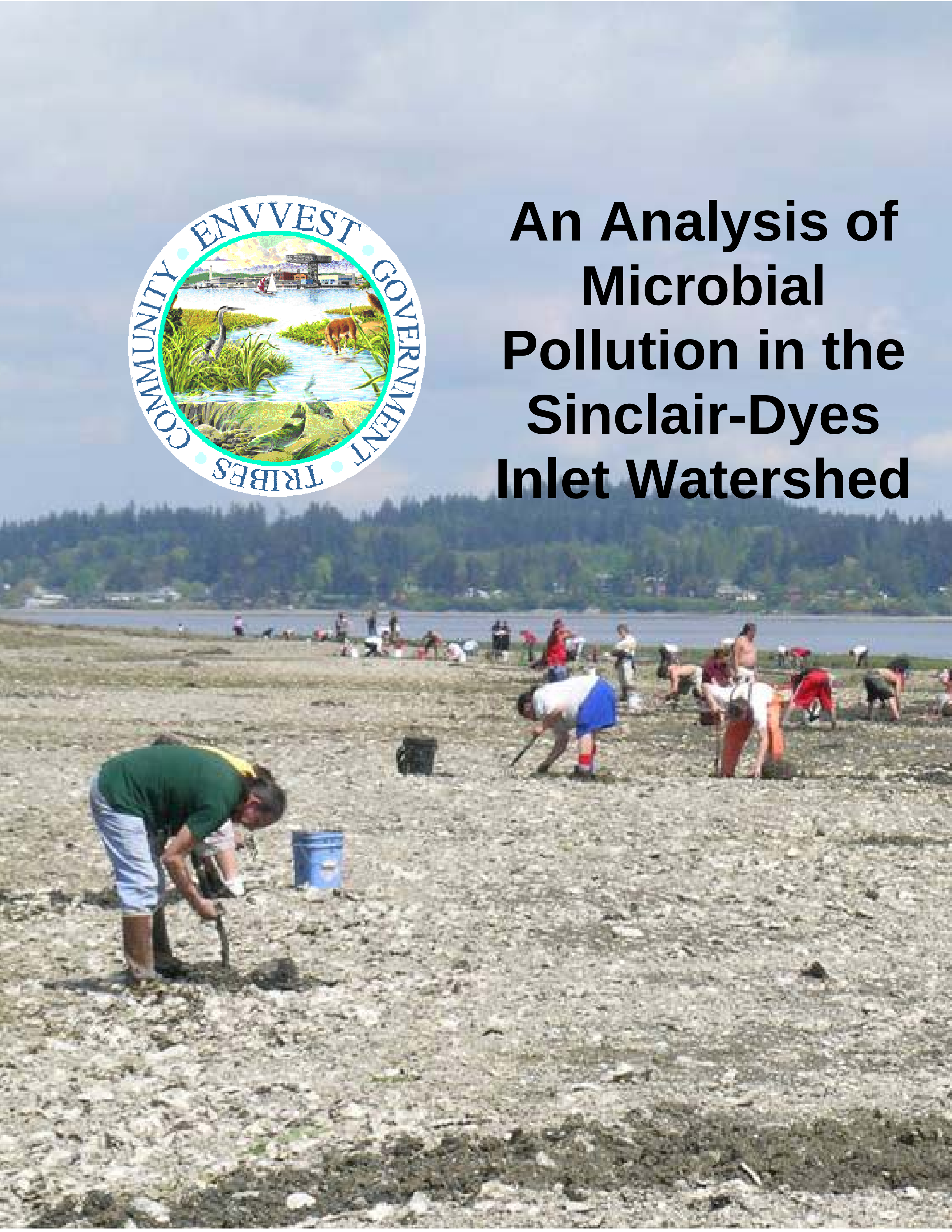
An Analysis of Microbial Pollution in the Sinclair-Dyes Inlet Watershed



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An Analysis of Microbial Pollution in the Sinclair-Dyes Inlet Watershed

C. W. May
V. I. Cullinan

Marine Sciences Laboratory
Sequim, Washington

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

This assessment of fecal coliform sources and pathways in Sinclair and Dyes Inlets is part of the Project ENVironmental InVESTment (ENVVEST) being conducted by the Navy's Puget Sound Naval Shipyard and Intermediate Maintenance Facility in cooperation with the U.S. Environmental Protection Agency, Washington State Department of Ecology, the Suquamish Tribe, Kitsap County, the City of Bremerton, the City of Port Orchard, and other local stakeholders. The goal of this study was to identify microbial pollution problems within the Sinclair-Dyes Inlet watershed and to provide a comprehensive assessment of fecal coliform (FC) contamination from all identifiable sources in the watershed. This study quantifies levels of contamination and estimated loadings from known sources within the watersheds and describes pollutant transport mechanisms found in the study area. In addition, the effectiveness of pollution prevention and mitigation measures currently in place within the Sinclair-Dyes Inlet watershed is discussed. This comprehensive study relies on historical data collected by several cooperating agencies, in addition to data collected during the study period from spring 2001 through summer 2005. This report is intended to provide the technical information needed to continue current water quality cleanup efforts and to help implement future efforts.

The major objectives of Sinclair-Dyes Inlet microbial pollution assessment technical study were as follows:

- Identify and quantify the contribution of significant sources of microbial pollution to the system by measuring concentrations and loading from these sources
- Investigate the effects of seasonal factors, storm events, and land-use conditions on microbial pollution loading to the system
- Model the distribution of microbial pollution within the Sinclair-Dyes Inlet watershed as it is affected by loads from point and non-point sources (NPS), tidal circulation and transport, and the natural process of die-off of bacteria and other microbial organisms
- Use the developed model to predict the effect of pollution on water quality at various locations in the Sinclair-Dyes Inlet watershed
- Compare the levels of microbial contamination to current water-quality standards for the protection of beneficial uses (e.g. shellfish harvest and contact recreation). Provide information to determine the pollution reductions that are needed so that local communities, agencies, and other affected parties can develop and implement appropriate source-control, mitigation, and cleanup strategies.

The findings of the Sinclair-Dyes Inlet microbial pollution assessment study indicate the presence of numerous sources of bacterial pollution in the Sinclair-Dyes Inlet watershed and multiple modes of transport of FC bacteria from sources to receiving waters and shellfish growing areas. In general, FC levels are higher in more developed watersheds with greater population densities, in areas with a greater percentage of impervious area, and in areas served by older sewer infrastructure or onsite wastewater treatment (septic) systems (OWTS). Water quality violations are more likely in urbanizing streams served by stormwater infrastructure and in those draining more developed watershed areas. Higher FC levels and violations of water-quality standards (WQS) are also more likely following a major storm event that produces stormwater runoff that enters the marine receiving waters via streams and stormwater outfalls; engineered stormwater systems can be an efficient means of transporting microbial pollution from source areas to receiving waters. However, elevated nearshore FC levels appear to be localized and persist for only a short period of time after storm events or during extended periods of rainfall with

significant stormwater runoff and stormflow inputs. In nearshore and estuarine areas where shoreline development is intense or where urbanized streams and stormwater outfalls are common, elevated FC levels can persist as a chronic pollution problem. In general, the FC levels found during storm season sampling are an order of magnitude greater than those for non-storm periods, especially for nearshore sites with adjacent highly urbanized drainage subbasins. Relationships between bacterial pollution and land-use were also investigated. The loss of natural forest cover and the increase in impervious surfaces associated with suburban and urban levels of development were found to be correlated with FC contamination levels and the resultant violations of WQS.

This study found that the main underlying sources of bacterial pollution into the Sinclair-Dyes Inlet watershed include

1) failing OWTS
2) sewage spills, combined sewer overflow events, and failing sewer infrastructure
3) NPS pollution in stormwater runoff from urbanizing areas
4) improper or ineffective livestock and pet waste-management practices
5) illegal discharges from boats or marinas.

Effective mitigation of bacterial pollution based on the most likely sources of contamination listed above, should include the following:

1) proper operation and maintenance of onsite septic systems and municipal sewage treatment systems
2) elimination of all illicit discharges, including land-based sources and boats or marinas
3) control and treatment of stormwater runoff draining to receiving waters
4) implementation of farm and livestock source-control and best management practices
5) public education to encourage bacterial pollution source control, such as pet waste-management programs.

In addition to these mitigation measures, recommendations for improving the water quality in the Sinclair-Dyes Inlet and its watershed might include enhancing natural systems, such as wetlands and riparian buffers, and the use of new technologies, such as innovative disinfection treatments.

The value of an integrated watershed approach to water-quality management has been demonstrated during this project. The number and variety of sources for bacterial pollution throughout the study area does not support a conventional “end-of-pipe” approach to pollution control. In addition to ecological concerns, the link between human health and water quality is extremely strong. Therefore, the detection, quantification, and correction of existing sources of microbial pollution should be a high priority for watershed and water-resource managers, as should the development and implementation of an effective prevention program.

Acknowledgments

This report was prepared as part of the Puget Sound Naval Shipyard (PSNS) Project ENVVEST, a cooperative project among the U.S. Navy, U.S. Environmental Protection Agency, Washington State Department of Ecology, and technical stakeholders to help improve the environmental quality of the Sinclair-Dyes Inlet Watershed. This work was conducted under the direction of G.M. Sherrell, Project ENVVEST Program Manager, and R.K. Johnston, Project ENVVEST Technical Coordinator, with contributions from members of the working group. The work plan was approved by the Washington State Department of Ecology, Environmental Assessment Program. The technical information provided in this document are the opinions and views of the authors and do not necessarily represent the official views of the U.S. Navy, U.S. EPA, Washington State Department of Ecology, or any other official government agency. Mention of trade names and products are for information purposes only and are not intended as an endorsement for use. The authors of this report thank the following members of the Project ENVVEST technical working group for their significant contributions to this work:

Puget Sound Naval Shipyard & Intermediate Maintenance Facility: *G.M. Sherrell, D. Leisle, B. Beckwith, B. Walpole, and W. Boucher*

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Kitsap County Health District: *S. Whitford, J. Zimny, John Keiss, and M. Fohn*

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Washington State Department of Health: *F. Meriwether*

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Kitsap Public Utilities District: *J. LeCuyer*

Pacific Northwest National Laboratory, Marine Sciences Laboratory: *E. Crecelius, J. Brandenberger, N. Evans, L. O'Rourke and M. Miller*

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Acronyms

ADP	antecedent dry period
BEACH	Beach Environmental Assessment, Communication, and Health
BI	Bainbridge Island
B-IBI	benthic index of biological integrity
BOD	biochemical oxygen demand
BST	bacteria source tracking
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
CFU	colony forming units
CH3D	Curvilinear Hydrodynamics in 3-dimensions (marine model)
COB	City of Bremerton
COBI	City of Bainbridge Island
CV	coefficient of variation
CPO	City of Port Orchard
CS	chromogenic substrate
CSO	combined sewer overflows
CWA	Clean Water Act
DEM	Digital Elevation Model
DO	dissolved oxygen
EC	E. coli
Ecology	Washington State Department of Ecology
ENVVEST	ENVironmental InVESTment
EPA	Environmental Protection Agency
FC	fecal coliform
FIB	fecal indicator bacteria
FPI	Fecal Pollution Index
GAS	growing area standard
GIS	geographic information system
GMV	geometric mean value

Acronyms (contd)

HD	high-density
HSPF	Hydraulic Simulation Program FORTRAN (watershed model)
KCD	Kitsap Conservation District
KC-DCD	Kitsap County Department of Community Development
KCHD	Kitsap County Health District
KCSD	Karcher Creek Sewer District
KC-SSWM	Kitsap County Surface and Stormwater Management
KPUD	Kitsap Public Utilities District
LULC	land-use and land-cover
LA	load allocation
LD	low-density
LID	low impact development
MD	medium-density
MF	membrane filter
MGD	million gallons per day
MPN	most probable number
MST	microbial source tracking
NAD83	North American Datum of 1983
NLCD	National Land Cover Data
NSQD	National Stormwater Quality Database
NSSP	National Shellfish Sanitation Program
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NWS	National Weather Service
OBM	optical brightener monitoring
OWTS	onsite waste treatment system (septic tank)
PAM	polyacrylamide
PIC	pollution identification and correction
PSAT	Puget Sound Action Team
PSL	Puget Sound Lowland
PSNS & IMF	Puget Sound Naval Shipyard and Intermediate Maintenance Facility

Acronyms (contd)

QA/QC	quality assurance / quality control
RPD	residual percent difference
SCCWRP	Southern California Coastal Water Research Project
SGA	shellfish growing area
SOP	standard operating procedure
SSURGO	Soil Survey Geographic
SSWM	Surface and Stormwater Management
TEC	The Environmental Company
TIA	total impervious area
TM	Thematic Mapper
TMDL	total maximum daily load
USGS	U.S. Geological Survey
USN	U.S. Navy
UV	ultraviolet
UW	University of Washington
WAC	Washington Administrative Code
WA-DOH	Washington State Department of Health
WLA	waste-load allocation
WMC	Watershed Management Committee
WQCB	Water Quality Control Boards
WQS	water quality standards
WRIA	Water Resource Inventory Area
WWTP	wastewater treatment plant

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1.0 Introduction

This technical report was prepared as part of the Puget Sound Naval Shipyard (PSNS) Project ENVironmental InVESTment (ENVVEST), a cooperative project among the United States Navy (USN), United States Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), the Suquamish Tribe, Kitsap County, City of Bremerton, City of Port Orchard, and other local stakeholders to improve the environmental quality of the Sinclair-Dyes Inlet Watershed.

1.1 Project Goals

The overall goals of the Project ENVVEST Sinclair-Dyes Inlet watershed study are as follows:

1) To better understand the ecological structure and function of the Sinclair-Dyes Inlet ecosystem
2) To define the extent of beneficial-use impairment and to identify and quantify human-related stressors
3) To develop a toolbox of ecological (physical, chemical, and biological) metrics for long-term monitoring and adaptive management
4) To implement appropriate actions to protect, restore, and/or rehabilitate the ecosystem of the Sinclair-Dyes Inlet watershed
5) To educate and involve the public and stakeholders in watershed management.

The conceptual model of the Sinclair-Dyes Inlet watershed illustrated in Figure 1-1 provides the framework for several ecologically based water-quality studies currently underway in this region. The first of these studies involved microbial contamination, which is the focus of this report.

The purpose of this study is to identify microbial pollution problems within the Sinclair-Dyes Inlet watershed and to provide a comprehensive assessment of microbial contamination from all identifiable sources in the watershed. This report includes quantification of all identified sources of microbial pollution, including levels of contamination and estimated loadings from these sources, as well as pollutant transport mechanisms. In addition, the effectiveness of current pollution prevention and mitigation measures currently in place within the Sinclair-Dyes Inlet watershed is discussed. This comprehensive study relies on historical data collected by several cooperating agencies, in addition to data collected during the ENVVEST study period. This study is intended to provide the technical information needed to continue water quality cleanup efforts currently underway and to help implement additional efforts not yet funded.

The major objectives of this technical study are to

- Determine the contribution of significant sources of microbial pollution to the system by measuring or modeling loading from these sources
- Determine the effects of storm events and other disturbance events on microbial pollution loading to the system
- Model the distribution of microbial pollution within the Sinclair-Dyes Inlet watershed as it is affected by loads from point and nonpoint sources (NPS), tidal circulation and transport, and the natural process of die-off of bacteria and other microbial organisms

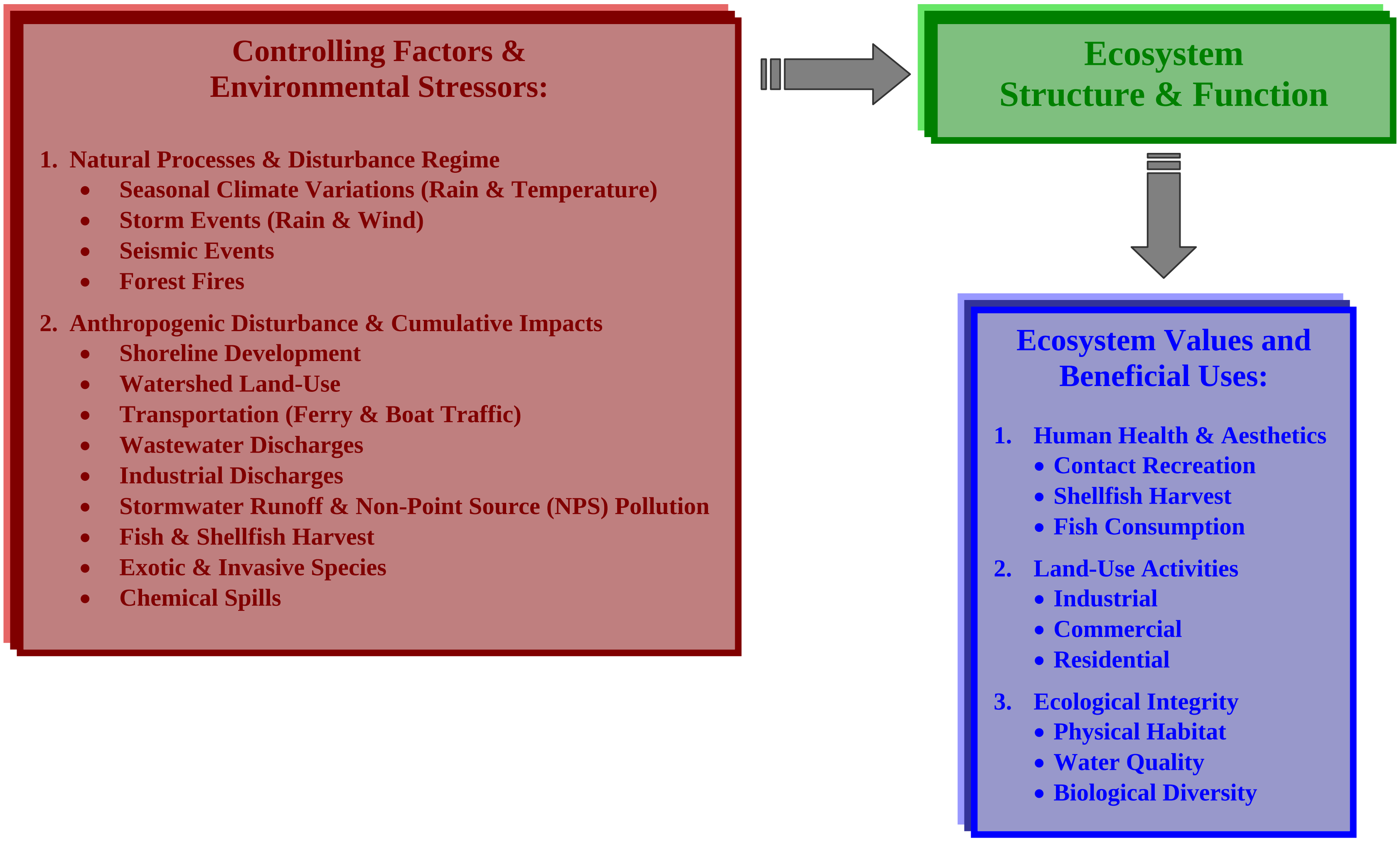


Figure 1-1. Sinclair-Dyes Inlet Watershed Conceptual Model

- Utilize the developed model to predict the effect of pollution events on water quality at various locations in the Sinclair-Dyes Inlet watershed
- Compare the levels of microbial contamination to current water-quality standards for the protection of beneficial uses. Provide information to determine the pollution reductions that are needed so that local communities, agencies, and other affected parties can develop and implement appropriate source-control, mitigation, and cleanup strategies.

1.2 Water Quality Overview

Ecology is responsible for administering the water-quality management program under the authority of state law and under the direction of the EPA and the Federal Clean Water Act (CWA). To that end, Ecology has established surface water quality standards (WQS) to protect the beneficial water uses of the state, such as swimming, fish and shellfish harvesting, aquatic life habitat, and domestic water supply (WDOE 2003). These WQS establish goals for lakes, rivers, and marine waters by assigning appropriate combinations of beneficial uses to each water body, and by setting criteria to ensure those uses are protected. These criteria are often quantitative limits on how much of a particular toxic chemical or other pollutant can exist in a water body without harming the various beneficial uses. Section 303(d) of the CWA and EPA regulations (40 CFR 130) require that states prepare a list of water body segments that do not attain state WQS (http://cfr.law.cornell.edu/cfr/cfr.php?title=40&type=part&value=130). Degradation of surface waters by pollutants can result in a 303(d) listing. Contaminants in fish and shellfish (either measured or extrapolated from bioaccumulation factors) that pose a human risk via consumption can also result in a 303(d) listing (http://www.ecy.wa.gov/programs/wq/303d/).

For each *impaired water body* on the 303(d) list, Ecology is required to determine the maximum pollutant load the water body can accept and still meet WQS. This total maximum daily load (TMDL) is then used to develop a *Water Cleanup Plan* (or TMDL Plan), which is a strategy to improve water quality in the impaired water body and achieve WQS. The TMDL is a tool for implementing WQS and is based on the relationship between water-quality conditions and pollution sources. The allowable pollutant loadings or other quantifiable parameters for a water body are established by a TMDL and thereby provide the basis for establishing water-quality-based pollution controls. Ecology has developed guidance for Water Cleanup Plans or TMDLs (WA-DOE 2002). In addition, the EPA has established guidance for the TMDL development and implementation process (EPA 1993, 2001b, and 2002).

A TMDL is a science-based approach to cleaning up a polluted water body so that it meets WQS. Typically, a TMDL involves an assessment of existing water-quality problems, a technical analysis of water-quality data to determine how far pollution must be reduced to support beneficial uses, and the selection and implementation of appropriate pollution control or water-quality treatment methods to achieve the water-quality goals. The goal of a TMDL is to set limits on the discharge of pollution into discrete water bodies to attain WQS and support beneficial uses. Ecology guidance also states “individual attention must be given to tribal governments with reservation land or treaty interests in the affected watershed” (WDOE 2002).

Specifically, a TMDL includes a written, quantitative assessment of water-quality problems and associated pollutant sources. The TMDL determines the amount of a given pollutant that can be discharged to the water body and still meet WQS (Figure 1-2). The TMDL may also determine loading capacity and allocate that loading capacity among the various sources.

A TMDL is the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background (40 CFR 130.2) with a margin of safety (CWA section 303(d)(1)(c)). The TMDL can be generically described by the following equation:

$$TMDL = LC = WLA + LA + MOS$$

Where:
- LC = loading capacity*, or the greatest loading a water body can receive without exceeding water quality standards;
- WLA = waste load allocation, or the portion of the TMDL allocated to existing or future point sources;
- LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
- MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

*TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures.

Figure 1-2. Total Maximum Daily Load Basics (EPA 2001c)

If the pollutant comes from a discrete source (point-source), such as an industrial facility discharge pipe, that facility's share of the loading capacity is called a waste-load allocation (WLA). If pollution comes from a diffuse source (i.e., an NPS), such as agricultural runoff or stormwater from developed areas, that nonpoint share is called a load allocation (LA).

The TMDL must include a margin of safety that takes into account the lack of knowledge about the causes of the water-quality problem or its loading capacity. The TMDL must also account for seasonal variability and may also address future population growth and the associated potential increases in pollution. The sum of the individual allocations and the MOS must be equal to or less than the loading capacity of the receiving waters. In addition to meeting WQS, the designated beneficial uses of that water body must be protected. The TMDL must also include an implementation plan (including a timeline for achieving the TMDL goals) and an effectiveness-monitoring plan (Figure 1-3). This study, along with previous water-quality monitoring and improvement efforts, will form the scientific basis for development of a TMDL and Water-Quality Cleanup Plan for the Sinclair-Dyes Inlet watershed.

1.3 Problem Statement

Degradation of water quality due to contamination by microbial pollution, including bacterial contamination and potential pathogens, represents a health risk and economic loss to many parts of Puget Sound. In general, pathogens are a serious concern for water resource managers because excessive quantities of fecal bacteria in human sewage and NPS runoff have been known to indicate an increased risk of pathogen-induced illness in humans (Kay et al., 1994; Fleisher et al., 1998; Haile et al., 1999). The bacteria and associated pathogens of primary concern to humans are the disease-causing bacteria and viruses. Some of these bacteria are free-living organisms able to survive on their own and grow in an aquatic habitat. Viruses, on the other hand, can grow only inside of a suitable host. Of the many different viruses associated with fecal material, most are responsible for causing gastrointestinal illness, but some can also cause other significant illnesses. Pathogenic bacteria found in fecal material are responsible for a variety of diseases.

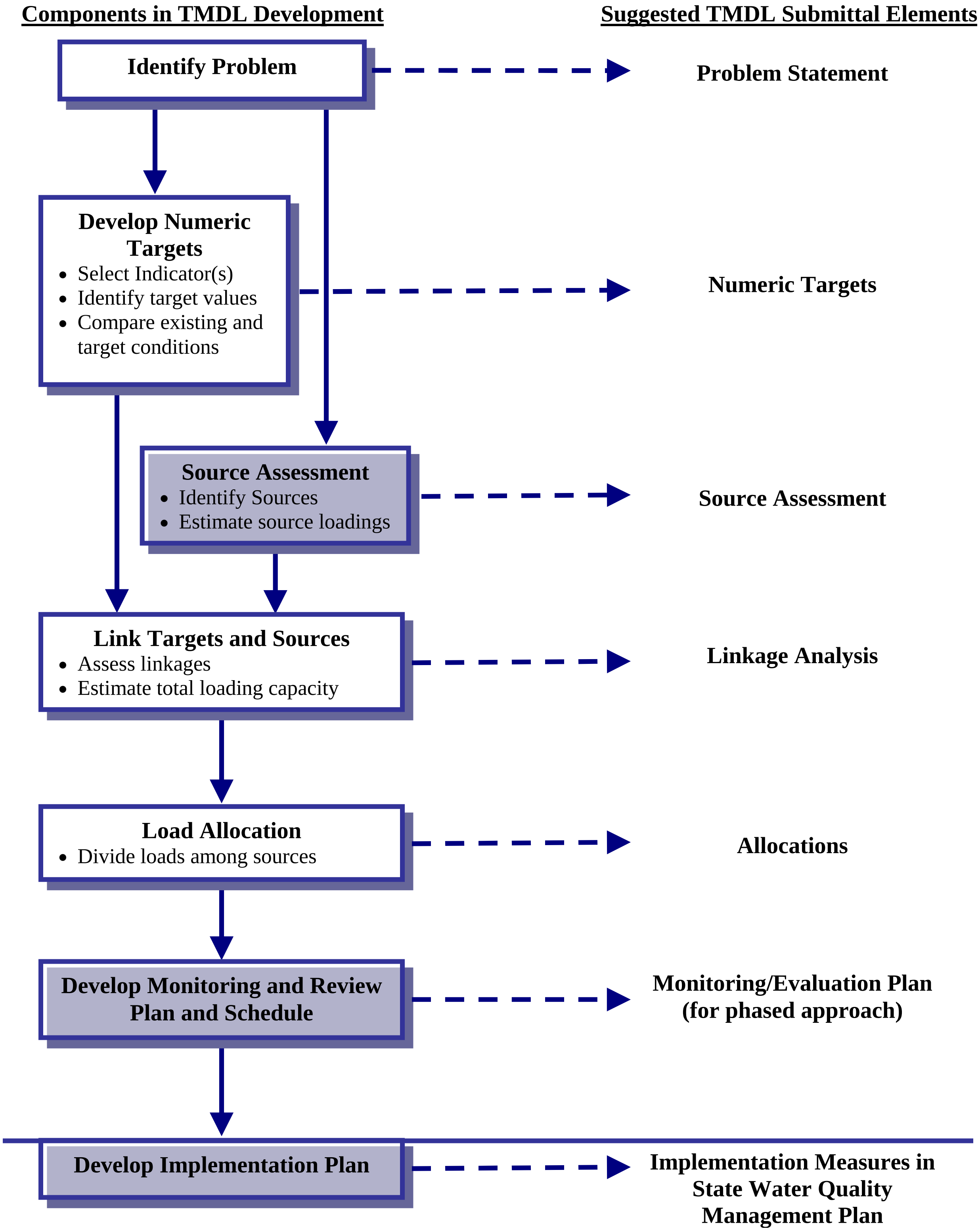


Figure 1-3. Components of Total Maximum Daily Load Development (EPA 2001c)

Public health organizations, state environmental agencies, and the EPA have developed several water-quality criteria to protect human health. Over 100 different enteric pathogens may be found in sewage, including viruses, parasites, and bacteria (NRC 1993). However, it is very difficult and expensive to directly measure the presence of pathogenic organisms (viruses, bacteria, and protozoans). Because public health agencies are not able to measure the entire host of human pathogens directly, they have relied on "indicator" organisms to assess the probability of the presence of pathogens. The most commonly used measure of fecal pathogenic bacteria is the abundance of fecal coliform (FC) bacteria. Measurements of fecal indicator bacteria (FIB) have been used as the basis of regulatory action back to the 1920s (Dadswell 1993; Jagals et al., 1995; Pitt 1998; NRC 2004).

Not all natural bacteria pose a human health or water-quality problem. Of human health concern, is the coliform bacteria group, which consists of several genera of bacteria belonging to the family enterobacteriaceae. FC bacteria are a member of this family. Large numbers of FC bacteria are present in the intestinal tracts and fecal material of all warm-blooded animals, including mammals, birds, and humans. Coliform bacteria and others may also be naturally present in soils and sediment. FC themselves are not usually pathogenic, but are often found associated with other organisms that do cause disease in humans. When predetermined concentrations of FC are reached, an area is considered unsafe for certain uses. If a large number of FC bacteria are present in a water body, it is possible that pathogenic organisms are also present in the water. For this reason, FC is the primary FIB used in Washington (WDOE 2003). An excellent review of microbial pathogens found in the coastal environment can be found in the National Research Council Report, *Managing Wastewater in Coastal Urban Areas* (NRC 1993).

Contact with bacterial-contaminated water increases the risk of developing an illness or infection from pathogens entering the body through ingestion, inhalation, or skin contact via open wounds. The presence of FIB (FC) is an indicator of the possible presence of pathogens. In all cases, the concentration of FIB is significantly greater than the concentration of pathogens. Waterborne diseases that could be contacted from contaminated water include the following (EPA 2001c):

- Viral Hepatitis or Hepatitis A
- Viral Gastroenteritis
- Hemorrhagic colitis (*Escherichia coli*)
- Campylobacteriosis or Gastroenteritis (*Campylobacter jejuni*)
- Dysentery or Shigellosis (Shigella)
- Salmonellosis (Salmonella spp.)
- Legionellosis (*Legionella pneumophilia*)
- Leptospirosis (Leptospira spp.)
- Typhoid Fever (*Salmonella typhi*)
- Cholera (*Vibrio cholerae*)
- Peptic Ulcer (*Helicobacter pylori*)
- Amebiasis (*Entamoeba hystolytica*)
- Giardiasis (*Giardia lamblia*)
- Cryptosporidiosis (*Cryptosporidium parvum*).

Research has also indicated that an increased risk of adverse health outcomes may be associated with swimming in waters that are contaminated by untreated stormwater runoff (Stevenson 1953; Cabelli et al., 1979; Cabelli et al., 1982; Corbett et al., 1993; Fleisher et al., 1993; Kay et al. 1994; Haile et al., 1999; Noble et al., 2000; Hendrickson et al., 2001; Lipp et al., 2001a; Gaffield et al., 2003). In addition, these health risks are generally higher for those swimming in close proximity to stormwater outfalls (Haile et al., 1999; Noble et al., 2000; Schiff et al., 2003; Ackerman and Weisberg 2004; Noble et al., 2004a) or areas of high septic system density (Lipp et al., 2001).

Pathogenic enteric bacteria typically enter the freshwater and nearshore environment from human and animal waste products discharged from wastewater treatment systems, entrained in agricultural runoff, or carried in stormwater runoff (Maiolo and Tschetter 1981; Gannon and Busse 1989; Pitman 1995; Macfarlane 1996; Pitt 1998; Mallin et al., 2000b; Lipp et al., 2001a; Mallin et al., 2001; Gaffield et al., 2003). The pathogen Cryptosporidium, a protozoan parasite, can be found in surface waters, especially those containing high amounts of sewage contamination or animal waste (Atherholt et al., 1998). Giardia is another commonly identified pathogen in surface waters (Atherholt et al., 1998). Giardia is the intestinal parasite that causes the disease giardiasis.

Viruses in animal waste also pose a potential health threat to humans. Pathogenic, enteric viruses are the most significant virus group affecting water quality and human health (Griffin et al., 2003). Enteric viruses may be found in livestock excrement from barnyards, pastures, rangelands, feedlots, and uncontrolled manure storage areas, as well as in areas of land application of manure and sewage biosolids (EPA 2001a). When animal waste is applied to agricultural land for irrigation or fertilization purposes, enteric viruses can survive in soil for periods of weeks or even months (EPA 2001c). Enteric viruses in land-applied manure or sewage sludge can leach into groundwater and eventually be transported by overland flow into surface water bodies, thus creating a potential for the contamination of water resources.

Consumption of contaminated water or consumption of contaminated shellfish or finfish can lead to human health problems (Craun et al., 1997; Lipp and Rose 1997; Lees 2000; White et al., 2000; Lipp et al., 2001a). Shellfish beds are especially vulnerable to bacterial contamination, because they are often located in close proximity to shoreline development and human activities that are potential sources of bacterial pollution (Maiolo and Tschetter 1981; Pitman 1995; Macfarlane 1996; Pitt 1998; Mallin et al., 2000b; Leecaster and Weisberg 2001; Lipp et al., 2001; Mallin et al., 2001; PSAT 2002; Griffin et al., 2003).

Numerous studies have been conducted that show an increased health risk from exposure to water containing high levels of indicator bacteria (see Pruss 1998 for an excellent review). However, the results of these epidemiology studies of FIB and health risks are not always consistent and have provoked some controversy, leading to discussion of the appropriateness of current FIB as compared with other indicators such as enterococci or *E. coli* bacteria (Valiela et al., 1991; Ferguson et al., 1996; Elliot 1997; Schiff et al., 2001; Schiff et al., 2003; Noble et al., 2003a and b; Noble et al., 2004c and d). Although the relationship between FIB (such as FC) and the risk to public health may not be without some uncertainty, there is still cause for concern when any FIB level is above the normal ambient background level (Ferguson et al., 1996; Schiff et al., 2001; Turbow et al., 2004). Some of the inherent problems with current FIB include the following (NRC 2004):

- FIB levels may not reflect pathogen levels or risk of disease
- Natural populations of FIB can be found in soil and plants
- FIB survival times in water may be less than some pathogens
- Current FIB methods cannot distinguish between sources

- FIB is not a good indicator for the presence of biotoxins
- Indicators are not good models for viruses or protozoans.

For this project, FC was used as the FIB, based on current Washington State Department of Health (WA-DOH) and Ecology standards. Sinclair-Dyes Inlet and several contributing tributary streams are listed on the current section 303(d) list for high microbial contamination.

1.4 Designated Beneficial Uses

In accordance with Washington State WQS, Sinclair- Dyes Inlet has the following freshwater designated beneficial uses (WAC 173-201A-200):

- Aquatic Life Uses
- Recreational Uses
- Water Supply Uses.

In accordance with Washington State WQS, Sinclair-Dyes Inlet has the following marine water designated beneficial uses (WAC 173-201A-210):

- Aquatic Life Uses
- Recreational Uses
- Shellfish Harvest Uses.

Aquatic life uses specifically identify the protection of salmon and trout spawning, rearing, and migration habitat, as well as other associated aquatic life. The water-quality criteria that apply to aquatic life include temperature, dissolved oxygen (DO), turbidity, and pH.

With respect to bacterial pollution, Sinclair-Dyes Inlet is designated for primary contact recreation for both freshwater (WAC 173-201A-200) and marine water (WAC 173-201A-210) areas (Tables 1-1 and 1-2). In addition, marine waters in the Sinclair-Dyes Inlet watershed are subject to shellfish harvest bacterial criteria. The nearshore and marine waters of Sinclair and Dyes Inlet are also within the “usual and accustomed” fishing and shellfishing areas of the Suquamish Tribe. Tribal subsistence harvest and consumption of fish and shellfish is considered part of this beneficial use. Commercial and recreational shellfishing are also designated beneficial uses of these waters.

1.5 Water Quality Standards

The purpose of WAC 173-201A is to establish water quality standards for surface waters of the state of Washington consistent with public health and public enjoyment of the waters and the propagation and protection of fish, shellfish, and wildlife, pursuant to the provisions of RCW Chapter 90.48. Surface waters include lakes, rivers, ponds, streams, inland waters, saltwater, wetlands, and all other surface waters and watercourses within the jurisdiction of Washington State. All surface waters are protected by narrative criteria, designated beneficial uses, and an anti-degradation policy. Based on the use designations, numeric and narrative criteria are assigned to a water body to protect the designated uses.

WAC 173-201A describes the designated water uses and criteria for the state of Washington. These criteria were established based on existing and potential water uses of the surface waters of the state.

Table 1-1. Revised Washington State Department of Ecology Water Contact Recreation Bacteria Water Quality Criteria for Freshwater (WAC 173-201A-200)

Table 200 (2)(b) Water Contact Recreation Bacteria Criteria in Fresh Water	
Category	**Bacteria Indicator**
Extraordinary Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.
Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies /100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200 colonies /100 mL.
Secondary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 200 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 400 colonies /100 mL.

Table 1-2. Revised Washington State Department of Ecology Water Contact Recreation Bacteria Water Quality Criteria for Marine Waters (WAC 173-201A-200)

Table 210 (3)(b) Water Contact Recreation Bacteria Criteria in Marine Water	
Category	**Bacteria Indicator**
Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 14 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 41 colonies/100 mL.
Secondary Contact Recreation	Enterococci organism levels must not exceed a geometric mean value of 70 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 208 colonies/100 mL.

Consideration was also given to both the natural water-quality potential and its limitations. Compliance with surface WQS requires compliance with WAC 173-201A, *Water Quality Standards for Surface Waters of the State of Washington*, WAC 173-204, *Sediment Management Standards*, and other applicable federal regulations.

The Washington WQS are currently undergoing revision and approval by EPA. Because the revised WQS are expected to be approved in the near future, the revised standards are being used throughout this report for comparison purposes only. Under these WQS, both the marine waters and freshwater resources of Sinclair-Dyes Inlet are designated primary contact recreation (WAC 173-201A-200) with respect to bacterial contamination. All waters designated primary contact recreation must meet the following WQS for FC bacterial contamination indicator organisms (Tables 1-1 and 1-2):

A. Freshwater - Levels of FC shall 1) not exceed a geometric mean value of 100 fecal colonies / 100 mL, and 2) not have greater than 200 fecal colonies/100 mL in more than 10% of all samples used for calculating the geometric mean value

B. Marine water – Levels of FC shall 1) not exceed a geometric mean value of 14 colonies / 100 mL, and 2) not have greater than 43 fecal colonies / 100 mL in more than 10% of all samples used for calculating the geometric mean value.

1.6 Shellfish Harvesting Standards

In addition to the Ecology WQS, WA-DOH has its own bacterial water-quality criteria for marine-nearshore waters that are used for shellfish harvesting. The WA-DOH has adopted the guidelines set by the National Shellfish Sanitation Program (NSSP) water classification system (ISSC 1999). This system requires an adequate distribution of bacterial sampling stations and a minimum of 30 samples taken under a variety of environmental (season, weather, and tidal) conditions. WA-DOH classifies all commercial shellfish growing areas in Washington State as *Approved*, *Conditionally Approved*, *Restricted*, or *Prohibited*. These classifications have specific standards associated with them, which are derived from the NSSP (ISSC 1999). The following key NSSP shellfish *growing area standards* (GAS) are used as shellfish harvest criteria (WA-DOH 2003a):

A. The geometric mean shall not exceed 14 MPN / 100 mL (MPN is the most probable number FC method, using at least 30 samples)

B. The 90th percentile (calculated using the NSSP formula, using at least 30 samples) shall not exceed 43 MPN / 100 mL.

WA-DOH classifies a shellfish area as approved if both GAS criteria are met and no significant pollution sources (e.g., sewage treatment plant outfalls) are present. WA-DOH may classify a growing area as approved when pollution source evaluations and the bacteriological water quality data show that fecal material, pathogenic microorganisms, and poisonous or deleterious substances are not present in dangerous concentrations. An area may also be classified as approved when a sanitary survey shows that the area is not subject to contamination that presents an actual or potential public health hazard. An approved classification authorizes both public harvesting and commercial growing and harvesting of shellfish.

Even if the approved criteria are met for FC bacteria, WA-DOH may classify a growing area as conditionally approved, restricted, or prohibited (see definitions below) if pollution source investigations show that contamination may impact the sanitary condition of shellfish in the area. Because FC bacteria are not always good indicators of the presence of disease-causing viruses and other pathogens, WA-DOH depends on thorough evaluations of all potential pollution sources. In some cases, WA-DOH will temporarily close approved shellfish growing areas when events such as floods or biotoxin blooms occur.

An area may be classified as conditionally approved when it meets approved criteria, but only during predictable periods. For example, during dry weather, a growing area may meet approved water-quality standards, but after a certain size rainfall event, the water quality declines. In this example, the conditionally approved area is temporarily closed to harvest for a set period of time after a rainfall event. The length of closure is predetermined for each conditionally approved area, and is based on water-sample data that show the amount of time it takes for water quality to recover and again meet approved criteria. Once that time period has elapsed, the area is reopened for shellfish harvesting.

A restricted classification is used for areas that do not meet water-quality standards for an approved classification, but for which the sanitary survey indicates only a limited and unpredictable degree of pollution from non-human sources. Shellfish harvested from restricted growing areas cannot be marketed directly. They must be transplanted to an approved growing area for a specified amount of time, allowing shellfish to naturally cleanse themselves of contaminants before they are harvested. The cleansing period required is generally a few weeks to several months. Restricted classifications are only considered where levels of pollution are low and relay times are shown to purify the shellfish prior to marketing.

A shellfish growing area must be classified as prohibited when pollution is chronically excessive and unpredictable. A growing area is also classified as prohibited when the sanitary survey indicates that fecal material, pathogenic microorganisms, or poisonous or harmful substances may be present in concentrations that pose a health risk to shellfish consumers. Growing areas adjacent to wastewater treatment plant (WWTP) outfalls, marinas, and other persistent or unpredictable pollution sources may be classified as prohibited. Growing areas that have not undergone a sanitary survey are also typically classified as prohibited. Commercial shellfish harvests are not allowed from prohibited areas.

2.0 Background

Human development and land-use activities in the nearshore environment have the potential to significantly alter the aquatic ecosystems of estuaries and coastal marine areas. In addition, land-cover alterations and land-use activities in upland watersheds can significantly modify natural conditions within freshwater streams, lakes, and wetlands. These upland land-use activities can also impact estuaries and nearshore areas where the upland watersheds drain. Among the cumulative impacts of human activities on aquatic ecosystems are the following:

- NPS pollution
- industrial point-source discharges
- spills and leakage of petroleum hydrocarbons
- releases of toxic chemicals into the environment
- WWTP discharges
- combined sewer overflow (CSO) events
- physical modification of instream and nearshore habitat
- overharvest of freshwater and marine resources.

NPS pollution, unlike point-source pollution from industrial outfalls or sewage treatment plants, comes from many diffuse sources. NPS pollution includes the following:

- runoff from agricultural activities
- runoff from timber harvest operations and roads
- stormwater runoff from developed areas
- construction site runoff
- highway and road runoff.

NPS pollution is caused by storm runoff moving over and through the ground. As the runoff moves over the landscape, it picks up natural materials and anthropogenic pollutants, eventually depositing these compounds in lakes, rivers, wetlands, coastal waters, and ground water. The most common water pollutants include

- excess fertilizers (nutrients), herbicides, and insecticides from agricultural lands and residential areas
- oil, grease, and other hydrocarbons from vehicles and energy production
- toxic chemicals from industrial and commercial activities
- sediment from improperly managed construction sites, timber harvest, croplands, and eroding streambanks
- salt from irrigation practices and road or runway deicers
- acid drainage from poorly operated or abandoned mines
- bacteria and nutrients from livestock, pet wastes, sewage discharges, failing onsite septic systems, and faulty wastewater treatment systems

- litter, excessive organic matter (or biological oxygen demand), and floatable solids
- atmospheric deposition of pollutants from energy production and industrial operations.

According to the EPA, NPS pollution is the nation's largest remaining water-quality problem (EPA 2002). Everyone contributes to NPS pollution in some way, often without realizing it. NPS pollution results from a wide variety of human activities on the built landscape. The effects of NPS pollutants on specific waters vary and may not always be fully assessed. However, it is known that these pollutants can have negative effects on drinking water supplies, recreation, fisheries, and wildlife. NPS pollution can have a variety of impacts on the marine-nearshore environment (Figure 2-1), as well as on freshwater ecosystems. These impacts include the following:

- nutrient eutrophication and algal blooms
- high turbidity levels and fine sediment deposition
- low DO levels
- degradation of aquatic habitat
- food-web modification or disruption
- toxic effects on organisms.

This section of the report provides a general background on microbial pollution, including the main sources of microbial pollution, the common problems found throughout the United States, and a review of current literature applicable to the microbial pollution problem. Information specific to the study area is included in a later section of the report.

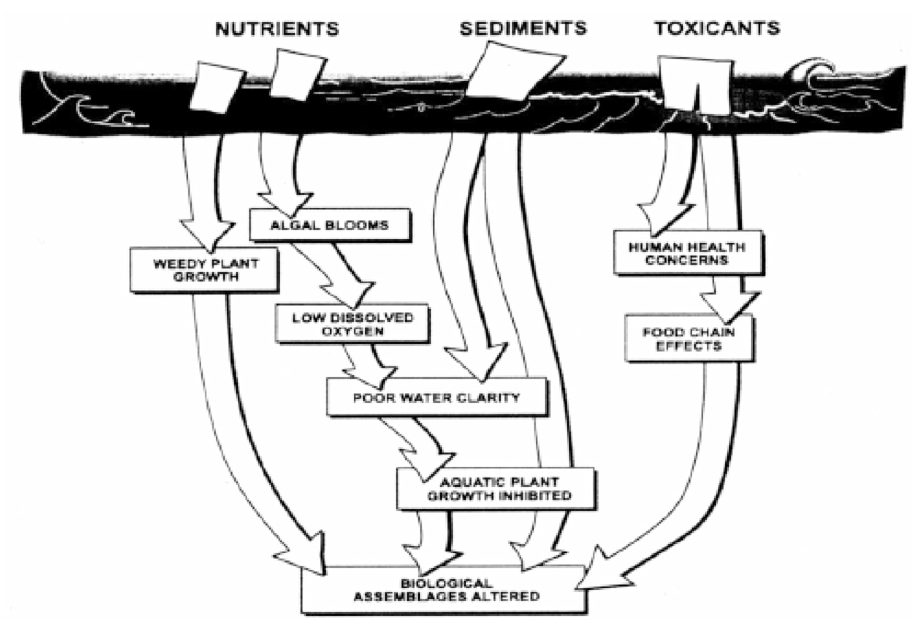


Figure 2-1. Effects of NPS Pollutants on Nearshore-Marine Aquatic Ecosystems (EPA 2001b)

2.1 Bacterial Pollution

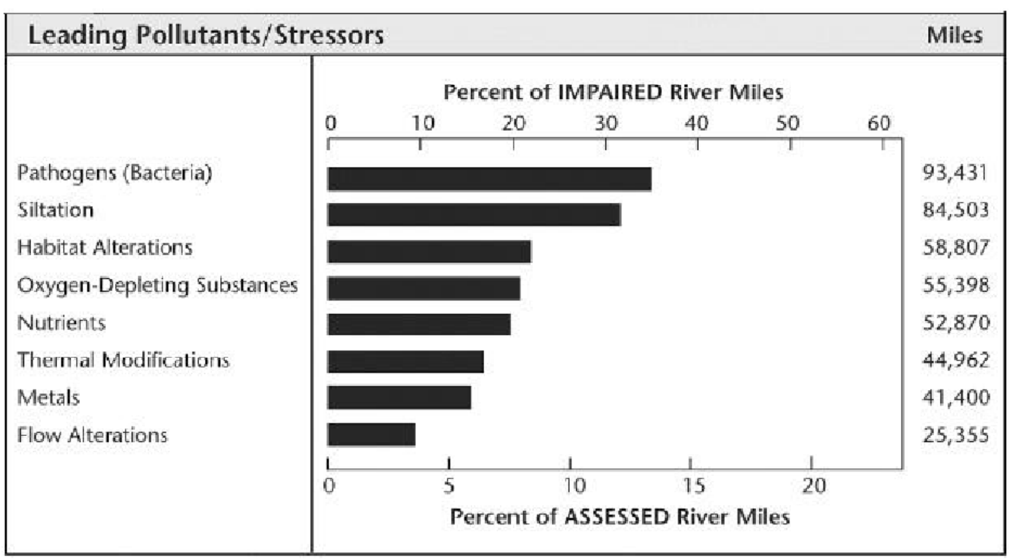
In terms of freshwater and nearshore-estuarine areas identified as impaired under CWA 303(d) listings, bacterial contamination has been identified as one of the most commonly violated WQS in the United States. Bacterial contamination ranks among the top causes of "non-attainment" for streams and estuaries, with nutrients and sediment also in the mix (Tables 2-1 and 2-2). Bacterial contamination is considered one of the single greatest obstacles to full compliance with the CWA "fishable and swimable" goals for both marine and freshwater areas (EPA 2002). A review of these bacteria-impaired waters reveals that these impairments are typically associated with the more developed marine shorelines and upland watersheds (EPA 2002). In addition to ecological impacts, FC bacterial contamination of nearshore areas has a direct economic impact to coastal and estuarine communities through the loss of shellfish revenues and the restrictions placed on recreational uses (NOAA 1992).

Table 2-1. Leading Sources of Water Quality Impairment in the United States (EPA 2002)

	Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Pollutants	Siltation (38%)[a]	Nutrients (44%)[a]	Pathogens (47%)[a]
	Pathogens (36%)	Metals (27%)	Organic enrichment (42%)
	Nutrients (28%)	Siltation (15%)	Metals (27%)
Sources[b]	Agriculture (59%)	Agriculture (31%)	Municipal point sources (28%)
	Hydromodification (20%)	Hydromodification (15%)	Urban runoff/storm sewers (28%)
	Urban runoff/storm sewers (12%)	Urban runoff/storm sewers (12%)	Atmospheric deposition (23%)

[a]Values in parentheses represent the percentage of surveyed river miles, lake acres, or estuary square miles that are classified as impaired.
[b]Excluding unknown, natural, and "other" sources.

Table 2-2. U.S. Environmental Protection Agency Leading Pollutant-Stressors in Streams and Rivers of the United States (EPA 2002)



Source: U.S. EPA 305(b) 2000 Report, released September 2002.

Watershed-wide NPS pollution can be a significant source of bacterial contamination (Jagals et al., 1995; Wyer et al., 1997; Embry 2001; Pennington et al., 2001; EPA 2002; Fiandrino et al., 2003). Bacterial contamination in a typical watershed can come from a variety of sources, both natural and anthropogenic. Figure 2-2 illustrates a conceptual model of bacterial contamination for watersheds that ultimately drain to marine waters.

As human population and development within the nearshore area and in adjacent watersheds has increased, there has generally been an increase in the number and extent of beach and water body closures for fishing, contact recreation, and shellfish harvest (EPA 2002). As of 1991, shellfish harvesting was prohibited, restricted, or conditional in over 40% of all historical shellfish beds in the United States as a result of high bacteria levels (NOAA 1992). This trend is common to numerous coastal areas such as the North Carolina coast (NOAA 1992), major estuaries such as the Chesapeake Bay (McConnell 1995), and to Puget Sound (PSAT 2002). The latest data from Washington State show that almost half of the monitored shellfish beds in Puget Sound are showing a worsening trend for bacterial contamination (PSAT 2002). A U.S. Geological Survey (USGS) study in the Puget Sound also linked human-related NPS bacterial pollution sources to microbial water quality in freshwater streams (Embry 2001).

Due to the popularity of shorelines, development of coastal watersheds is common throughout the country. The following are potential human-related sources of bacterial contamination:

- onsite septic systems
- sanitary sewer leakage
- CSO events
- WWTP discharges
- agricultural and livestock runoff
- stormwater runoff from developed areas
- marinas and shipyard facilities.

According to current research, the levels of FC characteristic of specific sources are as follows (Pitt 1998; CWP 1999; Pitt et al., 2004):

- sewage system leakage: ~106 to 107 CFU / 100 mL
- failing septic systems: ~104 to 106 CFU / 100 mL
- stormwater runoff: ~103 to 104 CFU / 100 mL
- wildlife and natural sources: ~101 to 126 CFU / 100 mL

In addition to the human population and land-use activities, these developed areas usually include high population densities of many animal species that also harbor indicator pathogens (Bohn and Buckhouse 1985). Included in these animal populations are livestock (horses, cows, sheep, goats), pets (dogs and cats), and domestic fowl (chickens, ducks, and geese), as well as waterfowl and wildlife that have adapted to the built environment. So-called “urban wildlife” can be considered anthropogenically influenced based on their adaptation to the developed environment (Prange et al., 2003) and the increasingly smaller habitat area available to them within the built environment (e.g., raccoons, geese, pigeons, seagulls, opossum, mice, and rats).

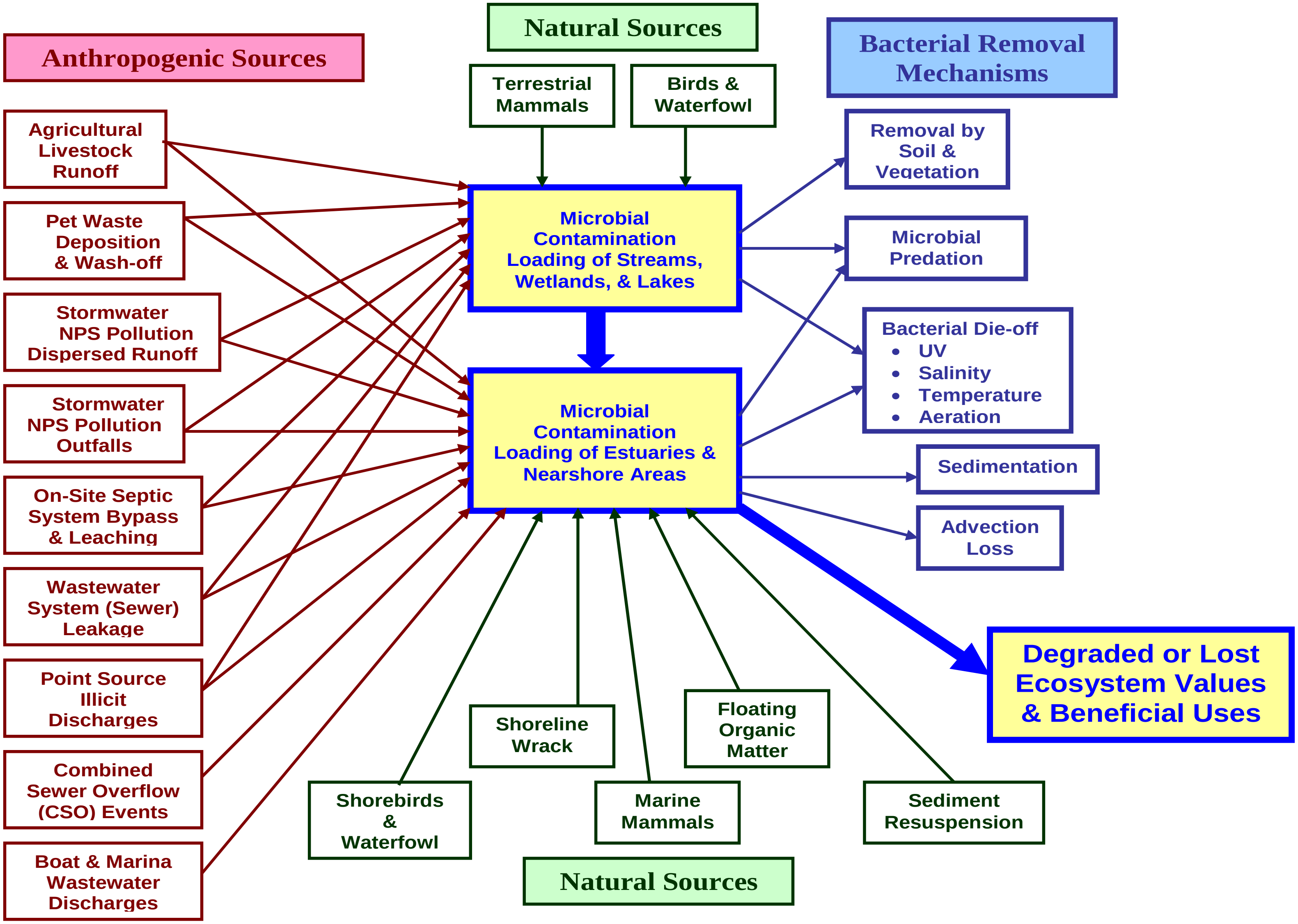


Figure 2-2. Sinclair-Dyes Inlet Watershed Microbial Contamination Conceptual Model

Bacteria source tracking (BST) studies conducted to date indicate all of these categories can be significant within urbanizing coastal watersheds, depending on the land-use and land-cover (LULC) patterns found (Mallin et al., 2000a). Recent studies indicate that levels of FC contamination in nearshore areas is strongly correlated with human population, the level of watershed development, and the quantity of impervious surfaces within a watershed area (Bannerman et al., 1993; Weiskel et al., 1996; Wyer et al., 1997; Lee and Glover 1998; CWP 1999; Young and Thackston 1999; Mallin et al., 2000a; Eisele et al., 2001; Dwight et al., 2002; Fiandrino et al., 2003). Bacterial population levels are generally lower in marine, estuarine, and nearshore waters because of a number of factors that contribute to bacterial "die-off" in these areas (Burkhardt et al., 2000). These environmental factors include salinity, sunlight, and natural populations of bacterial predators (Serrano et al., 1998). Bacterial populations can survive and grow in marine waters if turbidity and sedimentation are high and organic material is present on the beach (Serrano et al., 1998).

The natural tidal fluctuations of an embayment or nearshore area can also influence bacterial pollution. A study in North Carolina found that the level of FC bacterial contamination was highest at or near low tide and lowest during high tides (Mallin et al., 1999). This study also confirmed a general inverse relationship between FC levels and salinity, and a direct correlation of FC bacteria and turbidity (Mallin et al., 1999). Overall turbidity was also inversely correlated with both tidal height and salinity. The researchers concluded that the abundance of FC bacteria in tidally influenced areas was due to a number of factors, including the proximity of freshwater FC sources draining into the nearshore, the natural die-off associated with higher salinity levels, and the natural affinity of FC bacteria for sediment particles (Mallin et al., 1999).

Tidal resuspension of FC in sediment was also a significant factor in some areas (Roper and Marshall 1979). All of these factors supported the findings of higher FC levels at low tide, including the import of polluted water from upland areas and the stirring of nearshore sediment by tidal action (Mallin et al., 1999). Several recent studies have examined the potential of nearshore sediment as reservoirs for FC bacteria (Ferguson et al., 2003; Feng et al., 2004; Ferguson 2004; Gruber 2004; Hartel et al., 2005). Although these studies found aquatic sediment could be a major source of FC bacteria, they all concluded that the level of understanding of these sediment source areas is rudimentary at best. Most of these studies also concluded that a continuous influx of FC bacteria is likely needed to create a significant bacterial contamination problem, as die-off and predation tend to reduce bacterial levels over time if not resupplied (Ferguson et al., 2003; Feng et al., 2004; Hartel et al., 2005). Similar results have been found for freshwater sediment (Burton et al., 1987) and for sediments found in stormwater collection and conveyance systems (Marino and Gannon 1991; Butler et al., 1995; Ellis and Yu 1995).

2.2 Natural Sources

Natural, or background, sources include marine and terrestrial mammals, as well as shorebirds and waterfowl (Gould and Fletcher 1978; Alderisio and DeLuca 1999; Levesque et al., 2000). For example, the FC levels found in seagull droppings range from 2 to 6 million cfu/gm (Gould and Fletcher 1978; Benton et al., 1983; Valiela et al., 1991; Alderisio and DeLuca 1999; Levesque et al., 2000). Other natural sources include sediment resuspension, elution from shoreline deposits of decaying vegetation (often called "wrack"), and floating organic matter (Weiskel et al., 1996). Although the annual loading of bacteria into coastal and estuarine waters from waterfowl and other wildlife can be locally significant, the effects are generally mitigated by the often seasonal nature of these inputs, their wide distribution across the surface area of marine waters, natural die-off and predation effects, and the limited dispersal from deposited fecal pellets (Weiskel et al., 1996).

Natural die-off of FC occurs mostly from exposure to sunlight (Fujioka et al., 1981; Davies and Evison 1991; Auer and Niehaus 1993), but water temperature, salinity, pH, nutrient deficiency, natural predation, particulate levels, osmotic stress, and DO levels also play a part (Hanes and Fragala 1967; Mancini 1978; McCambridge and McMeekin 1981; Valiela et al., 1991; Auer and Niehaus 1993; Davies-Colley et al., 1994; Howell et al., 1996; Barcina et al., 1997; Burkhardt et al., 2000; Wait and Sobsey 2001). In the most recent study of bacterial inactivation, lower temperatures and more exposure to sunlight had the most significant effect on bacterial concentrations (Noble et al., 2004b).

Natural microbial predation is also a loss factor in both freshwater and marine environments (Kapuscinski and Mitchell 1980; McCambridge and McMeekin 1981; Iriberri et al., 1994; Barcina et al., 1997). Bacteria also have strong affinity for sediment and organic particulates, which leads to sedimentation being a significant loss factor, especially in estuarine waters. In general, natural estuarine and nearshore habitat can provide excellent mitigation of FC bacterial pollution (Burkhardt et al., 2000).

Because of the natural affinity of bacteria for soil particles and especially organic matter (plants and vegetative material), marine, nearshore, estuarine, lake, and stream sediments can also be a source of bacterial contamination (Van Donsel and Geldreich 1971; Gerba and McLeod 1976; Hood and Ness 1982; LaLiberte and Grimes 1982; WDOE 1985; Struck 1988; Burton et al., 1987; Valiela et al., 1991; Shere et al., 1992; Davies et al., 1995; Crabill et al., 1999; An et al., 2002; Ferguson et al., 2003; Feng et al., 2004; Ferguson 2004; Gruber 2004; Hartel et al., 2005). Studies show that nearshore bacterial contamination is often highly correlated with water-column turbidity and nutrient concentration, as well as being inversely correlated with salinity (Haile et al., 1967; Roper and Marshall 1979; LaBelle 1980; Ferguson et al., 1996; Burkhardt et al., 2000; Mallin et al., 2000b). In addition, the natural release of FC bacteria during the resuspension of nutrient-rich, subtidal sediment has been found to be a minor source of FC contamination, as is the loading from shoreline wrack (Weiskel et al., 1996). However, under certain conditions, nearshore sediment-related bacterial pollution could cause high FC problems. FC in marine sediments can grow in-situ from natural stocks or they may be the result of accumulation from a variety of external sources over long periods of time (Gerba and McLeod 1976; Struck 1988; Valiela et al., 1991). Nutrient-rich fine sediment in subtidal areas that are not penetrated by sunlight are the most likely bacteria sources. In this type of environment, natural bacteria die-off is low and growth of FC populations can be high. In addition, sediment attachment may allow bacteria to escape predation and provides good habitat for population growth (Gerba and McLeod 1976; Roper and Marshall 1979; LaBelle 1980; Barcina et al., 1997).

In a study of a coastal embayment on the east coast, FC levels in nearshore sediment were found to be an order of magnitude greater than the levels found in the water column or in beach wrack (Valiela et al., 1991). In the same study, resuspension of marine sediments caused FC levels to exceed shellfishing WQS on several occasions (Valiela et al., 1991). In addition, FC levels in shellfish were found to be highly correlated with sediment FC levels, but not correlated to FC levels in the water column (Valiela et al., 1991). On-going, unpublished studies on both the east and west coasts have also found evidence that nearshore sediment can be an important source of bacteria even after external sources have been eliminated (Ferguson et al., 2003; Feng et al., 2004; Ferguson 2004; Gruber 2004; Hartel et al., 2005).

Resuspension of FC in nearshore sediment can occur due to a number of disturbances, both natural and anthropogenic. Tidal currents, wave action, and storms can all cause sediment resuspension and subsequent FC release. Boating activity (An et al., 2002) or dredging could also cause significant sediment resuspension (Grimes 1975). In freshwater streams, storm-event high flows can also cause sediment resuspension and FC release (Crabill et al., 1999).

A study in the Puget Sound region found that FC levels in freshwater sediment were typically several orders of magnitude greater than those found in the water column at the same sampling stations

(Struck 1988). This research showed that FC bacteria can become acclimated to freshwater stream-sediment environments and in some cases, can reproduce at a rate greater than the natural die-off (Struck 1988). Sediment samples from the study stream averaged over 100,000 FC per 100 mL (Struck 1988). This stream drained to a shellfish production area that was closed because of high bacterial contamination. Water and sediment samples in the marine waters (Burley Lagoon located within both Pierce County and Kitsap County, Washington) had lower FC levels than the stream (Burley Creek) as a result of the natural die-off mechanisms discussed above (Struck 1988). During storm events, stormwater runoff resulted in high instream flows, which caused sediment resuspension in the creek. This high level of runoff resulted in elevated FC levels in water samples in the creek and the estuary (WDOE 1985). This study concluded that FC populations in the sediment were generally not self-sustaining. Without the near-constant input of FC bacteria from livestock waste and failing septic systems, or the deposition of nutrient-rich fine sediment from runoff, FC levels generally remained low. This observation was verified by sampling a similar natural stream system in the same area (Struck 1988).

2.3 Boats and Marinas

Untreated boat sewage can be a problem when discharged into surface waters. Although the quantity of fecal material discharged by recreational boaters is typically much less than that from WWTP discharges or CSO events, sewage from boats is often more concentrated than that from either CSO or WWTP, because marine heads use little water for flushing and the sewage in marine heads is not diluted by water from bathing, dishwashing, or rain. Boat sewage may contain pathogens (bacteria and viruses), which can cause human health problems directly through contact in the water or indirectly through the consumption of contaminated seafood (EPA 2001b).

Several studies have shown that pet waste and overboard sewage discharge can be sources for bacterial pollution (Chmura and Ross 1978; Cardwell and Koons 1981; Fisher et al., 1987; McMahon 1989; NCDEM 1990; NCDEM 1991; McAllister et al., 1996; Kelsey et al., 2003). Some violations of health standards for FC bacteria have been related to periods of high-intensity recreational use, such as holiday weekends. These violations can be attributed to boater discharges and the stirring up of sediment in which pathogens are concentrated (Chmura and Ross 1978; Cardwell and Koons 1981; Fisher et al., 1987; McMahon 1989; McAllister et al., 1996). Studies conducted in Puget Sound, Long Island Sound, Narragansett Bay, North Carolina, and Chesapeake Bay have shown that boats can be a source of FC bacteria in areas with high boat densities and poor flushing (EPA 2001b). Human health problems can result, especially if nearby waters are used for swimming, surfing, wind surfing, water skiing, or other recreational activities that involve significant water contact.

Bacterial and viral contamination of waters can also result from improper use of marine sanitation devices (MSD). If a vessel has an installed toilet, the laws in most states require that it be equipped with an MSD. Incorrect configuration of the toilet and MSD can lead to direct discharge of waste to surface waters. Intentional discharge of the contents of portable toilets to surface waters also results in contamination of marine waters. Boats with portable toilets are not required to have an MSD, and their contents should be disposed of at a marina sanitation facility.

A number of states currently have designated nearly all of their surface waters as no discharge zones (EPA 2001b), and as a result, much progress has been made toward implementing measures that reduce contaminant loading, such as eliminating discharges of sanitary waste from boats, installation of pump-out stations in marinas, and a growing number of boater education programs. Consequently, boaters and marinas are usually not considered primary sources of pathogen contamination in surface waters in most areas (EPA 2001b). Marinas can, however, still be a significant source of bacterial contamination, especially if clean marina regulations, best management practices (BMPs), and monitoring are not in place (McLellan and Salmore 2003). The EPA Clean Marina Program provides guidance for marina BMPs (EPA 1996).

Additional sources of pollutants that might be generated at a marina and enter a marina basin include sediment (from parking lot runoff and shoreline erosion), fish waste (from dockside fish cleaning), petroleum hydrocarbons (from fuel and oil drippings and spills and from solvents), toxic metals (from antifouling paints and hull and boat maintenance debris), and liquid and solid wastes (from engine and hull maintenance and general marina activities).

Although a potential contributor to water-quality degradation, marinas are not typically reported as a major source of NPS pollutants, as are agriculture and urban source areas, though the location of marinas in the nearshore zone can lead to their being affected by other pollutant sources. Pollutants from upstream point sources and NPS contaminants in a watershed might flow into a marina area, adding to any pollutants released at the marina itself. Water quality in a marina, therefore, is often a reflection of not only pollutants generated at the marina but also a cumulative load of pollutants from several other sources.

The construction of a marina can also create a condition of reduced water circulation. Installing structures such as bulkheads and jetties, which are often necessary to ensure the safety of vessels, docks, and shoreline structures, can reduce water circulation in the basin. In an area already protected from wave action, such as a cove or inlet, marinas can potentially introduce pollutants to an area with limited natural circulation or water exchange. Over time, reduced circulation and increased pollutant generation can increase pollutant concentrations in the water column, sediment, and aquatic organisms in these nearshore areas (EPA 2001b).

2.4 Agricultural Sources

Animal waste or manure includes the fecal and urinary wastes of livestock and poultry; process water (such as from a milking parlor); and the feed, bedding, litter, and soil with which the waste products become intermixed. This waste matter can become entrained in runoff following storm events (Aitken 2003). When such runoff enters surface waters, excess nutrients and organic materials are deposited in receiving water bodies. Increased nutrient levels can cause excessive growth of aquatic plants and algae. The decomposition of aquatic plants can deplete the oxygen supply in the water, creating anoxic or anaerobic conditions, which can lead to fish kills. Amines and sulfides are also produced in anaerobic waters, causing the water to acquire an unpleasant odor, taste, and appearance. These polluted waters can become unsuitable for drinking, fishing, and other recreational uses. In addition to nutrients, diseases can be transmitted to humans through contact with animal feces, which contains bacteria and other microbes, some of which may be pathogenic (Pell 1997). Runoff from fields receiving manure, feedlots, or pasture areas typically can contain extremely high numbers of microorganisms (Thelin and Gifford 1983). Shellfishing and beach closures can result from high FC counts from agricultural runoff. Although not the only source of pathogens, farm animal waste has been responsible for both shellfish contamination in some coastal waters and fish kills in freshwater lakes, streams, and rivers (EPA 2001c).

