WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Lower Nooksack River Basin Bacteria Total Maximum Daily Load Evaluation

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Lower Nooksack River Basin
Bacteria
Total Maximum Daily Load Evaluation

by
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Abstract

The Washington State Department of Ecology conducted a total maximum daily load (TMDL) evaluation of the lower Nooksack River basin in 1997-1998. Because the lower river basin has a history of state bacteria standard violations, the TMDL focused on fecal coliform bacteria loading to the river from tributaries, sewage treatment plants, and other sources. Historical and TMDL data demonstrated the need for an aggressive approach to preventing fecal bacteria criteria violations.

The TMDL evaluation proposes fecal coliform bacteria targets more restrictive than the 100 cfu/100 mL geometric mean count criterion for Class A waters. A geometric mean of 39 cfu/100 mL is recommended for the lower Nooksack River. Compliance with this criterion should result in only 10% of the samples exceeding 200 cfu/100 mL, and a 48% reduction in annual bacteria loads. In addition, ten tributaries that are the major sources of bacteria loading to the river will require similarly stringent bacteria criteria to reduce their loads by 23% to 98%. A 4.5% reduction is recommended in upper watershed loads to meet the river TMDL target, and to ensure Class AA standards are met. Although a less significant source of bacteria loading, waste water treatment plants (WWTPs) will be required to undergo quality assurance testing on a quarterly basis, and they will need to meet a more stringent permit limit for bacteria. All dairies and animal feeding operations (AFOs) under permit have waste load allocations of zero.

Identifying and eliminating individual sources of contamination in Fishtrap and Bertrand creeks and other sub-basins that hold a high density of AFOs, dairies, and manured fields will be essential for the success of the TMDL. Also, a quick response to illegal discharges from manure lagoons, manure-spreading equipment, sewage pump stations, and WWTP outfalls will be required for the TMDL targets to be met. Limiting livestock access to waterbodies, correcting individual on-site systems, and controlling bacteria discharges to urban stormwater will also be necessary to achieve target compliance.

The recommended bacteria targets will bring Nooksack basin watercourses into compliance with Class A fecal coliform criteria, and will support recreational contact uses, as well as reduce the risk of drinking water contamination. Monte Carlo simulation results of a simple bacteria model for Portage Bay indicated that attaining the new bacteria target in the river would sufficiently protect water quality in the shellfish harvesting areas.

Waterbody Numbers

WA-01-1010	WA-01-1110	UZ70KA
WA-01-1012	WA-01-1115	BX84LO
WA-01-1015	WA-01-1120	AR42TO
WA-01-1020	WA-01-1125	LLPL Drain

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Executive Summary

The Washington Department of Ecology (Ecology) conducted field surveys to support a total maximum daily load (TMDL) evaluation of the lower Nooksack River basin from 1997 to 1998. The purpose of the TMDL was to evaluate the bacteria contamination problem in the lower valley from municipal point sources, animal feeding operation (AFO) point sources, and general nonpoint sources. In addition, the evaluation included the cumulative effect of bacteria sources into the Nooksack estuary (Portage Bay). Historical and field survey data were used to determine the seasonal and spatial patterns of bacteria loading as represented by fecal coliform bacteria.

The lower Nooksack River, several tributaries, and NPDES-permitted point sources need moderate to severe reductions in annual fecal coliform (FC) loads to meet state standards. *Ecology recommends a geometric mean fecal coliform bacteria target of 39 cfu/100 for the lower Nooksack River at river mile (RM) 3.5. Cumulative FC bacteria sources need to be reduced 48% to meet the geometric mean target.* Cumulative FC reduction to the lower basin will be approximately 56% when TMDL compliance is met in the tributaries and upper basin. The TMDL target is more restrictive than the 100 cfu/100 mL Class A fecal coliform criterion.

The TMDL survey data demonstrate that river FC bacteria densities double between Lynden (RM 18.1) and Ferndale (RM 5.9). Tributaries discharging to this river reach had consistently high bacteria loads from agricultural areas with high AFO, dairy, and manured field densities. Disinfection problems at the Lynden wastewater treatment plant (WWTP) also created an intermittent source of elevated bacteria loading to the reach. As a result, *Ecology recommends that eight tributaries located between RM 5.9 and RM 18.1 reduce FC loads from 23% to 98%. The geometric mean targets calculated for these tributaries have a FC density range of 59 to 19 cfu/100 mL.* Fishtrap and Bertrand creeks, located here, accounted for 44% of the annual fecal coliform bacteria load to the lower basin. They will be the highest priority areas for source identification and reduction. All dairies and AFOs under permit in the Nooksack River basin have waste load allocations of zero. *Ecology also recommends water quality-based permit limits for Lynden, Ferndale, and Everson WWTPs to meet the 39 cfu/ 100 mL FC target in the Nooksack River. Lynden WWTP will need to reduce FC concentrations by 81% from TMDL survey sample results.*

The upper Nooksack River watershed and two tributaries between Lynden and North Cedarville (RM 30.9) also require FC load reductions. *Ecology recommends FC reductions of 89% for Anderson Creek, and 60% for Smith Creek to meet Class A fecal coliform criteria. In addition, Ecology recommends that FC loads be reduced by 4.5% in the Nooksack River above North Cedarville.* If the upper watershed target is met, the river quality will conform to Class AA fecal coliform criteria, and ensure that high quality water is delivered to the lower basin.

Shellfish harvest closures in Portage Bay by the Lummi Nation and the Washington Department of Health (DOH) in Portage Bay create an urgent need to control bacteria in the river. Ecology used survey data from the TMDL, the Lummi Nation, and DOH to construct a simple model of a hypothetical critical condition of Nooksack River impacts on Portage Bay fecal coliform bacteria quality. *The model results suggest that Portage Bay shellfish harvest areas will have* *substantially fewer criteria violations if the Nooksack River basin FC targets recommended in the TMDL are met.*

The following were other significant TMDL evaluation findings:

- Fecal coliform (FC) bacteria standard violations were evident at many sites and during all seasons in the historical record and during the TMDL surveys.
- Nonpoint sources, AFOs, and dairies with direct discharge activities are suspected primary sources of bacteria. The basin has a high density of animals and a shrinking land base to use for manure spreading. Also, the number of hobby farms is growing. The bacteria problem from these sources has been recognized, but it has not been previously documented on a basin-wide scale.
- Analysis of 1997-98 data indicated up to 84% of the annual FC bacteria loads in tributaries and approximately 58% of annual basin load in the lower main stem occurred during runoff events after 0.5 inches of rainfall per day.
- Monthly FC data collected near the mouth of the Nooksack River show improvements in bacterial quality over the past 20 years, but no significant improvements over the last 10 years, and the lower river still is not meeting Class A standards.
- Sediment storage and resuspension may be a mechanism for bacteria loading to the river during quickly rising river stages. Their effect on future FC loads after other sources of bacteria loading have been reduced is unknown.
- Additional samples for *Escherichia coli* (*E. coli)* and enterococcus were taken to establish a database for any future changes in bacteria criteria. These samples also confirmed that the likely source of fecal bacteria contamination is wastes from warm-blooded animals.
- The statistical rollback method (Ott, 1995) was used to estimate the geometric mean density when the FC distribution complies with the criterion that 10% of samples must not exceed 200 cfu/100 mL (cfu = colony forming units). The distribution for the last 10 years of FC data collected by Ecology at the Nooksack River at Brennan (RM 3.4) was used. The statistical rollback method approach appears to produce a consistent geometric mean target for membrane filter (MF) and most probable number (MPN) distributions using 1997-98 TMDL data. Both distributions required targets of 34 – 50 units/100 mL, but the increased variability in the MPN method increased the calculated bacteria load reduction that was required relative to the MF results.
- Lynden WWTP had unreliable effluent disinfection and FC sample analyses during the TMDL surveys. Ecology recommends that better quality assurance testing be conducted until confidence in low FC counts is regained. Permit violations should decrease with more vigilance, but a more stringent monthly average limit is recommended for all the WWTPs to ensure effluent does not increase instream FC densities.
- Initial remedial work is recommended in Fishtrap, Bertrand, Kamm, and Tenmile creeks sub-basins that contributed 54% of load during the monitoring period. LLPL Ditch and Scott Ditch also have an elevated loading when evaluated by unit area. Sources include runoff from manure applied to fields, dairy facility waste management, hobby-farm animal access to waterways, septic system failure, urban-rural storm runoff, and wildlife.

- Additional FC reductions could be realized if sources were mitigated in ungaged areas along the main stem river.
- The Washington Dairy Nutrient Management Act of 1998 requires all dairies to be inspected by October 2000 and to have nutrient management plans in place by 2003. Implementing and maintaining the best management practices (BMPs) in these plans should improve water quality in all Nooksack River tributaries and in the main stem.
- Adherence to the manure management ordinance passed in Whatcom County in 1998 that prevents application of manure to bare fields between October and April should have a measurable effect on manure transport to tributaries.
- Water quality data contain evidence of illegal discharges throughout the year. Increased presence of Ecology and USEPA inspectors should reduce the number of illegal discharges. Also, increased monitoring, application, and maintenance of BMPs may make a difference.
- Better monitoring by Whatcom County inspectors for compliance with riparian corridor ordinance has been proposed. Whatcom County Health and Human Services Department inspections of on-site systems should improve performance.

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Introduction

Background

The Nooksack River basin is located in northwestern Washington State between the city of Bellingham and the Canadian border (Figure 1). The basin's 826 square miles (mi^2) encompass the northwestern slopes of the Cascade Mountain Range through foothills and lowlands to Bellingham Bay. The eastern mountainous part of the basin, the upper basin with an area of 589 mi^2, is drained by three forks of the Nooksack River. The North and Middle forks are glacial fed. The lower basin, the focus of the TMDL study, lies below river mile (RM) 36.6 and mostly drains valley lands below 500 ft elevation. Anderson Creek and Smith Creek are exceptions with some of their drainage areas above 3,000 ft elevation. Most of the basin is located in Whatcom County. Small portions (48.6 mi^2) of the lowland and North Fork basins are in Canada, and some of the upper South Fork Nooksack River is located in Skagit County (Figure 1). The Lummi Reservation is located on 33 mi^2 of land at the mouth of the Nooksack River. The Nooksack Tribal offices are at Deming near the confluence of the three forks. The Nooksack basin is ceded land under the Treaty of Point Elliot, and the tribes maintain usual and accustomed rights within the basin.

The upper and lower basins have distinctively different land use characteristics. Timber management and recreational activities on private, federal, and state lands predominate in the upper basin. Some agriculture, commercial, and residential developments occur along the valley floors. In contrast, most land in the lower basin is privately held, and is intensively used for agricultural purposes. Dairy farms are abundant, especially on the Lynden Terrace between Bertrand Creek and the Sumas River. Until 1998, Whatcom County, and the lower Nooksack River valley in particular, had the highest concentration of dairy cows in the state, and the seventh highest poultry production (Washington Agricultural Statistics Service, 1997). Whatcom County also is a top producer of raspberries, and is western Washington's leading harvester of forage crops (silage corn and hay).

Few point sources are located within the basin. Most towns support agricultural or timber industries, and all have fewer than 10,000 residents. The largest municipalities are in the lower basin: Lynden, Ferndale, Everson, and Nooksack. Suburban and rural housing developments have been expanding along the Interstate 5 corridor and toward Ferndale and Lynden in response to growth around Bellingham. Municipal sewage plants discharging to the Nooksack River are located at Everson, Lynden, and Ferndale. Darigold at Lynden is the only direct industrial discharger to the Nooksack River. Condensate water from the dry milk process is discharged to the river, and other wastewater is discharged to the Lynden sewage plant. Dean Foods and RECOMP (waste incinerator) are two other industrial facilities that may have indirect discharges to groundwater from surface applications of wastewater. However, the Dean Foods plant has been closed and the wastewater lagoon was fully drained in October 1997.

The Nooksack River has Class A and Class AA waters. Table 1 lists the characteristic beneficial uses and water quality criteria for these classifications. Waters with these classifications support

Nooksack River Bacteria TMDL Study Area

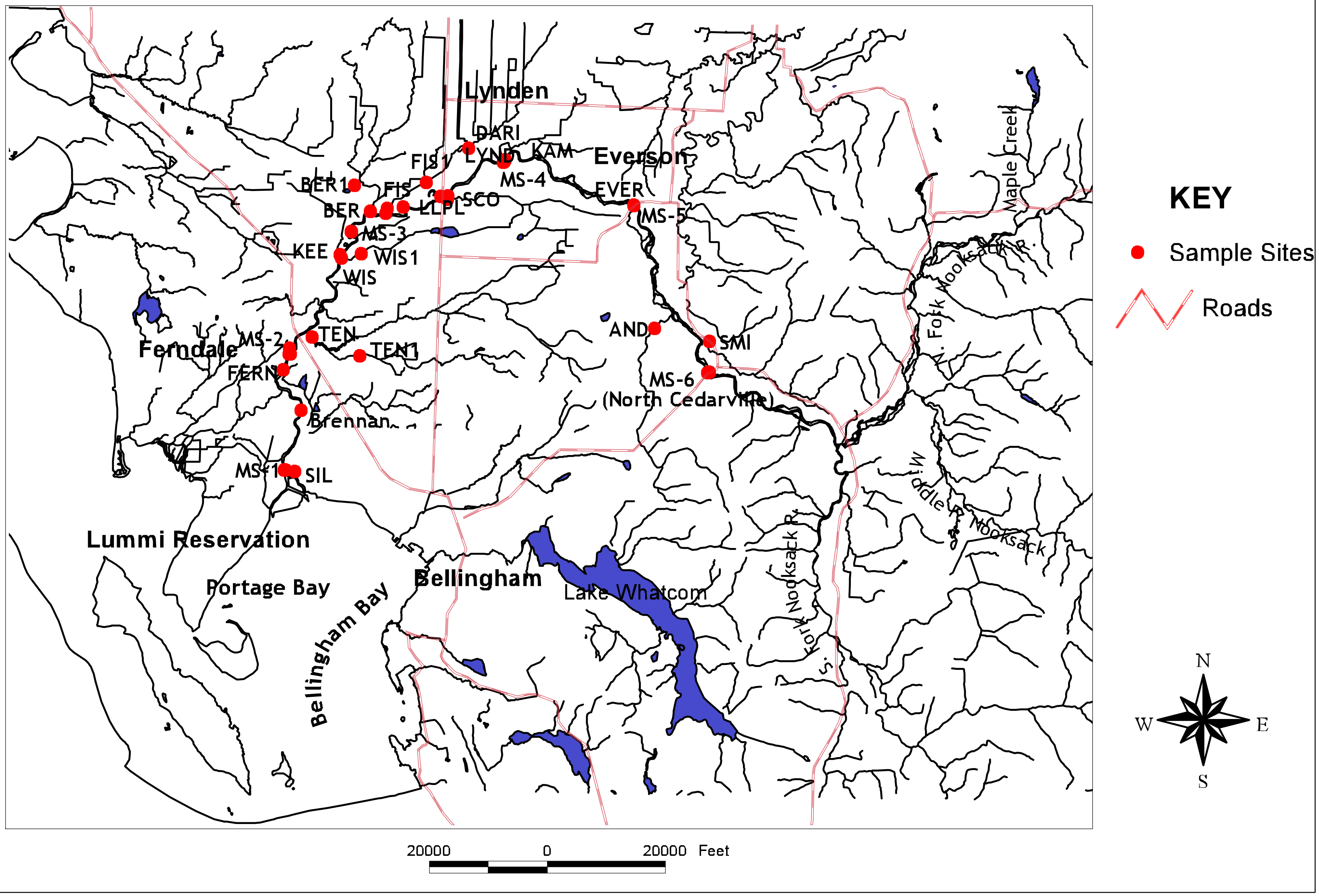

Figure 1. The Nooksack River bacteria total maximum daily load (TMDL) study area with Washington Dept. of Ecology water quality sites monitored from March 1997 to February 1998.

Table 1. Class AA (extraordinary) and Class A (excellent) freshwater quality standards and characteristic uses.

	Class AA	Class A
General Characteristic:	Shall markedly and uniformly exceed the requirements for all, or substantially all uses.	Shall meet or exceed the requirements for all, or substantially all uses.
Characteristic Uses:	Shall include, but not be limited to, the following: domestic industrial, and agricultural water supply; stock watering; salmonid and other fish migration, rearing, spawning, and harvesting; wildlife habitat; primary contact recreation, sport fishing, boating, and aesthetic enjoyment; and commerce and navigation.	Same as AA.
Water Quality Criteria		
Fecal Coliform:	Shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10% of samples exceeding 100 organisms/100 mL.	Shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10% of samples exceeding 200 organisms/100 mL.
Dissolved Oxygen:	Shall exceed 9.5 mg/L.	Shall exceed 8.0 mg/L.
Total Dissolved Gas:	Shall not exceed 110% saturation.	Same as AA.
Temperature:	Shall not exceed 16.0°C due to human activities. When conditions exceed 16.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C. Increases from non-point sources shall not exceed 2.8°C.	Shall not exceed 18.0°C due to human activities. When conditions exceed 18.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C . Increases from non-point sources shall not exceed 2.8°C.
pH:	Shall be within the range of 6.5 to 8.5 with a man-caused variation with a range of less than 0.2 units	Shall be within the range of 6.5 to 8.5 with a man-caused variation with a range of less than 0.5 units.
Turbidity:	Shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10% increase in turbidity when the background is more than 50 NTU.	Same as AA.
Toxic, Radioactive, or Deleterious Material:	Shall be below concentrations which have the potential singularly or cumulatively to adversely affect characteristic uses, cause acute or chronic conditions to the most sensitive aquatic biota, or adversely affect public health.	Same as AA.
Aesthetic Values:	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.	Same as AA.

the broadest range of uses, though numeric water quality standards are slightly more stringent for Class AA waters. State law does not establish a ranking or priority among the beneficial uses, but individual waters are expected to support all uses within the classification.

The river is classified Class A from its mouth to river mile (RM) 49.7, at Maple Creek (Figure 1). Above Maple Creek, the river is Class AA. The Middle Fork is Class AA. The South Fork is Class A to RM 14.3, at Skookum Creek. Above Skookum Creek, it is Class AA. All tributaries to the Class AA portions of the Nooksack system are AA; likewise, tributaries to the Class A part are Class A. Bellingham Bay is a Class A marine water.

Water is taken from the Nooksack River and its tributaries for domestic, industrial, and irrigation uses. Bellingham, the largest city in the region with a population of 65,000, diverts water from the Middle Fork Nooksack River to Lake Whatcom for drinking water. Lynden and Public Utility District #1 of Whatcom County draw water from the Nooksack River for municipal and industrial uses. High bacterial and chemical water quality are important for maintaining a safe water supply. Most small tributaries in the lower basin are used as irrigation sources for adjacent fields and livestock watering. Most of these streams and drainage ditches are closed to further consumptive withdrawals.

The Abbotsford-Sumas Aquifer is a large unconfined groundwater source in the Nooksack basin and the Fraser basin, British Columbia. Groundwater from the aquifer is an important source of water for farms, municipalities, and industries in the region. It also feeds small streams, lakes, and wetlands of the Nooksack basin between Everson and Bertrand creeks during the drier season of the year. The interaction between the aquifer and Nooksack River is not completely understood, but the water quality of the aquifer influences the river.

Salmon are considered a cultural, economic, recreational, and biological asset for northwest rivers and streams. The lower Nooksack River and its tributaries provide migration routes, and spawning and rearing habitat, for several salmon species throughout the year. Some of these salmon runs have been diminished by over-fishing, and from degraded water quality and habitat. Other fish, invertebrate, and aquatic plant species have not been so closely observed, but all require a high level of water quality, as well as a stable and high-quality habitat to support healthy aquatic communities.

The Nooksack River empties into Bellingham Bay where tribal and commercial shellfish beds are cultivated. The shellfish resources lay along Portage Channel on the southwestern shore of the bay on the Lummi Reservation. The bacterial water quality of the harvest area is influenced by the river's bacteria load (Washington Department of Health, 1997). Since shellfish can accumulate bacteria and toxins, U.S. Food and Drug Administration water quality standards for shellfish harvesting are restrictive. Water samples analyzed for fecal coliform bacteria cannot have a geometric mean count exceeding 14 MPN/100 mL, and cannot have a 90th percentile density exceeding 43 MPN/100 mL (MPN = most probable number). The Washington Department of Health Office of Shellfish Programs (DOH) certifies Portage Bay shellfish beds for commercial harvests through water quality monitoring and other criteria in consultation with the Lummi Nation.

Fishing, boating, and swimming are recreational resources enjoyed by local residents and tourists visiting the Nooksack River basin. The South Fork Nooksack is especially popular for summer floating trips. Although no major park facilities are located along the lower river, small municipal parks, and boat launches provide recreational access. These swimmers, boaters, fishermen, and waders require adequate protection from exposure to disease-causing bacteria and harmful chemical pollutants.

Problem Description

Under the federal Clean Water Act, states must submit a list of impaired waters to the U.S. Environmental Protection Agency (USEPA) every two years. Impaired waters are those that are not meeting, or are not expected to meet, water quality standards with technology-based controls or other legally required pollution control mechanisms. For those waters, states are required to conduct total maximum daily load (TMDL) evaluations which set water quality-based controls on sources.

The lower Nooksack River and several of its tributaries are included in Washington's Section 303(d) list of impaired waters, because of fecal coliform bacteria and other water quality criteria violations (Ecology, 1996). Elevated fecal coliform bacteria counts prevent many points in the basin from meeting Washington State Class A water quality standards that protect primary and secondary contact recreation (Ecology, 1995). Violations of fecal coliform criteria are most numerous in the lower valley. In addition, water quality in some tributaries is impaired by one or more of the following: ammonia, dissolved oxygen, temperature, pH, arsenic, and fine sediment (Table 2). Many basin and sub-basins tributaries have not been monitored.

Long-term monitoring data suggest a distinct increase in bacteria criteria violations and in nutrients and other marker contaminants as the river flows through the lower basin. Upper basin water meets Class A bacteria and other water quality criteria, but water quality is significantly degraded over the final 31 river miles to Bellingham Bay. Nooksack River bacteria sources have been implicated as a significant reason for the recent shellfish harvest restrictions by DOH (Washington Department of Health, 1997). The harvest closure triggered a Shellfish Closure Response Strategy and formation of the Portage Bay Shellfish Protection District in 1998.

Water quality investigations have been performed by Ecology, the U.S. Geological Survey, the Lummi Nation, Nooksack Tribe, Western Washington University (WWU), Whatcom County Conservation District (WCCD), and others in the Nooksack basin. For example, the technical evaluation study for a TMDL project was conducted on Fishtrap Creek in 1993 (Erickson, 1995). Water quality evaluations associated with watershed characterizations or action plans were performed in the Silver, Tenmile, and Kamm sub-basins (Tetra Tech, 1989a, 1989b; Dickes, 1992; Institute for Watershed Studies, 1994). The USEPA made a focused effort to conduct inspections of some dairies, those that qualified as animal feeding operations (AFOs), in 1998. However, a comprehensive analysis of the cumulative effects of bacteria and nutrient loading from tributary and point sources to the Nooksack River has not been conducted.

