridge or just upstream during the July through October TMDL period. Monitoring should occur during neap tide conditions either at high tide or preferably as 24 to 48 hour continuous monitoring with a datalogging meter.

- It is not clear what processes cause the dip in DO in the South Fork observed at high neap tides. If greater understanding of this phenomenon is desired, a detailed study with monitoring and dynamic modeling could be conducted.

- Bacteria should be monitored year-round in the South Fork Skagit River at Conway and in the North Fork Skagit River near Rexville for compliance with the marine standards target values. Monitoring should be at least monthly, although monitoring that targets rainfall periods would probably be more effective for documenting the highest FC levels.

- Bacteria should be monitored in the Skagit River above Sedro-Woolley and in tributary streams and drainage areas as part of nonpoint control activities using appropriate BMP assessment protocols and strategies.

- Long-term periodic monitoring of bacteria should be conducted in tributary streams and drainage areas that are meeting water quality standards to ensure their continued compliance with standards.

- Quality assurance plans should be developed for all monitoring that identify appropriate monitoring objectives, strategies, schedules, and resources. Monitoring can either be conducted by Ecology or by other interested parties such as tribal or local governments, watershed groups, or drainage districts.

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Appendix

Methods

Samples and measurements were taken as grabs for all samples, except for certain parameters taken as 24-hour composite samples from the WWTPs. Samples were taken from mid-stream in tributaries, while samples from some mainstem sites were taken at 2 or 3 locations equidistant across the channel. Dry season mainstem sites at the downstream boundary were sampled twice during the survey at different times during the tidal cycle. Pump stations were sampled either from the pumping wet wells or from the drainage channels adjacent to the pumps.

A reconnaissance survey was conducted in September 1994 that included profiles and 48-hour datalogger readings with Hydrolab® multi-parameter meters. Wet season monitoring consisted of 8 two-day surveys conducted every two weeks beginning the last week of December 1994 and continuing through the first week of April 1995. Two dry season monitoring surveys were conducted on September 19 and October 3, 1995.

Flows were measured in tributary open channels with measurable flow using Marsh-McBirney® or Swoffer® current meters, either with wading rod and tape transect or by using a bridge as the transect. Flows were measured in the Skagit River above Sedro-Woolley and in the North and South Forks using a Swoffer® meter on a boat rig. A cable transect was used on the North Fork and mainstem Skagit River, while the bridge at Conway was used as the transect for flows in the South Fork.

Wet season field data were collected with Orion® 250A pH meters, Beckman Solu-bridge conductivity meters, and thermometer. Dry season data were collected with Hydrolab® multi-parameter meters, a YSI® DO meter, and laboratory sampling. Field readings were taken as grabs directly from the water or from a bucket. Laboratory samples were taken directly into the sample bottle, except at locations with access difficulties where samples were taken from a bucket. All bacteria samples were collected directly into the sample bottle except for a few samples from the Sedro-Woolley WWTP which were taken from a bucket.

Figure 1 shows the study area and the locations sampled. The upper end of the study area was upstream of the city of Sedro-Woolley under the pipeline crossings, just downstream of Skiyou Slough where Class AA Water Quality Standards end and Class A standards begin. The downstream boundary was the Fir Island bridges over the South Fork Skagit River at Conway, and over the North Fork Skagit River at Rexville. The wet and dry season surveys monitored the mainstem and forks of the Skagit River, as well as the loading sources to the river in the study area. Sources include municipal wastewater treatment plants (WWTPs), combined sewer overflows (CSOs), urban stormwater, drainage district pump stations, and tributary creeks.

Conditions during surveys varied widely. The Skagit River during the December 27-28 survey was near flood level, and was also very high during the February 21-22 survey. Some surveys occurred during rainfall or after recent rains, while others took place following short or long periods of dry weather.

Table A.1. Summary of field and laboratory measurements, target detection limits, and methods.

Parameter	**Accuracy**	**Method**[1]
Field Measurements		
Velocity	± 0.05 feet/second	Current meter
Specific Conductivity	± 5 % (at 25°C)	Field Meter (Electrode)
pH	± 0.2 standard units	Field Meter (Electrode)
Temperature	± 0.2 °C	Red Liquid Thermometer Field Meter (Thermistor)
Dissolved Oxygen	± 0.1 mg/L ± 0.2 mg/L	Winkler Modified Azide (EPA 360.2) Field meter (Polarographic Probe)
General Chemistry	**Reporting Limit**	
Turbidity	1 NTU	EPA 180.1
Specific Conductivity	1 µmho/cm	Conductivity Bridge
Alkalinity	1 mg/L (as $CaCO_3$)	EPA 310.1
Fecal coliform	1 cfu/100mL	SM18 Membrane Filter 9222D
Ammonia nitrogen	0.01 mg/L	EPA 350.1
Nitrate + nitrite nitrogen	0.01 mg/L	EPA 353.2
Total persulfate nitrogen	0.01 mg/L	SM 4500 NO3-F Modified
Chloride	0.1 mg/L	EPA 330.0
5-day BOD	2 mg/L	EPA 405.1
Ultimate Carbonaceous BOD	2 mg/L	NCASI (1987)

[1]SM = Standard methods for the examination of water and wastewater. Eighteenth edition (1992). American Public Health Association, American Water Works Association, and Water Environment Federation. Washington, D.C.

EPA = Methods for the chemical analysis of water and wastes. Environmental Monitoring Supply Laboratory. U.S. Environmental Protection Agency. Cincinnati, OH. EPA-600/4-74-020. 1983.

NCASI = A procedure for the estimation of ultimate oxygen demand (biochemical). National Council of the Paper Industry for Air and Stream Improvement, Inc. Special Report No. 87-06. May 6, 1987.