Several studies have documented the high levels of bacterial pollution that are commonly found in agricultural runoff (Doran et al., 1981; Crane et al., 1983; Kress and Gifford 1984; Baxter-Potter and Gilliland 1988; Niemi and Niemi 1991; Edwards et al., 1997; Fraser et al., 1998; Edwards et al., 2000). In general, the level of FC in agricultural-dominated watersheds can be significantly higher than in natural, undeveloped watersheds. These levels of FC contamination often can result in violations of WQS and impairment of beneficial uses (Niemi and Niemi 1991; Fraser et al., 1998; Edwards et al., 1997; Edwards et al., 2000).

The cumulative impact of agricultural runoff and bacterial pollution on receiving waters is also well-documented (Kunkle 1970; Edwards et al., 1983; Moore et al., 1988; Howell et al., 1995; Aitken 2003). In Minnesota, turbidity and FC levels were consistently higher in areas where grazing was allowed within the riparian corridor of streams than in areas where livestock was excluded and riparian buffers were established (Sovell et al., 2000). Direct application of manure to fields as a fertilizer is a common farming practice that can lead to bacterial pollution problems. The method, timing, and rate of manure application are significant factors in determining the likelihood that water-quality contamination will result. Manure is generally more likely to be transported in runoff when applied to the soil surface than when incorporated into the soil. In Illinois, studies have demonstrated the impacts of animal waste on water quality, including fish kills associated with a hog facility, a cattle feeding operation, and surface application of liquid waste to farm fields (Ackerman and Taylor 1995). Correll and others (1995) summarized the effect of livestock and pastureland management on the water quality of streams in the Chesapeake Bay watershed. A study of Herrings Marsh Run in the coastal plain of North Carolina showed that nutrient and FC levels in stream and ground water were highest in areas with the greatest concentration of swine and poultry production (Hunt et al., 1995). Runoff from feedlots has long been associated with severe stream pollution. Feedlots or areas that are devoid of vegetation and subjected to concentrated animal activity generate runoff containing large amounts of bacteria, which may cause violations of WQS (Baxter-Potter and Gilliland 1988).

In general, livestock wastes contain large numbers of bacteria and other microorganisms (EPA 2003). Although many of these organisms tend to die rapidly outside the animal, some can survive under favorable conditions. Microorganisms can survive for ex-tended periods in fecal deposits on pasture, in soils, and in aquatic sediments (Thelin and Gifford 1983; Kress and Gifford 1984; Sherer et al., 1992; Aitken 2003). Conditions that promote die-off of microorganisms after land application include low soil moisture, low pH, high temperatures, direct solar radiation, and predation by protozoa found naturally in the soil. Proper manure storage generally promotes die-off as well, although pathogens can remain dormant at certain temperatures. Composting the wastes can be quite effective in decreasing the number of bacteria (EPA 2003).

2.5 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems (OWTS) are designed to the remove settleable solids, floatable material, nutrients, and pathogens from residential and commercial wastewater discharges. These systems play an extremely important role in protecting human health and environmental resources in most rural and suburban watersheds (Huang 1983).

A conventional onsite system consists primarily of a septic tank and a soil absorption field, also known as a subsurface wastewater infiltration system, or drain field (Figure 2-3). Septic tanks (single or multi-chamber sedimentation vaults) remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter. Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption areas via a perforated piping network for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils. Treated effluent that is not drawn into plant roots, incorporated into microbial soil biomass, or evaporated ultimately reaches ground waters and possibly nearby surface waters (Wilhelm et al., 1994).

Conventional systems work well if they are installed in areas with appropriate soils and hydraulic capacities; designed to treat the incoming waste load to meet public health, ground water, and surface water performance standards; installed properly; and maintained to ensure long-term performance.

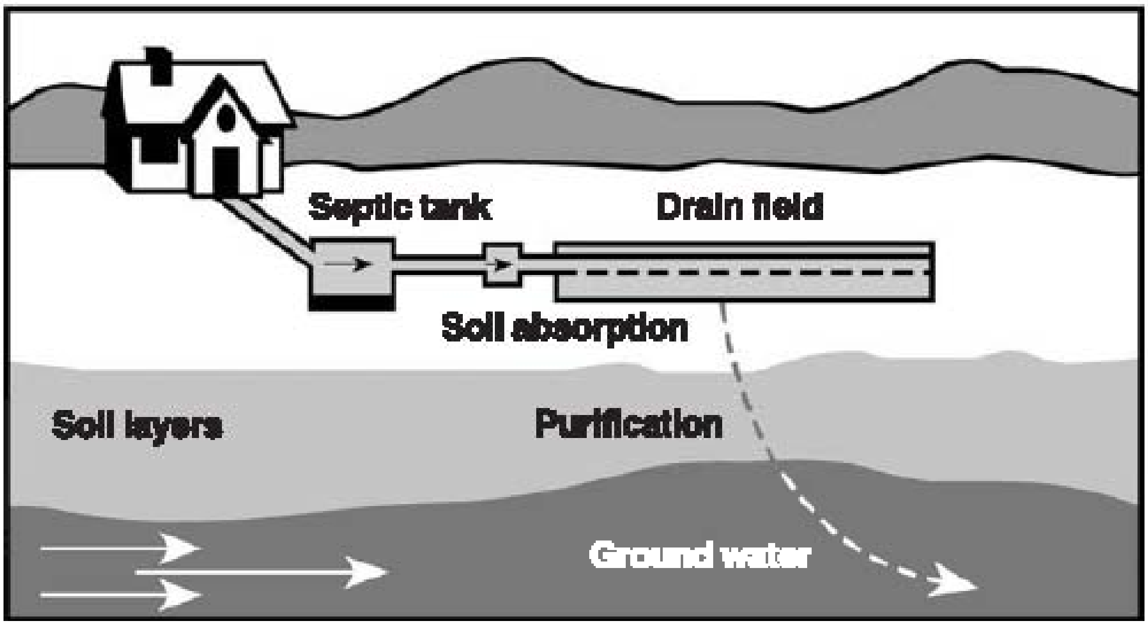


Figure 2-3. Conventional Onsite Wastewater Treatment System Design (EPA 2002)

Pollutants of concern from OWTS include pathogens, nitrogen compounds (e.g., nitrates), phosphorus, biochemical oxygen demand (BOD), and other chemicals disposed of via the residential and commercial wastewater system.

As was discussed above, when properly planned, designed, installed, operated, and maintained, OWTS can effectively remove or treat contaminants such as pathogens, BOD, and nutrients in human sewage. However, OWTS can fail because of age, inappropriate design, hydraulic over-capacity, pollutant overloading, or poor maintenance (Table 2-3). Detrimental impacts from onsite systems can occur when they are sited in sensitive ecological areas (such as wellhead protection zones, near nitrogen/phosphorus limited waters, or near beaches or shellfish habitat) or when they are installed at densities that exceed the hydraulic and hydrologic assimilative capacities of regional soils and aquifers. In some cases, OWTS densities in some areas exceed the capacity of even suitable soils to assimilate wastewater flows and retain and transform their contaminants (Bicki and Brown 1991). In addition, some systems are located too close to groundwater or surface waters. In some areas, conventional OWTS installations might not be adequate for minimizing nitrate contamination of ground water, removing phosphorus compounds, and attenuating pathogenic organisms (e.g., bacteria, viruses). Nitrates that leach into ground water used as a drinking water source can cause public health problems. Nitrates and phosphorus discharged into surface waters directly or through subsurface flows can cause algal blooms and lead to eutrophication and low dissolved oxygen in lakes, rivers, and coastal areas. In addition, pathogens reaching ground water or surface waters can cause human disease through direct consumption, recreational contact, or ingestion of contaminated shellfish. Sewage might also affect public health as it backs up into residences or commercial establishments because of OWTS failure (CWP 1998).

Over the years, a wide range of alternative technologies designed to address increasing hydraulic loads and water contamination by nutrients and pathogens have been developed. These technologies can achieve significant pollutant removal rates. With proper management oversight, alternative systems (e.g., recirculating sand filters, peat-based systems, package aeration units, or so-called mound systems) can be installed in areas where soils, bedrock, fluctuating groundwater levels, or lot sizes limit the use of conventional systems.

Table 2-3. Common Causes for Onsite Wastewater Treatment System Failure (EPA 2002)

Type of failure	Contributing causes
Hydraulic	Excessive hydraulic loadings to undersized systems, low soil permeability, excessive ponding at the infiltrative surface, poor maintenance. Increases in water usage over a period of years can exceed the design capacity of the wastewater treatment system.
Organic	Excessive organic loading from unpumped or sludge-filled tanks results in biomat loss of permeability.
Soil depth to ground water table or bedrock	Insufficient soil depths (i.e., soil thickness between the subsurface wastewater infiltration system [SWIS] and ground water tables, impermeable strata, or bedrock is less than the recommended depth for soil texture and structure). High ground water is deleterious to pathogen removal and hydraulic performance.
System age	Systems more than 25 to 30 years old. Systems less than 25 to 30 years old experience considerably fewer hydraulic failures. Failure rates can more than triple for older systems. Regular tank pumping and use of alternating SWISs can prolong system life indefinitely.
Design failure	Inappropriate system design for the site; failure to adequately consider or characterize wastewater strength and flow (average daily and/or peak flows); failure to identify and consider restrictive soil/rock layers (e.g., fragipan) or regional geology (e.g., karst features, creviced bedrock); failure to assess landscape position.
System density	Cumulative effluent load from all systems in watershed or ground water recharge area exceeds the hydrologic capacity of the area to accept and/or properly treat effluent.

Alternative technologies typically are applied as a *treatment-train* beyond the septic tank. Alternative treatment technologies often provide environments (e.g., sand, peat, and artificial media) that promote additional biological treatment and remove pollutants through filtration, absorption, and adsorption. All of the alternative treatment technologies in current use generally require more intensive management and monitoring than conventional OWTS units because of mechanical components (e.g., pumps and flow-control systems), and additional excavation or structures might be required to house some treatment system components, including the disinfection devices (e.g., chlorinators or ultraviolet lamps). In some situations, a community or cluster system can be an efficient and effective means of collecting and treating septic tank effluent from clusters of individual sources (CWP 1998).

According to the EPA (2002), approximately 25% of homes in the United States are served by OWTS. Estimates of onsite system failure rates range from 5% to 35% and higher depending on ambient soil conditions and other environmental factors (EPA 2002), resulting in contamination of drinking water, beaches, shellfish beds, and surface water resources. Failing septic systems were reported as a contributing source of pollution for more than one-third (36%) of the impaired miles of ocean shoreline surveyed (NOAA 1995). NOAA reported in 1995 that the discharge of partially treated sewage from malfunctioning septic systems was identified as a principal or contributing factor in 32% of all shellfish harvest-limited growing areas (NOAA 1995).

2.6 Wastewater Treatment Plants

Every WWTP operates under an approved permit, which specifies permissible concentrations of FC allowed in the effluent. Treatment technologies make use of physical, chemical, and biological processes to remove constituents from wastewater. As with most waste management efforts, the most desirable approach is to eliminate the production of waste in the first place. This is often termed *source control*. Although the complete elimination of sewage is not possible in a populated area, there are several approaches that can reduce the discharge of some constituents and decrease the overall volume of water discharged (reclamation and re-use). Industrial waste pretreatment, wastewater recycling, and water conservation measures are examples of such efforts.

No single wastewater technology or BMP will resolve all wastewater problems. An effective system of tailored BMPs and WWTP technologies must be developed for each area. Experience has demonstrated that to be successful, this approach must also include an aggressive pollution-prevention, source-control component (NRC 1993). WWTP technology has evolved over the years, such that the components of modern wastewater treatment is categorized as *primary*, *secondary* and *tertiary* treatment (Metcalf and Eddy 1972).

Primary treatment involves the removal of floatables and suspended solids. This removal typically includes screening, grit removal, and settling of suspended solids from wastewater. Gravity is the main mechanism of removal in the primary treatment process. Chemical flocculants can be added to enhance the settling of solids from wastewater. Metals, organics, and BOD are also reduced during primary treatment, as these pollutants tend to be attached to solids (NRC 1993). Significant improvements in primary treatment have occurred over the years. These technological advances are often referred to as the optimization of primary stage treatment (Metcalf and Eddy 1972).

Secondary treatment makes use of both physical (settling) and biological (microbial decomposition) processes to treat wastewater. This treatment is designed to remove suspended solids and BOD. Activated sludge treatment is the most commonly used biological process in secondary treatment. This first stage of this process includes aeration and microbial decomposition of organic matter. The second stage involves settling of sludge and continued microbial activity. The sludge or biosolids remaining after secondary treatment must be disposed of at an approved site (Metcalf and Eddy 1972). Secondary-treated wastewater is often high in nutrients, which can cause eutrophication problems in the receiving waters (NRC 1993). There have also been significant innovations and improvements in biological treatment processes based on experience in WWTP operation.

Tertiary or *advanced* treatment uses a wide variety of chemical, physical, and biological processes that focus on the removal of nutrients from the wastewater. The wastewater is treated using an approved disinfectant method (chlorination, ozonation, or ultraviolet) and discharged through a diffuser into a receiving water body. If chlorination is used, wastewater will need to be dechlorinated prior to discharge into receiving waters. The sludge created by the secondary and tertiary treatment processes is also treated using anaerobic digestion (microbial activity) and must also be dewatered prior to disposal or approved use as a fertilizer component (NRC 1993).

The disinfection of wastewater does significantly reduce the level of bacteria or pathogens in WWTP effluent; however, it does not inactivate them completely (NRC 1993). The effectiveness of the disinfection method depends on a number of factors, including the concentration of the disinfection agent, the contact time, and the characteristics of the wastewater.

Treated wastewater is typically discharged into the designated receiving water through a diffuser system that creates a mixing zone, where the discharge is diluted and dispersed by natural currents.

2.7 Combined Sewer Overflow Events

Many older cities have combined stormwater and wastewater collection and conveyance systems. Combined sewer systems are sewers that are designed to collect stormwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. Figures 2-4 through 2-6 illustrate typical CSO configurations and typical CSO events.

In most cases, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearshore areas, streams, rivers, or lakes. In the Puget Sound region, most CSO discharges are into marine waters. This is true of all CSO outfalls in the Sinclair-Dyes Inlet watershed (Figure 2-7).

Combined sewer overflow (CSO) events can be a significant, although intermittent and “pulsed” (rainfall-event driven), source of bacterial pollution and contributor to water-quality problems in coastal waters (NRC 1993). In isolated cases, CSO events have also been linked to actual pathogens in receiving waters (Gibson et al., 1998). In addition to bacterial pollution, CSO events can contribute nutrients, fine sediment, litter, and toxic pollutants to receiving waters. Pollution from CSO events can have a negative impact on the water quality and ecological integrity of receiving waters (NRC 1993; Weyand 1996; Borchardt and Sperling 1997; Hall et al., 1998; Leeming et al., 1998; Welker et al., 1999; Kelsey et al., 2003).

Reducing pollutant loads from urban runoff and CSO events is often significantly more challenging and potentially more costly than treating municipal sewage at a WWTP (NRC 1993). CSO events tend to be intermittent, pulsed events, and the CSO pollutant load can be quite variable. The combination and concentration of pollutants in a CSO event is dependent on the storm conditions (antecedent dry period [ADP], rainfall intensity, and rainfall quantity) and the drainage basin characteristics (road density, stormwater collection and conveyance network, and land use). Assessments of the impacts of CSO events on aquatic ecosystems and human health should take into account the variable and intermittent nature of these pollution inputs. High FC levels are frequently found in receiving waters during CSO events, often for a substantial period of time after the CSO event (Novotny 2003). Methods for reducing and treating CSO events include source-control measures, sewer system flow optimization, enhanced WWTP capacity, satellite CSO treatment, and sewer system separation (NRC 1993).

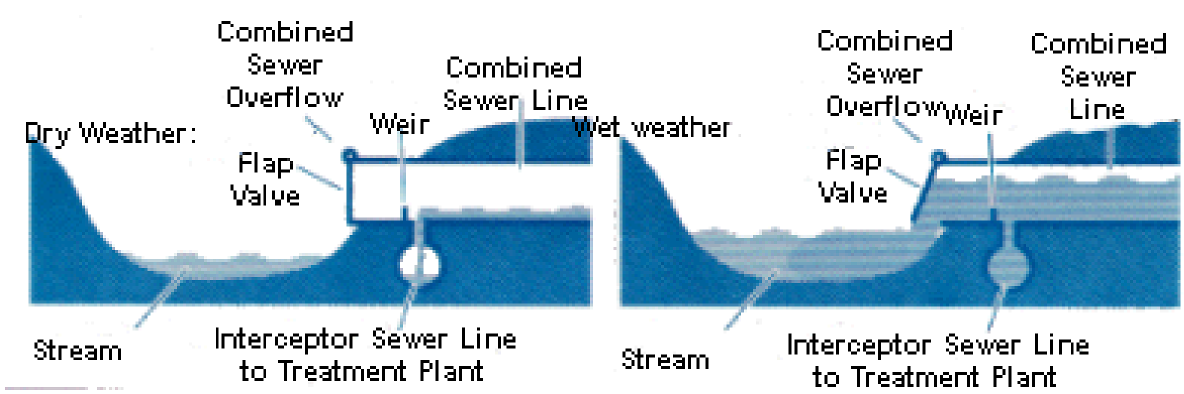


Figure 2-4. Generalized Combined Sewer Overflow Diagram (EPA 2002)

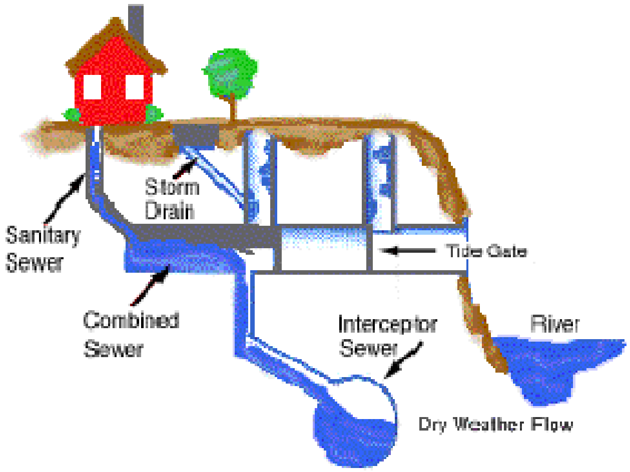


Figure 2-5. Generalized Combined Sewer System during Dry Weather (EPA 2002)

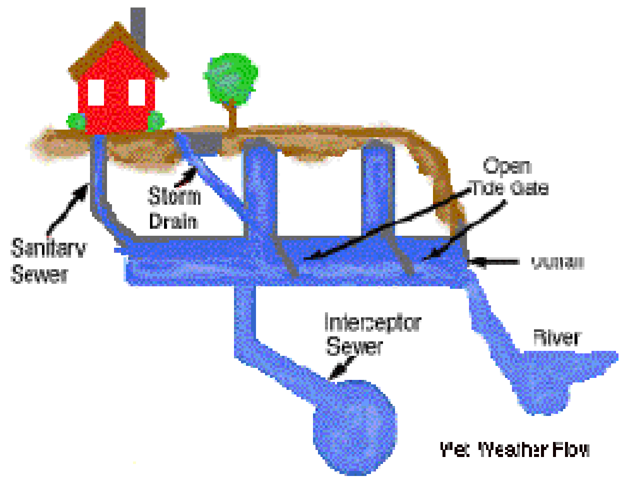


Figure 2-6. Generalized Combined Sewer System during Wet Weather (EPA 2002)

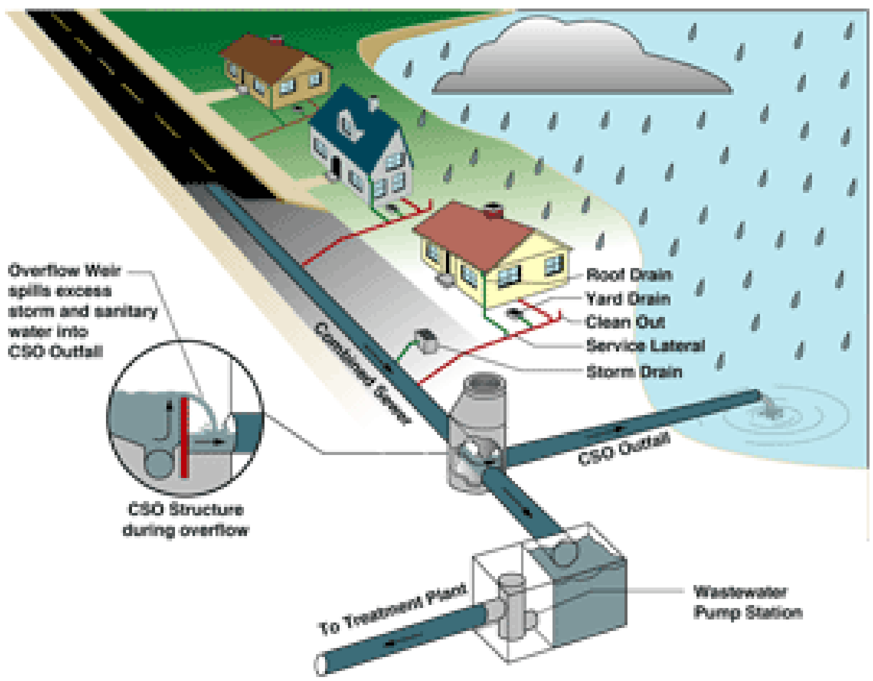


Figure 2-7. Combined Sewer System during Wet Weather, Showing Hypothetical Overflow Event (COB 2003)

2.8 Stormwater

Stormwater, although not technically a source of bacterial contamination, can be a major transport mechanism, especially in more urbanized watersheds. As discussed, the sources of bacterial contamination in urbanizing watersheds are numerous and widespread. In many cases, impervious areas such as roads, driveways, sidewalks, and lawns act as source areas, collecting and concentrating NPS pollutants during dry weather. Rainstorms tend to wash these pollutants, including fecal material, into the stormwater drainage system and from there on into the natural drainage network and ultimately into receiving waters. Anthropogenic sources found in the built-environment include CSO event overflows, stormwater outfalls, illicit sewage-stormwater connections, boat or marina wastewater discharges, sewage conveyance spills, WWTP outfalls, domestic animal and pet waste, stormwater runoff, and failing septic systems (NRC 1993; Gaffield et al., 2003; Novotny 2003; O'Keefe et al., 2005).

Elevated FC levels are typically found in developing watersheds that contain a mixture of land-use and human activities (CWP 1999). In most cases, there is no single source of bacterial pollution to target, but rather a collection of several sources all contributing to the overall problem. A typical watershed may contain rural-agricultural areas where livestock and manure management may be a primary source of FC contamination. The same watershed could also include suburban residential development where failing septic (OWTS) systems and pet waste may be major bacterial sources. This same watershed may also contain urban-residential and commercial-industrial land uses, which may have CSO- and stormwater-related sources, as well as illicit discharges or accidental WWTP discharges. Stormwater treatment facilities, such as detention ponds or vaults, can also be a source of microbial pollution (CWP 1999).

The most extreme bacteria (FC) concentrations found in receiving waters typically are associated with inappropriate human sewage discharges, such as failing septic systems, sanitary sewer overflows or leaks, CSO events, and illicit connections to the storm drainage network (Davis et al., 1995). In these rare and serious situations, FC levels can be several orders of magnitude above WQS (Pitt 1998). In general, human sources of sewage should be suspected when FC levels are consistently between 10^3 and 10^6 (Pitt 1998). Typically, however, FC levels in freshwater streams and drainage channels are relatively low. Exceptions include the situations identified previously in which human sewage sources are present during stormwater runoff events or "wet-weather" flows (CWP 1999; Kelsey et al., 2003; Schiff et al., 2003).

The National Stormwater Quality Database (NSQD) includes data from across the country (Pitt et al., 2004). Figures 2-8 and 2-9 illustrate the current stormwater FC levels documented in the NSQD. The NSQD data indicate that FC levels in stormwater can vary from under 1,000 cfu/100 mL to over 1,000,000 cfu/100 mL, depending on the land-use characteristics of the contributing watershed (Pitt et al., 2004). Stormwater FC levels are also highly variable, with concentrations varying by as much as five orders of magnitude at individual sites (Pitt et al., 2004). This variability is influenced by drainage-basin conditions, land-use characteristics, rainfall intensity, FC sources present, and drainage-system characteristics (Burton and Pitt 2002). Illustrating the importance of source-area LULC characteristics, the NSQD reported average FC levels (cfu/100 mL) of 7500 for residential areas, 4500 for commercial areas, and 2500 for industrial areas (Pitt et al., 2004).

As discussed, septic systems can be a significant source of bacterial contamination in nearshore or streamside areas where development is present (Duda and Cromartie 1982; Pitt 1998; Young and Thackston 1999). If designed, operated, and maintained properly, most OWTS are not a significant problem. Due to attenuation and filtering during subsurface transport, very little FC bacterial contamination usually reaches receiving waters from these widely dispersed sources (Duda and Cromartie 1982). The exceptions are when septic systems have failed, are improperly designed or installed, or are located in areas where septic system density has overwhelmed the assimilative capacity of the native soils (Bicki and Brown 1991). In many cases, urbanizing areas can have a mixture of areas that are serviced by sanitary sewers and areas that are still on OWTS. In these situations, there could be leaks in sewer lines, accidental sewage overflows, and failing OWTS all contributing to bacterial contamination of receiving waters. These types of problems can result in violations of bacterial WQS during dry and/or wet weather conditions.

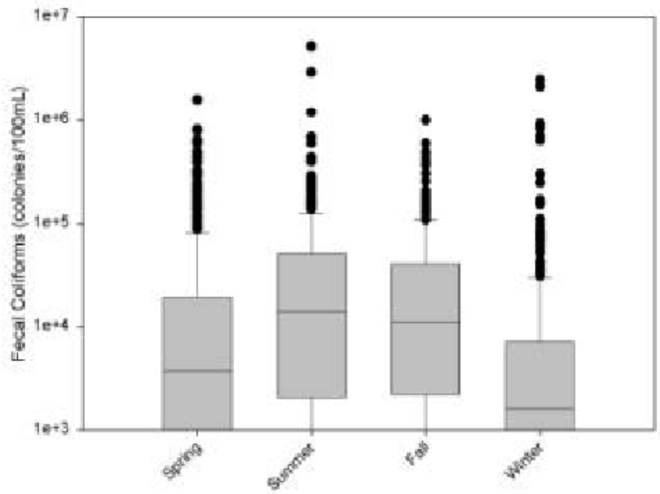


Figure 2-8. Data from the National Stormwater Quality Database for Fecal Coliform (Pitt et al., 2004)

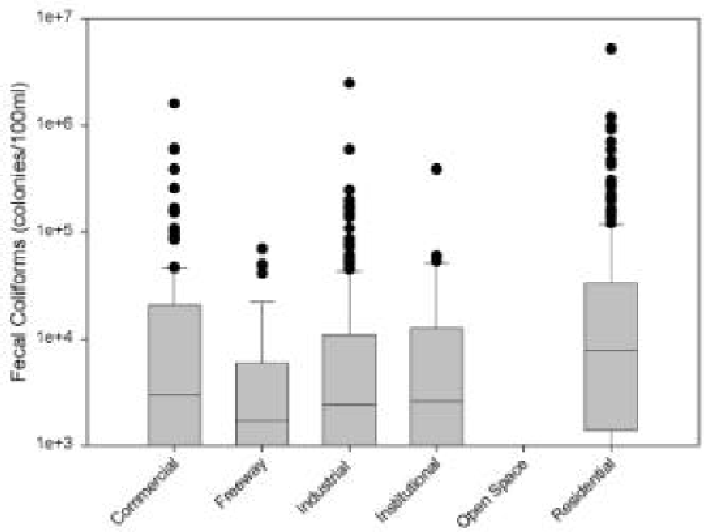


Figure 2-9. Data from the National Stormwater Quality Database for Fecal Coliform (Pitt et al., 2004)

Illicit connections are defined as "illegal and/or improper connections to storm drainage systems and receiving waters" (EPA 2002). A discharge of industrial or sanitary wastewater to a storm sewer is "illicit" because discharges of that type would ordinarily require a National Pollutant Discharge Elimination System (NPDES) permit. Identification of illicit and improper connections is necessary for all sanitary and storm sewer systems, especially in areas where pollutants with unknown sources have been detected in receiving waters. The level and type of human activities and the surrounding land uses will affect the methods used to identify illicit connections. Illicit discharge detection and elimination programs are designed to prevent contamination of surface- and groundwater supplies by monitoring, inspection, and removal of these non-stormwater discharges, which are illegal. An illicit discharge detection program can be an effective method to reduce the quantity of pollutants related to industrial and commercial activities that enter the storm drain system.

Another potentially significant source of FC bacteria is rural-agricultural runoff containing livestock wastes, particularly in developing areas where farming or livestock production is still a major land use. "Hobby farms" located in rural residential areas can also be potential sources of bacterial contamination from livestock waste runoff (Crane et al., 1983; Samadapour and Checkowitz 1998; Francy et al., 2000).

Pet waste can also contribute to higher levels of bacterial pollution, especially in more densely populated suburban and urban areas where large numbers of cats and dogs are present. Pet owners have several options for properly managing pet waste. Collecting the waste and flushing it down the toilet, where it can be treated by a WWTP or OWTS, is the preferred method. Small quantities can also be buried in vegetated areas, where the waste can decompose slowly. When buried, the waste should be at least 5 inches below the ground surface and away from waterbodies and vegetable gardens. In public areas, the waste can be sealed in a plastic bag and thrown in the trash, which is legal in most parts of the country (EPA 2002).

Many communities implement pet waste management programs by posting signs in parks or other areas frequented by pet owners, sending mailings, and making public service announcements. Many communities have "pooper scooper" ordinances that govern pet waste cleanup. Some of these laws specifically require anyone who takes an animal off his or her property to carry a bag, shovel, or scoop. Any waste left by the animal must be cleaned up immediately. In addition to postings, many communities have also installed "pet waste stations" in popular dog parks. These stations contain waste receptacles, as well as a supply of waste collection bags, scoops, and shovels.

Microbial contamination in stormwater is mainly associated with the particulate fraction of the polluted runoff (Borst and Selvakumar 2003). High FC levels are relatively common in sediment of polluted streams and from stormwater drain inlets and piping systems (Marino and Gannon 1991). In addition, sediment from stormwater ponds (Pitt 1998) and from roadside gutters (Bannerman et al., 1993) can also be a source of FC contamination. Studies using genetic analysis have shown that up to 95% of the FC found in stormwater runoff is from nonhuman sources, mostly dogs and livestock (Lim and Oliveri 1982; Trial 1993; van der Wel 1995; Alderiso et al., 1996; Samadapour and Checkowitz 1998). For example, dog feces may contain upwards of 20 million FC bacteria per gram (van der Wel 1995).

In urbanized and urbanizing watersheds, stormwater runoff or NPS pollution can be a significant transport mechanism for bacterial contamination sources in upland watersheds (CWP 1999; Mallin et al., 2000b; Stein and Tiefenthaler 2004). This contaminated surface runoff can flow directly into estuaries or nearshore waters from developed shoreline areas via storm drain outfalls or as overland flow. In addition, FC bacteria contamination and other NPS pollution can indirectly enter the nearshore via streams that drain developed upland watersheds.

Microbes are almost always present in stormwater, but are highly variable in concentration depending on watershed conditions (Gaffield et al., 2003). Recent studies have shown that stormwater runoff from impervious surfaces (e.g., roads and parking lots) and from stormwater drainage networks (drain inlets, stormwater piping, and outfalls) are the most significant sources of FC contamination in urbanizing watersheds and nearshore drainages (Geldreich et al., 1968; Olivieri et al., 1977; Weiskel et al., 1996; Moorhead et al., 1998; Young and Thackston 1999; Mallin et al., 2000b; Schiff and Kinney 2001; Frenzel and Couvillion 2002; Tuford and Marshall 2002; Borst and Selvakumar 2003; Olyphant et al., 2003; O'Keefe et al., 2005).

Bacterial contamination will generally settle from the water column during low-flow periods and settle into sediment. There, they can persist for weeks or even months if the sediment is moist and rich in organic material (Burton et al., 1987). As a result, sediment resuspension from streams and ditches that drain urbanizing watersheds can be significant sources of FC bacterial contamination to the nearshore environment (Burton et al., 1987; Struck 1988; Gaffield et al., 2003).

The transport pathway of FC contamination in developed watersheds is generally very similar. When fecal material is deposited on or near an impervious surface, such as a road or driveway, the fecal contamination and other NPS pollutants (e.g., litter, sediment, nutrients, metals, and organics) are provided with a means of concentration and rapid conveyance to downstream water bodies. During “dry” periods, fecal material accumulates on impervious areas, with little decline in FC density for up to 30 days and possibly longer, depending on ambient conditions (Weiskel et al., 1996). When storm events occur, these pollutants (mostly in particulate form) are washed off the impervious surfaces and transported downstream with stormwater runoff (Borst and Selvakumar 2003).

The stormwater conveyance network may be in the form of roadside ditches or vegetated swales in rural watersheds. In suburban and urban watersheds, the stormwater conveyance system is typically much more “efficient,” including curbs and gutters, drain inlets or catch basins, and a storm-drain piping network that routes runoff directly to streams, rivers, and lakes, as well as into nearshore marine waters. Therefore, it is not just the intensity or level of development that is important to downstream pollutant loading, but the type of land-use activity, the location of that development, the amount of impervious surface area, and the type of stormwater infrastructure present (White et al., 2000). Compounding this complex situation, bacterial levels do not always correlate well with adjacent land uses, making management especially difficult (CWP 1999).

In Buzzards Bay, Massachusetts, it was found that bacterial yields from impervious areas served by stormwater drainage-piping networks were two to three orders of magnitude greater than those from areas of rural or low-intensity residential land use that were served by “unimproved” (grassy swales and vegetated ditches) stormwater conveyance systems (Weiskel et al., 1996). Similar results were found in a study of urbanized Ballona Creek in Los Angeles, California (Stein and Tiefenthaler 2004). Portions of the creek located downstream of stormwater drain inputs had consistently higher concentrations of bacterial pollution.

A Wisconsin study (Bannerman et al., 1993) found that residential lawns, driveways, sidewalks, and streets were the major source areas for bacterial contamination. In the Wisconsin study, as with others, the source of this suburban bacterial contamination was mostly nonhuman (i.e., domestic dogs, cats, and livestock).

Except in cases in which inappropriate human sewage discharge (e.g., broken sewer lines, illicit connections) is present in an urbanized watershed or where failing septic systems are present, most of the bacteria present in stormwater runoff is generally from nonhuman sources (CWP 1999). Recent national evaluations of stormwater bacterial contamination reported that mean FC concentrations in stormwater were generally between 1,000 and 20,000 colonies per 100 mL, with extremely high variability at individual sample sites and between sample sites (Pitt 1998; CWP 1999; EPA 2002). This high variability is a characteristic of bacterial contamination in stormwater runoff.

It has also been shown that FC bacteria counts can be higher in urbanized watersheds that are served by sanitary sewers than in non-sewered (septic) basins (Young and Thackston 1999; Frenzel and Couvillion 2002; Tuford and Marshall 2002). This could be due to failing sewer infrastructure or improperly operating sewer systems. In most cases, areas served by sanitary sewers also have engineered stormwater collection and conveyance systems consisting of curb and gutter streets, drain inlet stormwater collection sumps, and piped conveyance networks. In these situations, FC densities are typically related to human population level, the density of development, and the percentage of total impervious area (TIA), as well as the pet, domestic animal, and urban wildlife populations (CWP 1999). As discussed, this fecal material deposited on and near impervious surfaces, such as roads and driveways, as well as on residential lawns and park areas, is transported by stormwater runoff into natural streams and stormwater systems. From there, it is transported downstream to estuaries or nearshore waters.

Compounding the problems of higher bacteria loadings associated with higher human and animal populations, the level of imperviousness in urban stream and nearshore ecosystems tends to inhibit soil infiltration and vegetative filtration of stormwater runoff, limits natural bacteria predation, and reduces natural mechanisms of bacteria die-off. For example, a storm drain system that has replaced a stream channel in an urbanized watershed is an anthropogenic factor that inhibits die-off by blocking exposure to solar radiation. In addition, storm drains, with their characteristic moist, dark environments and buffered, narrow temperature ranges, do not support natural bacterial die-off, and often harbor their own specially adapted microbial communities that adhere to surfaces or grow in sediment within drain inlets, culverts, or stormwater piping (Waye 2002). In addition, stormwater piping networks generally preclude infiltration and filtration of stormwater runoff (CWP 1999). Typically, more urbanized and older developed watersheds may contain several miles of underground storm drains and piping networks in each square mile of drainage area. Therefore, the potential impacts of the stormwater infrastructure must be considered. If the conveyance route includes vegetated drainage swales, vegetated filter strips, or wetland areas, the level of bacterial contamination can be significantly reduced (Weiskel et al., 1996; Young and Thackston 1999; Mallin et al., 2000b). In addition, if the runoff can be infiltrated and allowed to flow through the shallow groundwater layer prior to reaching downstream receiving waters (much as septic systems are designed to do), the level of FC contamination can typically be reduced even further (Weiskel et al., 1996; CWP 1999; Young and Thackston 1999; Mallin et al., 2000b).

In undeveloped, natural watersheds, bacteria source loadings are generally lower than they are in urbanized watersheds, typically by one or more orders of magnitude. Natural stream systems also tend to have a balance of predator-prey microbial communities that tend to keep bacterial levels low (Waye 2002). In natural microbial communities, heterotrophic nanoflagellates, paramecia, rotifers, and other larger microbial bacterivores, prey on FC and other bacteria to help keep their populations in check (Waye 2002). In urbanized stream systems, the microbial community may be out of balance, as bacteria may be considerably more adaptable to urbanized conditions than to their natural predators (Waye 2002).

The physical characteristics of the receiving water body also play a role in the existing bacterial contamination conditions. Shallow embayments that do not flush well because of natural or manmade configurations tend to be more susceptible to higher levels of FC than well-flushed areas (Young and Thackston 1999; Mallin et al., 2000a; Mallin et al., 2001; Ackerman and Weisberg 2003; Bay et al., 2003; Schiff et al., 2003; Holland et al., 2004). Therefore, local conditions, tidal characteristics, and weather (e.g., prevailing winds and precipitation patterns) also play a role in determining watershed conditions.

2.9 Coastal Development, Microbial Pollution, and Shellfish Harvest

As discussed earlier, estuaries and nearshore areas support numerous beneficial uses, most of which are strongly dependent on high water quality. Tribal, commercial, and recreational shellfish harvesting is probably the most dependent on clean water, but contact recreation (swimming and boating) is also very water-quality dependent.

Studies relating coastal development and shellfish contamination have been conducted in many parts of the country using a variety of research designs and techniques over the past two decades. Much of this work has occurred along the east coast, although a fair amount of research has been done on the west coast as well. This body of research indicates that there is a tenuous balance between human development and utilization of coastal areas and the health of nearshore ecosystems. The Puget Sound

Action Team (PSAT) recently completed a comprehensive literature review of bacterial pollution in urbanizing coastal areas and the impacts on shellfish harvesting (Glasoe and Christy 2004). This section summarizes the findings of the PSAT review along with additional scientific literature.

Recent studies have linked nearshore bacterial contamination to upland landscape changes (Simmons et al., 1995; Mallin et al., 2001; Ackerman and Weisberg 2003; Bay et al., 2003; Holland et al., 2004). Maiolo and Tschetter (1981) evaluated the relationship between urbanization, population growth, bacterial contamination, and shellfish closures over a 27-year period in coastal North Carolina. The researchers correlated population increases with shellfish closures and reduced shellfish harvest. The findings of this report attributed the impacts mainly to growth that had outpaced sewage management capacity. Maiolo and Tschetter (1981) also used the results of their study to forecast shellfish closures and economic losses that could be expected with continued population increases.

Duda and Cromartie (1982) assessed coastal North Carolina watersheds during the same period and also documented sharp increases in residential development and corresponding shellfish closures. The analysis correlated bacterial levels with septic-system densities and identified stormwater runoff from impervious surfaces as a contributing factor in the urbanized watersheds. They found that many septic systems were installed in unsuitable soils that often were subsequently ditched and drained to overcome the limitations of the site (Duda and Cromartie 1982). In most cases, these modifications only exacerbated the pollution problem as the drainfields became more hydraulically connected with the tidal creeks. As a result, septic-system densities as low as one system per seven acres resulted in shellfish closures (Duda and Cromartie 1982). Recommendations for remedying the situation focused on better sewage management, as well as revegetation, restoration, and protection of the natural drainage system. Crane and Moore (1986) in a similar study developed a management strategy to reduce bacterial pollution in shellfish growing areas.

Mallin and others (2000a, 2001) also examined the effects of development on some of these same tidal creeks in North Carolina between the years 1984 and 1997. The period of research followed the completion of major sewage treatment projects in the early 1980s and allowed for more focused evaluation of NPS pollution impacts. On a regional scale, the researchers found correlations between increases in population and increases in shellfish bed closures. Watershed-scale analysis of five tidal creeks correlated bacterial levels with population, more strongly with percentage of developed land, and even more strongly with percentage of TIA. Watersheds with less than 10% TIA had generally good water quality and large areas open to shellfish harvesting. Watersheds with greater than 10% TIA had water quality that was impaired by high bacterial levels in most segments of the tidal creeks. Watersheds with greater than 20% TIA had waters that were severely polluted with all areas closed to shellfish harvesting (Mallin et al., 2000b). The researchers also evaluated the effects of rainfall on water quality in coastal plain streams and found correlations between rainfall events with FC counts and turbidity, but not in watersheds with extensive wetland cover. The findings underscore the combined importance of reducing impervious cover, as well as retaining native forest cover and natural drainage features in mitigating microbial contamination of coastal waters.

Research in Jumping Run Creek watershed in North Carolina underscores the importance of natural hydrologic function (White et al., 1998). Population increases in this 800-acre coastal watershed coincided with shellfish closures in the adjoining waters, but the bacterial loadings did not correlate with common landscape indicators, such as developed area and impervious surfaces. Instead, the researchers found a relationship between the contamination levels and extensive ditching, bulkhead construction, and channeling across the watershed. Because of the hydrologic modifications, runoff that once took days or weeks to pass through the native wetlands now moved in greater volumes and reached the shellfish beds in hours, allowing little time for natural reduction and die-off of the microorganisms. Evidence pointed to pet and wildlife wastes and possible subsurface flows from septic drain fields as the main pollution sources (White et al., 1998, 2000).

In coastal South Carolina, scientists have employed a variety of techniques to monitor and contrast land uses and ecosystem responses in highly urbanized Murrells Inlet versus relatively undeveloped North Inlet (Vernberg 1997; Scott et al., 1999; Kelsey et al., 2003). Among other differential impacts, 67% of the sampling stations in Murrells Inlet did not meet the shellfish harvest standard compared with 33% in North Inlet, and Murrells Inlet also had a higher occurrence of *E. coli* bacteria, fewer coliform-negative stations, and fewer bacterial species comprising the coliform group—findings that reflect the influence of urbanization and associated higher densities of septic systems and other urban activities (Scott et al., 1999). Subsequent analysis of the Murrells Inlet watershed by Kelsey et al. (2003, 2004) correlated bacterial densities with proximity to urban areas, proximity to septic tanks, and rainfall events.

In Florida, researchers have documented widespread and chronic microbial contamination and directly associated those impacts with costal development (Griffin et al., 1999; Lipp et al., 2001a, b; Marchman 2000). In Apalachicola Bay, Marchman (2000) identified extensive NPS pollution in the lower Apalachicola River watershed and correlated bacterial loadings in the bay with rainfall events, river flows, and urbanization. The analysis also identified impervious surfaces, deteriorating infrastructures, lack of natural land cover, inadequate pollution source controls, and inappropriate land-use practices as contributing factors. In Charlotte Harbor, researchers studied the spatial and seasonal distribution of FC bacteria and enteric pathogens and documented higher concentrations of bacterial pollution in areas of low salinity and high septic-system densities (Lipp et al., 2001b). This researcher also associated fecal indicators with rainfall, streamflow, turbidity, and water temperature. Studies of Sarasota Bay also established a relationship between septic-system densities and bacterial levels, and determined that subsurface flow was a primary transport mechanism for the contaminants into nearshore areas (Lipp et al., 2001a). These studies reveal a high level of pollution in tidally influenced streams and canals of southwest Florida, and highlight the importance of physical factors, such as tides, surface runoff, and streamflow, in the distribution of human pathogens in coastal areas.

A regional survey of microbiological water quality along the shoreline of the Southern California Bight from just north of Santa Barbara south to Ensenada, Mexico, found that most areas met WQS, but the poorest water quality was associated with urbanized shorelines containing multiple stormwater outfalls (Noble et al., 2000). A follow-on study of these urban shoreline areas found that 60% of the shoreline areas tested failed microbial WQS after storm events that produced runoff, compared with only a 6% failure rate during dry weather conditions. Areas immediately adjacent to stormwater outfalls had a 90% failure rate after storm events (Noble et al., 2004a). In another related study, it was found that larger storm events were generally associated with larger runoff volumes in urbanized areas, and these larger storm events also tended to result in higher bacterial concentrations and more violations of WQS in shoreline receiving waters (Ackerman and Weisberg 2004).

A retrospective evaluation of shoreline water quality in Southern California (Santa Monica Bay), conducted by the Southern California Coastal Water Research Project (SCCWRP), found that most of the water-quality exceedances occurred near urbanized areas with stormwater outfalls, even though these areas represented only a small portion of the total area of shoreline (Schiff et al., 2003). In addition, the study found that the number of violations of WQS during infrequent Southern California storm events was about the same order of magnitude as dry weather exceedances. This observation indicates that wet-weather stormwater runoff is as much a problem as dry-weather sources, such as failing OWTS or municipal WWTP. The study concluded that nearshore bacterial pollution problems were most common during the dry season in poorly flushed embayments and in urbanized areas with multiple stormwater outfalls or sewage outfalls. During the wet season, bacterial pollution problems were found to be more widespread, and were especially acute during major storm events (Schiff et al., 2003).

These southern California studies are mainly concerned with swimming beach closures, but the health concerns are similar to those of shellfish harvesting beaches. The results of these studies indicate that beaches adjacent to urbanized areas are, in general, more at risk for bacterial contamination. In addition, storm events are major forcing-functions for nearshore WQS violations. In most cases, the high FC bacteria levels found on southern California beaches were associated with runoff from storm events. These periods of high FC bacteria levels were generally short in duration, and in most cases, would not have been detected by routine, periodic sampling. These results are common to several studies in the southern California region (Leecaster and Weisberg 2001; Schiff and Kinney 2001; Boehm et al., 2002; Boehm et al., 2003; Schiff et al., 2003; Gruber et al., 2005).

Coastal development and microbial contamination have also been studied in the New England states, but with a more pointed emphasis on the remediation of stormwater impacts. An assessment of bacterial pollution sources, loadings, and pathways in the Buttermilk Bay watershed in southeastern Massachusetts determined that waterfowl and surface runoff from storm drains and urban streams accounted for most of the bacterial loading into Buttermilk Bay (at 67% and 24% respectively), with lesser inputs attributed to beach wrack (decaying shoreline vegetation), sediment resuspension, and subsurface flow from local sewage treatment systems (Weiskel et al., 1996). Although they also found that waterfowl loadings were substantial, related effects appeared to be mitigated by seasonality, spatial distribution across the bay, and other factors. In contrast, surface runoff carrying feces from domestic pets and wildlife had a disproportionately high impact on nearshore bacterial levels (Weiskel et al., 1996). Bacterial loadings were also correlated with urban land uses, as bacterial yields from impervious surfaces served by storm drains were 300 to 8000 times higher than those from areas of low-intensity land use drained by streams or vegetated drainage channels (Weiskel et al., 1996). Among other conclusions, the researchers recommended that direct stormwater discharges to coastal waters should be prevented and, where feasible, infiltrated to capitalize on the natural capacity of native soils and vegetation to filter and adsorb pollutants (Weiskel et al., 1996).

In the Cape Cod region of Massachusetts, rapid coastal development was found to be a major cause for shellfish closures that were attributed primarily to bacterial contamination from stormwater runoff, onsite sewage systems, and animal feces (Macfarlane 1996). In the Town of Orleans, resource managers identified stormwater discharges as the main problem and retrofitted the town's five largest drainages with stormwater treatment devices to reduce bacterial loadings to the shellfish beds. The treatment systems achieved substantial reductions in bacterial concentrations, and the shellfish beds were subsequently reopened to harvest (Bingham et al., 1996). Similar efforts in other coastal areas of New England to treat runoff using a variety of stormwater BMPs have achieved mixed results, but have generally proven effective in helping to reduce bacterial loads when properly designed, installed, and maintained (Bingham et al., 1996; Macfarlane 1996; Weiskel et al., 1996).

A TMDL study in Little Harbor, Cohasset, Massachusetts, found that stormwater, failing or substandard septic systems, and illegal discharge of boat sewage were the primary sources of bacterial contamination to nearshore waters (M-DEP 2002). This report recommended improvements in septic system operation and maintenance, correction of failed wastewater treatment systems (sewer and septic), enhanced stormwater treatment (state-of-the-art BMPs, street cleaning, and regular catch basin cleanouts), and an increased emphasis on proper marina and boat sewage disposal as the primary TMDL implementation methods.

Another TMDL study in Greenwich Bay, Rhode Island, found that stormwater runoff from urbanized upland and shoreline areas was the primary cause of shellfish closures (RI-DEM 2004). This study characterized LULC characteristics in the contributing watersheds of Greenwich Bay and identified over

150 stormwater outfalls along the shoreline of the bay and tributary streams. The study found that almost all WQS violations occurred during wet weather or stormwater runoff conditions (RI-DEM 2004).

In addition, recent studies of California's coastal waters have highlighted significant microbial contamination problems associated with the state's intense coastal development (Leecaster and Weisberg 2001; Dwight et al., 2002; Ackerman and Weisberg 2003; Bay et al., 2003; Rasmus and Weldon 2003; Schiff et al., 2003). Studies have documented widespread and chronic coastal contamination in southern California that correlated strongly with river flows and stormwater discharges. Further north and more specific to shellfish, Pitman (1995) evaluated the impact of two marine sewage outfalls on shellfish beds located midway between the coastal California communities of Goleta and Santa Barbara, and concluded that the treated discharges from the two outfalls did not adversely affect the shellfish growing areas. In contrast, surface runoff and creek discharges from the coastal area between the two outfalls did correlate with high bacterial levels in the shellfish growing area. The studies documented bacterial levels in the tens of thousands per 100 mL during storm events, and concluded that the mass emission of bacteria from creeks during one rainy day exceed the year-long mass emission from two disinfected discharges (Pitman 1995).

Preliminary results of an ongoing study in the Puget Sound indicate that there is a relationship between landscape-level changes in upland watersheds and the decline in water quality in coastal waters (Alberti and Bidwell 2004). In this Puget Sound study, a landscape-scale empirical analysis of several urbanizing basins was conducted. The study sites were selected to span gradients of urban land-use and land-cover patterns. Using bacterial contamination as the indicator of nearshore water-quality conditions, a cross-sectional analysis was conducted across the Puget Sound to assess what landscape factors best explain water-quality conditions in shellfish growing areas. Preliminary results from this research indicate that forest fragmentation in the drainage basin, impervious surface area, and road density are the best predictors of nearshore water-quality conditions (Alberti and Bidwell 2004). Within the more urbanized areas, the amount and connectivity of the impervious surface explained most of the variance in bacterial pollution (Alberti and Bidwell 2004).

3.0 Watershed Characterization

The Sinclair-Dyes Inlet watershed is located in Kitsap County Washington (Figure 3-1) and Water Resource Inventory Area 15 (WRIA-15). The boundaries of the watershed include the receiving waters of Sinclair-Dyes Inlet extending out from the Inlet into the passages that connect them with the main body of the Puget Sound and the surrounding landscape that drains into the Inlet.

Flows in Sinclair Inlet are governed primarily by tides that propagate from the Pacific Ocean into Puget Sound and then into Sinclair Inlet through two narrow passages: Port Orchard in the north and Rich Passage in the southeast. These tidal influences are transferred to Dyes Inlet via the Port Washington Narrows. Tides in the Puget Sound region are semi-diurnal and diurnal-mixed modes with two high and two low tides every diurnal cycle (24.8 hours). Once reaching the entrances to the two passages and into the Inlet, the tides are further modulated in a nonlinear fashion by a number of forcing mechanisms, including freshwater inflows, wind, water-depth variations, and waterbody geometry. Tidal flows in the Inlet are modulated both spatially and temporally, with maximum tidal ranges reaching 5.5 meters during spring tides (Wang and Richter 1999).

Historically, the Sinclair-Dyes Inlet watershed was typical of the Puget Sound Lowland (PSL) ecoregion (Figure 3-2). Under natural conditions, the watershed was almost entirely forested, with native conifers (fir, spruce, cedar, and hemlock) dominating the upland landscape (Kruckeberg 1991). Patches of hardwoods were also common in areas where natural disturbance events (fire, wind-throw, landslides, and flooding) had recently occurred (Kruckeberg 1991). Under natural historical conditions, the shorelines of the Sinclair-Dyes Inlet watershed were also almost completely forested, with mixed conifers (cedar, spruce, fir, and hemlock) and hardwoods (alder, willow, madronna, and maple) common (Kruckeberg 1991). The natural nearshore areas within the watershed were a complex mosaic of tidal wetlands, rocky beaches, sand spits, eelgrass meadows, small-stream estuaries, brackish lagoons, and eroding bluffs (Kruckeberg 1991). The developed landscape of the watershed is quite different, as can be seen in a recent aerial photo (Figure 3-3).

The Sinclair-Dyes Inlet watershed consists of 62,348 acres (25,231 hectares). Approximately half of the watershed is still covered by native forest, but this remaining forest is concentrated mostly in a few undeveloped subwatersheds. The other half of the watershed is developed, of which about one-third is classified as impervious. Development can be found in all subwatersheds, as well as along a majority of the Sinclair-Dyes Inlet shoreline; however, most of the impervious surfaces are located in the urban centers of Bremerton, Silverdale, the Bremerton Naval Station and Puget Sound Naval Shipyard (PSNS), and areas around Port Orchard. The natural stream network drains about 80% of the watershed, with the other 20% draining directly to marine waters. Approximately one third of the impervious surfaces (approximately 11% of the entire watershed) are located in areas not drained by streams (Figure 3-4). Most of the impervious surfaces that are not drained by streams are shoreline urban areas predominantly located in West Bremerton, portions of East Bremerton, Port Orchard, and Silverdale.

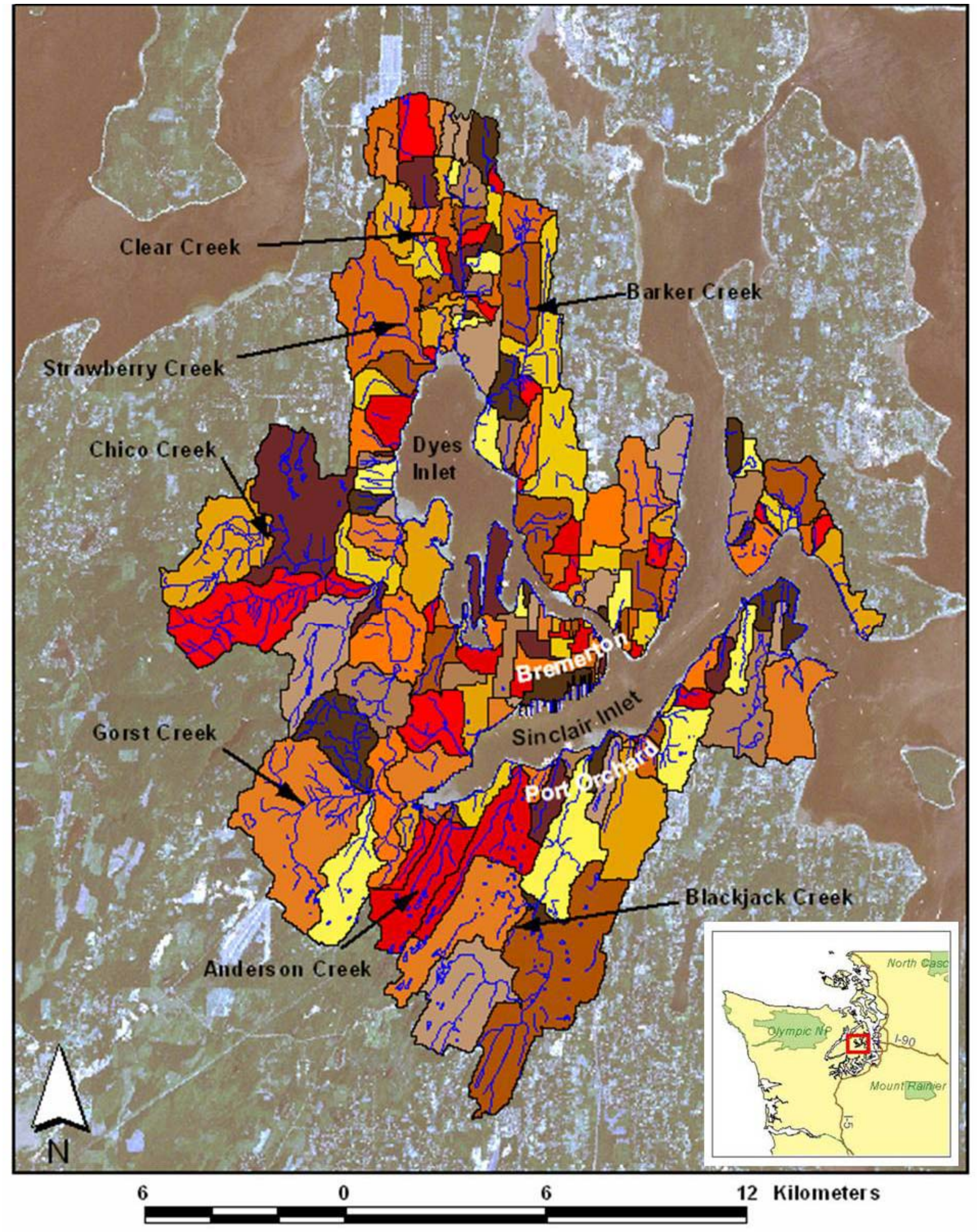


Figure 3-1. Sinclair-Dyes Inlet Watershed

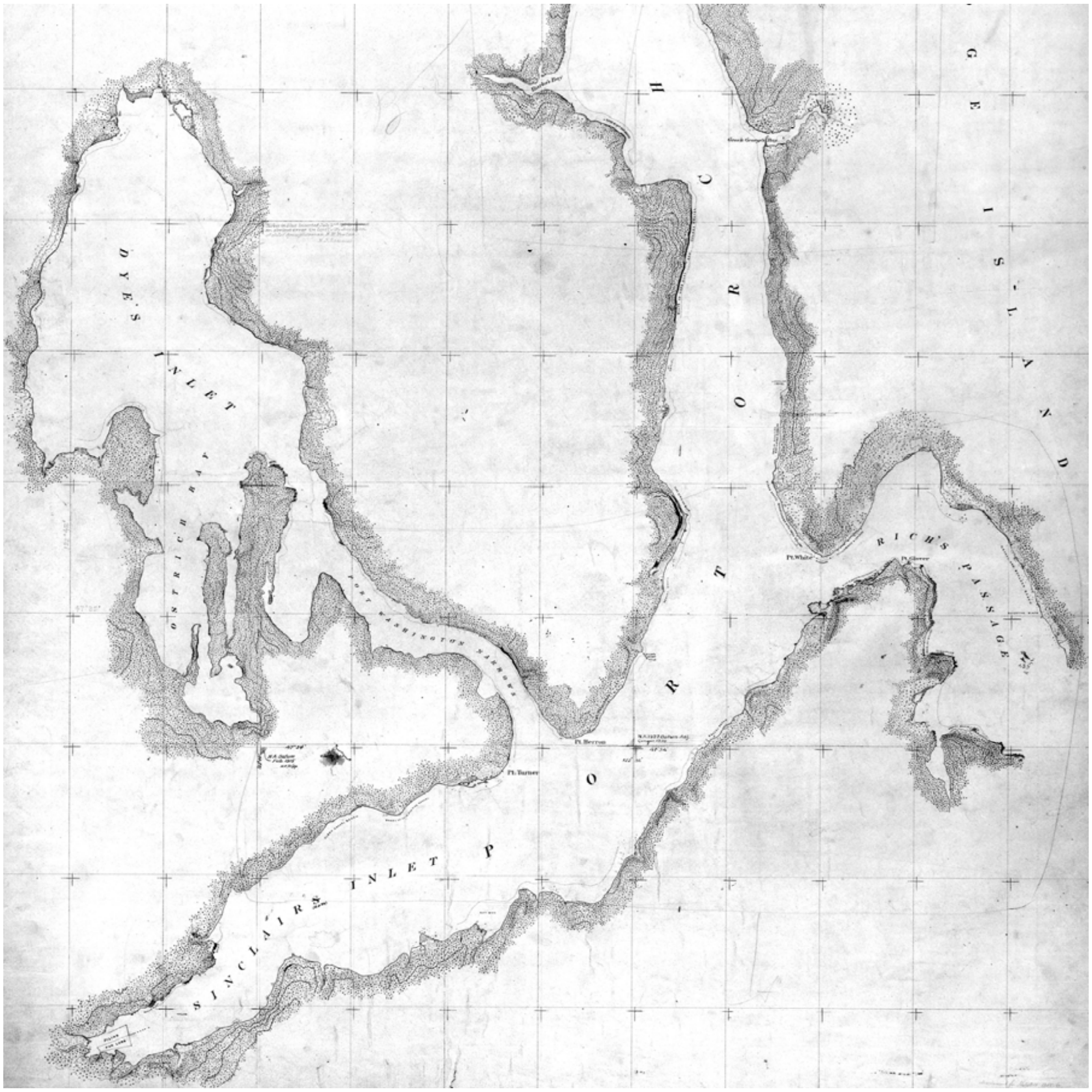


Figure 3-2. Sinclair-Dyes Inlet Watershed Circa 1890

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Figure 3-3. Sinclair-Dyes Inlet Watershed Circa 2000

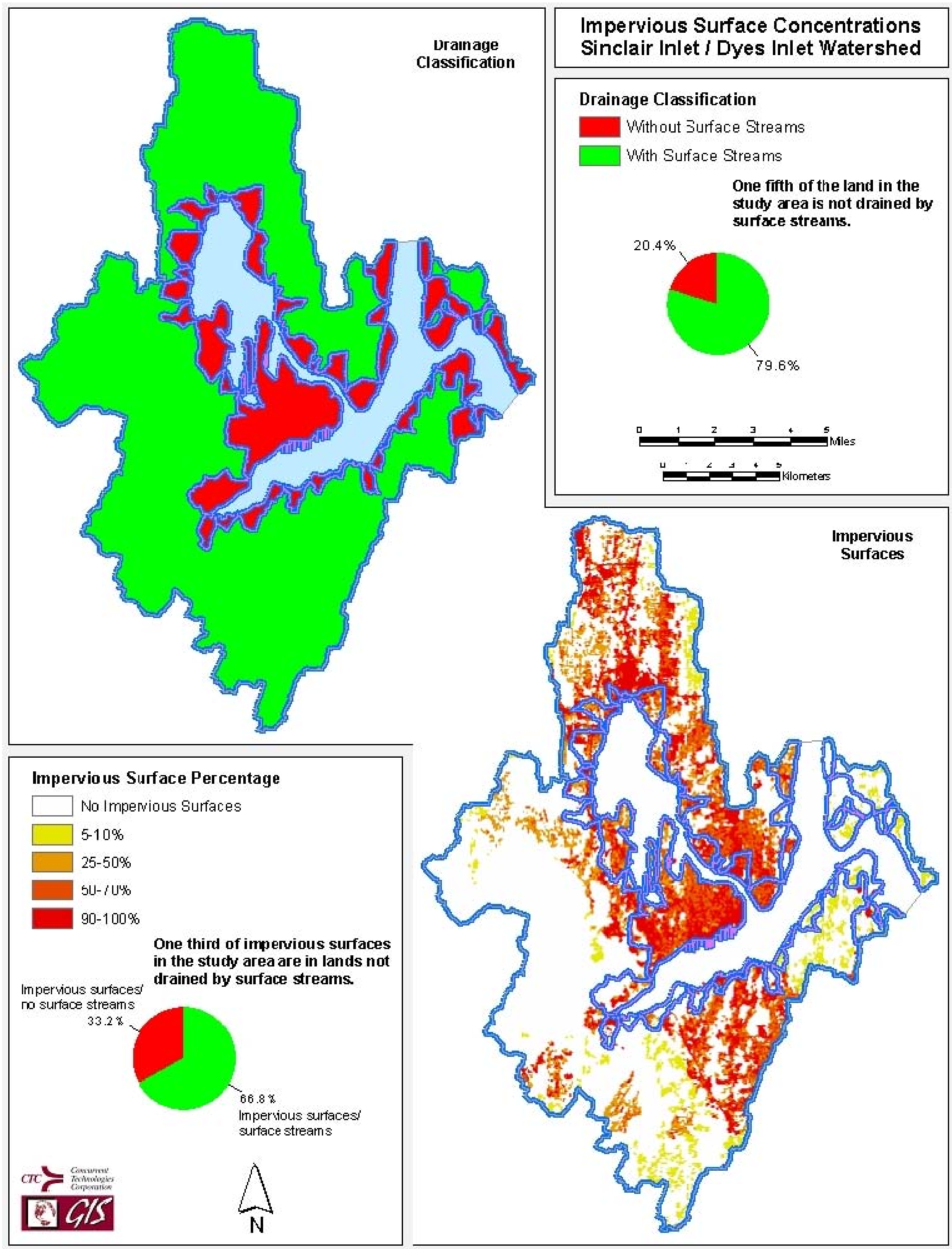

Figure 3-4. Sinclair-Dyes Inlet Watershed Drainage Classifications and Impervious Surface Distribution

3.1 Population Growth

Located within commuting distance to the greater Seattle-Tacoma metropolitan area, and providing good employment opportunities (Navy and private commercial-industrial businesses), Kitsap County has been an area of relatively steady population growth. Figure 3-5 shows the historical growth of the human population of Kitsap County. Figure 3-6 shows the projected population growth for the county through 2025.

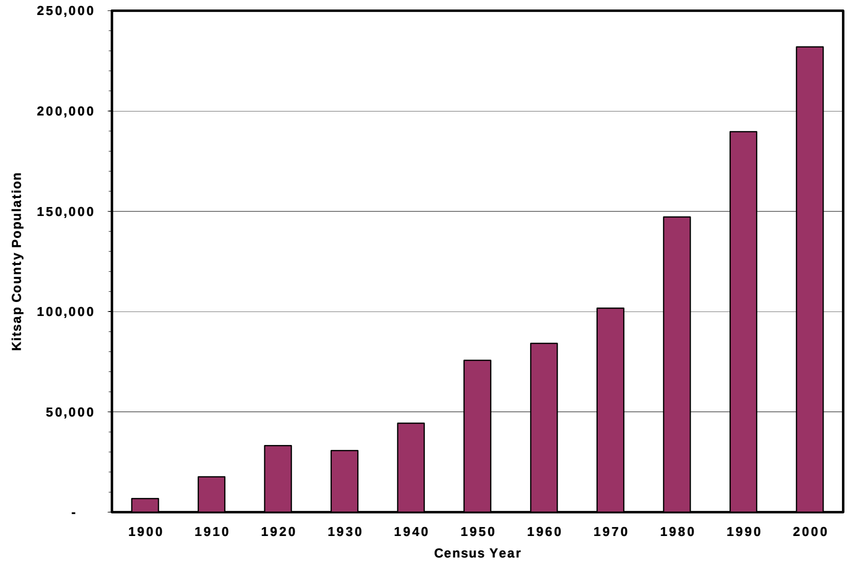

Figure 3-5. Historical growth of Human Population in Kitsap County (Washington State Office of Financial Management 2005)

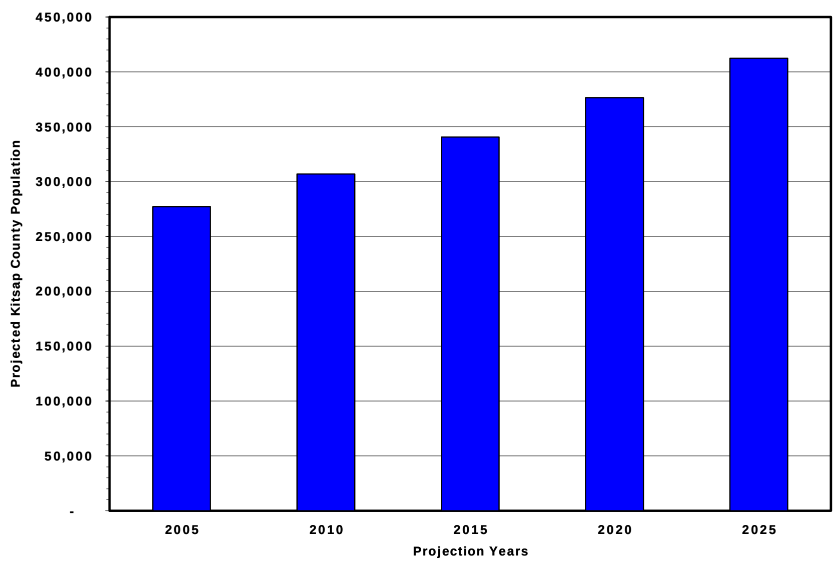

Figure 3-6. Projected Growth of Human Population in Kitsap County (Washington State Office of Financial Management 2005)

The population of Kitsap County is dispersed between the unincorporated and incorporated areas, which include the cities of Poulsbo, Port Orchard, Bremerton, and Bainbridge Island. The Sinclair-Dyes Inlet study includes the Cities of Bremerton, Port Orchard, and a portion of Bainbridge Island (Figure 3-1). Silverdale is the most significant developed, unincorporated area of Kitsap County that lies within the study area. Table 3-1 shows the population data from 1990 through 2003 for the incorporated and unincorporated areas of Kitsap County that are part of this study. Table 3-2 shows the population density trends for Kitsap County in persons per square mile of area.