A lower Nooksack River fecal coliform TMDL evaluation was proposed as a priority action by Ecology's Bellingham Field Office (BFO) after a 1995 Watershed Needs Assessment

Table 2. Water quality limited segments in the Nooksack River basin

1996 Washington 303(d) List

Waterbody Number	Waterbody Name	Parameters Exceeding Standards
WA-01-1010	Nooksack River	Chromium, Mercury, Fecal Coliform
WA-01-1012	Tenmile Creek	Ammonia N, Dissolved Oxygen, Temperature, Fecal Coliform
WA-01-1014	Deer Creek	Ammonia N, Dissolved Oxygen, pH, Fecal Coliform
WA-01-1015	Kamm Creek (Slough)	Dissolved Oxygen, pH, Fecal Coliform
WA-01-1016	Mormon Ditch	Dissolved Oxygen, pH, Fecal Coliform
WA 01 1030	Nooksack River, SF	Fine Sediment, Instream Flow
WA 01 1040	Nooksack River, SF	Fine Sediment, Instream Flow, Temperature
WA-01-1060	Nooksack River, MF	Temperature
WA-01-1080	Nooksack River	Fine Sediment
WA-01-1101	Silver Creek	Dissolved Oxygen, Fecal Coliform
WA-01-1102	Unnamed Creek	Dissolved Oxygen, Fecal Coliform
WA-01-1103	Tennant Creek	Dissolved Oxygen, Fecal Coliform
WA-01-1104	Anderson Ditch	Dissolved Oxygen, Fecal Coliform
WA-01-1110	Bertrand Creek	Dissolved Oxygen, Fecal Coliform, Instream Flow
WA-01-1111	Duffner Ditch	Dissolved Oxygen, Temperature
WA-01-1115	Fishtrap Creek	Fecal Coliform, Instream Flow
WA-01-1116	Double Ditch Drain	Fecal Coliform
WA-01-1117	Benson Road Ditch	Dissolved Oxygen, Fecal Coliform
WA-01-1118	Depot Road Ditch	Dissolved Oxygen, Fecal Coliform
WA-01-1119	Bender Road Ditch	Dissolved Oxygen, Fecal Coliform
WA 01 1120	Anderson Creek	Fine Sediment
WA-01-1124	Hoff Creek	Temperature
WA 01 1145	Racehorse Creek	Fine Sediment, Temperature
WA-01-1155	Boulder Creek	Temperature
WA-01-1170	Cornell Creek	Temperature
WA-01-1175	Gallop Creek	Temperature
WA 01 1290	Howard Creek	Fine Sediment
WA-01-1310	Canyon Lake Creek	Temperature
WA-01-3300	Lummi River	Fecal Coliform

(Dorf, 1996). The sources of the fecal coliform problem throughout the lower Nooksack basin also are tied to the nutrient, dissolved oxygen, and ammonia problems. BFO staff reasoned that if it conducted a TMDL evaluation and implementation plan on fecal coliform, the implemented activities would help eliminate many of the other water quality problems as well. Ecology's Environmental Assessment Program (EAP) staff wrote a quality assurance plan for the TMDL project in 1997 which was significantly amended to include comments by the Lummi Nation and Nooksack Tribe (Joy, 1997a; Joy, 1997b). Water quality monitoring following the project plan was conducted from March 1997 to February 1998.

Monitoring was accomplished with help and resources provided by the two Indian tribes and DOH.

Ecology will be collaborating with local stakeholders to complete the TMDL process and integrate this TMDL with work started in Fishtrap and Tenmile watersheds.

Project Objectives and Strategy

The goal of the TMDL project is to recommend bacteria discharge limits for point sources and tributaries in the lower Nooksack River basin. Implementation of the TMDL will bring the lower main stem Nooksack River and other 303(d) listed areas back into compliance with Class A water quality standards. Primary and secondary recreational contact uses will be protected. The TMDL should also reduce (1) fecal bacteria counts in drinking water intakes, (2) bacteria loading to Portage Bay, and (3) the number of bacteria violations in the shellfish harvesting areas reported by DOH.

This bacteria TMDL evaluation report will:

- Identify the relative magnitude of bacteria loading to the lower Nooksack River from municipal point sources, tributaries, and other nonpoint sources from the mouth to the three forks area near North Cedarville (river mile 31).
- Evaluate the cumulative effect of bacteria sources on lower main stem water quality and the Nooksack estuary (Portage Bay).
- Address seasonal differences in bacteria source loading.
- Recommend bacteria load reductions and target bacteria counts for point sources, tributaries, and other nonpoint sources in the project area.
- Estimate the effect of the proposed river bacteria reduction targets on Portage Bay bacteria densities.
- Evaluate the effectiveness of controls in watersheds with existing watershed action plans and implementation strategies.
- Outline source identification strategies, general best management practices (BMPs), and other actions needed in the TMDL implementation plan to meet bacteria load reductions and targets.

The TMDL evaluation report will provide Ecology's Bellingham Field Office (BFO) with a document that describes the major sources of bacterial contamination in the lower Nooksack River. The Lummi Nation, Nooksack Tribe, DOH, the Whatcom Conservation District, and others were brought into the TMDL process at an early stage to discuss the data results and evaluation approach. This evaluative report and a summary implementation strategy written by BFO staff will be presented in a public forum. The comments received during the public forum will be used to modify any technical or policy issues included in the bacteria TMDL documents. The evaluation report, the implementation plan, the schedule of remedial actions, and records of all subsequent discussions and decisions will then be presented to Region 10 of the U.S. Environmental Protection Agency for final approval.

Methods

TMDL Study Plan

The Nooksack River TMDL study required data to characterize bacteria loads to the river from various sources, and to describe the transport and fate of those loads to the estuary (Joy 1997a, 1997b). A combination of historical studies and water quality monitoring from April 1997 through March 1998 were used to collect data on bacteria sources, their effect on the river, and seasonal differences in sources and effects. At the request of reviewers of the draft quality assurance project plan (QAPP), the monitoring was extended from eight to 12 months (Joy, 1997b).

As mentioned earlier, detailed water quality studies had been performed in parts of the TMDL study area. Data from these studies were used to check bacteria load characteristics calculated from 1997-98 data, and for evaluating the overall effectiveness of best management practices placed in the watershed during the early 1990s.

Sampling Sites

A primary monitoring network of six main stem sites, 11 tributary sites, and four point sources was used (Figure 1 and Table 3). The main stem sites were distributed approximately every sixth river mile between Marine Drive (RM 1.3) and North Cedarville (RM 30.9). The uppermost site near North Cedarville recorded the less effected forested/rural upper basin. The site is co-located with other Ecology and USGS data collection efforts. The lowermost site at Marine Drive was co-located with a site for the DOH sampling network in the Nooksack River estuary and Portage Bay.

Four point sources were evaluated (Table 3). The three municipal wastewater treatment plants (WWTP) were sampled at the end of the chlorine contact chamber, and the Darigold discharge at Lynden was sampled at a sampling port used by the city of Lynden for sample collection.

All site locations were given longitude and latitude coordinates by either using corrected global positioning system (GPS) data or digital data maps (Appendix A, Table A1).

Field and Laboratory Methods

The Nooksack River channel is broad, and water entering from tributaries or drains may not mix across the channel for several thousand feet downstream. Two bacteria samples and various field parameters were collected at each main stem site. Sites on tributaries were located as close to the mouth as possible where the tributary was not experiencing main stem backwater effects. Single bacteria samples were collected for most of the tributaries.

Table 3. Sampling sites for the lower Nooksack River TMDL study, 1997-98.

Site Number	Site Name	River Mile	Site Type	Drainage (mi^2)
SIL	Silver Creek	0.7	Tributary	15.8
MS-1	Marine Drive	1.3	Main stem	826
FERN	Ferndale WWTP	5.5	Point Source	3
MS-2	Ferndale	5.9	Main stem	786
TEN	Tenmile Creek	6.9	Tributary	34
WIS	Wiser Lake Creek	10.2	Tributary	7
KEE	Keefe Lake Creek	10.3	Tributary	5.1
MS-3	Below Bertrand/Fishtrap Cr.	11.2	Main stem	• 726
BER	Bertrand Creek	12.6	Tributary	42.5
FIS	Fishtrap Creek	13.2	Tributary	36.8
LLPL	Left bank ditch below Lynden	14.7	Tributary	1.5
SCO	Scott Ditch	15.5	Tributary	9.8
DARI	Darigold Condensate	17.4	Point Source	--
LYND	Lynden WWTP	17.5	Point Source	3
MS-4	Lynden	18	Main stem	• 630
KAM	Kamm Creek	18.1	Tributary	8
EVER	Everson WWTP	23.7	Point Source	1
MS-5	Everson	23.8	Main stem	• 620
AND	Anderson Creek	28.2	Tributary	14.3
SMI	Smith Creek	29.8	Tributary	10.6
MS-6	North Cedarville	30.9	Main stem	594

Standard Ecology protocols were used for sample collection, preservation, and shipping to the Manchester Environmental Laboratory (Manchester Environmental Laboratory, 1994). EAP field methods (Table 4) were followed for the collection of flow, dissolved oxygen, pH, temperature, and specific conductance (Watershed Assessments Section, 1993).

Field meter calibration followed EAP protocols (Watershed Assessments Section, 1993) under manufacturer's instructions (Table 4). Samples for analysis at Manchester Environmental Laboratory (MEL) were collected directly into pre-cleaned containers supplied by MEL. Samples were stored in the dark, on ice, and shipped to the MEL. Samples were available at MEL for analysis within 24 hours of collection. Standard procedures were used to analyze samples (Table 4). All samples were analyzed within recommended method holding times except one set of fecal coliform and *Escherichia coli (E. coli)* samples that were delayed in transit. Those samples were discarded.

Table 4. Summary of field and laboratory measurements of water, target detection limits, and methods.

Analysis	Resolution	Method[1]	Lower Reporting Limit
Field Measurements			
Velocity	± 0.1 f/s		0.05 f/s
pH	± 0.1 su	150.1/4500H	
Temperature	± 0.1 °C	/2550B	- 1°C
Dissolved Oxygen	± 0.2 mg/L	360.2/4500-OC	0.1 mg/L
Specific Conductivity	± 20 umhos/cm	/2510	10 umhos/cm
General Chemistry			
Fecal Coliform/ E. coli (MF)		/9222D/G	1 cfu/100 mL
Fecal Coliform/ E. coli (MPN)		/9221C/F	3 MPN/100mL
Enterococcus		/9330C or 9330B	1 cfu/100mL or 3 MPN
Turbidity		180.1/2130B	1 NTU
Chloride		300/4110D	0.1 mg/L
Total Persulfate Nitrogen		Valderrama, 1981	25 ug/L
Ammonia Nitrogen		350.1/4500-NH3D	10 ug/L
Nitrate & Nitrite Nitrogen		353.2/4500-NO3F	10 ug/L
Orthophosphate P		365.3/4500PF	5 ug/L
Total Phosphorus		365.3/4500PF	10 ug/L

[1] USEPA, 1983 /APHA, 1995

Provisional USGS flow data were retrieved from the ADAPS/NWIS database for currently active gaging sites at North Cedarville (12210700), Fishtrap Creek (12212100), and Ferndale (12213100). WWTP discharge monitoring records were obtained from Ecology files. Stream flows in other tributaries were measured during surveys using standard cross-sectional and velocity probe techniques (Watershed Assessments Section, 1993).

Nutrient analyses were also conducted on samples and included inorganic (nitrate & nitrite, ammonia) and total (persulfate) forms of nitrogen, and orthophosphate and total phosphorus. These data will be made available in a separate data summary.

Coordination and Cooperation with Other Studies

Ecology EAP program activities in the project area during the study period included ambient monitoring, Class II inspection work at the Ferndale WWTP, and groundwater studies. Data and resources were shared between these activities and the TMDL project.

Efforts were made to reduce redundant sampling, and increase data collection effectiveness. USGS, Lummi Nation, Nooksack Tribe, WWU, and DOH staff involved in Nooksack basin monitoring were contacted to coordinate sampling schedules and parameter coverages. Monitoring runs were scheduled to coincide with DOH presence in Portage Bay. Cooperative monitoring opportunities during the survey allowed EAP staff to work with treatment plant operators, the Lummi Nation, the Nooksack Tribe, and DOH.

Data Analysis

TMDL survey data were directly loaded from MEL data files into a Microsoft® ACCESS database and into EXCEL workbooks. Field data were entered into the ACCESS database by hand. Spot checks of laboratory data, and complete review of field data entries were conducted. Data from the Ecology ambient water quality monitoring database (Ecology, 1998) was obtained after internal quality assurance (QA) review. Data from the Nooksack Tribe (Woodward, 1998), the Lummi Nation (Lummi Water Resources, 1999), and DOH (Washington Department of Health, 1998) were also used. Data quality was judged acceptable based on QA procedures reported by these cooperators.

Many of the historical and TMDL survey data analyses were performed using *WQHYDRO*®, a statistical software package (Aroner, 1995). The Monte Carlo analysis was performed using @Risk® for Microsoft Windows® software (Palisade, 1997).

Stream flow analyses were performed on all tributaries after developing artificial hydrographs from the Fishtrap Creek continuous gaging station record obtained from USGS. Instantaneous discharge data on monitored tributaries were matched by date with Fishtrap Creek data to develop statistical relationships. Some sites required stratified data sets with multiple regression equations. These equations, or sets of equations, were then used to estimate daily flow records for each tributary.

Quality Assurance and Quality Control

Completion

Several changes occurred during the course of the field surveys that affected sample continuity at one or more stations. The initial QAPP identified 16 regularly monitored events at 19 stations from March to November. Additional data at other sites were to be collected during special surveys (Joy, 1997a). Initial field surveys suffered some setbacks and losses of data from unforeseen difficulties in the field, (e.g., boat launching difficulties, sample shipping losses, equipment failures, and time-related safety constraints). After initial field surveys, a station was added to monitor Smith Creek, but the creek dried-up at the monitoring location during the summer months. Another station, LLPL, was added after July to monitor a small, unnamed ditch. The station at Silver Creek was dropped after April because backwater effects from the Nooksack River were evident during the first few monitoring runs, and no adequate site was found as a substitute. Table 5 provides a summary of completion for the stations.

Table 5. Number of visits to each Nooksack TMDL site compared to QAPP expectations.

Site	Routine Survey		Storm Event	
Name	Number	%	Number	%
MS-6	20	83%	18	100%
MS-5	22	92%		
MS-4	23	96%	18	100%
MS-3	22	92%		
MS-2	22	92%	18	100%
MS-1	23	96%	18	100%
Smith Cr.	10	56%		
Anderson Cr.	13	72%		
Kamm Cr.	16	89%		
Scott Ditch	16	89%		
LLPL Ditch	8	44%		
Fishtrap Cr.	24	100%	18	100%
Bertrand Cr.	16	89%		
Keefe Outlet	10	56%		
Wiser Outlet	13	72%		
Tenmile Cr.	23	96%	18	100%
Silver Cr.	4	22%		
Everson WWTP	13	72%		
Lynden WWTP	13	72%		
Darigold	13	72%		
Ferndale WWTP	13	72%		

Midway through the field tasks of the project, the scope was changed after the QAPP was reviewed by the Lummi Nation and Nooksack Tribe (Joy, 1997b). Monitoring tasks of the study were expanded to include February 1998, but with emphasis on storm events (greater than 0.3 inches of rainfall in 24 hours for two or more days) for the period September 1997 to February 1998. Routine surveys in September, November, and February were altered to four days. Samples were collected on main stem stations, Fishtrap Creek, and Tenmile Creek on all four days, while the other sites were sampled on only two days (Joy, 1997b). Storm event monitoring in October, December, and January focused on Fishtrap Creek and Tenmile Creek and on four main stem stations (MS-6, MS-4, MS-2, and MS-1). Storm event monitoring was successful in terms of data collection (Table 5).

Special diel and biomass surveys related to nutrient assessment were dropped because resources were shifted to monitoring bacteria. A second bacteria die-off study and a second assessment of small drains were not conducted because of lack of resources.

Replicate Sample Comparison

Field and laboratory sample variables were addressed by using duplicate samples at various stages of the sample process. Bacteria samples appear to have a high coefficient of variation compared to other water quality analyses because they have a positively skewed distribution (APHA, 1995). Field replicates from the Nooksack TMDL survey data were similar to survey data from the Ecology ambient monitoring program (Hallock and Hopkins, 1994), and TMDL monitoring surveys conducted by Coots (1994) and Cusimano (1997). The root mean square error (RMSE) of the coefficient of variation (cv) had a range from 8.3% for chloride to 30% for *Escherichia coli* (*E. coli)* (Table 6). The RMSE of the cv improved on the logarithmically transformed pairs of total phosphorus, fecal coliform, *E. coli*, and enterococcus samples (Table 6). Calculating the RMSE of the cv on transformed data may be a more appropriate since these samples fit lognormal distributions.

Table 6. Root mean square error (RMSE) of the coefficient of variation (cv) for duplicate field samples collected during the Nooksack TMDL surveys. *Values in parentheses are for data that were lognormally transformed.*

Nooksack River Bacteria TMDL
QA Results: RMSE of coefficient of variation

Parameter	No. of pairs	RMSE of cv
Chloride	33	8.3%
Ammonia	40	16.0%
Nitrate+Nitrite	40	9.7%
Total Nitrogen	27	8.2%
Ortho-Phosphate	14	11.6%
Total Phosphorus	40	20.8% (9.7%)
Fecal Coliform	52	27.9% (8.3%)
E. coli	52	30.0% (8.9%)
Enterococcus	12	28.7% (7.3%)

Water Quality Assessment

Historical Data and 1997 Survey Data

Trend analysis shows a decrease in fecal coliform (FC) counts in monthly samples collected by Ecology at Brennan (RM 3.5) over the past 20 years (Figure 2). Data were first transformed to their natural logarithms (log base e) to normalize the distribution. The decreasing trend is significant at the 95% confidence level using the Seasonal Kendall test with correction for discharge. When data are stratified into two seasons, the trend is more significant for the drier months of May to September. Trend analyses performed on data collected over the last six water years (October 1991 through September 1997) do not show significant trends.

Fecal coliform bacteria data indicated very poor water quality in the late 1970s and early 1980s. More than half the monthly samples collected at Brennan from 1978 to 1984 were over 100 cfu/100 mL (Figure 3). The majority of those samples were collected when the two-day antecedent rainfall was less than 0.1 inches. A low antecedent rainfall would reduce the probability that the source of bacteria was runoff from manure spread on fields (considered one of the major sources of bacteria in the basin). The sources of contamination were more likely to have been direct waste discharges, e.g., livestock in the river, WWTP disinfection failures, direct discharges from dairies or other animal raising operations, and poor manure application practices.

Improvements in FC river quality were observed from 1985 to 1988. Fewer FC counts were over 100 cfu/100 mL, and fewer of the criterion violations occurred during dry antecedent dates. One reason for the FC reductions may be that milk cow populations were reduced by 22% between 1985 and 1987 because of the federal dairy termination program (Gillies, 1999). Ecology also began to fund local watershed monitoring and planning projects during this period. Whatcom County Conservation District increased its education and outreach activities to dairies, as part of the watershed plan implementation.

The number of samples over 100 cfu/100 mL again increased in the period 1989 to 1992. Less than half of the samples over the criterion were observed during dry periods. From 1993 to 1997, FC counts again declined. Only a quarter of the samples collected were greater than 100-cfu/100 mL. In 1993, 1994, and 1996, none of the samples over the standard was from a dry period.

Samples collected during the routine surveys over the TMDL study period yielded statistics similar to recent and historical monthly ambient data (Table 7). A quarter of the routine TMDL FC samples collected from March 1997 to February 1998 at Marine Drive (RM 1.3) were greater than 100-cfu/100 mL. The geometric mean and 90th percentile FC count at Marine Drive collected by the TMDL project team were similar, but slightly lower than were calculated from data at Brennan by the Ecology Ambient Monitoring Unit over the same period. More samples over 200 cfu/100 mL (18%) were collected in the routine TMDL data set, but the percentage of samples over 200 cfu/100 mL is similar to historical observations at Brennan. FC data collected

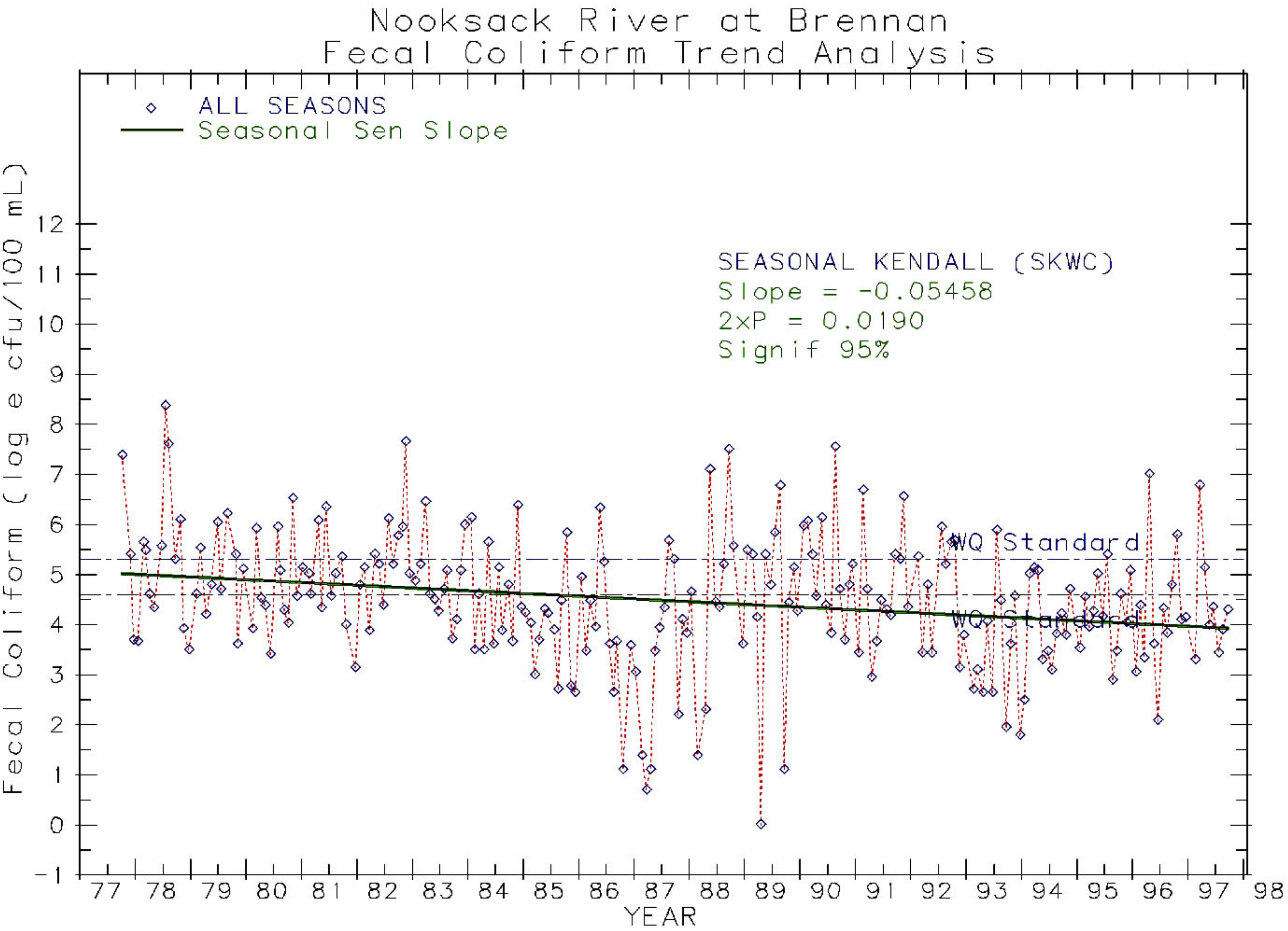

Figure 2. A trend analysis of monthly fecal coliform samples collected from the Nooksack River at Brennan (1977 - 97).