Table 3-1. Population Data for the Incorporated and Unincorporated Areas of Kitsap County that Are Part of this Study (Washington State Office of Financial Management)

Kitsap County Population Growth								
	1990	**1995**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Kitsap County-Total Population	189,731	220,600	229,000	229,700	230,200	233,400	234,700	237,000
Annual Growth Rate	2.9%	2.4%	-0.2%	0.3%	0.2%	1.4%	0.6%	2.8%
Kitsap County-Unincorporated	157,400	158,740	159,125	159,890	159,896	160,625	161,345	162,000
City of Bainbridge Island	14,947	18,920	19,080	19,840	20,150	20,740	20,920	21,350
Annual Growth Rate	4.0%	2.1%	0.9%	4.0%	1.6%	2.9%	0.9%	2.0%
City of Bremerton	38,142	38,610	37,260	36,270	36,160	37,260	37,530	38,730
Annual Growth Rate	0.8%	0.8%	-3.5%	-2.7%	-0.3%	3.0%	0.7%	3.1%
City of Port Orchard	4,984	6,240	6,945	7,255	7,270	7,810	7,900	7,910
Annual Growth Rate	0.4%	5.8%	-0.3%	4.5%	0.2%	7.4%	1.2%	0.1%
Data Source: Office of Financial Management Washington State								

Table 3-2. Historical Population Density Data for Kitsap County (Washington State Office of Financial Management)

	Land Area (sq mi)	**2000**	**2001**	**2002**	**2003**	**2004**
Kitsap County	396	586	589	593	599	605
Data Source: Office of Financial Management Washington State						

3.2 Watershed Assessment

A watershed assessment involves the quantitative characterization of landscape conditions on a watershed or subwatershed scale. LULC data are used for a wide variety of purposes, including municipal and regional planning, land management, and habitat research to name a few. Digital databases of land use, land cover, and associated datasets are widely available in geographic information system (GIS) formats from the Internet. *Land use* is commonly defined as human operations on land that intend to obtain products and/or benefits from the land, whereas *land cover* is defined as vegetation or anthropogenic constructions on the earth's surface. Consequently, these maps and databases involve some interpretation and may take into account either or both land use and land cover. LULC databases are derived from numerous forms of remote sensing and aerial photography, and are available in varying spatial scales ranging from small parcels to statewide coverages to worldwide images.

LULC data are available in GIS format for most of the United States. LULC data are available from the U.S. Geological Survey (USGS) based upon 1:100,000-scale and 1:250,000-scale USGS topographic quadrangle maps. The data are obtained from interpretation of aerial photography, as well as using secondary sources, such as land-use maps and ground surveys. The data are typically in a universal transverse mercator projection, referenced to the North American Datum of 1983 (NAD83). Additionally, LULC data use the *Anderson* classification scheme for delineation of the different LULC categories (Anderson et al., 1976). The classification scheme originally had two levels. *Anderson-1* includes 9 general levels of classification, whereas *Anderson-2* contains 21 more specific classifications that further define and delineate the Level 1 classifications. Higher levels of classification have also been developed up to Level 5, although few go beyond a third level. Because the original focus for the *Anderson* system was natural-resource based as opposed to the current more standard usage of LULC data for management of development, the standard classification system is commonly altered to meet the needs of an individual project. Table 3-3 shows the LULC categories for the *Anderson* system.

For this project, LULC in the Sinclair-Dyes Inlet watershed was analyzed using the 1999 Landsat-7 Thematic Mapper (TM) remote-sensing satellite data within a GIS at 30-meter pixel resolution. The Landsat system uses the National Land Cover Data (NLCD), which is a set of GIS-accessible, single band raster images with a 21-class land-cover classification scheme for the United States. The classification scheme for NLCD differs from the *Anderson-2* classification scheme and is sometimes referred to as a modified *Anderson-2* classification scheme. Some classifications have been combined, whereas others are indistinguishable using TM imagery and have been eliminated from the classification scheme. Table 3-4 shows the LULC categories for the NLCD system.

In addition, a more recent (2002) parcel-based LULC data set (Table 3-5) was used to check for significant changes within the watershed and to validate the Landsat-based remote-sensing data. These two LULC classifications proved to be highly comparable for the study area (Carlson 2003). Figure 3-7 illustrates this correlation. For the purposes of FC data analysis, the Landsat-based LULC data set was used in most cases, because these data were used for the watershed modeling effort. However, some analyses were also conducted using the parcel-based LULC data.

The first step in the LULC analysis was to delineate the Sinclair-Dyes Inlet watershed into subwatersheds. This delineation process was driven by several factors. Subwatersheds were first delineated by major stream drainage basins. Next, each stream system was further subdivided based on its major tributaries. In addition to these “natural” subwatershed boundaries, streams were further subdivided based on the designation of specific *pour-points* that were determined by one of the following:

- Streamflow gage locations
- Water quality sampling sites
- Biological monitoring sample sites
- Instream habitat survey locations.

For the bacterial contamination TMDL portion of the project, the FC sample sites served as the primary pour-points for subbasin delineation. Figure 3-8 shows the primary subbasin delineations for the study area.

Table 3-3. Level-2 *Anderson* classification scheme for Land Use and Land Cover Data (Anderson et al., 1976)

Value	Definition
1	**Urban or built-up land**
11	Residential
12	Commercial and services
13	Industrial
14	Transportation, communication, utilities
15	Industrial and commercial complexes
16	Mixed urban or built-up land
17	Other urban or built-up land
2	**Agricultural land**
21	Cropland and pasture
22	Orchards, groves, vineyards, nurseries, and ornamental horticultural
23	Livestock feeding operations
24	Other agricultural land
3	**Rangeland**
31	Herbaceous rangeland
32	Shrub and brush rangeland
33	Mixed rangeland
4	**Forest land**
41	Deciduous forest land
42	Evergreen or coniferous forest land
43	Mixed forest land
5	**Water**
51	Streams and canals
52	Lakes
53	Reservoirs
54	Bays and estuaries
6	**Wetland**
61	Forested wetland
62	Non-forested wetland
7	**Barren land**
71	Dry salt flats
72	Beaches
73	Sandy areas not beaches
74	Bare exposed rock
75	Strip mines, quarries, gravel pits
76	Transitional areas
8	**Tundra**
81	Shrub and brush tundra
82	Herbaceous tundra
83	Bare ground
84	Wet tundra
85	Mixed tundra
9	**Perennial snow or ice**
91	Perennial snowfields
92	Glaciers

Level-1 classifications are shown in bold.

Table 3-4. The National Land Cover Data (NLCD) Land-Use and Land-Cover Classification Scheme

	Water
11	Open Water
12	Perennial Ice/Snow
	Developed
21	Low Density (LD) Residential
22	High-Density (HD) Residential
23	Commercial/Industrial/Transportation
	Barren
31	Bare Rock/Sand/Clay
32	Quarries/Strip Mines/Gravel Pits
33	Transitional
	Vegetated; Natural Forested Upland
41	Deciduous Forest
42	Evergreen/Coniferous Forest
43	Mixed Forest
	Shrub
51	Shrub
	Non-natural Woody
61	Orchards/Vineyards/Other
	Herbaceous Upland
71	Grasslands/Herbaceous
	Herbaceous Planted Cultivated
81	Pasture/Hay
82	Row Crops
83	Small Grains
84	Fallow
85	Urban/Recreational Grasses
	Wetlands
91	Woody Wetlands
92	Emergent Herbaceous Wetlands

Table 3-5. Parcel-based Land-Use and Land-Cover Classification Scheme

Undeveloped	**Commercial/Industrial**	**Public Facilities and Utilities**
Vacant/Grass	Commercial Retail	Utilities
Open Space	Commercial Service	Facilities
Forest/Wooded	Light Industrial	Airports
	Heavy Industrial	Cemetery
Low Density Residential	Parking Lots	Schools
Rural	Streets/Roads	Phone/TV/Radio
Estate	Hotel/Motel	Water
Urban LD Residential	Hospital	Gas
	Docks	Electric Power
Medium Density Residential	Church	
Urban MD Residential	Mines	**Parks**
Mobile Home (RV) Park		Parks
Suburban	**Transportation**	Golf Courses
	Highway	Resorts
High-Density Residential	Right-of-Way	
Urban HD Residential	Railroad Lines	
Multi-Family Residential		

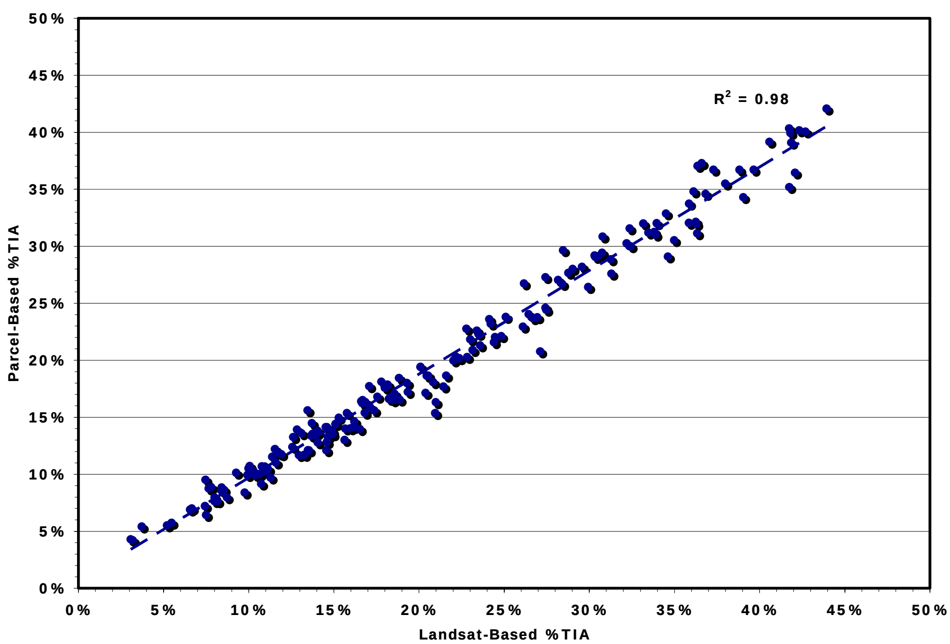

Figure 3-7. Comparison of Parcel-Based and Landsat-Based Total Impervious Area Measurements (Carlson 2003)

The next step in the LULC analysis was to overlay the LULC GIS layers with the subwatershed layer and calculate the LULC parameters for each subbasin. Figure 3-9a shows the Landsat-based LULC classes (based on Anderson et al., 1976) and their distribution throughout the study area. Figure 3-9b shows the corresponding parcel-based LULC map.

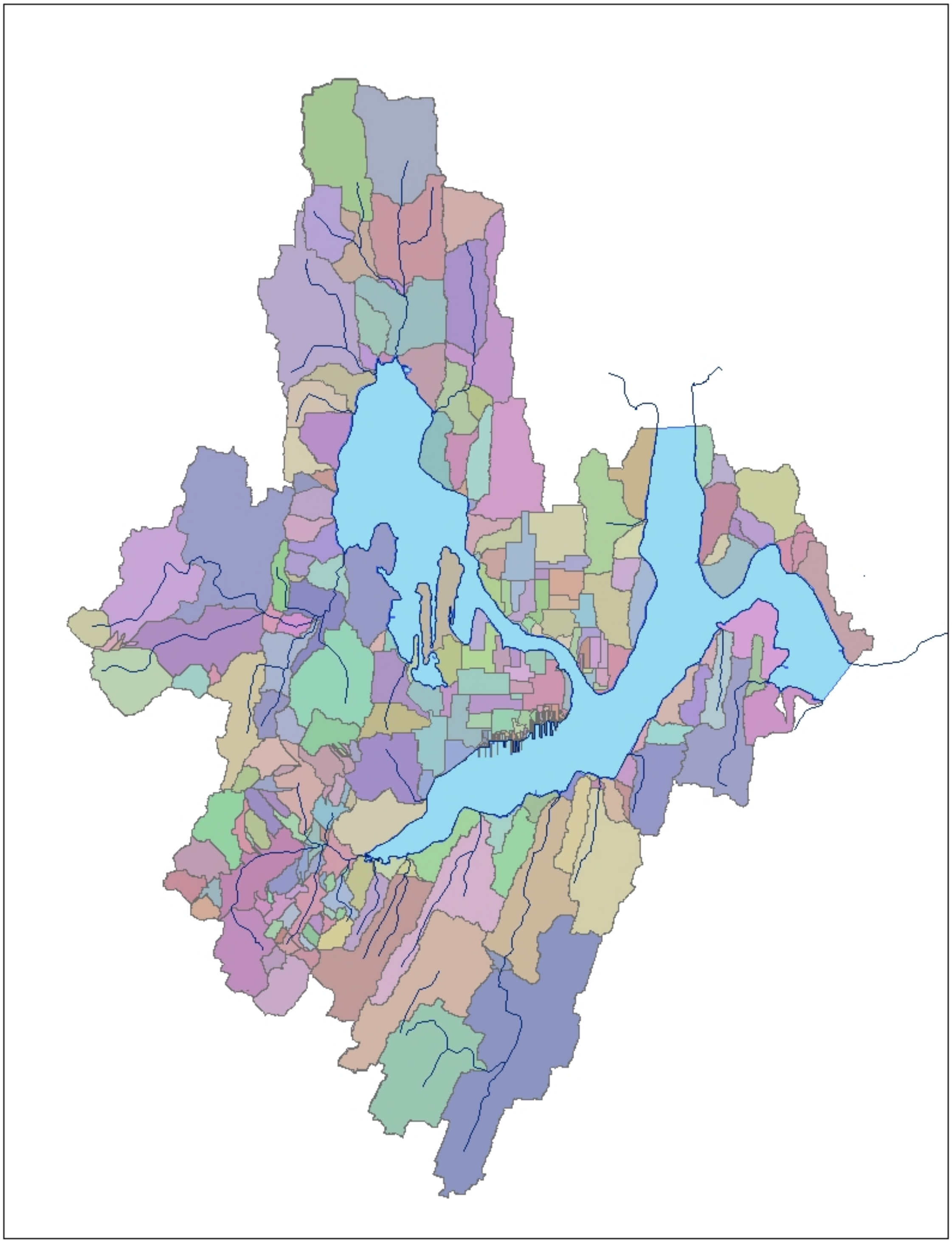

Figure 3-8. Subwatershed Delineations in Sinclair-Dyes Inlet Watershed

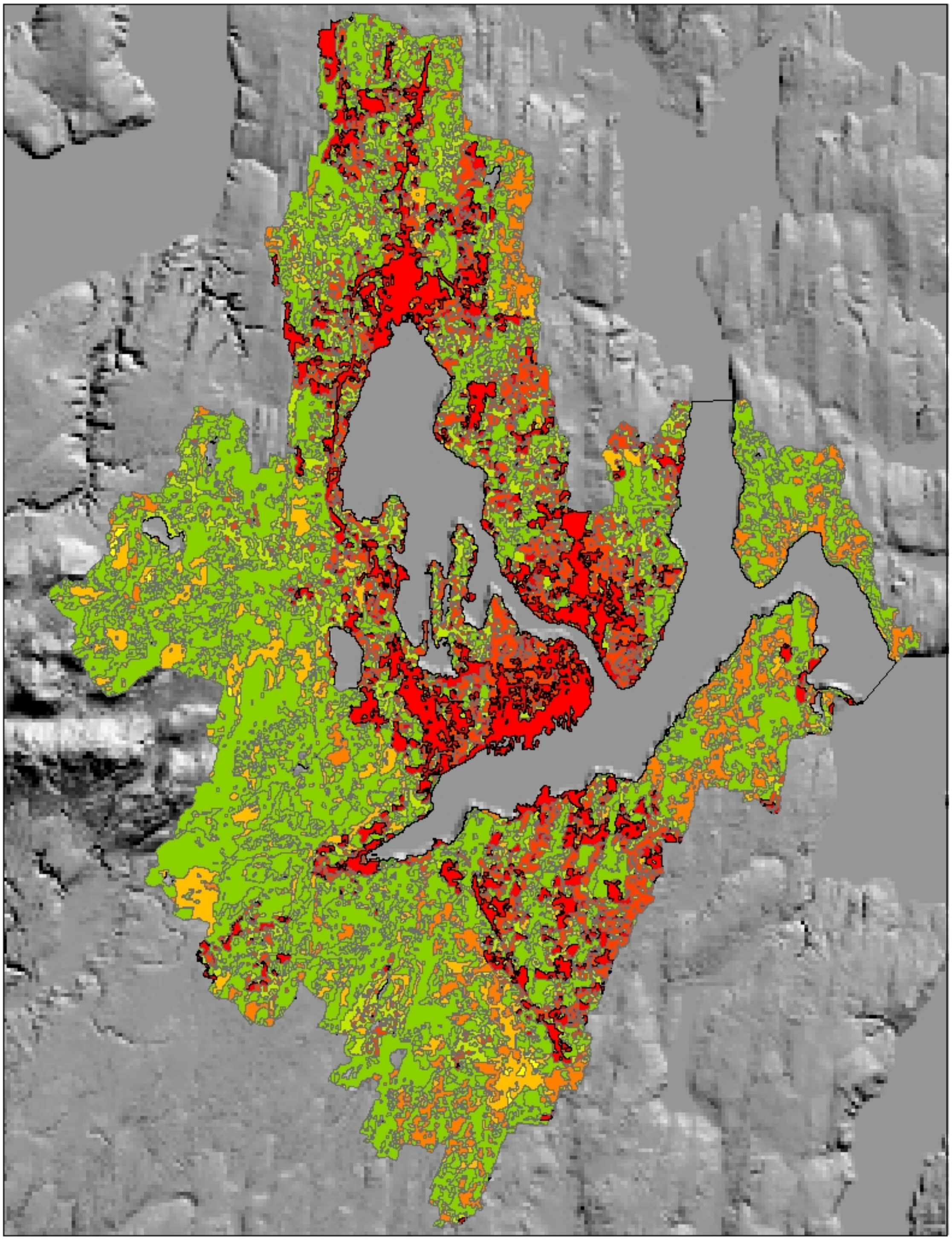

Figure 3-9a. Sinclair-Dyes Inlet Watershed Land-Use and Land-Cover Map (Landsat-based)

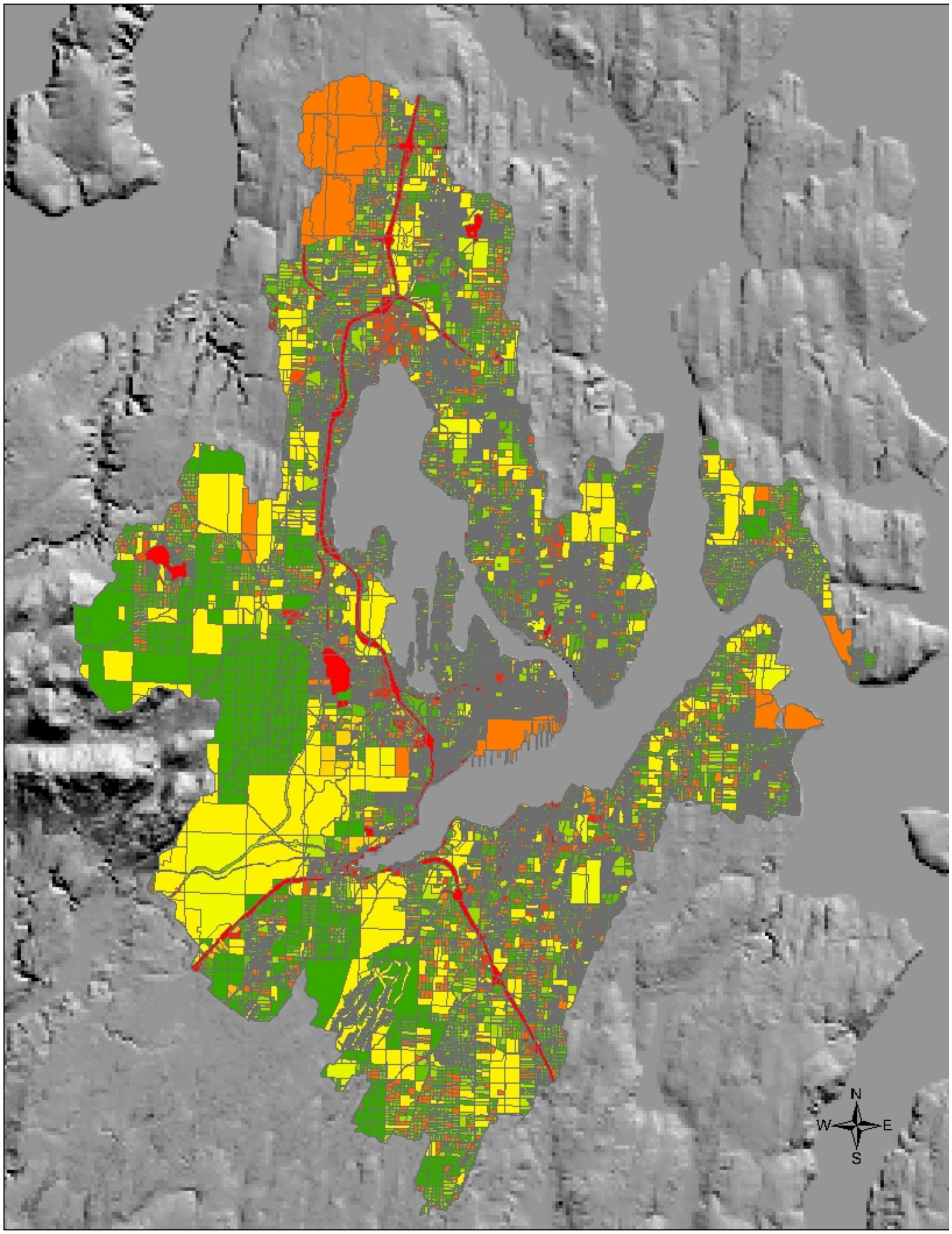

Figure 3-9b. Sinclair-Dyes Inlet Watershed Land-Use and Land-Cover Map (Parcel-based)

The following LULC classifications (based on Landsat-7 TM data) were used for this project:

- Lakes and Wetlands (open water)
- Coniferous Forest (greater than 60% coniferous canopy cover)
- Deciduous Forest (greater than 60% deciduous canopy cover)
- Mixed Forest (coniferous and deciduous mixture)
- Shrub or Transitional Vegetation
- Grassland, Prairie, or Pasture
- Turf-grass (lawn/golf courses/recreational fields)
- Shoreline or Beach
- Quarries, Gravel Pits, or Bare Ground (construction sites)
- Commercial-Industrial Areas
- High-Density (HD) Residential (urban) Development
- Medium-Density (MD) Residential (suburban) Development
- Low-Density (LD) Residential (rural) Development.

To calculate the total impervious area for each subwatershed, it was necessary to convert from LULC classifications. Standard conversion factors for the Puget Sound region were used to determine appropriate LULC-to-impervious conversion factors (Hill et al., 2000). The impervious conversion factors used in this study are shown in Table 3-6. These conversion factors were then used to calculate watershed TIA.

Table 3-6. Land-Use and Land-Cover Classifications and Total Impervious Area Conversion Factors (%TIA CF)

Land-Use and Land-Cover Class	**%TIA CF**
LD Residential-Rural	15%
MD Residential-Suburban	35%
HD Residential-Urban	55%
Commercial and Industrial	65%
Quarries/Strip Mines/Gravel Pits/Bare Ground	25%
Grassland/Prairie/Pasture	10%
Turf/Recreational Grasses	15%
Shrub and Transitional Vegetation	5%
Deciduous Forest	3%
Coniferous Forest	1%
Mixed Forest	2%
Lakes/Wetlands	0%
Shoreline/Beach	0%

Figure 3-10 illustrates the level of imperviousness found in the study area. Subwatershed imperviousness in the Sinclair-Dyes Inlet watershed ranges from less than 5% TIA to almost 50% TIA. Figure 3-11 shows the relationship between the loss of natural forest cover (coniferous, deciduous, and mixed) and the increase in the percentage of TIA that is typical of the development process in the Puget Sound region (May et al., 1997a, b). Figure 3-12 illustrates the typical shift in land-use distribution from rural to urban, with a transitional change to suburban that is also common in the Puget Sound region. Note how rural land-use peaks at around 15% TIA and then declines when suburban and urban begin to dominate as the development process steadily increases. Roads are a major component of watershed development, and road density (length of road per basin area) is an excellent measure of development. Figure 3-13 shows the close relationship between imperviousness (%TIA) and road density (measured in km/km^2).

An examination of the LULC data for individual subwatersheds within the Sinclair-Dyes Inlet study area shows the remaining natural areas and the pattern of development (Tables 3-7 and 3-8 and Figures 3-14 through 3-16). In general, the subwatersheds of Sinclair and Dyes Inlets show land-use patterns typical of developing areas found throughout the Puget Sound lowlands.

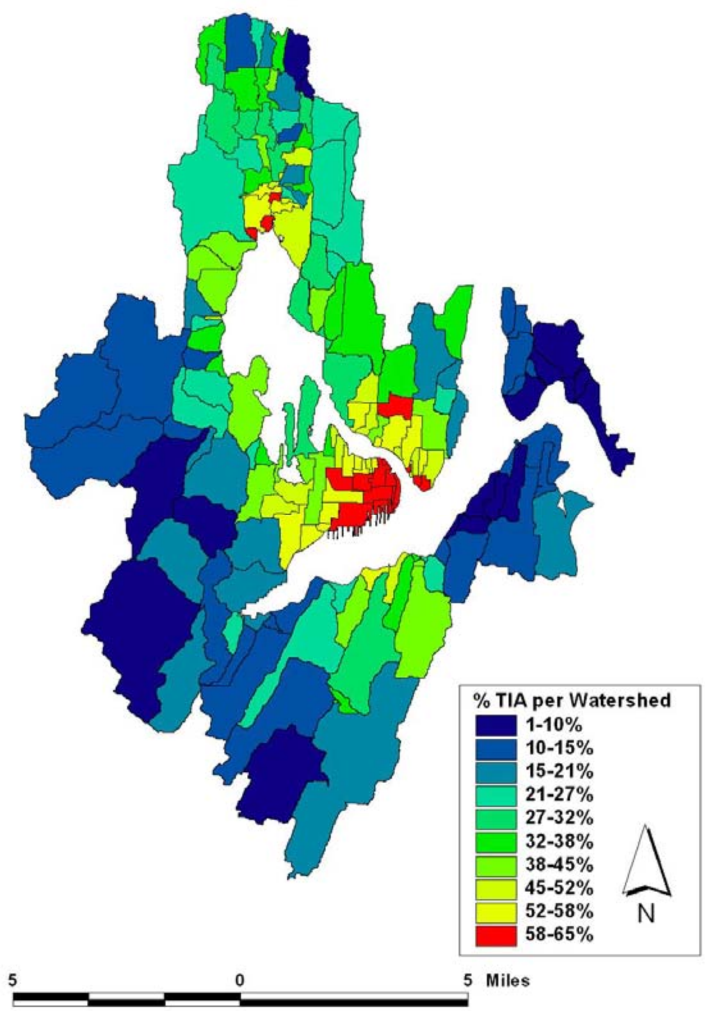

Figure 3-10. Distribution of Imperviousness in the Sinclair-Dyes Inlet Watershed as Measured by Total Impervious Area

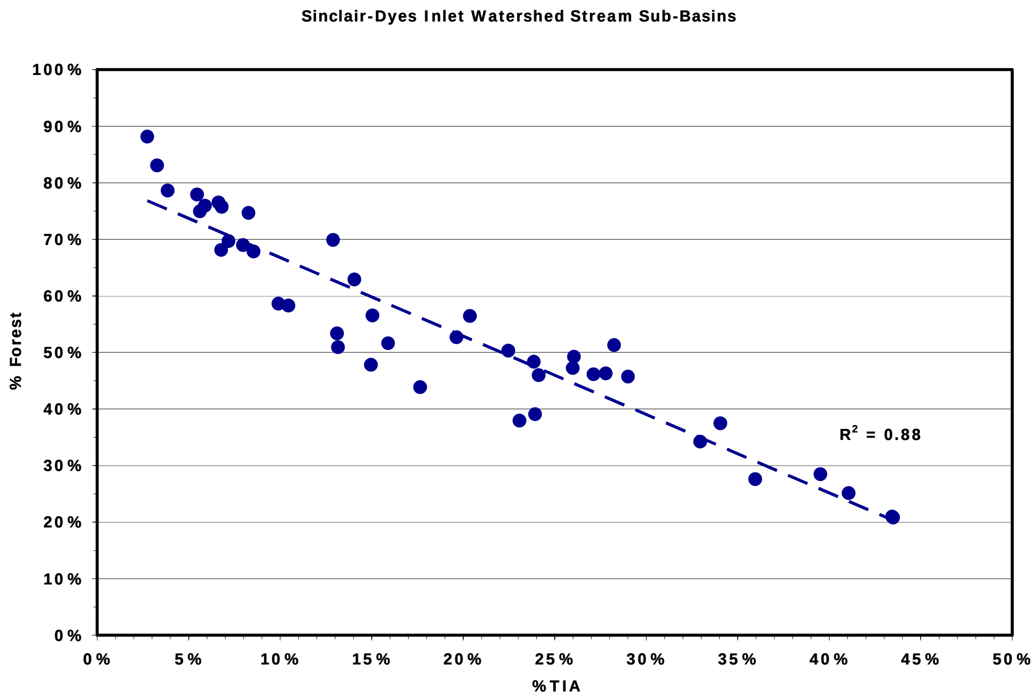

Figure 3-11. Watershed Land-Use Change in Sinclair-Dyes Inlet

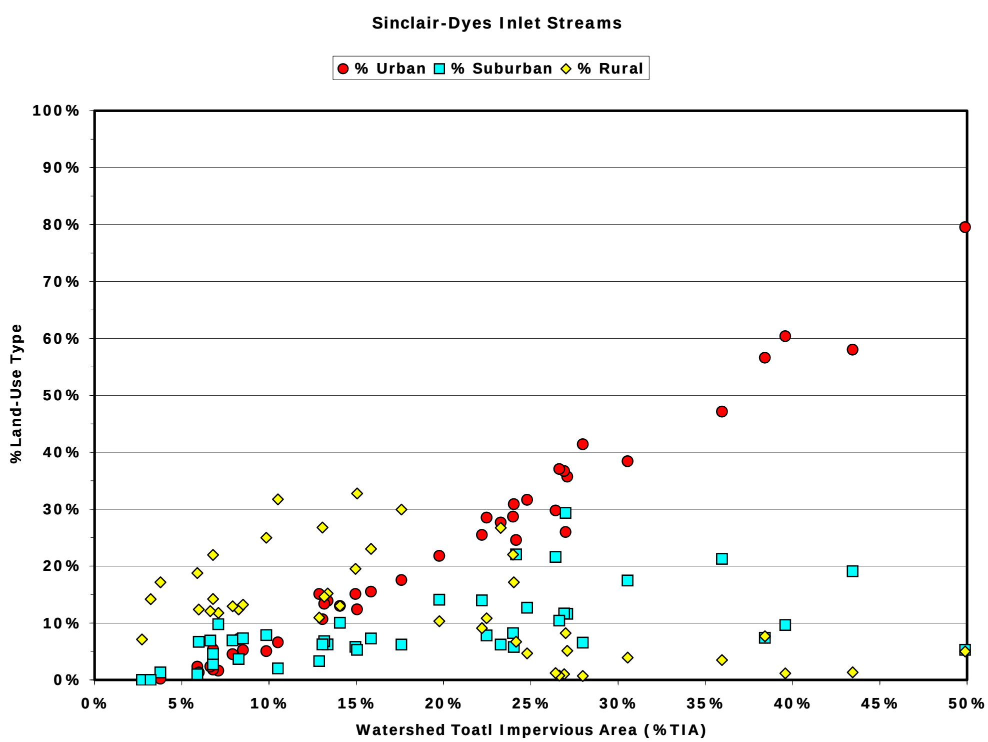

Figure 3-12. Sinclair-Dyes Inlet Watershed Land Use

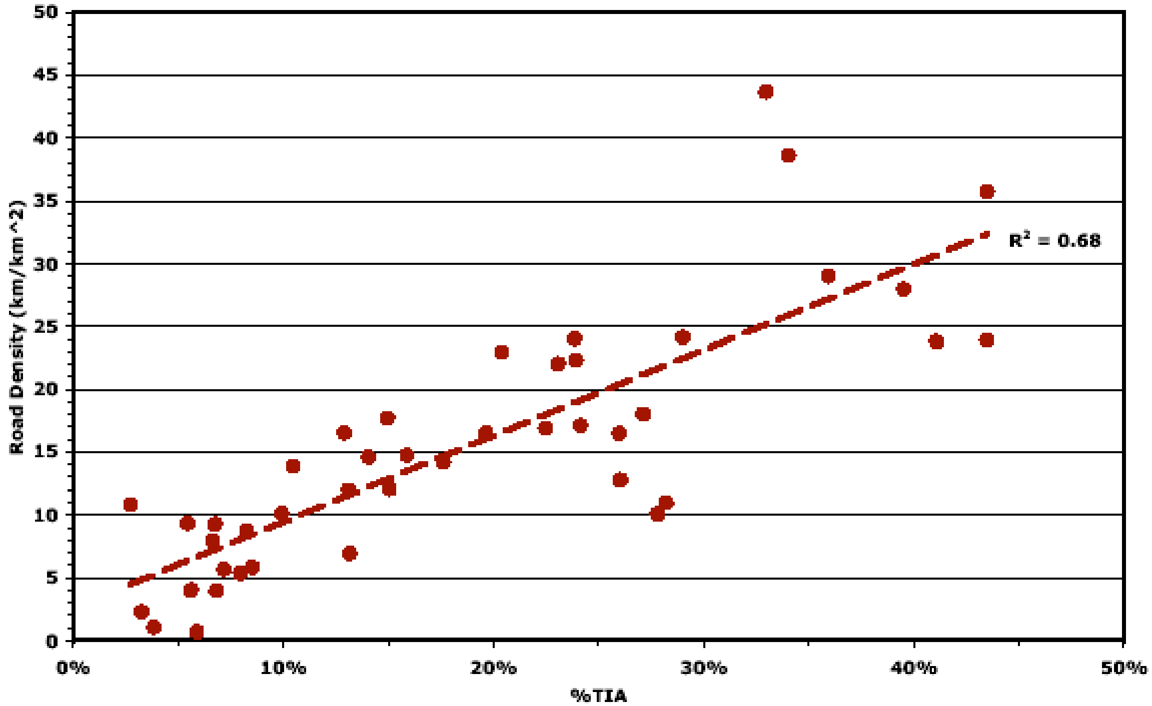

Figure 3-13. Sinclair-Dyes Inlet Watershed Road Density

Several subwatersheds in the study area remain largely undeveloped and are still dominated by native forest cover. Most of Anderson, Chico, Gorst, and Square Creeks are greater than 70% forest and less than 10% TIA. On the other end of the development spectrum, several subwatersheds are highly developed, with little natural land-cover remaining. Examples of these urbanized watersheds include Dee, Annapolis, Olney, and Ostrich Bay Creeks. The major urban areas include the cities of Bremerton and Port Orchard, as well as the Silverdale and Gorst areas. For the most part, however, the majority of the subwatersheds in the study area are a mixture of forested areas, rural land-use (residential and small-scale agricultural activities), and low-to-medium density suburban development, with average imperviousness between 20% and 30% and the range of forest cover between 40% and 60%. This distribution reflects the generally rural-suburban character of Kitsap County as a whole, but also indicates that there is significant potential for growth and future development within the Sinclair-Dyes Inlet watershed.

In addition to the watershed scale of assessment, each stream network was analyzed based on LULC conditions within its riparian corridor. The same LULC classes and categories that were used for the watershed-scale analysis were used for the riparian-scale analysis. Two riparian corridor widths were used for this analysis: 50 m and 100 m (measured from the stream centerline outward on both sides of the creek). Using the master GIS stream channel (hydro) layer, a "buffer" (50 m and 100 m) was created around each stream. These *GIS buffers* were then analyzed for LULC characteristics just as the subwatersheds were. In addition to stream channels, the marine shorelines of Sinclair-Dyes Inlet were also analyzed for nearshore riparian conditions. Figures 3-17 through 3-20 show the riparian buffer conditions for Sinclair-Dyes Inlet watershed in map format. Table 3-9 summarizes the riparian conditions for the 50-m buffer width.

Table 3-7. Land-Use and Land-Cover Data for Major Stream Subbasins in the Sinclair-Dyes Inlet Watershed

Watershed	Stream Sub-Watershed	WQ ID	Basin Area (acres)	% Mixed Forest	% Deciduous Forest	% Coniferous Forest	% Shrub	% Grass	% Rural (LD Resident)	% Suburban (MD Resident)
Yukon Harbor	Beaver Crk	BVR	1235.0	1.7%	46.7%	9.9%	1.1%	10.6%	21.6%	1.6%
PO Passage	Dee Crk	DEE	396.8	0.7%	17.2%	7.2%	0.3%	2.5%	0.0%	10.4%
PO Passage	Illahee Crk	ILL	801.7	1.3%	32.9%	18.5%	1.1%	10.3%	0.9%	13.0%
PO Passage	Springbrook Crk	BI-SBC	1539.6	25.0%	19.1%	33.8%	3.7%	0.2%	13.7%	0.0%
Sinclair Inlet	Sacco Crk	SACCO	651.2	0.7%	41.5%	5.6%	1.8%	7.3%	26.0%	4.7%
Sinclair Inlet	Olney Crk	OC	1245.4	0.3%	11.6%	16.5%	0.0%	1.2%	0.4%	9.2%
Sinclair Inlet	Annapolis Crk	ANNP	401.6	1.1%	16.4%	3.5%	0.6%	1.3%	0.0%	19.1%
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	1711.8	0.9%	13.4%	44.3%	1.0%	11.5%	13.5%	7.9%
Sinclair Inlet	Square Crk Tributary	BL-SQR	1665.3	3.0%	19.1%	46.0%	1.1%	5.7%	16.5%	4.3%
Sinclair Inlet	Upper Blackjack Crk	BL-HW	3525.6	1.0%	15.3%	27.6%	0.8%	14.5%	15.6%	6.1%
Sinclair Inlet	Blackjack Crk @ SR-16	BL	6902.7	1.5%	15.7%	36.2%	0.9%	11.6%	15.3%	6.1%
Sinclair Inlet	Blackjack Crk	BL-KFC	8347.4	1.4%	17.6%	32.6%	0.9%	10.4%	12.7%	7.2%
Sinclair Inlet	Ross Crk	ROSS	1273.4	1.8%	28.9%	19.6%	1.0%	6.1%	4.7%	7.8%
Sinclair Inlet	Anderson Crk	AC	1265.9	4.3%	29.3%	43.0%	1.9%	9.3%	2.8%	6.9%
Sinclair Inlet	Heins Crk Headwaters	GC-HW	1005.4	14.0%	41.4%	32.8%	2.2%	7.1%	0.0%	0.0%
Sinclair Inlet	Heins & Jarstad Crk Tributaries	GC-HNS	848.0	1.9%	24.2%	43.8%	0.7%	6.2%	4.7%	3.3%
Sinclair Inlet	Parish Crk Tributary	GC-PA	1092.0	1.8%	19.8%	41.4%	1.0%	5.5%	7.5%	10.0%
Sinclair Inlet	Upper Gorst Crk	GC-JAR	3196.9	2.7%	16.9%	56.1%	1.0%	13.1%	1.2%	2.1%
Sinclair Inlet	Gorst Crk	GC	6142.3	4.3%	22.4%	48.0%	1.1%	9.8%	2.6%	3.3%
Sinclair Inlet	Wright Crk	WC	725.9	1.3%	34.6%	20.6%	2.5%	19.5%	0.0%	5.9%
Dyes Inlet	Ostrich Bay Crk	OBC	402.1	1.1%	16.3%	3.4%	0.6%	1.4%	0.0%	19.1%
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	3950.2	6.8%	19.0%	43.9%	1.8%	9.0%	2.8%	9.8%
Dyes Inlet	Lost Crk Tributary	CH-LST	1912.6	10.7%	33.8%	38.6%	2.2%	13.3%	0.9%	0.0%
Dyes Inlet	Dickerson Crk Tributary	CH-DI	1474.0	4.5%	15.5%	58.7%	1.2%	17.2%	0.0%	1.3%
Dyes Inlet	Upper Kitsap Crk	CH-KL	777.9	4.7%	35.7%	35.6%	1.5%	6.9%	11.9%	1.0%
Dyes Inlet	Kitsap Crk Tributary	CH-KC	1968.2	3.0%	23.6%	24.3%	1.1%	9.5%	5.1%	6.8%
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	7516.3	7.2%	22.3%	45.5%	1.8%	11.6%	1.7%	5.6%
Dyes Inlet	Chico Crk @ Golf Course	CH	10033.1	6.3%	22.1%	40.6%	1.6%	10.7%	2.3%	6.9%
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	10475.5	6.1%	22.2%	39.6%	1.5%	11.0%	2.2%	7.3%
Dyes Inlet	Strawberry Crk	SC	1914.2	0.8%	14.4%	30.7%	0.5%	3.7%	3.2%	22.0%
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	1117.5	0.7%	6.6%	42.0%	2.0%	3.7%	1.9%	6.9%
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	713.2	0.4%	3.0%	47.9%	0.3%	0.4%	0.2%	5.6%
Dyes Inlet	Clear Crk - West Fork	CC-CW	2706.8	0.9%	9.3%	36.1%	1.2%	4.3%	0.8%	9.1%
Dyes Inlet	Clear Crk - East Fork Mountainview	CC-MTV	1217.6	1.4%	22.0%	33.0%	0.5%	3.2%	4.6%	12.0%
Dyes Inlet	Clear Crk - East Fork Ridgetop	CC-RTP	344.9	0.5%	16.2%	20.7%	0.0%	1.7%	0.0%	11.8%
Dyes Inlet	Clear Crk - East Fork	CC-CE	2297.6	0.9%	20.1%	27.4%	0.6%	7.2%	2.4%	12.2%
Dyes Inlet	Clear Crk @ Silverdale Way	CC	5004.3	0.9%	14.3%	32.1%	0.9%	5.0%	1.6%	10.5%
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	5394.6	0.8%	14.3%	31.0%	0.9%	4.7%	1.4%	10.0%
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	2223.9	1.0%	19.5%	17.4%	0.6%	8.3%	17.5%	6.8%
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	373.8	2.0%	23.6%	20.2%	0.0%	1.1%	0.0%	15.3%
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	2597.8	1.2%	20.1%	17.8%	0.5%	7.3%	15.0%	8.0%
Dyes Inlet	Pharman Crk	PA	303.3	0.7%	19.8%	13.7%	0.1%	2.4%	0.0%	19.6%
Dyes Inlet	Mosher Crk	MS	1096.9	0.8%	15.2%	11.6%	0.5%	3.5%	0.0%	21.2%

Table 3-8. Land-Use and Land-Cover Data for Major Stream Subbasins in the Sinclair-Dyes Inlet Watershed

Watershed	Stream Sub-Watershed	WQ ID	Road Length (km)	Road Density (km/km^2)	Basin Area (sq-km)	Stream Length (km)	Drainage-Density (km / km^2)
Yukon Harbor	Beaver Crk	BVR	69.2	13.8	5.0	11.3	2.3
PO Passage	Dee Crk	DEE	38.2	23.8	1.6	1.5	0.9
PO Passage	Illahee Crk	ILL	53.6	16.5	3.2	6.3	1.9
PO Passage	Springbrook Crk	BI-SBC	58.3	9.4	6.2	14.7	2.4
Sinclair Inlet	Sacco Crk	SACCO	46.7	17.7	2.6	5.3	2.0
Sinclair Inlet	Olney Crk	OC	140.9	28.0	5.0	8.8	1.7
Sinclair Inlet	Annapolis Crk	ANNP	38.9	23.9	1.6	3.2	2.0
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	70.0	10.1	6.9	13.4	1.9
Sinclair Inlet	Square Crk Tributary	BL-SQR	62.6	9.3	6.7	14.9	2.2
Sinclair Inlet	Upper Blackjack Crk	BL-HW	202.2	14.2	14.3	23.5	1.6
Sinclair Inlet	Blackjack Crk @ SR-16	BL	334.8	12.0	27.9	51.8	1.9
Sinclair Inlet	Blackjack Crk	BL-KFC	497.8	14.7	33.8	61.8	1.8
Sinclair Inlet	Ross Crk	ROSS	87.1	16.9	5.2	12.1	2.3
Sinclair Inlet	Anderson Crk	AC	40.9	8.0	5.1	11.1	2.2
Sinclair Inlet	Heins Crk Headwaters	GC-HW	44.0	10.8	4.1	15.8	3.9
Sinclair Inlet	Heins & Jarstad Crks	GC-HNS	56.8	16.6	3.4	8.5	2.5
Sinclair Inlet	Parish Crk Tributary	GC-PA	64.6	14.6	4.4	6.7	1.5
Sinclair Inlet	Upper Gorst Crk	GC-JAR	51.3	4.0	12.9	25.3	2.0
Sinclair Inlet	Gorst Crk	GC	216.7	8.7	24.9	56.3	2.3
Sinclair Inlet	Wright Crk	WC	35.5	12.1	2.9	5.4	1.8
Dyes Inlet	Ostrich Bay Crk	OBC	58.1	35.7	1.6	3.5	2.2
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	90.9	5.7	16.0	33.1	2.1
Dyes Inlet	Lost Crk Tributary	CH-LST	17.5	2.3	7.7	22.8	2.9
Dyes Inlet	Dickerson Crk Tributary	CH-DI	6.3	1.1	6.0	14.9	2.5
Dyes Inlet	Upper Kitsap Crk	CH-KL	2.2	0.7	3.1	6.4	2.0
Dyes Inlet	Kitsap Crk Tributary	CH-KC	55.4	7.0	8.0	14.9	1.9
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	122.6	4.0	30.4	73.0	2.4
Dyes Inlet	Chico Crk @ Golf Course	CH	218.0	5.4	40.6	92.3	2.3
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	246.5	5.8	42.4	97.4	2.5
Dyes Inlet	Strawberry Crk	SC	132.6	17.1	7.7	11.5	1.5
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	12.6	12.8	4.5	3.7	0.8
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	14.5	11.0	2.9	3.8	1.3
Dyes Inlet	Clear Crk - West Fork	CC-CW	110.3	10.1	11.0	13.7	1.2
Dyes Inlet	Clear Crk - East Fork Mountainview Tributary	CC-MTV	113.1	23.0	4.9	6.0	1.2
Dyes Inlet	Clear Crk - East Fork Ridgetop Tributary	CC-RTP	53.9	38.6	1.4	2.5	1.8
Dyes Inlet	Clear Crk - East Fork	CC-CE	223.4	24.0	9.3	13.7	1.5
Dyes Inlet	Clear Crk @ Silverdale Way	CC	333.8	16.5	20.3	27.3	1.3
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	394.2	18.1	21.8	28.6	1.3
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	198.2	22.0	9.0	23.4	2.6
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	36.5	24.1	1.5	4.5	3.0
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	234.7	22.3	10.5	27.9	2.7
Dyes Inlet	Pharman Crk	PA	53.6	43.7	1.2	2.0	1.6
Dyes Inlet	Mosher Crk	MS	128.7	29.0	4.4	4.6	1.0

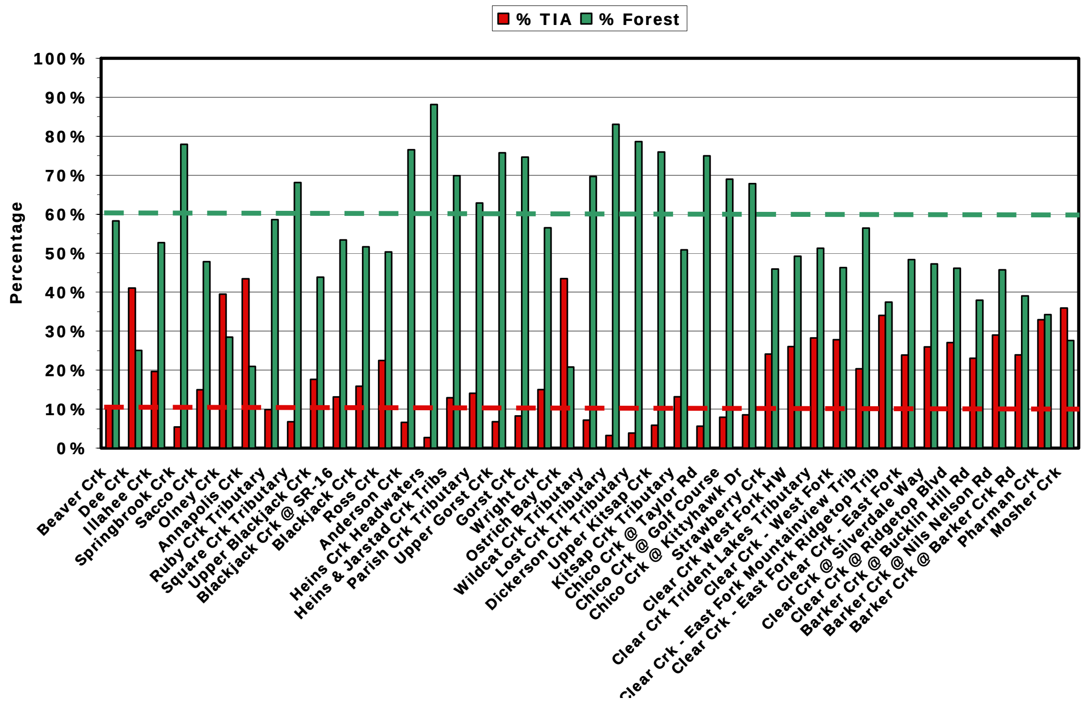

Figure 3-14. Sinclair-Dyes Inlet Watershed Stream Subbasin Land Use and Land Cover

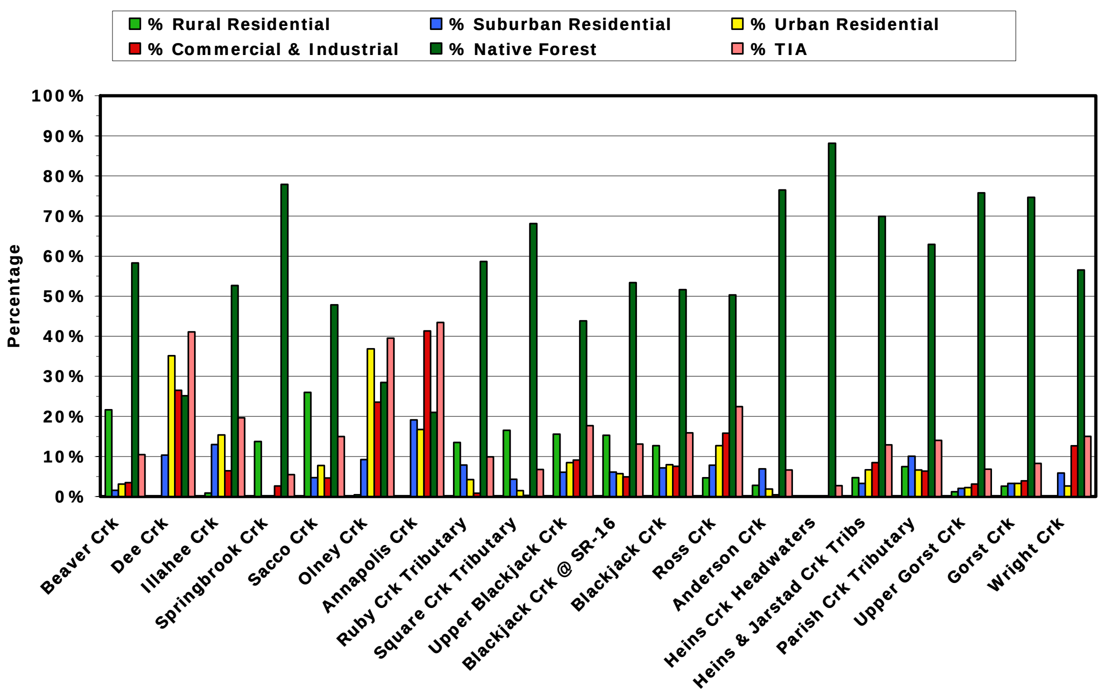

Figure 3-15. Sinclair Inlet Watershed Stream Subbasin Land Use and Land Cover

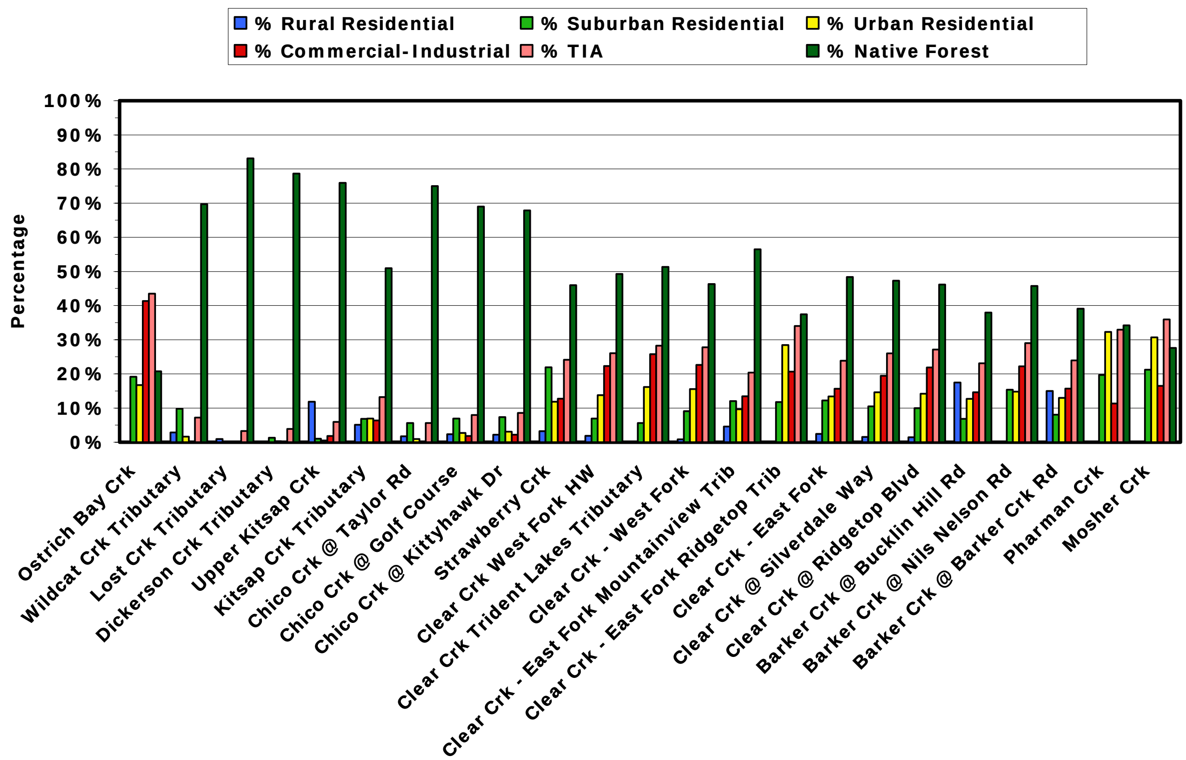

Figure 3-16. Dyes Inlet Watershed Stream Subbasin Land Use and Land Cover

In general, the streams in more developed subwatersheds have less natural, narrower, and more fragmented riparian corridors. The more undeveloped subwatersheds, such as Anderson, Chico, and Gorst Creeks have relatively intact riparian corridors, although there is a general lack of mature conifers in most riparian zones due to historical land-use practices and timber harvest. Figures 3-21 through 3-23 show the riparian conditions in the Sinclair-Dyes Inlet watershed.

Several of the streams in the study area also have long-term, continuous-flow gages installed on them (Table 3-10). In addition, several precipitation gages are also located within the study area (Figure 3-24). These monitoring stations were used to characterize weather and streamflow conditions within the Sinclair-Dyes Inlet watershed. Figures 3-25 and 3-26 show the typical streamflow and rainfall patterns for the study area, which typify the “wet” and “dry” seasons of the Pacific Northwest.

Additional streamflow gage stations installed for the Sinclair-Dyes Inlet watershed project include the following (2001 to 2004 streamflow coverage):

- Clear Creek East Fork
- Clear Creek West Fork
- Gorst Creek Headwaters
- Chico Creek Headwaters
- Dickerson Creek
- Kitsap Creek.

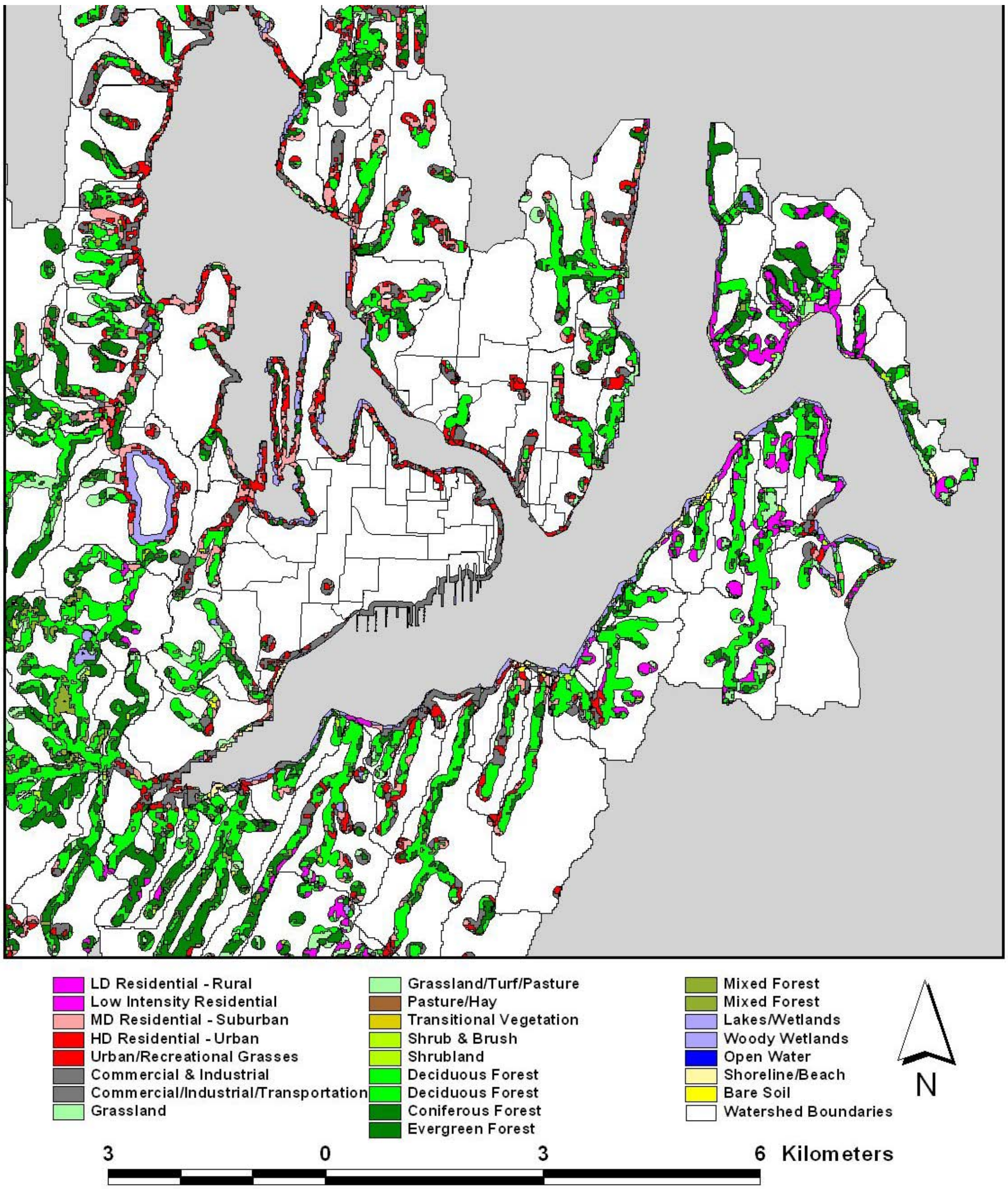

Figure 3-17. Sinclair-Dyes Inlet Watershed Riparian Assessment Results

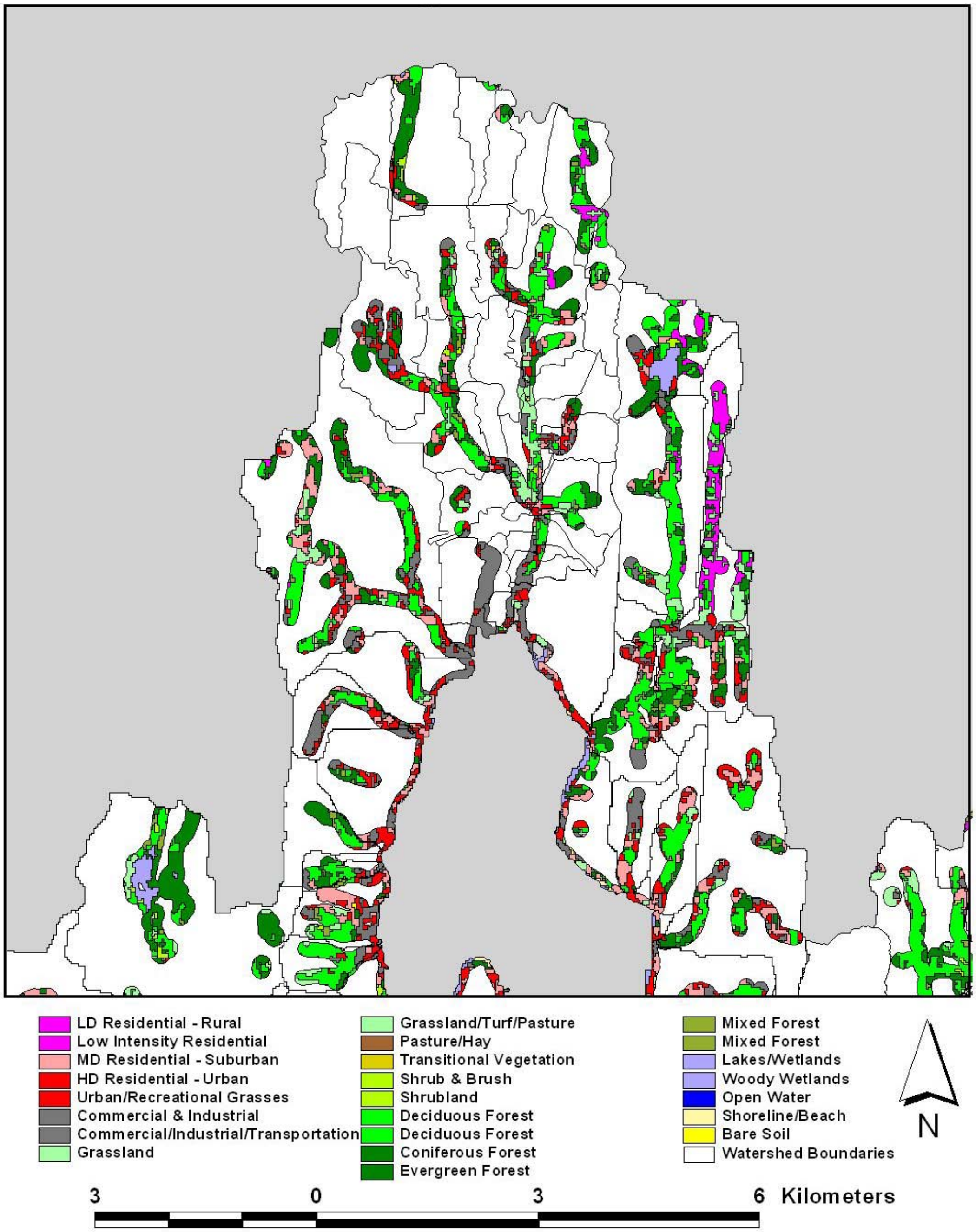

Figure 3-18. Sinclair-Dyes Inlet Watershed Riparian Assessment Results

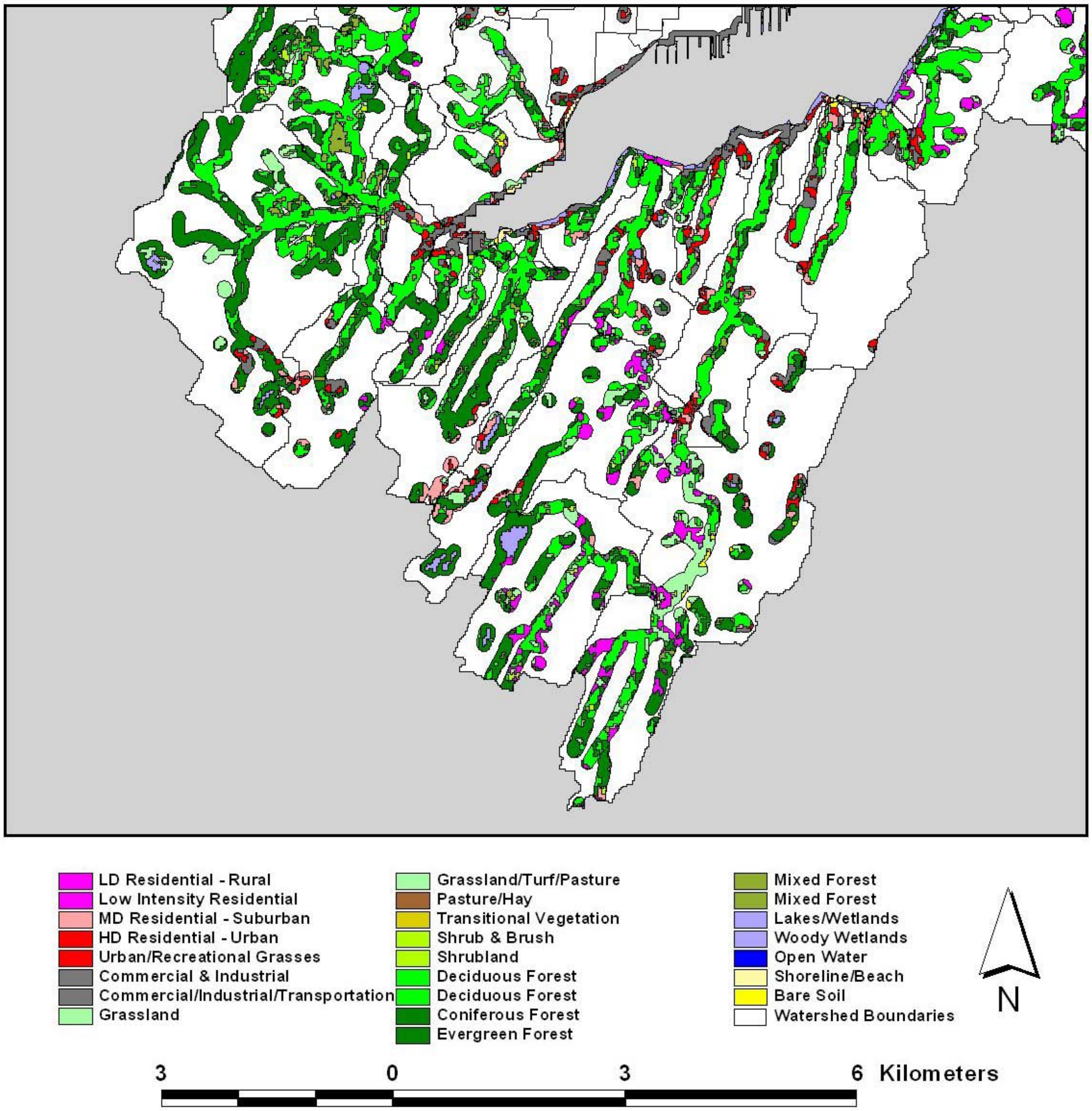

Figure 3-19. Sinclair-Dyes Inlet Watershed Riparian Assessment Results

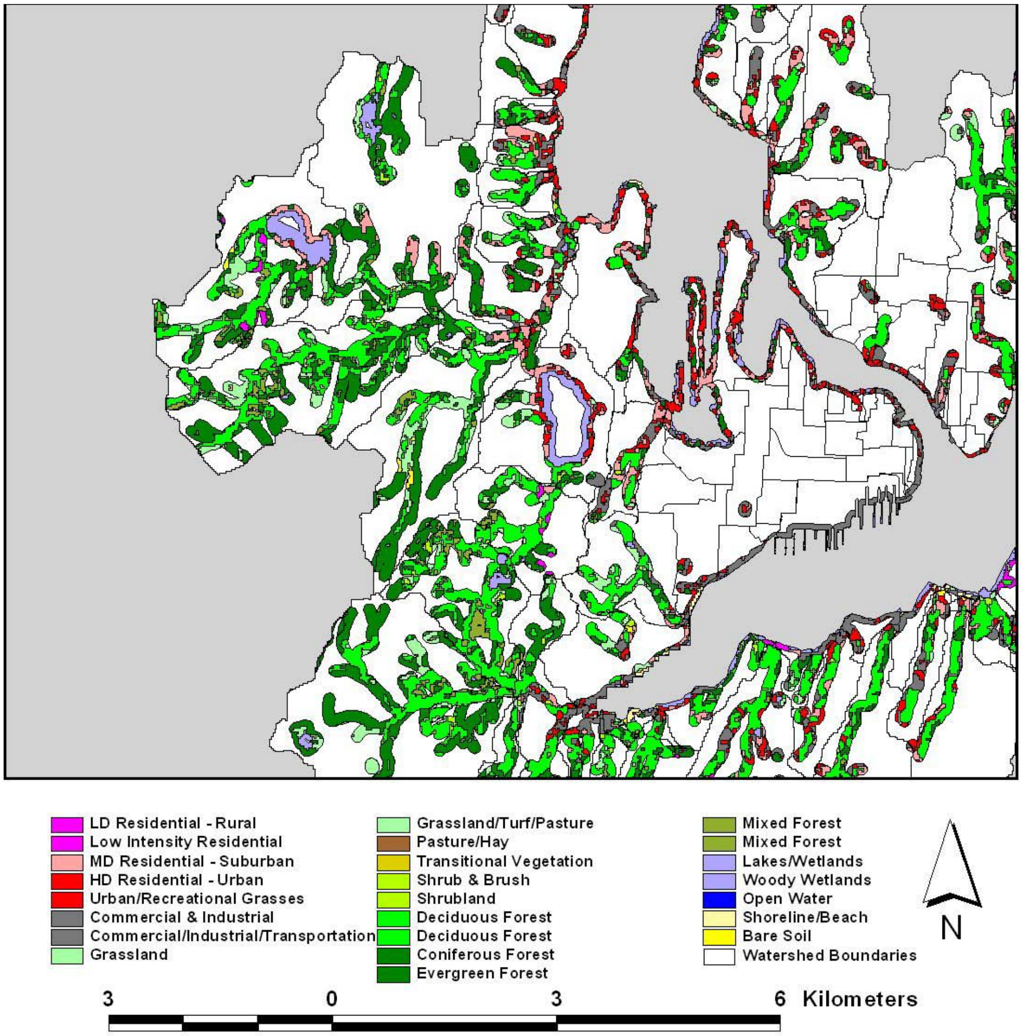

Figure 3-20. Sinclair-Dyes Inlet Watershed Riparian Assessment Results

Table 3-9. Land-Use and Land-Cover Data for Major Stream Riparian Corridors in the Sinclair-Dyes Inlet Watershed

	Stream Subwatershed	WQ ID	% Urban (HD Resident)	% Commercial & Industrial	% Suburban (MD Resident)	% Rural (LD Resident)	% Agricultural	% Developed	%TIA	% Deciduous Forest	% Coniferous Forest	% Mixed Forest	% Forest	Stream-Road Crossings (#/km)
Yukon Harbor	Beaver Crk	BVR	1.6%	2.2%	1.1%	10.1%	14.1%	29.0%	7.6%	60.5%	8.3%	0.8%	70%	0.6
Rich Passage	Sacco Crk	SACCO	8.0%	4.7%	1.8%	7.6%	2.3%	24.5%	11.7%	71.0%	2.6%	0.9%	74%	1.1
Sinclair Inlet	Olney Crk	OC	5.5%	1.3%	7.0%	0.0%	0.0%	13.8%	9.0%	74.2%	9.2%	0.2%	84%	1.0
Sinclair Inlet	Annapolis Crk (LMK136)	ANNP	13.9%	19.4%	8.9%	0.0%	3.3%	45.4%	25.3%	47.1%	4.5%	0.0%	52%	2.2
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	1.3%	0.4%	4.2%	10.6%	18.1%	34.6%	6.8%	18.6%	37.0%	0.0%	56%	0.2
Sinclair Inlet	Square Crk Tributary	BL-SQR	0.0%	0.3%	0.5%	9.3%	8.6%	18.8%	4.1%	29.5%	35.8%	2.4%	68%	0.3
Sinclair Inlet	Upper Blackjack Crk	BL-HW	1.6%	3.6%	2.6%	10.0%	22.3%	40.1%	9.1%	25.6%	29.8%	1.5%	57%	0.8
Sinclair Inlet	Blackjack Crk @ SR-16	BL	1.0%	1.9%	2.4%	10.0%	17.4%	32.7%	7.1%	25.0%	33.3%	1.4%	60%	0.5
Sinclair Inlet	Blackjack Crk	BL-KFC	1.9%	2.7%	2.8%	8.4%	15.2%	31.1%	8.0%	30.3%	30.5%	1.6%	62%	0.6
Sinclair Inlet	Ross Crk	ROSS	7.0%	5.7%	5.7%	2.4%	4.6%	25.4%	12.0%	42.8%	21.0%	3.4%	67%	0.6
Sinclair Inlet	Anderson Crk	AC	2.3%	0.7%	5.8%	0.5%	3.9%	13.2%	5.7%	26.2%	56.8%	2.9%	86%	0.5
Sinclair Inlet	Heins Crk Headwaters	GC-HW	0.0%	0.0%	0.0%	0.0%	5.4%	5.4%	2.8%	53.6%	19.9%	13.3%	87%	0.4
Sinclair Inlet	Heins & Jarstad Crk Tributaries	GC-HNS	1.3%	1.8%	1.1%	0.0%	8.7%	12.9%	4.7%	32.5%	47.9%	3.4%	84%	0.7
Sinclair Inlet	Parish Crk Tributary	GC-PA	4.0%	6.3%	5.6%	1.3%	2.9%	20.1%	10.4%	38.9%	38.0%	1.5%	78%	0.7
Sinclair Inlet	Upper Gorst Crk	GC-JAR	0.0%	0.0%	0.0%	0.0%	5.4%	5.4%	2.8%	53.6%	19.9%	13.3%	87%	0.4
Sinclair Inlet	Gorst Crk	GC	2.1%	2.7%	1.5%	0.4%	6.4%	13.1%	5.9%	39.5%	37.6%	5.7%	83%	0.5
Sinclair Inlet	Wright Crk	WC	0.1%	4.9%	2.1%	0.0%	17.2%	24.3%	7.7%	59.6%	10.8%	1.3%	72%	0.9
Dyes Inlet	Ostrich Bay Crk	OBC	16.0%	20.8%	19.0%	0.0%	1.1%	56.9%	29.3%	33.7%	5.6%	1.6%	41%	3.1
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	0.2%	0.0%	6.7%	1.5%	7.1%	15.5%	4.8%	30.4%	33.0%	4.2%	68%	0.4
Dyes Inlet	Lost Crk Tributary	CH-LST	0.0%	0.0%	0.0%	0.0%	6.8%	6.8%	2.8%	49.0%	32.7%	9.5%	91%	0.1
Dyes Inlet	Dickerson Crk Tributary	CH-DI	21.4%	0.0%	15.4%	0.0%	0.0%	36.8%	18.0%	4.3%	56.8%	0.0%	61%	0.5
Dyes Inlet	Upper Kitsap Crk	CH-KL	0.0%	0.0%	2.5%	5.4%	9.1%	16.9%	4.7%	62.2%	16.3%	3.2%	82%	0.2
Dyes Inlet	Kitsap Crk Tributary	CH-KC	8.8%	2.2%	8.1%	2.2%	8.0%	29.3%	11.4%	31.9%	16.5%	2.0%	50%	0.5
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	0.2%	0.3%	4.2%	0.8%	6.9%	12.5%	4.3%	37.9%	32.8%	6.3%	77%	0.3
Dyes Inlet	Chico Crk @ Golf Course	CH	2.0%	0.8%	5.4%	0.9%	8.4%	17.5%	6.1%	34.8%	32.2%	4.9%	72%	0.4
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	2.3%	1.4%	5.7%	0.9%	8.4%	18.5%	6.7%	35.2%	31.4%	4.7%	71%	0.4
Dyes Inlet	Strawberry Crk	SC	9.3%	11.0%	20.4%	0.6%	6.6%	47.9%	21.3%	31.1%	19.2%	1.2%	52%	1.2
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	5.1%	6.9%	8.8%	4.0%	2.4%	27.2%	12.0%	23.3%	47.9%	1.3%	72%	0.8
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	24.9%	25.4%	7.1%	0.0%	0.0%	57.4%	23.3%	8.1%	29.8%	1.3%	39%	0.9
Dyes Inlet	Clear Crk - West Fork	CC-CW	12.3%	12.2%	8.7%	0.0%	2.8%	36.0%	19.3%	25.8%	32.5%	2.5%	61%	1.0
Dyes Inlet	Clear Crk - East Fork Mountainview Tributary	CC-MTV	20.4%	9.2%	3.5%	0.0%	0.6%	33.8%	20.1%	36.2%	24.9%	0.1%	61%	1.5
Dyes Inlet	Clear Crk - East Fork Ridgetop Tributary	CC-RTP	13.2%	9.9%	18.5%	0.0%	23.5%	65.1%	23.5%	31.3%	3.3%	0.0%	35%	3.3
Dyes Inlet	Clear Crk - East Fork	CC-CE	7.4%	4.1%	7.7%	6.6%	12.9%	38.7%	13.2%	40.3%	17.7%	2.4%	60%	1.5
Dyes Inlet	Clear Crk @ Silverdale Way	CC	10.1%	8.5%	8.3%	3.0%	7.4%	37.2%	16.5%	32.4%	25.7%	2.5%	61%	1.2
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	11.2%	9.7%	8.3%	2.2%	11.4%	42.9%	18.2%	32.6%	20.6%	2.0%	55%	1.3
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	5.3%	7.4%	4.9%	4.1%	4.8%	26.5%	11.9%	35.9%	20.9%	0.1%	57%	1.0
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	6.1%	8.4%	5.3%	11.5%	11.2%	42.6%	14.7%	31.0%	17.0%	0.8%	49%	0.4
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	6.2%	8.3%	7.0%	9.0%	8.8%	39.3%	14.7%	33.4%	18.8%	1.5%	54%	0.9
Dyes Inlet	Pharman Crk	PA	10.1%	11.2%	17.4%	0.0%	2.8%	41.5%	20.4%	32.1%	13.4%	0.9%	46%	2.0
Dyes Inlet	Mosher Crk	MS	13.3%	8.7%	24.1%	0.0%	2.3%	48.4%	22.8%	31.8%	17.4%	2.3%	52%	1.7
PO Passage	Dee Crk	DEE	17.2%	4.7%	20.0%	10.0%	1.4%	53.3%	22.2%	44.1%	0.1%	0.0%	44%	2.0
PO Passage	Illahee Crk	ILL	2.4%	2.5%	5.5%	0.0%	7.4%	17.8%	7.9%	69.2%	10.2%	0.9%	80%	0.6
PO Passage	Springbrook Crk	BI-SBC	0.0%	0.0%	15.0%	10.0%	0.0%	25.0%	7.0%	40.0%	20.0%	15.0%	75%	0.3

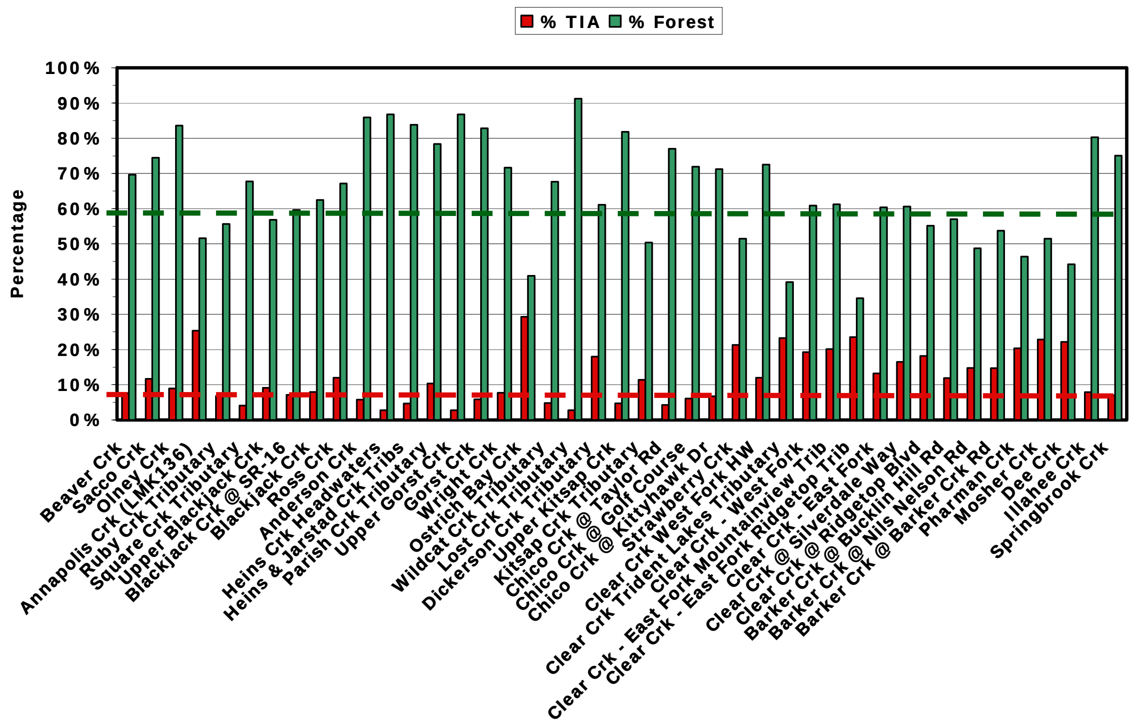

Figure 3-21. Land-Use and Land-Cover Conditions for Major Stream Riparian Corridors in the Sinclair-Dyes Inlet Watershed

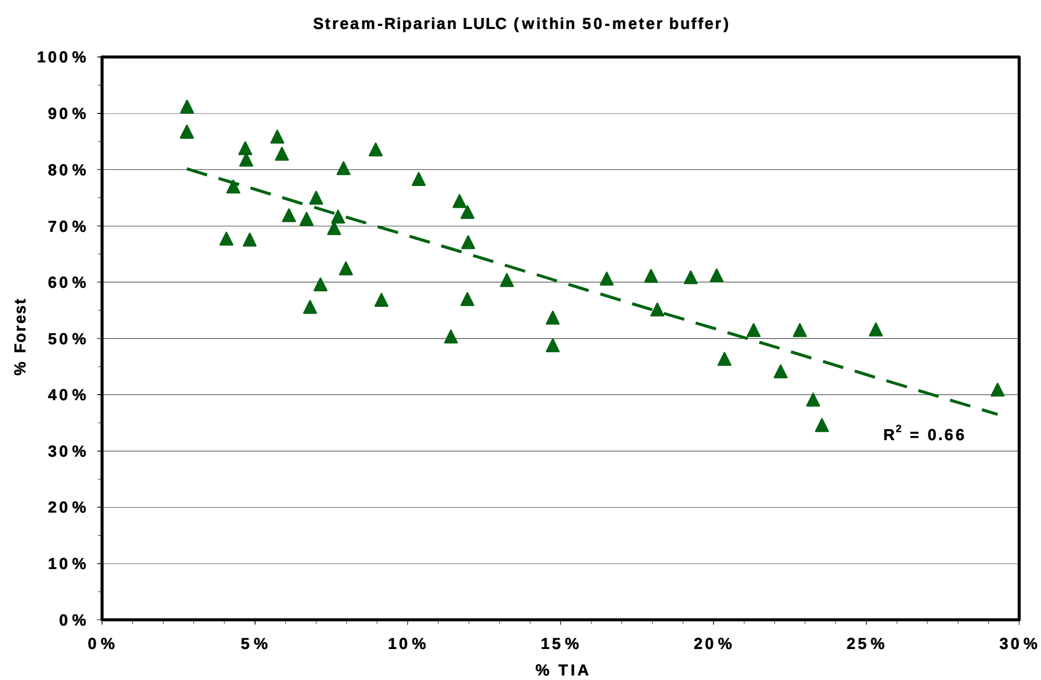

Figure 3-22. Land-Use and Land-Cover Conditions for Major Stream Riparian Corridors in the Sinclair-Dyes Inlet Watershed

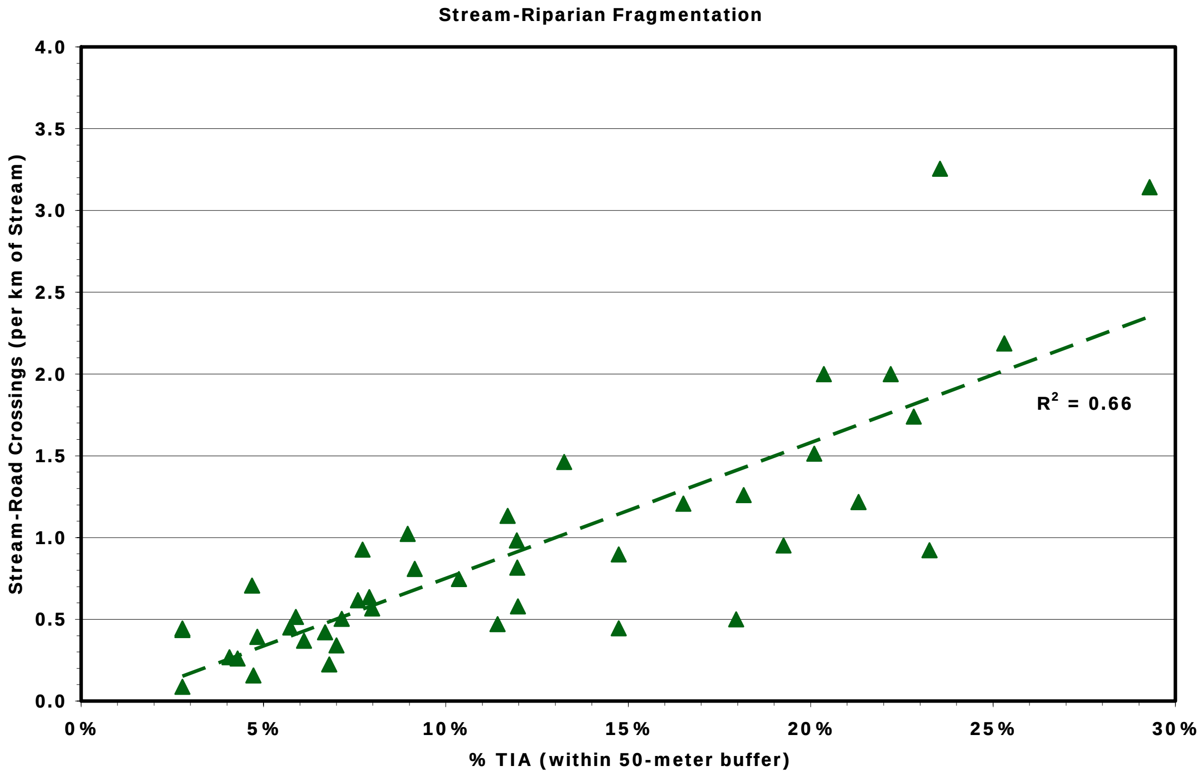

Figure 3-23. Land-Use and Land-Cover Conditions for Major Stream Riparian Corridors in the Sinclair-Dyes Inlet Watershed

Table 3-10. Kitsap Public Utilities District Streamflow Gage Stations

Stream	KPUD ID	WRIA-15#	Period of Flow Data Record
HANSVILLE CREEK	HC	166	1996 - Present (KPUD)
GAMBLE CREEK	GA	158	1994 - 96 (USGS) & 1996 - Present (KPUD)
DOGFISH CREEK	DC	207	1990 - Present (KPUD)
JOHNSON CREEK	LJ	208	1994 - 96 (USGS) & 1996 - Present (KPUD)
CLEAR CREEK	CC	246	1990 - Present (KPUD)
BARKER CREEK	BA	245	1991 - Present (KPUD)
STRAWBERRY CREEK	SC	248	1991 - Present (KPUD)
CHICO CREEK	CH	259	1991 - 96 & 1999 - Present (KPUD)
GORST CREEK	GC	268	1990 - 96, 2000 - Present KPUD
ANDERSON CREEK	AC	272	1991 - Present (KPUD)
BLACKJACK CREEK	BL	279	1993 - 1997 & 2000 - Present (KPUD)
OLNEY CREEK	OC	282	1997 - Present (KPUD)
BIG ANDERSON CREEK	AN	096	1994 - Present (KPUD)
BURLEY CREEK	BC	356	1990 - Present (KPUD)
BOYCE CREEK	BO	111	1999 - Present (KPUD)
LITTLE ANDERSON CREEK	AS	124	1999 - Present (KPUD)
GOLD CREEK	GO	655	2000 - Present (KPUD)
SEABECK CREEK	SE	117	1999 - Present (KPUD)

Highlighted sites are in the Sinclair-Dyes Inlet Watershed

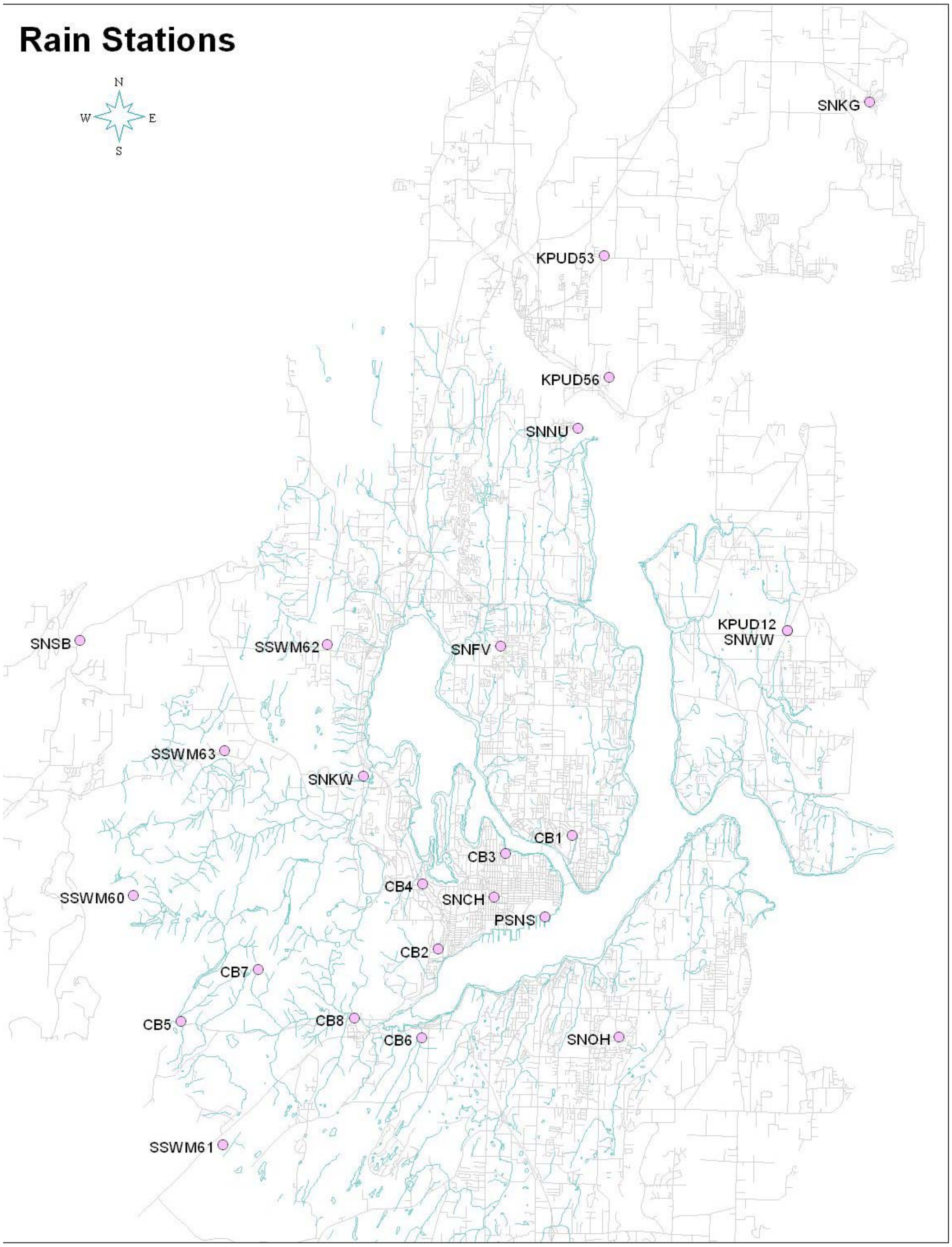

Figure 3-24. Sinclair-Dyes Inlet Watershed Precipitation Gage Stations

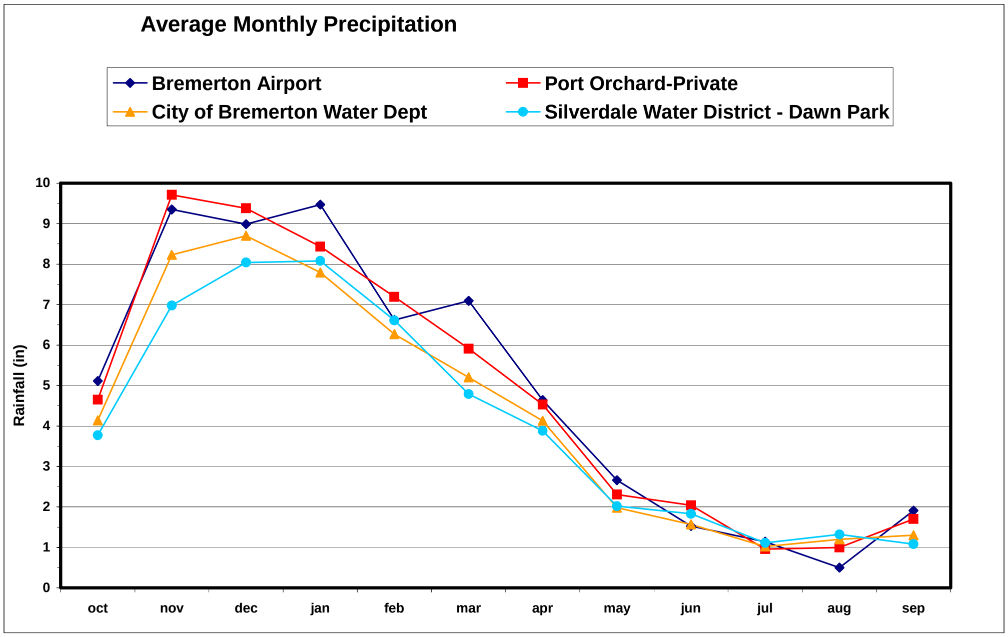

Figure 3-25. Sinclair-Dyes Inlet Watershed Rainfall Data

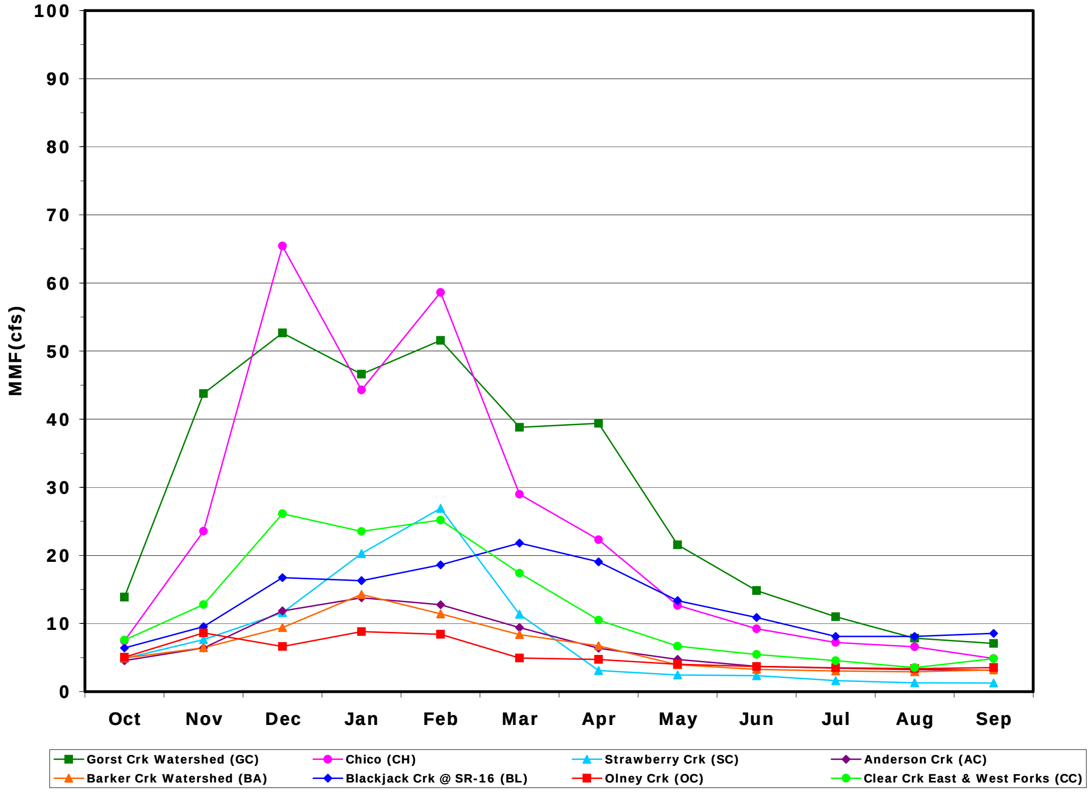

Figure 3-26. Sinclair-Dyes Inlet Watershed Streamflow Data

3.3 Ecological Assessment

An *ecological assessment* is simply the quantitative evaluation of selected ecosystem attributes. This process is often conducted on a watershed scale, especially when water resources are a primary concern. Proper ecosystem management requires an understanding of physical, chemical, and biological conditions. Without an objective, scientifically defensible assessment of current conditions and trends, it is impossible to design management strategies to preserve natural resources in the face of human activities. Therefore, assessment represents the first step in an ongoing process of compiling and analyzing technical information on ecosystem conditions and the effect of human activities on those conditions.

Assessment methods and approaches range widely, based on the question being asked and available knowledge. For example, multi-metric indices of habitat quality and condition are composites of several environmental variables that have been developed to evaluate aquatic resources and to assess the effects of anthropogenic degradation. In the case of this study, FC is being used as the primary assessment parameter to measure bacterial pollution from human-related sources. However, in addition to FC levels, the biological condition of streams flowing into Sinclair-Dyes Inlet was monitored to assess the cumulative effects of human activities on the natural system. An evaluation of the biological condition of freshwater resources is one of the primary components of the overall ecological assessment of the watershed. In the context of this report, the information obtained from a biological assessment can be used to supplement bacterial contamination data in evaluating the impacts of pollution on the ecosystem.

Biological assessments have become increasingly important tools for managing water quality to meet the goals of the Clean Water Act (CWA). These methods, which use measurements of aquatic biological communities, are particularly important for evaluating the impacts of pollutants for which there are no WQS, and of non-chemical stressors, such as flow alteration, siltation, and invasive species. However, although biological assessments are critical tools for detecting impairment, they do not identify the cause or causes of the impairment. Linking biological effects with their causes is particularly complex when multiple stressors affect a water body. Investigation procedures are needed that can successfully identify the stressor(s) and lead to appropriate corrective measures. Water management programs have historically shown that aquatic life protection can be accomplished most effectively using integrated information from various sources.

In addition to detailed biological monitoring data, other assessment methods may integrate information on habitat distribution and change, land use, and human activities to guide regional ecosystem management efforts. For example, watershed assessments form the basis for managing water resources and rely on conceptual models of watershed structure to help determine how well a watershed is functioning and how it responds to natural and human disturbances. GIS-based landscape models have been increasingly used to evaluate ecological conditions in watersheds and to quantify factors, both natural and human-caused, that affect the physical, biological, and chemical attributes of a watershed. These watershed attributes include hydrologic conditions, soil erosion, sediment load and sources, natural vegetation patterns and characteristics, habitat conditions within the watershed, biological communities, and water quality conditions. Regardless of the assessment approach, it is often useful for management purposes to ultimately describe conditions in terms of a few qualitative categories.

One final measure of watershed condition used in this project was biological integrity, which is an extremely important component of measuring ecological conditions within a watershed (Karr 1991). In accordance with the CWA, *biological integrity* is defined as a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region. Monitoring the native biota of an ecosystem is critical to understanding the cumulative impacts of all stressors, of which bacterial pollution is one of many in the urbanizing environment.

As was discussed earlier, *aquatic life* is a beneficial-use designation identified by the state, in which a water body provides suitable habitat for the survival and reproduction of desirable fish, shellfish, and other aquatic organisms. Measuring biological integrity, along with water quality criteria such as bacterial (FC) levels, is one way to monitor the attainment of this beneficial use or its impairment.

The specific method of biological assessment applied to this project is the benthic index of biological integrity (B-IBI), a multi-metric index based on attributes of the benthic invertebrate community (Karr 1991; May et al., 1997a,b; Karr and Chu 1999; Morley 2000). This method of biological monitoring is widely accepted in the Pacific Northwest (Oregon / Washington) and with a majority of jurisdictions in North America.

Benthic dwelling macroinvertebrates are particularly well-suited for biological monitoring. Many are relatively sedentary and nonmigratory, usually diverse and abundant, sensitive to human disturbance, long-lived, and serve as good indicators of stream condition in that they are key components of the aquatic food web (Rosenberg and Resh 1993; Reynoldson et al., 1997; Karr and Chu 1999). Macroinvertebrate communities also tend to have greater diversity than do fish communities (especially true of salmon) in the same stream, which makes evaluation with community diversity metrics more meaningful. Also, sport fishing, stocking of hatchery fish, and the introduction of exotic species often compromise the natural biological integrity of fish communities. In addition, in the case of salmon, the fish are only in the stream during specific periods of the year and so may not be exposed to the full suite of disturbances.

The B-IBI is composed of ten metrics of taxa richness and diversity, population attributes, disturbance tolerance, and feeding and other habits (Table 3-11). For a given invertebrate attribute to be included as a metric in the B-IBI, it must respond predictably along a gradient of anthropogenic disturbance (Fore et al., 1996; Horner and May 1999; Karr and Chu 1999). This dose-response relationship was tested during initial B-IBI development in the Puget Sound region (Karr and Chu 1999) and has been replicated in subsequent years of study (Fore et al., 1996; May et al., 1997a,b; Horner and May 1999; Karr and Chu 1999; Morley 2000). When values from the ten metrics are combined, B-IBI ranges from a minimum of 10 to a maximum of 50 and can detect five categories of resource condition (Table 3-12).

The Sinclair-Dyes Inlet biomonitoring sites are shown in Figure 3-27. Table 3-13 and Figure 3-28 show a summary of the B-IBI data collected in the study area. Figure 3-29 shows the B-IBI scores in relation to overall watershed urbanization or development level, expressed in terms of the total percentage of the watershed that is covered by impervious surfaces (TIA). Studies in the Puget Sound region and elsewhere in the country have displayed a similar characteristic relationship between human influence on a watershed scale and the level of degradation of aquatic ecosystems (Richards and Host 1994; Richards et al., 1996; Richards et al., 1997; May et al., 1997a,b; Horner and May 1999).

A majority of the sites sampled in the Sinclair-Dyes Inlet watershed scored in the fair-good range. However, several streams were rated as either “poor” or “impaired,” indicating that conditions are not fully functional in several locations. Although development has had an effect on the aquatic ecosystems within the study area, the level of development has not yet reached the level at which a majority of the water resources are severely degraded, except in a few locations where development levels can be considered HD suburban or urban (e.g., Clear, Olney, and Strawberry Creeks). Several B-IBI sample sites showed the effects of local development conditions around the stream, which lowered the scores below that which would be expected based on the level of watershed development (e.g., lower Gorst Creek, Kitsap Creek below Kitsap Lake, and Blackjack creek above State Route 16).

Table 3-11. Metrics of the Pacific Northwest Benthic Index of Biological Integrity and their Predicted and Observed Responses to Watershed Development (Karr and Chu 1999)

Metric	Category	Response	Scoring Criteria		
			1	**3**	**5**
Total Taxa (#)	Richness	Overall biodiversity decreases as aquatic ecosystem is altered	0-19	20-40	>40
Mayfly (*Ephemeroptera*)	Richness	Diversity of Mayflies generally declines with human influences. Particularly sensitive to chemical pollutants and changes in nutrients or food sources.	0-4	5-8	>8
Stonefly (*Plecoptera*)	Richness	Some of the most sensitive organisms. Very sensitive to sedimentation of substrata and to higher stream temperature.	0-3	4-7	>7
Caddis-fly (*Tricoptera*)	Richness	Diversity declines steadily with human influences, especially hydrologic changes	0-4	4-9	≥10
Long-Lived Taxa	Richness	Live in stream for more than 1 year. Sensitive to human influences that change annual cycles such as hydrologic regime	0-2	3-4	>4
Dominance of the 3 most common Taxa (%)	Relative Abundance	As biodiversity declines with human influence, a few taxa tend to dominate the macroinvertebrate assemblage. Opportunistic species tend to increase.	>75%	50-75%	<50%
Sensitive Taxa	Richness	Intolerant taxa are the first to disappear with human influence	0-2	3	>3
Tolerant Taxa (%)	Relative Abundance	Tolerant taxa are always present, but as human disturbance increases, these organisms begin to dominate the macroinvertebrate assemblage.	>50%	20-50%	<20%
Clinger Taxa	Richness	These organisms live on the streambed substrata. Very sensitive to siltation and flow increases resulting from human land-use activities.	0-10	11-20	>20
Predators (%)	Relative Abundance	Represent the top of the benthic macroinvertebrate food-web. Depend on abundance and diversity of other macroinvertebrate organisms. Less disturbed sites tend to support a greater diversity of prey and thus have more predators.	0-10%	10-20%	>20%

In the case of the Gorst Creek restoration site, which had a relatively low B-IBI score, the natural recovery process has begun after recent completion of the restoration effort; therefore, the biological integrity is likely to improve as recovery continues. Finally, no Sinclair-Dyes Inlet watershed streams were rated as “excellent” or what would generally be considered a natural, reference condition. This quality of streams is generally only found in undeveloped areas, usually with extensive native forest cover, wetlands, and relatively intact riparian corridors.

Table 3-12. Descriptive Categories of Biological Condition Using the Benthic Index of Biological Integrity (Morley 2000)

Biological Condition	B-IBI Score	Description
Excellent	46-50	Comparable to least disturbed reference condition; overall high taxa diversity, particularly of mayflies, stoneflies, caddis-flies, long-lived, clinger, and intolerant taxa. Relative abundance of predators high.
Good	38-44	Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of mayflies, stoneflies, and caddis-flies; proportion of tolerant taxa increases.
Fair	28-36	Total taxa richness reduced - particularly intolerant, long-lived, stoneflies, and clinger taxa. Relative abundance of predators declines; proportion of tolerant taxa continues to increase.
Poor	18-26	Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; dominance by three most abundant taxa often very high.
Very Poor	10-16	Overall taxa diversity very low and dominated by a few highly tolerant taxa; mayfly, stonefly, caddis-fly, clinger, long-lived and intolerant taxa largely absent. Relative abundance of predators very low.

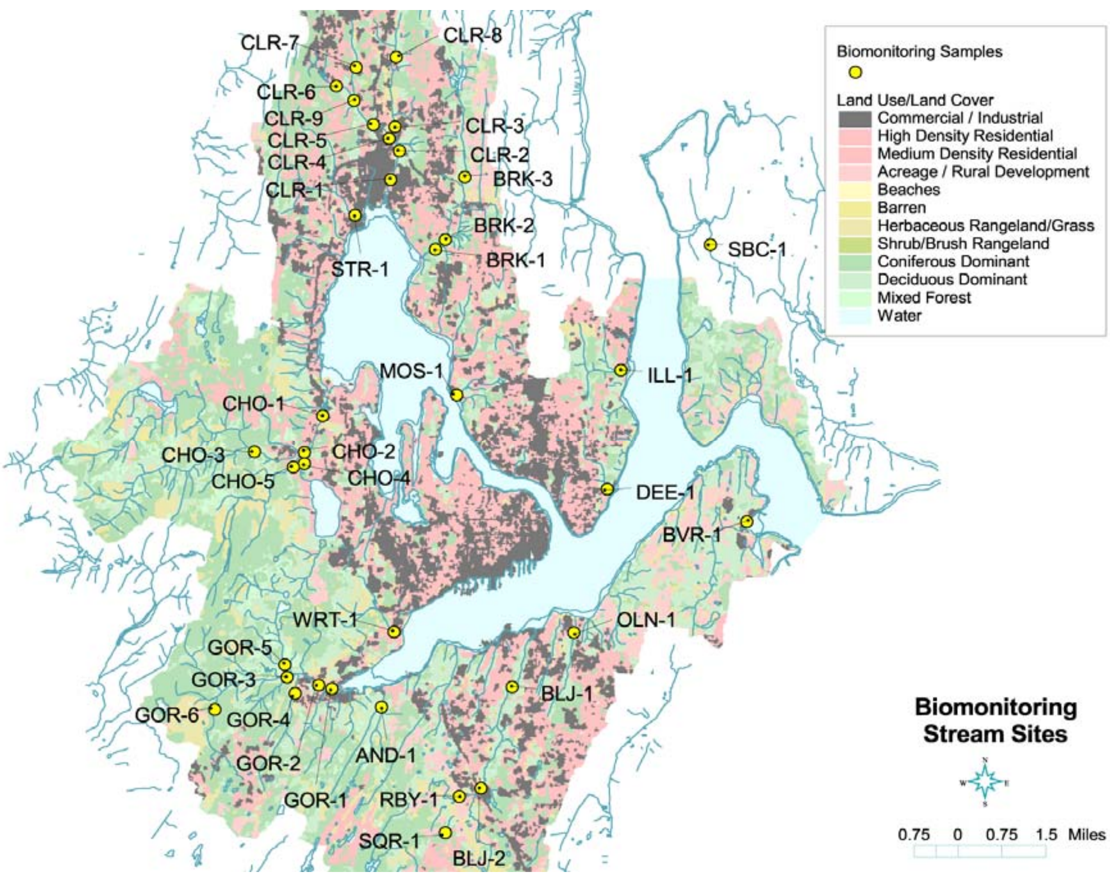

Figure 3-27. Biological Monitoring Sites in the Streams in the Sincalir-Dyes Inlet Watershed

Table 3-13. Summary of Benthic Index of Biotic Integrity Scores for Streams in the Sinclair-Dyes Inlet Watershed Study Area. (In addition to the actual B-IBI score, the percentage of optimal score is also shown for comparison.)

Kitsap Biological Monitoring Data Summary				2003	2003	2002	2002	2001	2001	2000	2000
Stream	**Site ID#**	**Sample Team**	**Site Location/Description**	**B-IBI**	**B-IBI**	**B-IBI**	**B-IBI**	**B-IBI**	**B-IBI**	**B-IBI**	**B-IBI**
Anderson	AND-1	PSNS-UW	100 m upstream of Bremerton Water Facilities and KPUD Gage Site	**37**	**68%**	**38**	**70%**			**32**	**55%**
Annapolis	ANP-1	PSNS-UW	Lower Mainstem @ Marine Drive	**24**	**35%**						
Barker	BRK-1	Stream Team	Lower Mainstem @ Barker Creek Road	**36**	**65%**	**32**	**55%**	**40**	**75%**	**36**	**65%**
Barker	BRK-2	PSNS-UW	Middle Mainstem @ Nils Nelson Road	**34**	**60%**					**38**	**70%**
Barker	BRK-3	PSNS-UW	Upper Mainstem upstream of Waaga Way	**26**	**40%**					**44**	**85%**
Beaver	BVR-1	PSNS-UW	10 m downstream of Beaver creek Road Culvert @ Manchester	**34**	**60%**	**36**	**65%**				
Blackjack	BLJ-1	Stream Team	100 m upstream of Kendall Street trail bridge	**36**	**65%**	**32**	**55%**	**36**	**65%**	**30**	**50%**
Blackjack	BLJ-2	PSNS-UW	10 m upstream of SR-16 Culvert @ KPUD Gage Site	**28**	**45%**	**28**	**45%**			**22**	**30%**
Chico	CHO-1	SSWM	Lower Mainstem @ Earlands Point Road	**30**	**50%**	**36**	**65%**	**32**	**55%**	**34**	**60%**
Chico	CHO-2	PSNS-UW	Middle Mainstem - 10 m upstreram of Taylor Road Bridge	**40**	**75%**	**36**	**65%**	**36**	**65%**	**36**	**65%**
Chico	CHO-3	SSWM	Upper Mainstem @ Mountaineers	**40**	**75%**	**38**	**70%**	**46**	**90%**	**42**	**80%**
Chico	CHO-4	SSWM	Kitsap Creek Tributary @ Taylor Road	**20**	**25%**	**18**	**20%**	**18**	**20%**	**18**	**20%**
Chico	CHO-5	SSWM	Dickerson Creek upstream of RR bridge	**34**	**60%**	**38**	**70%**	**46**	**90%**	**42**	**80%**
Chico	CHO-6	PSNS-UW	Lost Creek @ Mountaineers	**32**	**55%**						
Chico	CHO-7	PSNS-UW	Wildcat Creek @ Mountaineers	**34**	**60%**						
Clear	CLR-1	PSNS-UW	Lower Mainstem @ Silverdale (10 m downstream of Ridgetop Blvd)	**24**	**35%**	**22**	**30%**			**16**	**15%**
Clear	CLR-2	PSNS-UW	Middle Mainstem @ KPUD Gage Site @ Silverdale Way	**22**	**30%**	**30**	**50%**			**32**	**55%**
Clear	CLR-3	PSNS-UW	East Fork - 10 m upstream of Schold Road	**32**	**55%**	**40**	**75%**			**34**	**60%**
Clear	CLR-4	PSNS-UW	West Fork - 10 m upstream of Schold Road	**22**	**30%**	**24**	**35%**			**28**	**45%**
Clear	CLR-5	PSNS-UW	West Fork - @ Clear Creek Road @ KPUD Gage Site			**26**	**40%**			**30**	**50%**
Clear	CLR-6	PSNS-UW	West Fork - Trident lakes Tributary - 100 m downstream of NSB Bangor	**30**	**50%**	**32**	**55%**			**42**	**80%**
Clear	CLR-7	PSNS-UW	West Fork - North Tributary @ Melody Lane	**30**	**50%**	**38**	**70%**			**46**	**90%**
Clear	CLR-8	PSNS-UW	East Fork - Mountainview Tributary - 100 m downstream of SR-3 Culvert	**34**	**60%**	**32**	**55%**			**40**	**75%**
Clear	CLR-9	Stream Team	West Fork - North Tributary @ Half-Mile Road (100 m upstream)	**42**	**80%**	**34**	**60%**	**44**	**85%**	**35**	**63%**
Dee	DEE-1	PSNS-UW	Lower Mainstem @ access road	**30**	**50%**						
Gorst	GOR-1	PSNS-UW	Lower Mainstem - 500 m upstream of Estuary in Gorst	**18**	**20%**	**26**	**40%**			**20**	**25%**
Gorst	GOR-2	PSNS-UW	Lower Mainstem @ Jarstad Park Restoration Site	**28**	**45%**	**28**	**45%**			**26**	**40%**
Gorst	GOR-3	PSNS-UW	Middle Mainstem @ KPUD Gage Site	**34**	**60%**	**30**	**50%**			**42**	**80%**
Gorst	GOR-4	PSNS-UW	Parish Tributary @ Old Belfair Road (10 m downstream of culvert)	**34**	**60%**	**36**	**65%**			**34**	**60%**
Gorst	GOR-5	PSNS-UW	Heins Tributary 10 m upstream of Bremerton Access Road Culvert	**36**	**65%**	**46**	**90%**			**44**	**85%**
Gorst	GOR-6	PSNS-UW	Jarstad Tributary 10 m upstream of Bremerton Access Road Culvert	**30**	**50%**						
Gorst	GOR-7	PSNS-UW	Headwaters - 100 m upstream of Old Belfair Road @ Golf Course Road	**32**	**55%**	**40**	**75%**			**48**	**95%**
Illahee	ILL-1	Stream Team	100 m upstream of Illahee Road culvert	**30**	**50%**	**28**	**45%**	**22**	**30%**		
Mosher	MOS-1	PSNS-UW	10 m upstream of Tracyton Blvd Culvert	**30**	**50%**	**34**	**60%**				
Olney	OLN-1	PSNS-UW	100 m upstream of mouth @ Annapolis Sewage Treatment Plant	**18**	**20%**	**16**	**15%**				
Ross	RSS-1	PSNS-UW	101 m upstream of mouth @ Mexican Resturant	**28**	**45%**						
Ruby	RBY-1	PSNS-UW	100 m upstream of Glenwood Road Culvert @ Nature Preserve	**30**	**50%**	**36**	**65%**				
Sacco	SAC-1	PSNS-UW	Lower Mainstem upstream of estuary	**22**	**30%**						
Schel-Schelb	SSB-1	Bainbridge I.	Middle Mainstem @ private property	**26**	**40%**						
Springbrook	SPB-1	Bainbridge I.	100 m upstream of Fletcher Bay Road Culvert	**26**	**40%**						
Square	SQR-1	PSNS-UW	100 m upstream of Sidney Road Crossing (Freeberg Property)	**36**	**65%**	**38**	**70%**			**48**	**95%**
Strawberry	STR-1	PSNS-UW	10 m downstream of Old Silverdale Way Culvert	**30**	**50%**	**26**	**40%**			**33**	**58%**
Wright	WRT-1	PSNS-UW	100 m upstream of Estuary	**30**	**50%**	**34**	**60%**				

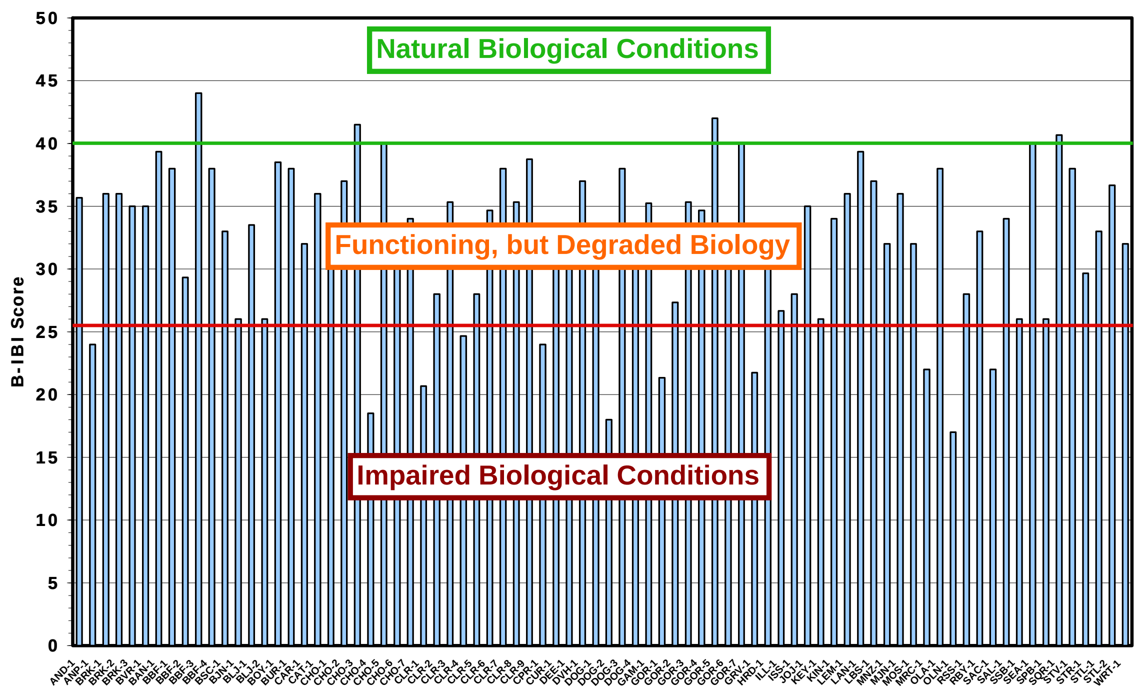

Figure 3-28. Biological Integrity of Streams in the Sinclair-Dyes Inlet Watershed as Measured by the Benthic Index of Biological Integrity for Sampled Streams

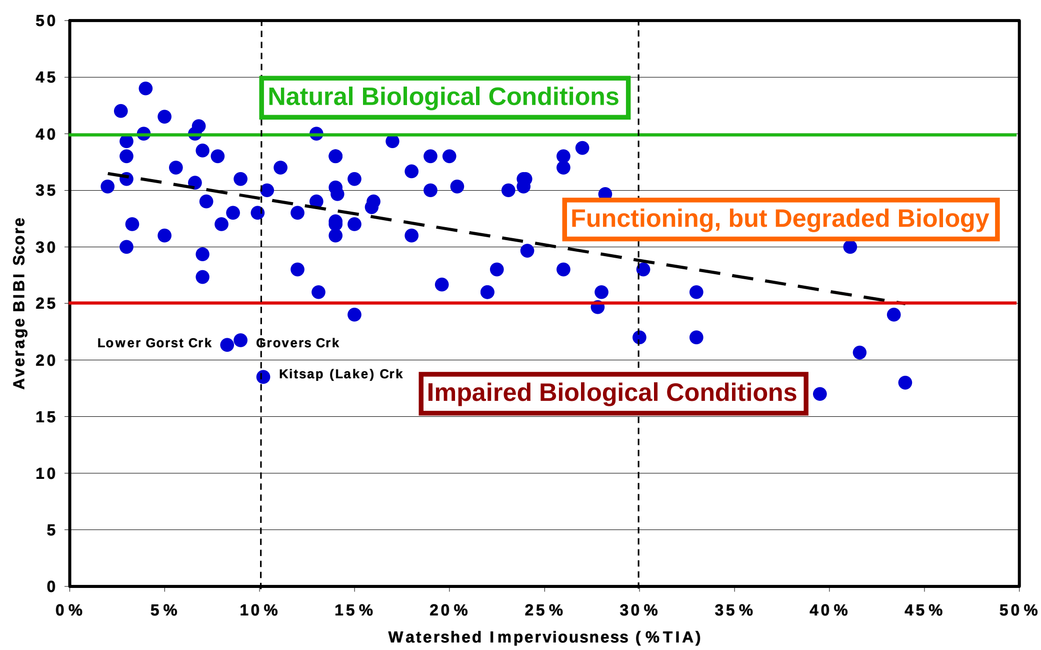

Figure 3-29. Biological Integrity of Streams in the Sinclair-Dyes Inlet Watershed as Measured by the Benthic Index of Biological Integrity in relation to Subbasin Imperviousness

4.0 Methods

Bacterial contamination data used in this study were obtained from multiple sources and included both existing historical data and current data obtained specifically for this study. Currently, there are several agencies and jurisdictions collecting data on bacterial contamination in Sinclair-Dyes Inlet. The agencies or groups that have jurisdiction within the Sinclair-Dyes Inlet watershed and that have FC data available include the following:

- Washington State Department of Health (WA-DOH)
- Washington State Department of Ecology (Ecology)
- Kitsap County Surface and Stormwater Management Department (KC-SSWM)
- Kitsap County Health District (KCHD)
- City of Bremerton
- City of Port Orchard
- City of Bainbridge Island
- Puget Sound Naval Shipyard (PSNS).

These data are primarily based on periodic FC sampling in the nearshore, marine waters, and freshwater streams draining to the Sinclair-Dyes Inlet watershed. Very few data are available from stormwater outfalls or runoff from developed areas within the watershed. The data from periodic sampling cover wet weather, storm events, and dry-weather periods, but mainly reflect weather conditions during a scheduled sampling event, rather than the results of a sampling scheme that specifically targeted a particular storm. Nevertheless, a wealth of data is available that provides a good foundation for developing an effective FC sampling plan to support the TMDL process. The available data from each organization were obtained and analyzed to identify known sources of bacterial contamination and to quantify those sources based on the most current existing data (Section 5). The elements of the Project ENVVEST sampling plan include the following:

- Base flow (dry weather) samples from major stormwater outfalls
- Storm event samples from major stormwater outfalls
- Base flow (dry weather) samples from major stream outlets
- Storm event samples from major stream outlets
- Base flow (dry weather) samples from major stream tributaries
- Storm event samples from major stream tributaries
- Nearshore marine samples during extended dry-weather periods
- Nearshore marine samples following major storm events.

Figure 4-1 shows the locations of FC sample stations in the Sinclair-Dyes Inlet watershed study area, and Table 4-1 shows the FC sample sites (only Project ENVVEST sampling sites are shown – historical sampling sites will be discussed in Section 5 of the report). Figures 4-2 through 4-12 show representative sample sites located within the Sinclair-Dyes Inlet watershed. Many of the FC sample stations were also equipped for automated water-quality sampling and flow measurement as part of the overall water-quality and stormwater monitoring effort. Flow monitoring is also needed to calculate pollutant loading in support of the TMDL process.

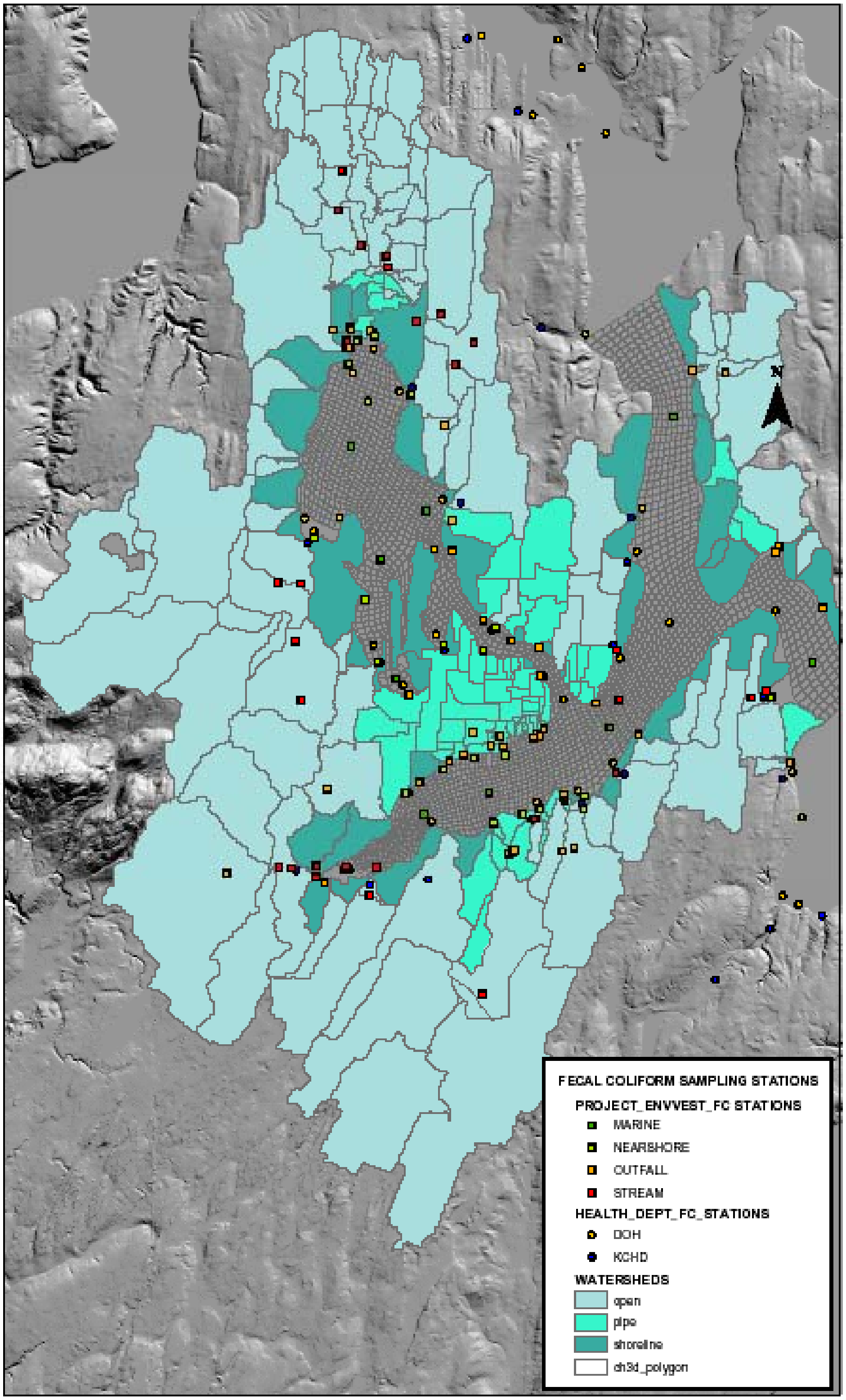

Figure 4-1. Sinclair-Dyes Inlet Watershed Bacterial Sample Stations

Table 4-1. Sinclair-Dyes Inlet Fecal Coliform Sample Sites

Sampling Stations	Jurisdiction	FC Sample Station ID	Target Sampling Frequency	Target Sample Type	Sample Site Location
City of Bremerton Stormwater Outfalls					
Callow Ave	City of Bremerton	SW1	3/Week	Storm Event	Outfall near Missouri Gate
Pacific Ave	City of Bremerton	SW2	3/Week	Storm Event	Outfall under PSNS Pier 7
Pine Rd	City of Bremerton	SW3	3/Week	Storm Event	Outfall at Lions Park Boat Ramp
Trenton Ave	City of Bremerton	SW4	3/Week	Storm Event	Outfall at bottom of Trenton Road near Gazebo
Stephenson Creek	City of Bremerton	SW5	3/Week	Storm Event	Outfall at Lendt Park Beach
Oyster Bay Ave	City of Bremerton	B-ST26	3/Week	Storm Event	Outfall at Oyster Bay Ave
Campbell Way	City of Bremerton	B-ST04	3/Week	Storm Event	Outfall at Campbell Way near Wheaton Ave
Evergreen Park	City of Bremerton	B-ST27	3/Week	Storm Event	Evergreen Park @ 14th St.
Kitsap County Stormwater Outfalls					
Silverdale at Sandpiper	Kitsap SSWM	LMK002	3/Week	Storm Event	Bucklin Hill Rd outfall next to Sandpipers
Silverdale West Bucklin Hill Road	Kitsap SSWM	LMK001	3/Week	Storm Event	Bucklin Hill Rd outfall next to Sandpipers
Silverdale at Bayshore	Kitsap SSWM	LMK004	3/Week	Storm Event	Old Silverdale
Phinney Bay	Kitsap SSWM	LMK020	3/Week	Storm Event	Rocky Point residential area
Silverdale East Bucklin Hill Road	Kitsap SSWM	LMK026	3/Week	Storm Event	Located west of Clear Creek
Tracyton Boat Dock 055	Kitsap SSWM	LMK055	3/Week	Storm Event	Residential drainage ditch outfall
Tracyton 060	Kitsap SSWM	LMK060	3/Week	Storm Event	Residential drainage ditch outfall
Gorst Subaru	Kitsap SSWM	LMK128	3/Week	Storm Event	Located behind Subaru Auto Dealership
Port Orchard 155	Kitsap SSWM	LMK155	3/Week	Storm Event	Residential drainage ditch outfall
Gorst Navy City Metals	Kitsap SSWM	LMK122	3/Week	Storm Event	West of PSNS in residential Bremerton
DEE CREEK	Kitsap SSWM	DEECRK	3/Week	Periodic	End of Jacobson Rd
National Ave. 164	Kitsap SSWM	LMK164	3/Week	Storm Event	Residential drainage ditch outfall
Manchester 038	Kitsap SSWM	LMK038	3/Week	Storm Event	Just East of dock on E. Main in Manchester
PSNS Stormwater Outfalls					
PSNS CIA	PSNS	PSNS124	3/Week	Storm Event	CIA Industrial Waterfront - W of Dry Dock 3
PSNS Dry Dock	PSNS	PSNS115.1	3/Week	Storm Event	CIA Industrial Waterfront - W of Dry Dock 1
Upstream of 115.1 SW Bldg 856	PSNS	PSNS115.1A	3/Week	Storm Event	CIA Industrial Waterfront - Upstream of Dry Dock 1
Upstream of 115.1 Bldg 500 GUTTER	PSNS	PSNS115.1B	3/Week	Storm Event	CIA Industrial Waterfront - Upstream of Dry Dock 3
PSNS Motor Pool	PSNS	PSNS081.1	3/Week	Storm Event	CIA Industrial Waterfront Dry Dock 6/5 Bldg 455
Upstream of 081.1 DD6 CRANE	PSNS	PSNS081.1A	3/Week	Storm Event	CIA Industrial Waterfront Dry Dock 6 Crane
PSNS Industrial Nondrydock	PSNS	PSNS082.5	3/Week	Storm Event	CIA Industrial Non Dry Dock Bldg 480
Naval Station (Coml/Res/Rec)	PSNS	PSNS015	3/Week	Storm Event	Naval Station - McDonalds
Upstream of 015 MC MAIN LINE	PSNS	PSNS015A	3/Week	Storm Event	Naval Station - McDonalds
Upstream of 015 MC BALL FLD	PSNS	PSNS015B	3/Week	Storm Event	Naval Station - McDonalds
Naval Station Industrial	PSNS	PSNS008	3/Week	Storm Event	Naval Station Inactive Ships
PSNS Downstream of CSO 16	PSNS	PSNS126	3/Week	Storm Event	Outfall downstream of City CSO 16; Bldg 460
PSNS Industrial Nondrydock	PSNS	PSNS101	3/Week	Storm Event	CIA Bldg 431
Port Orchard Stormwater Outfalls					
Port Orchard Business District	Port Orchard	PO-BAYST	3/Week	Storm Event	Off Bay Street by City Hall
Port Orchard Urban	Port Orchard	PO-BETHAL	3/Week	Storm Event	Bethel Road
Port Orchard Mixed TBD	Port Orchard	PO-WILKENS	3/Week	Storm Event	Wilkens Road
Port Orchard Residential MD TBD	Port Orchard	PO-POBLVD	3/Week	Storm Event	Port Orchard Blvd
Bainbridge Island					
Springbrook Creek @ New Brooklyn Rd	Bainbridge Island	BI-SBC	3/Week	Periodic	North Side of Bridge on New Brooklyn Rd.
Lynwood Center SW	Bainbridge Island	BI-LCSW	3/Week	Storm Event	Manhole in Harley Unruh's drive way
Fort Ward SW	Bainbridge Island	BI-FWSW	3/Week	Storm Event	we didn't find this one yet so this is just an approx
Fletcher Bay Nearshore	Bainbridge Island	BI-FBNS	1/Week	Periodic	Mouth of Fletcher Bay
Lynwood Center Cove	Bainbridge Island	BI-LCNS	1/Week	Periodic	off shore of Harley Unruh's Condo
Fort Ward Nearshore	Bainbridge Island	BI-FWNS	1/Week	Periodic	between salmon pens and shore

Table 4-1. (contd)

Sampling Stations	Jurisdiction	FC Sample Station ID	Target Sampling Frequency	Target Sample Type	Sample Site Location
Major Streams					
BARKER CREEK	KPUD	BA	3/Week	Periodic	At Gaging Site
BLACKJACK CREEK	KPUD	BL	3/Week	Periodic	At Gaging Site
CLEAR CREEK	KPUD	CC	3/Week	Periodic	At Gaging Site
CHICO CREEK (Main Stem)	KPUD	CH	3/Week	Periodic	At Gaging Site
PARISH CREEK	KPUD	PA	3/Week	Periodic	At Gaging Site
STRAWBERRY CREEK	KPUD	SC	3/Week	Periodic	At Gaging Site
ANDERSON CREEK - BREM.	KPUD	AC	3/Week	Periodic	At Gaging Site
OLNEY CREEK (KARCHER CREEK)	KPUD	OC	3/Week	Periodic	At Gaging Site
Tributary Streams					
Clear Creek East	PSNS	CE	3/Week	Periodic	At Gaging Site
Clear Creek West	PSNS	CW	3/Week	Periodic	At Gaging Site
Bangor Trident Lake	PSNS	BTL	3/Week	Periodic	Halfmile Rd
Bangor Storm Water Ponds	PSNS	BSWP	3/Week	Periodic	Melody Lane
BARKER CREEK Bulklin Hill Rd	ECOLOGY	BA-BHRD	3/Week	Periodic	Bucklin Hill Rd
BARKER CREEK Nels Nelson	ECOLOGY	BA-NN	3/Week	Periodic	Nels Nelson Rd
BLACKJACK CREEK (KFC)	ECOLOGY	BL-KFC	3/Week	Periodic	Behind KFC
GORST CREEK below Sam Christopherson	ECOLOGY	GC-1	3/Week	Periodic	Behind apartment
ANNAPOLIS CREEK	ECOLOGY	ANNAP	3/Week	Periodic	South of Bay St off Maple Ave
BEAVER CREEK Lower segment	ECOLOGY	BE-LOW	3/Week	Periodic	At culvert on road to Manchester Lab
GORST CREEK @ Jarsted Park	ECOLOGY	GC-JAR	3/Week	Periodic	Entrance to Jarsted Park
SACCO CR	ECOLOGY	SACCO	3/Week	Periodic	Stream Mouth south of Beach Drive
Chico @ Taylor Rd	Kitsap NR	CT	3/Week	Periodic	At Gaging Site
Dickerson	Kitsap NR	DI	3/Week	Periodic	At Gaging Site
Kitsap Creek	Kitsap NR	KC	3/Week	Periodic	at Lake outfall
Kitsap Lake	Kitsap NR	KL	3/Week	Periodic	at lake inlet
Nearshore Stations					
Clam Bay	Nearshore	N1	Weekly	Periodic	head of clam bay
Sinclair Inlet	Nearshore	N2	Weekly	Periodic	Offshore of Karcher Creek STP
Sinclair Inlet	Nearshore	N3	Weekly	Periodic	mouth of Blackjack estuary
Sinclair Inlet	Nearshore	N4	Weekly	Periodic	Port Orchard Waterfront
Sinclair Inlet	Nearshore	N5	Weekly	Periodic	Port Orchard Marinas
Sinclair Inlet	Nearshore	N6	Weekly	Periodic	Head of Sinclair Inlet
Sinclair Inlet	Nearshore	N7	Weekly	Periodic	Charleston Beach
Port Washington Narrows	Nearshore	N8	Weekly	Periodic	Evergreen Park
Port Washington Narrows	Nearshore	N9	Weekly	Periodic	Lions Park - North of Boat Ramp
Port Washington Narrows	Nearshore	N10	Weekly	Periodic	Anderson Cove
Phinney Bay	Nearshore	N11	Weekly	Periodic	Phinney Bay
Dye's Inlet - Ostrich	Nearshore	N12	Weekly	Periodic	Jackson Park Recreation Area
Dye's Inlet - Ostrich	Nearshore	N13	Weekly	Periodic	Head of Ostrich Bay
Dyes Inlet - Chico Bay	Nearshore	N14	Weekly	Periodic	Chico Bay - mouth of estuary
Dyes Inlet - Silverdale Waterfront Park	Nearshore	N15	Weekly	Periodic	Sliverdale Waterfront Park
Dyes Inlet - North	Nearshore	N16	Weekly	Periodic	Silverdale West Coast Hotel
Dyes Inlet - North	Nearshore	N17	Weekly	Periodic	Clear Creek Estuary
Dyes Inlet - North	Nearshore	N18	Weekly	Periodic	Barker Creek Estuary
Marine Stations					
Port Orchard Passage	Marine	M1	Weekly	Periodic	
Rich Passage	Marine	M2	Weekly	Periodic	
Sinclair Outer	Marine	M3	Weekly	Periodic	
Sinclair Inner	Marine	M4	Weekly	Periodic	
Rocky Point	Marine	M5	Weekly	Periodic	
Erlands Point	Marine	M6	Weekly	Periodic	
Windy Point	Marine	M7	Weekly	Periodic	
Oyster Bay	Marine	M8	Weekly	Periodic	
Stream Storm-Event Stations					
BARKER CREEK	PSNS/TEC	BA	3	Storm Event	At Gaging Site
BLACKJACK CREEK	PSNS/TEC	BL	3	Storm Event	At Gaging Site
CLEAR CREEK	PSNS/TEC	CC	3	Storm Event	At Gaging Site
CHICO CREEK (Main Stem)	PSNS/TEC	CH	6	Storm Event	At Gaging Site
GORST CREEK (Above Jarsted Park)	PSNS/TEC	GC	3	Storm Event	At Gaging Site
STRAWBERRY CREEK	PSNS/TEC	SC	3	Storm Event	At Gaging Site
ANDERSON CREEK - BREM.	PSNS/TEC	AC	3	Storm Event	At Gaging Site
OLNEY CREEK (KARCHER CREEK)	PSNS/TEC	OC	3	Storm Event	At Gaging Site
Clear Creek East	PSNS/TEC	CE	3	Storm Event	At Gaging Site
Clear Creek West	PSNS/TEC	CW	3	Storm Event	At Gaging Site
CHICO @ Taylor Rd	PSNS/TEC	CT	3	Storm Event	At Gaging Site

Figure 4-2. Barker Creek Water Quality Sample Station, Showing Automated Sampling System Enclosure and Sample Pipe

Figure 4-3. Water Quality Sample Station Located at the Mouth of Blackjack Creek in Port Orchard. Puget Sound Naval Shipyard Is Visible Across Sinclair Inlet

Figure 4-4. Typical Automated Sampling System and Enclosure

Figure 4-5. Silverdale Stormwater Outfall Water Quality Sample Station, Showing Automated Sampling System Enclosure and Sample Pipe

Figure 4-6. Manchester Stormwater Outfall Water Quality Sample Station, Showing Automated Sampling System Enclosure and Sample Pipe

Figure 4-7. Manchester Stormwater Outfall

Figure 4-8. East Bremerton (Stephenson) Stormwater Outfall

Figure 4-9. East Bremerton (Pine Road) Stormwater Outfall

Figure 4-10. Olney (Karcher) Creek Outfall

Figure 4-11. Manhole-Type Stormwater Water-Quality Sample Station

Figure 4-12. Manhole-Type Stormwater Water-Quality Sample Station, Showing Flowmeter

4.1 Marine and Nearshore Sampling

Historical bacterial contamination (FC) sample data for the marine and nearshore areas of the Sinclair-Dyes Inlet watershed were obtained from WA-DOH and KCHD. Both of these agencies conduct routine monthly sampling at set stations throughout the watershed. The WA-DOH is primarily concerned with shellfish beds and, therefore, concentrates its sampling efforts on nearshore areas of Dyes Inlet and Port Orchard Passage. The KCHD has sample stations in both Dyes-Sinclair Inlet and Port Orchard Passage. Currently, surface-water grab samples are the only marine FC samples collected in the study area. Information on sample collection, laboratory procedures, and quality assurance / quality control (QA/QC) can be found in the Sinclair-Dyes Inlet FC Study Plan. The existing sampling locations were not considered to be adequate for this project, because there were no nearshore sample locations that targeted stormwater outfalls. Additional sampling stations were added to close this data gap; this supplemental sampling was conducted during the 2002 - 2003 storm season (Figure 4-1).