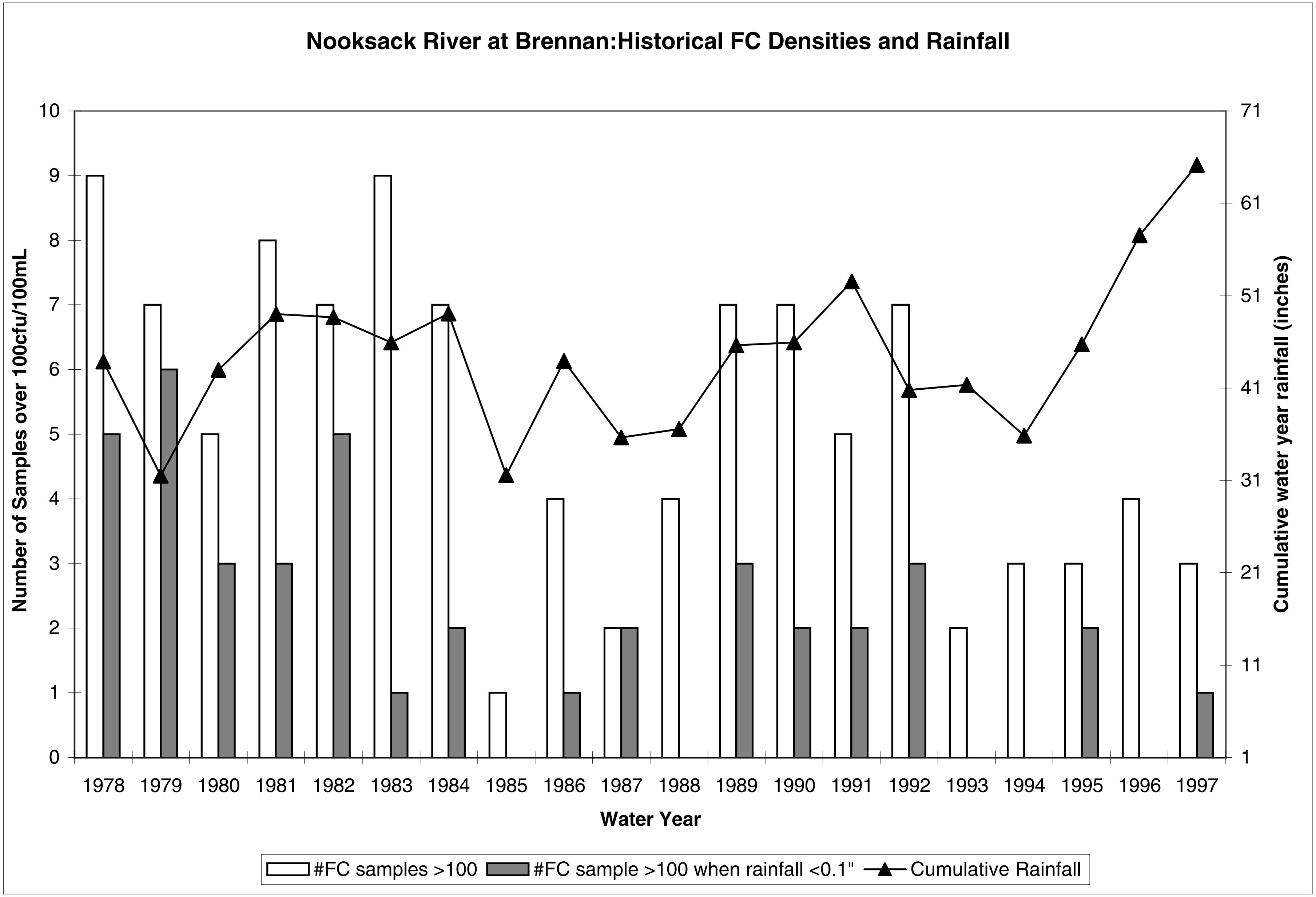

Figure 3. The number of monthly fecal coliform samples collected from the Nooksack River that exceed 100 cfu/100 mL and the cumulative annual rainfall that occurred two days prior to each sample collection.

by the two groups from North Cedarville (RM 30.9) yielded similar geometric mean statistics (Table 7). However, the Ecology ambient monitoring data gave a higher 90th percentile value than the routine TMDL data. The TMDL 90th percentile statistics were within the range of values observed during the past five years, but 90th percentile statistic for the 1997–98 ambient monitoring data set was the highest since 1989.

Table 7. A comparison of statistics between the 1997-98 TMDL study data and data taken by the Ecology Ambient Monitoring Program over the same period and in the past five years. *Last column includes TMDL and Nooksack Tribe storm event data.*

	Statistic	Past 5-yrs. Ecology Ambient*	Ecology Ambient 1997-98	TMDL routine survey data	TMDL w/intensive storm data
Brennan or Marine Dr.	Number of Samples	11 - 12	12	28	39
	Geometric Mean	38 – 88	76	58	81
	90th Percentile	163 – 333	285	253	416
	Samples>100	1 – 4	4 (33%)	7 (25%)	14 (36%)
	Samples>200	0 – 2	1 (8.3%)	5 (18%)	12 (31%)
North Cedarville	Number of Samples	0 – 12**	12	24	36
	Geometric Mean	7 – 18	15	14	17
	90th Percentile	36 – 100	105	65	89
	Samples>100	0 – 2	1 (8.3%)	1 (4.1%)	3 (8.3%)
	Samples>200	0 - 1	1 (8.3%)	0	2 (5.5%)

* Historical data presented as a range of values

** Samples were not collected at North Cedarville from October 1993 to September 1994.

In some cases the TMDL data statistics are significantly changed when samples collected during September, October, and December intensive storm events are added to the data set (Table 7). The geometric mean and 90th percentile statistics at Marine Drive increase because the number of samples greater than 100 or 200 cfu/100 mL doubled. The percentage of samples greater than 200 cfu/100 mL is nearly twice that observed for any of the past five years of ambient monitoring. On the other hand, the addition of data from intensive storm events did not have a significant effect on the statistics for the North Cedarville station. The implications of the storm event data will be discussed later in more detail (see Fecal Coliform Loading).

Historical data for tributaries collected by Ecology (Dickes, 1992; Erickson, 1995) and others (Matthews and Vandersypen, 1998; TetraTech, 1989a, 1989b; Whatcom Conservation District and Whatcom County Health District, 1990) were compared to TMDL survey data. The few data available indicate bacterial quality in the tributaries has not improved significantly over the past five years. This was the same conclusion Matthews and Vandersypen (1998) derived after analyzing FC data collected from Kamm Creek from 1993 to 1998. In another example, data collected during the TMDL at Fishtrap Creek was not significantly different from data collected during the fall and winter of 1993-4 by Erickson (1995).

All tributary data sets have elevated FC counts during both runoff and dry periods. The chronically elevated bacteria counts in Tenmile, Fishtrap, Bertrand and Kamm creeks suggest a mix of sources: direct delivery of wastes from livestock, onsite systems, manure guns and spreaders, or animal confinement areas, and runoff from manured fields, septic fields, stormwater systems, or residential areas. Best management practices (BMPs) are available to alleviate or reduce bacterial contamination from these sources (USEPA, 1993; USDA-SCS, 1983). Whatcom Conservation District (CD) staff have been actively helping dairy farmers and agricultural growers in the lower Nooksack River basin assess pollution problems and implement nutrient management plans.

Unfortunately, not all farmers and growers have come to the CD for plans, not all plans have been fully implemented, and not all BMPs have been maintained. Researchers have observed that installation of specific BMPs do not necessarily assure an improvement in bacterial water quality. As noted earlier, Matthews and Vandersypen (1998) of the Institute for Watershed Studies could find no significant changes in FC counts in Kamm Creek even after BMPs worth over $600,000 were installed to reduce manure transport and livestock access to the creek. These improvements may have been offset by poor maintenance of manure lagoons, conversions of pasture with lower manure runoff potential to corn silage with higher runoff potential, and increased herd sizes without concomitant increases in waste management systems.

The 1997 TMDL data and historical record contain evidence of unexpected or unaccounted bacteria sources. One of these unexpected sources in 1997 was the Lynden WWTP. Effluent from the sewage treatment plant was sampled as part of the TMDL study in May. Although self-monitoring reports had indicated the effluent was meeting National Pollutant Discharge Elimination System (NPDES) permit limits, the FC and *E. coli* bacteria counts in the samples collected by Ecology were extremely high even while a chlorine residual was present. In contrast, the treatment plant laboratory did not find a high FC count. Subsequent inspections found a problem with the laboratory equipment at the Lynden plant that prevented technicians from obtaining accurate results. Later, high bacteria counts were found to occur sporadically in the effluent. The problem is still under investigation.

Although the Lynden WWTP had these extremely high bacteria counts in its effluent, the bacteria load was not enough to account for the high FC count found during the first day of the May survey in the lowest six-mile reach of the river. The five-day antecedent rainfall at that time was zero, and counts in the river were 200 to 400 cfu/100 mL. The next day, counts were less than 80 cfu/100 mL. This type of short-term bacteria contamination incident is difficult to detect and to track back to its source. As shown earlier, these incidents appear to have decreased in frequency, but they have not been eliminated. It will be important to eliminate these types of contaminant spills before monitoring data can be used to evaluate the effectiveness of BMP local measures.

The results of the TMDL survey show a consistent pattern along the main stem (Figure 4). Two multiple comparison statistical tests, Tukey and Student Newman-Keuls (Zar, 1984), were used

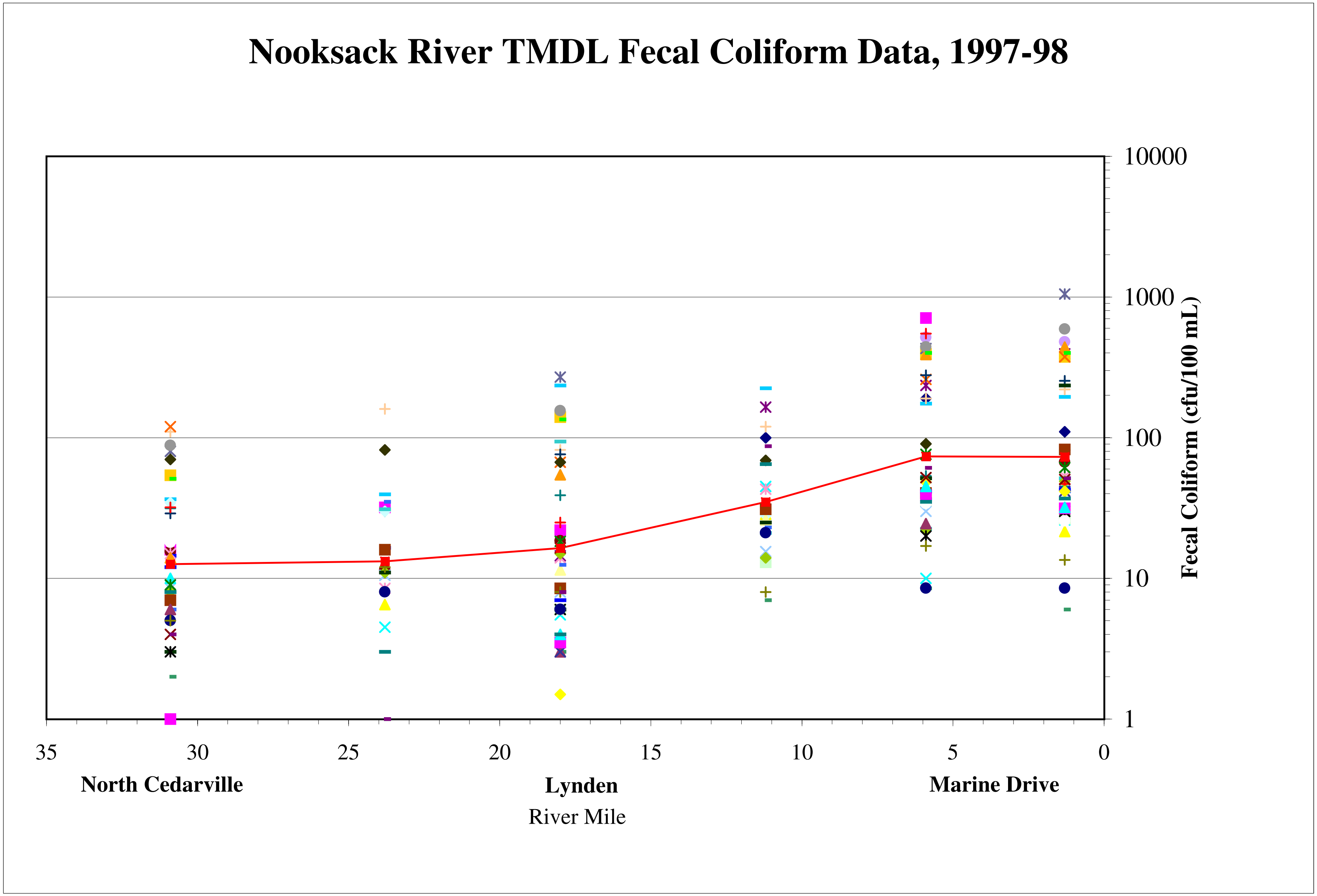

Figure 4. Main stem Nooksack River fecal coliform data collected at six sites from March 1997 to February 1998.

to detect differences between logarithmically transformed FC data at the six main stem sites. As mentioned earlier, the geometric mean of 14 cfu/100 mL for all samples collected at North Cedarville was within the range of historical averages for the past 20 years (2.6 to 17.6 cfu/ 100 mL). The geometric mean FC density at North Cedarville was not significantly different from the FC geometric mean of 13.2 cfu/100 mL at Everson (RM 23.8) and 16.4 cfu/100 mL at Hannegan Road Bridge above Lynden (RM 18). Increased FC densities during storm events at Hannegan Bridge were influenced by the upstream proximity of Kamm Creek, but they were not significantly different from North Cedarville storm event data.

The most noticeable and consistent increase in river FC densities occurred between Lynden and Ferndale (Figure 4). The geometric mean FC densities at all three sites below Lynden were significantly different from the three sites above Lynden. Storm event FC data at the Ferndale and Marine Drive sites also were significantly different from the FC data collected at Hannegan Road and North Cedarville. The geometric mean FC density of 34.9 cfu/100 mL at site MS-3 (RM 11.2), below Bertrand Creek, was not significantly different from the 74 cfu/100 mL at Ferndale (RM 5.9) and 73 cfu/100 mL at Marine Drive Bridge (RM 1.3). Only samples collected from the Ferndale and Marine Drive sites exceeded 200 cfu/100 mL over 10% of the time. Storm event FC counts at Ferndale and Marine Drive were not significantly different from each other, even with several cases where there was an FC increase between the two sites. Although the average FC count met the state geometric mean criterion at Marine Drive, it was almost six times that of North Cedarville. In addition, 31% of the values were over 200 cfu/100 mL, and not in compliance with second part of the fecal coliform criteria for Class A freshwater.

Fecal Coliform Loading

Fecal coliform counts are important to evaluate a waterbody's compliance with criteria. Fecal coliform loading calculations can provide a more comprehensive water quality analysis than FC count evaluations. Loading is a function of both contaminant concentration (or bacteria density) and discharge quantity. Loading analysis can reveal the presence of additional contaminant sources, dilution and dispersion characteristics, and transport mechanisms.

Before a loading analysis can be performed, the routing and balance of water must be made for the basin. A water balance was calculated to show the annual average discharge characteristics of the lower Nooksack River basin during the 1997-98 TMDL study period (Figure 5). Gage records in the main stem, and simulated hydrographs for the tributaries based on regression equations developed with the continuous gage at Fishtrap Creek, were used for the calculations (see Data Analysis). It is evident that the annual average discharge at Ferndale is dominated by snow-melt and rainfall generated in the upper watershed, i.e., approximately 90% of the average annual discharge at Ferndale (RM 5.8) is recorded at Deming (RM 36.6). In the water balance, groundwater in the lower basin appeared to be insignificant compared to surface sources. On the other hand, even the two largest sub-basins in the lower valley, Bertrand and Fishtrap, together supplied only 4% of the annual average discharge recorded at Ferndale. These findings are consistent with an earlier comprehensive hydrologic study (Department of Conservation, 1960).

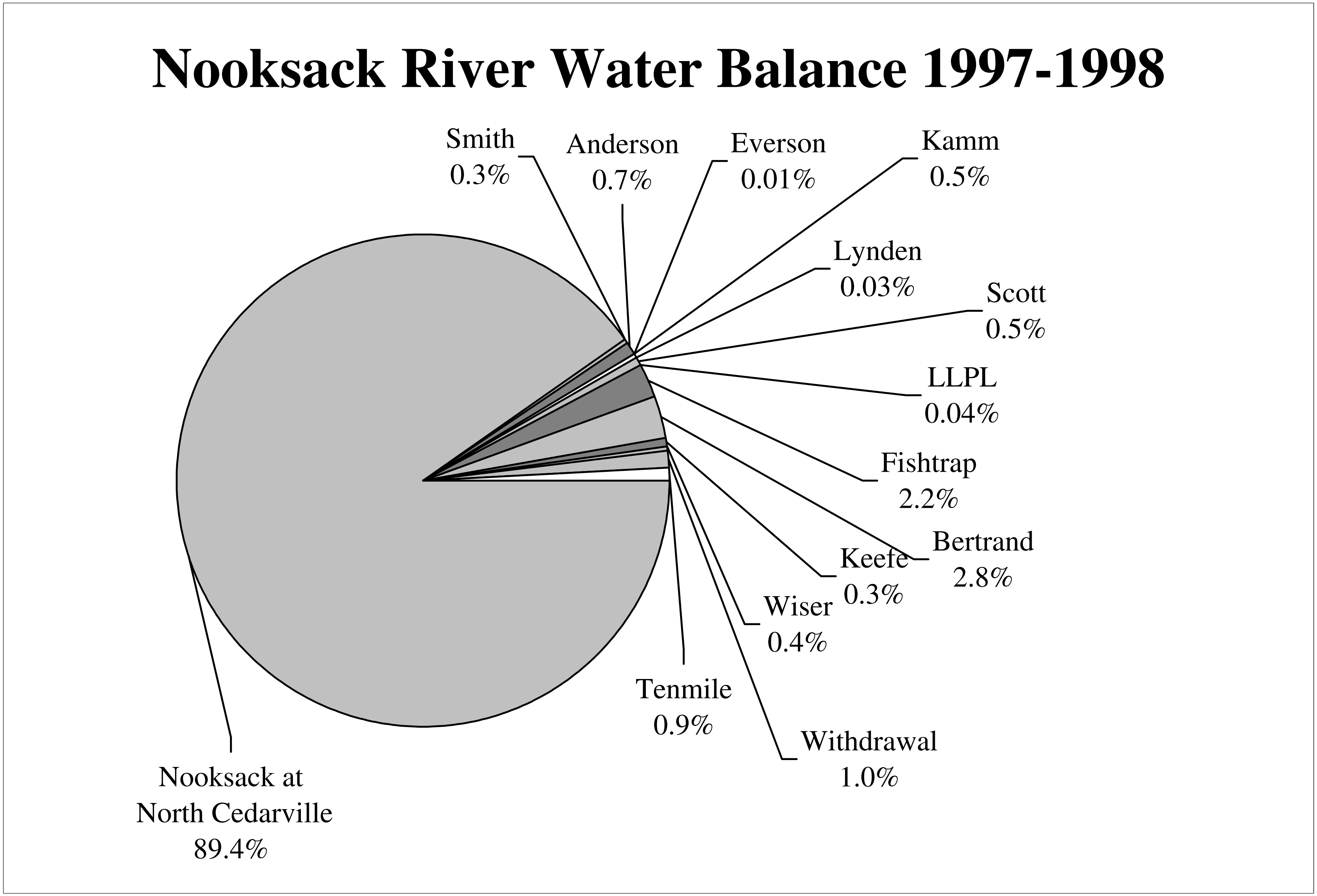

Figure 5. Estimated annual discharge contributions of sub-basins to the lower Nooksack River basin from March 1997 to February 1998.

Fecal coliform loads were calculated from the entire project database which included TMDL routine and storm event data, Ecology ambient monitoring data, Institute for Watershed Studies data, and Nooksack Tribe storm event data. In contrast to the water balance results, the lower basin is a very significant source of FC loading, especially when bacteria loads from rain events are included. Rainstorms are significant delivery mechanisms of contaminant loads in many watersheds. Researchers have found that high flow events that account for less than 20% of the annual discharge can contribute 40% to 90% of the annual bacteria load (Wyer et al., 1996). Ecology and the two Indian tribes collected FC samples during some intensive storm events from September 1997 to February 1998. Data from those events demonstrated dramatic increases in bacteria concentrations and loads in the tributaries and the main stem.

The water balance data and FC sample results taken during the TMDL surveys were applied to the Beales ratio estimator formula (see Appendix B) to calculate annual average FC loads (Thomann and Mueller, 1987). Fecal coliform loads are expressed simply as cfu/100 mL*cfs/day. Two sets of FC loads were estimated. The first used all TMDL data (n=31). The second eliminated 14 results collected during days, or just following days, with rainfall greater than 0.5 inches. From the loading analysis, up to 84% of the annual FC load from Fishtrap Creek and 58% of the annual FC load at Marine Drive occurred during periods of daily rainfall greater than 0.5 inches (Table 8). Over the TMDL survey period, 0.5 inches of rain occurred on 38 of 365 days.

Table 8. Nooksack River main stem and tributary load estimates for fecal coliform bacteria showing the influence of days with storm events (greater than 0.5 inches per day). *Load expressed as cfu/100 mL*cfs/day.*

	All Data	No Storm Data	Load Difference	Percent Storm Load
Nooksack at N. Cedarville	265,524	125,297	140,227	52%
Kamm Creek	51,051	18,735	32,316	63%
Fishtrap Creek	187,374	30,078	157,296	84%
Tenmile Creek	50,475	13,063	37,412	74%
Nooksack at Marine Dr.	995,118	416,433	578,685	58%

The loading response to rainfall could be expected since the lower Nooksack basin has a high percentage of low permeability soils (Hydrologic Group C and D) that are characterized as having moderate to high runoff (Figure 6). Most of the dairies and the fields they use for manure spreading also have these soil types (Figure 6). Fall and winter manure spreading on these soils increases the risk of substantial surface and groundwater contamination. Septic systems built in these soils also have a high potential for failure and significant bacterial loading to surface and groundwater.