4.2 Freshwater Stream Sampling

Historical bacterial contamination (FC) sample data for the streams draining into the Sinclair-Dyes Inlet watershed were obtained from the KCHD. Currently, KCHD is collecting monthly samples in all the major streams within the study area. Several stations were added for this project to cover tributaries of the major streams and some smaller streams of interest. Bacterial (FC) samples targeting storm events were also added to the existing KCHD base-flow sampling effort on all major streams. These sample stations were co-located at stream-flow gage sites and at automated water-quality monitoring stations installed for the Sinclair-Dyes Inlet watershed project (Figure 4-1). A subset of all stream sites was also sampled multiple times during several discrete storm events to determine whether FC levels varied between storms and within storms at multiple sites. Storm-event sampling was conducted under contract to PSNS by The Environmental Company (TEC).

4.3 Stormwater Outfall Sampling

Currently, no agency is routinely collecting bacterial contamination (FC) samples from stormwater outfalls. A review of current scientific literature and existing data indicates that stormwater outfalls can be a significant source of bacterial contamination. Because of the large number of stormwater outfalls and the limitations in manpower and budget, only a small fraction of the existing outfalls were monitored for this project. The Cities of Bremerton and Port Orchard identified their major stormwater outfalls and Kitsap Surface and Stormwater Management (SSWM) identified their most significant outfalls (based on sub-basin area, outlet size, and results of the initial screening samples). The most significant stormwater outfalls located on the PSNS were also included in the sampling plan (Figure 4-1).

4.4 Laboratory Analytical Methods

The methods for measuring densities of the bacterial indicators on which WQS are based have evolved over the years. Standard methods are now available for total coliform, FC, enterococci, and *E. coli*. Specially equipped microbiological laboratories and highly trained technicians are usually required to conduct these tests, and appropriate QA/QC procedures must be followed to reduce uncertainties in the estimates of the pathogens (Clesceri et al., 1998). Basic methods are presented in the 19th edition of the *Standard Methods for the Examination of Water and Wastewater* (APHA 1995). Newer and improved methods are now being developed and tested for some groups of pathogens, especially viruses and protozoans. A few techniques are able to distinguish between human and animal wastes as a means of tracing the sources of pathogens.

FC samples collected by WA-DOH and KCHD were processed by the individual agency using the multiple-tube fermentation or *Most-Probable-Number* (MPN) technique (APHA 1995). In the multiple-tube fermentation technique, a set of tubes containing enriched broth are inoculated with different amounts of the water sample and incubated at 35°C for 24 hours. The appearance of gas, indicating fermentative growth of bacteria using lactose as a carbon source, is interpreted as a positive presumptive test for total coliform bacteria. If gas is produced in the tube, a sample of the bacteria in the broth is transferred to one or more additional media to confirm the presence of FC bacteria. Additional biochemical tests can be performed to identify the bacteria to genus and species or higher to verify that the bacteria found are coliforms (APHA 1995). The total number of tubes producing gas is converted to express the results of the test as the MPN per 100 mL water, a statistical estimation of the number of coliform bacteria that would give the results shown by the laboratory examination. The MPN is based on the application of the Poisson distribution for extreme values to the analysis of the number of positive and negative results obtained when testing multiple portions of equal volume and in portions constituting a geometric series (Metcalf and Eddy 1991). The MPN provides a statistical probability number, not an actual enumeration, and has an approximately 23% positive bias associated with it. This method may give higher results because of this built-in positive bias.

The Ecology laboratory at Manchester, Washington, processed all FC samples for the storm event sampling periods using the *Membrane Filter* (MF) technique (APHA 1995). The MF technique is an EPA-certified method for testing water for coliform bacteria. In this technique, a measured amount of sample is filtered through a membrane with a nominal pore size of 0.45 µm. Bacteria are retained on the membrane, and the filter is placed on a surface of selective agar medium and incubated at 44.5°C for 24 hours. When using a FC medium, blue colonies formed by the growth of the bacterial cells are counted as fecal coliform using as low a magnification as necessary. Thus, the MF technique provides an estimate of the number of FC bacteria that form colonies when cultured (colony-forming units or CFU per 100 mL). The count is considered to be an estimate, because some of the colonies can be from more than one bacterium (APHA 1995). The MF technique is highly reproducible, can be used to test relatively large volumes of samples, and yields numerical results more rapidly than the multiple-tube (MPN) procedure. However, the MF technique has limitations, particularly when testing waters with high turbidity or non-coliform (background) bacteria. Waters with high turbidity or high non-coliform (background) bacterial levels can interfere with the MF procedure by clogging the filter or suppressing coliform growth (Geldreich et al., 1967). In addition to FC, other bacteria, such as *E. coli* and fecal streptococci, can also be detected by the MF procedure. For such waters or when the MF technique has not been used previously, it is desirable to conduct parallel tests with the multiple-tube fermentation technique to demonstrate applicability and comparability (EPA 1978).

Parallel tests using both procedures have been performed to demonstrate applicability and comparability (Grandi et al., 1989). Prior to the adoption of MF method as a “standard method” for the enumeration of coliform bacteria in environmental waters, comparisons were made in different laboratories to assess the comparability of this newer technique against the well-established MPN method. The results of coliform counts by the MF and MPN procedures were compared on the basis of the 95% confidence limits of the MPN value. When MF coliform values fell within the 95% confidence limits, they were considered to be in agreement with those determined by the MPN method applied to the same split sample. Over a 1-year period, nine participating laboratories collected water samples representing raw water sources, finished waters, and other sources, including wells, rivers, and streams. In the committee report describing the results of this comparative testing, Kabler (1954) concluded that the two procedures do not measure precisely the same group of bacteria. However, in testing 1706 samples representing a variety of water sources, results for coliform bacteria were in agreement for 1260 of these samples (73.8%). In testing freshwater surface samples (rivers, reservoirs, and lakes), agreement ranged from 60% to 88%.

A similar study conducted on marine-nearshore samples in southern California, concluded that results from another technique called chromogenic substrate (CS) were highly correlated with both the MF technique and the multi-tube fermentation technique, showing that most of the accepted test methods yield comparable results in saltwater (Nobel et al. 2003b, 2004c).

Completion of any of the methods to detect the presence of coliform bacteria requires not only technical expertise, but also judgment based on training and experience. Values reported as coliform bacteria using the MF method generally have a higher verification rate, i.e., when coliform colonies are subjected to further identification of individual bacteria, they are more frequently verified as members of the coliform group. In an analysis 91 samples representing a variety of surface waters and sewage, it was reported that overall, the MF method had a higher rate of coliform verification (78.1%) than did the MPN-confirmed test (70.3%) for all samples (Geldreich et al., 1967). However, these results varied depending upon the source of the water sample, with a higher percentage of verification resulting from the MPN method when isolates were recovered from sewage and freshwater samples (Geldreich et al., 1967).

In general, the results obtained from the two different methods are in the same order of magnitude. However, an exact match of FC count obtained from the two sampling methods should not be expected. The analytical laboratory is responsible for calibration and maintenance of analytical laboratory equipment and instruments and the maintenance of laboratory personnel qualifications. The laboratory is also responsible for timely completion of calibration and maintenance. Standard data quality acceptance criteria were used throughout the project. Acceptance criteria focused on ensuring an appropriate level of data quality to meet the project objectives. Method blanks and laboratory duplicate samples were analyzed to evaluate and monitor analytical results. Throughout this study, acceptance criteria were periodically reviewed for appropriateness and adequacy in meeting the study goals and objectives.

5.0 Summary of Historical Watershed Information

Water quality in the Sinclair-Dyes Inlet watershed has been monitored and studied for several years, and there is a great deal of information available that is relevant to microbial pollution and the ENVVEST project. This section of the report summarizes the local research and data collection efforts for the Sinclair-Dyes Inlet watershed study area.

5.1 Kitsap County Department of Community Development

Beginning in the early 1980s, watershed-based assessments were conducted in the Sinclair and Dyes Inlets. These studies were funded by Ecology and managed by Kitsap County Department of Community Development (KC-DCD). The goal of these programs was to develop a *Watershed Action Plan* for each major watershed in the county. These programs focused on NPS-pollution problems and involved state and local government agencies, private business representatives, and volunteer citizen representatives from within the watershed. The Watershed Management Committee (WMC) was formed to work on a consensus basis to identify problems and recommend protective or corrective actions. The main reports of interest to this project are as follows:

- *Dyes Inlet - Clear Creek Watershed Action Plan* (KC-DCD 1992)
- *Sinclair Inlet Watershed Action Plan* (KC-DCD 1995)

The *Dyes Inlet - Clear Creek Watershed Action Plan* (KC-DCD 1992) includes a description of current conditions in the watershed, a water-quality assessment project report that identifies existing and potential problems, and a watershed action plan with recommendations for correcting problems and improving the watershed.

The *Dyes Inlet - Clear Creek Watershed Action Plan Water Quality Assessment Report* (KCHD 1991) summarizes the findings of water-quality sampling efforts that formed the basis for the *Dyes Inlet - Clear Creek Watershed Action Plan*. This report indicated that as of 1991, all 24 marine water-quality monitoring stations in Dyes Inlet exceeded the WQS for FC bacteria (KCHD 1991). In addition, only 44% of all shellfish sampled met WA-DOH FC criteria (KCHD 1991). Wet-weather water-quality problems were identified as being more pronounced than dry weather problems, but violations of WQS occurred during both wet and dry seasons. The major sources of FC bacterial pollution were identified as streams that drain developing watersheds (Clear, Barker, and Strawberry Creeks), City of Bremerton CSO events, and stormwater runoff from developed shoreline areas such as Silverdale, Tracyton, Port Washington Narrows, Ostrich Bay, Oyster Bay, and Phinney Bay (KCHD 1991). In general, Clear and Barker Creeks had higher FC levels during wet weather storm events than during dry weather periods (KCHD 1991).

Over half of the shoreline of Dyes Inlet was also surveyed for FC bacterial sources during the water-quality assessment effort, and over 33% of all stormwater outfalls surveyed (57 of 173) were identified as high FC sources (KCHD 1991). In addition, 38 failing OWTS were identified during the project period (KCHD 1991). A large majority (93%) of these failing OWTS were designed and installed prior to the existing regulations (KCHD 1991). Also, 75% of the failed OWTS were located within 100 feet of Dyes Inlet or a tributary stream (KCHD 1991).

In addition to the water-quality monitoring, shoreline surveys, and OWTS inspections conducted by the KCHD, the Kitsap Conservation District (KCD) conducted an inventory of farm-related activities in the watershed. This report was also included in the *Dyes Inlet - Clear Creek Watershed Action Plan* as a technical appendix. The KCD report found that a majority of farms in the Clear Creek basin had farm plans and BMPs in place, but problem areas still remained. Barker Creek had several farm-related water-quality problems that needed to be corrected, especially in the upper subbasin.

The *Sinclair Inlet Watershed Action Plan* (KC-DCD 1995) includes a description of current conditions in the watershed, a water-quality assessment project report that identifies existing and potential problems, and a watershed action plan with recommendations for correcting problems and improving the watershed.

The *Sinclair Inlet Watershed Action Plan* identified the following categories of NPS pollution (KC-DCD 1995):

- agricultural practices
- boats and marinas
- forest practices
- landfills
- oil spills from manchester fuel depot
- on-site sewage systems
- stormwater runoff from urban areas
- toxic chemicals from PSNS.

The *Sinclair Inlet Watershed Action Plan Water Quality Assessment Report* (KCHD 1994) summarizes the findings of water-quality sampling efforts that formed the basis for the *Sinclair Inlet Watershed Action Plan*. This report indicated that the major pollution sources were the PSNS industrial area, City of Bremerton CSO and stormwater runoff, and the City of Bremerton WWTP. The report also pointed out that improvements to water quality in Sinclair Inlet were evident and were a direct result of efforts made to correct problems in the above source areas (KCHD 1994). These efforts continue. The report also identified the low natural flushing or seawater exchange rate of the inlet as a major limiting factor in improving water quality (KCHD 1994). The flushing is mainly tidally driven, and the turnover time for Sinclair Inlet was estimated to be around 14 days, with freshwater inflow representing only about 1% of the exchange (KCHD 1994). This low natural flushing rate has significant implications for water quality and indicates that any pollutants that enter the inlet are likely to settle there, thus making pollutant source control an important management goal (KCHD 1994).

The water-quality assessment also concluded that the City of Bremerton WWTP was operating according to permit requirements and was discharging a relatively high-quality effluent with very low FC levels (KCHD 1994). Urban stormwater runoff from Bremerton, Port Orchard, and Gorst was identified as a major FC pollution problem (KCHD 1994). Sources of FC contamination identified in stormwater included CSO events, agricultural runoff, marina operations, failing OWTS, and leaking sewer lines.

The water-quality assessment report (KCHD 1994) found high FC levels in marine waters near Gorst and Port Orchard, as well as at the mouth of Olney, Ross, Blackjack, and Gorst Creeks. Of the 24 marine stations monitored, 86% (22 of 24) were in compliance with bacterial (FC) WQS (KCHD 1994). This report also concluded that marine stations closer to a developed shoreline or a freshwater discharge (stream or outfall) that drains a developed drainage area were more likely to have high FC levels, especially during the wet weather storm season (KCHD 1994). Shellfish tissue samples were also analyzed for FC bacteria and toxic chemicals. Shellfish from the Gorst area generally had the highest FC levels (KCHD 1994).

The KCHD also conducted a shoreline and stormwater outfall survey in Sinclair Inlet. The results of this survey indicated that OWTS problems were common for many shoreline residences, especially in older developed areas (KCHD 1994). The Gorst area was singled-out for particular concern regarding failing OWTS, with 20% to 30% (22 OWTS) of the surveyed sites not operating properly (KCHD 1994). Port Orchard, Annapolis, and Manchester were also identified as problem areas. Of the 145 homes surveyed in the Annapolis shoreline section, 15% (21) had failing OWTS (KCHD 1994).

The KCHD also surveyed 8 streams in the Sinclair Inlet watershed. Overall, 69% (20 of 29 stations) of the survey stations were in compliance with WQS (KCHD 1994). High FC bacteria levels were found in Annapolis, Wright, Gorst, Blackjack, and Beaver Creeks. The sources of FC pollution were identified as stormwater and agricultural runoff, as well as failing OWTS and leaking sewers (KCHD 1994).

The *Sinclair Watershed Action Plan and Dyes Inlet - Clear Creek Watershed Action Plan* recommendations were divided into the following categories:

1) Broad-Ranging Guidance
2) Public Education
3) Stormwater Management
4) Onsite Sewage Systems
5) Agricultural Practices
6) Forest Practices
7) Toxic Chemicals
8) Boats and Marinas
9) Litter Reduction.

One of the most significant recommendations to come out of the *Dyes Inlet - Clear Creek Watershed Action Plan* and the *Sinclair Inlet Watershed Action Plan* was that a long-term water-quality monitoring program should be implemented in the Sinclair-Dyes Inlet watershed to identify and correct bacterial pollution problems. To accomplish this task, the Kitsap County Surface and Stormwater Management (SSWM) program was formed in 1994. The SSWM program, established to protect and restore the waters of Kitsap County, is a combined effort of the Kitsap County Public Works Department, the KC-DCD, the KCD, and the KCHD. The water-quality monitoring program administered by KCHD, with funding from SSWM, has been conducting water-quality trend monitoring since 1996. The KCHD *Pollution Identification and Correction* (PIC) Program is also a direct result of the recommendations found in the *Dyes Inlet - Clear Creek Watershed Action Plan* and the *Sinclair Inlet Watershed Action Plan*.

5.2 Kitsap County Health District

Based on the recommendations of the *Sinclair Inlet Watershed Action Plan* and the *Dyes Inlet - Clear Creek Watershed Action Plan* the KCHD implemented a watershed-wide, long-term bacterial pollution (FC) monitoring program. As a result of these efforts, the KCHD has the most extensive bacterial pollution database for the Sinclair-Dyes Inlet watershed. Figures 5-1 through 5-5 show the locations of long-term KCHD water-quality monitoring sites in the study area (KCHD 2003a).

In addition to routine FC monitoring, the KCHD also implemented the PIC program to determine the causes or sources of bacterial pollution and to correct those problems (KCHD 2003b). The PIC program is conducted in coordination with the KCD, with funding from the SSWM program. The water-quality monitoring program aids in developing a prioritized list of areas in Kitsap County that are in need of a PIC project. These PIC projects are then funded by the SSWM program or by grants from Ecology. The goals of the PIC program are to protect public health, protect shellfish resources, foster a proactive effort to reduce water pollution in Kitsap County, and to preserve or restore water quality in support of beneficial uses. The PIC program also has a strong public education element to inform and educate residents about proper operation and maintenance of OWTS to prevent unnecessary system failures and about animal manure management to prevent NPS pollution runoff (KCHD 2003b).

The PIC projects that have been conducted in the Sinclair-Dyes Inlet watershed are listed in Table 5-1. The 2004 PIC projects in the study area include the Barker Creek watershed and Windy Point. The planned 2005 PIC projects include Ostrich Bay Creek, Phinney Bay Creek, and Chico Creek watersheds. Many other Sinclair-Dyes Inlet water bodies are currently on the KCHD 2003-2004 Priority Area Work List and will be cleaned up on a prioritized basis. These areas of concern include Dee Creek, Annapolis Creek, Olney Creek, Strawberry Creek, Clear Creek, Beaver Creek, Mosher Creek, and Blackjack Creek. In part, PIC projects are prioritized based on the level of FC contamination found in a specific area. Those areas with a geometric mean value (GMV) FC level greater than 500 FC/100 mL are classified as "high priority," areas with a GMV FC of 200 to 500 FC/100 mL are classified as "medium priority," and those with a GMV FC less than 200 FC/100 mL are classified as "low priority" PIC projects.

Based on the results of these PIC surveys, failing OWTS and poor animal (livestock and pet) waste management are the major contributors to bacterial (FC) contamination of NPS runoff pollution and receiving waters (KCHD 2003b). KCHD estimates that about 4% to 8% of the approximately 50,000 OWTS in Kitsap County may be in a state of failure at any given time (KCHD 2003b). PIC program protocols and specific criteria for rating OWTS based on PIC inspections are included in the KCHD guidance manual (KCHD 2003b).

As part of their water-quality monitoring and PIC programs, the KCHD also conducts *sanitary surveys* of project areas to identify and correct failing OWTS that are contributing to bacterial pollution problems. The following surveys are applicable to the Sinclair-Dyes Inlet watershed:

- Rock Point and Marine Drive Area (KCHD 1995a)
- West Shore Dyes Inlet (KCHD 1995b)
- Gorst Area (KCHD 1996)
- Watauga beach Drive Area (KCHD 1997a)
- Tracyton Area (KCHD 1997b).

Between 1993 and 1995, the KCHD conducted a sanitary survey of the Rocky Point and Marine Drive areas to identify failing OWTS (KCHD 1995a). A secondary goal of this survey was to determine the long-term suitability for the use of OWTS in this area. The survey consisted of marine water-quality sampling, a shoreline survey, and OWTS inspections. Monitoring results showed that during dry weather conditions, 96% of the marine sample sites met the FC WQS, but during wet weather conditions, only 50% of the sites sampled met FC WQS. Shoreline surveys indicated that these areas with high FC levels during wet weather were located adjacent to shoreline areas with failing OWTS. In this shoreline survey, 32% (89 of 277 sites) had FC concentrations greater than 200 FC/100 mL. Of the 89 problem sites, 45 (16%) had FC concentrations greater than 1600 FC/100 mL, indicating the presence of raw sewage. Based on inspections of the 89 problem sites, 80 (90%) were determined to be caused by OWTS that were not operating properly. In all, 42 OWTS were classified as failing, with 27 of those in the Rocky Point area and 15 on Marine Drive.

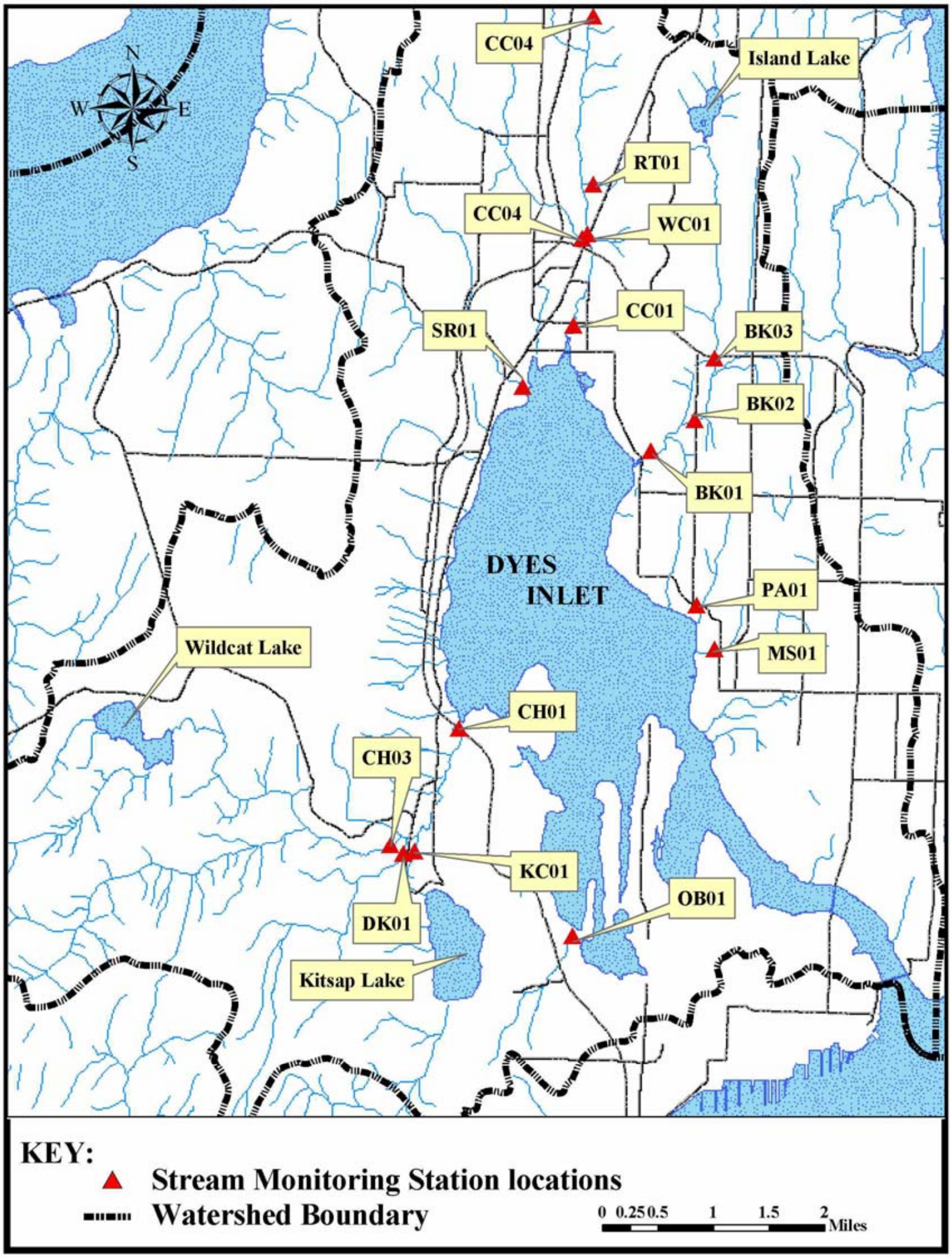

Figure 5-1. Kitsap County Health District Stream Sampling Sites in Dyes Inlet Watershed (KCHD 2003a)

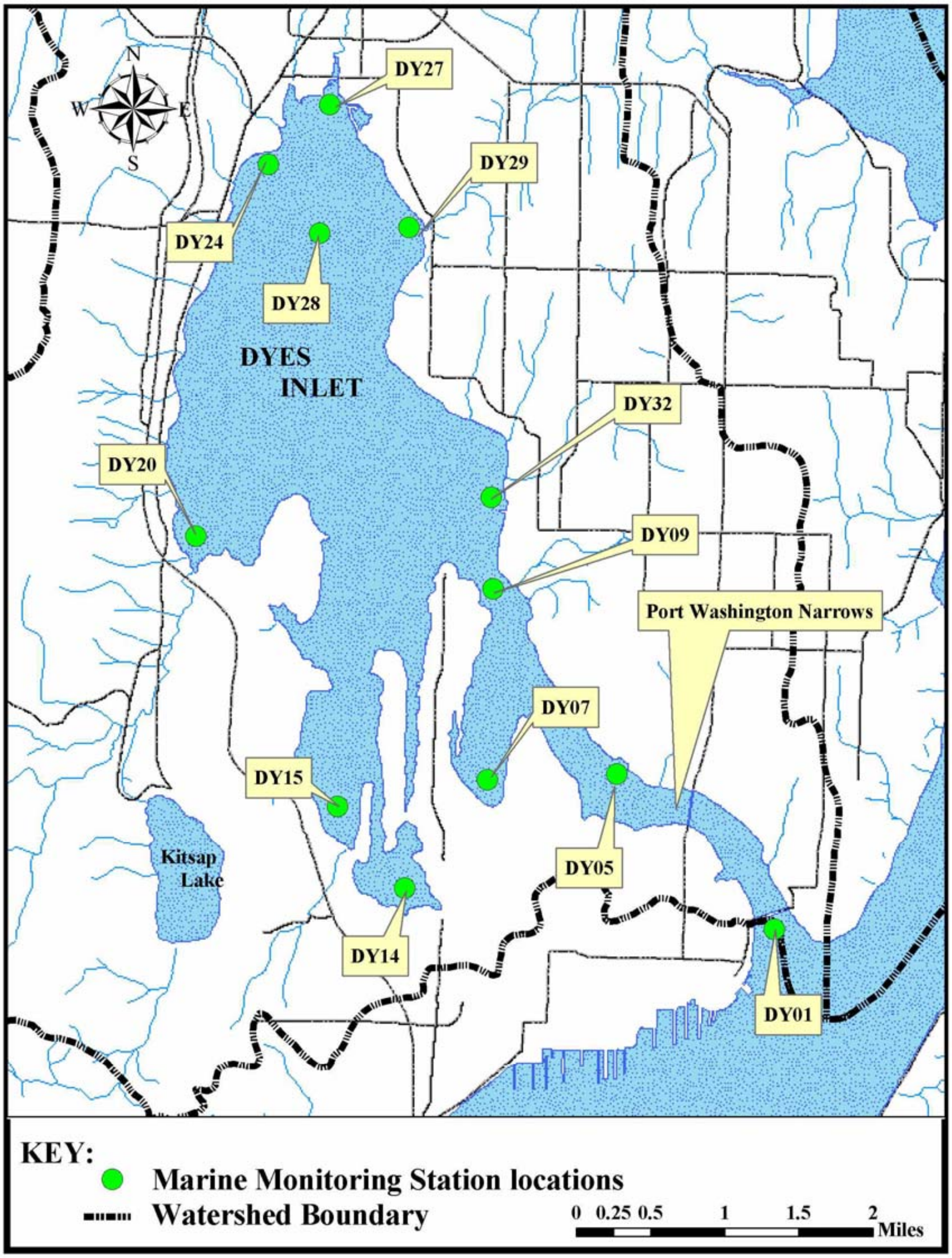

Figure 5-2. Kitsap County Health District Marine Sampling Sites in Dyes Inlet Watershed (KCHD 2003a)

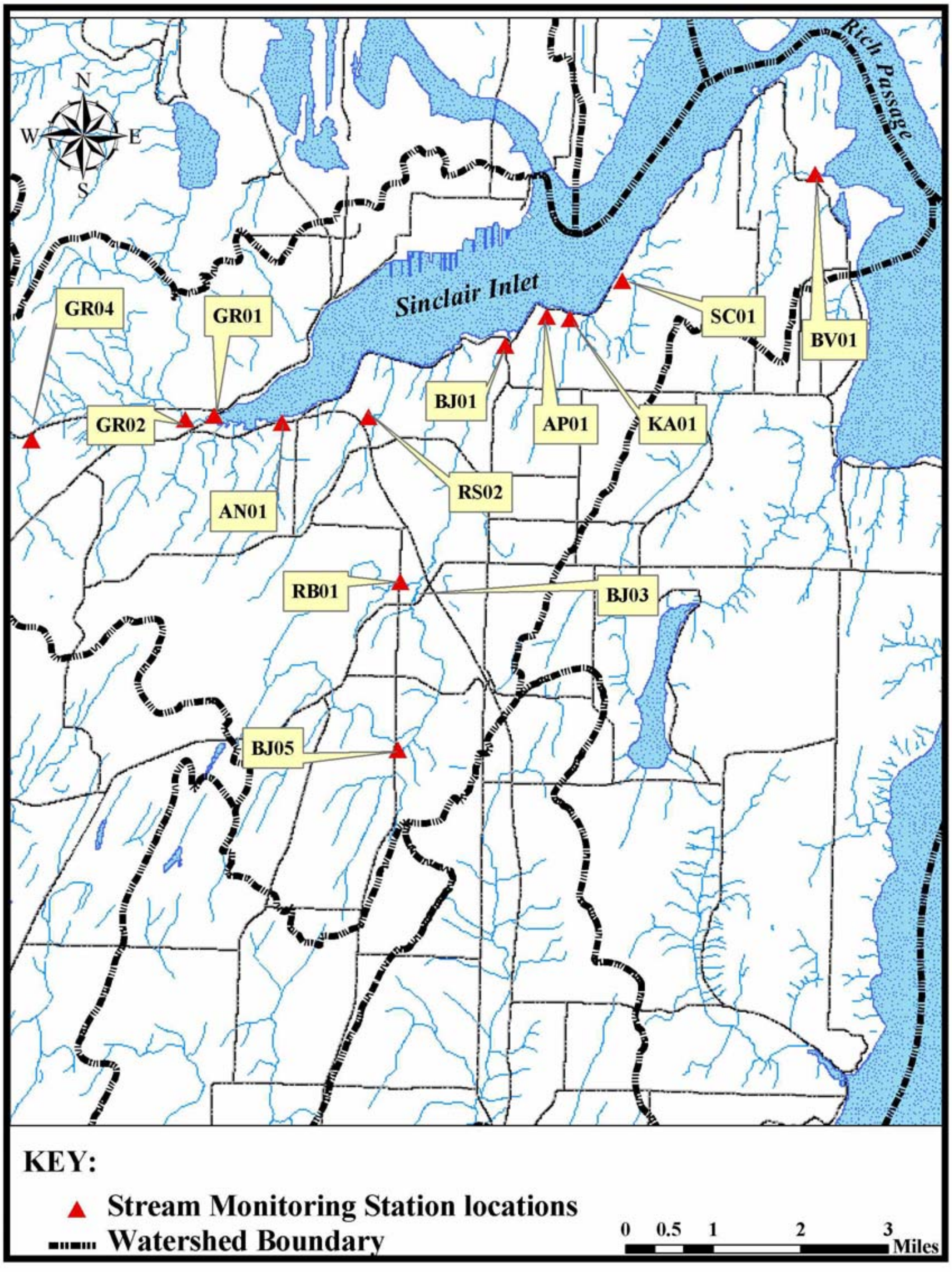

Figure 5-3. Kitsap County Health District Stream Sampling Sites in Sinclair Inlet Watershed

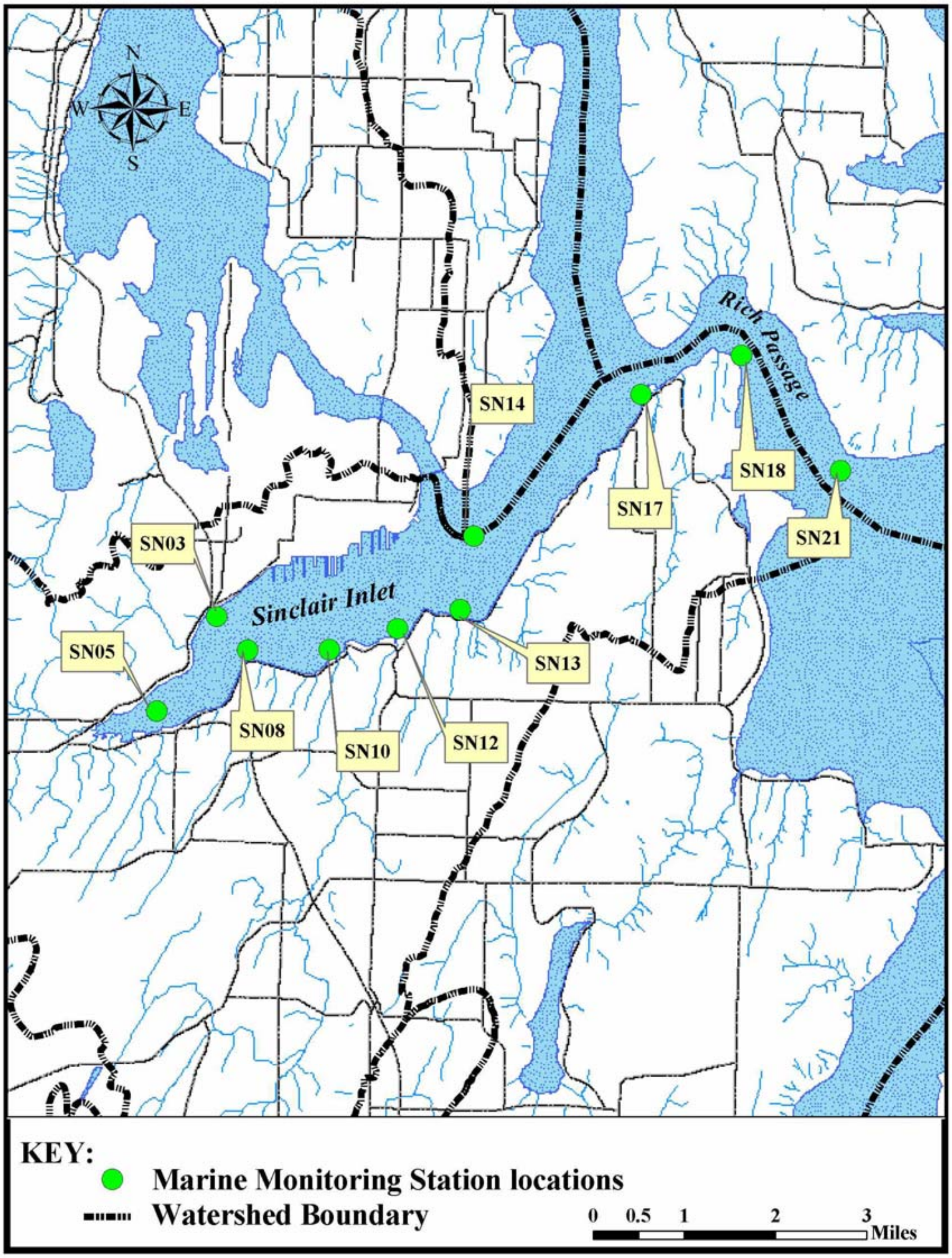

Figure 5-4. Kitsap County Health District Marine Sampling Sites in Sinclair Inlet Watershed

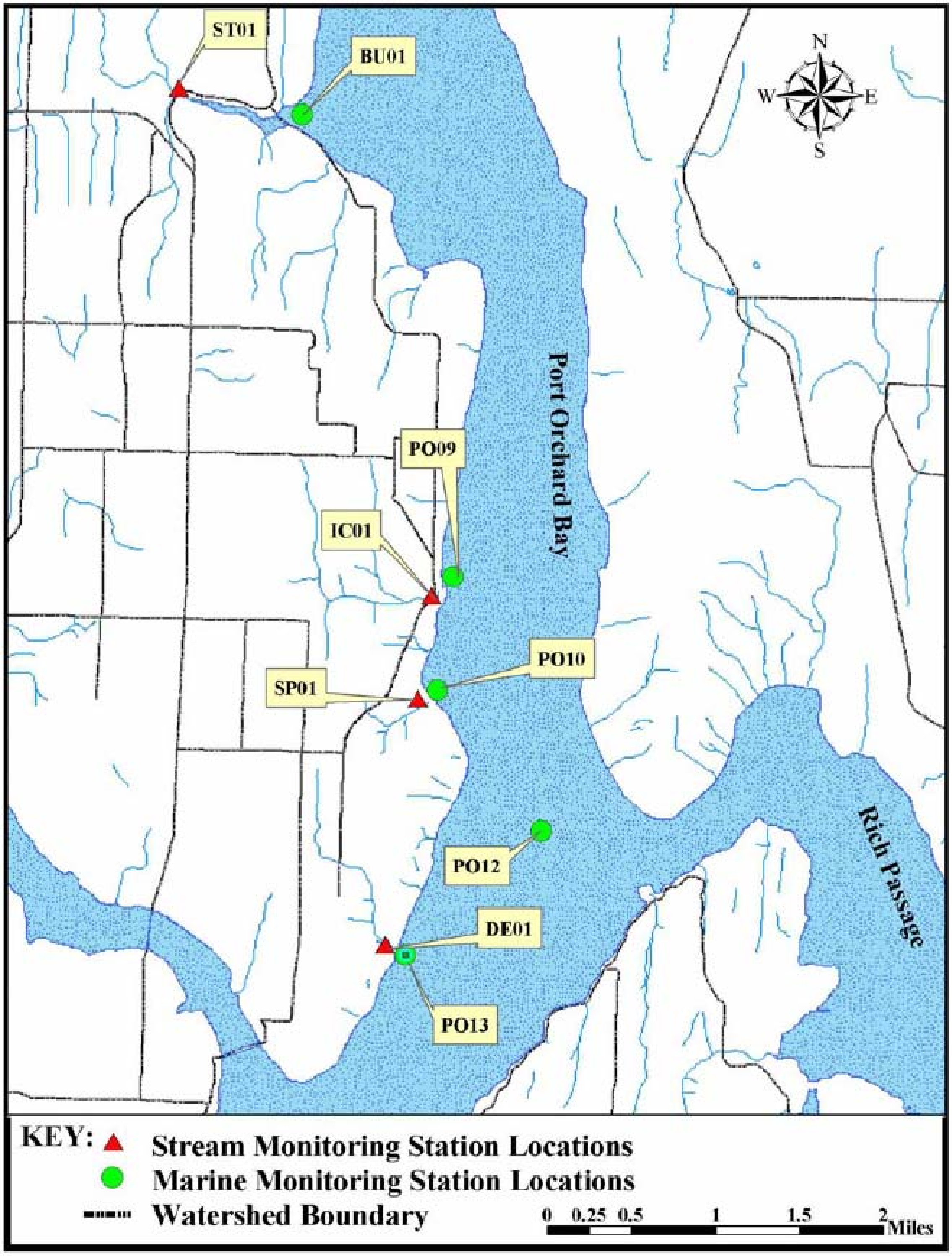

Figure 5-5. Kitsap County Health District Marine and Freshwater Sampling Sites in Port Orchard and Rich Passages

Table 5-1. Kitsap County Health Department Pollution Identification and Correction Program Activities in the Sinclair-Dyes Inlet Watershed (KCHD 2003a)

				Number of OSS [1]		
Project Area	**Watershed**	**Project Period**	**Funding Source [2]**	**Inspected [5]**	**Failures [3]**	**Repaired [4]**
Erlands Point	Dyes Inlet	1991-1992		331	25	25
Rocky Point/Marine Drive	Dyes Inlet	1993 - 1995	CCWF	331	42	42
West Shore Dyes Inlet	Dyes Inlet	1995	KC, SSWM	139	4	4
Gorst	Sinclair Inlet	1995 - 1996	SSWM	341	63	49
Tracyton	Dyes Inlet	1997	KC, SSWM	137	9	9
Kitsap Lake/Chico Bay	Dyes Inlet	1993-5	CCWF, SSWM, COB*	62	5	4
TOTALS				1,341	148	133

Notes:

[1] OSS = On-site sewage systems.

[2] CCWF = Centennial Clean Water Fund Grant from the Department of Ecology.
KC = Subcontract with Kitsap County (Source: CCWF).
SSWM = Kitsap County Surface and Storm Water Management Program.
SOS = Special On-Site Sewage/Shellfish Grant from the Department of Ecology.

[3] Failure = OSS malfunction as defined in BKCBH Ordinance No. 1996-8.

[4] In the Gorst project area 14 residences (rentals) have been vacated instead of repaired (8 in one complex).

[5] Additional follow-up work planned.

*City of Bremerton

Most of the failures on Rocky Point were at the northern tip of the point. There were also 42 OWTS classified as “suspect” and 138 rated as “marginal” in performance. Of the OWTS found to be failing, 50% had already been repaired once and 23% had been repaired more than once (KCHD 1995a). In spite of these generally poor results, the sanitary survey report did not find enough evidence to support a “public health emergency,” which would justify mandatory connection to a municipal sewage treatment system (KCHD 1995a). However, the report did conclude that the combined number of failing, suspect, and marginal OWTS in the project area (67% of those surveyed) suggests that the area is not well-suited for OWTS and that the best long-term solution for adequately treating wastewater is connection to the Bremerton municipal WWTP system (KCHD 1995a). As a result of this survey, the Rocky Point and Marine Drive areas are now served by sanitary sewers.

The *West Shore Dyes Inlet Water Quality Project* (KCHD 1995b) was conducted as a result of recommendations found in the *Dyes Inlet - Clear Creek Watershed Action Plan*. This project consisted of freshwater and marine water-quality monitoring, a shoreline survey, and a sanitary survey of OWTS in the study area. As part of this project, stormwater, agricultural runoff, and forestry practices were also evaluated for possible contribution to water-quality problems. Results of freshwater stream sampling were generally good, with only Strawberry Creek and a small, unnamed creek in Chico Bay in violation of FC WQS during the period of the study (KCHD 1995b). Marine sampling results indicated that Chico Bay (Station DY03) and the Clear Creek estuary (Station DY10) were problem areas for bacterial (FC) contamination. Based on the sampling done for this study and previous monitoring efforts, marine water quality appears to be improving but is still problematic, especially during rainfall events and wet weather conditions (KCHD 1995b). Based on the shoreline survey, only 8 of 104 sample sites (8%) exceeded 200 FC/100 mL (KCHD 1995b). During the sanitary survey portion of the study, 4 of 139 (3%) OWTS inspected were failing, with 3% classified as “suspect” and 62% rated as “marginal” in operational performance (KCHD 1995b). Of the failing, suspect, or marginal OWTS, most were of older design and/or were located such that their drain fields flowed toward the beach (KCHD 1995b). Continued monitoring of this area was recommended.

Between 1995 and 1996, the KCHD conducted a sanitary survey of the Gorst area to identify failing OWTS (KCHD 1996). The results of this sanitary survey showed that the Gorst area was found to have a total OWTS failure rate of 14% (49 of 341 OWTS surveyed). Of the 49 failing OWTS, 28 were residential and 21 were commercial sites (KCHD 1996). In total, 81% (277 of 341 sites) of the OWTS in Gorst were classified as either failing, suspect, or marginal (KCHD 1996). The majority of these problems were clustered within the SR-3 and SR-16 highway corridor that parallels the Sinclair Inlet shoreline. Most of these problem sites were located on small lots with poorly drained soils and with little or no receiving water setback area (KCHD 1996). It was determined that failing OWTS in Gorst were responsible for the contamination of freshwater (Gorst Creek) and marine (Sinclair Inlet) areas (KCHD 1996). During this project, 21% of nearshore samples and 47% of stormwater outfall samples exceeded 1600 FC/100 mL, indicating the presence of raw sewage (KCHD 1996). Based on the findings of this study, KCHD has declared the Gorst area as a “severe public health hazard” with regard to bacterial pollution (KCHD 1996). The results of this project suggest that the area is not well-suited for OWTS and that the best long-term solution for adequately treating wastewater is connection to a municipal WWTP system (KCHD 1996).

In 1997, KCHD completed a shoreline and sanitary survey of the Watauga area along Beach Drive near Port Orchard. Of the 90 shoreline outfalls sampled, 8 (9%) were found to be greater than 200 FC/100 mL and 5 (6%) were greater than 1600 FC/100 mL (KCHD 1997a). A total of 8 (out 44 surveyed) OWTS failures were found for an 18% failure rate, with another 4 (9%) classified as suspect and 18 (40%) more classified as marginal (KCHD 1997a). This failure rate was considered high relative to other sites in Kitsap County (KCHD 1997a). The age and proximity of the OTWS to marine waters was acknowledged as the major reason for failures (KCHD 1997a).

During the spring of 1997, KCHD conducted a stormwater survey, shoreline survey, a sanitary survey, and an inspection of OWTS in the Tracyton area (KCHD 1997b). The sanitary survey discovered that 7% (9 of 137) of the OWTS in Tracyton were failing, along with 5% (7) suspect and 41% (56) marginal (KCHD 1997b). All 9 of the failing OWTS were repaired during 1997. Marine and freshwater samples taken during this study indicated that the OWTS failures were at least partially responsible for some FC WQS violations in receiving waters (KCHD 1997b). Age and improper OWTS maintenance were cited as the main reasons for failure (KCHD 1997b). In general, more FC WQS violations occurred during wet weather conditions than dry weather periods (KCHD 1997b).

A PIC survey of portions of the Chico Creek watershed is currently underway. As of June 2003, 48 of 75 (69%) lakeshore properties in the Kitsap Lake drainage basin have been surveyed. So far, 3 (6%) failing OWTS have been confirmed (1 has been repaired and 2 are in the repair process). Shoreline surveys of the Chico Bay project area are ongoing. Property surveys in both Kitsap Lake and Chico Bay shoreline will be finished in January 2004 (KCHD 2003a).

With regard to discharges from boats and marinas, Kitsap County has had Marina Sewage Regulations in place since 1999 (http://www.kitsapcountyhealth.com/environtal_health/water_quality/marina_sewage.htm). This program has been very effective in reducing FC pollution from boats and marinas in the Sinclair-Dyes Inlet watershed.

Kitsap County also has a comprehensive solid waste management program in place. This program specifically addresses the problem of bacterial contamination due to pet waste and has been very effective (http://www.kitsapcountyhealth.com/environtal_health/solid_waste/docs/swregs.pdf).

The KCHD has been monitoring marine waters and streams in the Sinclair-Dyes Inlet watershed study area for bacterial (FC) pollution since 1996. This long-term dataset provides a statistically significant basis for trend analysis, enabling KCHD to evaluate the effectiveness of their public education and PIC programs. A brief summary of the results of this trend analysis is included here. Details can be found in the most recent KCHD Water Quality Reports (KCHD 2002, 2003a, 2004, and 2005).

The KCHD Dyes Inlet watershed water quality monitoring stations are shown in Figures 5-1 and 5-2. As mentioned earlier, KCHD began water-quality monitoring in the Dyes Inlet watershed on a regular basis in 1996. In water year 2003 (October 1, 2002 through September 30, 2003), 12 stream and 11 marine water-quality monitoring events were completed in this watershed (KCHD 2004). Dyes Inlet watershed FC monitoring currently includes 16 freshwater stations on 6 streams and 12 marine stations located within Dyes Inlet and Port Washington Narrows. The KCHD Dyes Inlet watershed stream water-quality monitoring stations include

- Barker Creek (multiple sites)
- Chico Creek (multiple sites)
- Clear Creek (multiple sites)
- Lake
- Mosher Creek
- Pahrmann Creek
- Dickerson Creek (tributary to Chico Creek)
- Kitsap Creek (tributary to Chico Creek)
- Kitsap
- Ostrich Bay Creek
- Ridgetop Creek (tributary to Clear Creek)
- Strawberry Creek.

Kitsap Lake, Barker and Clear Creeks, northern Dyes Inlet, and the Port Washington Narrows are on the 303(d) list for FC bacteria WQS violations (KCHD 2004).

As was discussed earlier, KCHD has completed several PIC projects within the Dyes Inlet watershed since 1990. The PIC projects also include OWTS sanitary surveys at Rocky Point/Marine Drive, Tracyton, Erlands Point, and the western shoreline of Dyes Inlet. In 2001, the KC-DCD received an Ecology Centennial Clean Water Fund grant to perform land-use planning and a PIC project in the Chico Creek subwatershed. KCHD, under a subcontract with KC-DCD, began a PIC project on Kitsap Lake and the Chico Bay shorelines in January 2003. Currently, 85 property surveys have been completed, 69 of them on Kitsap Lake and 16 on Chico Bay. Nine failing septic systems were identified, eight of which have been repaired (KCHD 2004). In 2004, under contract with Kitsap County, KCHD initiated the Barker Creek Restoration Project. Under this project in the Barker Creek subwatershed, KCHD will conduct a sanitary survey of streamside homes to locate FC pollution sources and correct them. In 2005, KCHD will initiate the Dyes Inlet Restoration and Protection Project. KCHD is currently scheduled to conduct sanitary surveys along Clear Creek, Ostrich Bay Creek, Phinney Creek, Chico Creek and portions of the marine shoreline to locate and correct FC sources (KCHD 2004).

During the 2003 water year, KCHD stream-mouth monitoring stations at Chico Creek (CH01), Strawberry Creek (SR01), and Mosher Creek (MS01) watershed met all FC WQS. KCHD data show that the stream-mouth monitoring stations at Barker Creek (BK01) and Clear Creek (CC01) met Part 1 but failed Part 2 of the FC WQS. Ostrich Bay Creek (OB01) failed both parts of the FC WQS. Marine water quality in the Dyes Inlet watershed for the 2003 water year was good overall. All 14 marine water-quality monitoring stations met the marine water FC WQS (KCHD 2004).

Statistical analysis was performed on KCHD stream and marine FC data collected from January 1996 to September 2003. Sufficient data were available to determine FC trends for all stream-mouth stations. All streams demonstrated stationary FC trends (KCHD 2004). Statistically, the Dyes Inlet marine water quality demonstrates a significant improvement, with all stations meeting the marine FC WQS. Eight of 11 marine water-quality monitoring stations demonstrated an improving FC trend. Global trend analysis showed an improving FC trend for all of Dyes Inlet (KCHD 2004).

Based on an analysis of KCHD monitoring data, overall water quality appears to be improving in the Dyes Inlet watershed. This improvement in water quality can be linked to FC pollution source-reduction efforts performed by local agencies in this watershed, including KCHD PIC projects and the City of Bremerton’s ongoing efforts to reduce CSO events (KCHD 2004).

Figure 5-6 presents a box plot of all FC samples collected by KCHD at Dyes Inlet marine water monitoring stations between January 1996 and September 2003. The diamond is the most recent 12-sample geometric mean and the bar (within the box) is the median. The median is the middle FC value for that station, such that 50% of all samples had values greater than the median and 50% of all samples had values less than the median. The whiskers (the vertical lines extending from the box) show the minimum and maximum FC results and the box itself represents the range in which the middle 50% of the FC results fell. Each segment of the box plot contains 25% of the FC values. Stations not represented or without a diamond in the box did not have sufficient samples for statistical analysis. Figure 5-6 shows that all the KCHD water-quality monitoring stations from January 1996 through September 2003 met Part 1 of the marine FC WQS. The stations with the occasional high FC results, such as DY20 (near the Chico Creek stream mouth) and DY27 (near the Clear Creek stream mouth) do not meet Part 2 of the marine water FC standard for the last 12 samples. These stations are influenced by major freshwater inputs, which can potentially contribute FC on a periodic basis (KCHD 2004).

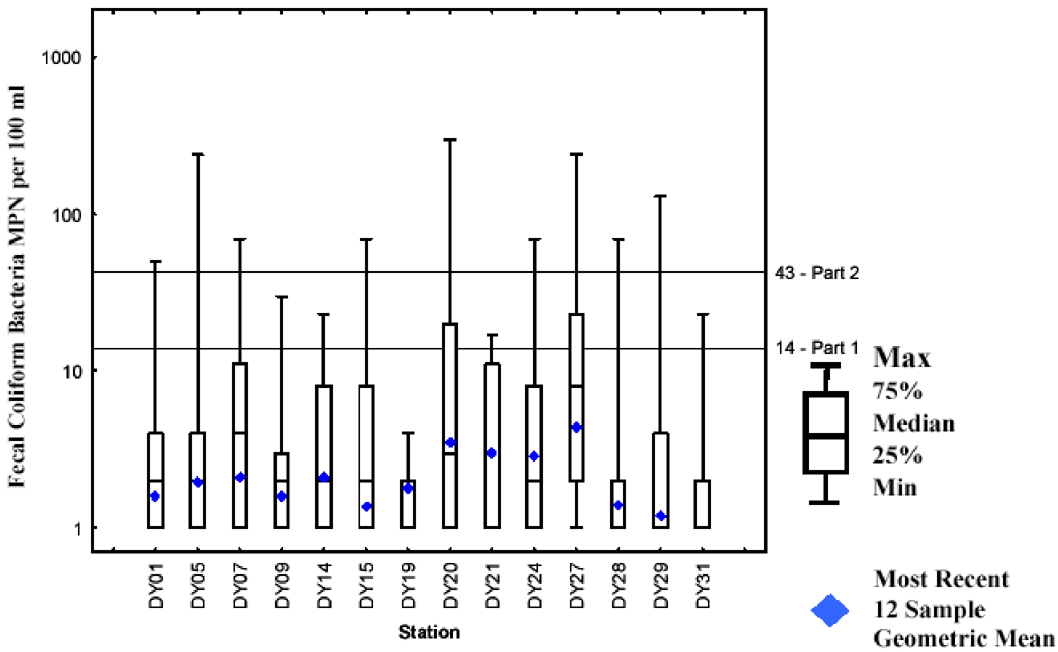

Figure 5-6. Dyes Inlet Marine Water-Quality Data Summary for 1996-2003 (KCHD 2004)

As with Dyes Inlet, KCHD began water-quality monitoring in the Sinclair Inlet watershed on a regular basis in 1996. In water year 2003 (October 1, 2002-September 30, 2003), 12 stream and six marine water-quality monitoring events were completed. Monitoring events currently include data collection at 15 freshwater stations on 8 streams and 10 marine stations in Sinclair Inlet and Rich Passage (Figures 5-4 and 5-5). The KCHD Sinclair Inlet watershed stream water-quality monitoring stations include the following:

- Anderson Creek
- Annapolis Creek
- Beaver Creek
- Blackjack Creek
- Gorst Creek
- Olney or Karcher Creek
- Ross Creek
- Sacco Creek.

Annapolis, Beaver, Blackjack, and Gorst Creeks, as well as some marine areas of Sinclair Inlet, are on the 303(d) list for FC bacteria (KCHD 2004).

As previously noted, KCHD has completed several PIC projects within the Sinclair Inlet watershed. KCHD performed sanitary surveys in the Gorst area beginning in 1995 in response to documented FC contamination of Gorst Creek and the Sinclair Inlet shoreline at Gorst (KCHD 1996). Since 1995, KCHD has documented 48 of 341 OWTS in the area (14%) as failing. The majority of failing OWTS were clustered within a "failure zone" that runs along the SR-3 and SR-16 highway corridor and parallels the Sinclair Inlet shoreline. Failing OWTS were either repaired in conformance with local regulations or allowed to continue with "temporary repairs." Because of inherently poor soils for proper disposal of onsite sewage, KCHD recommended installation of a sanitary sewer for the protection of public and environmental health. Kitsap County recently submitted a grant application to the U.S. Department of Housing and Urban Development as part of an effort to bring sewers to Gorst (KCHD 2004).

During the 2003 water year, Blackjack Creek (BJ01) and Gorst Creek (GR01) met both parts of the freshwater FC WQS. KCHD data show the stream-mouth monitoring stations at Anderson Creek (AN01), Ross Creek (RS02), and Sacco Creek met Part 1 of the FC WQS but failed Part 2. Annapolis Creek (AP01), Beaver Creek (BV01), and Karcher Creek (KA01) failed both parts of the FC WQS. Marine water quality in the Sinclair Inlet for the 2003 water year was generally good. All 10 marine water-quality monitoring stations met both parts of the marine FC WQS.

Statistical analysis was performed on KCHD stream and marine FC data collected from January 1996 through September 2003. Sufficient data were available to determine FC trends for all 8 stream-mouth stations. Only Sacco Creek (SC01) showed a statistically significant improving FC trend. All other streams monitored showed stationary FC trends (KCHD 2004). Sinclair Inlet marine water quality demonstrated a statistically significant improvement over the same time period; 2 of 10 (SN12 near the Blackjack Creek outfall and SN14, the mid-channel station between Point Heron and Olney-Karcher Creek) stations demonstrated a statistically significant improving FC trend (KCHD 2004). All Sinclair Inlet marine water-quality monitoring stations met the marine FC WQS (KCHD 2004).

In conclusion, overall water quality appears to be improving in Sinclair Inlet. Fecal coliform pollution source-reduction efforts have been performed by several local agencies in this watershed, including KCHD PIC projects in the Gorst area and ongoing work by the KCD with local farmers. In addition, the City of Bremerton's ongoing efforts to reduce CSO events has also contributed significantly to improving Sinclair Inlet water quality (KCHD 2004).

Figure 5-7 presents a box plot showing the distribution of all KCHD samples collected at Sinclair Inlet marine FC-monitoring stations between January 1996 and September 2001. The diamond is the most recent 12-sample geometric mean and the bar within the box is the median. The median is the middle FC value for that station (50% of all samples had values greater than the median, and 50% of all samples had values less than the median). The whiskers (the vertical lines extending from the box) show the minimum and maximum FC results, and the box itself represents the range in which the middle 50% of the FC results fell. Each segment of the box plot contains 25% of the FC values. Stations not represented or without a diamond in the box did not have sufficient samples for statistical analysis. Figure 5-7 demonstrates all stations from January 1996 through September 2003 met Part 1 of the marine water FC WQS. Marine monitoring stations SN05 (near the stream mouth of Gorst Creek), SN10 (near the Port Orchard Yacht Club), SN12 (near the stream mouth of Blackjack Creek), and SN13 (near the Karcher Creek WWTP outfall and mouth of Olney-Karcher Creek) do not meet Part 2 of the marine FC WQS. These stations are influenced by major freshwater inputs, WWTP outfalls, or marinas that can potentially contribute FC on a periodic basis (KCHD 2004).

KCHD began water-quality monitoring in Port Orchard Passage on a regular basis in 1996. In water year 2003 (October 1, 2002-September 30, 2003), 12 stream and 11 marine water-quality monitoring events were completed in this watershed. Monitoring events currently include data collection at 3 fresh water stations on the major streams and 4 marine stations located within Port Orchard Passage (Figure 5-7). KCHD water-quality monitoring stations are also located in Burke Bay, but these are outside the ENVVEST study area.

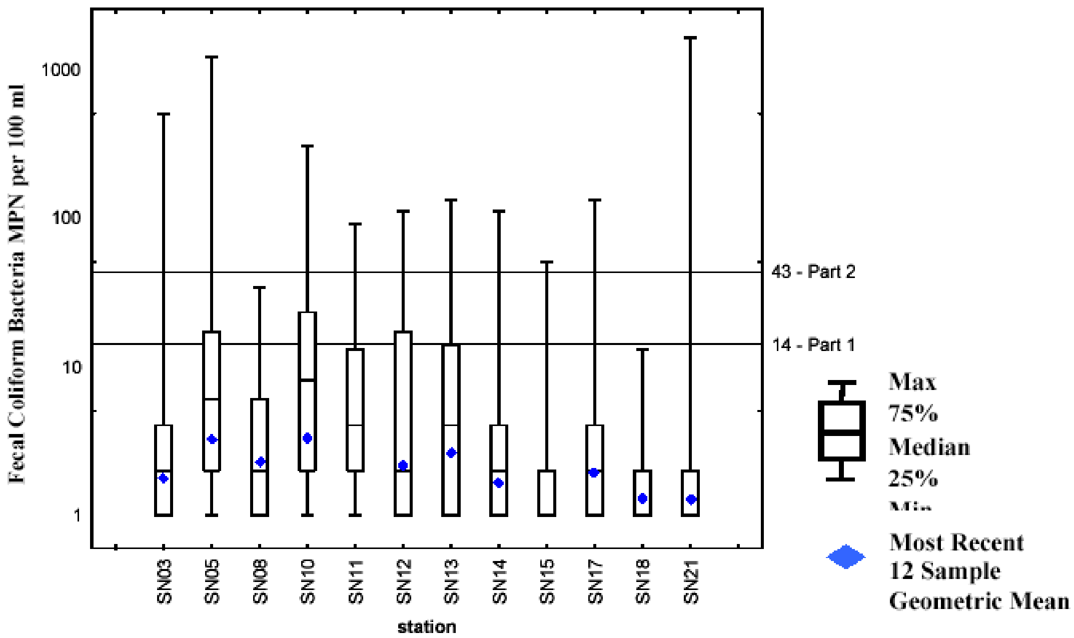

Figure 5-7. Sinclair Inlet Marine Water-Quality Data Summary for 1996-2003 (KCHD 2004)

The following freshwater stations are monitored in Port Orchard Passage:

- Dee Creek
- Illahee Creek
- Illahee State Park Creek

Currently, no freshwater or marine stations within the Port Orchard Passage are on the 303(d) list for FC pollution; however, some problem areas can still be noted. KCHD water-quality monitoring data collected since 1996 show that Dee Creek (also known as Enatai Creek) is severely contaminated with FC bacteria. As a result, the KCHD is taking the following actions (KCHD 2004):

- KCHD recommends that the public not contact this stream, given an increased risk of waterborne illness related to the FC contamination.
- Additional monitoring stations have been sited on the stream to help determine the sources of the FC contamination.
- KCHD is researching the watershed to provide estimates of average lot size, type, and suitability of soil for OWTS, septic systems repair history, and other factors.
- This information, along with the water-quality data, was presented at a public meeting in summer 2004. The purpose of the meeting was to educate property owners about the water-quality problem and encourage them to form a limited improvement district to bring sanitary sewers into the area.

During the 2003 water year, 2 of 4 (50%) stream-mouth monitoring stations, Dee Creek (DE01) and Illahee State Park Creek (SP01), failed both parts of the state freshwater FC WQS, whereas Illahee Creek (IC01) met both parts of the WQS (KCHD 2004). Marine water quality in the Port Orchard Passage during the 2003 water year was generally good. All marine water-quality monitoring stations met the marine FC WQS (KCHD 2004).

Statistical analysis was performed on KCHD stream and marine FC data collected from January 1996 through September 2003. Sufficient data were available to determine trends for all 4 stream-mouth stations. All 4 streams demonstrated a stationary FC trend. Sufficient data were also available to determine trends for four of five marine stations. The monitoring station located near the mouth of Illahee State Park Creek indicates a statistically significant improving FC trend. The three other stations demonstrated a stationary FC trend. As a group, marine water stations in the Port Orchard Passage demonstrate a statistically significant improving FC trend (KCHD 2004).

Figure 5-8 presents a box plot showing the distribution of all KCHD FC samples collected in Port Orchard Passage and Burke Bay water-quality monitoring stations between January 1996 and September 2003. The diamond is the most recent 12-sample geometric mean and the bar (within the box) is the median. The median is the middle FC value for that station at which 50% of all samples had values greater than the median and 50% of all samples had values less than the median. The whiskers (the vertical lines extending from the box) show the minimum and maximum FC results and the box itself represents the range at which the middle 50% of the FC results fell. Each segment of the box plot contains 25% of the FC values. Stations not represented or without a diamond in the box did not have sufficient samples for statistical analysis (KCHD 2004). Figure 5-8 demonstrates all stations from January 1996 through September 2003 met Part 1 of the marine FC WQS. Station PO10 is located near the mouth of Illahee State Park Creek. This stream may be affected by upland FC pollution sources, including failing OWTS urban stormwater runoff, pet wastes, and uncontrolled construction activities (KCHD 2004). Global trend analysis demonstrates a statistically significant improving FC trend for the combined stations of Port Orchard Passage and Burke Bay. Individually, stations BU01, PO09, and PO12 show stationary FC trends, whereas PO10 demonstrates a statistically significant improving FC trend (KCHD 2004).

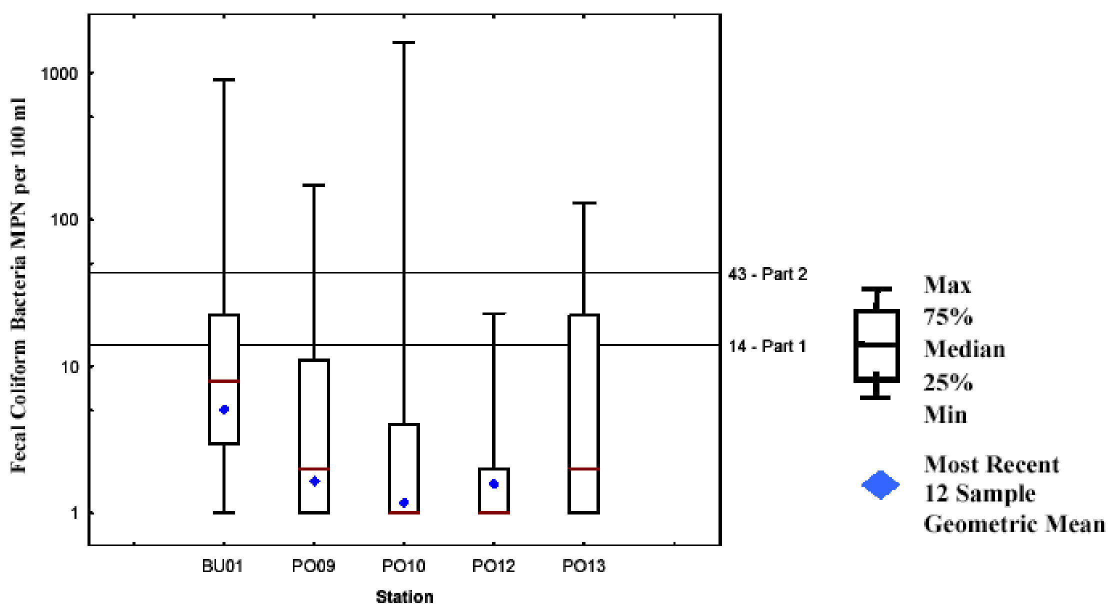

Figure 5-8. Port Orchard Passage Marine Water-Quality Data Summary for 1996 to 2003 (KCHD 2004)

Although the KCHD PIC programs and other measures (e.g., stormwater BMP enhancements, CSO reductions, KCD farm plans) taken to improve water quality in the Sinclair-Dyes Inlet watershed have been very successful, bacterial pollution problems still exist. In 2005, for the first time in recent history, KCHD posted several streams to warn the public of the potential danger from bacterial contamination. These streams include Ostrich Bay Creek and Phinney Creek (outfall) in Dyes Inlet, Dee Creek near Illahee, and Olney (Karcher) Creek and Annapolis Creek in Sinclair Inlet, near Port Orchard (KCHD 2005).

5.3 Kitsap County Surface and Stormwater Management

Under the KC-SSWM Program, shoreline surveys of Dyes and Sinclair Inlets have been conducted and the majority of outfalls draining to receiving waters have been located. These outfalls have been characterized by size and condition and screened for contaminants. The surveys were conducted in conjunction with the ongoing SSWM program of illicit discharge detection and elimination. The illicit discharge detection and elimination effort is one of six minimum-control measures required in the EPA NPDES Phase II final rule as a stormwater permit condition for regulated small municipalities. Figures 5-9 and 5-10 show the known stormwater outfalls located in Sinclair and Dyes Inlets. This master outfall list was used during the TMDL project to select outfalls that were candidates for stormwater-quality monitoring. Future ENVVEST work will include characterizing outfall water quality and evaluating the need for installation of stormwater BMPs to treat runoff prior to discharge via outfalls into receiving waters.

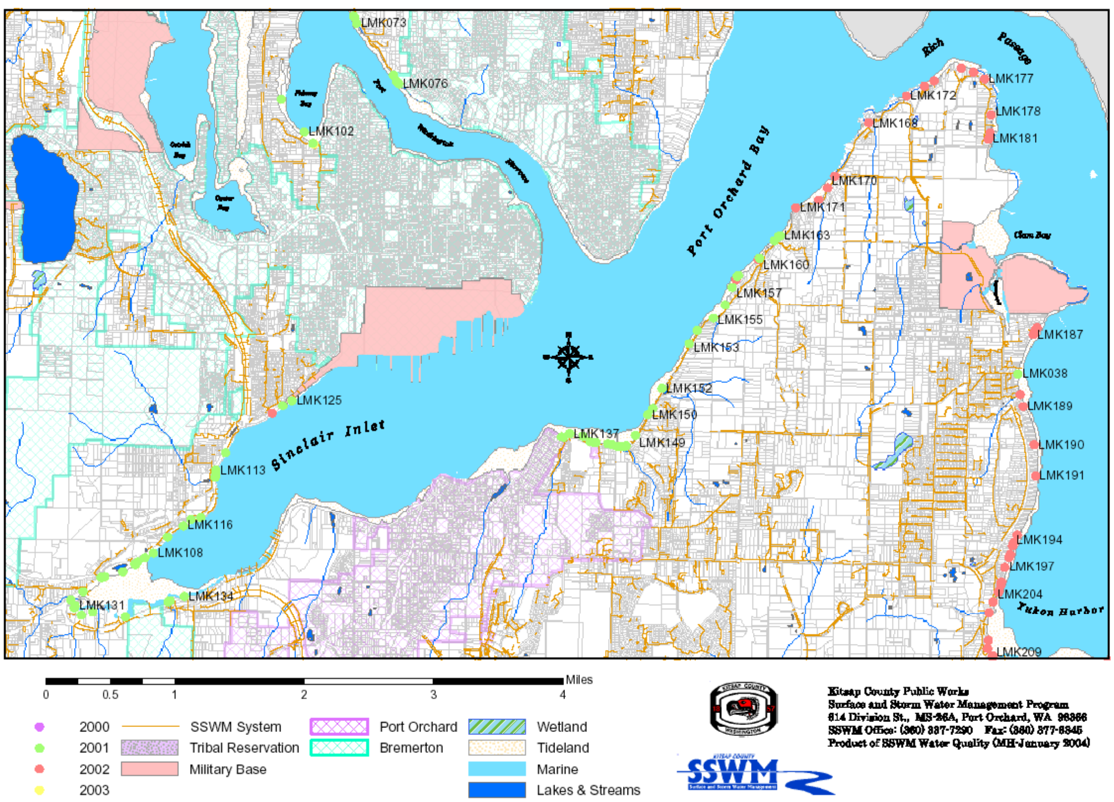

Figure 5-9. Kitsap County Stormwater Outfall Locations in Sinclair Inlet

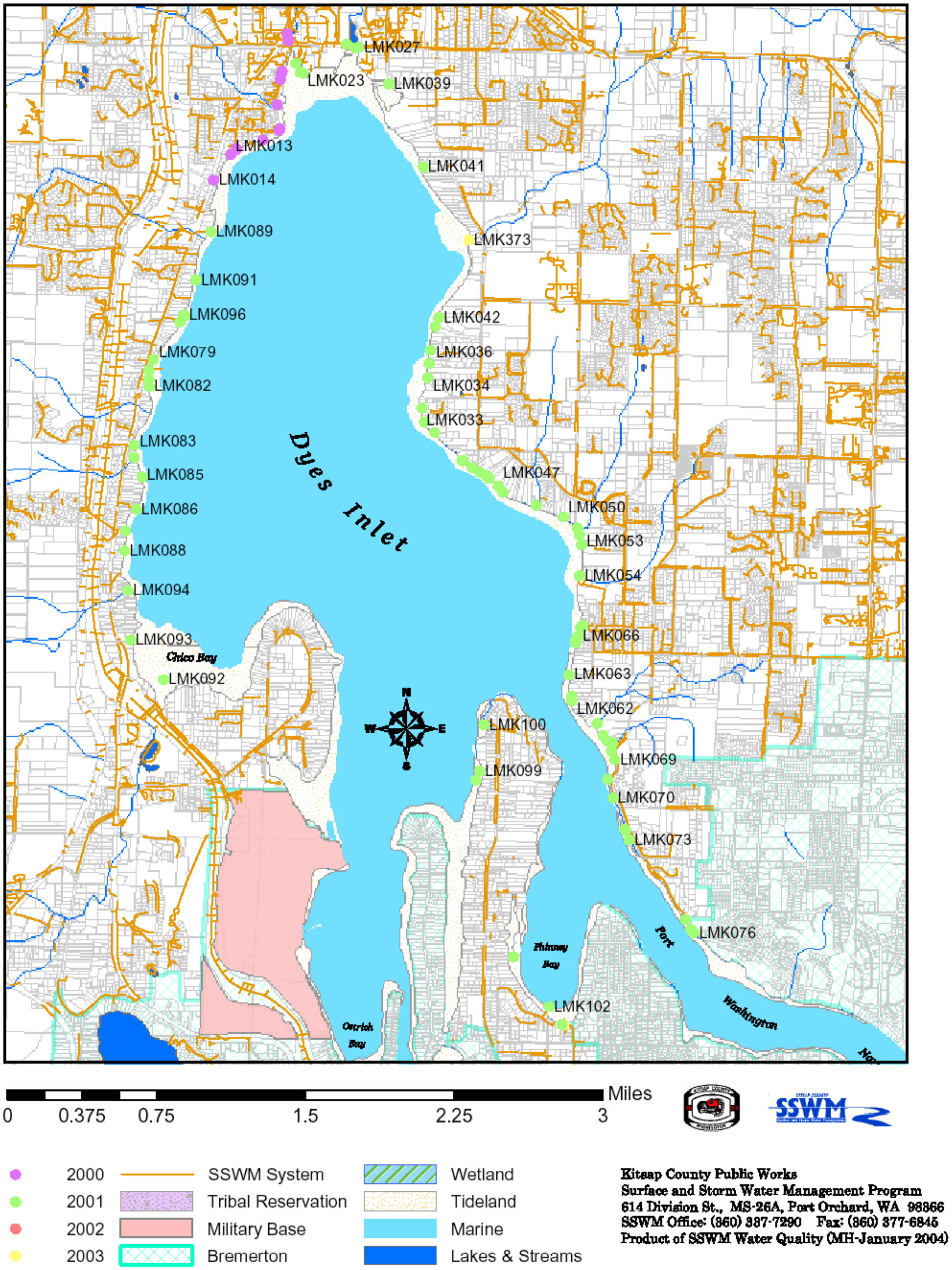

Figure 5-10. Kitsap County Stormwater Outfall Locations in Dyes Inlet

5.4 City of Bremerton

The City of Bremerton has an active stormwater management program that includes long-term monitoring, infrastructure improvement, stormwater BMP implementation, illicit discharge elimination, stormwater disconnect program, and CSO reduction components.

As of 2003, the Bremerton wastewater collection and conveyance network includes 14 CSO sites (Figure 5-11). These structures are in the older portion of the city wastewater system, with some even pre-dating the WWTP that was constructed in 1946 (COB 2004).

Significant progress has been made by the City of Bremerton toward completion of their CSO reduction program since 1989 when regulations limiting CSO discharges were instituted. In 1993, Bremerton also settled a lawsuit with the Puget Sound-Keeper Alliance that resulted in additional CSO reduction and monitoring requirements. The current CSO reduction plan was approved by Ecology in 2000 (COB 2004). In addition, the National CSO Control Policy was finalized by EPA in 1994. By 2003, the City of Bremerton had completed most of the required CSO reduction projects, many ahead of schedule (COB 2004). Figure 5-12 shows the reduction in CSO volume since the program was implemented. In 2003, there was a 95% reduction in CSO volume discharged and a 91% reduction in CSO overflow-events or frequency when compared to program baseline values (COB 2004). This overall reduction in CSO events and overflow volume is the result of continued wastewater infrastructure system improvements, including the Eastside Treatment Facility, which has an ultraviolet disinfection system (COB 2004). Figure 5-13 shows the CSO data for 2003. In 2003, half of the 14 CSO outfalls had only a single CSO event (COB 2004).

Completed CSO reduction program projects are summarized below (COB 2004):

- Warren Avenue drainage basin CSO separation (1996)
- East Park drainage basin CSO separation (1996)
- Stevens Canyon drainage basin CSO reduction (2000)
- Pine Road, Eastside CSO Treatment Facility (2001)
- Callow Avenue drainage basin CSO reduction (2003)

In-progress CSO reduction program projects are summarized below (COB 2004):

- Anderson Cove drainage basin CSO reduction
- Trenton Avenue drainage basin CSO reduction
- Cherry Avenue drainage basin CSO reduction
- Pacific Avenue drainage basin CSO reduction

Figures 5-14 through 5-19 illustrate the history of CSO in Bremerton.

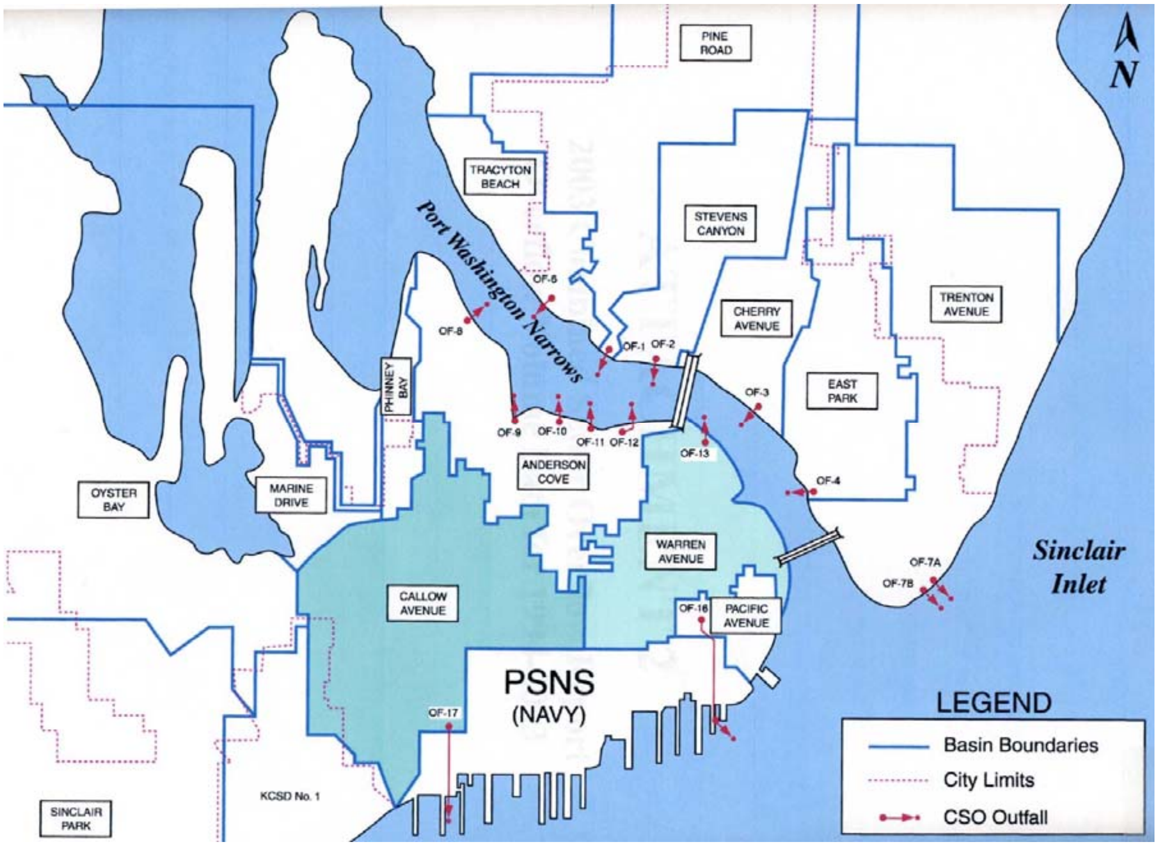

Figure 5-11. City of Bremerton Combined Sewer Overflow Outfall Locations (COB 2004)

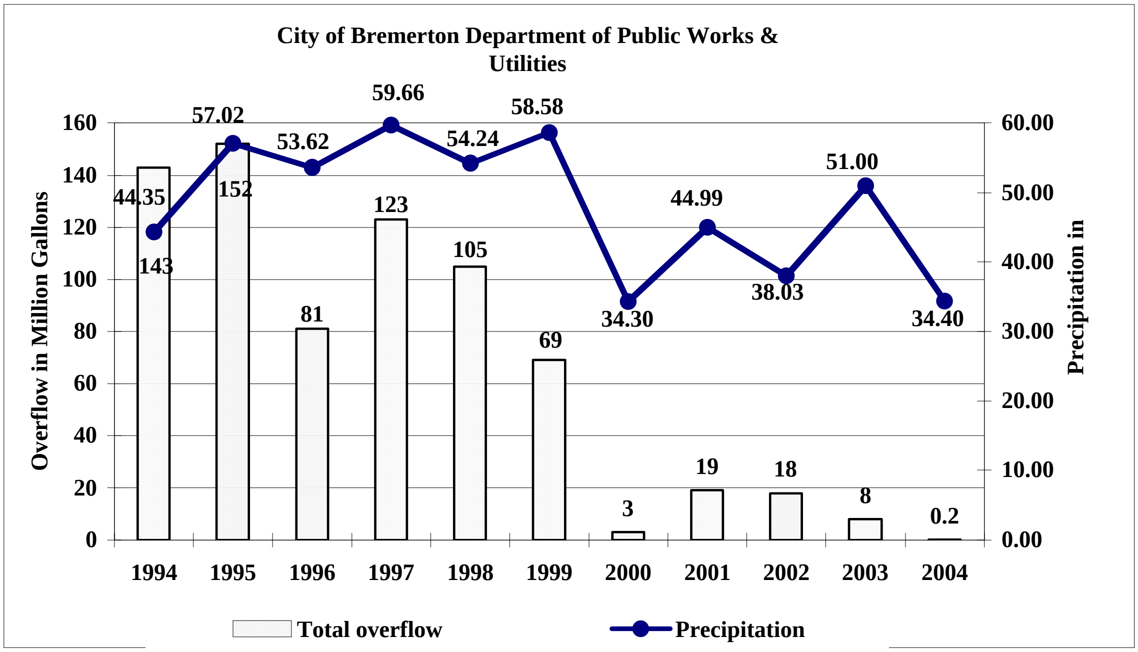

Figure 5-12. City of Bremerton Combined Sewer Overflow Historical Data Summary (COB 2004)

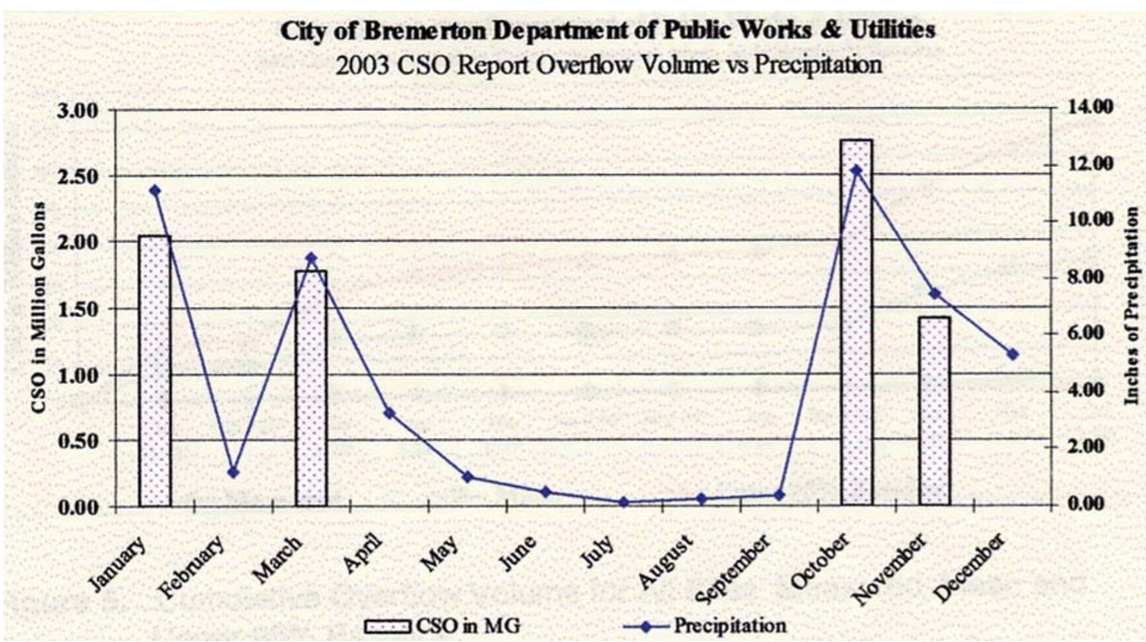

Figure 5-13. City of Bremerton Combined Sewer Overflow Data Summary for 2003 (COB 2004)

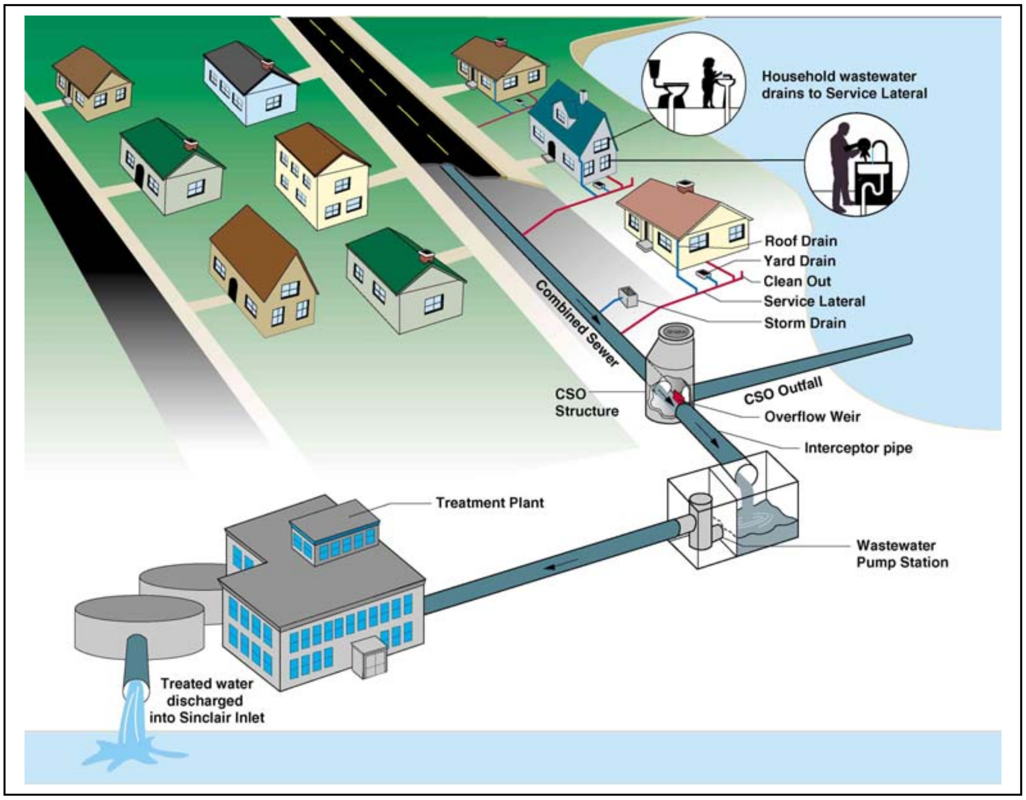

Figure 5-14. 1946: All Domestic and Industrial Wastewater Discharged Directly to the Puget Sound Without Treatment

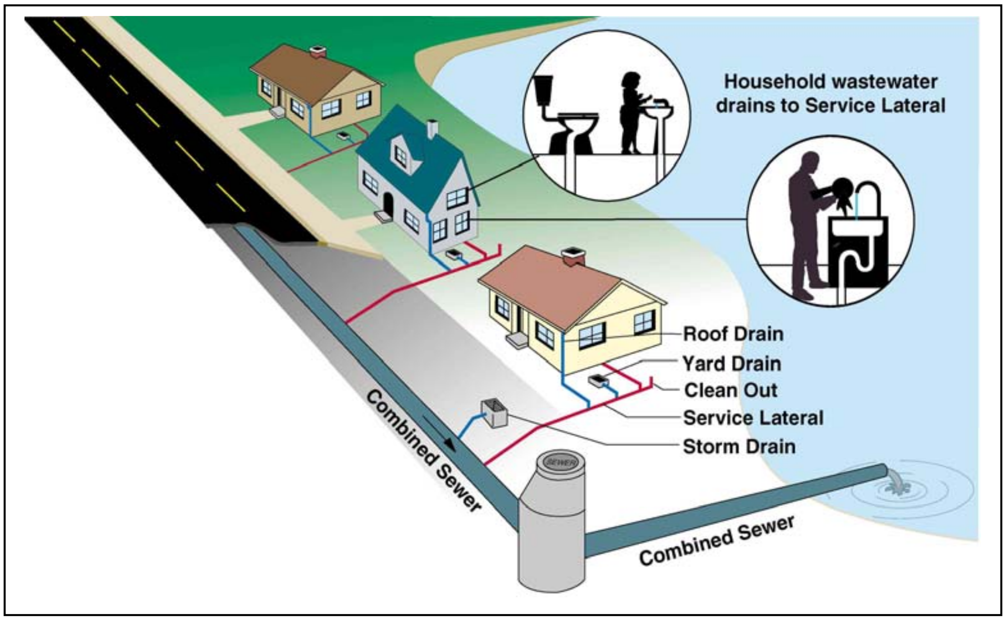

Figure 5-15. 1947: System Upgrade Allows Flows to be Intercepted Prior to Discharge and Rerouted to a Wastewater Treatment Plant

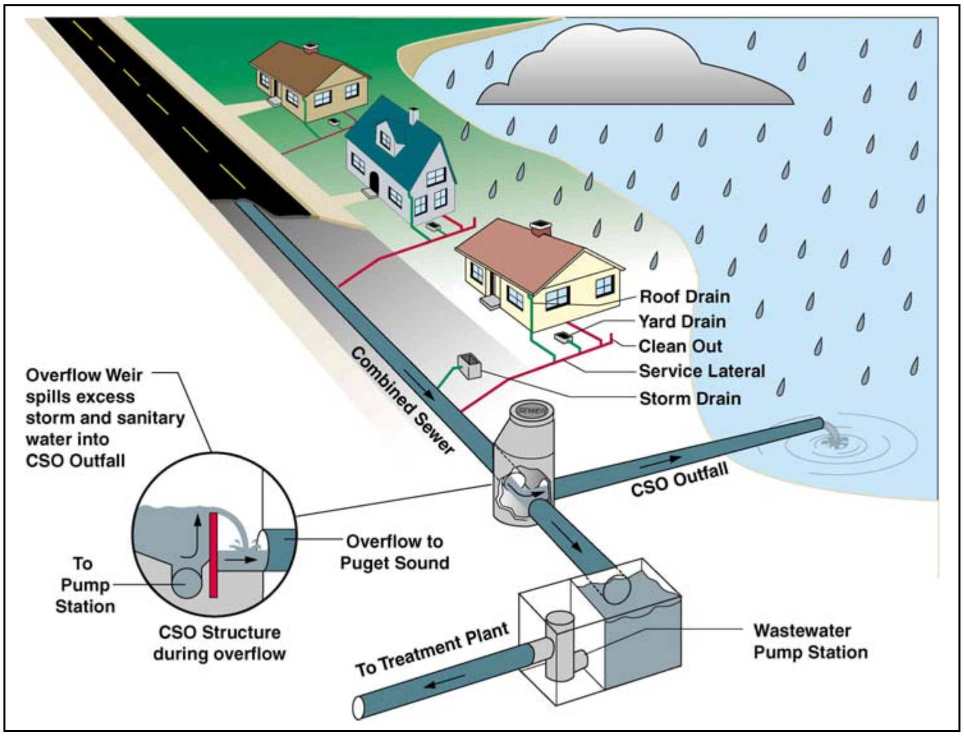

Figure 5-16. 1992: A Combined Sewer Systems Overflow Accommodates Volumes of Stormwater from Streets, Roofs, Driveways, and Foundation Drains, as well as from Infiltration Sources (COB 2005)

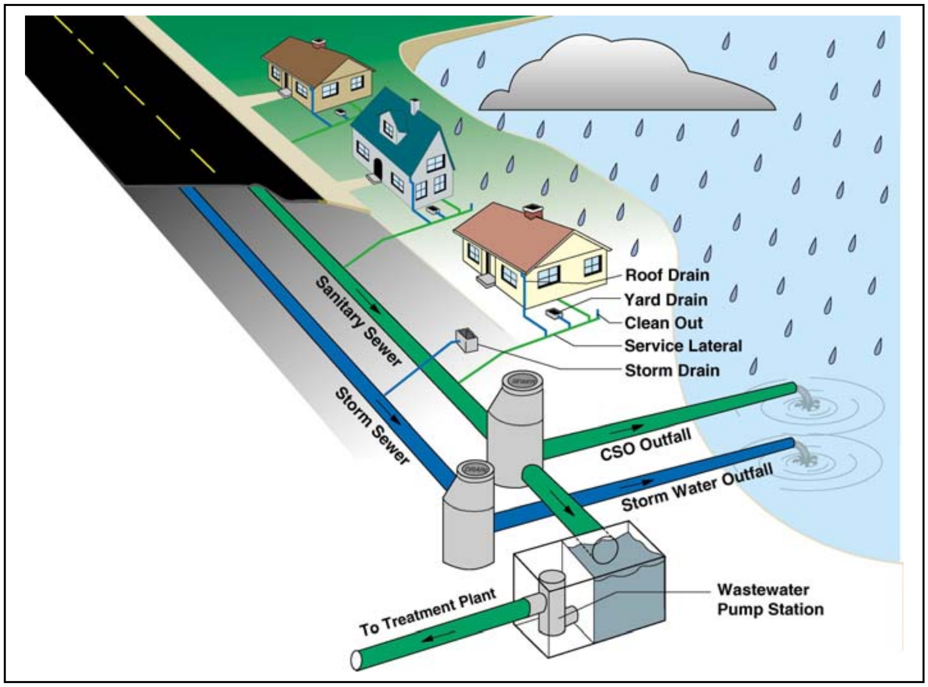

Figure 5-17. 2000-Current: Combined Sewer Overflows Reduced through Separated Stormwater Systems; Street Runoff Removed from System; Private Property Stormwater Runoff Still Enters the Sanitary Sewer System and Causes Combined Sewer Overflows (COB 2005)

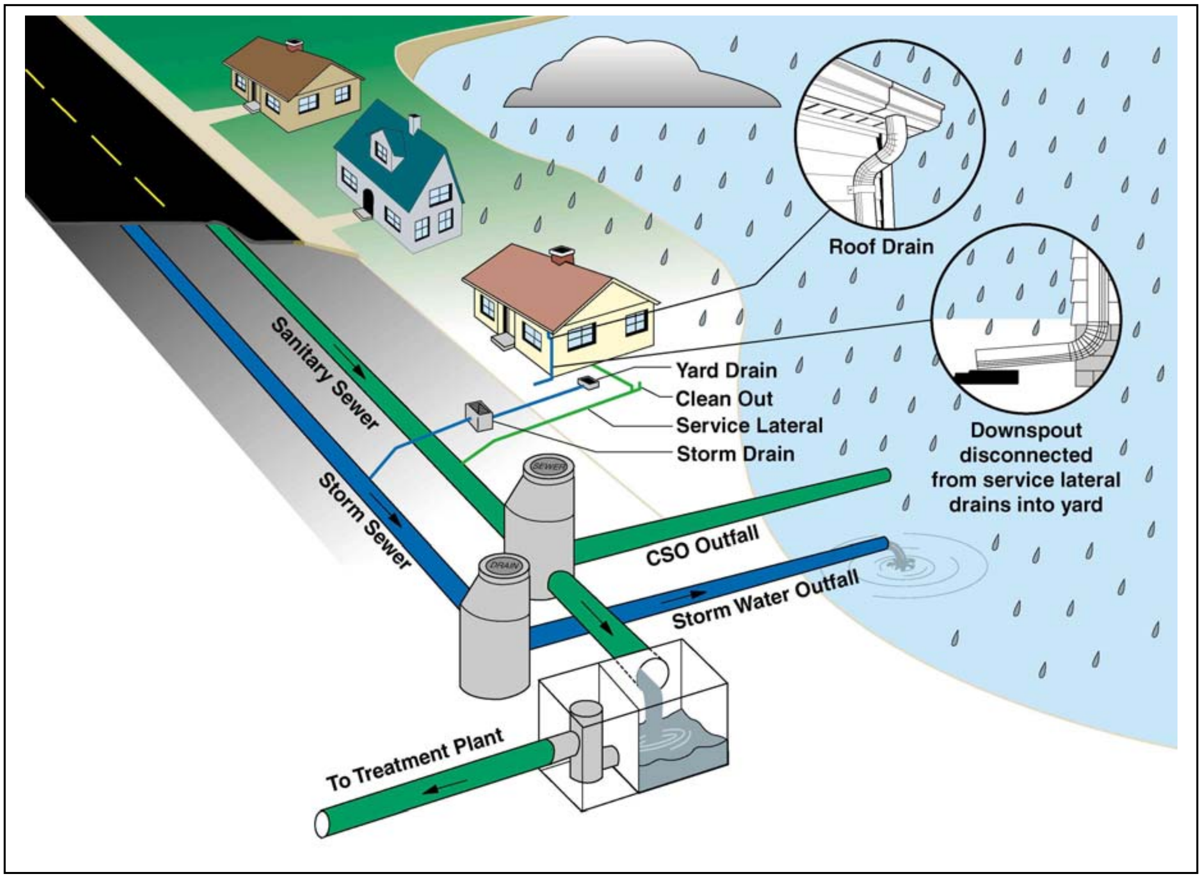

Figure 5-18. Program Goal: Route Stormwater Runoff to Ground Surface or a Stormwater System Where it is Cost Effective (COB 2005)

5.5 Puget Sound Naval Shipyard & Intermediate Maintenance Facility

Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS&IMF) has an active stormwater-quality enhancement program that includes installation of BMPs, drainage infrastructure improvements, and illicit discharge detection and elimination efforts. The locations of the major stormwater outfalls are shown in Figure 5-19. A subset of outfalls was selected for monitoring during this TMDL development process.

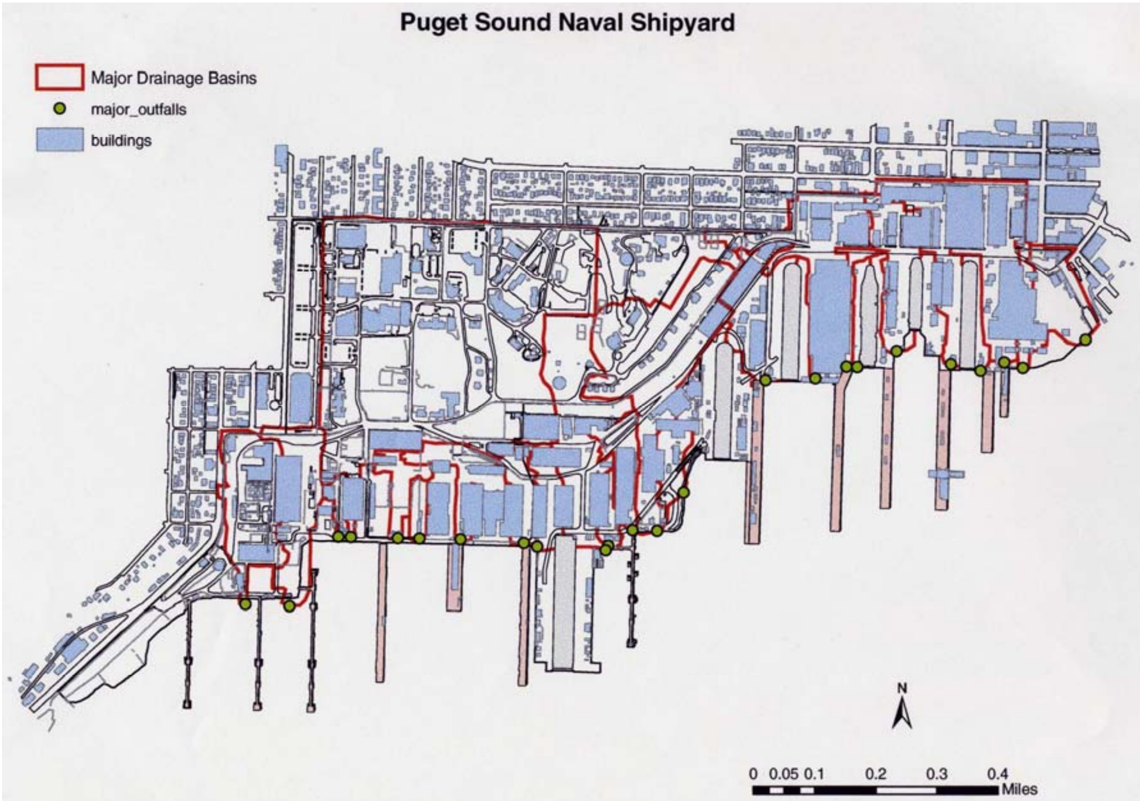

Figure 5-19. Puget Sound Naval Shipyard Stormwater Outfall Locations.

5.6 Washington Department of Health

As part of it's shellfish growing area (SGA) monitoring program, the WA-DOH has been sampling for bacterial pollution in Dyes Inlet and Port Orchard Passage for over 10 years (WA-DOH 2001b, 2002b, and 2003b). Figures 5-20 and 5-21 show the locations of WA-DOH sample sites in Sincalir-Dyes Inlet. No WA-DOH sampling is currently done in Sinclair Inlet. In September 2003, WA-DOH completed a sanitary survey of northern Dyes Inlet (WA-DOH 2003c). Under the Growing Area Classification Program, all commercially harvested shellfish growing areas in Washington State are evaluated to determine their suitability for harvest. Because shellfish are filter feeders, the quality of the water in which they grow plays a key factor in whether they are safe to eat. Each commercially harvested growing area is assigned a classification according to the results of this evaluation. A commercial growing area may be classified as *Approved*, *Conditionally Approved*, *Restricted*, or *Prohibited*. The typical WA-DOH sanitary survey consists of the following three parts:

1) The Shoreline Survey: an investigation of point and NPS pollution sources that may impact shellfish sanitation
2) The Marine Water-Quality Evaluation: an analysis of the bacterial water quality in the marine water
3) The Meteorological and Hydrographic Evaluation: an analysis of meteorological and hydrographic factors that may affect the distribution of pollutants in the area.

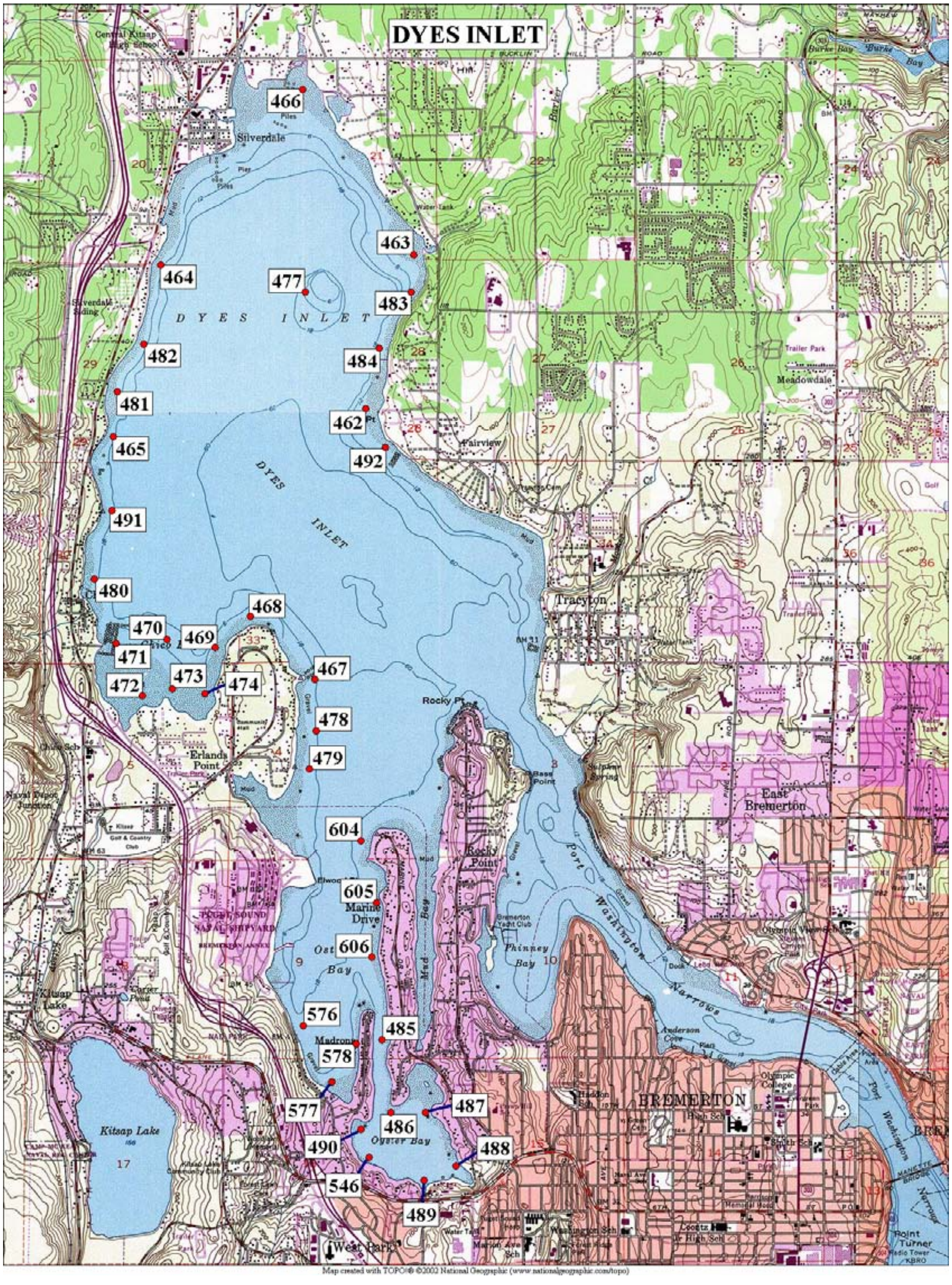

Figure 5-20. Washington Department of Health Long-Term Water-Quality Monitoring Stations in Dyes Inlet (WA-DOH 2003)

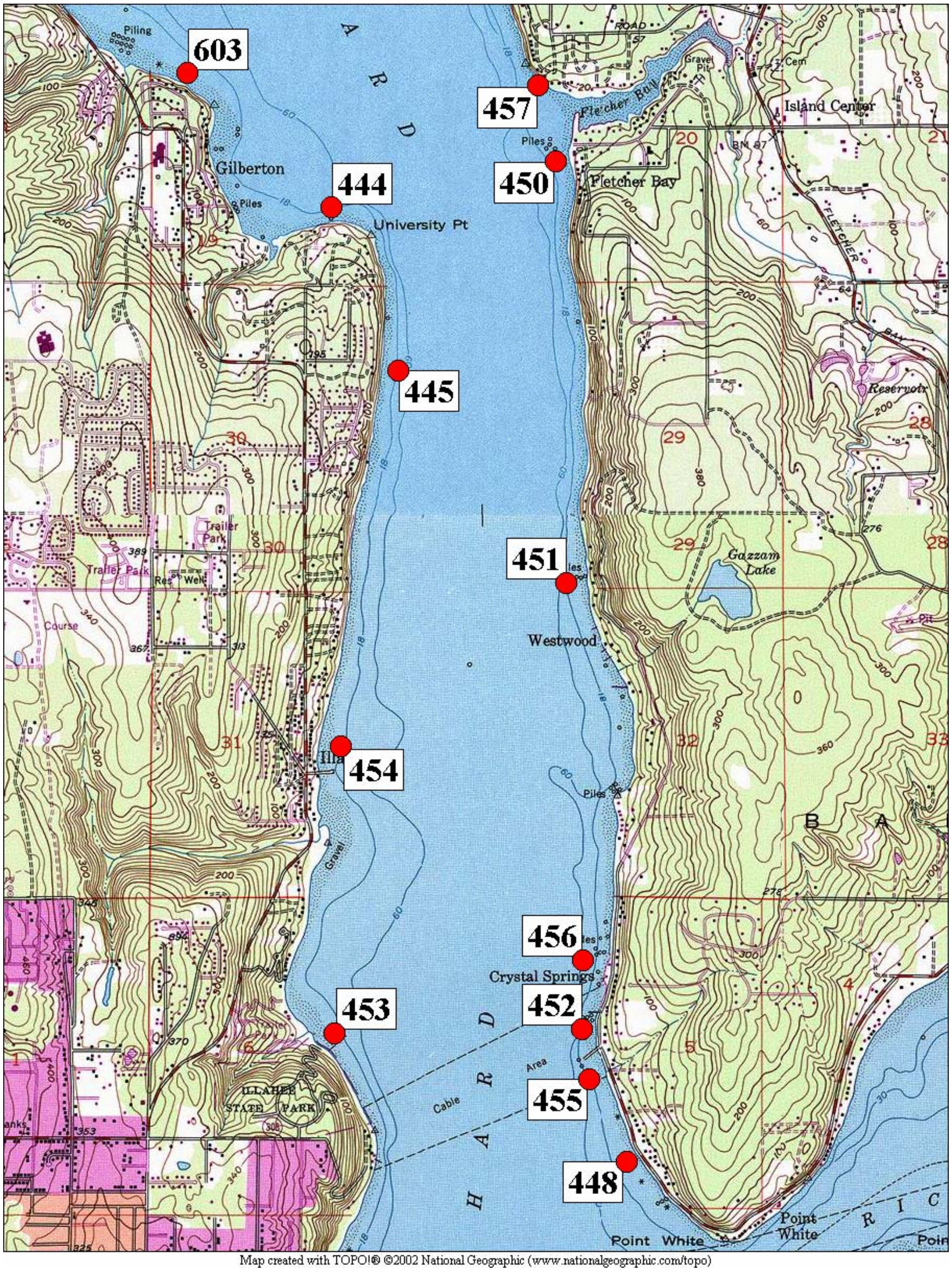

Figure 5-21. Washington Department of Health Long-Term Water-Quality Monitoring Stations in Port Orchard Passage (WA-DOH 2003)

The purpose of the pollution source or *shoreline surveys* and water-quality evaluations is to ensure that the area complies with the standards associated with its classification, to modify the classification when needed, and to notify the responsible agencies about identified contamination sources. Monitoring data and reports resulting from these studies are transmitted to local governments and Ecology. Once classified, all active commercial shellfish growing areas are regularly monitored. Marine water samples are collected throughout the year. Shoreline surveys are conducted less frequently, but each year dozens of commercial shellfish growing areas are surveyed. During those surveys, all potential pollution sources that may affect water quality are evaluated.

The most recent shoreline surveys conducted in Dyes Inlet include the following:

1) <u>2000 Shoreline Survey of Chico Bay SGA</u>
   - 51 shoreline properties surveyed
   - 3 perennial streams surveyed
   - No direct or indirect discharges found
   - 5 OWTS classified as "potential sources"
   - Waterfowl in Chico Bay identified as the most likely source of periodic high FC samples and potential cause for the current restricted classification.

2) <u>2001 Shoreline Survey of the West Shore of Dyes Inlet SGA</u>
   - 139 shoreline properties surveyed
   - 14 natural and man-made drainage ways surveyed
   - 4 failed OWTS identified and repaired
   - Classified as prohibited due to concerns about possible CSO event impacts.

3) <u>2001 Shoreline Survey of the Windy Point of SGA</u>
   - 36 shoreline properties surveyed
   - 2 perennial streams surveyed
   - No direct or indirect discharges found
   - 4 OWTS classified as "potential sources"
   - Classified as prohibited due to concerns about possible CSO event impacts and discharge from Barker Creek.

4) <u>2001 Shoreline Survey of the Erlands Point SGA</u>
   - 49 shoreline properties surveyed
   - 1 perennial stream surveyed
   - 11 OWTS classified as "potential sources"
   - 1 failed OWTS identified and repaired
   - Classified as prohibited due to concerns about possible CSO event impacts.

The *Sanitary Survey of North Dyes Inlet* (WA-DOH 2003c) used data from the above shoreline surveys, KCHD and WA-DOH water-quality data, and other data sources to reclassify some portions of the northern Dyes Inlet SGA. The 2003 sanitary survey reclassified portions of Dyes Inlet from *prohibited* to *conditionally approved* status for shellfishing (WA-DOH 2003c). The North Dyes Inlet SGA was *conditionally approved* in 2003. This classification was made possible by years of work by the City of Bremerton on reducing CSOs, and by countless watershed residents who have corrected failing septic systems and poor livestock waste management practices as part of KCHD and KCD water-quality projects. The Chico Bay SGA remains *restricted* and the western shore of Chico Bay is *unclassified* because of periodic high FC levels. Port Washington Narrows is classified as *prohibited*. In addition, a small closure zone has been established by WA-DOH at the mouth of Barker Creek as a result of periodic high FC contamination levels coming from upstream sources (WA-DOH 2003c).

This sanitary survey also includes an evaluation of the current impacts of the City of Bremerton CSO system (WA-DOH 2003c). The report acknowledges that Bremerton has significantly reduced the frequency and quantity of CSO events over the past decade and was one of the main reasons for the upgrading of the northern Dyes Inlet SGA (WA-DOH 2003c). Preliminary modeling work conducted under the cooperative ENVVEST project was used to predict the transport and dilution of CSO discharges into the Port Washington Narrows (WA-DOH 2003c). Thus far, the results of the modeling indicate that major discharges from the West Bremerton CSO outfalls and the Eastside CSO Treatment Facility can reach the shellfish beds in the North Dyes Inlet shellfish growing area. However, the dilution and die-off of FC bacteria appears to be sufficient to meet the shellfish WQS of 14 FC/100 mL at the shellfish beds in the North Dyes Inlet shellfish growing area (WA-DOH 2003c).

As was outlined earlier in this section, over the past several years, the quantity of CSO discharged to the Port Washington Narrows has ranged from 0.4 to 7.5 million gallons each year (COB 2004). The quantity of these CSO discharges is expected to decrease significantly over the next several years. However, WA-DOH is concerned in the immediate future about the potential magnitude of CSO discharges to the Narrows. There are over 100 known human enteric viruses, many of which are likely in the CSO discharges into the Port Washington Narrows (WA-DOH 2003). As a result, WA-DOH has decided to implement a 1-week closure of shellfish harvesting in the North Dyes Inlet growing area following notification by the City of Bremerton of any known CSO discharge into the Port Washington Narrows. The basis for this closure period is to provide adequate time for natural removal (e.g., die-off, settling) of viable pathogens from the water column and for adequate cleansing of any potentially affected shellfish (WA-DOH 2003).

5.7 Washington Department of Ecology

The Ecology BEACH program also monitors water quality within the Sinclair-Dyes Inlet study area. The BEACH Program stands for Beach Environmental Assessment, Communication, and Health (BEACH). The BEACH Program is a state-wide marine water-quality monitoring and public notification program designed to reduce the risk of disease to the users of Washington's highly used saltwater recreational beaches. The BEACH Program was developed in response to the BEACH Act, which was passed by the U.S. Congress in 2000. The BEACH Act amends the CWA by authorizing the EPA to appropriate funds to states for the development of monitoring and notification programs that will provide a more uniform system for protecting the users of marine waters. The primary focus of the BEACH program is to protect public health at swimming beaches. The BEACH Program is managed by Ecology and WA-DOH. Beaches are sampled for bacteria during the summer by local environmental health or surface water departments or by local volunteers (WA-DOE 2002). BEACH Program information, sample results, and beach advisory information is available at the BEACH Program web site (www.doh.wa.gov/beach).

The goal of the BEACH Program is to reduce the risk of disease to users of beaches. The program includes the following components (WA-DOE 2002):

- monitoring bacteria levels at saltwater recreational beaches used by the public
- managing a notification system that alerts users of saltwater beaches when monitoring results are above threshold limits and when human health or safety is at risk because of a pollution event
- educating the public about the risk of illness associated with increased levels of bacteria in recreational waters.

The BEACH Program educates the public and provides them necessary information to

- make informed decisions
- better understand the connection between exposure to bacteria levels in saltwater and the potential for recreational users to becoming ill
- identify potential areas of pollution.

The BEACH Program monitors water quality for bacteria that indicate the possibility of pollution from sewage treatment plant problems, boating waste, malfunctioning septic systems, and animal waste. For this program, water quality is monitored using the indicator organism, enterococci. Other indicators, such as FC and EC are tracked when deemed necessary (WA-DOE 2002).

Notification of bacteria levels above threshold limits and pollution events or unsafe conditions at a beach is communicated to the public through

- warning signs posted at the beach
- public information Web sites
- telephone hotlines
- publication in the mass media of potential bacterial hazards.

The BEACH Program is implemented as a collaborative effort between state, county and local agencies, tribal nations, and volunteer organizations. Washington State has over 3500 miles of coastal waters with over 800 public recreational beaches. Using a risk prioritization matrix, 72 of the 800 recreational beaches were identified as priority beaches (WA-DOE 2002). Figure 5-22 shows the locations of BEACH Program monitoring sites.

The following BEACH Program sites are monitored within the Sinclair-Dyes Inlet study area:

- Evergreen Park (Bremerton)
- Lions Park (Bremerton)
- Silverdale Waterfront Park (Silverdale)
- Illahee State Park (Port Orchard Passage)
- Pomeroy Park (Manchester)

Priority beaches are chosen based on the number of people swimming, scuba diving, surfing, wind surfing, wading, or otherwise using the water for recreation; nearby sources of potential fecal pollution; stormwater discharges to the beach; whether there are marinas in the vicinity; the proximity of areas known as wildlife habitat; and other associated potential pollution sources. Public opinion is also factored in when choosing the priority beaches (WA-DOE 2002).

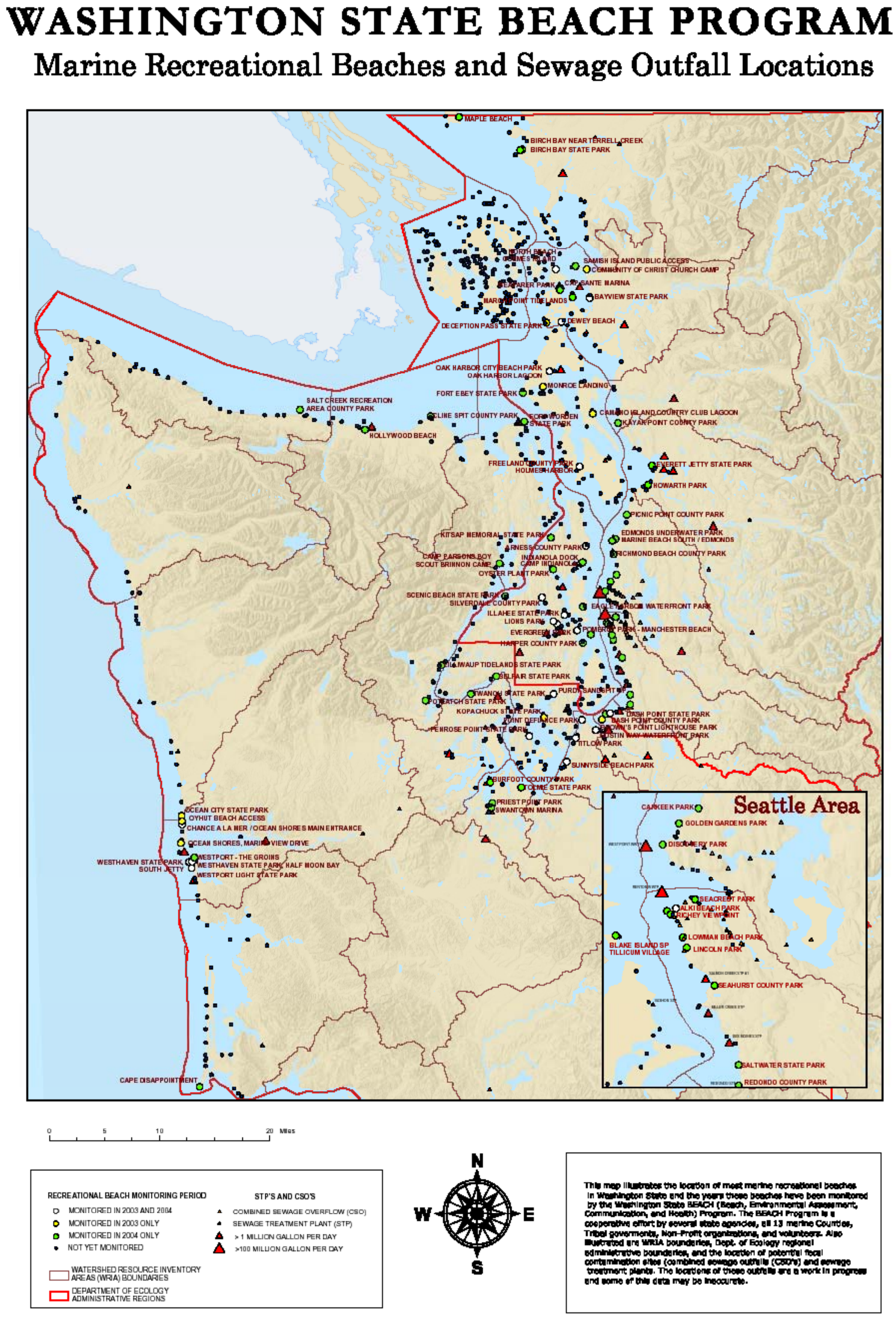

Figure 5-22. Ecology BEACH Program Water-Quality Monitoring Site Map (WA-DOE 2002)

Three samples are collected across the beach and are analyzed by state accredited labs within 6 hours of sample collection. Results are e-mailed or faxed within 24 hours. The three samples are averaged and then compared with threshold limits. Geometric means are calculated using all the sample results from the 5 previous weeks. Advisories are posted on the BEACH Web site within 24 hours, and all sample results are posted within 48 hours (WA-DOE 2002). The results of BEACH program water-quality monitoring for 2003 through 2005 are shown in Tables 5-2 through 5-4.

In general, the results of BEACH Program monitoring indicate that recreational beaches in the Sinclair-Dyes Inlet watershed are relatively low in bacterial pollution levels, but that periodically there are samples that test above the health-advisory thresholds used in the BEACH Program. In most cases, when an elevated bacterial level is detected, follow-up sampling is within limits and no beach-health advisory is posted. However, in the case of storms that result in a CSO event and/or excessive stormwater runoff, beach closure advisories have been posted. The BEACH sites located within the Sinclair-Dyes Inlet study area that appear to have the greatest potential for bacterial pollution and beach closures are Evergreen Park and Lions Park (both located in Bremerton in the Port Washington Narrows) and Silverdale Waterfront Park (located at the head of Dyes Inlet in Silverdale). The Bremerton beach sites are likely affected by CSO events and stormwater runoff, whereas the Silverdale site is more than likely affected by stormwater runoff.

The results for the Sinclair-Dyes Inlet area mirror the results found in other BEACH Program sites throughout the Puget Sound region. Most beaches show little sign of chronic bacterial contamination. Those sites that do have frequent health-advisory closures tend to share a common profile. They are usually in highly developed areas, have poor natural tidal flushing, and are exposed to stormwater runoff from urbanized shoreline areas or CSO events (WA-DOE 2002).

Ecology also conducted a basic assessment of the Sinclair-Dyes Inlet watershed as part of the Puget Sound Estuary Study and the Urban Bay Action Program (EPA 1990). The findings of this study were similar to more recent assessments, but were not as up-to-date and, therefore, were not included in this study. Another useful Ecology publication applicable to the Sinclair-Dyes Inlet watershed is *Shellfish Protection Through Land-Use Management* (WA-DOE 1992).

Table 5-2. Washington Department of Ecology BEACH Program Water-Quality Results (2003)

KITSAP	5/28	6/1	6/3	6/7	6/9	6/21	6/28	7/1	7/6	7/12	7/14	7/19	7/26	8/2
	CSO	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero	Entero
CAMP INDIANOLA		<10		NS		<10	<10		<10	<10		30	<10	51
INDIANOLA DOCK		<10		<10		16	144	23	38	194	17	31	31	223
ARNESS COUNTY PARK		13		13		42	16		<10	31		<10	<10	20
KITSAP MEMORIAL STATE PARK		<10		<10		20	123	<10	<10	<10		<10	16	13
OYSTER PLANT PARK		<10		<10		<10	<10		<10	13		<10	55	<10
EAGLE HARBOR		<10		<10		13	197		40	<10		19	19	<10
SCENIC BEACH STATE PARK		<10		<10		13	264	20	<10	23		<10	46	<10
HARPER COUNTY PARK		13		20		179	17		17	<10		13	<10	<10
POMEROY PARK / MANCHESTER		483		488	102	41	17		34	27		17	13	53
EVERGREEN PARK	CSO	20		<10		<10	34		<10	<10		<10	<10	<10
ILLAHEE STATE PARK		189	50	16		20	<10		64	17		<10	<10	154
LIONS PARK		13		<10		<10	<10		<10	31		<10	<10	<10
SILVERDALE COUNTY PARK	CSO	20		<10		<10	31			<10		55	10	13

Average of Samples Above Advisory Threshold of 104 cfu / 100 ml. Further Investigation Determined Advisory Posting Unnecessary

Advisory Posted

Resample Result

Combined Sewage Overflow (CSO) Event - Beaches Closed

Table 5-3. Washington Department of Ecology BEACH Program Water-Quality Results (2004)

KITSAP	5/28	6/1	6/3	6/7	6/9	6/21	6/28	7/1	7/6	7/12	7/14	7/19	7/26	8/2
	CSO	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**	**Entero**
CAMP INDIANOLA		<10		NS		<10	<10		<10	<10		30	<10	51
INDIANOLA DOCK		<10		<10		16	144	23	38	194	17	31	31	223
ARNESS COUNTY PARK		13		13		42	16		<10	31		<10	<10	20
KITSAP MEMORIAL STATE PARK	CSO	<10		<10		20	123	<10	<10	<10		<10	16	13
OYSTER PLANT PARK		<10		<10		<10	<10		<10	13		<10	55	<10
EAGLE HARBOR		<10		<10		13	197		40	<10		19	19	<10
SCENIC BEACH STATE PARK		<10		<10		13	264	20	<10	23		<10	46	<10
HARPER COUNTY PARK		13		20		179	17		17	<10		13	<10	<10
POMEROY PARK / MANCHESTER		483		488	102	41	17		34	27		17	13	53
EVERGREEN PARK	CSO	20		<10		<10	34		<10	<10		<10	<10	<10
ILLAHEE STATE PARK	CSO	189	50	16		20	<10		64	17		<10	<10	154
LIONS PARK		13		<10		<10	<10		<10	31		<10	<10	<10
SILVERDALE COUNTY PARK	CSO	20		<10		<10	31			<10		55	10	13

Average of Samples Above Advisory Threshold of 104 cfu / 100 ml. Further Investigation Determined Advisory Posting Unnecessary

Advisory Posted

Resample Result

Combined Sewage Overflow (CSO) Event - Beaches Closed

Table 5-4. Washington Department of Ecology BEACH Program Water-Quality Results (2005)

KITSAP	5/23	5/31	6/1	6/6	6/13	6/20	6/22	6/26	6/27	6/29	7/5	7/11	7/18	7/25
	Entero	Entero	CSO	Entero	Entero	Entero	CSO	Entero	Entero	Entero	Entero	Entero	Entero	Entero
CAMP INDIANOLA	13	<10		<10		16		10		GOOD	<10	19	<10	<10
INDIANOLA DOCK	<10	<10		<10		<10		<10		GOOD	10	<10	<10	20
ARNESS COUNTY PARK	44	13		<10		10		<10		GOOD	GOOD	<10	17	13
FAYE BAINBRIDGE STATE PARK	<10	31		<10		<10		<10		GOOD	34	16	<10	<10
EAGLE HARBOR	16	55		34		<10		<10		GOOD	23	<10	<10	16
SCENIC BEACH STATE PARK	<10	212		23		<10			<10	GOOD	GOOD	<10	<10	341
HARPER COUNTY PARK	13	13		21		74			13	GOOD	20	<10	<10	20
POMEROY PARK / MANCHESTER	13	122		59		63			24	GOOD	44	<10	23	27
EVERGREEN PARK	<10	61	CSO	<10		<10	CSO		<10	CSO	<10	<10	10	<10
ILLAHEE STATE PARK	<10	<10		13		13			<10	GOOD	<10	<10	<10	<10
LIONS PARK	<10	49	CSO	<10		13	CSO		<10	CSO	<10	<10	<10	<10
SILVERDALE COUNTY PARK	<10	76	CSO	<10		11	CSO		<10	CSO	CSO	16	<10	<10

Average of Samples Above Advisory Threshold - Further Investigation Needed

Average of Samples Above Advisory Threshold of 104 cfu / 100 ml. Further Investigation Determined Advisory Posting Unnecessary

Advisory Posted

Resample Result

Combined Sewage Overflow (CSO) Event - Beaches Closed

6.0 Bacterial Pollution Monitoring Results

This section of the report summarizes the microbial pollution data available for the Sinclair-Dyes Inlet watershed for the primary study period of the ENVVEST project (2000-2003). Several sources of data are included in this section, including WWTPs located within the study area, WA-DOH marine FC monitoring stations, KCHD marine-nearshore and stream monitoring stations, KC-SSWM stormwater outfall FC data, and the data collected by ENVVEST team members as part of this project as described in the Methods section of this report. This composite dataset includes FC-sample stations that cover a majority of the potential bacterial pollution sources located within the study watershed, including WWTP outfalls, CSO outfalls, stormwater outfalls, streams impacted by NPS runoff, failing OWTS, and marinas.

6.1 Wastewater Treatment Plant Data

The City of Bremerton WWTP is located on Sinclair Inlet in Bremerton. The WWTP is an activated-sludge system with primary and secondary treatment capability. The WWTP discharge diffuser is located in Sinclair Inlet between Bremerton and Gorst. The Bremerton WWTP operates under an approved NPDES Permit issued by Ecology. The FC effluent limits are based on colony forming units, or CFUs. The limits are 200 cfu/100 mL for a monthly average and 400 cfu/100 mL for a weekly average (based on a geometric mean of FC samples). Five FC grab samples are required per week. In addition to FC samples, flow (discharge volume) and several other priority pollutants (e.g., metals, nutrients) are monitored periodically. The design maximum discharge rate is 10.1 million gallons per day (MGD). Acute and chronic toxicity testing is also performed on a routine basis. The WWTP relies on design dilution ratios of receiving waters to plant effluent in the mixing zone of the diffuser to meet acute and chronic aquatic life and human health criteria.

The City of Port Orchard WWTP is also located on Sinclair Inlet just east of downtown Port Orchard and is operated by the Karcher Creek Sewer District (KCSD). The plant is an activated-sludge system with primary and secondary treatment capability. The WWTP discharge diffuser is located in Sinclair Inlet, just east of Annapolis and Retsil. Like Bremerton, the Karcher Creek WWTP operates under an approved NPDES permit issued by Ecology. The FC effluent limits are a monthly average of 200 cfu/100 mL and a weekly average of 400 cfu/100 mL (based on a geometric mean of FC samples). Five FC grab samples are required per week. In addition to FC samples, flow (discharge volume) and several other priority pollutants (e.g., metals, nutrients) are monitored periodically. The design maximum discharge rate is 2.8 MGD.

The Bainbridge Island (BI) WWTP located at Fort Ward is also in the study area. The Fort Ward WWTP discharges into Rich Passage. No details are available on the design and operation of the Bainbridge Island WWTP. Monitoring requirements for the Bainbridge Island WWTP are similar to those of the Bremerton and Port Orchard facilities. WWTPs are also located in Manchester and Brownsville. Both of these facilities and their discharge points are located outside the Sinclair-Dyes Inlet ENVVEST project study area, although they do treat wastewater from within the study area. Wastewater from the commercial and high-density residential portions of Silverdale area is piped to Brownsville for treatment.

Figures 6-1 through 6-5 show the results of WWTP monitoring for the treatment plants of interest to this study (data for water-years 2002 and 2003 shown). Note that some sample data indicate that elevated FC levels do occur periodically; however, the regulatory permit that governs the operation of a WWTP is typically based on weekly and monthly average FC levels and not on individual samples, which can "spike" for a number of reasons (as discussed earlier in this report).