Rainfall events can also activate other bacteria sources. Storm drains from urban and rural areas can be significant sources. For example, FC and *E. coli* samples from a Ferndale storm drain contained approximately 38,000 cfu/100 mL during a small rainstorm in August. Bacteria that have been precipitated with sediments and archived in stream and river channels also could be significant contributors of bacteria loading as stream velocities increase in response to storm

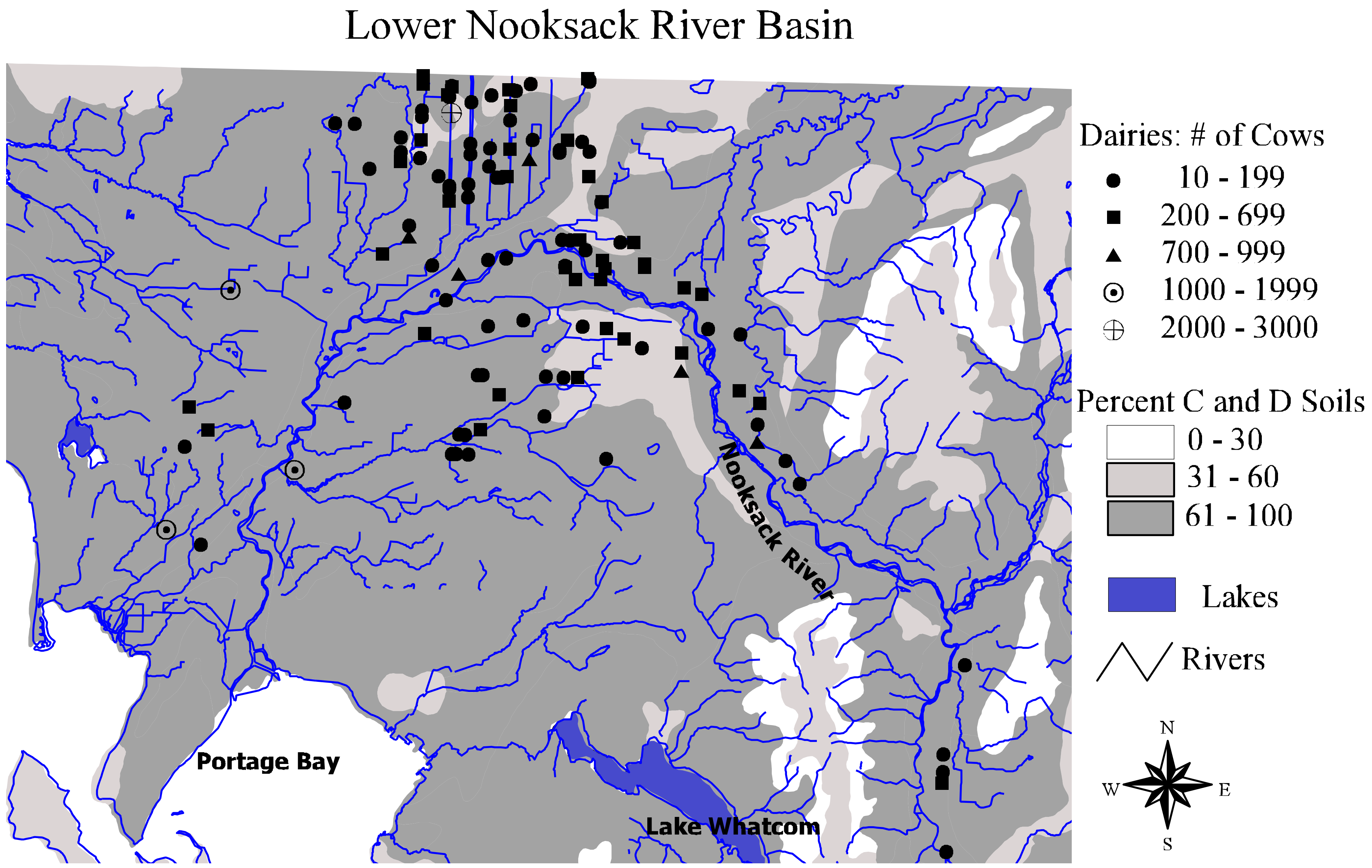

Figure 6. The location and size of dairies relative to Hydrologic Group C & D soils in the lower Nooksack River basin.

events (McDonald, Kay, and Jenkins, 1982; Wilkinson, Jenkins, Wyer, and Kay, 1995). Livestock access areas near streams also contain sediment-bound bacteria that are resuspended as discharge increases (Sherer, Miner, Moore, and Buckhouse, 1988).

The correlation between rainfall and fecal bacteria loads in the lower Nooksack basin is statistically significant, but not strong enough to make accurate predictions (Figure 7). Confounding factors that weaken the predictability of the relationship may include:

- The presence of multiple sources at varying distances from monitoring points.
- Sample timing upstream and downstream of source areas during variable discharge conditions.
- Spatial and temporal variability in rainfall.
- Frequent waste discharge incidents during dry weather that have nothing to do with rainfall (e.g., livestock defecating in creeks, poor manure handling practices, and poor WWTP effluent disinfection).
- The non-linearity of contaminated runoff from soils that is influenced by soil moisture conditions, cover crop, antecedent rainfall, distance to water courses, manure or septic effluent strength, manure application rate and timing, and rain storm intensity.
- The presence of drain tile and temporary surface ditches used to enhance field drainage that may short-circuit manure transport from fields to watercourses.
- The tendency for FC counts to increase with the rising part of the hydrograph, but not to match a particular discharge volume in the stream.

The 1997-98 TMDL FC loading analysis is summarized in a pie diagram similar to the water balance diagram (Figure 8). The loads calculated for tributaries without intensive storm event data (e.g., Smith, Anderson, Scott, LLPL, Bertrand, Keefe, and Wiser) were increased by factors of 1.2 to 3.8. These factors were estimated from individual tributary responses to rainfall during routine monitoring surveys. The loads from drainages in the study area that are not included in any of the tributary basin areas or municipal service areas (16.4 mi^2) were estimated as an "Ungaged" load. The average tributary FC load per square mile was used to make the "Ungaged" load estimate. More FC load was delivered to the Marine Drive site (MS-1) than was accounted for from the monitored and estimated inputs, so the residual load is shown in Figure 8 as "Unidentified".

The estimated loads closely parallel the river FC response depicted in Figure 4. The pie diagram shows that 27% of the 1997-98 (March to February) load was delivered from the upper watershed. This percentage is within the upper part of the range calculated for past years of Ecology monitoring (2% to 33%). The upper watershed FC load is high while the FC densities are low because 90% of the water (discharge) is delivered from the upper valleys (i.e., FC load = fecal density * discharge). The 2.7% combined load from Smith Creek and Anderson Creek does not significantly increase the river FC counts on average between Deming and Everson. Kamm Creek delivered 5% of the FC load to the study area. FC densities at the Hannegan Road (RM 18) monitoring site increased slightly. Cross-channel monitoring suggested that "Unidentified" and "Ungaged" sources also provide a portion of the load upstream of RM 18.

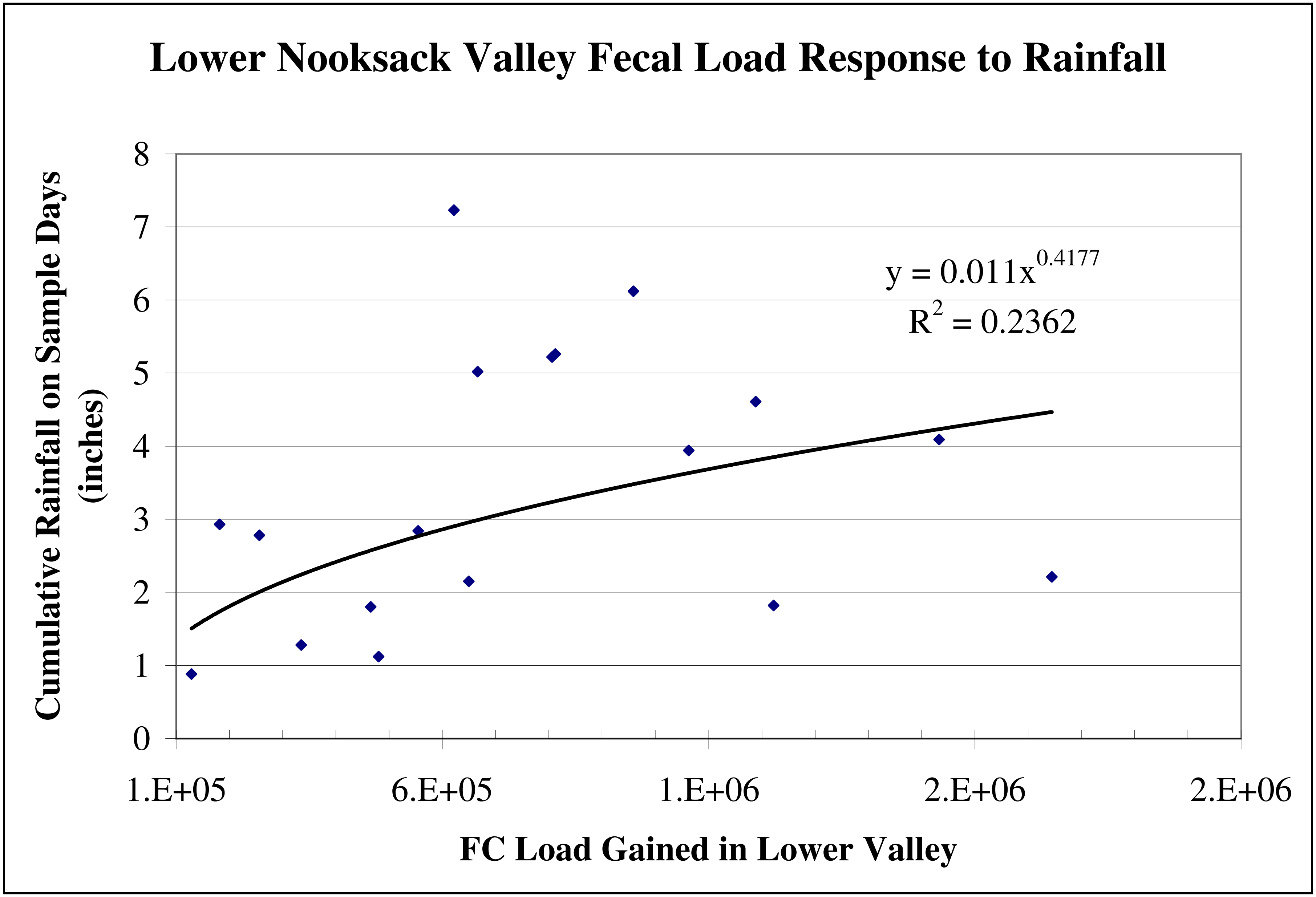

Figure 7. The relationship between rainfall before sampling events and fecal coliform load increases in the lower Nooksack River basin.

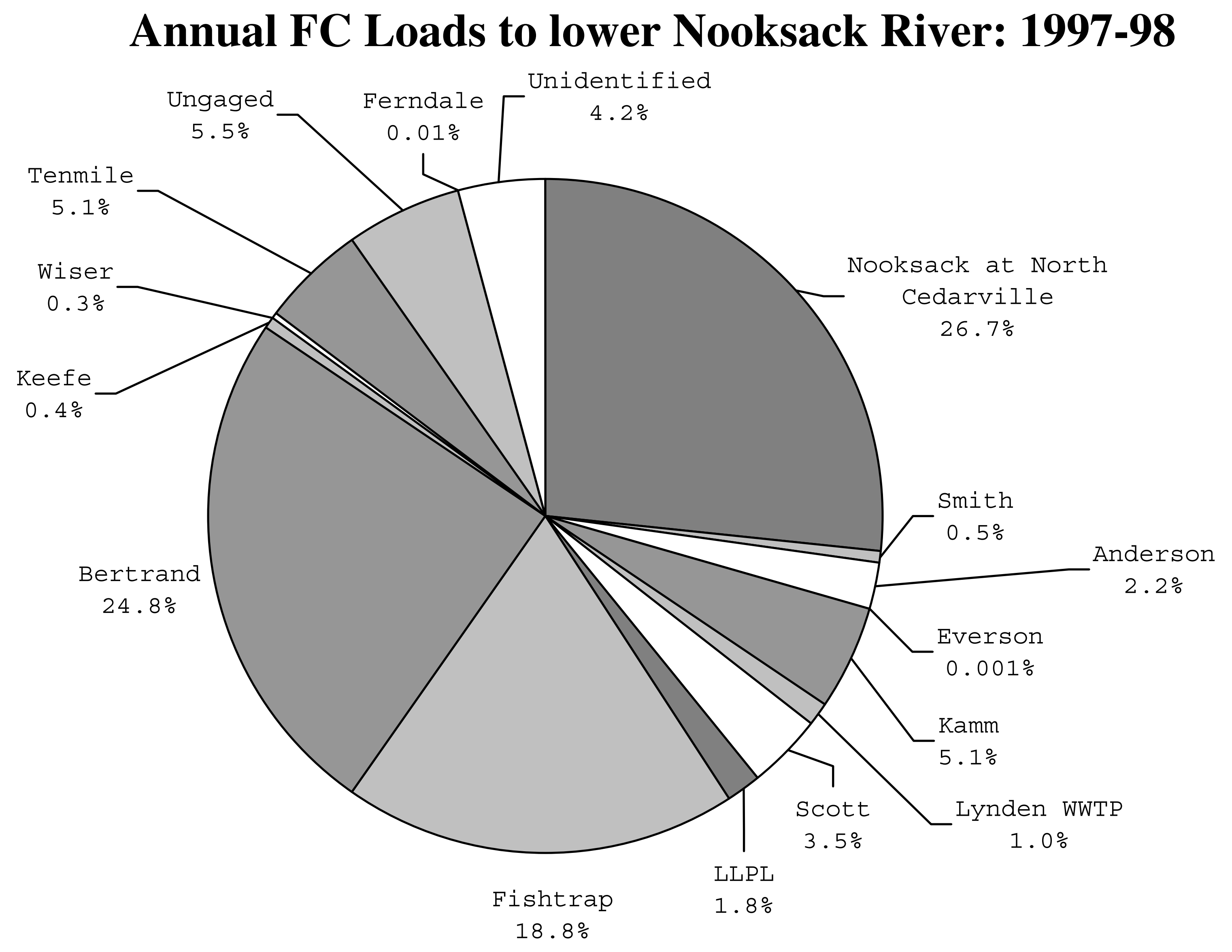

Figure 8. The estimated average percentage of fecal coliform loading contributed from sub-basins to the lower Nooksack River from March 1997 to February 1998.

The highest calculated loads enter the next reach of river: Lynden to Ferndale. Approximately 58% of the FC load was delivered from sources located between Hannegan Bridge and Ferndale. Fishtrap Creek and Bertrand Creek together account for nearly 44% of the FC load. The Lynden WWTP delivered an average of 1% of the annual FC load. Tenmile Creek delivered about the same load as Kamm Creek. "Unidentified" and "Ungaged" sources may also be contributing in this reach or downstream of Ferndale. The estimated FC load from the Ferndale WWTP was insignificant to other sources.

Other observations that can be taken from the FC loading analysis include:

- Fecal coliform decay rates appear to be low or non-existent in the Nooksack River. If fecal coliform die-off were a significant factor in the river, a reduction in fecal coliform concentrations or loads would be expected between points along the river. In contrast, the data indicate either a very low FC die-off rate, or the widespread presence of significant FC sources without significant surface water discharge. Fecal coliform samples taken during a drogue study in June 1997 also supports this contention (Figure 9). During two four-mile passes through the lowest reach of the river, no significant reduction of fecal coliform density was detected.
- "Ungaged" areas along the river and "Unidentified" sources may be contributing 10% of the annual FC load. These sources could include any of the following: riverside animal access or manure application areas, bacteria archived in sediments and resuspended during rising hydrographs, wildlife/waterfowl inputs, and urban storm drains. They also may represent the cumulative errors in the FC analysis and loading calculations.
- Insignificant discharges in terms of volume (Lynden WWTP and LLPL Ditch) can have higher pollutant loads than larger tributaries (Wiser Lake outlet and Keefe Lake outlet).
- Tributaries with lakes or large wetlands near their mouths (Wiser, Keefe, and Tenmile) appear to deliver lower FC loads than similarly sized tributaries without these features (Kamm and Scott).
- Fishtrap and Bertrand sub-basins are the most significant FC load sources in the lower basin. LLPL is the most significant source in terms of FC load per square mile.
- Everson and Ferndale WWTPs usually had adequate effluent disinfection and contributed insignificant FC loads to the river.

Indicator Bacteria Comparisons

Most of the bacterial samples collected during the TMDL study were analyzed for fecal coliform (FC) bacteria using the membrane filter (MF) method. However, samples were also analyzed for FC using the most probable number method (MPN), and for enteroccoci and *Escherichia coli* (*E. coli*). The Department of Health Office of Shellfish Programs (DOH) and the U.S. Food and Drug Administration only recognize FC results using the MPN method for assessing shellfish harvest areas (APHA, 1970). In addition, the State of Washington is considering changes in the water quality criteria for recreational uses (WQP, 1999). The USEPA is recommending that the state use enteroccoci and *E. coli* as better indicators of water quality for primary contact uses

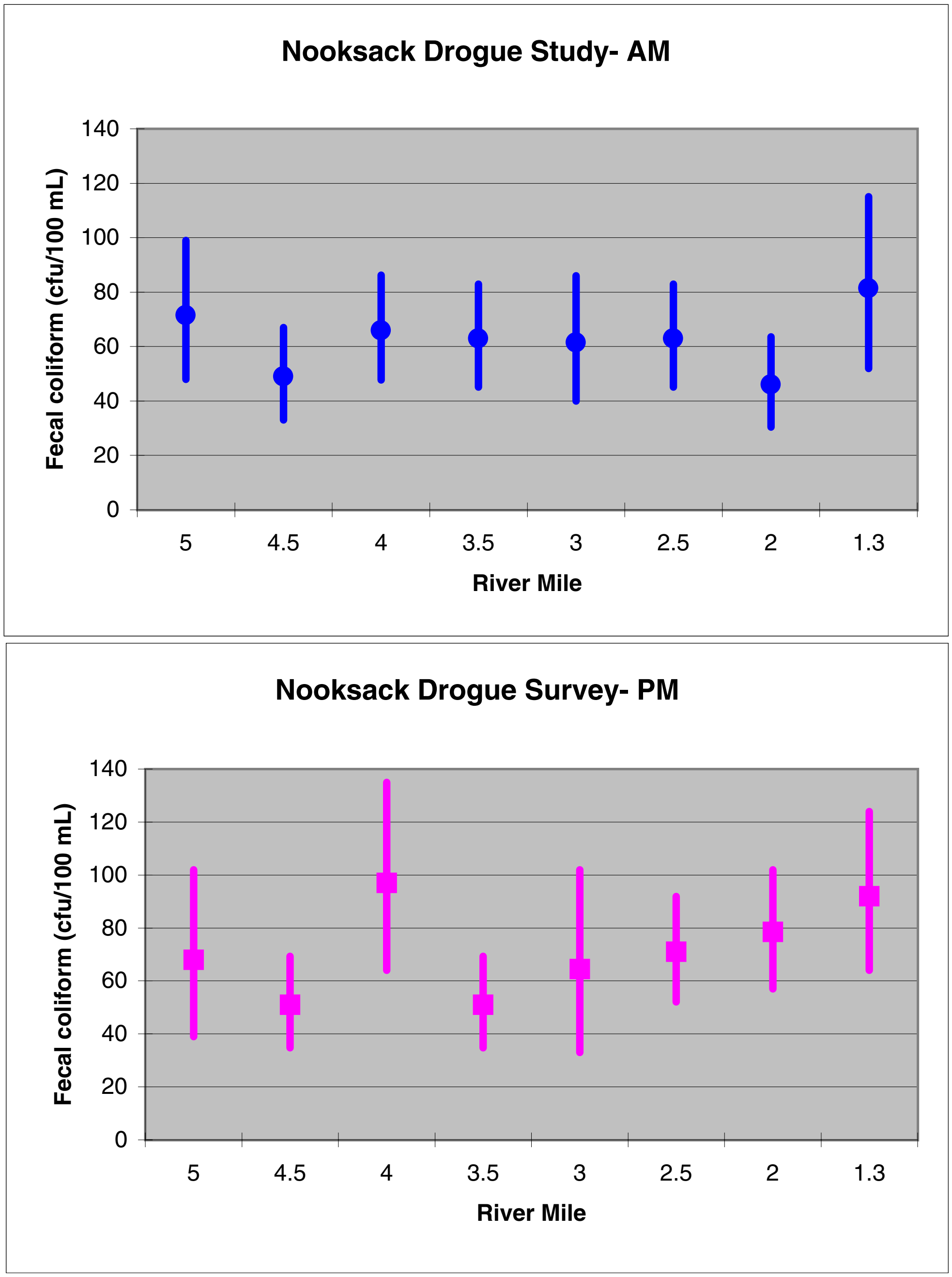

Figure 9. Fecal coliform data from two drogue runs on 17 June 1997. Average FC density and 95% confidence intervals for site data are shown.

(USEPA, 1986). These additional analyses were performed during the TMDL study to better prepare for future modifications in criteria, and to better understand sources of bacterial contamination.

Of the 103 pairs of FC samples collected and analyzed using MPN and MF methods, 24 (23%) MF samples were outside the 95% confidence interval of their MPN companion sample. Standard Methods (APHA, 1995) states this should be expected. The MPN results have a wider confidence interval than MF, and a built-in positive statistical bias. Some researchers believe the MPN method is better at enumerating injured or stressed organisms. Therefore, MPN and MF databases are not usually mixed. The overall relationship between MPN and MF pairs shown in Figure 10 was significant after lognormal transformation, but not highly correlated (r^2=0.533). The positive bias of the MPN results is also evident in the graph.

E. coli is the species of the fecal coliform group most commonly associated with wastes from warm-blooded animals. However, a large basin like the Nooksack could have several other members of the fecal coliform group that are not *E. coli* (e.g., members of the genus *Klebsellia, Citrobacter*, and *Enterobacter*). For example, *Klebsellia sp*. are associated more with decaying vegetation, and not necessarily an indication of fecal contamination from warm-blooded animals. State and federal fecal coliform criteria do not make allowances for the type of organisms reported as fecal coliform. Identifying specific types of organisms within the fecal coliform group is helpful for identifying probable sources, and planning methods of their control.

A close correlation between *E. coli* and FC was found in TMDL survey samples. Over a broad range of bacteria densities, membrane filter *E. coli* and FC samples were highly correlated (r^2= 0.985) with a slope near 1.0. In 58% of the pairs, the *E. coli* and FC results were identical. The relationship between the MF data pairs is shown as a graph in Figure 11. The MPN data pairs were slightly less correlated (r^2= 0.983). Notwithstanding, the results show that *E. coli* are the predominant FC organisms in Nooksack basin samples, and wastes from warm-blooded animals are the likely sources of contamination.