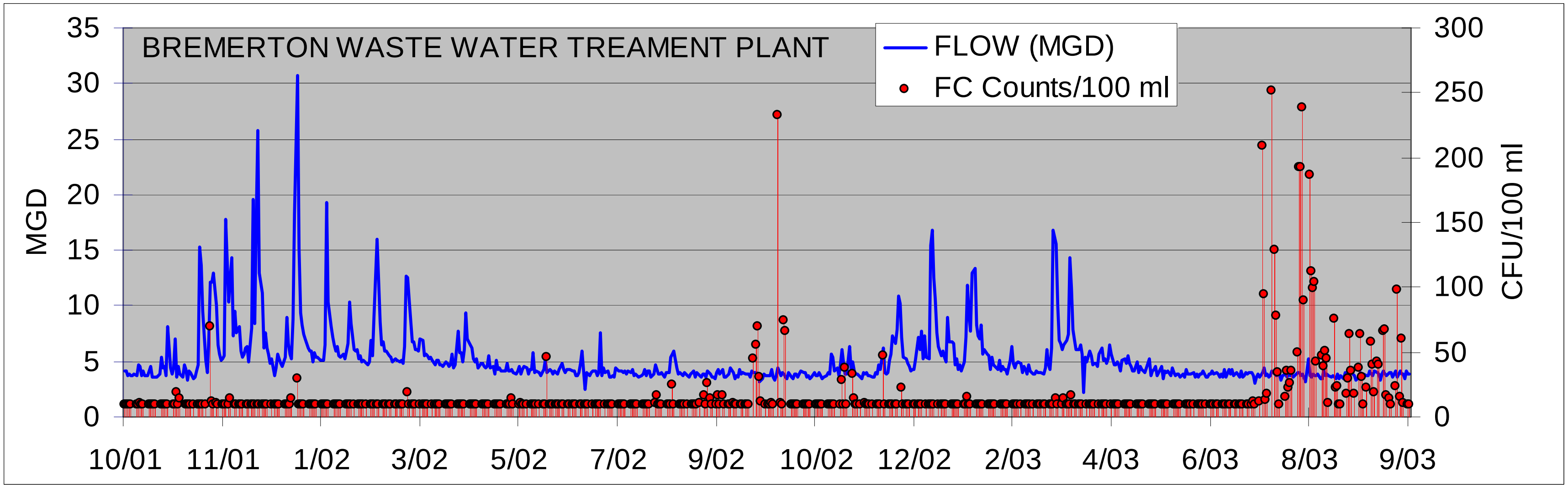

Figure 6-1. Bremerton Wastewater Treatment Plant Fecal Coliform and Flow (MGD) Data

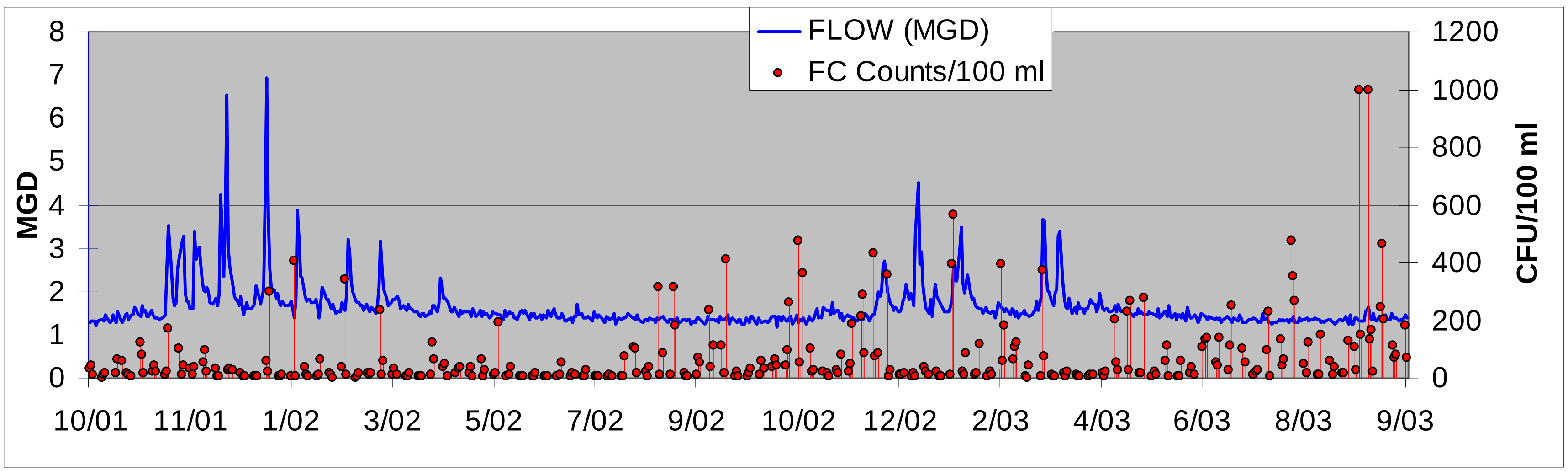

Figure 6-2. Port Orchard Wastewater Treatment Plant Fecal Coliform and Flow (MGD) Data

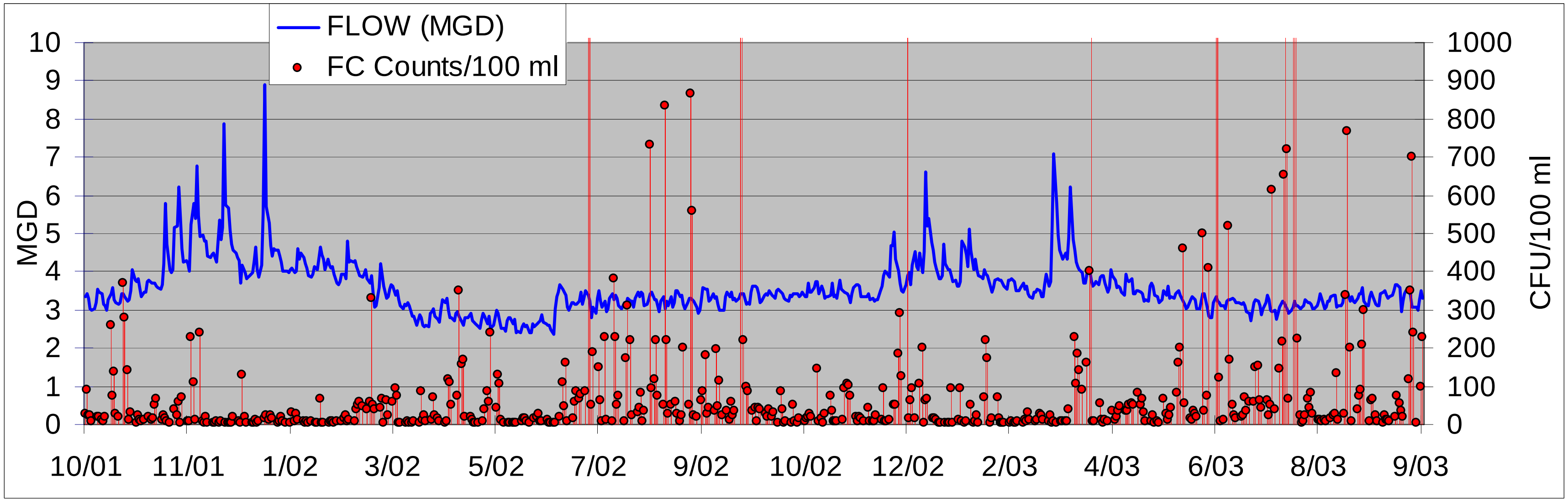

Figure 6-3. Brownsville Wastewater Treatment Plant Fecal Coliform and Flow (MGD) Data

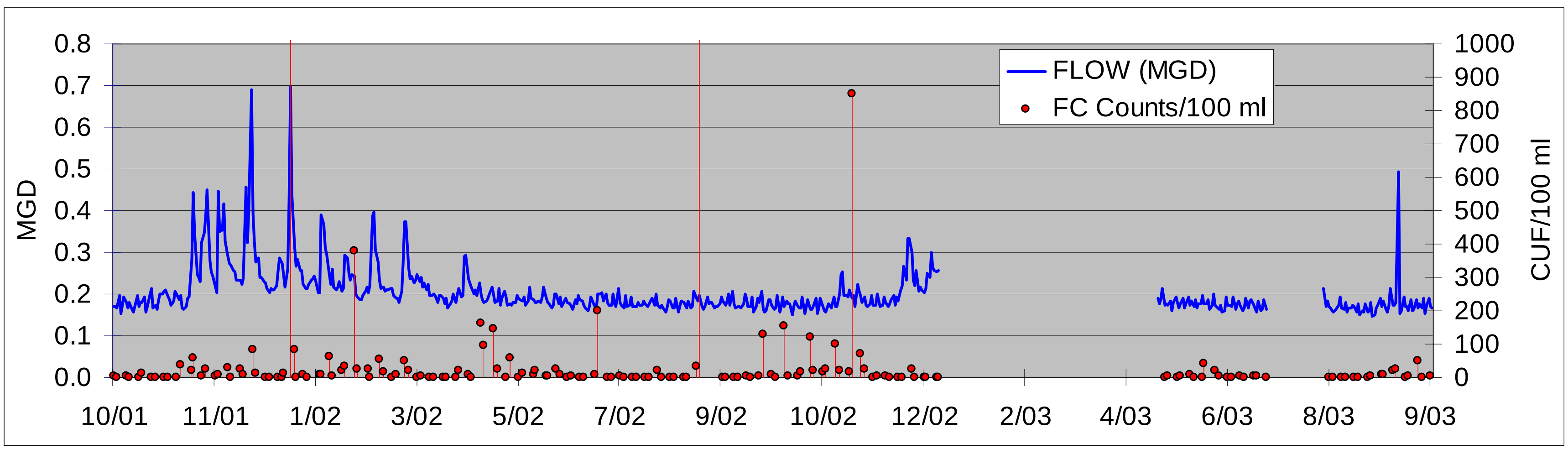

Figure 6-4. Manchester Wastewater Treatment Plant Fecal Coliform and Flow (MGD) Data

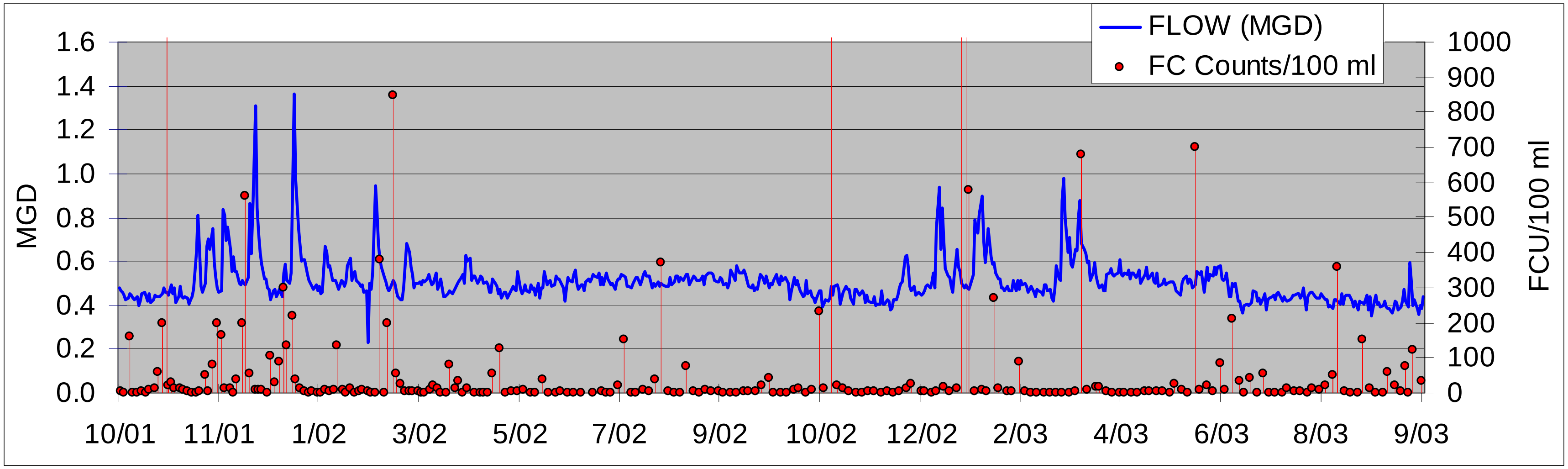

Figure 6-5. Bainbridge Island Wastewater Treatment Plant Fecal Coliform and Flow (MGD) Data

6.2 Marine-Nearshore Fecal Coliform Data

6.2.1 Washington Department of Health Nearshore Fecal Coliform Data

Because of the presence of shellfish harvesting areas within the Sinclair-Dyes Inlet watershed, WA-DOH has several nearshore marine sampling sites in Dyes Inlet and Port Orchard Passage. The main objective of WA-DOH monitoring is to assess bacterial contamination of historical shellfish growing areas. Because WTTP outfalls are located in Sinclair Inlet, WA-DOH currently does not allow shellfish harvesting within Sinclair Inlet. Therefore, WA-DOH has no active sampling stations in Sinclair Inlet. An analysis of WA-DOH sample data from the study period (2000-2003) indicates that, in general, the levels of bacterial contamination are relatively low in marine waters; however, periodic violations of WQS can be found. WA-DOH FC data for 2002 to 2003 are summarized in Table 6-1.

Based on WA-DOH FC data from the 2000-2003 study period, four WA-DOH sample sites do not meet the marine FC WQS. One site, Clear Creek estuary in Silverdale (WA-DOH-466), does not meet Part I of the WQS because the geometric mean FC level exceeds 14 cfu/100 mL. This site also violates Part 2 of the marine FC WQS criteria for sample variability (more than 10% of samples have greater than 43 FC/100 mL). In addition, this site (#466) does not meet the WA-DOH shellfish growing area standard (GAS) due to the 90th percentile (measure of sample variability) being greater than 43 FC/100 mL. This sampling site is located at the mouth of Clear Creek near Silverdale. The lower reaches of this creek are highly developed, and the upland watershed contains extensive suburban development. The shoreline and local drainage area around the estuary is also highly developed with commercial (Silverdale Mall) and high-density residential areas. Additionally, there are several stormwater outfalls that drain into this portion of Dyes Inlet that likely contribute bacterial pollution to the Clear Creek estuary. Another urbanized watershed, Strawberry Creek, empties nearby into that part of Dyes inlet. The watershed of this creek is also largely developed and may be contributing to the bacterial contamination of the nearshore around Silverdale, as well as to the Clear Creek estuary. Potential FC sources include failing OWTS, sewer system leakage, livestock and pet waste, and urban wildlife. Finally, looking at the trend in data at the Clear Creek estuary site (WA-DOH-466), there appears to be no significant change in bacterial levels at this site in recent years, although water-quality conditions may be slightly worsening. Three sites in Chico Bay (WA-DOH-472, 473, and 474) also violate Part 2 of the WQS criteria for sample variability (more than 10% of samples have greater than 43 FC/100 mL).

WA-DOH also uses a Fecal Pollution Index (FPI) to classify sites with regard to shellfish-harvest water-quality status. To determine the FPI, two statistical values are calculated based on the "most probable number" (MPN) fecal concentration, using the most recent 30 FC samples (approximately 3 years of data). First, the *geometric mean* cannot exceed 14 MPN/100 mL, and second, the *90th percentile* (calculated using the WA-DOH formula described in ISSC 1999) must not exceed 43 MPN/100 mL. In addition, no more than 10% of samples can exceed 43 MPN/100 mL. Based on these data, each station is categorized as "Good," "Fair," or "Bad," based on the following definitions. A shellfish area is rated as "Good" if the 90th percentile value does not exceed the WA-DOH early-warning threshold of 30 MPN/100 mL. A "Fair" rating is applied if the 90th percentile is greater than 30 MPN/100 mL but does not exceed the GAS of 43 MPN/100 mL. Finally, an area is categorized as "Bad" if the 90th percentile exceeds the GAS criteria of 43 MPN/100 mL. The percentages of each category are then calculated and those values multiplied by the assigned weighting factors (Good = 1, Fair = 2, and Bad = 3) to determine the FPI.

Table 6-1. Summary of Washington Department of Health Bacterial Fecal Coliform Data for 2000-2003

Sinclair-Dyes Inlet WDOH Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Windy Point (Dyes)	WDOH-462	3	53	2	79	2	3	7	YES	1	2%	YES
Barker Creek Estuary (Dyes)	WDOH-463	4	51	2	70	2	9	16	YES	2	4%	YES
Northwest Shore Dyes Inlet	WDOH-464	3	52	2	33	2	7	11	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-465	4	49	2	920	2	8	22	YES	4	8%	YES
Clear Creek Estuary	WDOH-466	14	47	2	350	5	40	99	NO	12	26%	NO
Earlands Point (East Shoreline)	WDOH-467	3	24	2	23	2	5	7	YES	0	0%	YES
Earlands Point (North Shoreline)	WDOH-468	3	51	2	79	2	5	11	YES	1	2%	YES
Earlands Point (West Shoreline)	WDOH-469	5	49	2	540	2	11	25	YES	2	4%	YES
Chico Bay (Mid-Bay)	WDOH-470	4	50	2	170	2	7	17	YES	3	6%	YES
Chico Bay (NW)	WDOH-471	4	50	2	350	2	8	19	YES	3	6%	YES
Chico Bay (SW)	WDOH-472	8	50	2	240	2	20	54	YES	9	18%	NO
Chico Bay (SE)	WDOH-473	6	48	2	220	2	15	32	YES	6	13%	NO
Chico Bay (NE)	WDOH-474	6	49	2	540	2	13	35	YES	5	10%	NO
Dyes Inlet (Central)	WDOH-477	2	53	2	79	2	2	7	YES	2	4%	YES
Earlands Point (East Shoreline)	WDOH-478	2	25	2	79	2	2	7	YES	1	4%	YES
Earlands Point (East Shoreline)	WDOH-479	3	23	2	31	2	7	11	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-480	3	51	2	240	2	5	11	YES	1	2%	YES
West Shore Dyes Inlet	WDOH-481	4	52	2	540	2	8	14	YES	1	2%	YES
West Shore Dyes Inlet	WDOH-482	3	52	2	22	2	5	8	YES	0	0%	YES
East Shore Dyes Inlet	WDOH-483	3	53	2	130	2	5	11	YES	1	2%	YES
East Shore Dyes Inlet	WDOH-484	3	53	2	33	2	7	11	YES	0	0%	YES
Ostrich-Oyster Passage	WDOH-485	3	51	2	13	2	5	6	YES	0	0%	YES
North Oyster Bay	WDOH-486	4	51	2	130	2	6	14	YES	1	2%	YES
Northeast Oyster Bay	WDOH-487	4	52	2	49	2	8	14	YES	1	2%	YES
Southeast Oyster Bay	WDOH-488	4	51	2	350	2	8	19	YES	3	6%	YES
South Oyster Bay	WDOH-489	4	51	2	79	2	6	14	YES	3	6%	YES
West Oyster Bay	WDOH-490	4	52	2	130	2	8	17	YES	2	4%	YES
West Shore Dyes Inlet	WDOH-491	4	50	2	49	2	5	15	YES	2	4%	YES
Windy Point (East Dyes Inlet)	WDOH-492	2	51	2	22	2	2	5	YES	0	0%	YES
Southwest Oyster Bay	WDOH-546	4	38	2	70	2	8	20	YES	3	8%	YES
West Ostrich Bay	WDOH-576	3	20	2	17	2	3	7	YES	0	0%	YES
South Ostrich Bay	WDOH-577	4	20	2	70	2	8	20	YES	1	5%	YES
Southeast Ostrich Bay	WDOH-578	3	20	2	49	2	3	11	YES	1	5%	YES
East Ostrich Bay	WDOH-604	2	13	2	7	2	2	4	YES	0	0%	YES
East Ostrich Bay	WDOH-605	2	12	2	8	2	3	4	YES	0	0%	YES
East Ostrich Bay	WDOH-606	2	12	2	8	2	3	5	YES	0	0%	YES
Port Orchard Passage (University Point)	WDOH-444	2	24	2	5	2	2	4	YES	0	0%	YES
Port Orchard Passage (West-side)	WDOH-445	2	22	2	8	2	2	6	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-446	3	20	2	8	2	5	9	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-447	2	23	2	13	2	2	6	YES	0	0%	YES
Port Orchard Passage (BI Point White)	WDOH-448	2	24	2	8	2	2	3	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-449	2	24	2	9	2	2	4	YES	0	0%	YES
Fletcher Bay (BI South)	WDOH-450	2	22	2	9	2	2	6	YES	0	0%	YES
Port Orchard Passage (BI Gazzam)	WDOH-451	2	19	2	8	2	2	13	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-452	2	23	2	5	2	2	4	YES	0	0%	YES
Port Orchard Passage (Illahee SP)	WDOH-453	2	24	2	17	2	2	5	YES	0	0%	YES
Port Orchard Passage (Illahee West)	WDOH-454	3	24	2	33	2	3	8	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-455	2	24	2	8	2	2	3	YES	0	0%	YES
Port Orchard Passage (BI Crystal Springs)	WDOH-456	3	24	2	14	2	4	6	YES	0	0%	YES
Fletcher Bay (BI North)	WDOH-457	4	24	2	49	2	6	12	YES	1	4%	YES
Rich Passage (BI)	WDOH-461	3	24	2	33	2	3	8	YES	0	0%	YES

Note: Highlighted sample sites are in violations of WQS.

The Clear Creek estuary is categorized as “Bad” and Chico Bay is somewhere between the “Good” and “Fair” categories. Consequently, shellfish harvest restrictions have been imposed for these areas. An assessment of water-quality samples at WA-DOH Station 463 (near the mouth of Barker Creek) shows that this station sometimes fails the shellfish WQS on flood tides (WA-DOH 2003a). As a result, there are shellfish harvest restrictions at the mouth of Barker Creek due to its documented elevated concentrations of FC in the stream (WA-DOH 2003a). In general, however, conditions in Dyes Inlet as a whole have improved over the study period. Table 6-2 shows a summary of the FPI data for Dyes Inlet.

6.2.2 Kitsap County Health Department Marine Fecal Coliform Data

The KCHD has the most extensive FC sampling database for Sinclair and Dyes Inlet. Samples are taken on a regular basis (generally monthly). The database extends back to 1996 for most sample sites. KCHD publishes an annual summary report of water-quality data. These reports contain data on Dyes and Sinclair Inlet nearshore sample sites, as well as on contributing stream watersheds. Table 6-3 summarizes the KCHD FC data for the 2000-2003 study period.

Analysis of KCHD nearshore FC data indicates that only the FC sampling station located at the mouth of Clear Creek (DY27) is in violation of marine WQS (Part II: more than 10% of samples have greater than 43 FC/100 mL). This site is located very near the WA-DOH sampling station in the Clear Creek estuary (WA-DOH-466). In general, the level of FC contamination of marine waters in the study area (as measured by the geometric mean) is quite low.

6.3 Wet and Dry Season Marine Fecal Coliform Data

The combined historical sampling data from KCHD and WA-DOH were used to compile a “wet” and “dry” season FC dataset for the study period (2000-2003). By convention, in the Pacific Northwest, the wet season is considered to run from late October through late April. Based on historical records, the great majority of rainfall occurs during this period, with May through September typically being quite dry. For this data analysis, these wet and dry periods were used as guidelines, and rainfall records were checked to verify the actual start of the rainy season for each of the years during the 2000-2003 study period. Figures 6-6 and 6-7 and Table 6-4 show the key results for the wet season data and Figures 6-8 and 6-9 and Table 6-5 show the dry season data results.

For the study period, about the same number of sites violated bacterial WQS during the wet season as in the dry season. However, looking at the individual FC sample results for Sinclair and Dyes Inlets for the study period, 7% of the wet season samples exceeded 43 cfu/100 mL, whereas only 1% of the dry season samples exceeded 43 cfu/100 mL. Therefore, it does appear that most of the marine WQ problems do occur during the wet season as opposed to the dry season, as might be expected for nearshore samples in developed areas where NPS runoff and other potential upland sources are present.

Only one site (Clear Creek estuary-nearshore) violated Part I of the marine WQS (geometric mean of FC greater than 14 cfu/100 mL). By far, the greatest number of sites that violated of Part II of the WQS are located near the mouths of streams draining urbanized watersheds or near stormwater outfalls:

- Clear Creek Estuary (wet & dry season Part I & II WQS violations)
- Dee Creek Nearshore (dry season Part II WQS violation)
- Blackjack Creek Nearshore (wet season Part II WQS violation)
- Olney Creek Nearshore (wet season Part II WQS violation)
- Sacco Creek Nearshore (wet season Part II WQS violation).

Table 6-2. Summary of Washington Department of Health Fecal Pollution Index Data (WA-DOH 2003a)

DOH	# of Occurences				% of Each Category			Weighted Fraction			2001	2002
Site#	GOOD	FAIR	BAD	TOTAL	GOOD	FAIR	BAD	GOOD(a)	FAIR(b)	BAD(c)	FPI	FPI
462	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
463	2	0	0	2	100%	0%	0%	100%	0%	0%	1.00	**1.00**
464	3	0	0	3	100%	0%	0%	100%	0%	0%	1.00	**1.00**
465	1	0	0	1	100%	0%	0%	100%	0%	0%	1.00	**1.00**
466	0	0	3	3	0%	0%	100%	0%	0%	300%	3.00	**3.00**
467	8	0	0	8	100%	0%	0%	100%	0%	0%	1.00	**1.00**
468	8	0	0	8	100%	0%	0%	100%	0%	0%	1.00	**1.00**
469	8	0	0	8	100%	0%	0%	100%	0%	0%	1.00	**1.00**
470	8	0	0	8	100%	0%	0%	100%	0%	0%	1.00	**1.00**
471	8	0	0	8	100%	0%	0%	100%	0%	0%	1.67	**1.00**
472	2	6	0	8	25%	75%	0%	25%	150%	0%	2.92	**1.75**
473	4	4	0	8	50%	50%	0%	50%	100%	0%	2.00	**1.50**
474	5	3	0	8	63%	38%	0%	63%	75%	0%	2.58	**1.38**
477	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
478	1	0	0	1	100%	0%	0%	100%	0%	0%	1.00	**1.00**
479	1	0	0	1	100%	0%	0%	100%	0%	0%	1.00	**1.00**
480	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
481	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
482	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
483	6	0	0	6	100%	0%	0%	100%	0%	0%	1.00	**1.00**
484	7	0	0	7	100%	0%	0%	100%	0%	0%	1.00	**1.00**
485	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
486	3	0	0	3	100%	0%	0%	100%	0%	0%	1.00	**1.00**
487	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
488	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
489	4	0	0	4	100%	0%	0%	100%	0%	0%	1.00	**1.00**
490	6	0	0	6	100%	0%	0%	100%	0%	0%	1.00	**1.00**
491	2	0	0	2	100%	0%	0%	100%	0%	0%	1.00	**1.00**
492	2	0	0	2	100%	0%	0%	100%	0%	0%	1.00	**1.00**
546	1	0	0	1	100%	0%	0%	100%	0%	0%	1.00	**1.00**
576	1	0	0	1	100%	0%	0%	100%	0%	0%	1.00	**1.00**
577	1	0	0	1	100%	0%	0%	100%	0%	0%	3.00	**1.00**
578	1	0	0	1	100%	0%	0%	100%	0%	0%	3.00	**1.00**

Chico Bay also violated Part II of the marine WQS during both the wet and dry seasons. Chico Bay is a relatively enclosed embayment that appears to have a low natural flushing rate. Bacterial pollution is not significant in Chico Creek, which drains to the bay, but sources related to shoreline development could be contributing bacterial contamination to the bay. Also, natural FC sources, such as waterfowl, are common in the bay. In addition, a major chum salmon run utilizes Chico Creek each fall, and the volume of salmon carcasses that wash into the bay can be quite high relative to other creeks in the area. This may attract scavengers, which could also contribute to the FC load during the salmon spawning period. The sampling site near the Port Orchard marina also violated Part II of the WQS during the dry season for the 2000-2003 study period. This violation may be due to multiple sources (stormwater, boats, waterfowl, and others), as well as because of the relatively poor flushing in the confined area where the marina is located.

Table 6-3. Summary of Kitsap County Health Department Fecal Coliform Sample Data

Sinclair-Dyes Inlet KCHD Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Port Washington Narrows (South)	DY01	2	26	1	13	1	2	5	YES	0	0%	YES
Port Washington Narrows (Mid)	DY05	3	30	1	64	1	7	12	YES	1	3%	YES
Phinney Bay	DY07	3	30	1	70	1	6	15	YES	2	7%	YES
Port Washington Narrows (North)	DY09	2	26	1	30	1	2	6	YES	0	0%	YES
Oyster Bay	DY14	2	26	1	13	1	4	6	YES	0	0%	YES
Ostrich Bay	DY15	2	34	1	30	1	4	9	YES	0	0%	YES
Chico Bay	DY19	2	13	1	4	1	2	3	YES	0	0%	YES
Chico Bay	DY20	4	32	1	300	1	13	37	YES	3	9%	YES
Chico Bay	DY21	3	13	1	17	1	11	14	YES	0	0%	YES
Nearshore @ Old Silverdale	DY24	3	30	1	170	1	6	16	YES	1	3%	YES
Clear Creek Estuary	DY27	7	31	1	190	2	20	53	YES	5	16%	NO
Dyes Inlet Mid-Bay	DY28	1	25	1	30	1	2	4	YES	0	0%	YES
Barker Creek Estuary	DY29	2	32	1	30	1	4	8	YES	0	0%	YES
Mosher Creek Estuary	DY32	2	11	1	23	1	2	8	YES	0	0%	YES
Nearshore @ Mosher Creek	DY32	2	14	1	14	1	4	9	YES	0	0%	YES
Nearshore @ Illahee Boat Dock	PO09	2	26	1	23	1	4	9	YES	0	0%	YES
Nearshore @ Illahee SP Creek	PO10	2	26	1	17	1	2	4	YES	0	0%	YES
Illahee State Park Dock	PO11	1	9	1	7	1	1	4	YES	0	0%	YES
Mid-Channel PO Bay South	PO12	2	24	1	13	1	2	4	YES	0	0%	YES
Nearshore @ Dee Creek	PO13	5	11	1	130	2	18	38	YES	1	9%	YES
Sinclair Inlet @ COB WWTP Diffuser	SN03	3	31	1	30	1	4	10	YES	0	0%	YES
Sinclair Inlet Mid-Bay near Gorst	SN05	3	31	1	80	1	8	17	YES	1	3%	YES
Sinclair Inlet nearshore at Windy Point	SN08	2	26	1	17	1	4	6	YES	0	0%	YES
Port Orchard Marina	SN10	6	31	1	80	2	14	30	YES	2	6%	YES
Port Orchard Marina Boat Ramp	SN11	5	11	1	90	2	13	34	YES	1	9%	YES
Blackjack Creek Estuary (PO)	SN12	3	31	1	110	1	5	18	YES	2	6%	YES
Nearshore @ Olney Creek Mouth	SN13	5	31	1	130	1	16	36	YES	3	9%	YES
Sinclair Inlet Mid-Bay @ Narrows	SN14	2	26	1	13	1	2	4	YES	0	0%	YES
Nearshore @ Sacco Creek Mouth	SN15	2	11	1	50	1	2	13	YES	1	9%	YES
Nearshore @ Rich Cove	SN17	2	26	1	34	1	4	7	YES	0	0%	YES
Rich Passage Nearshore (Pt. Glover)	SN18	1	26	1	13	1	2	3	YES	0	0%	YES
Rich Passage Mid-Channel (Orchard Pt.)	SN21	2	26	1	30	1	2	5	YES	0	0%	YES

Note: Highlighted sample sites are in violations of WQS

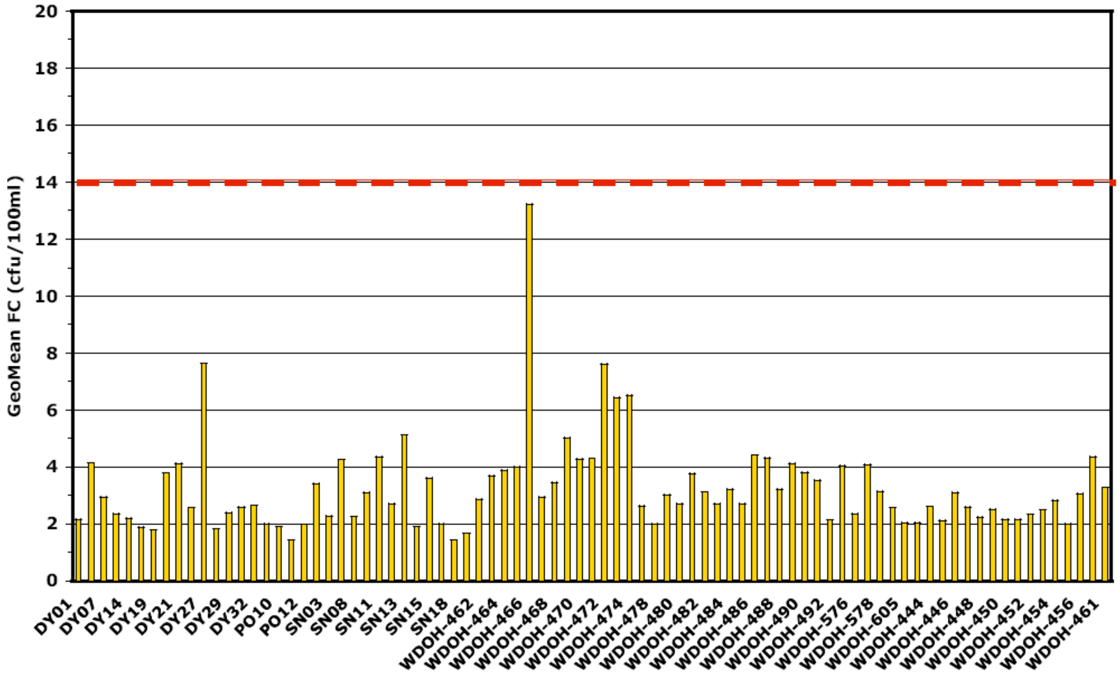

Figure 6-6. Geometric Mean (Part I WQS) Fecal Coliform Data for the 2000-2003 Wet Season in the Sinclair-Dyes Inlet Study Area

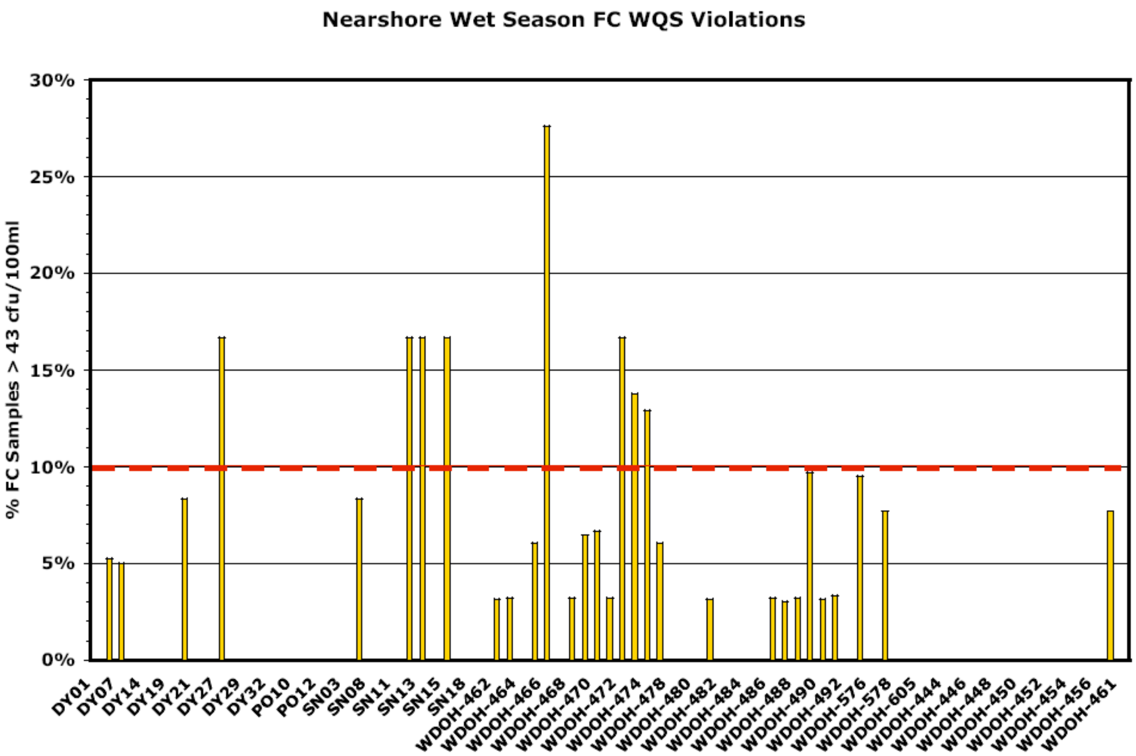

Figure 6-7. Variability (Part II WQS) of Fecal Coliform Data for the 2000-2003 Wet Season in the Sinclair-Dyes Inlet Study Area

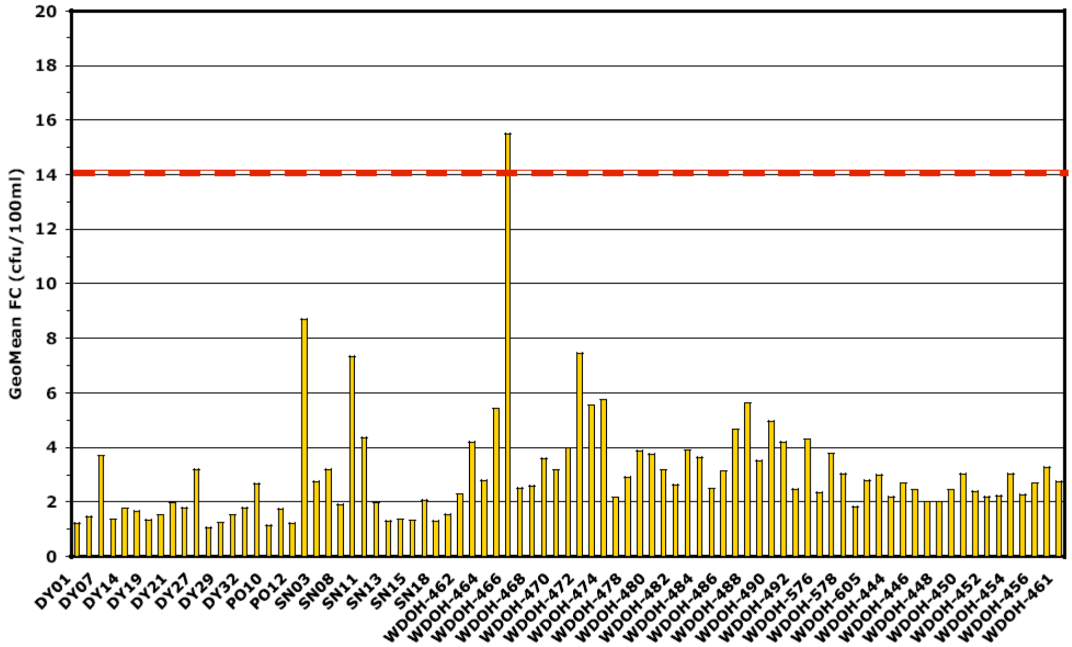

Figure 6-8. Geometric Mean (Part I WQS) Fecal Coliform Data for the 2000-2003 Dry Season in the Sinclair-Dyes Inlet Study Area

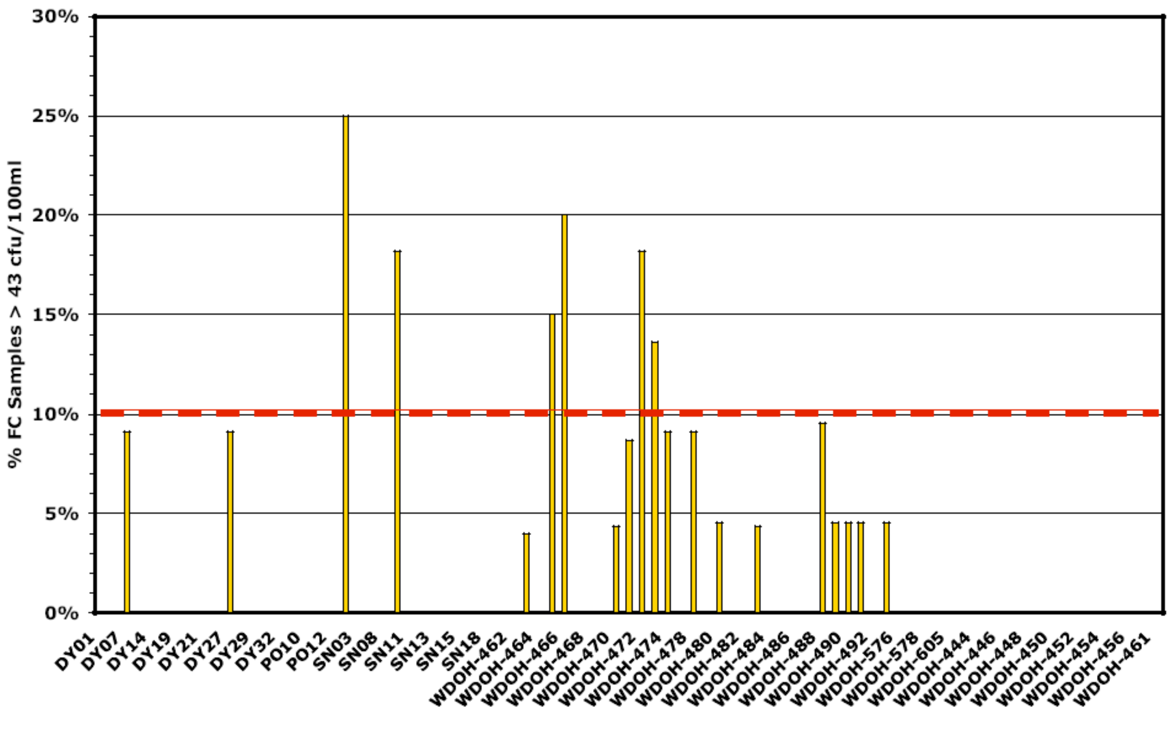

Figure 6-9. Variability (Part II WQS) of Fecal Coliform Data for the 2000-2003 Dry Season in the Sinclair-Dyes Inlet Study Area

Table 6-4. 2000-2003 Wet-Season Fecal Coliform Data for Nearshore Sites in Sinclair-Dyes Inlet

Wet Season Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Port Washington Narrows (South)	DY01	2	15	1	13	1	3	7	YES	0	0%	YES
Port Washington Narrows (Mid)	DY05	4	19	1	64	2	8	20	YES	1	5%	YES
Phinney Bay	DY07	3	20	1	70	1	7	13	YES	1	5%	YES
Port Washington Narrows (North)	DY09	2	15	1	30	1	6	10	YES	0	0%	YES
Oyster Bay	DY14	2	15	1	13	1	6	8	YES	0	0%	YES
Ostrich Bay	DY15	2	13	1	30	1	2	8	YES	0	0%	YES
Chico Bay	DY19	2	6	1	4	1	4	4	YES	0	0%	YES
Chico Bay	DY20	4	12	1	170	1	9	32	YES	1	8%	YES
Chico Bay	DY21	4	6	1	17	1	13	23	YES	0	0%	YES
Nearshore @ Old Silverdale	DY24	3	12	1	22	1	5	10	YES	0	0%	YES
Clear Creek Estuary	DY27	8	12	1	70	2	25	56	YES	2	17%	NO
Dyes Inlet Mid-Bay	DY28	2	15	1	30	1	2	7	YES	0	0%	YES
Barker Creek Estuary	DY29	2	12	1	30	1	4	10	YES	0	0%	YES
Mosher Creek Estuary	DY31	3	6	1	23	1	10	17	YES	0	0%	YES
Nearshore @ Mosher Creek	DY32	3	8	1	14	1	13	15	YES	0	0%	YES
Nearshore @ Illahee Boat Dock	PO09	2	15	1	23	1	2	8	YES	0	0%	YES
Nearshore @ Illahee SP Creek	PO10	2	15	1	17	1	3	7	YES	0	0%	YES
Illahee State Park Dock	PO11	1	4	1	4	1	2	3	YES	0	0%	YES
Mid-Channel PO Bay South	PO12	2	13	1	13	1	4	6	YES	0	0%	YES
Nearshore @ Dee Creek	PO13	3	7	1	23	2	9	17	YES	0	0%	YES
Sinclair Inlet @ COB WWTP Diffuser	SN03	2	12	1	17	1	4	9	YES	0	0%	YES
Sinclair Inlet Mid-Bay near Gorst	SN05	4	12	1	80	1	17	31	YES	1	8%	YES
Sinclair Inlet nearshore at Windy Point	SN08	2	15	1	17	1	4	7	YES	0	0%	YES
Port Orchard Marina	SN10	3	12	1	30	1	8	14	YES	0	0%	YES
Port Orchard Marina Boat Ramp	SN11	4	6	1	13	3	9	15	YES	0	0%	YES
Blackjack Creek Estuary (PO)	SN12	3	12	1	110	1	5	29	YES	2	17%	NO
Nearshore @ Olney Creek Mouth	SN13	5	12	1	130	1	16	45	YES	2	17%	NO
Sinclair Inlet Mid-Bay @ Narrows	SN14	2	15	1	13	1	3	6	YES	0	0%	YES
Nearshore @ Sacco Creek Mouth	SN15	4	6	1	50	1	17	34	YES	1	17%	NO
Nearshore @ Rich Cove	SN17	2	15	1	17	1	3	6	YES	0	0%	YES
Rich Passage Nearshore (Pt. Glover)	SN18	1	15	1	13	1	1	4	YES	0	0%	YES
Rich Passage Mid-Channel (Orchard Pt.)	SN21	2	15	1	30	1	2	6	YES	0	0%	YES
Windy Point (Dyes)	WDOH-462	3	32	2	79	2	4	8	YES	1	3%	YES
Barker Creek Estuary (Dyes)	WDOH-463	4	31	2	70	2	7	13	YES	1	3%	YES
Northwest Shore Dyes Inlet	WDOH-464	4	32	2	33	2	8	14	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-465	4	33	2	49	2	8	15	YES	2	6%	YES
Clear Creek Estuary	WDOH-466	13	29	2	240	5	46	89	YES	8	28%	NO
Earlands Point (East Shoreline)	WDOH-467	3	14	2	23	2	4	8	YES	0	0%	YES
Earlands Point (North Shoreline)	WDOH-468	3	31	2	79	2	5	14	YES	1	3%	YES
Earlands Point (West Shoreline)	WDOH-469	5	31	2	540	2	16	35	YES	2	6%	YES
Chico Bay (Mid-Bay)	WDOH-470	4	30	2	49	2	8	18	YES	2	7%	YES
Chico Bay (NW)	WDOH-471	4	31	2	49	2	8	15	YES	1	3%	YES
Chico Bay (SW)	WDOH-472	8	30	2	240	2	17	47	YES	5	17%	NO
Chico Bay (SE)	WDOH-473	6	29	2	79	2	14	34	YES	4	14%	NO

Table 6.4 (contd)

Wet Season Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Chico Bay (NE)	WDOH-474	6	31	2	540	2	12	40	YES	4	13%	NO
Dyes Inlet (Central)	WDOH-477	3	33	2	79	2	2	9	YES	2	6%	YES
Earlands Point (East Shoreline)	WDOH-478	2	14	2	4	2	2	3	YES	0	0%	YES
Earlands Point (East Shoreline)	WDOH-479	3	14	2	23	2	6	9	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-480	3	31	2	23	2	4	6	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-481	4	32	2	540	2	8	18	YES	1	3%	YES
West Shore Dyes Inlet	WDOH-482	3	33	2	22	2	5	8	YES	0	0%	YES
East Shore Dyes Inlet	WDOH-483	3	32	2	22	2	3	8	YES	0	0%	YES
East Shore Dyes Inlet	WDOH-484	3	32	2	23	2	5	8	YES	0	0%	YES
Ostrich-Oyster Passage	WDOH-485	3	31	2	13	2	4	6	YES	0	0%	YES
North Oyster Bay	WDOH-486	4	31	2	130	2	9	20	YES	1	3%	YES
Northeast Oyster Bay	WDOH-487	4	33	2	49	2	8	14	YES	1	3%	YES
Southeast Oyster Bay	WDOH-488	3	31	2	46	2	6	10	YES	1	3%	YES
South Oyster Bay	WDOH-489	4	31	2	79	2	9	20	YES	3	10%	YES
West Oyster Bay	WDOH-490	4	32	2	130	2	8	15	YES	1	3%	YES
West Shore Dyes Inlet	WDOH-491	4	30	2	49	2	5	13	YES	1	3%	YES
Windy Point (East Dyes Inlet)	WDOH-492	2	30	2	5	2	2	3	YES	0	0%	YES
Southwest Oyster Bay	WDOH-546	4	21	2	70	2	8	19	YES	2	10%	YES
West Ostrich Bay	WDOH-576	2	13	2	13	2	2	5	YES	0	0%	YES
South Ostrich Bay	WDOH-577	4	13	2	70	2	8	25	YES	1	8%	YES
Southeast Ostrich Bay	WDOH-578	3	13	2	23	2	5	9	YES	0	0%	YES
East Ostrich Bay	WDOH-604	3	7	2	7	2	3	5	YES	0	0%	YES
East Ostrich Bay	WDOH-605	2	7	2	4	2	2	3	YES	0	0%	YES
East Ostrich Bay	WDOH-606	2	7	2	5	2	2	3	YES	0	0%	YES
Port Orchard Passage (University Point)	WDOH-444	3	13	2	5	2	4	4	YES	0	0%	YES
Port Orchard Passage (West-side)	WDOH-445	2	12	2	4	2	2	5	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-446	3	11	2	8	2	6	9	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-447	3	13	2	13	2	2	6	YES	0	0%	YES
Port Orchard Passage (BI Point White)	WDOH-448	2	13	2	8	2	2	4	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-449	3	13	2	9	2	2	5	YES	0	0%	YES
Fletcher Bay (BI South)	WDOH-450	2	13	2	5	2	2	3	YES	0	0%	YES
Port Orchard Passage (BI Gazzam)	WDOH-451	2	11	2	5	2	2	10	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-452	2	12	2	5	2	2	6	YES	0	0%	YES
Port Orchard Passage (Illahee SP)	WDOH-453	2	13	2	17	2	2	5	YES	0	0%	YES
Port Orchard Passage (Illahee West)	WDOH-454	3	13	2	33	2	2	8	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-455	2	13	2	2	2	2	2	YES	0	0%	YES
Port Orchard Passage (BI Crystal Springs)	WDOH-456	3	13	2	14	2	4	8	YES	0	0%	YES
Fletcher Bay (BI North)	WDOH-457	4	13	2	49	2	5	17	YES	1	8%	YES
Rich Passage (BI)	WDOH-461	3	13	2	33	2	2	11	YES	0	0%	YES

Table 6-5. 2000-2003 Dry-Season Fecal Coliform Data for Nearshore Sites in Sinclair-Dyes Inlet

Dry Season Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Port Washington Narrows (South)	DY01	1	11	1	2	1	2	2	YES	0	0%	YES
Port Washington Narrows (Mid)	DY05	1	11	1	4	1	2	3	YES	0	0%	YES
Phinney Bay	DY07	4	11	1	50	1	6	19	YES	1	9%	YES
Port Washington Narrows (North)	DY09	1	11	1	2	1	2	2	YES	0	0%	YES
Oyster Bay	DY14	2	11	1	8	1	3	5	YES	0	0%	YES
Ostrich Bay	DY15	2	11	1	8	1	2	4	YES	0	0%	YES
Chico Bay	DY19	1	7	1	2	1	2	2	YES	0	0%	YES
Chico Bay	DY20	2	11	1	13	1	2	4	YES	0	0%	YES
Chico Bay	DY21	2	7	1	17	1	4	9	YES	0	0%	YES
Nearshore @ Old Silverdale	DY24	2	11	1	17	1	2	5	YES	0	0%	YES
Clear Creek Estuary	DY27	3	11	1	80	1	6	20	YES	1	9%	YES
Dyes Inlet Mid-Bay	DY28	1	10	1	2	1	1	1	YES	0	0%	YES
Barker Creek Estuary	DY29	1	10	1	4	1	1	2	YES	0	0%	YES
Mosher Creek Estuary	DY32	2	5	1	2	1	2	2	YES	0	0%	YES
Nearshore @ Mosher Creek	DY32	2	6	1	4	1	2	3	YES	0	0%	YES
Nearshore @ Illahee Boat Dock	PO09	3	11	1	17	1	9	12	YES	0	0%	YES
Nearshore @ Illahee SP Creek	PO10	1	11	1	2	1	1	2	YES	0	0%	YES
Illahee State Park Dock	PO11	2	6	1	7	1	3	5	YES	0	0%	YES
Mid-Channel PO Bay South	PO12	1	11	1	2	1	2	2	YES	0	0%	YES
Nearshore @ Dee Creek	PO13	9	4	1	130	2	49	152	YES	1	25%	NO
Sinclair Inlet @ COB WWTP Diffuser	SN03	3	11	1	30	2	4	10	YES	0	0%	YES
Sinclair Inlet Mid-Bay near Gorst	SN05	3	11	1	23	1	8	15	YES	0	0%	YES
Sinclair Inlet nearshore at Windy Point	SN08	2	11	1	17	1	2	6	YES	0	0%	YES
Port Orchard Marina	SN10	7	11	1	80	3	21	49	YES	2	18%	NO
Port Orchard Marina Boat Ramp	SN11	4	5	1	30	2	13	27	YES	0	0%	YES
Blackjack Creek Estuary (PO)	SN12	2	11	1	13	1	3	6	YES	0	0%	YES
Sinclair Inlet @ Olney Creek Mouth	SN13	1	11	1	4	1	2	2	YES	0	0%	YES
Sinclair Inlet Mid-Bay @ Narrows	SN14	1	11	1	2	1	2	2	YES	0	0%	YES
Nearshore @ Sacco Creek Mouth	SN15	1	5	1	2	1	2	2	YES	0	0%	YES
Nearshore @ Rich Cove	SN17	2	11	1	34	1	3	10	YES	0	0%	YES
Rich Passage Nearshore (Pt. Glover)	SN18	1	11	1	2	1	2	2	YES	0	0%	YES
Rich Passage Mid-Channel (Orchard Pt.)	SN21	2	11	1	4	1	2	3	YES	0	0%	YES
Windy Point (Dyes)	WDOH-462	2	23	2	17	2	2	5	YES	0	0%	YES
Barker Creek Estuary (Dyes)	WDOH-463	4	25	2	46	2	8	17	YES	1	4%	YES
Northwest Shore Dyes Inlet	WDOH-464	3	25	2	8	2	5	6	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-465	5	20	2	920	2	9	44	YES	3	15%	NO
Clear Creek Estuary	WDOH-466	16	20	2	350	5	33	109	NO	4	20%	NO
Earlands Point (East Shoreline)	WDOH-467	2	10	2	8	2	4	5	YES	0	0%	YES
Earlands Point (North Shoreline)	WDOH-468	3	23	2	9	2	4	6	YES	0	0%	YES
Earlands Point (West Shoreline)	WDOH-469	4	21	2	22	2	8	11	YES	0	0%	YES
Chico Bay (Mid-Bay)	WDOH-470	3	23	2	170	2	2	17	YES	1	4%	YES
Chico Bay (NW)	WDOH-471	4	23	2	350	2	5	25	YES	2	9%	YES
Chico Bay (SW)	WDOH-472	7	22	2	240	2	21	60	YES	4	18%	NO
Chico Bay (SE)	WDOH-473	6	22	2	220	2	15	35	YES	3	14%	NO

Table 6.5 (contd)

Dry Season Marine FC Data Site Name	Site ID	GeoMean FC	Count(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<14	#FC >43	%FC >43	Meets WQS
Chico Bay (NE)	WDOH-474	6	22	2	79	2	14	29	YES	2	9%	YES
Dyes Inlet (Central)	WDOH-477	2	23	2	33	2	2	5	YES	0	0%	YES
Earlands Point (East Shoreline)	WDOH-478	3	11	2	79	2	2	13	YES	1	9%	YES
Earlands Point (East Shoreline)	WDOH-479	4	9	2	31	2	7	15	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-480	4	22	2	240	2	5	19	YES	1	5%	YES
West Shore Dyes Inlet	WDOH-481	3	20	2	23	2	5	11	YES	0	0%	YES
West Shore Dyes Inlet	WDOH-482	3	22	2	13	2	4	6	YES	0	0%	YES
East Shore Dyes Inlet	WDOH-483	4	23	2	130	2	8	18	YES	1	4%	YES
East Shore Dyes Inlet	WDOH-484	4	23	2	33	2	9	14	YES	0	0%	YES
Ostrich-Oyster Passage	WDOH-485	2	22	2	9	2	4	5	YES	0	0%	YES
North Oyster Bay	WDOH-486	3	22	2	23	2	5	9	YES	0	0%	YES
Northeast Oyster Bay	WDOH-487	5	22	2	31	2	12	15	YES	0	0%	YES
Southeast Oyster Bay	WDOH-488	6	21	2	350	2	13	36	YES	2	10%	YES
South Oyster Bay	WDOH-489	4	22	2	46	2	6	11	YES	1	5%	YES
West Oyster Bay	WDOH-490	5	22	2	49	2	8	19	YES	1	5%	YES
West Shore Dyes Inlet	WDOH-491	4	22	2	49	2	12	21	YES	1	5%	YES
Windy Point (East Dyes Inlet)	WDOH-492	2	23	2	22	2	2	6	YES	0	0%	YES
Southwest Oyster Bay	WDOH-546	4	22	2	70	2	8	17	YES	1	5%	YES
West Ostrich Bay	WDOH-576	2	6	2	11	2	2	6	YES	0	0%	YES
South Ostrich Bay	WDOH-577	4	7	2	23	2	6	13	YES	0	0%	YES
Southeast Ostrich Bay	WDOH-578	3	7	2	43	2	2	14	YES	0	0%	YES
East Ostrich Bay	WDOH-604	2	6	2	2	2	2	2	YES	0	0%	YES
East Ostrich Bay	WDOH-605	3	5	2	8	2	5	7	YES	0	0%	YES
East Ostrich Bay	WDOH-606	3	5	2	8	2	5	7	YES	0	0%	YES
Port Orchard Passage (University Point)	WDOH-444	2	11	2	5	2	2	3	YES	0	0%	YES
Port Orchard Passage (West-side)	WDOH-445	3	11	2	13	2	2	6	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-446	2	8	2	5	2	3	10	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-447	2	10	2	2	2	2	8	YES	0	0%	YES
Port Orchard Passage (BI Point White)	WDOH-448	2	11	2	2	2	2	2	YES	0	0%	YES
Port Orchard Passage (BI North)	WDOH-449	2	11	2	8	2	2	4	YES	0	0%	YES
Fletcher Bay (BI South)	WDOH-450	3	10	2	11	2	4	9	YES	0	0%	YES
Port Orchard Passage (BI Gazzam)	WDOH-451	2	8	2	8	2	2	18	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-452	2	11	2	5	2	2	3	YES	0	0%	YES
Port Orchard Passage (Illahee SP)	WDOH-453	2	11	2	7	2	2	4	YES	0	0%	YES
Port Orchard Passage (Illahee West)	WDOH-454	3	11	2	13	2	4	8	YES	0	0%	YES
Port Orchard Passage (BI South)	WDOH-455	2	11	2	8	2	2	4	YES	0	0%	YES
Port Orchard Passage (BI Crystal Springs)	WDOH-456	3	11	2	8	2	4	5	YES	0	0%	YES
Fletcher Bay (BI North)	WDOH-457	3	11	2	11	2	7	8	YES	0	0%	YES
Rich Passage (BI)	WDOH-461	3	11	2	11	2	4	6	YES	0	0%	YES

Note: Highlighted sample sites are in violations of WQS.

6.4 2002-2003 Storm Season ENVVEST Nearshore Data

Based on an analysis of existing nearshore FC data from the combined WA-DOH and KCHD databases, it was determined that the principle data gaps with respect to marine waters included sampling during (or immediately following) storm events and sampling in the nearshore areas near stormwater outfalls, also during a period of rainy weather. These data gaps were targeted for correction during the 2002-2003 storm season. In addition to sampling sites that were targeted as indicated above, several marine sites not currently monitored by KCHD or WA-DOH were sampled by ENVVEST sampling teams. Table 6-6 summarizes the marine-nearshore FC data for the 2002-2003 storm season. Figures 6-10 and 6-11 also show the key results for the 2002-2003 storm season data. It should be noted that the number of storm season samples obtained was much lower than is normally used to compare with WQS for regulatory use. Therefore, for the purposes of this report, Table 6-6 and Figures 6-10 and 6-11 show the WQS for relative comparison only.

As was the case with the KCHD and WA-DOH marine-nearshore data, many of the sites monitored during storm events had relatively low bacteria contamination levels. However, as can be seen from the data, the results of the storm season sampling effort for several sites were quite different than those of the historical KCHD and WA-DOH routine sampling data. In particular, sites that were located near the mouths of urbanized streams, highly developed shorelines, stormwater outfalls, CSO outfalls, and/or other potential urban-related sources had significantly higher FC concentrations than were indicated by the historical KCHD and WA-DOH datasets. These results are likely due to the combination of sample site location (near potential FC source outfalls) and the timing of the sampling (during or immediately after storm events). Although these contamination levels during storm events are generally quite transient and cannot be attributed a specific source(s), the proximity to potential development-related sources is notable.

What may be even more significant with respect to what is different about the storm season sampling data, is that most of the sites that had high FC levels during the storm season violated both Part I and Part II of the WQS criteria. In other words, all of these sites had geometric mean FC levels that exceeded criteria and also exhibited high FC variability, as opposed to the results of wet and dry season sampling, which only showed violations of Part II of the WQS. As was the case with the historical nearshore fecal data, sites that had violations of WQS were located near urbanized upland or shoreline areas, and each site had multiple sources of stormwater-related bacterial pollution (stormwater outfalls and/or urbanized creeks). This observation confirms the potential for bacterial contamination during storm events from developed areas with more intense human activities than was seen in the analysis of historical data sets. In addition, the FC results obtained by targeting periods of stormy weather also reinforces these findings and points out the potential increased risk of bacterial contamination being present in nearshore areas during or immediately following storm events in urbanized shoreline areas. Fortunately, it also appears that these elevated FC levels in nearshore areas are highly transient.

Table 6-6. Summary of Marine-Nearshore FC Data for the 2002-2003 Storm Season

2002-2003 Storm Season Marine FC Data						25th	75th	90th	GeoMean	#FC	%FC	Meets
Site Name	**Site ID**	**GeoMean FC**	**Count(N)**	**Max FC**	**Min FC**	**Percentile**	**Percentile**	**Percentile**	**FC<14**	**>43**	**>43**	**WQS**
Anderson Cove NS (Dyes)	ANCOVE	32	5	2000	2	5	50	968	NO	2	40%	NO
Rich Passage NS (BI)	BI-CSNS	30	3	140	9	16	81	182	NO	1	33%	NO
Fort Ward NS (BI)	BI-FWNS	44	4	1330	9	12	351	849	NO	1	25%	NO
Lynwood Center NS (BI)	BI-LCNS	63	4	140	11	61	136	292	NO	3	75%	NO
Blackjack Estuary (Sinclair)	BJ-EST	34	5	80	13	21	45	83	NO	2	40%	NO
Clam Bay NS (Rich Passage)	CLAMBAY	9	5	22	4	5	12	22	YES	0	0%	YES
Evergreen Park NS (Dyes)	EVGPK	9	5	18	6	6	13	18	YES	0	0%	YES
Jackson Park NS (Dyes)	JACKPK	2	5	3	1	1	3	4	YES	0	0%	YES
Silverdale Hotel NS (Dyes)	SHOTEL	57	4	750	1	52	338	2216	NO	3	75%	NO
PO Passage (M1)	M1	1	8	4	1	1	2	3	YES	0	0%	YES
Rich Passage (M2)	M2	1	8	3	1	1	1	2	YES	0	0%	YES
Sinclair Inlet (M3)	M3	4	8	8	1	3	5	9	YES	0	0%	YES
Sinclair Inlet (M4)	M4	3	8	19	1	2	7	13	YES	0	0%	YES
Sinclair Inlet (M5)	M5	2	8	6	1	1	3	5	YES	0	0%	YES
Sinclair Inlet (M6)	M6	1	8	4	1	1	1	3	YES	0	0%	YES
Sinclair Inlet (M7)	M7	2	8	6	1	1	2	4	YES	0	0%	YES
Sinclair Inlet (M8)	M8	2	8	5	1	1	2	4	YES	0	0%	YES
Port Washington Narrows (Mid)	DY05	10	7	64	2	7	17	41	YES	1	14%	NO
Phinney Bay	DY07	5	7	13	1	4	9	16	YES	0	0%	YES
Ostrich Bay	DY15	4	7	23	1	2	11	19	YES	0	0%	YES
Chico Bay	DY20	21	7	80	11	15	22	48	NO	1	14%	NO
Nearshore @ Old Silverdale	DY24	8	7	170	1	2	24	89	YES	1	14%	NO
Clear Creek Estuary	DY27	11	7	190	2	4	33	93	YES	2	29%	NO
Barker Creek Estuary	DY29	6	6	24	1	5	11	26	YES	0	0%	YES
Sinclair Inlet @ COB WWTP Diffuser	SN03	5	6	25	2	3	7	17	YES	0	0%	YES
Sinclair Inlet Mid-Bay near Gorst	SN05	3	6	14	1	2	7	13	YES	0	0%	YES
Port Orchard Marina	SN10	13	6	40	2	11	22	47	YES	0	0%	YES
Blackjack Creek Estuary (PO)	SN12	11	5	29	5	5	27	35	YES	0	0%	YES
Nearshore @ Olney Creek Mouth	SN13	47	5	120	17	32	88	129	NO	2	40%	NO

Note: Highlighted sample sites are in violations of WQS.

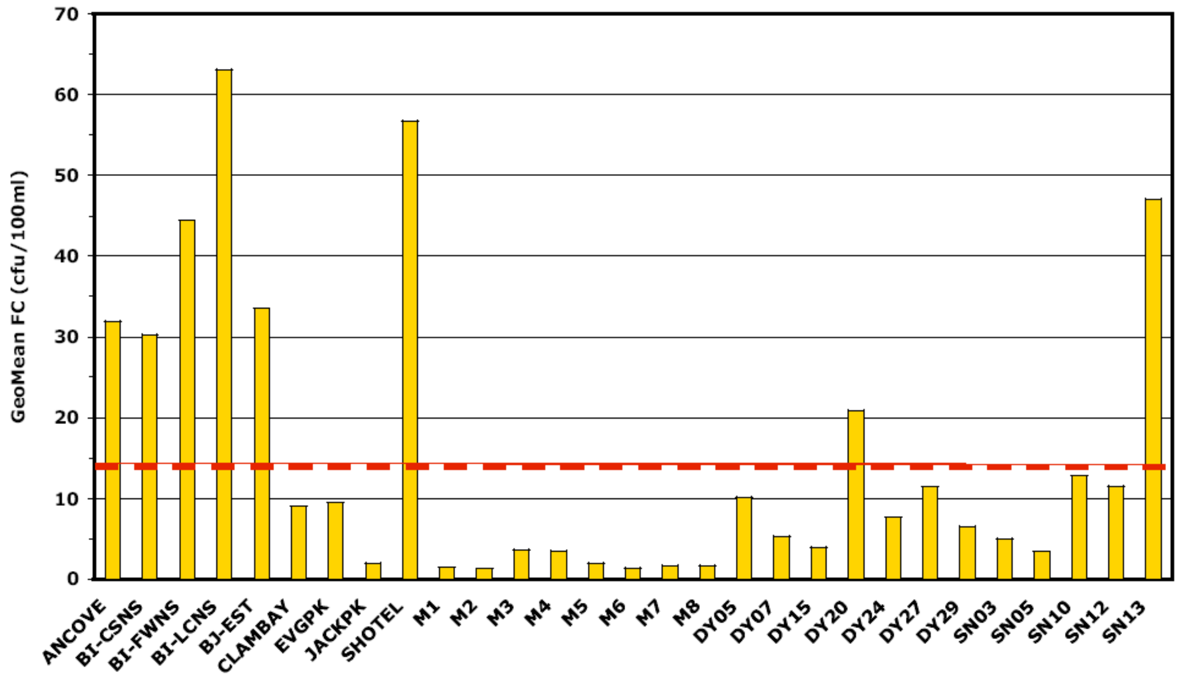

Figure 6-10. Geometric Mean (Part I WQS) Fecal Coliform Data for the 2002-2003 Storm Season in the Sinclair-Dyes Inlet Study Area.

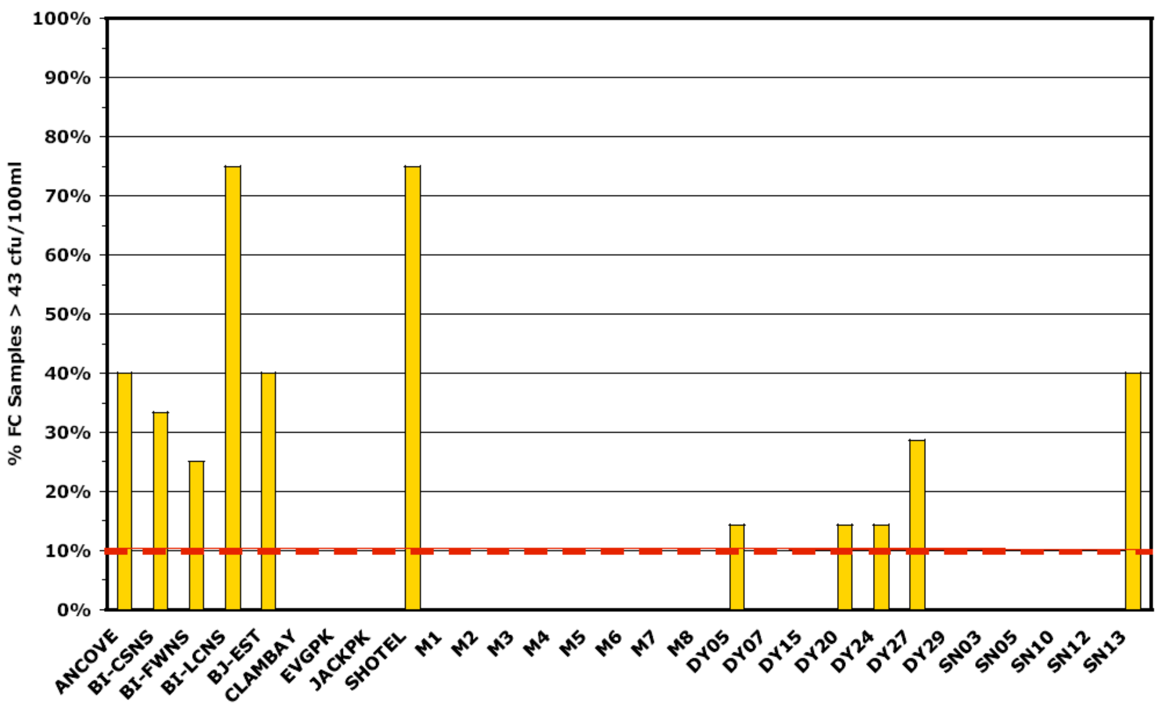

Figure 6-11. Variability (Part II WQS) of Fecal Coliform Data for the 2002-2003 Storm Season in the Sinclair-Dyes Inlet Study Area

6.5 Stormwater Outfall FC Data

Prior to the start of this project, there was almost no FC data from stormwater outfalls in the Sinclair and Dyes Inlet watershed. Through the KC-SSWM program, an outfall inventory was completed in 2001, in support of which several of the outfalls were sampled for FC and various other water-quality parameters during 2001-2003. These samples were “grab” samples taken during a variety of dry and wet weather conditions. Several SSWM stormwater outfalls had very high FC levels, some approaching or exceeding several thousand FC counts. This is fairly typical of stormwater runoff from developed areas. The NSQD found that the overall median value for stormwater was around 5000 cfu/100 mL (NSQD 2004). For residential land use, the median stormwater FC level was 7500; commercial was 4500; industrial 2500; highways 1700; and parks and open-space areas were 3000 cfu/100 mL (NSQD 2004).

The City of Bremerton has also been sampling several of its stormwater outfalls as part of its CSO monitoring program, but they do not monitor specifically for FC in stormwater. The City of Port Orchard currently has no stormwater monitoring program underway. During the recent CSO dye testing conducted by PSNS and Bremerton in 2003, four stormwater outfalls were monitored for FC over a 3-day period. This sampling coincided with stream sampling on the major tributary streams to Sinclair and Dyes Inlets and included a wet weather period followed by a dry weather period with little runoff.

The results of these preliminary sampling efforts and literature reviews indicated that in addition to streams draining urbanizing watersheds, stormwater outfalls were potentially significant sources of FC to Sinclair and Dyes Inlets. In general, stormwater FC levels tend to decrease significantly as rainfall decreases and runoff tapers off (NSQD 2004). Based on the preliminary sampling survey, several stormwater outfalls were selected to be intensively sampled during the 2002-2003 storm season. The criteria for selection of an outfall for sampling included the following:

- Representative of developed land uses
- High FC levels during the preliminary sampling survey
- A large drainage area dominated by developed land use
- Outfall access during all tidal periods for flexible sampling
- Geographically distributed throughout the study area.

Except for piped streams, stormwater outfalls generally only flow during and immediately after a storm event. Some stormwater outfalls are also former natural stream channels that have been piped through urban areas. Stormwater outfalls can also provide conveyance for CSO event flows. All three of these types of outfalls can be found in the study area, and representatives of each were included in the sample set.

Table 6-7 and Figures 6-12 and 6-13 summarize the stormwater outfall FC data for the 2002-2003 storm season sampling effort in the Sinclair-Dyes Inlet watershed. In general, FC samples from stormwater outfalls were relatively high and, at the same time, were highly variable and transient. Because no criteria currently exist for bacterial levels in stormwater, there are no WQS with which to compare these results. However, for purposes of comparison in this study only, the WQS for streams are illustrated on the stormwater data figures and tables.