The USEPA recommendations for *E. coli* criteria are health-risk based (USEPA, 1986). The USEPA recommends that states adopt criteria with, at most, an acceptable risk of eight highly credible gastrointestinal illnesses per 1,000 fully exposed swimmers. For five samples evenly spaced over 30 days, this risk translates to a monthly geometric mean *E. coli* count of 126/ 100 mL. In addition, single sample criteria are estimated for various intensities of bather use. For example, a beach with “light” bather use would use the upper 90% confidence interval of the geometric mean as a criterion, whereas a “designated bathing beach” would use the upper 75% confidence interval as a criterion.

Not enough *E. coli* data at any single site was collected within 30 days to properly compare to the USEPA recommendations. However, a general review of the data suggests that most tributary sites would pose unacceptable health risks to swimmers during the warmer months of June through September. Nooksack River main stem sites would have passed the USEPA recommended *E. coli* criteria in most cases. The June and August rainstorms could have created unacceptable health risks from MS-3 (RM 11.2) to the mouth of the river if the “designated bathing area” criteria were used.

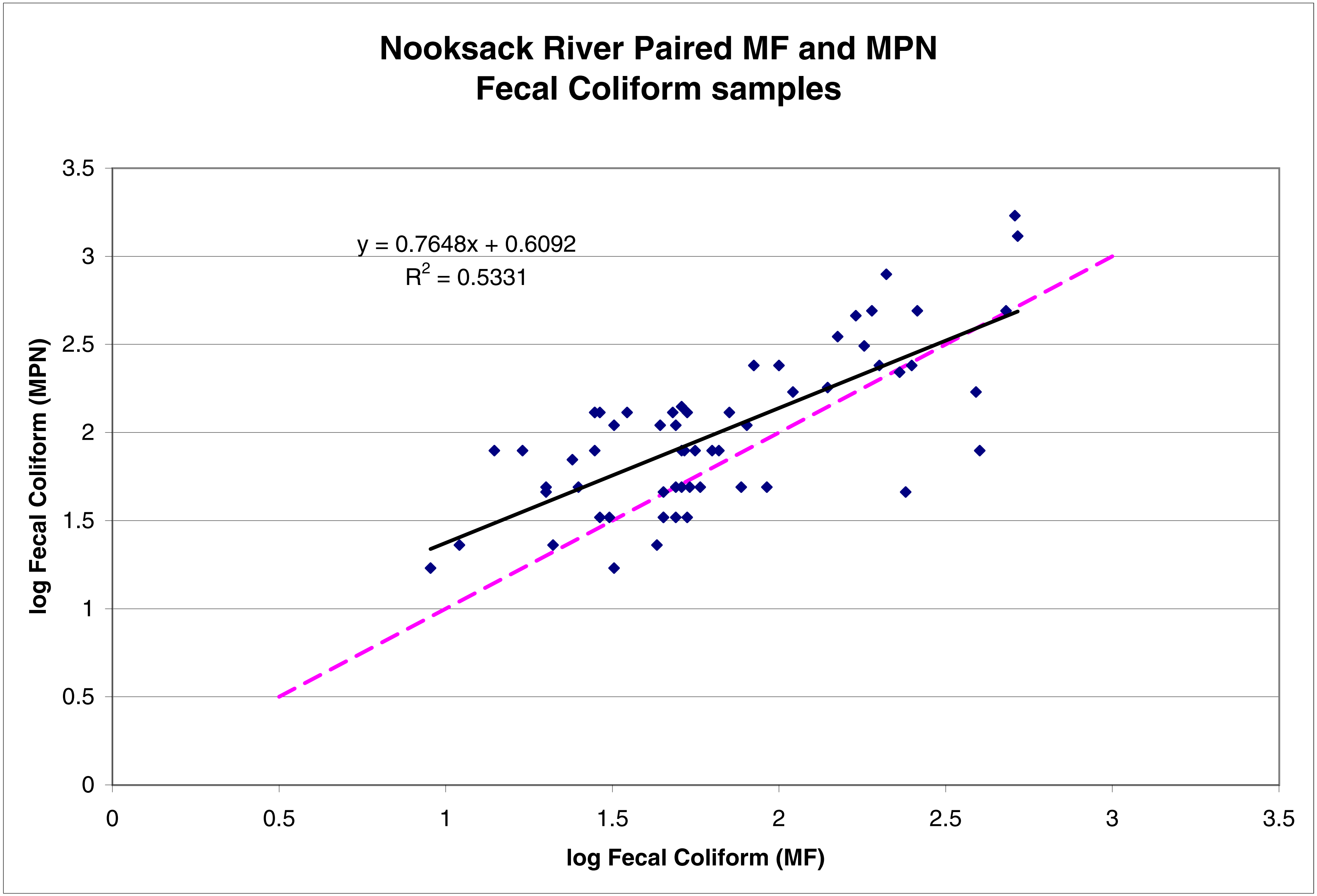

Figure 10. A comparison of paired fecal coliform samples that were analyzed using the most probable number (MPN) and membrane filter (MF) techniques. Dashed line denotes 1:1 relationship.

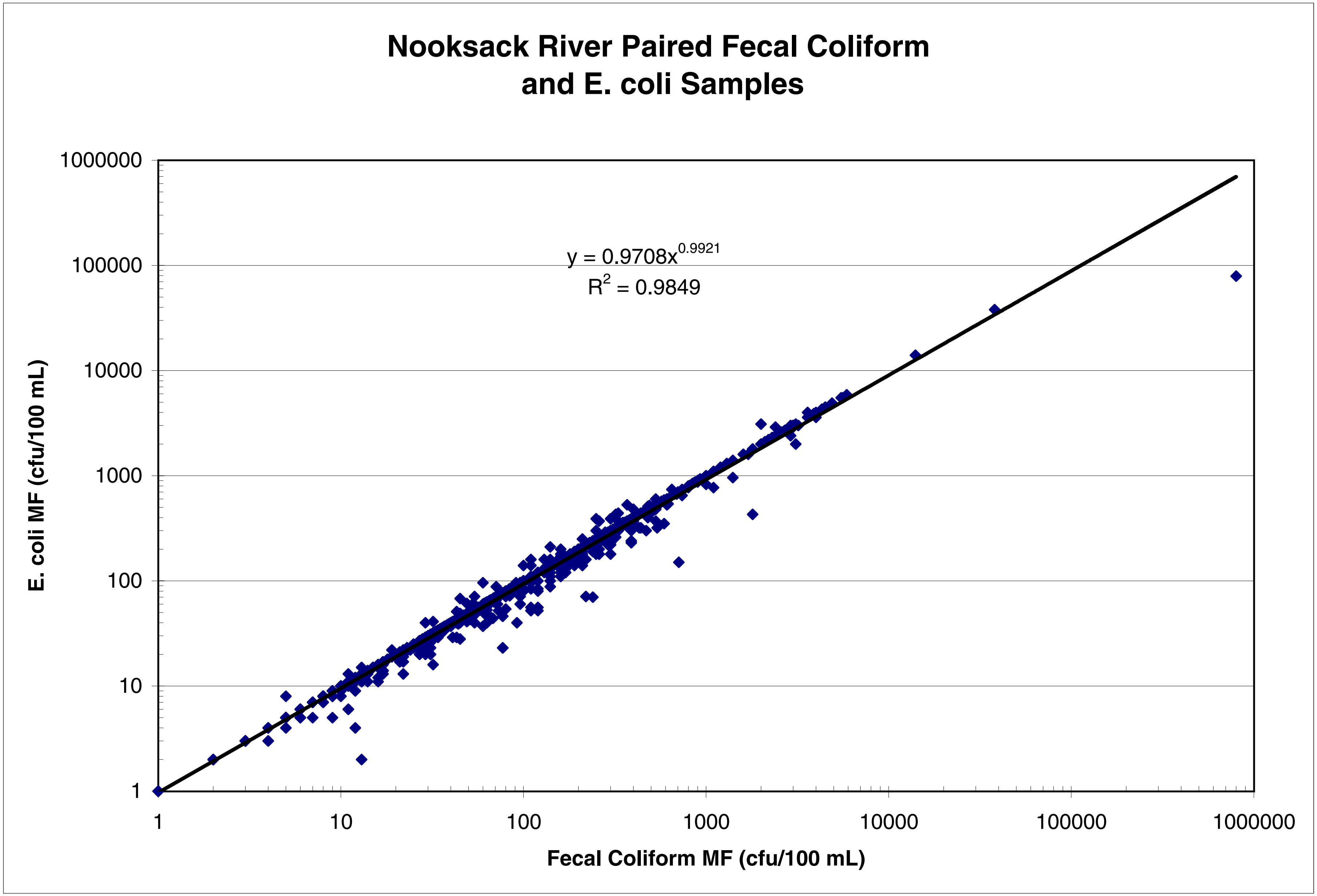

Figure 11. A comparison of paired fecal coliform and *E. coli* sample results collected from various sites during the Nooksack River bacteria TMDL survey.

The enterococcus group is a subgroup of fecal streptococcus. The enterococcus group includes *Streptococcus faecalis*, subspecies of *S. faecalis, Streptococcus faecium, Streptococcus gallinarum,* and *Streptococcus avium* but excludes *Streptococcus bovis* and *Streptococcus equinus* (APHA, 1995). Therefore, the enterococcus group includes predominant streptococcal species from humans, and eliminates some predominant streptococcus species in livestock and wildlife feces. Unfortunately, most livestock and wildlife feces are still sources of the enterococcus group species tested, so enterococcus densities do not exclusively indicate human fecal contamination (Seyfried and Harris, 1990; APHA, 1995).

As with *E. coli*, the USEPA recommendations for enterococci criteria are health-risk based (USEPA, 1986). The USEPA recommends that states adopt criteria with, at most, an acceptable risk of eight highly credible gastrointestinal illnesses per 1,000 fully exposed swimmers. For five samples evenly spaced over 30 days, this risk translates to a monthly geometric mean enterococci count of 33 cfu/100 mL. As with *E. coli*, single sample criteria are estimated for various intensities of bather use.

The enterococci data collected during the TMDL study pose the same limitations for comparison to recommended USEPA criteria as the *E. coli* data, e.g., sample frequency and beach use designation. More of the TMDL sites would have exceeded enterococci criteria than *E. coli* criteria during the June and August rainstorms. Criteria for “designated bathing area” and “lightly used areas” would have been exceeded from MS-4 (RM 18) to the mouth during the August rainstorm. The geometric mean of samples from most tributaries had enterococcus densities greater than 33 cfu/ 100 mL. Many of the samples were greater than 151 cfu/100 mL, the single sample criterion for “infrequently used” bathing areas.

Many water quality investigators previously analyzed the ratio of fecal coliform to fecal streptococcus in attempts to identify human and non-human sources. The variability of indicator bacteria densities in host types, and the complexity of die-off rates has made the practice unusable in most circumstances (APHA, 1995). No patterns in the river, individual tributaries, or WWTP sample ratios could be discerned in the TMDL data set. The 181 pairs of enterococcus and FC data collected during the TMDL were significantly correlated after lognormal transformation, so they may come from some of the same sources.

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Total Maximum Daily Load Analysis

Critical Conditions

The following factors were apparent from the analysis of historical data and TMDL survey data while attempting to define a critical condition for the TMDL:

- There is no single critical condition defining fecal coliform criteria violations in the Nooksack River and its tributaries. Bacteria violations occur during all seasons and under all kinds of climatic conditions. Multiple sources of bacteria contribute to criteria violations in the Nooksack River and to tributaries in the lower basin. Even the sources associated with dairy facilities, considered the primary source of FC loading, are unique for each facility so that a FC load/animal unit approach or AFO load allocation approach is impractical.
- "Incident" discharges of fecal wastes can occur throughout the year, although their frequency appears to have decreased in the past three years. The chronic problem was discussed earlier; high FC results were found with low antecedent rainfall in the Ecology ambient monitoring database, and during the May 1997 routine survey.
- Analysis of long-term data indicates that FC counts at Brennan are greater than 43 cfu/100 mL when a 2-day rainfall event of 0.44 inches or more occurs.
- Rainfall events definitely elevate bacteria *loading* from tributaries and other nonpoint sources (urban/residential storm drains). Loading analysis of the 1997-8 data suggests that up to 84% of the loads from tributaries were delivered during days with more than 0.5 inches rainfall. Approximately 58% of the main stem load was delivered during these events.
- Hydrologic group C and D soils that predominate in the lower valley are easily saturated. For example, in the dormant season, only 0.5 inches of cumulative rainfall over five days is needed to saturate these soils. Historical rainfall records at Clearbrook meteorological station indicate a greater than 50% probability for this situation from January to mid-April, and a greater than 60% probability from mid-October to January. Under these conditions, a fallow field yields significant runoff with a 24-hr. rainfall of 0.2 inches. Pastures in fair condition will begin to respond at with a 24-hr. rainfall of 0.3 inches. When the 5-day cumulative rainfall is over 1.1 inches, these soils have very little capacity to hold additional water – a probability of greater than 25% during the dormant season. As little as 0.1 inches of additional rain is needed to yield runoff when fields are in this condition. Manure from numerous dairies and AFOs in the valley is spread over fields with these soil types. Under these climatic conditions, dormant season manure spreading will result in a high probability of contaminating adjacent drains and streams with bacteria unless extraordinary care is taken.
- The drogue study and the FC loading analysis of the TMDL survey data indicate that no significant die-off of bacteria occurs in the freshwater column. Under some conditions, dilution, dispersion, and die-off occur as the bacteria are delivered to the saline waters of Portage Bay.
- Eighty percent of the upper watershed (above North Cedarville at RM 30.9) drains to Class AA water. The upper watershed should meet Class AA criteria at North Cedarville to protect downstream beneficial uses. The bacteria loads from the upper watershed transferred to the lower watershed need to be controlled since bacteria die-off in the river appears to be absent.

These factors speak against any single climatic event, season, or pollutant source activity that could be considered a critical condition. The Nooksack bacteria TMDL must encompass the entire year, and address the possibility of bacteria contamination from several potential sources with different delivery and transport mechanisms.

Setting TMDL Targets in the Nooksack River

As mentioned earlier, the Class A fecal coliform criteria must be met on two levels: the geometric mean must not exceed 100 cfu/100 mL, and not more than 10% of the samples can exceed 200 cfu/100 mL. State standards set no averaging period on which to calculate these criteria other than limiting the calculation period in cases where a shorter period will show a violation, and extending the calculation period will mask the violation (WAC 173-201A-060(3)). The historical databases and the TMDL survey data have shown that the lower Nooksack River usually meets the geometric mean criterion for whatever season or annual calculation period used. Nevertheless, the lower river fails the second part of the criteria because more than 10% of the values exceed the 200 cfu/100 mL limit. As shown earlier, all of the tributaries had more than 10% of their samples over 200 cfu/100 mL, and most tributaries sampled during the TMDL survey did not meet the geometric mean criterion.

Since there is not a critical condition that defines bacteria contamination in the lower Nooksack basin, the entire annual record of a main stem or tributary site should be used, (i.e., the complete distribution of samples collected at a site). The statistical rollback method proposed by Ott (1995) describes a way to use the statistical characteristics of a set of water quality parameter results to estimate the distribution of future results after abatement processes are applied to sources. The method relies on basic dispersion and dilution assumptions and their effect on the mean and standard deviation of chemical or bacteria sample results at a monitoring site downstream from a source. (Further explanation of the assumptions and statistics are provided in Appendix B). The rollback method then provides a statistical estimate of the new population after a chosen reduction factor is applied to the existing pollutant source. In the case of the TMDL, compliance with the most restrictive of the dual fecal coliform criteria will determine the bacteria reduction needed.

As with many water quality parameters, fecal coliform counts collected over time at individual sites from the Nooksack River basin follow a lognormal distribution. That is, over the course of a yearlong sampling period, most of the counts are low, but some are quite high. When monthly FC data collected at Brennan from 1988 to 1998, and TMDL data from Marine Drive are plotted on a logarithmic-probability graph, it appears as nearly a straight line (Figure 12). Statistical tests confirmed that the results are lognormally distributed, and that the statistical rollback method can be applied. The 50th percentile, an estimate of the geometric mean, and the 90th percentile, a representation of the level over which 10% of the samples lie, can be located along the plot or they can be calculated. These numbers are 75 cfu/100 mL and 383 cfu/100 mL, respectively. Using the statistical rollback method, the 90th percentile value is then located at 200 cfu/100 mL, and the new distribution is plotted parallel to the original. The estimate of the geometric mean for this new distribution, located at the 50th percentile, is 39 cfu/100 mL. The result is a geometric mean target of a sample distribution for the Nooksack River that would likely have less than 10% of its samples over 200 cfu/100 mL. A 48% FC reduction in the geometric mean is required from combined sources to meet this target distribution.

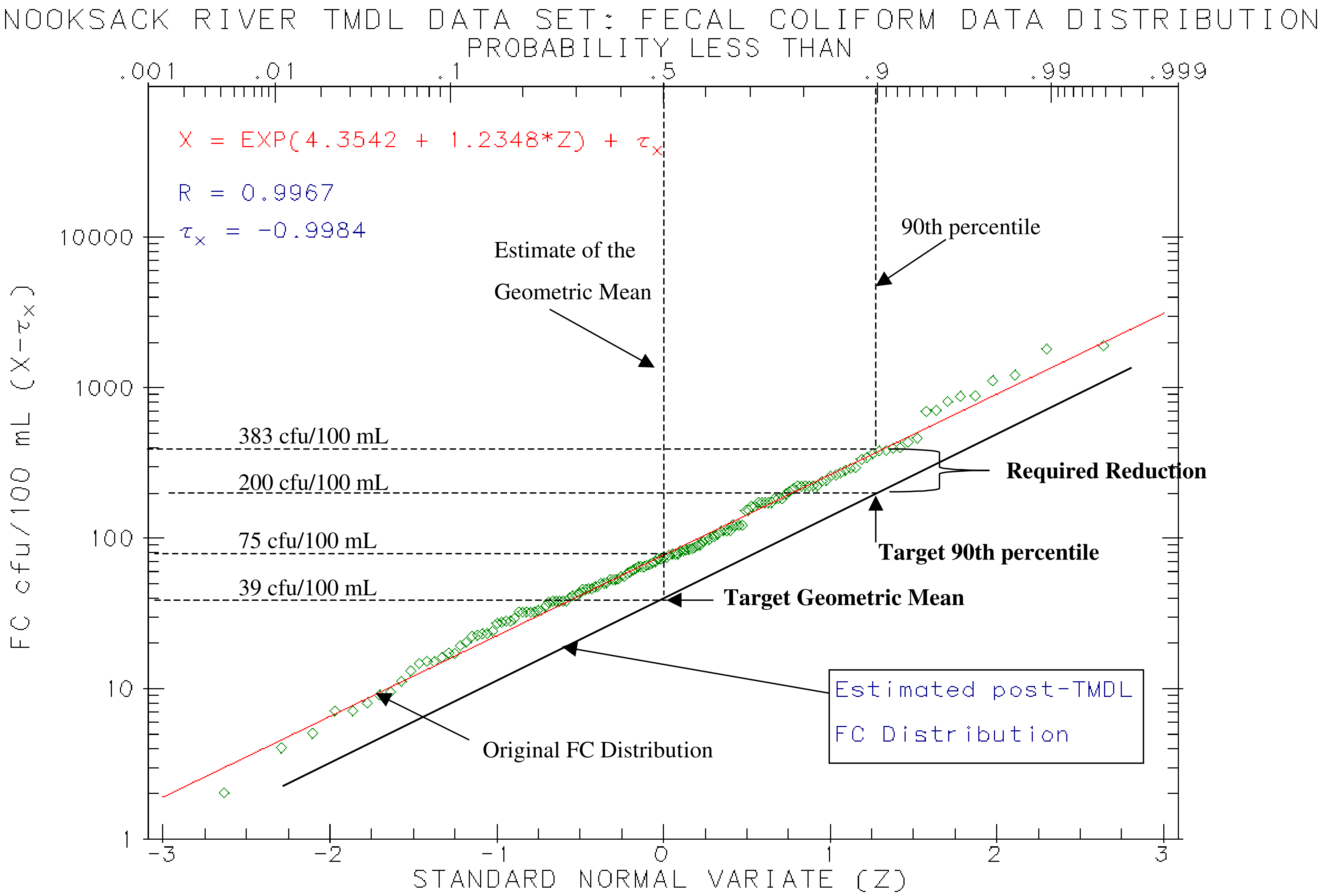


Figure 12. Graphical demonstration of the statistical rollback method (Ott, 1995) used to calculate the fecal coliform TMDL target on the lower Nooksack River.

As shown earlier, different periods of record, sampling frequencies, and analytical methods influence the distribution and its statistical characteristics. Analysis of the historical data suggests that bacterial contamination has declined since 1974, but has remained stable since about 1988. In addition, distributions of MF and MPN data collected during the TMDL showed significant difference both in variability and in bias. Nevertheless, performing the statistical rollback method on these distributions gave similar geometric mean targets for the TMDL (Table 9):

- Using Ecology data collected at the Brennan monitoring station from 1988 to 1998, the geometric mean of 37 cfu/100 mL was calculated and a 53% reduction is required.
- In the case of the 1997-98 TMDL data, a target geometric mean of approximately 47 cfu/100 mL was calculated that would have required a 29% FC reduction. MPN numbers for the same period gave a higher geometric mean target of 50 MPN/100 mL, with a 51% FC reduction required. This may be because of the larger 90th percentile density for the MPN data set.
- Combining the 1988 to 1998 Brennan Bridge data with the Marine Drive TMDL data, the calculated geometric mean target is 39 cfu/100 mL which will require an annual FC reduction of 48%.

Ecology decided that combining the 1988 to 1998 Ecology monthly monitoring data set with the TMDL data set from Marine Drive represented the best estimate of current conditions in the lower Nooksack River (Table 9). By combining the data sets, the statistical power of long-term random sampling is joined with more intensive storm event data from the highest bacteria loading periods. Although there are some differences in targets generated by MPN and MF data sets, the MF method is recommended since it was used to generate the large majority of the FC data. *The TMDL lower main stem target will be an annual geometric mean of 39 cfu/100 mL at the Brennan monitoring station as measured using the membrane filter method. The target will require an approximate FC reduction of 48% in the lower basin from cumulative bacteria sources.*

Table 9. A comparison of fecal coliform targets after applying the statistical rollback method to different lower Nooksack River data sets. *Recommended targets for the TMDL are in bold.*

Data Set	Years of Record	N	Geometric Mean	90th Percentile	Target Geometric Mean	Required Reduction
Brennan (Ecology)	1974-1998	248	88	458	38	56%
Brennan (Ecology)	1988-1998	113	78	424	37	53%
Brennan (Ecology)	1993-1998	62	57	224	51	11%
Brennan+ Marine Dr.	1997-1998	36	67	283	47	29%
Brennan +TMDL	**1988-1998**	**151**	**75**	**383**	**39**	**48%**
Marine Drive TMDL (MPN)	1997-1998	23	102	409	50	51%
MPN (DOH+TMDL)	1996-1999	36	71	413	34	52%
North Cedarville (Ecology)	**1997-1998**	**12**	**15**	**105**	**14**	**4.5%**

The FC counts and load from the upper watershed set the baseline for the lower watershed. For the TMDL framework to work, it is essential that high quality water is consistently delivered from the upper watershed. Table 7 showed that historical ambient monitoring data collected at the North Cedarville monitoring station have usually met Class AA FC criteria (50 cfu/100 mL geometric mean with not more than 10% of the samples exceeding 100 cfu/100 mL). Although the site is located in a Class A reach, over 80% of the upstream drainage area monitored at North Cedarville is Class AA. Nevertheless, 1997-98 ambient monitoring data reported a 90th percentile FC count of 105 cfu/100 mL, the highest since 1989 and not within the Class AA criterion (Table 7). Ecology applied the rollback method to the 1997-98 Ecology ambient monitoring data set to prevent future degradation of water quality in the upper basin. Setting the target to Class AA criteria also provides an additional margin of safety to the lower target by reducing the FC load to the lower basin. A 4.5% reduction will be required for the 90th percentile FC density to meet the Class AA criterion of 100 cfu/100 mL. The estimated annual geometric mean target will be 14 cfu/100 mL (Table 9). *Therefore, the TMDL target for the main stem at the North Cedarville site (RM 30.9) will be an annual geometric mean of 14 cfu/100 mL and a 90th percentile of 100 cfu/100 mL.*

Setting TMDL Targets for Nooksack Tributaries and Point Sources

All of the monitored tributaries and point sources in the lower Nooksack River basin require TMDL targets. These are necessary to bring the tributaries into compliance with the same Class A fecal coliform criteria as the main stem. The TMDL targets and FC reductions required for the tributaries can be calculated using the statistical rollback method, the same as was done for the main stem targets. The three WWTPs usually are required to meet standard secondary treatment effluent standards of a monthly geometric mean of 200 cfu/100 mL, with a weekly geometric mean of not more than 400 cfu/100 mL. Lynden WWTP was not meeting these NPDES permit limits during the TMDL surveys. With a TMDL recommended for the river, the WWTP effluents must meet water quality-based permit limits to pose no potential for increasing FC densities in the river above the TMDL target limit of 39 cfu/100 mL. The recommended effluent limits are calculated using water quality-based permit methodology (Ecology, 1994).

Although there are relatively few data available for the analysis, tributary data collected during the 1997-98 TMDL survey season appear to be representative of bacterial quality observed in past studies. TMDL storm event data collected approximately every seven hours from Tenmile Creek and Fishtrap Creek were averaged into single daily values and included in the analysis. Additional data collected in 1997-98 by the Institute for Watershed Studies (Matthews and Vandersypen, 1998) and the Nooksack Tribe (Woodward, 1998) were used in the Kamm Creek analysis. Nooksack Tribe data collected from Bertrand Creek and Fishtrap Creek in 1997-98 were also included. All tributary data, with and without storm event data, followed a lognormal distribution. The tributary TMDL fecal coliform targets calculated using the statistical rollback method are shown in Table 10. *Fecal coliform reductions of 23% to 98% are required in the sub-basins to meet the TMDL tributary targets and bring tributaries back into compliance with Class A water quality standards.* The TMDL targets are based on data from monitoring sites closest to the tributary's confluence with the Nooksack River.

The two dairies and AFOs with NPDES permits are located in these tributaries (Appendix C). The permits allow no discharges from these facilities, except under extreme climatic conditions. Therefore, no fecal coliform load allocations will be made to the dairies with NPDES permits.

Fecal coliform data collected from the three municipal wastewater treatment plants (WWTPs) during the TMDL survey were evaluated for adjustment under the TMDL. Only Lynden WWTP results warranted initial adjustment. Lynden WWTP discharge monitoring report (DMR) data from July 1997 to March 1998 and Ecology TMDL survey data were combined. The weekly geometric mean density exceeded the 400 cfu/100 mL NPDES permit limit in seven of the 38 weeks of monitoring. The criterion was probably exceeded in earlier weeks of the study period, but adequate data are not available because of WWTP laboratory problems. All point source limits were evaluated using water quality-based methodology (Ecology, 1994). The limiting long-term average effluent FC density of 21 cfu/100 mL is required to meet 39 cfu/100 mL in the river when the background FC density is 39 cfu/100 mL (see Appendix B). The calculated monthly average FC limit is 28 cfu/100 mL, and the maximum daily FC limit is 64 cfu/100 mL (Table 10).

Table 10. Recommended TMDL fecal coliform targets for Nooksack River tributaries and point sources. *NT = Nooksack Tribe data; IWS = Institute for Watershed Studies data; w/Storm = with TMDL storm event data.*

Tributary or Point Source	N	Geometric Mean	90th Percentile	Target Geometric Mean	Required Reduction
Smith Creek	**10**	**215**	**503**	**85**	**60%**
Anderson Creek	**13**	**355**	**1778**	**40**	**89%**
Kamm Ecology, IWS & NT	**41**	**582**	**3282**	**35**	**94%**
Scott Ditch	**16**	**247**	**1004**	**49**	**80%**
LLPL Ditch	**7**	**805**	**8556**	**19**	**98%**
Fishtrap w/Storm & NT	**40**	**457**	**2314**	**39**	**91%**
Bertrand w/Storm & NT	**20**	**301**	**1229**	**49**	**84%**
Wiser Lk Outlet	**13**	**77**	**260**	**59**	**23%**
Keefe Lk Outlet	**10**	**89**	**399**	**45**	**50%**
Tenmile w/Storm & NT	**40**	**304**	**1570**	**39**	**87%**
Lynden WWTP	**38**	**144**	**2054**	**28***	**81%**
Ferndale WWTP**	56	26	210	28*	-
Everson WWTP**	56	3	12	28*	-

* NPDES permit limit targets are a monthly geometric mean of 28 cfu/100 mL with a daily maximum not to exceed 64 cfu/100 mL.

** NPDES permit limits appeared to be met for these facilities

The recommended change in the NPDES permits for the three WWTPs requires that the effluent FC densities not cause the lower main stem target of 39 cfu/100 mL to be exceeded. The estimated monthly geometric mean effluent target for the WWTPs will be 28 cfu/100 mL with a daily maximum density of 64 cfu/100 mL. The target should protect water quality and should be attainable by the WWTPs when all planned improvements that eliminate chronic disinfection failures are installed.

Samples from the Darigold condensate line contained fecal coliform, E. coli, and enterococcus. The geometric mean of the 13 fecal coliform samples collected during the TMDL was 12 cfu/100 mL, and the 90th percentile was 102 cfu/100 mL. The source of the bacterial contamination is unknown; sources other than condensate may be entering the outfall line. Darigold has no permit limits for FC or other indicator bacteria, so none of these bacteria should be present. Darigold will need to eliminate the source(s) of contamination.

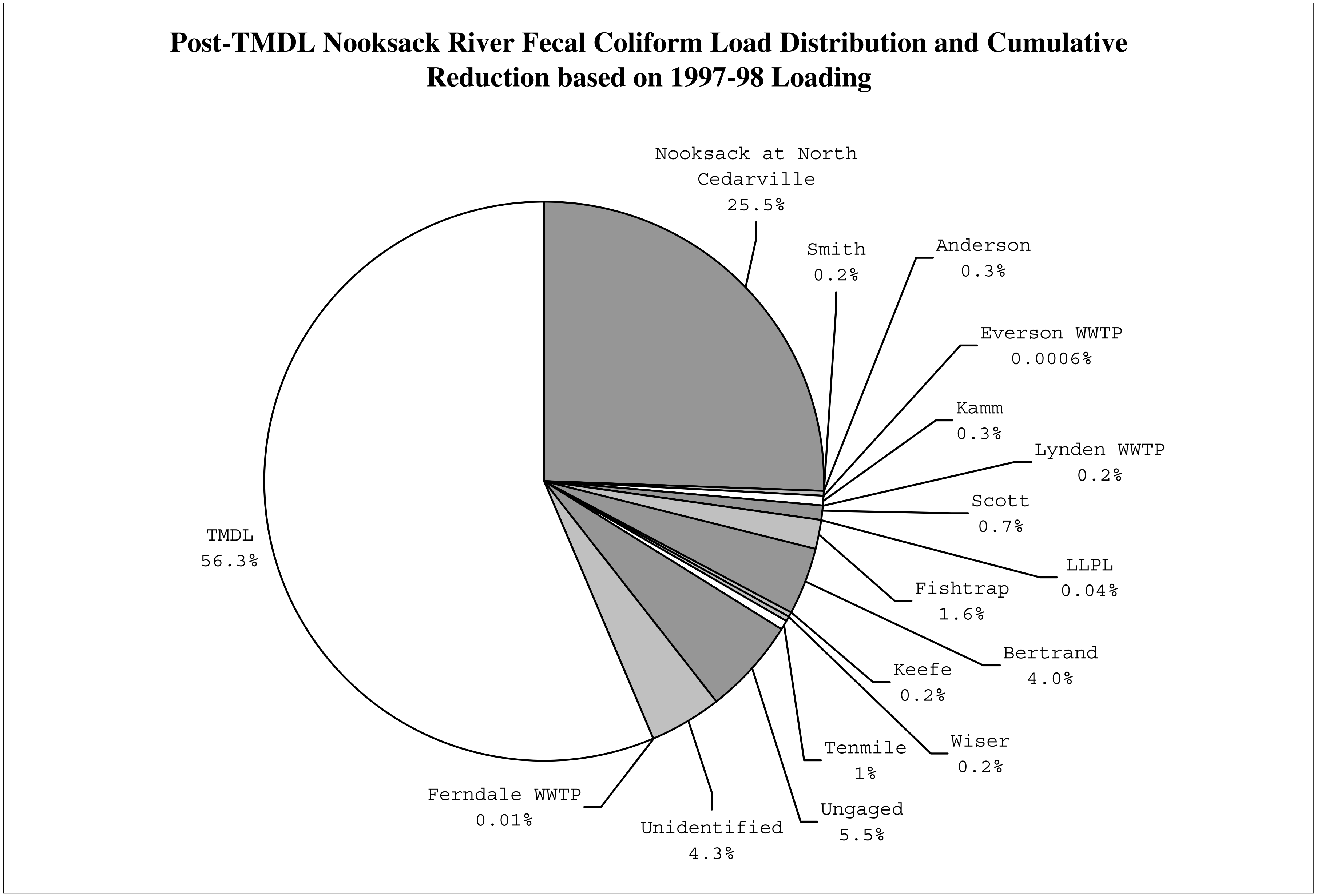
Loading analysis shows how the tributary and point source targets are more than adequate to support the lower main stem Nooksack River target. The reduction values in Table 10 were applied to the 1997-98 tributary and point source load calculations described earlier (Figure 8). The upper watershed reduction of 4.5% from Table 9 was also included. The resulting pie chart shows a cumulative FC load reduction of 56% in the lower main stem when the tributary, point source, and upper watershed TMDL targets and resultant FC reductions are met (Figure 13). The cumulative TMDL reduction is almost twice the 29% reduction calculated as a lower river target for the 1997-98 TMDL data set (Table 9). The cumulative FC loading from the tributaries in 1997-98 would have been reduced by 87% if all of the targets had been met. The cumulative 56% reduction in fecal coliform load in the lower main stem is also 8% greater than the 48% reduction needed for the recommended TMDL target based on the long-term data set.

Protection of Downstream Uses

The TMDL targets and FC reductions for the Nooksack River, tributaries, and point sources need to be protective of all downstream beneficial uses. The use with the most restrictive fecal coliform criteria is shellfish harvesting in Portage Bay. Currently, the most northerly parts of the commercial harvest area are restricted because water quality does not meet the National Shellfish Sanitation Program criteria (Washington Department of Health, 1997). The water quality in the harvesting area must have a geometric mean of no more than 14 MPN/100 mL with a 90th percentile density less than 43 MPN/100 mL. The recommended TMDL target for the river is based on a 90th percentile FC density of 200 cfu/100 mL – much higher than the 90th percentile density of 43 MPN/100 mL allowed in the bay.

Washington Department of Health Office of Shellfish Programs (DOH) collected data at the mouth of the Nooksack River, in the shellfish harvest area of Portage Bay, and half-way between (Midway) to monitor water quality compliance (Washington Department of Health, 1998). The DOH data, and those collected cooperatively during the TMDL surveys by Ecology and the Lummi Nation (Lummi Water Resources, 1999), comprise a record of 42 survey events. These data were used to construct a simple equation to evaluate the effect of bacteria densities from the Nooksack River on the water quality of the Portage Bay shellfish area. A Monte Carlo analysis was then performed on equation parameters to estimate the potential success of the TMDL target in the lower Nooksack River to improve the bacteria water quality in the shellfish area.

The northernmost section of the Portage Bay shellfish harvest area lies approximately six miles from the Marine Drive Bridge (MS-1) on the Nooksack River (Figure 1). Sampling crews observed that a southeasterly wind often keeps the river's plume against the Lummi shore. This wind condition can occur at any time of year, and influences all river discharge scenarios. The actual dispersion, dilution, and mixing of the river plume into estuarine water have not been studied; however, the observed phenomenon could be considered a critical condition for



Post-TMDL Nooksack River Fecal Coliform Load Distribution and Cumulative Reduction based on 1997-98 Loading

Figure 13. The estimated percentages of fecal coliform loads from lower Nooksack sub-basins after TMDL targets are met. Load reductions are applied to 1997 - 1998 (Figure 8) estimates.

transport of bacteria from the Nooksack River to the shellfish harvest area. Ecology used simplifying assumptions to create an extreme condition, and constructed an equation relating the bacteria density of the Nooksack River to the shellfish harvest area. The equation was applied to the field data from the 42 survey events to determine bacteria change rates. The simplifying assumptions were:

- The river plume is directed fully to the shellfish beds with the same channel cross-section and at the same velocity as it left the river's mouth. The time of travel is then simplified to velocity divided by distance.
- Dilution or dispersion of river water with estuarine water occurring between the mouth of the Nooksack River at Marine Drive and the shellfish beds are generalized in the bacteria reduction rate (k). In addition, the general bacteria reduction rate (k) incorporates the effects of temperature, salinity, predation, ultraviolet light, settling, resuspension, and regrowth in the estuarine environment (Thomann and Mueller, 1987).
- Although incoming bacteria densities can dramatically change in the river within minutes, samples collected on the same day or within a few hours of each other at Marine Drive, Midway, and in the shellfish area (DOH Station 12 and 13) represent the bacteria quality of the same block of river water.
- Events with samples collected and analyzed by DOH using the MPN method can be directly compared to events with samples collected by Ecology and the Lummi Nation using the MF method.

FC counts from Marine Drive, Midway, and the shellfish area were plotted against the hypothetical time of travel from Marine Drive for each monitored event, based on the assumptions listed above (Figure 14). In contrast to the river, a reduction in bacteria was usually observed once the bacteria were exposed to the estuarine conditions. Sometimes bacteria increases were observed. Another pattern observed in the plot was that Nooksack River discharge volumes over 7000 cfs with Marine Drive FC counts over 43/100 mL usually yielded shellfish area counts over 43/100mL. These are the lines with the square symbols in Figure 14. When river discharge was less than 7000 cfs, fewer samples taken in the shellfish area exceeded 43/100 mL. The average of the first-order bacteria reduction rates calculated for all 42 events was 18.3 per day with a range of –10.9 to 54 per day. The average reduction rate for events with discharge volumes over 7000 cfs was 30.2 per day, and 14.9 per day for those discharge events below 7000 cfs. The equation developed for the bacteria reduction observed in the bay was:

$$FC_{PORT}=FC_{MD} * e^{-k*t}$$

where,

FC_{PORT} = the average fecal coliform count at Sta.12 and 13 as cfu/100 mL or MPN/100 mL
FC_{MD} = the fecal coliform count at Marine Drive (MS1) as cfu/100 mL or MPN/100 mL
k = the general FC reduction rate per day
t = the time of travel based on the velocity of the river in days

Adequate protection to the shellfish area under TMDL target conditions appeared to be provided when average discharges, FC reduction rates, and FC counts at Marine Drive were used in the equation. However, the dual FC criteria for the harvest area require protection at the 90th percentile level as well. What parameters would be best to evaluate the risk of violating the

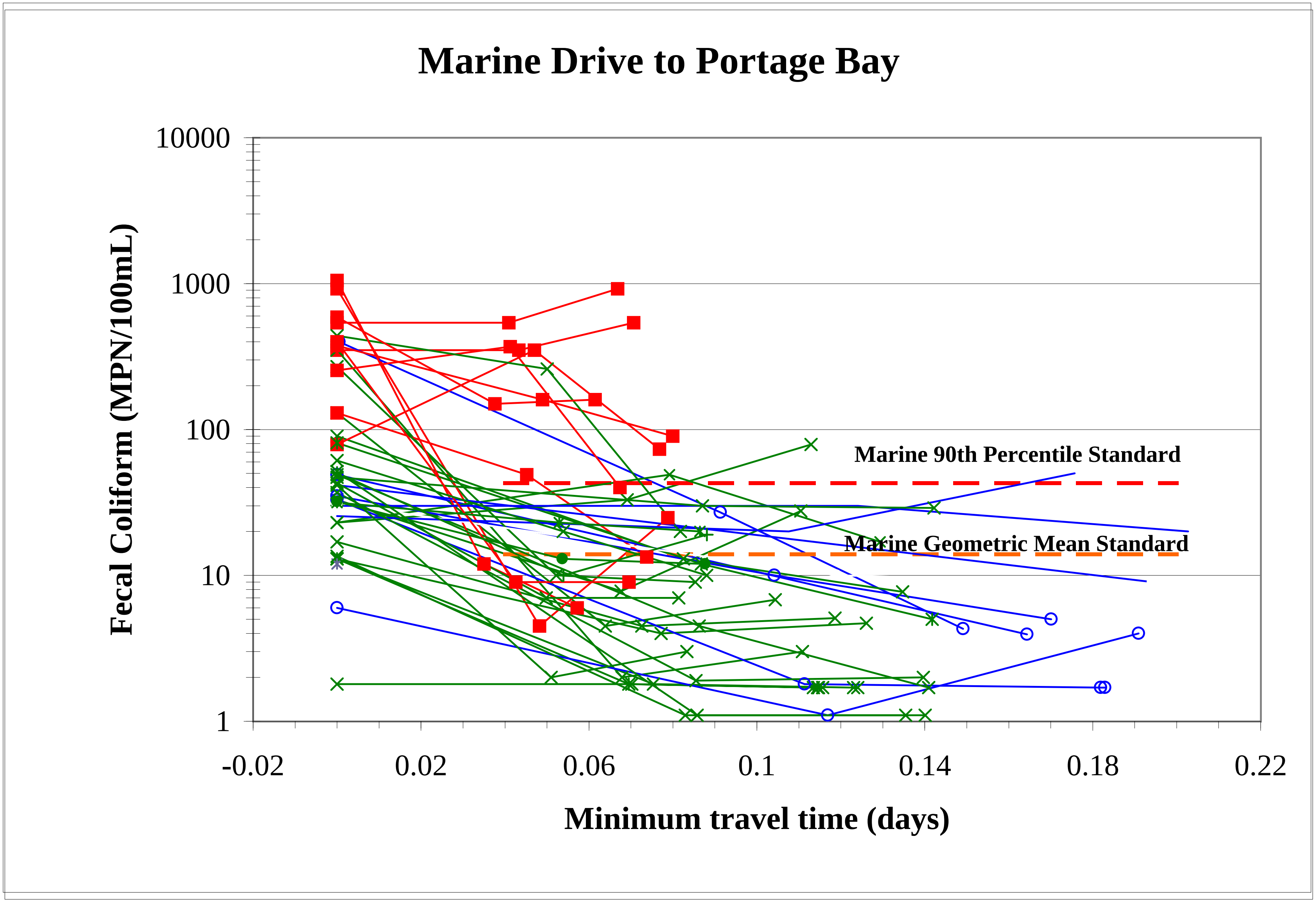


Figure 14. Fecal coliform samples collected from Marine Drive, Midway, and DOH Sta. 12-13 during 42 survey events. Discharge range: 🟥 >7000 cfs; × 2500 - 7000 cfs; ○ < 2500 cfs

second part of the criteria? For example, a discharge of 7000 cfs occurs approximately 10% of the time on an annual basis, but it occurs more than 10% of the time in the months of January, February, May, June, November, and December. Variability in fecal coliform counts at Marine Drive and the wide range of FC loss rates make it difficult to judge the frequency of criteria violations in the shellfish area now, and in the future (i.e., if the TMDL will improve the status of the shellfish beds).

A Monte Carlo simulation analysis was used to address this type of risk-based question. In the analysis, the distributions for monthly discharge, fecal coliform densities, and FC reduction rates were subjected to Latin hypercube sampling (Palisade, 1997). The randomly selected variables were then supplied to the equation. This selection and calculation process was repeated 10,000 times for each month, and for pre-TMDL target and post-TMDL target conditions. The randomly selected FC value was reduced by 48% to simulate post-TMDL compliance. Tables with the parameter distributions used for the analysis are given in Appendix B. The resulting distribution of monthly FC counts in the shellfish area (FC_{PORT}) can then be evaluated as the combined variability in the equation parameters. Detailed statistics of the simulation results are presented in Appendix B.

Simulation results for the pre-TMDL condition were compared to DOH data collected at Station 13 in Portage Bay from 1989 to July 1998. To evaluate water quality compliance, DOH generates running geometric mean and 90th percentile statistics at each site from 30 consecutive samples. These samples need not be collected at a monthly frequency, but as a FC sample result is added to the data set, one is dropped from the beginning of the set so that "n" always equals 30 samples. The 37 pairs of statistics generated for the 67 fecal coliform samples collected at Station 13 between January 1989 to July 1998 were compared to 37 pairs of statistics generated from the data set of the simulation results (Figure 15). Only the month of collection in the DOH data set was used to randomly select a value from the Monte Carlo data set.

The relative percent differences (RPD) between the two sets of FC statistical results are 12% for the geometric mean and 18% for the 90th percentile. The simulation statistics are slightly higher than the DOH statistics – 20% more of the 90th percentile statistics from the simulation were greater than 43/100 mL (Figure 15). A greater difference between the statistics was expected since the FC reduction equation assumes only one type of critical condition in the estuary. The reason for the close similarity in the results is unknown.

The simulation results for pre- and post-TMDL conditions in the shellfish area are compared using the monthly FC medians and 90th percentiles (Figure 16). The Monte Carlo and Ecology equation results suggest that reducing the FC densities by 48% in the river will significantly decrease Portage Bay FC densities in the shellfish harvest area. If Nooksack River counts are the main source of the criteria violations, the TMDL should bring the shellfish area back into approved status. Additionally, further reductions could occur if all tributary and point source targets were met.

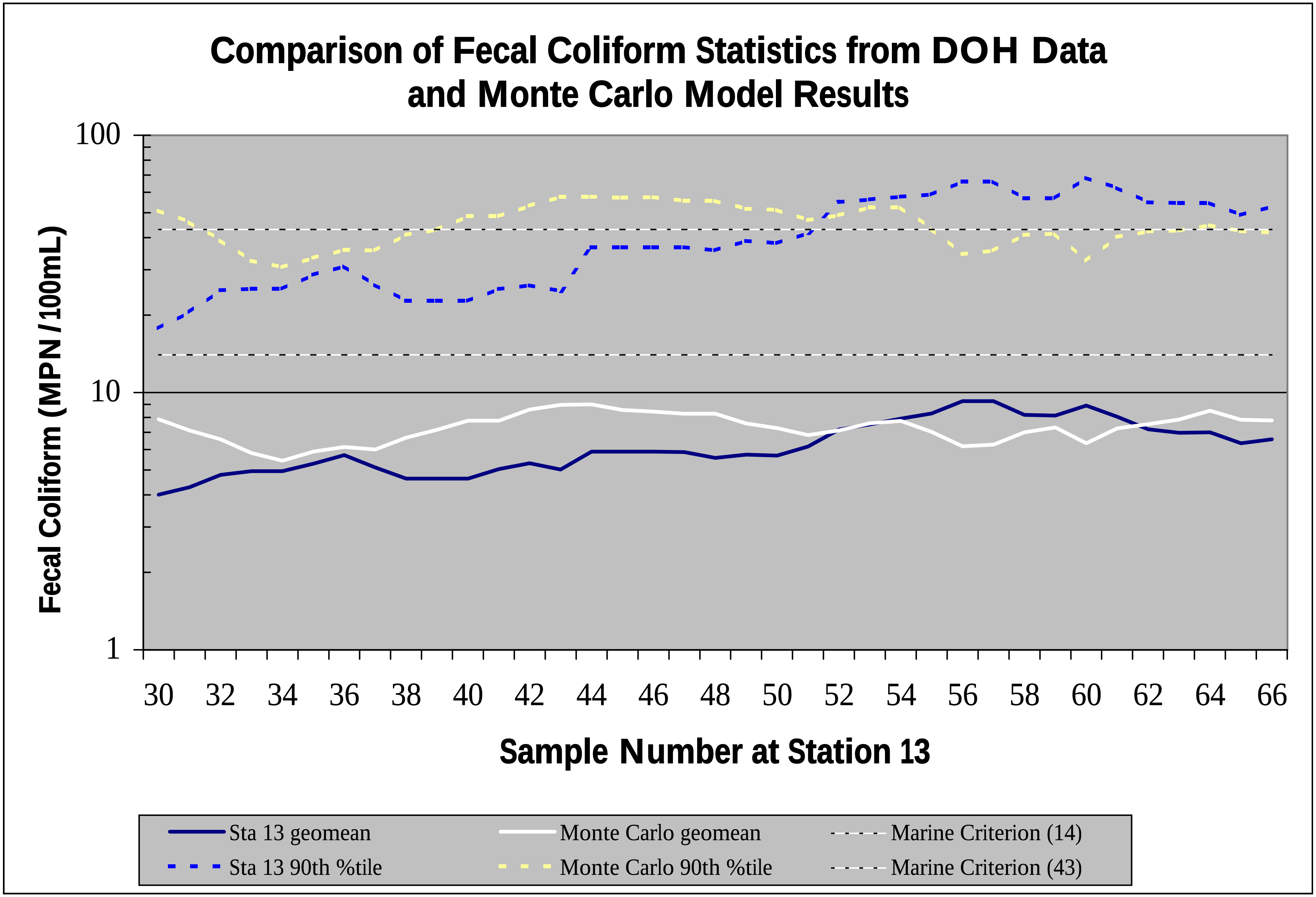


Figure 15. A comparison of geometric mean and 90th percentile statistics generated from DOH fecal coliform data at Station 13, and those statistics generated from the TMDL Monte Carlo simulation output.

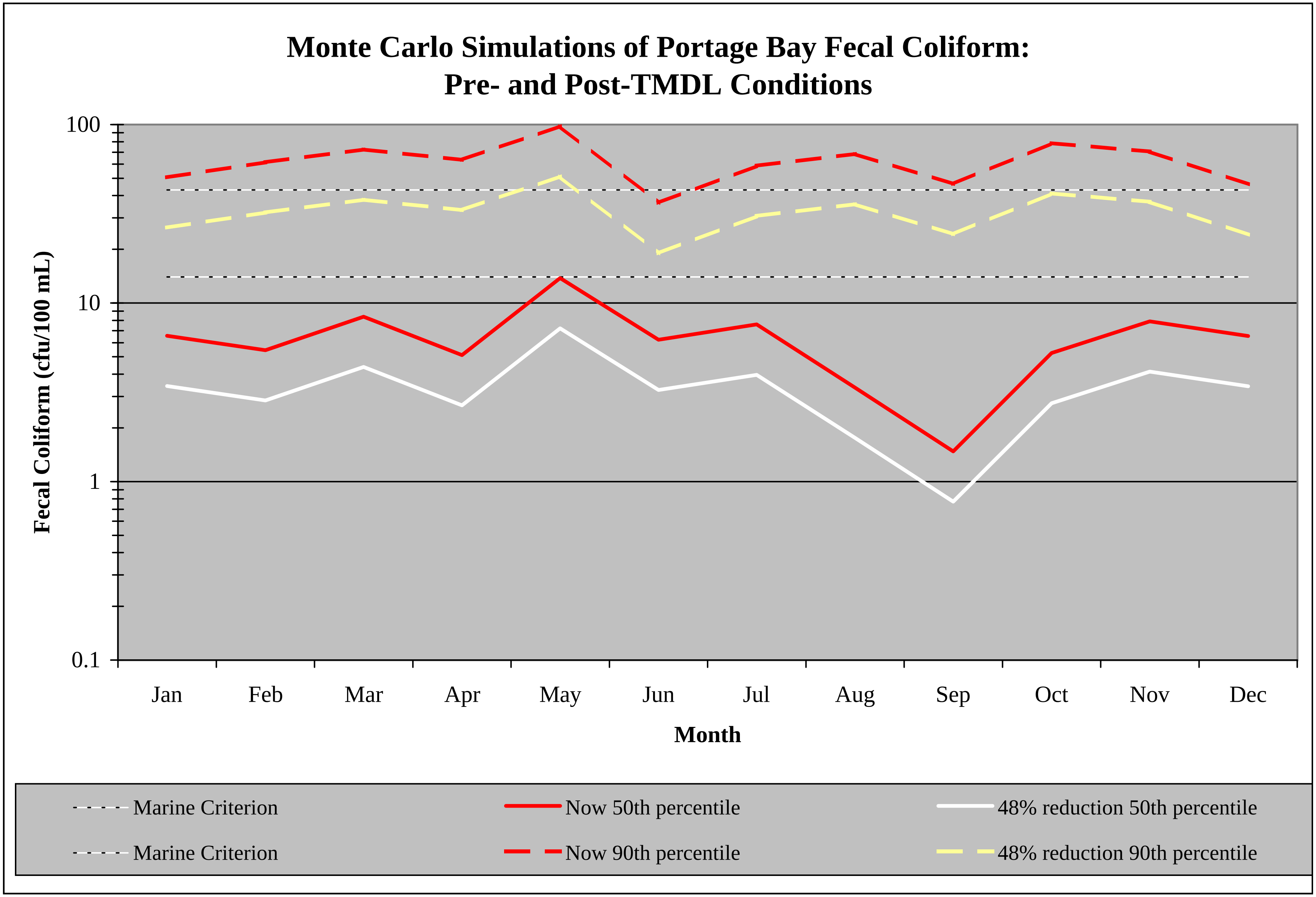


Figure 16. Monthly geometric mean and 90th percentile statistics for Stations 12 and 13 fecal coliform samples collected under pre- and post-TMDL (48% reduction) conditions.

Margin of Safety

A requirement of the TMDL technical evaluation is a discussion of the margin of safety in the TMDL targets and recommendations. The size of the margin of safety is inversely proportional to the confidence in the data used to make TMDL load allocations or targets. The margin of safety can be placed either implicitly in the assumptions, or explicitly as a separate load allocation or an additional target component. The FC targets recommended for the Nooksack River TMDL contain the following implicit margin of safety factors:

- There is a better technical basis that the geometric mean and 90th percentile criteria will be met with the statistical rollback method than if targets were arbitrarily set at the usual Class A or AA criteria. The statistical rollback method uses the variability of the fecal coliform distribution at a site to generate a more restrictive geometric mean count than the Class A or AA geometric mean criteria.

- The water quality-based permit limits recommended for Ferndale, Lynden, and Everson WWTPs are more restrictive than current technology-based limits. The recommended limits assume a background FC density of 39 cfu/100 mL so that effluent will not have an effect.

- The 39 cfu/100 mL lower main stem target and 48% FC reduction are based on a 10-year monthly monitoring record, plus the 1997 and 1998 TMDL data. Data from the past five years, or from the TMDL survey alone, would be much less restrictive.

- The TMDL targets for the tributaries, point source, and the upper basin yield a cumulative FC load reduction to the lower river of 56%. That is 8% more than the 48% reduction required by the main stem target, and almost twice the 29% reduction needed for the main stem based on the 1997-98 data set.

- The upper watershed TMDL target is set to be protective of Class AA criteria. The water being monitored is both Class A and AA. In addition, the rollback method was applied to the 1997-98 Ecology ambient database where a 90th percentile count over the Class AA criterion of 100 cfu/100 mL was calculated. Calculations applied to the long-term data set do not generate a 90th percentile count this high.

- The loading equations and calculations for the targets assume there is no FC decay rate in the river water column, (i.e., all FC bacteria entering the river from tributaries or other sources will make it to the mouth of the river). A drogue study suggested that this may be the case, but more studies would be required to verify this assumption in other river reaches and during different seasons.

TMDL Evaluation Summary

Based on an evaluation of historical and recently collected survey data, Ecology recommends fecal coliform TMDL targets in the Nooksack River, ten tributaries, and three municipal WWTPs. These targets are set to bring lower Nooksack basin water quality into compliance with Class A bacterial water quality criteria, and to keep the upper Nooksack basin within

Class AA bacteria criteria. The river and tributary geometric mean targets have been set from data collected annually to ensure water quality compliance with the 90th percentile requirement of the bacteria criteria. The WWTP targets have been derived from water quality-based methodology. The calculations used to set targets contain elements for an adequate margin of safety. If basin-wide bacteria source reductions successfully meet the lower Nooksack River TMDL target, substantial reductions in bacteria loading from the Nooksack River to Portage Bay will improve water quality in the shellfish harvest area.

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TMDL Schedule, Actions, and Monitoring

Schedule

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

The compliance schedule will be part of Ecology's TMDL action plan. The plan will be drafted by the Bellingham Field Office, and reviewed under the TMDL public process. The compliance schedule should be closely coordinated with Whatcom County's Portage Bay Shellfish Response Strategy, the Nooksack Watershed Management Project, and other local initiatives. With the local activities already in place, the schedule can be aggressive. If stability in the local programs is assured, a complete evaluation of monitoring data should occur within five years to judge the effectiveness of the plan and the appropriateness of the TMDL targets.

Actions for Reducing Bacterial Source Impacts

The success of the TMDL is not in setting bacteria targets, but in meeting water quality criteria within a few years. The TMDL evaluation has shown the most significant sources of bacteria loading come from the lower basin tributaries. The bacteria sources within these tributaries need to be aggressively controlled – up to 98% reduction in one sub-basin. The Nooksack basin has a long history of sub-basin watershed plans and pollution abatement initiatives to draw from (Whatcom County Conservation District, 1986a, 1988; Ecology, 1995). Recent local ordinances, citizen interest, and government actions have revitalized bacteria reduction activities recommended in these plans. Attitude changes among dairy owners and municipalities in the basin should have a positive impact on renewed efforts at protecting water quality. The institutional and public support must be present for the bacteria TMDL to be successful.

Manure Management from Animal Feeding Operations and Other Sources

Sub-basins with a high density of dairies, animal feeding operations (AFOs), and manured fields delivered significant bacteria loads to the Nooksack River. One of the major areas where FC bacteria reductions are needed is in manure management at these sources. The basic strategy for implementing a source control program on AFOs is through the implementation of the Washington Dairy Nutrient Management Act of 1998.

This Act requires that all dairy farms be inspected by October 2000. Farms with water quality problems are referred to the Whatcom Conservation District for assistance to develop nutrient management plans (farm conservation plans). All dairy operators must have a nutrient management plan approved by the conservation district by July 31, 2002. The plans must be fully implemented, following USDA Natural Resources Conservation Service (NRCS) standards, by December 31, 2003. In early 1999, approximately 50% of the farms in the Nooksack basin had recent farm plans that meet or nearly meet the requirements of the Act. The other half of the farms still need to begin the process. Other livestock operations, including small "hobby" farms, will also need to develop and implement measures that protect water quality.

Farm plans address site-specific needs associated with the production, collection, handling, transfer, treatment, storage, and land application of agricultural waste as well as nutrients from other sources such as fertilizer, feed waste, and milking center wastewater. The planning process is comprehensive in addressing the protection and sustained use of soil, water, and animal and plant resources on specific land units through adoption and implementation of appropriate conservation practices. Conservation practices include structural, vegetative, and management measures used in combination to solve an identified resource concern or problem. Typical structural practices to address livestock waste management in the Nooksack watershed include waste storage and treatment facilities, manure transfer systems, fencing, stream crossings, watering facilities, pumping plants, and diverting rainwater through gutters, downspouts, and pipes. Vegetative practices include filter strips, cover and relay crops, tree and shrub establishment, critical area planting, and pasture planting. Management practices address operational considerations such as timing, application rates, testing, and record keeping. Nutrient management, forage harvest management, pest management, and waste utilization are examples.

By 2004, all dairy operations should have their conservation plans implemented. Bacterial, nutrient and sediment loads should decrease. Continued monitoring, enforcement, and operator access to technical assistance will be necessary to ensure the success of this TMDL implementation plan. If water quality goals are not achieved within a reasonable time, then it may be necessary to reevaluate and adjust this TMDL implementation plan.

The subsurface transport of bacteria through soils to watercourses or to groundwater is an issue that needs more investigation in the Nooksack basin. Over-application on the surface while adequate buffers are in place, or injection of manure under the wrong circumstances, may trade a surface water problem for a groundwater contamination problem.

In response to local interest, the USEPA, Ecology, and Whatcom County have strengthened a regulatory presence in the watershed. USEPA conducted inspections of dairies in 1997-98. The inspections generated intense public discussion about the need for dairies to conduct their business in an environmentally responsible manner. It may have also accelerated the appointment of an additional Ecology inspector for Whatcom County. A sustained regulatory presence should reduce chronic waste discharges that have occurred throughout the year, and reduce bacteria loading to the river and tributaries by ensuring best management practices are being effectively applied at dairies. For example, Ecology inspectors reported in February 1999 that half of the Whatcom County dairies that had been inspected. Of those, 10-20% had major problems, 50% had minor problems, and 25-35% had no detectable problems (Craig, 1999). Some of the problems cited by inspectors have led to fines.

Local government has been active in reducing bacteria through several recent programs. The Whatcom County Health and Human Services Department inspected onsite septic systems near the mouth of the Nooksack River and in the Tenmile Creek basin in 1998. Failure rates in the community of Marietta, at the mouth of the Nooksack, were 5% to 10%. The Health and Human Services Department will continue to monitor the integrity of systems in the county. In 1998, the Whatcom County Council funded enforcement staff for the critical areas ordinance which should prevent excessive livestock access to waterways, and prevent other pollutant sources from riparian areas. The staff work with large and small farms alike, to keep buffers intact in classified fish and wildlife Habitat Conservation Areas.

The Whatcom Conservation District, numerous dairy farmers, and other groups successfully convinced the Whatcom County Council to pass a manure management ordinance in October 1998. The ordinance prohibits manure applications to bare ground or to fields of corn stubble from September through March. The ordinance should reduce manure runoff from unprotected fields if it is adequately enforced. The District continues to be a lead agency in natural resource protection, including the Shellfish Protection District activities, nutrient management plan development, hobby-farm owner education, farm plan development, and several grant activities for monitoring and education.

Chapter 90.72 RCW, Shellfish Protection Districts, requires counties to create shellfish protection districts and programs, in response to downgrades of recreational or commercial shellfish beds caused by ongoing nonpoint source pollution. The partial closure of the Portage Bay commercial shellfish area in 1997 required Whatcom County to take action. In 1998, the Whatcom County Council voted to include the entire Nooksack River basin in the Portage Bay Shellfish Protection District. The Whatcom County Shellfish Response Strategy implemented within the Portage Bay Shellfish Protection District will be coordinated with relevant land-use and water quality plans to avoid duplication of effort. The response strategy implementation should be closely integrated with the TMDL implementation activities, since bacteriological quality is the focus of both efforts. The initial plan addressed all known point and nonpoint sources of bacteria contamination, and set an optimistic goal for reopening the commercial shellfish beds by December 31, 1999 (Whatcom County, 1999).

Actions for Municipal Point Sources

Although the municipal point sources contribute a minor portion of the bacteria load to the Nooksack River, the risk to human health from human waste effluent is much higher than from other sources (i.e., human pathogens are more prevalent in human waste than in wastes from other animals, and they pose a more serious threat to human health). Therefore, assuring the integrity of municipal sewage collection, treatment, and monitoring processes is a high priority for the bacteria TMDL. Municipalities should operate and maintain their collection and treatment systems to achieve reliable and consistent disinfection of sewage to protect the health of downstream users and other citizens. The Ecology Water Quality Program has the regulatory responsibility and authority to ensure the municipalities' actions in the Nooksack basin are meeting water quality standards and protecting beneficial uses in the basin.

Municipalities and Ecology must eliminate chronic problems of raw sewage overflows from collection systems. Although the TMDL survey did not document overflow events, the chronic nature of overflow events in Lynden were discovered when TMDL activities initiated discussions between Ecology and Lynden Pubic Works Department staff. The frequent overflow events at lift stations resulted in the discharge of raw sewage into Kamm Creek and Fishtrap Creek. Although the sewage is relatively small in volume, the practice poses a significant health risk and needs to be stopped.

The TMDL study results emphasize the need for better quality assurance (QA) on data generated by self-monitoring programs. The laboratory and data problems experienced by Lynden WWTP, and the consequent disinfection problems, would have been discovered earlier if a more rigorous QA procedure had been in place. The bacteria problem in the Nooksack basin warrants a stringent QA program which should include FC density confirmations by Ecology's Manchester Laboratory or a third party laboratory every two or three months. This level of QA should be followed until more reliable forms of disinfection are established at the WWTPs (e.g., ultraviolet disinfection at Lynden, or hyperchlorination followed by dechlorination now operating at Ferndale). Sample confirmations should continue under a QA plan, but at a less frequent interval. The Ecology Water Quality Program should establish stronger incentives for accurate and timely data reporting.

In addition, Ecology permit writers must review pretreatment agreements between industrial users and the municipal WWTPs, and review stormwater plans for municipal service areas. Some of the effluent disinfection problems reported by municipal treatment plant operators were caused by large industrial 'shock loads' which upset plant unit processes. Pretreatment or temporary storage at industrial facilities could alleviate some of the upset conditions. TMDL sampling results also indicated some sporadically high FC and *E. coli* densities from municipal stormwater, especially in Ferndale (39 to 38,000 cfu/100 mL).

As the Nooksack basin municipal areas grow, the bacteria loading from urban stormwater sources will have a greater effect on water quality unless adequate measures are in place. It is generally less expensive to put treatment measures in place as the service areas are expanded, rather than retrofitting after the stormwater collection and treatment systems are in place. Often the location and number of connections to municipal stormwater or wastewater lines is unknown. For example, the Darigold condensate line runs from the milk processing plant, through the city of Lynden, to the Nooksack River. The FC, *E. coli*, and enterococcus counts from TMDL survey samples indicated either a source of contamination at the Darigold facility, or a source connected to the condensate line as it passes through Lynden. Darigold and Lynden will need to work with Ecology to find the source of contamination.

Monitoring

Another requirement of the TMDL process is a monitoring plan. As mentioned earlier, monitoring allows direct evidence of target compliance or control measure effectiveness. It can also provide the data necessary to answer uncertainty issues identified in the TMDL, and to modify or adjust targets. Monitoring can be performed by Ecology or by others. Monitoring data will be reviewed at regular intervals, to see if compliance is achieved or if adjustments to targets are necessary. Land use changes, farm plan completion and implementation, and the application of other BMPs will require monitoring as well. The monitoring plan should also consider changes in indicator bacteria, which may occur in the future.

Monitoring in the lower Nooksack basin should continue to focus on fecal coliform bacteria as the TMDL compliance indicator, but also should consider concurrent *E. coli* analysis. The membrane filter technique is preferred for samples taken from the freshwater compliance sites. Compliance sites include the two Ecology long-term main stem stations at Brennan (RM 3.5) and North Cedarville (RM 30.9), and near the mouths of the ten tributaries listed in Table 10. Effluent from the three WWTPs also need to be sampled after the point of disinfection or dechlorinisation.

Washington State (WQP, 1999) is proposing changing the bacteria quality indicator to *E. coli* or enterococcus. Should the indicator be changed, fecal coliform should be collected concurrently with the *E. coli* or enterococcus samples to evaluate the degree of correlation between indicators, and to help with transferring targets to the new indicators. Using *E. coli* as a concurrent indicator would also help to assess if other types of bacteria in the fecal coliform group are becoming more predominant as manure and sewage sources are controlled. It is unlikely that a change from fecal coliform to some other indicator bacteria will occur for shellfish harvest area assessments in the near future. So, fecal coliform monitoring will be necessary in the Nooksack River even if the freshwater indicator for primary and secondary contact recreation is changed.

Additional data should be collected with the indicator bacteria samples. No particular auxiliary chemical analyses appeared to be necessary for evaluating the freshwater bacteria results, but temperature data are sometimes helpful. Discharge volumes should be measured at tributaries sites and at municipal point sources. USGS gage data and antecedent rainfall data should be retrieved from Nooksack basin stations. Marine water samples should have salinity and temperature data collected concurrently with bacteria samples. Tide phase and depth of sample should also be noted. Marine samples are more appropriately analyzed using the MPN method, so MPN and MF should be performed for additional bacteria evaluations in the estuary.

Since elevated bacteria densities appear to occur randomly during the year, sampling should occur throughout the year. However, runoff conditions need to be monitored to calculate bacteria loading changes and to evaluate BMP effectiveness. Runoff events occur in many areas of the basin during a 24-hr. rainfall of 0.2 inches. A complete loading evaluation would require data from storm flow and baseflow periods. Sampling twice a month could encompass this type of monitoring scheme.

Post-TMDL survey water quality monitoring is already underway at most TMDL compliance points, as a part of the Portage Bay Shellfish Protection District activities. The Northwest Indian College (NWIC) at the Lummi Reservation Campus obtained a Centennial Clean Water Grant in 1999, in part to monitor 23 sites in the Nooksack basin (Northwest Indian College, 1999). The grant is in support of the Whatcom County Shellfish Protection Strategy, which includes Portage Bay and Drayton Harbor. The NWIC staff are monitoring four of the main stem and six of the tributary sites established in the TMDL study. Some of these sites had been monitored by NWIC under a similar grant from April 1998 to March 1999 (Cochrane, 1999). Additional sites in the monitoring program are located on some of the main branches of Tenmile, Bertrand, Fishtrap, Kamm, and Scott creeks, and in Portage Bay (Northwest Indian College, 1999). These include the highest priority bacteria loading areas identified in the TMDL evaluation. Samples will be collected twice a month for a year. These data should be compatible with the TMDL database. The data can be used to (1) evaluate the annual variability (especially in some of the tributaries), (2) identify sources of contamination, and (3) watch trends over the coming years.

Portage Bay bacteriological data from the DOH Office of Shellfish Programs and from the Lummi Nation will continue to be important sources for TMDL evaluation. Meeting the fecal coliform criteria in Portage Bay to allow shellfish harvesting will be an essential milestone for the TMDL. The DOH sampling design provides the basic data DOH and the Lummi Nation need to assess the water quality of the shellfish beds under the National Shellfish Sanitation Program. The Lummi Nation and NWIC will be collecting additional data that may better define the transport mechanisms of Nooksack River bacteria to the shellfish beds.

Monitoring will continue monthly at the two Ecology long-term stations on the Nooksack River main stem. The data generated by this monitoring will continue to be used to analyze water quality trends. Additional stations will be available in the Nooksack basin in fiscal year 2001 through the Environmental Monitoring and Trends Section of Ecology's Environmental Assessment Program. These are operated for one year, and are placed at the discretion of Ecology's Bellingham Field Office and Northwest Regional Office. The stations would be best used to enhance local monitoring programs. For example, Silver Creek watershed was not adequately evaluated in the TMDL, and sources of contamination in the upper Nooksack basin require better definition. Additional data from point sources should be available through the Ecology Water Quality Program. Raw water monitoring records for Lynden and Whatcom County PUD are available from DOH. The WWTP effluent data and quality assurance data on bacteriological tests recommended earlier in this report are part of the TMDL data set that should be frequently reviewed.

A complete evaluation of TMDL monitoring data should be conducted within five years. Water quality data from Ecology, NWIC, the Lummi Nation, DOH, and others need to be brought together with the land use and farm plan implementation records for the evaluation. Coordination through the Portage Bay Shellfish Protection District monitoring plan could be helpful to ensure complete basin coverage. If the data coverage is inadequate, the Bellingham Field Office and Northwest Regional Office need to request additional data collection, or support local coordination and collection of additional data.

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Appendices

Appendix A. Sample Site Description Locations

Abbreviation	Station Name	Description	Digital Mapping Coordinates*	
SIL	Silver Creek at Marine Drive	Center span of bridge crossing at Marine Dr.	48.790816	122.581556
MS1	Marine Drive Bridge:Center	Center of riverchannel	48.791520	122.588481
MS1-R	Marine Drive Bridge: Right Channel	West side of channel approx. 1/3 distance from bank	48.791545	122.58900
MS1-L	Marine Drive Bridge: Left Channel	East side of channel approx. 1/3 distance from bank	48.791476	122.58799
FERN	Ferndale WWTP after dechlorination	Effluent from weir after dechlorination at end of contact chamber	48.837948	122.59196
MS2	Ferndale at Main Street Bridge: Center Channel		48.845464	122.586951
MS2-R	Ferndale at Main Street Br.: Right Channel	Northwest side of channel approx. 1/3 distance from bank	48.845544	122.587086
MS2-L	Ferndale at Main Street Br.: Left Channel	Southeast side of channel approx. 1/3 distance from bank	48.845391	122.586823
TEN	Tenmile Creek at Mouth	Boat access	48.856000	122.575563
TEN1	Tenmile Creek at Paradise Rd.	Used during all except one storm event	48.853551	122.572124
TEN2	Tenmile Creek at Northwest Road	Used during a single storm event sample only	48.854231	122.539543
WIS	Wiser Lake Creek at Mouth	Boat access from Nooksack River	48.890738	122.552732
WIS1	Wiser Lake Creek at Northwest Rd.	Sampled only during March 1997 survey	48.892714	122.539014
KEE	Keefe Lake Creek at Mouth	Boat access from Nooksack River	48.892451	122.553873
MS-3	Below Bertrand/Fishtrap at Mid-channel	Boat access only at near right bank pilings: river mile 11.5	48.903059	122.546625
MS-3R	Below Bertrand/Fishtrap: right channel		48.903036	122.547037
MS-3L	Below Bertrand/Fishtrap:left channel		48.903076	122.546325
BER	Bertrand Creek at Mouth	Boat access from Nooksack River	48.912547	122.533144
FIS	Fishtrap Creek at Mouth	Boat access from Nooksack River	48.912101	122.521742
FIS1	Fishtrap Creek at River Road	Used during all except one storm event	48.914159	122.519529
FIS2	Fishtrap Creek at Flynn Road	USGS gaging station at Flynn Rd. bridge	48.926649	122.495013
LLPL	Drain left bank- below Meridian Rd. bridge	Boat access from Nooksack River	48.914682	122.494160
SCO	Scott Ditch at Mouth	Boat access from Nooksack River	48.920969	122.479141
SCO1	Scott Ditch at Bylsma Rd.	Sampled only during March 1997 survey	48.919305	122.462663
DARI	Darigold Condensate from Access Port	Manhole located through hedge in field adjacent to Apts.	48.942966	122.448222
LYND	Lynden WWTP after chlorination	Effluent from weir at end of contact chamber	48.938461	122.451031
MS4	Lynden at Hannegan Bridge: Center Channel		48.937108	122.440698
MS4-R	Lynden at Hannegan Bridge: Right Channel	Northwest side of channel approx. 1/3 distance from bank	48.937262	122.440786
MS4-L	Lynden at Hannegan Bridge: Left Channel	Southeast side of channel approx. 1/3 distance from bank	48.936954	122.440622
KAM	Kamm Creek at Mouth	Boat access from Nooksack River	48.938480	122.439584
KAM1	Kamm Creek at Hampton Rd.	Sampled only during March 1997 survey	48.945445	122.440402
EVER	Everson WWTP after chlorination	Effluent from weir at end of contact chamber	48.920002	122.348857
MS-5	Everson at Hwy. 544 Bridge	Center of riverchannel	48.918414	122.348201
MS-5R	Everson at Hwy. 544 Bridge: Right channel		48.918571	122.347975
MS-5L	Everson at Hwy. 544 Bridge: left channel		48.918237	122.348468
AND	Anderson Creek at Martin Road	Approx. 50' downstream of bridge	48.861722	122.330495
SMI	Smith Creek at Lind Road	Approx. 50' downstream of bridge	48.855998	122.292710
MS-6	North Cedarville at Hwy. 542 Bridge	Center of riverchannel	48.841801	122.292406
MS-6R	North Cedarville at Hwy. 542 Br.: Right channel		48.841894	122.292156
MS-6L	North Cedarville at Hwy. 542 Br.: Left channel		48.841708	122.292669

* Mapping coordinates reference: NAD 1927

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Appendix B. Formulas and Monte Carlo Distributions

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

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

where,

$\overline{W}_p$ is the estimated average load for the period,

p is the period,

$\overline{Q}_p$ is the mean flow for the period,

$\overline{W}_c$ is the mean daily loading for the days on which pollutant samples were collected,

$\overline{Q}_c$ is the mean daily flow for days when samples were collected,

n is the number of days when pollutant samples were collected.

Also,

$$S_{QW} = [1 / (n-1)] * \left[\left(\sum_{i=1}^{n} Q_{ci} * W_{ci} \right) - n * \overline{W_c} \, \overline{Q_c} \right]$$

and

$$S^2_Q = [1 / (n-1)] * \left[\left(\sum_{i=1}^{n} Q_{ci}^2 \right) - n * \overline{Q_c^2} \right]$$

where,

Q_{ci} are the individually measured flows, and

W_{ci} is the daily loading for the day the pollutant samples were collected.

Statistical Theory of Rollback

The following is a brief summary of the Statistical Theory of Rollback (STR) from *Environmental Statistics and Data Analysis* by Ott (1995). The major Theorems and Corollaries associated with the method are:

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

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

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

Water Quality-based Permit Limit Calculations

Permit Limit Calculation Summary

PARAMETER	Acute Dil'n Factor	Chronic Dil'n Factor	Metal Criteria Translator Acute	Metal Criteria Translator Chronic	Ambient Concentration *cfu/100 mL*	Water Quality Standard Acute *cfu/100 mL*	Water Quality Standard Chronic *cfu/100 mL*	Average Monthly Limit (AML) *cfu/100 mL*	Maximum Daily Limit (MDL) *cfu/100 mL*
Ferndale FC	11.2	111.3	0	0	39	200	39	**28.4**	**64.1**
Lynden FC	5.4	53.8			39	200	39	**28.4**	**64.1**
Everson FC	37.5	375			39	200	39	**28.4**	**64.1**

Waste Load Allocation (WLA) and Long Term Average (LTA) Calculations

Statistical variables for permit limit calculation

WLA Acute *cfu/100 mL*	WLA Chronic *cfu/100 mL*	LTA Acute *cfu/100 mL*	LTA Chronic *cfu/100 mL*	LTA Coeff. Var. (CV) *decimal*	LTA Prob'y Basis *decimal*	Limiting LTA *cfu/100 mL*	Coeff. Var. (CV) *decimal*	AML Prob'y Basis *decimal*	MDL Prob'y Basis *decimal*	# of Samples per Month *n*	
1842.2	39	591.5	20.6	0.60	0.90	20.6	0.60	0.90	0.90	8	1.00
908.4	39	291.7	20.6	0.60	0.90	20.6	0.60	0.90	0.90	8	1.00
6076.5	39	1951.1	20.6	0.60	0.90	20.6	0.60	0.90	0.90	8	1.00

Calculations based on Permit Writer's Manual (Ecology, 1994).

Monte Carlo Distribution Statistics

Monte Carlo simulation techniques substitute probability distributions for single fixed values in an equation used to describe a process. Using probability distributions openly recognizes that there are uncertainties in the equation values that need to be reflected in the outcome (answer). During a simulation, an individual value from each distribution is randomly selected and used in the equation. This is an iteration. Simulations have thousands or hundreds of thousands of iterations that create a distribution of the outcome (answer). The distribution of the outcome can then be described in the usual ways, e.g., mean, median, 90th percentile, standard deviation.

Distributions were fit to the Nooksack River TMDL data so the Portage Bay fecal coliform bacteria reduction equation could be used. The following tables contain statistical descriptions of the Nooksack River fecal coliform, and Nooksack River discharge data. The calculated fecal coliform change rates during 42 surveys are also listed.

Table B-1. Fecal coliform statistics for samples collected at Marine Drive or Slater Rd. from 1988 to 1998. All densities as cfu/ 100 mL, except MVU standard deviation.

Month	No. of samples	Minimum FC	25th Percentile	Mean	Median	Geometric Mean	MVU mean	MVU std.dev	90th Percentile	Maximum
JAN	11	12	31	104	40	61	101	119	360	390
FEB	15	4	15	145	52	57	152	294	578	800
MAR	10	22	30	169	87	87	150	184	814	880
APR	13	1	17	152	71	47	173	400	728	1100
MAY	14	27	39	203	56	94	175	239	830	1200
JUN	11	8	32	74	77	55	80	81	180	195
JUL	11	22	31	150	75	91	152	181	376	380
AUG	13	18	48	306	88	124	262	404	1488	1900
SEP	13	3	37	220	68	66	199	401	1192	1800
OCT	14	16	39	195	150	111	216	311	532	690
NOV	13	6	59	142	96	85	148	190	514	700
DEC	11	6	37	93	63	63	101	113	269	291

MVU = an unbiased estimate of the lognormal distribution (Gilbert, 1987; Aroner, 1995)

Table B-2. Nooksack River discharge statistics from mean daily discharges 1966 to 1998.

Month	No. of samples	Minimum	Mean	Median	Geometric Mean	MVU mean	MVU std.dev	90th Percentile	Maximum
JAN	1005	740	4938	3630	3913	4940	4047	9978	35600
FEB	904	770	4413	3460	3667	4363	3032	8080	28500
MAR	992	1280	3769	3130	3318	3725	2139	5977	33700
APR	960	1420	3656	3220	3368	3648	1612	5619	14500
MAY	992	1870	4542	4115	4251	4560	1909	6917	11500
JUN	960	1910	4757	4230	4427	4762	1996	7296	17700
JUL	992	1500	3473	2990	3197	3466	1598	5350	19100
AUG	992	1040	2046	1850	1924	2042	782	3032	6910
SEP	960	691	1854	1475	1619	1831	1131	3037	12300
OCT	1023	469	2631	1700	1933	2712	2529	5542	21500
NOV	990	466	4950	3610	3664	4877	4344	9489	48200
DEC	1023	1060	5209	3720	4111	5227	4640	10860	35500

Table B-3. Marine Drive to Portage Bay Dept. of Health station 12 and 13 fecal coliform change rates 1997 - 1998.

All raw	<2500 cfs	2500-7000 cfs	< 7000 cfs	>7000 cfs
54.5	35.5	39.9	39.9	54.5
45.8	19.5	39.3	39.3	45.8
44.7	16.3	37.8	37.8	44.7
39.9	8.0	31.5	35.5	38.1
39.3	11.4	28.3	31.5	6.2
38.1	2.1	28.1	28.3	-6.1
37.8	6.4	23.9	28.1	-8.0
35.5	7.9	22.3	23.9	
31.5	2.0	20.9	22.3	
28.3	-3.8	20.6	20.9	
28.1		19.6	20.6	
23.9		19.2	19.6	
22.3		18.0	19.5	
20.9		17.9	19.2	
20.6		16.5	18.0	
19.6		11.2	17.9	
19.5		11.1	16.5	
19.2		7.4	16.3	
18.0		5.3	11.4	
17.9		3.4	11.2	
16.5		2.3	11.1	
16.3		2.3	8.0	
11.4		0.5	7.9	
11.2		0.0	7.4	
11.1		-10.9	6.4	
8.0			5.3	
7.9			3.4	
7.4			2.3	
6.4			2.3	
6.2			2.1	
5.3			2.0	
3.4			0.5	
2.3			0.0	
2.3			-3.8	
2.1			-10.9	
2.0				
0.5				
0.0				
-3.8				
-6.1				
-8.0				
-10.9				

Portage Bay equation simulation input and output results.

Simulations= 1	Iterations= 10000
# Input Variables= 48	Sampling Type= Latin Hypercube
# Output Variables= 38	Runtime= 00:01:42
	Run on 8/30/99, 3:00:24 PM

Summary Statistics

INPUT VALUES

Name	Minimum	Mean	Std Dev	10% tile	50% tile	75% tile	90% tile	Maximum
Flow / Jan	1000	5034	3846	1690	3924	6294	9657	35261
Flow / Feb	772	4375	2953	1638	3601	5485	8016	28062
Flow / Mar	1281	3840	2107	1802	3320	4712	6483	26782
Flow / Apr	1421	3698	1576	2029	3374	4467	5759	14220
Flow / May	1870	4571	1750	2618	4239	5521	6985	11481
Flow / Jun	1911	4819	1952	2722	4434	5795	7382	17376
Flow / Jul	1500	3570	1557	1962	3227	4299	5588	16864
Flow / Aug	1040	2101	750	1290	1951	2483	3095	6756
Flow / Sep	1000	2131	1086	1149	1823	2536	3484	11681
Flow / Oct	1000	3159	2381	1232	2404	3831	5966	21459
Flow / Nov	1000	5052	4208	1599	3802	6264	9879	47655
Flow / Dec	1061	5348	4262	1709	4066	6687	10501	35436
MS1 FC / Jan	12.0	91.2	74.1	23.2	67.3	120.4	196.7	389.7
MS1 FC / Feb	4.0	119.9	138.2	14.8	68.2	152.0	299.1	798.8
MS1 FC / Mar	22.0	147.0	135.8	36.0	101.1	185.5	319.0	879.5
MS1 FC / Apr	1.0	133.0	175.0	11.9	66.4	161.1	342.6	1097.8
MS1 FC / May	27.0	176.5	175.2	41.2	115.6	218.7	389.4	1198.2
MS1 FC / Jun	8.0	64.2	42.5	19.4	52.8	87.4	129.0	194.9
MS1 FC / Jul	22.0	120.2	82.9	35.9	95.7	163.7	247.7	379.9
MS1 FC / Aug	18.0	243.3	273.9	40.3	146.7	300.5	566.7	1893.0
MS1 FC / Sep	3.0	173.9	238.1	17.6	87.7	204.0	428.3	1794.1
MS1 FC / Oct	16.0	186.4	179.5	35.8	123.7	242.6	430.2	999.4
MS1 FC / Nov	6.0	130.2	122.2	25.8	89.1	169.6	294.1	699.3
MS1 FC / Dec	6.0	82.6	62.5	21.0	64.0	112.1	175.7	299.7
MS1 TMDL / Jan	12.0	91.2	74.1	23.2	67.3	120.4	196.7	389.9
MS1 TMDL / Feb	4.0	119.9	138.2	14.8	68.2	152.1	299.1	799.3
MS1 TMDL / Mar	22.0	147.0	135.8	36.0	101.1	185.6	319.0	877.4
MS1 TMDL / Apr	1.0	133.0	175.0	11.9	66.4	161.1	342.7	1099.9
MS1 TMDL / May	27.0	176.5	175.2	41.2	115.6	218.8	389.4	1196.9
MS1 TMDL / Jun	8.0	64.2	42.5	19.4	52.8	87.4	129.0	195.0
MS1 TMDL / Jul	22.0	120.2	82.9	35.9	95.7	163.7	247.7	379.8
MS1 TMDL / Aug	18.0	243.3	273.9	40.4	146.7	300.5	566.5	1893.7
MS1 TMDL / Sep	3.0	173.9	238.1	17.6	87.7	204.0	428.2	1798.0
MS1 TMDL / Oct	16.0	186.4	179.5	35.8	123.7	242.6	430.1	998.3
MS1 TMDL / Nov	6.0	130.2	122.2	25.8	89.1	169.6	294.1	699.0
MS1 TMDL / Dec	6.0	82.6	62.5	21.0	64.0	112.1	175.7	300.0
decay / Jan	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Feb	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Mar	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Apr	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / May	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Jun	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Jul	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Aug	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Sep	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Oct	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Nov	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5
decay / Dec	-11	22.2	13.7	7.9	20.2	31.1	42.9	54.5

Portage Bay equation simulation input and output results, continued.

Simulations= 1	Iterations= 10000
# Input Variables= 48	Sampling Type= Latin Hypercube
# Output Variables= 38	Runtime= 00:01:42
	Run on 8/30/99, 3:00:24 PM

Summary Statistics

	OUTPUT VALUES							
Name	Minimum	Mean	Std Dev	10% tile	50% tile	75% tile	90% tile	Maximum
Portage FC / Jan	2.4E-10	21.6	57	0.2	6.4	20.8	49.8	1713
Portage FC / Feb	9.1E-44	46.3	1870	0.1	5.6	20.6	60.0	186680
Portage FC / Mar	6.9E-06	31.9	99	0.3	8.4	27.6	71.1	2312
Portage FC / Apr	1.5E-05	29.0	104	0.2	4.9	20.1	61.9	3326
Portage FC / May	5.3E-03	41.4	106	1.1	13.5	39.2	95.1	4695
Portage FC / Jun	3.0E-03	15.2	30	0.5	6.1	16.5	36.0	739
Portage FC / Jul	3.2E-04	25.9	68	0.3	7.6	23.7	58.6	1986
Portage FC / Aug	1.3E-08	54.2	753	0.0	3.4	18.2	67.9	69210
Portage FC / Sep	1.5E-10	38.9	357	0.0	1.5	10.9	45.0	19295
Portage FC / Oct	8.8E-11	58.9	1225	0.0	5.2	25.0	80.6	118148
Portage FC / Nov	2.8E-10	32.5	127	0.2	8.0	27.7	70.3	5488
Portage FC / Dec	1.9E-08	21.1	83	0.2	6.3	19.7	46.8	5422
TMDL FC / Jan	1.2E-10	11.3	30	0.1	3.4	10.9	26.0	896
TMDL FC / Feb	4.8E-44	24.2	978	0.1	2.9	10.8	31.4	97596
TMDL FC / Mar	3.6E-06	16.7	52	0.2	4.4	14.4	37.2	1209
TMDL FC / Apr	7.8E-06	15.2	54	0.1	2.6	10.5	32.3	1739
TMDL FC / May	2.7E-03	21.6	56	0.6	7.1	20.5	49.7	2455
TMDL FC / Jun	1.6E-03	7.9	16	0.3	3.2	8.7	18.8	386
TMDL FC / Jul	1.7E-04	13.6	35	0.2	4.0	12.4	30.6	1038
TMDL FC / Aug	6.8E-09	28.3	393	0.0	1.8	9.5	35.5	36183
TMDL FC / Sep	8.0E-11	20.3	187	0.0	0.8	5.7	23.5	10087
TMDL FC / Oct	4.6E-11	30.8	640	0.0	2.7	13.1	42.1	61768
TMDL FC / Nov	1.5E-10	17.0	67	0.1	4.2	14.5	36.8	2869
TMDL FC / Dec	9.7E-09	11.0	44	0.1	3.3	10.3	24.5	2835

Simulation Sensitivities for Portage FC Model

	Pre & Post-TMDL Conditions		
Month	Name	Sensitivity	Rank Correlation Coefficient
January	k coeffic.	-0.424	-0.736
	MS1 FC	0.294	0.391
	Flow	0.084	0.454
February	k coeffic.	-0.037	-0.680
March	k coeffic.	-0.392	-0.791
	MS1 FC	0.285	0.396
	Flow	0.048	0.383
April	MS1 FC	0.359	0.563
	k coeffic.	-0.339	-0.723
	Flow	0.038	0.289
May	k coeffic.	-0.416	-0.803
	MS1 FC	0.391	0.477
	Flow	0.052	0.262
June	k coeffic.	-0.537	-0.831
	MS1 FC	0.339	0.413
	Flow	0.076	0.271
July	k coeffic.	-0.463	-0.842
	MS1 FC	0.263	0.381
	Flow	0.066	0.337
August	k coeffic.	-0.125	-0.815
	MS1 FC	0.077	0.324
September	k coeffic.	-0.186	-0.748
	MS1 FC	0.120	0.355
October	k coeffic.	-0.081	-0.724
	MS1 FC	0.055	0.357
November	k coeffic.	-0.300	-0.699
	MS1 FC	0.258	0.444
	Flow	0.040	0.462
December	k coeffic.	-0.290	-0.724
	MS1 FC	0.206	0.420
	Flow	0.040	0.457

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Appendix C. Nooksack River Basin Dairies with NPDES Permits

Name	Mailing Address	Permit Number
Sand Road Dairy Farm, Inc.	Bellingham	WAG 01- 3002A
Dyna-Moo Dairy	Everson	WAG 01- 3014A