Table 6-7. Summary of Stormwater Outfall Fecal Coliform Data for the 2002-2003 Storm Season

Sinclair-Dyes Inlet Stormwater FC Data		Basin Area				Count									
Location	Outfall ID#	(acres)	%TIA	% Forest	GeoMean FC/100ml	(N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<100	#FC >200	%FC >200	Meets WQS
PSNS	PSNS008	30	65%	0%	428	12	1	6100	130	2970	11570	NO	8	67%	NO
PSNS	PSNS015	103	60%	1%	1304	14	31	13000	601	5158	12178	NO	12	86%	NO
PSNS	PSNS082.5	22	61%	0%	1331	3	170	6600	1135	4350	14606	NO	2	67%	NO
PSNS	PSNS115.1	14	65%	0%	952	14	1	39000	385	5025	40974	NO	11	79%	NO
PSNS	PSNS101	17	63%	0%	14	14	1	90000	1	194	1676	YES	4	29%	NO
PSNS	PSNS081.1	16	63%	0%	7602	13	1100	99000	3200	18000	44528	NO	13	100%	NO
PSNS	PSNS124	9	65%	0%	10	14	1	1300	2	16	220	YES	3	21%	NO
PSNS	PSNS126	18	53%	0%	2473	13	1	133000	1733	14000	124917	NO	11	85%	NO
National Ave	LMK164	123	55%	0%	576	15	23	11000	270	1650	4678	NO	12	80%	NO
Evergreen	B-ST27	44	61%	0%	1239	9	290	4752	650	2200	4294	NO	9	100%	NO
Phinney Bay	LMK020	331	45%	26%	1539	21	69	19000	770	3200	10677	NO	18	86%	NO
Oyster Bay	B-ST26	211	49%	12%	609	14	54	2200	255	1550	2872	NO	12	86%	NO
Callow	B-ST28 (SW1)	455	56%	3%	1091	11	30	32000	315	2500	12956	NO	9	82%	NO
Stephenson	B-ST03 (SW5)	284	55%	14%	657	20	100	3800	303	1490	2888	NO	16	80%	NO
Pine Road	B-ST01 (SW3)	864	42%	31%	513	17	37	79200	108	1714	6281	NO	12	71%	NO
Campbell	B-ST07	222	58%	3%	1603	11	290	5500	1013	3254	5505	NO	11	100%	NO
Trenton	B-ST12 (SW4)	156	50%	21%	29	17	1	3600	3	450	910	YES	6	35%	NO
Pacific Ave	SW2	140	63%	0%	568	10	10	2376	538	1575	4874	NO	8	80%	NO
Silverdale (Bayshore)	LMK001	237	57%	9%	196	20	8	1300	61	603	1351	NO	11	55%	NO
Silverdale	LMK004	33	61%	0%	155	21	5	2904	33	500	1542	NO	11	52%	NO
Silverdale (Sandpiper)	LMK002	46	60%	4%	221	20	20	2500	59	650	1470	NO	11	55%	NO
Silverdale	LMK026	534	46%	14%	318	20	40	2640	121	718	1372	NO	13	65%	NO
Tracyton	LMK055	280	40%	42%	215	20	23	2100	71	645	1409	NO	10	50%	NO
Tracyton	LMK060	336	23%	72%	61	20	8	980	12	157	478	YES	5	25%	NO
Port Orchard	PO-Bethel	33	55%	0%	140	11	10	1100	46	376	881	NO	5	45%	NO
Port Orchard	PO-Bay	100	58%	3%	424	19	1	31000	64	3050	12443	NO	13	68%	NO
Port Orchard	PO-Blvd	87	48%	17%	413	19	20	21000	146	2084	5757	NO	11	58%	NO
Port Orchard	PO-Wilkens	143	24%	76%	64	19	7	640	19	260	430	YES	5	26%	NO
Gorst	LMK128	174	27%	81%	310	20	49	2900	124	658	1398	NO	12	60%	NO
Gorst	LMK122	346	22%	71%	123	20	14	2100	41	301	738	NO	6	30%	NO
Manchester	LMK038	132	13%	48%	345	34	16	4000	169	670	2080	NO	23	68%	NO
BI Lynwood Center	BI-LCSW	92	6%	67%	158	4	31	820	45	573	1272	NO	2	50%	NO
BI Fort Ward	BI-FWSW	470	7%	80%	459	4	300	1056	90	580	1440	NO	4	100%	NO

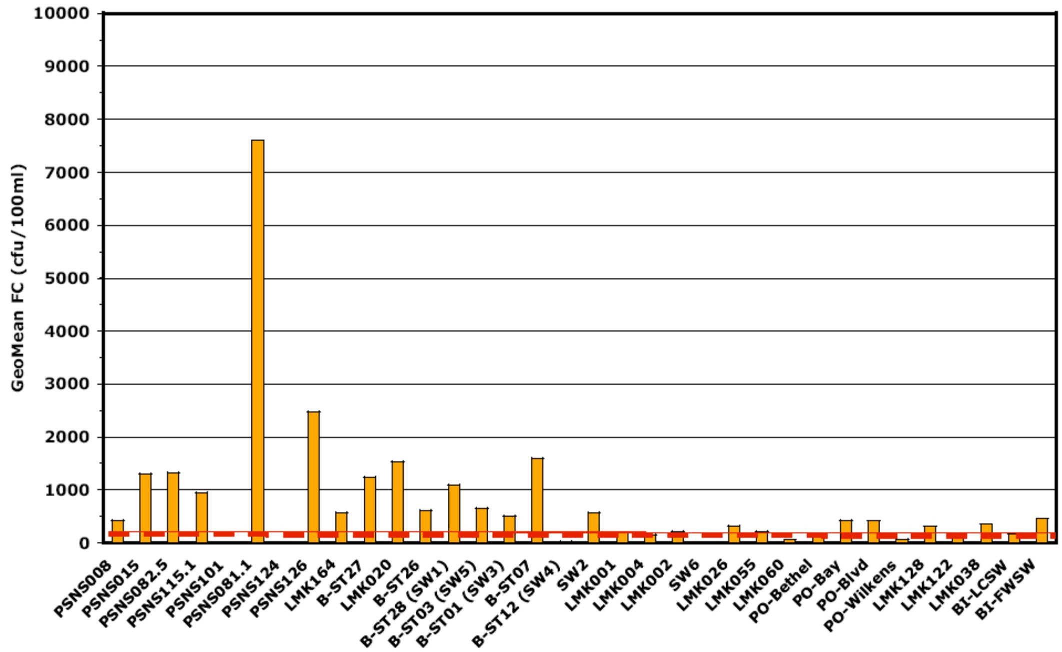

Figure 6-12. Geometric Mean (Part I WQS) Fecal Coliform Data for the 2002-2003 Storm Season for Stormwater Outfall Sample Sites

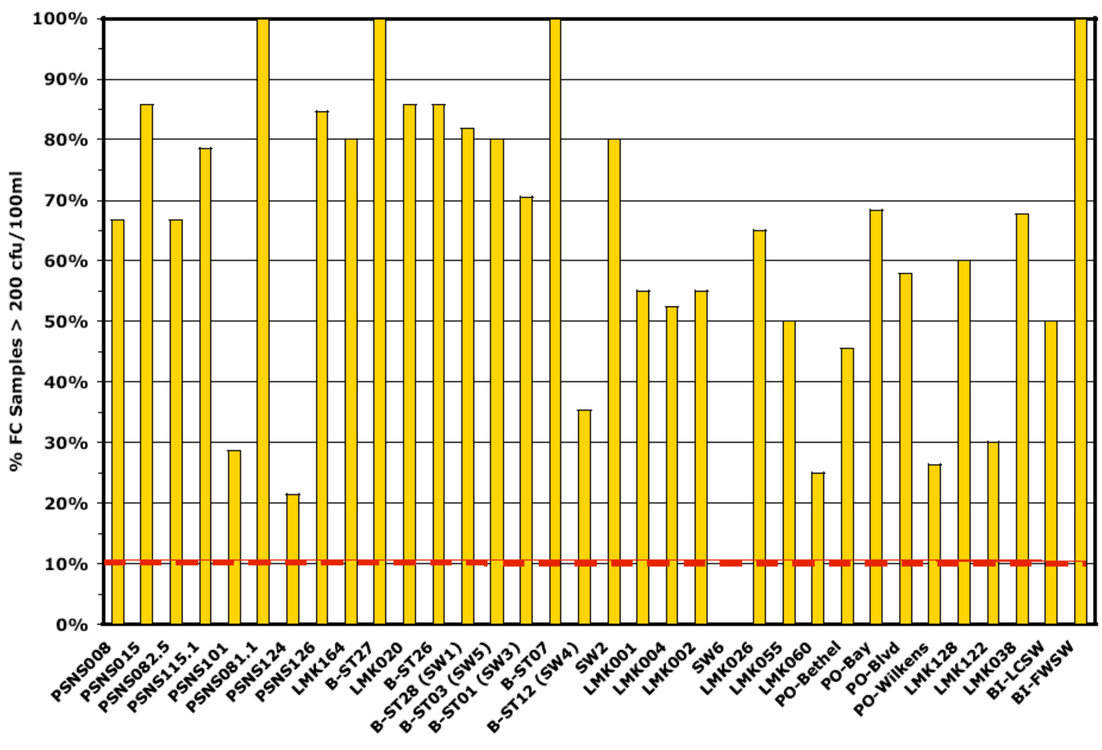

Figure 6-13. Variability (Part II WQS) of Fecal Coliform Data for the 2002-2003 Storm Season for Stormwater Outfall Sample Sites

6.6 Stream Fecal Coliform Data

Analysis of KCHD and ENVVEST freshwater FC sampling data indicates that streams (especially those draining developed subwatersheds) can potentially be major sources of bacterial contamination into the nearshore environment of Sinclair and Dyes Inlets. The Ecology FC WQS for freshwater *Primary Contact Recreation* requires that the geometric mean of all samples be less than or equal to 100 FC/100 mL (Part 1) and that less than 10% of all samples be more than 200 FC/100 mL (Part 2). For analysis purposes, stream FC data were divided into three categories, as follows:

- Dry Season (May-September) KCHD Data
- Wet Season (October-April) KCHD Data
- 2002-2003 Storm Season ENVVEST Data

The tables and figures on the following pages summarize stream data in the Sinclair-Dyes Inlet watershed for each of the above-noted categories during the 2000-2003 study period. Table 6-8 and Figures 6-14 and 6-15 summarize the stream dry season KCHD FC data; Table 6-9 and Figures 6-16 and 6-17 summarize the stream wet season KCHD FC data; and Table 6-10 and Figures 6-18 and 6-19 summarize the ENVVEST stream FC data. In general, FC samples from streams draining the more developed subwatersheds had higher geometric mean FC levels (Part I WQS) and were more highly variable (Part II WQS). The WQS for streams are illustrated on the storm season data figures and noted in the data tables.

Some interesting observations can be made in comparing the dry and wet season and storm-event data for the 2002-2003 storm season. There are more violations of Part I of the WQS (geometric mean FC greater than 100 cfu/100 mL) during the dry season than the wet season (Figures 6-12, 6-14, and 6-16). Based on these data, there were 13 stream WQS violations noted for the wet season as compared with 18 during the dry season. Generally, streams draining more developed (suburban and urban) subbasins have the highest FC geometric mean values, but WQS violations can also be found in rural watersheds. This situation illustrates the wide range of bacterial pollution sources present in all watersheds, most of which have the potential to cause water-quality problems. Storm-event geometric mean FC levels, although not generally as high as dry-season values, were typically much higher than wet-season baseflow FC levels, pointing to stormwater runoff inputs into urbanizing streams as a potential source of FC pollution.

Violations of Part II of the WQS (more than 10% FC samples have greater than 200 cfu/100 mL) were much more common for dry season, wet season, and storm event samples. As with the geometric mean FC values, Part II WQS violations were much more common and generally higher during the dry season, as compared with wet season or storm event samples in streams. In general, more developed stream subwatersheds are more likely to have Part II WQS violations than undeveloped, forested subbasins.

Very few streams met both WQS criteria during storm events sampled in the 2002-2003 storm season. Bacterial (FC) concentrations were generally higher for larger storm events (more rainfall and/or higher rainfall intensity) and when there was a longer pre-storm (antecedent) dry period; however, the connection between these factors and others (e.g., land use, land cover) appears to be highly dependent on local subbasin conditions. Although there were exceptions, FC levels also generally followed the storm hydrograph, peaking during the highest streamflow period of the storm and falling as the hydrograph dropped (TEC 2004). There also appears to be a relationship between FC levels and turbidity (TEC 2004), which would support the theory that fecal bacteria have a strong affinity for particulate matter. The relationship between bacterial contamination levels, water-quality parameters, and storm characteristics, as well as watershed land use and land cover, will be explored in more detail in the next section of this report.

Table 6-8. Summary of Stream Fecal Coliform Data for the Sinclair-Dyes Inlet Watershed for Dry Seasons in the 2000-2003 Study Period

Dry Season Stream FC Data									Dry Season FC Data						
Watershed	Stream Sub-Watershed	WQ ID	%TIA	% Forest	GeoMean FC/100ml	Count (N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<100	#FC >200	%FC >200	Meets WQS
Yukon Harbor	Beaver Crk	BVR	10.4%	58.3%	179	21	30	1600	110	300	588	NO	8	38%	NO
Rich Passage	Sacco Crk	SACCO	15.0%	47.8%	200	17	17	900	130	500	843	NO	11	65%	NO
Sinclair Inlet	Olney Crk	OC	39.5%	28.5%	232	17	50	900	140	500	704	NO	9	53%	NO
Sinclair Inlet	Annapolis Crk	ANNP	43.4%	21.0%	317	17	50	1600	170	500	952	NO	12	71%	NO
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	9.9%	58.6%	50	6	11	200	30	133	206	YES	0	0%	YES
Sinclair Inlet	Square Crk Tributary	BL-SQR	6.8%	68.1%											
Sinclair Inlet	Upper Blackjack Crk	BL-HW	17.6%	43.9%	54	18	2	220	35	88	208	YES	1	6%	YES
Sinclair Inlet	Blackjack Crk @ SR-16	BL	13.1%	53.4%	76	18	17	300	35	163	252	YES	3	17%	NO
Sinclair Inlet	Blackjack Crk	BL-KFC	15.9%	51.6%	123	17	30	900	50	240	400	NO	5	29%	NO
Sinclair Inlet	Ross Crk	ROSS	22.5%	50.3%	91	17	8	900	30	240	549	YES	6	35%	NO
Sinclair Inlet	Anderson Crk	AC	6.6%	76.5%	20	18	2	240	8	45	115	YES	1	6%	YES
Sinclair Inlet	Heins Crk Headwaters	GC-HW	2.7%	88.1%	11	14	1	80	4	30	78	YES	0	0%	YES
Sinclair Inlet	Heins & Jarstad Crk Tribs	GC-HNS	12.9%	69.9%											
Sinclair Inlet	Parish Crk Tributary	GC-PA	14.1%	62.9%											
Sinclair Inlet	Upper Gorst Crk	GC-JAR	6.8%	75.7%	83	18	11	1600	50	119	368	YES	3	17%	NO
Sinclair Inlet	Gorst Crk	GC	8.3%	74.7%	110	17	13	1601	50	220	494	NO	5	29%	NO
Sinclair Inlet	Wright Crk	WC	15.0%	56.5%											
Dyes Inlet	Ostrich Bay Crk	OBC	43.5%	20.8%	582	19	23	1601	240	1600	2948	NO	15	79%	NO
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	7.2%	69.7%											
Dyes Inlet	Lost Crk Tributary	CH-LST	3.3%	83.1%											
Dyes Inlet	Dickerson Crk Tributary	CH-DI	3.9%	78.6%	76	18	8	900	35	168	336	YES	1	6%	YES
Dyes Inlet	Upper Kitsap Crk	CH-KL	5.9%	76.0%											
Dyes Inlet	Kitsap Crk Tributary	CH-KC	13.2%	50.9%	49	19	8	900	27	75	199	YES	1	5%	YES
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	5.6%	75.0%											
Dyes Inlet	Chico Crk @ Golf Course	CH	8.0%	69.0%	41	20	4	300	23	73	141	YES	1	5%	YES
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	8.6%	67.8%	48	20	8	170	28	88	148	YES	0	0%	YES
Dyes Inlet	Strawberry Crk	SC	24.1%	46.0%	139	18	23	1600	55	430	629	NO	6	33%	NO
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	26.0%	49.2%											
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	28.2%	51.3%											
Dyes Inlet	Clear Crk - West Fork	CC-CW	27.8%	46.3%	90	15	13	500	40	240	409	YES	6	40%	NO
Dyes Inlet	Clear Crk - Mountainview Tributary	CC-MTV	20.4%	56.4%	69	15	2	1601	32	165	763	YES	3	20%	NO
Dyes Inlet	Clear Crk - Ridgetop Tributary	CC-RTP	34.1%	37.5%	126	20	14	1601	30	350	932	NO	8	40%	NO
Dyes Inlet	Clear Crk - East Fork	CC-CE	23.9%	48.4%											
Dyes Inlet	Clear Crk @ Silverdale Way	CC	26.0%	47.2%	104	20	8	1600	50	240	552	NO	6	30%	NO
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	27.1%	46.1%	255	20	50	1600	73	900	1408	NO	11	55%	NO
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	23.1%	38.0%	67	19	1	1600	27	205	843	YES	5	26%	NO
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	29.0%	45.7%	179	18	1	1600	73	800	1921	NO	10	56%	NO
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	23.9%	39.1%	109	21	1	900	50	220	656	NO	8	38%	NO
Dyes Inlet	Pharman Crk	PA	33.0%	34.2%	199	11	8	1601	132	950	2077	NO	8	73%	NO
Dyes Inlet	Mosher Crk	MS	36.0%	27.6%	82	20	8	900	45	130	298	YES	2	10%	YES
PO Passage	Dee Crk	DEE	41.1%	25.1%	403	19	30	1601	290	900	1582	NO	15	79%	NO
PO Passage	Illahee Crk	ILL	19.6%	52.7%											
PO Passage	Springbrook Crk	BI-SBC	5.5%	77.9%											

Note: Highlighted sample sites are in violations of WQS.

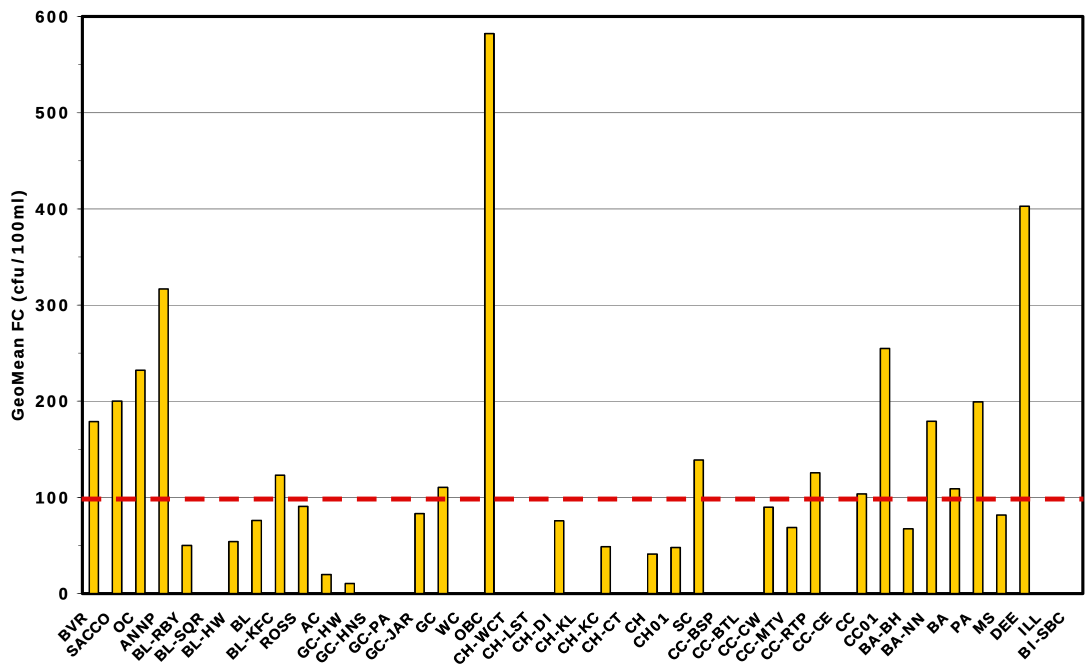

Figure 6-14. Geometric Mean (Part I WQS shown as a dashed red line) Fecal Coliform Data for Dry Seasons during the 2000-2003 Study Period for Stream Sample Sites

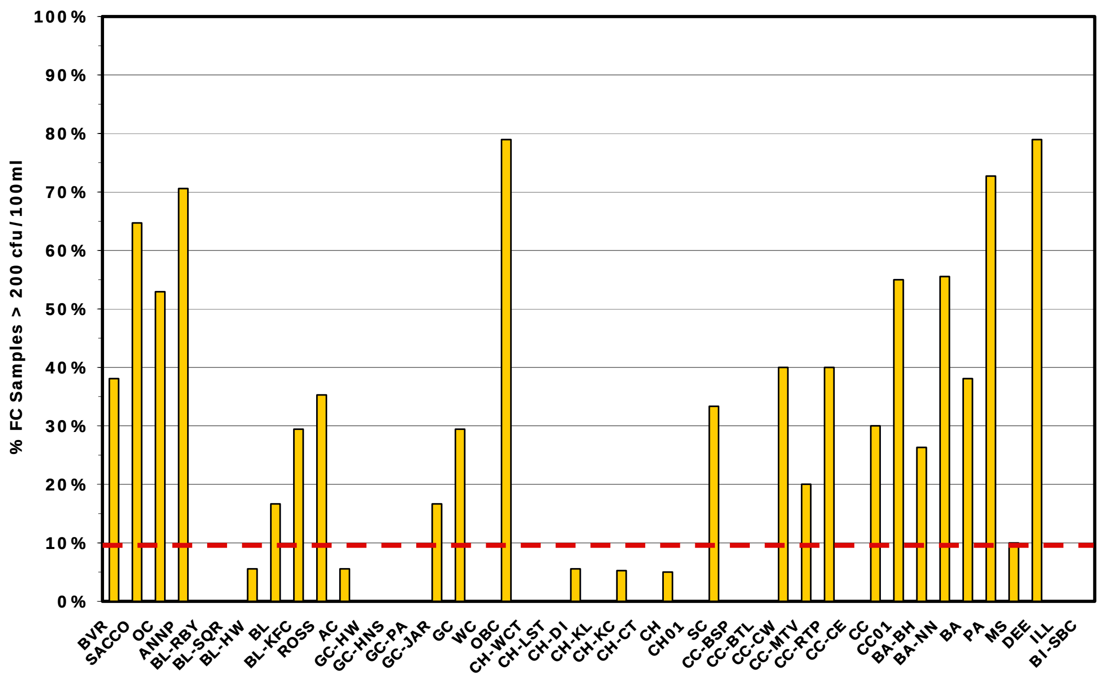

Figure 6-15. Variability (Part II WQS shown as a dashed red line) of Fecal Coliform Data for Dry Seasons during the 2000-2003 Study Period for Stream Sample Sites

Table 6-9. Summary of Stream Fecal Coliform Data for the Sinclair-Dyes Inlet Watershed for Wet Seasons in the 2000-2003 Study Period

Wet Season Stream FC Data									Wet Season FC Data						
Watershed	Stream Sub-Watershed	WQ ID	%TIA	% Forest	GeoMean FC/100ml	Count (N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<100	#FC >200	%FC >200	Meets WQS
Yukon Harbor	Beaver Crk	BVR	10.4%	58.3%	97	16	11	600	30	255	532	YES	6	38%	NO
Rich Passage	Sacco Crk	SACCO	15.0%	47.8%	143	18	4	1600	58	500	1091	NO	8	44%	NO
Sinclair Inlet	Olney Crk	OC	39.5%	28.5%	125	23	4	1600	42	400	956	NO	9	39%	NO
Sinclair Inlet	Annapolis Crk	ANNP	43.4%	21.0%	216	22	23	1600	65	800	1387	NO	11	50%	NO
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	9.9%	58.6%	21	15	2	1600	8	40	167	YES	1	7%	YES
Sinclair Inlet	Square Crk Tributary	BL-SQR	6.8%	68.1%											
Sinclair Inlet	Upper Blackjack Crk	BL-HW	17.6%	43.9%	12	22	2	300	7	17	56	YES	1	5%	YES
Sinclair Inlet	Blackjack Crk @ SR-16	BL	13.1%	53.4%	29	21	4	240	13	50	146	YES	2	10%	YES
Sinclair Inlet	Blackjack Crk	BL-KFC	15.9%	51.6%	31	19	1	170	19	81	153	YES	0	0%	YES
Sinclair Inlet	Ross Crk	ROSS	22.5%	50.3%	17	22	1	300	5	73	161	YES	2	9%	YES
Sinclair Inlet	Anderson Crk	AC	6.6%	76.5%	14	21	1	300	4	30	88	YES	1	5%	YES
Sinclair Inlet	Heins Crk Headwaters	GC-HW	2.7%	88.1%	3	20	1	17	2	4	9	YES	0	0%	YES
Sinclair Inlet	Heins & Jarstad Crk Tribs	GC-HNS	12.9%	69.9%											
Sinclair Inlet	Parish Crk Tributary	GC-PA	14.1%	62.9%											
Sinclair Inlet	Upper Gorst Crk	GC-JAR	6.8%	75.7%	38	19	2	1600	15	150	339	YES	4	21%	NO
Sinclair Inlet	Gorst Crk	GC	8.3%	74.7%	38	21	1	500	17	110	269	YES	3	14%	NO
Sinclair Inlet	Wright Crk	WC	15.0%	56.5%											
Dyes Inlet	Ostrich Bay Crk	OBC	43.5%	20.8%	140	21	8	1600	30	900	1564	NO	10	88%	NO
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	7.2%	69.7%											
Dyes Inlet	Lost Crk Tributary	CH-LST	3.3%	83.1%											
Dyes Inlet	Dickerson Crk Tributary	CH-DI	3.9%	78.6%	16	23	1	1600	8	50	175	YES	2	9%	YES
Dyes Inlet	Upper Kitsap Crk	CH-KL	5.9%	76.0%											
Dyes Inlet	Kitsap Crk Tributary	CH-KC	13.2%	50.9%	10	19	1	240	4	20	74	YES	1	5%	YES
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	5.6%	75.0%											
Dyes Inlet	Chico Crk @ Golf Course	CH	8.0%	69.0%	8	22	1	110	2	25	58	YES	0	0%	YES
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	8.6%	67.8%	15	23	1	80	7	40	69	YES	0	0%	YES
Dyes Inlet	Strawberry Crk	SC	24.1%	46.0%	38	23	4	900	10	105	219	YES	2	9%	YES
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	26.0%	49.2%											
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	28.2%	51.3%											
Dyes Inlet	Clear Crk - West Fork	CC-CW	27.8%	46.3%	19	22	2	900	8	28	92	YES	1	5%	YES
Dyes Inlet	Clear Crk - Mountainview Tributary	CC-MTV	20.4%	56.4%	16	16	1	130	4	95	130	YES	0	0%	YES
Dyes Inlet	Clear Crk - Ridgetop Tributary	CC-RTP	34.1%	37.5%	32	23	4	1600	11	95	242	YES	4	17%	NO
Dyes Inlet	Clear Crk - East Fork	CC-CE	23.9%	48.4%											
Dyes Inlet	Clear Crk @ Silverdale Way	CC	26.0%	47.2%	21	21	2	300	8	50	128	YES	3	14%	NO
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	27.1%	46.1%	50	22	4	1600	22	148	387	YES	4	18%	NO
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	23.1%	38.0%	30	21	8	1600	13	50	144	YES	2	10%	YES
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	29.0%	45.7%	54	21	7	1600	17	110	385	YES	3	14%	NO
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	23.9%	39.1%	53	23	1	900	27	95	351	YES	5	22%	NO
Dyes Inlet	Pharman Crk	PA	33.0%	34.2%	16	17	1	500	4	50	154	YES	1	6%	YES
Dyes Inlet	Mosher Crk	MS	36.0%	27.6%	17	23	1	900	6	40	141	YES	2	9%	YES
PO Passage	Dee Crk	DEE	41.1%	25.1%	253	19	22	1600	90	1050	1470	NO	10	53%	NO
PO Passage	Illahee Crk	ILL	19.6%	52.7%											
PO Passage	Springbrook Crk	BI-SBC	5.5%	77.9%											

Note: Highlighted sample sites are in violations of WQS.

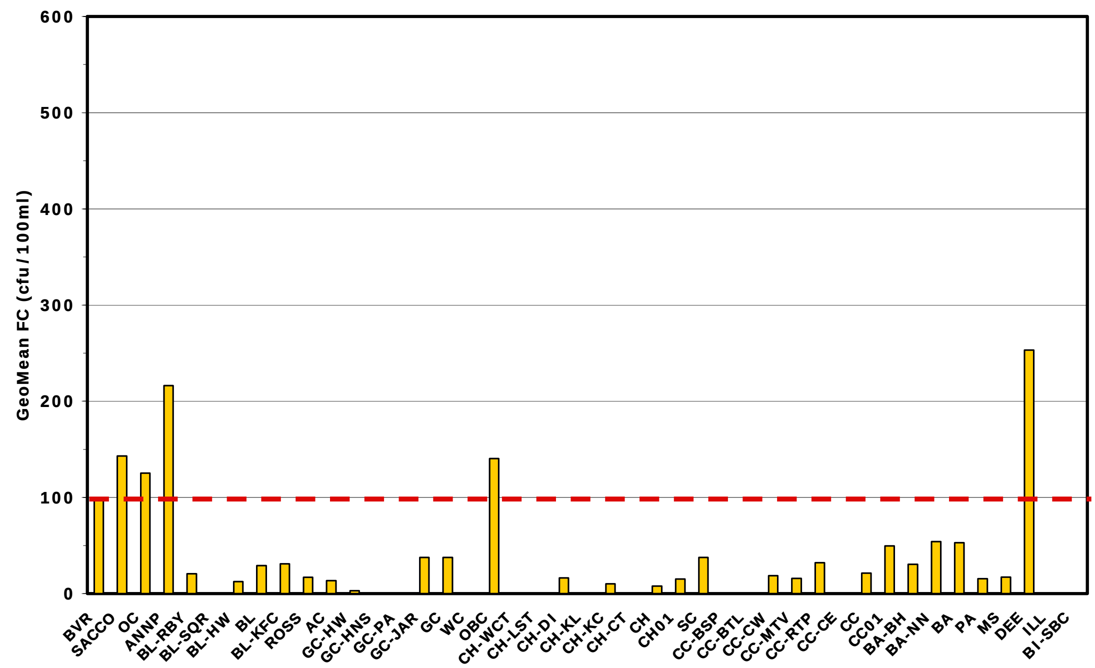

Figure 6-16. Geometric mean (Part I WQS shown as a dashed red line) Fecal Coliform Data for Wet Seasons during the 2000-2003 Study Period for Stream Sample Sites

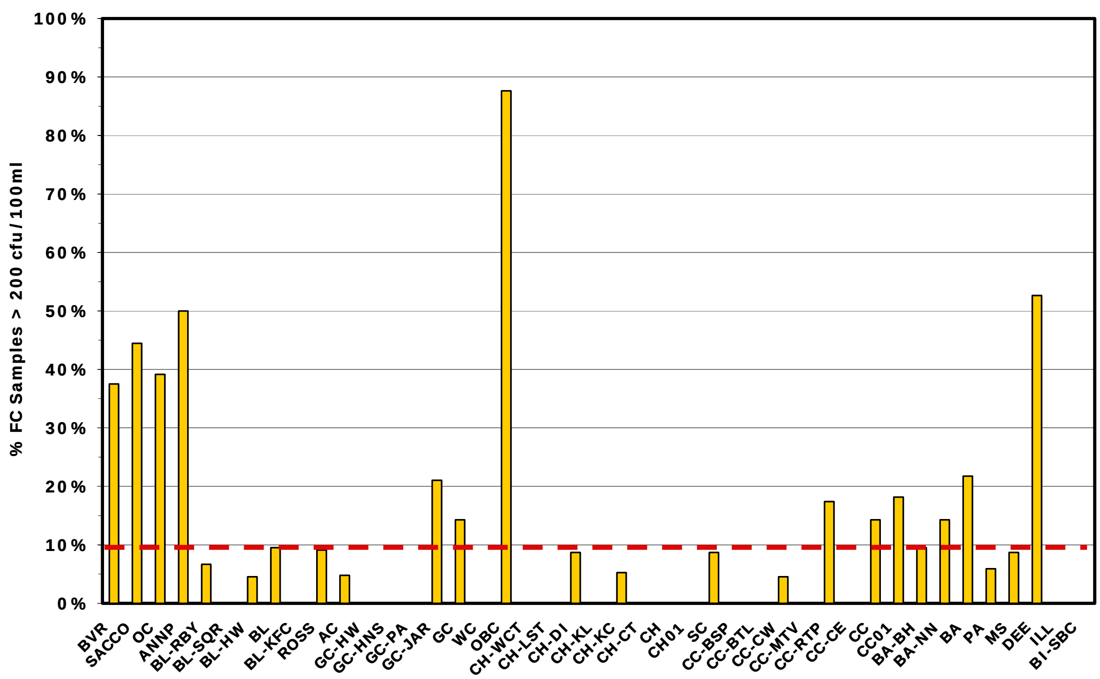

Figure 6-17. Variability (Part II WQS shown as a dashed red line) of Fecal Coliform Data for Wet Seasons during the 2000-2003 Study Period for Stream Sample Sites

Table 6-10. Summary of Stream Fecal Coliform Data for the Sinclair-Dyes Inlet Watershed for the 2002-2003 Storm Season

2002-2003 Storm Season Stream FC Data					2002-2003 Storm Event FC Data										
Watershed	Stream Sub-Watershed	WQ ID	%TIA	% Forest	GeoMean FC/100ml	Count (N)	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	GeoMean FC<100	#FC >200	%FC >200	Meets A WQ Std
Yukon Harbor	Beaver Crk	BVR	10.4%	58.3%	87	19	11	600	57	150	379	YES	4	21%	NO
Rich Passage	Sacco Crk	SACCO	15.0%	47.8%	109	19	8	1100	46	275	543	NO	7	37%	NO
Sinclair Inlet	Olney Crk	OC	39.5%	28.5%	365	25	27	5800	123	1233	2840	NO	15	60%	NO
Sinclair Inlet	Annapolis Crk	ANNP	43.4%	21.0%	263	19	29	3700	77	665	1547	NO	13	68%	NO
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	9.9%	58.6%											
Sinclair Inlet	Square Crk Tributary	BL-SQR	6.8%	68.1%											
Sinclair Inlet	Upper Blackjack Crk	BL-HW	17.6%	43.9%											
Sinclair Inlet	Blackjack Crk @ SR-16	BL	13.1%	53.4%	114	30	6	1100	58	300	523	NO	10	33%	NO
Sinclair Inlet	Blackjack Crk	BL-KFC	15.9%	51.6%	78	18	8	700	23	350	494	YES	5	28%	NO
Sinclair Inlet	Ross Crk	ROSS	22.5%	50.3%											
Sinclair Inlet	Anderson Crk	AC	6.6%	76.5%	12	23	1	250	5	24	85	YES	2	9%	YES
Sinclair Inlet	Heins Crk Headwaters	GC-HW	2.7%	88.1%											
Sinclair Inlet	Heins & Jarstad Crk Tribs	GC-HNS	12.9%	69.9%											
Sinclair Inlet	Parish Crk Tributary	GC-PA	14.1%	62.9%	24	19	1	460	9	69	159	YES	1	5%	YES
Sinclair Inlet	Upper Gorst Crk	GC-JAR	6.8%	75.7%	114	21	32	800	59	169	361	NO	4	19%	NO
Sinclair Inlet	Gorst Crk	GC	8.3%	74.7%	79	27	8	1100	35	262	409	YES	8	30%	NO
Sinclair Inlet	Wright Crk	WC	15.0%	56.5%											
Dyes Inlet	Ostrich Bay Crk	OBC	43.5%	20.8%											
Dyes Inlet	Wildcat Crk Tributary	CH-WCT	7.2%	69.7%											
Dyes Inlet	Lost Crk Tributary	CH-LST	3.3%	83.1%											
Dyes Inlet	Dickerson Crk Tributary	CH-DI	3.9%	78.6%	49	18	7	200	20	135	204	YES	0	0%	YES
Dyes Inlet	Upper Kitsap Crk	CH-KL	5.9%	76.0%	57	16	10	460	29	116	215	YES	1	6%	YES
Dyes Inlet	Kitsap Crk Tributary	CH-KC	13.2%	50.9%	23	16	8	110	18	32	54	YES	0	0%	YES
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	5.6%	75.0%	33	23	1	330	19	67	162	YES	1	4%	YES
Dyes Inlet	Chico Crk @ Golf Course	CH	8.0%	69.0%	71	38	14	560	39	150	223	YES	5	13%	NO
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	8.6%	67.8%											
Dyes Inlet	Strawberry Crk	SC	24.1%	46.0%	140	33	6	1300	37	340	837	NO	17	52%	NO
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	26.0%	49.2%	61	19	3	680	19	173	435	YES	4	21%	NO
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	28.2%	51.3%	42	21	9	460	11	88	221	YES	2	10%	YES
Dyes Inlet	Clear Crk - West Fork	CC-CW	27.8%	46.3%	49	32	6	360	13	175	304	YES	8	25%	NO
Dyes Inlet	Clear Crk - Mountainview Tributary	CC-MTV	20.4%	56.4%											
Dyes Inlet	Clear Crk - Ridgetop Tributary	CC-RTP	34.1%	37.5%											
Dyes Inlet	Clear Crk - East Fork	CC-CE	23.9%	48.4%	146	33	16	1680	54	380	722	NO	16	48%	NO
Dyes Inlet	Clear Crk @ Silverdale Way	CC	26.0%	47.2%	86	32	9	910	38	275	479	YES	9	28%	NO
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	27.1%	46.1%											
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	23.1%	38.0%	65	15	6	470	29	159	319	YES	3	20%	NO
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	29.0%	45.7%	99	16	16	480	48	185	321	YES	3	19%	NO
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	23.9%	39.1%	109	34	8	570	49	268	421	NO	11	32%	NO
Dyes Inlet	Pharman Crk	PA	33.0%	34.2%											
Dyes Inlet	Mosher Crk	MS	36.0%	27.6%											
PO Passage	Dee Crk	DEE	41.1%	25.1%	423	20	14	5700	194	1425	3228	NO	13	65%	NO
PO Passage	Illahee Crk	ILL	19.6%	52.7%											
PO Passage	Springbrook Crk	BI-SBC	5.5%	77.9%	83	5	43	231	51	88	192	YES	1	20%	NO

Note: Highlighted sample sites are in violations of WQS.

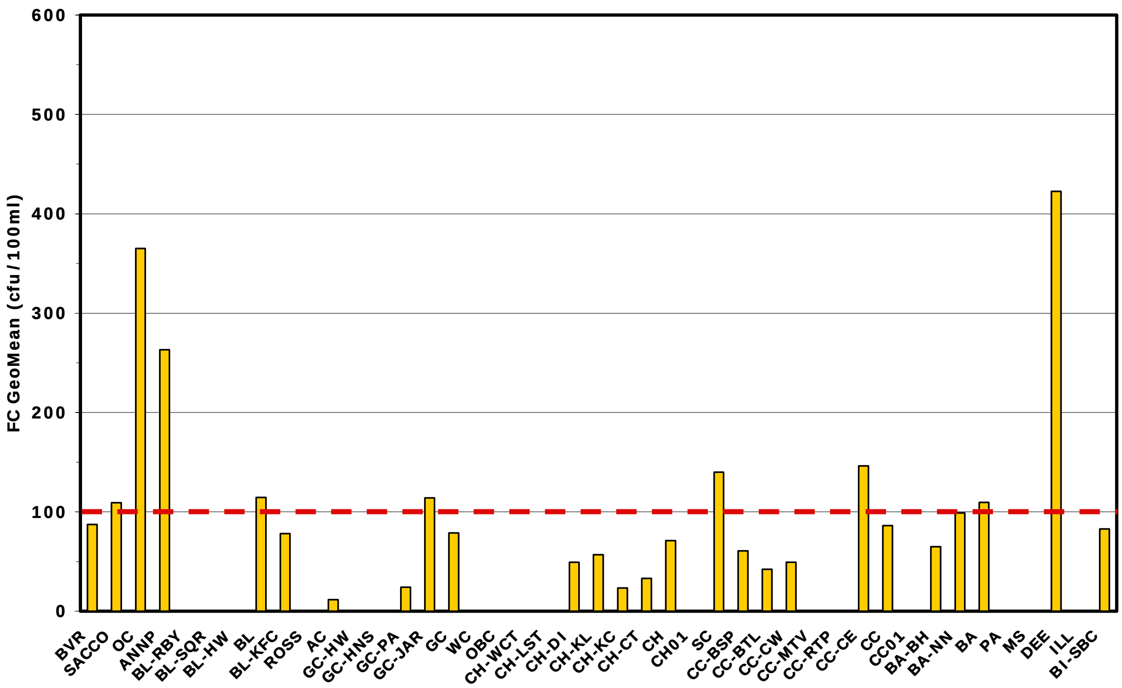

Figure 6-18 Geometric mean (Part I WQS shown as a dashed red line) Fecal Coliform Data for the 2002-2003 Storm Season at Stream Sample Sites

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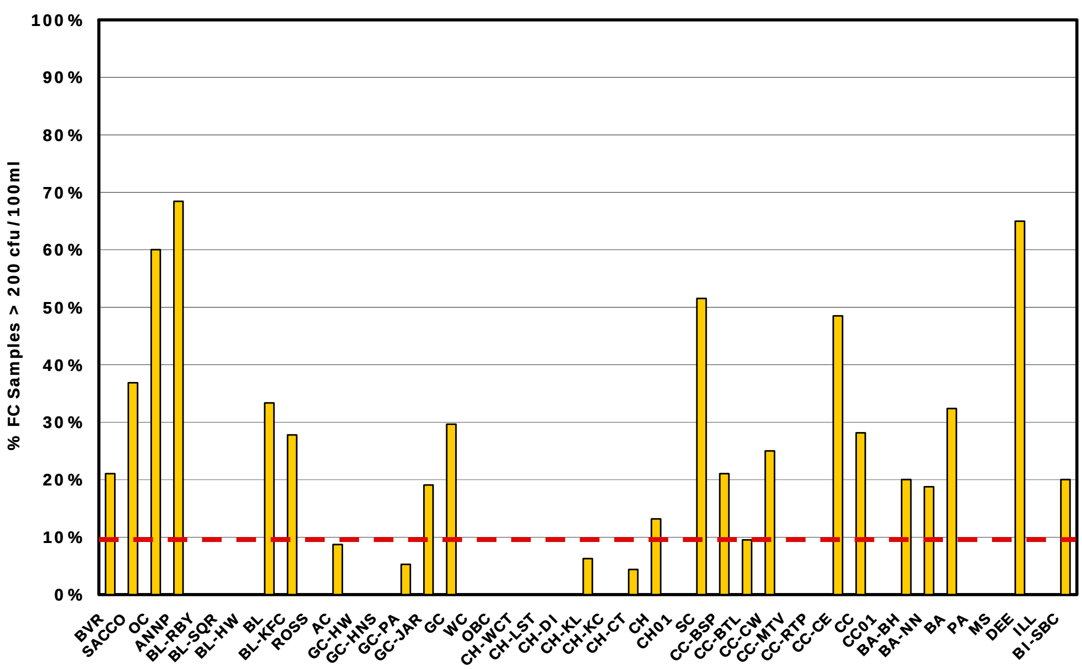


Figure 6-19. Variability (Part II WQS shown as a dashed red line) of Fecal Coliform Data for the 2002-2003 Storm Season at Stream Sample Site

7.0 Discussion and Data Analysis

7.1 Background

As discussed earlier in this report, there is often a relationship between human land-use activities and WQS violations directly related to elevated levels bacterial contamination in receiving waters. Several research studies on the east coast have documented this relationship (Maiolo and Tschetter 1981; Duda and Cromartie 1982; Weiskel et al., 1996; White et al., 1998; Griffin et al., 1999; Scott et. al., 1999; Mallin et al., 2000b; Marchman 2000; White et al., 2000; Lipp et al., 2001a; Mallin et al., 2001; Smith et al., 2001; Ackerman and Weisberg 2004; Bay et al., 2003; Kelsey et al., 2003; Holland et al., 2004; Kelsey et al., 2004). In addition, studies on the west coast confirm the applicability of the findings of eastern researchers and illustrate the problems common to the west coast (Leecaster and Weisberg 2001; Schiff et al., 2001; Dwight et al., 2002; Ackerman and Weisberg 2004; Bay et al., 2003; Schiff et al., 2003).

Preliminary results of an ongoing study in the Puget Sound also indicate a relationship between landscape-level changes in upland watersheds and the decline in water quality in coastal waters (Alberti and Bidwell 2004). In this Puget Sound study, a landscape-scale empirical analysis of several urbanizing basins was conducted. The study sites were selected to span gradients of urban LULC patterns. Using bacterial contamination as the indicator of nearshore water-quality conditions, a cross-sectional analysis was conducted across the Puget Sound to assess which landscape factors best explain water-quality conditions in shellfish-growing areas. Preliminary results from this research indicate that forest fragmentation in the drainage basin, impervious surface area, and road density are the best predictors of nearshore water-quality conditions (Alberti and Bidwell 2004). Within the more urbanized areas, the amount and connectivity of the impervious surface explained most of the variance in bacterial pollution (Alberti and Bidwell 2004). The findings of this nearshore research are also in agreement with research conducted in Puget Sound freshwater ecosystems. The Puget Sound lowland stream research effort also found a close correlation between watershed land use and stream water quality, with imperviousness, natural forest cover, and road density being the best predictors of water quality (May et al., 1997a, b).

Based on the findings of the research cited above, data from the Sinclair-Dyes Inlet watershed study were analyzed to determine what, if any, relationships exist between all available LULC parameters and bacterial pollution levels. Each subbasin within the Sinclair-Dyes Inlet watershed was characterized using a number of LULC categories, including native forest classes (coniferous, deciduous, and mixed), lawn or turf areas, agricultural areas, residential development types (rural, suburban, and urban), commercial and industrial development, and others.

The most obvious manifestation of watershed development is the loss of native forest cover accompanied by the increase in impervious surface area. Vegetation clearing, land grading, and soil compaction are all parts of the conventional development process. After the native land cover has been removed, a variety of impervious surfaces are commonly constructed within the built environment. Impervious surfaces include roads, parking lots, rooftops, sidewalks, lawns, and other landscaped areas. In general, imperviousness is defined along a gradient from “hard” surfaces (such as roads) that do not have any natural permeability to landscaped areas that have some permeability but are less than the natural landscape. Watershed urbanization is most often quantified in terms of the proportion of basin area covered by impervious surfaces (Scheuler 1994; Arnold and Gibbons 1996; May et al., 1997a, b). Impervious cover is also generally highly correlated with human population density within a watershed (Schueler 1994).

The most common measure of impervious cover is total impervious area (%TIA), which includes all impervious surfaces in the watershed. Imperviousness is a physical attribute of the landscape that provides a reliable indicator of the cumulative impacts of watershed development on receiving waters and aquatic ecosystems (Schueler 1994). Imperviousness is derived from the component LULC parameters that make up each watershed and, therefore, is an appropriate measure of overall watershed development. Imperviousness can be derived from LULC data, aerial photo analysis, and from GIS data. Because it includes all LULC categories, using imperviousness as the only measure of watershed development may not be advisable. In this study, %TIA is used in addition to the individual LULC categories, because different types of land-use activities tend to have differential impacts on water quality. Therefore, from a management perspective, it is desirable to identify and quantify any relationships between water quality and specific land-use categories.

Although impervious surfaces themselves do not generate pollution, they are the major contributor to the change in basin hydrologic regime that drives many of the physical changes affecting developed watersheds. Basin imperviousness and stormwater runoff are directly related (Schueler 1994). In addition, stormwater runoff quality is typically related to the types of land use that exist within a drainage basin. Therefore, the unit area pollutant load delivered to receiving waters by stormwater runoff increases in direct proportion to watershed imperviousness. This relationship should not be surprising, in that the pollutant load is the product of the average pollutant concentration and runoff volume. Given that runoff volume increases in direct proportion to %TIA, pollutant loads must also increase as %TIA increases, as long as the pollutant concentration stays the same (or increases). This relationship is a central assumption in most simple and complex pollutant loading models, such as the models used in this study (Carnale et al., 1993; Ventura and Kim 1993; Smith et al., 2001).

As has been discussed, in addition to conventional stormwater pollutant constituents, bacterial contamination is also found in runoff from developed areas. Recent research has shown that bacterial WQS are routinely violated during storm events at very low levels of impervious cover in coastal watersheds (Mallin et al., 2001; Vernberg et al., 1997; CWP 1999). In Maiolo and Tshetter (1981) a significant correlation was found between human population density and closed shellfish acreage in North Carolina. A study by Duda and Cromartie (1982) notes greater FC densities when septic tank density and impervious surface area increased in coastal watersheds on the east coast. A study of small estuaries in North Carolina (Mallin et al., 2000b) showed that bacterial pollution levels were significantly correlated with watershed population, developed land area, and impervious cover. The %TIA was the most statistically significant indicator, explaining 95% of the variability in FC concentrations (Mallin et al., 2000b). The study also found that shellfish bed closures were possible but not common in watersheds with less than 10% impervious cover, common in watersheds greater than 10%TIA, and almost certain in watersheds with more than 20%TIA (Mallin et al., 2000b). Although higher FC levels were generally observed in developed watersheds, salinity, tidal flushing, and proximity to pollution sources often resulted in higher concentrations as well (Mallin et al., 1999).

Therefore, in conjunction with analyzing FC data for specific LULC relationships, this study used impervious cover (%TIA) as a primary measure of overall watershed development and cumulative human impact. In addition, information on human population density, sewer and stormwater infrastructure, livestock and pet populations, tidal flushing conditions, and other characteristics of each subbasin were used in the analysis to identify possible pollution sources or relationships among parameters that would be helpful in developing a *Water Cleanup Plan*.

The results of FC bacterial sampling in the Sinclair-Dyes Inlet study area were characterized by a number of potentially influential parameters to determine any correlative relationships. The historical (KCHD and WA-DOH) FC data were separated into “dry” (May-September) and “wet” (October-April) season baseflow data sets. This seasonal dataset includes streams and marine-nearshore areas only. The

2002-2003 storm season (November-January) data were treated as an additional dataset. This storm event dataset includes streams, marine-nearshore areas, and stormwater outfalls. FC samples were taken during storms, after storms, and between storm events to characterize a typical storm event, as opposed to the "wet season" baseflow data already available. Several storm-event samples were taken at stream sample stations that were co-located with stream-flow gages and automated water-quality sample stations. These samples typically included discrete FC samples at the start, middle, and end of storm events. The FC samples associated with discrete "storm events" were also analyzed separately to determine whether trends exist between FC levels within storm events.

7.2 Marine-Nearshore Data Analysis

The level of shoreline development was measured using the standard LULC analysis methods discussed earlier. The drainage area associated with each marine-nearshore FC sample site included a combination of all shoreline subbasins directly adjacent to the sample site. In many cases, these shoreline subbasins typically consist of small shoreline areas with no perennial streams. Drainage is mainly by overland sheet-flow, small drainage channels, and groundwater seepage into the nearshore. In more developed areas (with a typical %TIA of 30% or higher), there are usually stormwater conveyance networks consisting of ditches or stormwater drainage pipes. In several cases, nearshore FC sample sites are located within the estuary at the mouth of streams. For these sites, the stream watershed was included in the contributing drainage area and LULC analysis. Figures 7-1 and 7-2 summarize the LULC conditions in the shoreline (direct runoff) subbasins within the Sinclair-Dyes Inlet watershed. Figure 7-3 shows the relationship between development (as measured by %TIA) and native forest cover in these shoreline areas. This relationship is characteristic of development in upland watersheds (May et al., 1997a, b) and coastal areas of the Puget Sound region (Alberti and Bidwell 2004). The loss of natural vegetative cover (mainly coniferous forest) and the replacement by impervious surfaces can have significant consequences for nearshore water quality and ecological function, as demonstrated in the analysis of nearshore bacterial pollution data.

In general, FC data indicate that water quality at most stations in Sinclair-Dyes Inlet is satisfactory. Analysis of the historical (WA-DOH and KCHD) FC data indicates that the estuaries of streams draining developed watersheds and nearshore areas adjacent to highly developed shoreline areas, especially those receiving piped runoff from stormwater outfalls, are more likely to violate bacterial water-quality criteria, resulting in restrictions on shellfish harvesting and/or contact recreation. There is a general relationship between watershed development, as measured by %TIA and individual land-use categories (e.g., urban, HD residential, commercial-industrial), and FC levels in the nearshore. However, this relationship is not strong and the statistical correlations are generally not significant (Figures 7-4 through 7-7). Nearshore FC measurements were analyzed with each LULC category in an effort to identify any specific relationships, but no statistically significant correlations were found.

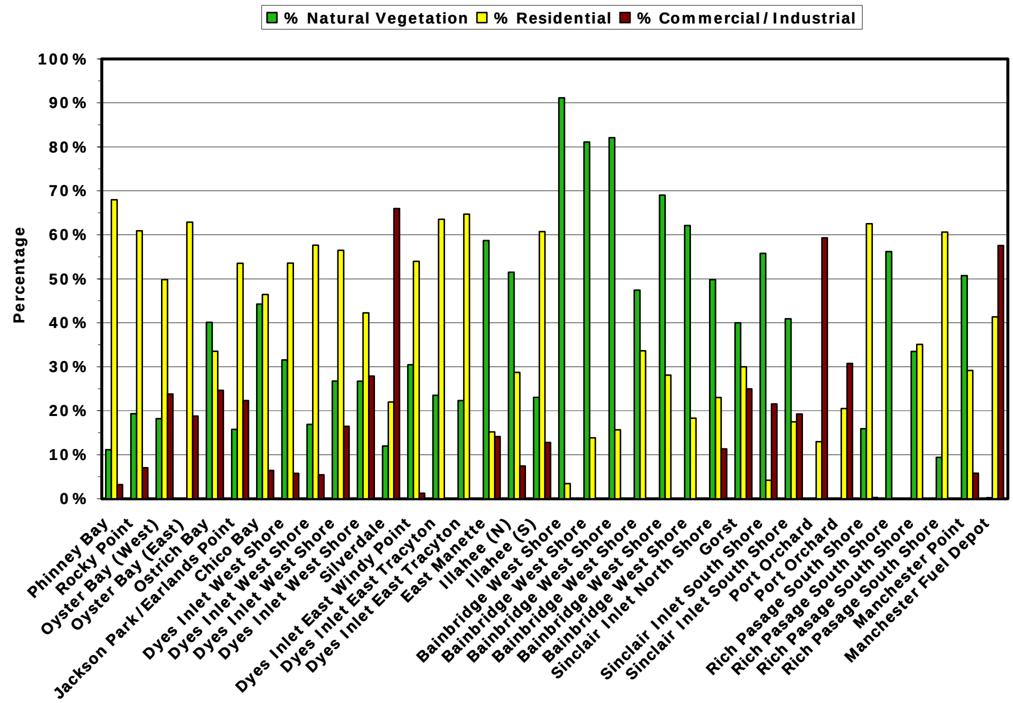


Figure 7-1. Shoreline Drainage Basin Land-Use and Land-Cover Summary for the Sinclair-Dyes Inlet Watershed

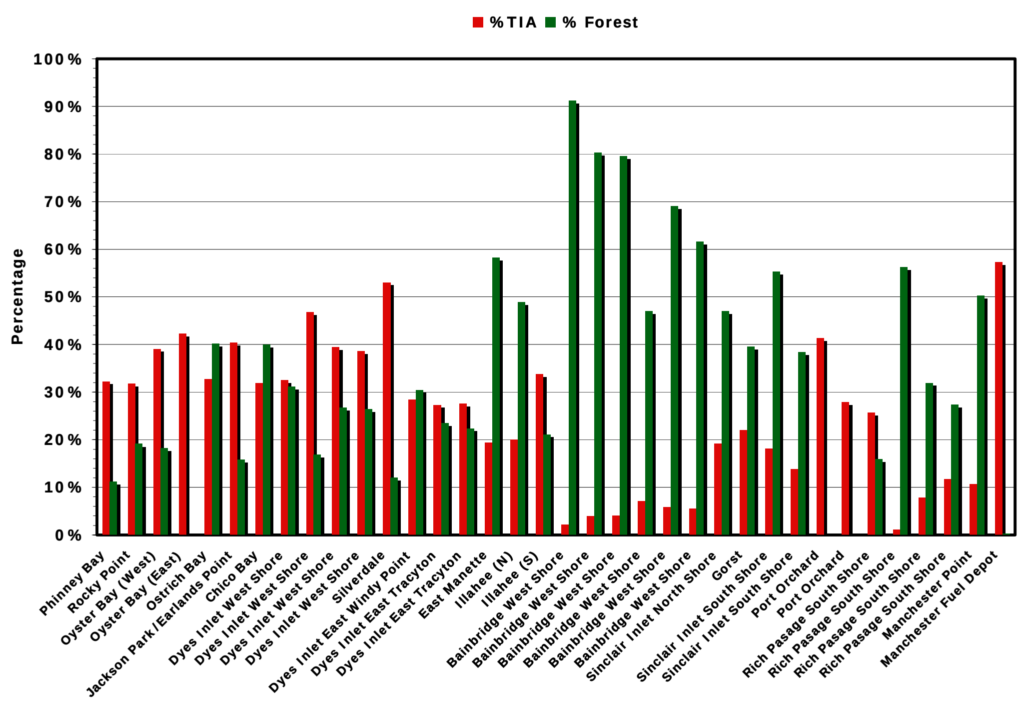


Figure 7-2. Shoreline Drainage Basin Total Impervious Area and Native Forest Cover Summary for the Sinclair-Dyes Inlet Watershed

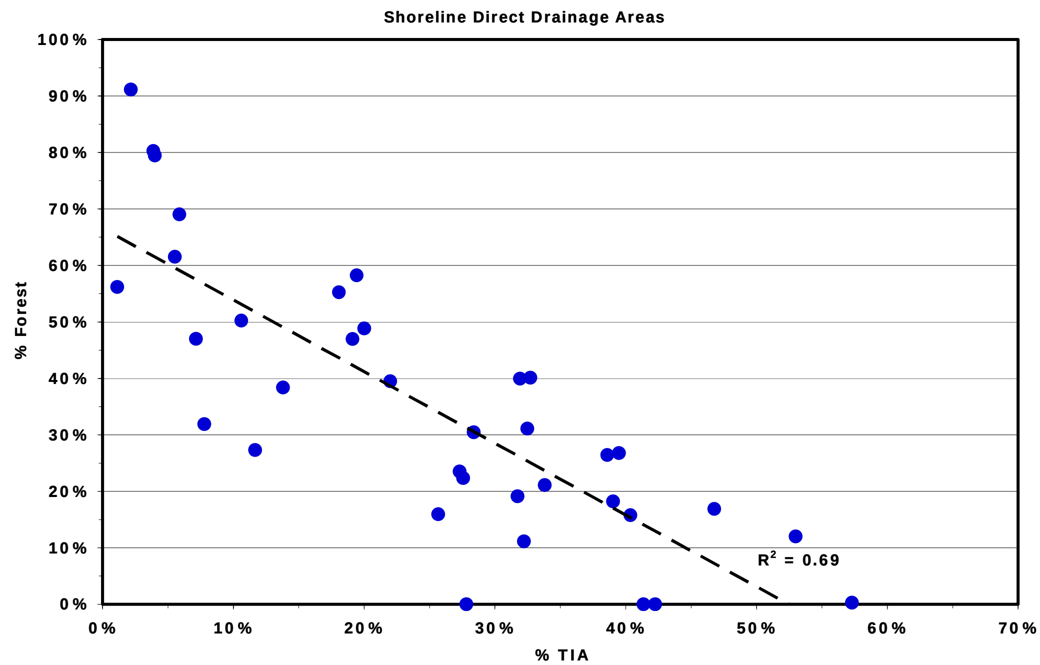


Figure 7-3. The Relationship between Total Impervious Area and Forest Cover for Shoreline (Direct-Runoff) Drainage Areas within the Sinclair-Dyes Inlet Watershed

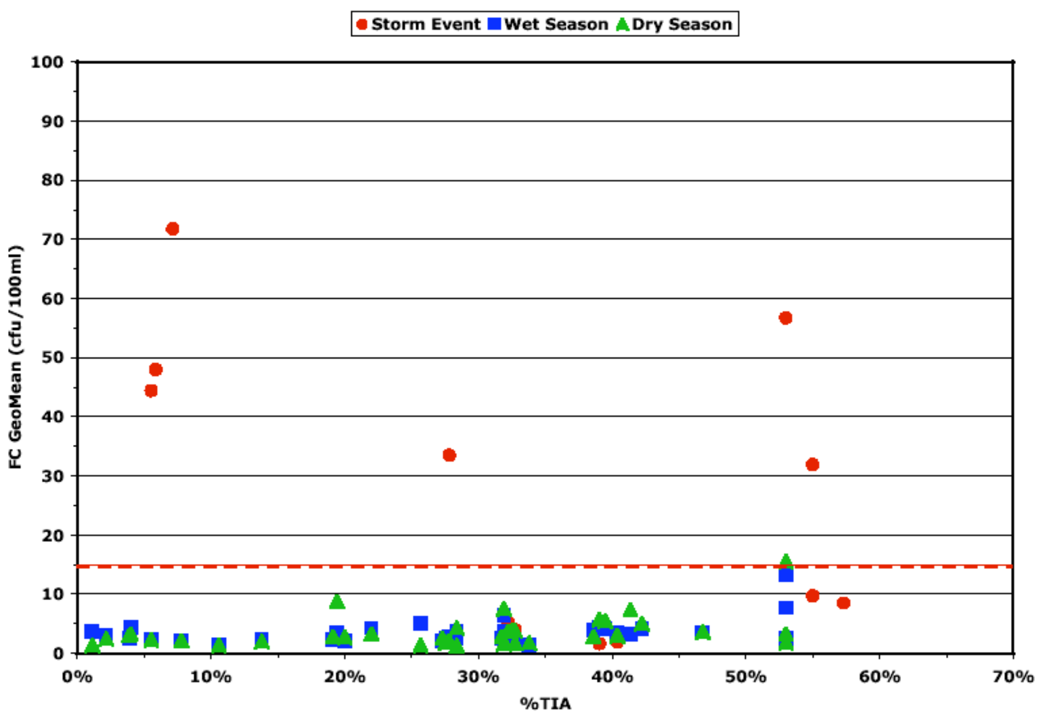


Figure 7-4. The Relationship Between Shoreline Drainage Basin Total Impervious Area and Fecal Coliform Levels Measured in Adjacent Marine-Nearshore Areas (Fecal Coliform Geometric Mean) for Wet, Dry, and Storm Seasons

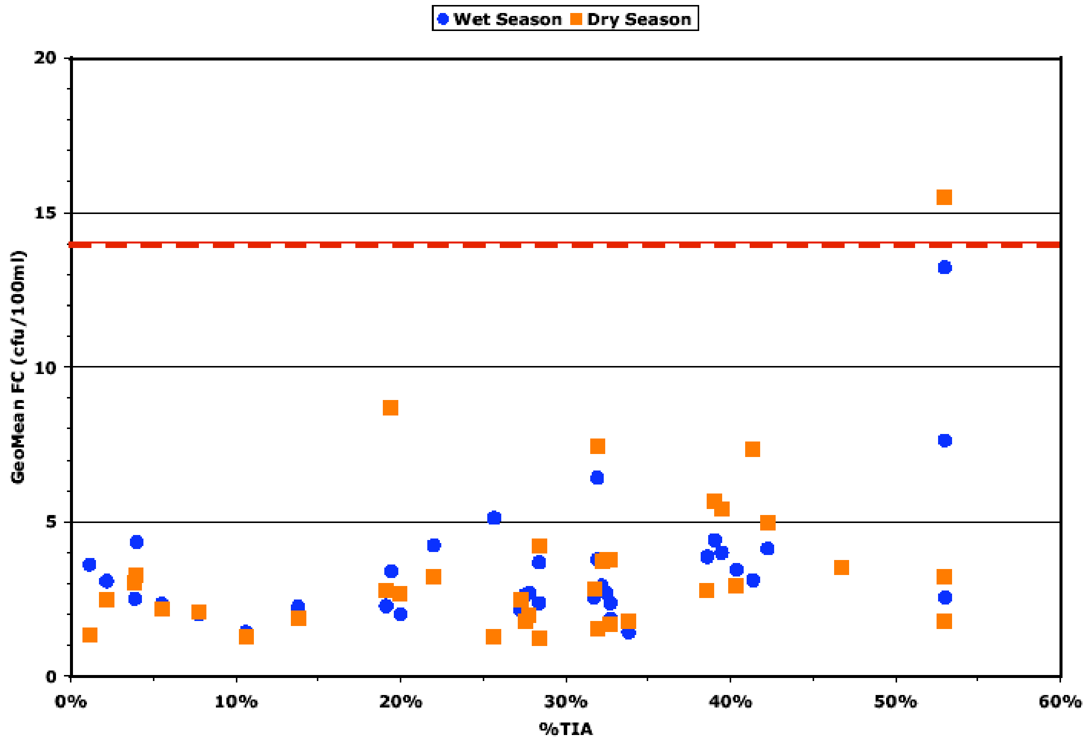


Figure 7-5. The Relationship Between Shoreline Drainage Basin Total Impervious Area and Fecal Coliform Levels Measured in Adjacent Marine-Nearshore Areas (Fecal Coliform Geometric Mean) for Wet and Dry Seasons Only

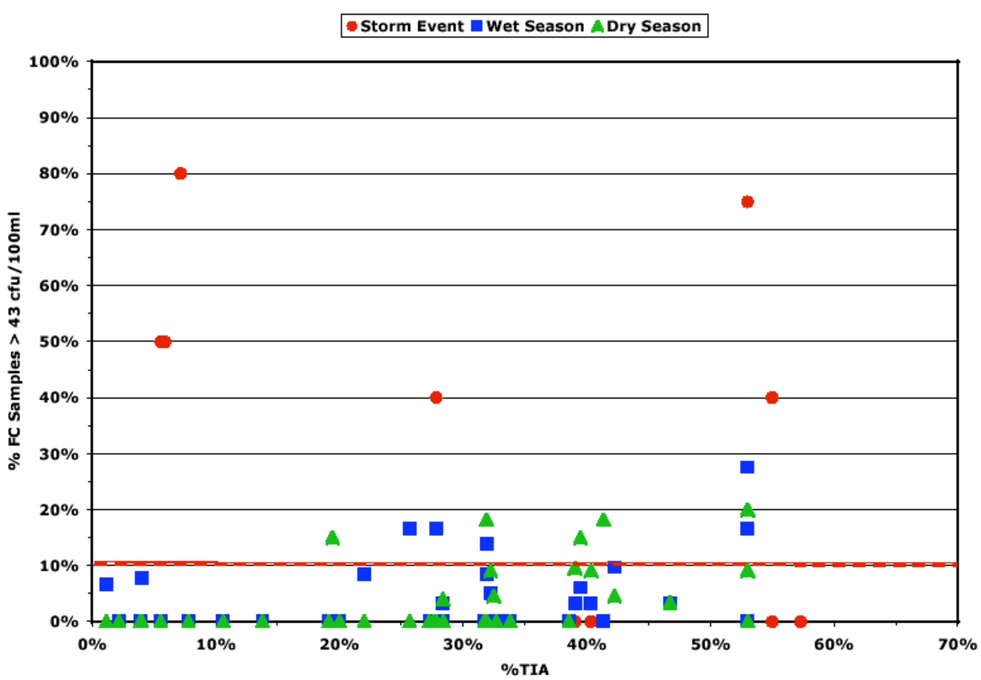


Figure 7-6. The Relationship Between Shoreline Drainage Basin Total Impervious Area and Fecal Coliform Levels Measured in Adjacent Marine-Nearshore Areas (Percentage of Fecal Coliform Samples that Violate Water-Quality Standards) for Wet, Dry, and Storm Seasons

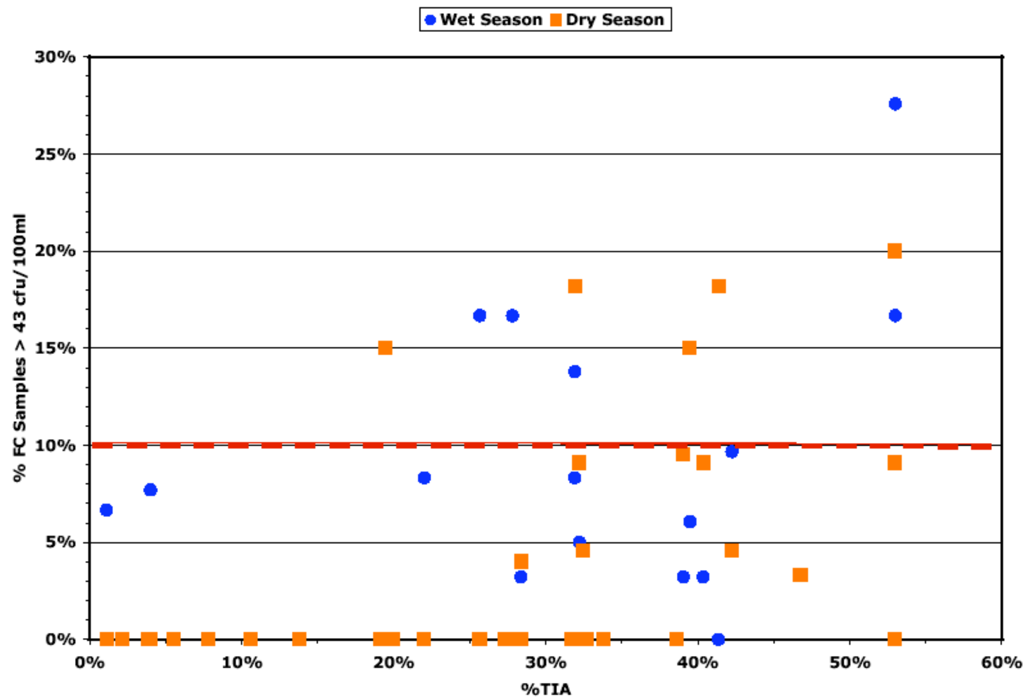


Figure 7-7. The Relationship Between Shoreline Drainage Basin Total Impervious Area and Fecal Coliform Levels Measured in Adjacent Marine-Nearshore Areas (Percentage of Fecal Coliform Samples that Violate Water-Quality Standards) for Wet and Dry Seasons Only

Although there appear to be no statistically significant correlations between drainage basin imperviousness (%TIA) and FC levels, some important trends and relationships that can be discerned from the data analysis. It can be seen from Figures 7-4 and 7-5 that a violation of the FC geometric mean (or Part I) WQS (greater than 14 cfu/100 mL) is not common in nearshore waters; however, it can occur in specific circumstances. This type of WQS violation appears to be much more common during storm events at all levels of development and can also occur during non-storm periods in highly developed shoreline locations. The latter is likely due to the greater number of potential FC sources that tend to exist in more developed areas, along with the greater chance of sewage spills or CSO events, failing septic systems, leaking sewage conveyance networks, and stormwater-runoff related sources. Violations during storm events are likely due to the many stormwater outfalls that currently drain to nearshore areas without water-quality treatment. Consequently, transient high bacterial levels may occur in nearshore zones, especially if tidal flushing is low or natural die-off is inhibited by storm-related turbidity or the low levels of sunlight common during the storm season. Freshwater inflow from streams draining developing watersheds is also likely a source of FC contamination of the nearshore, especially in estuarine areas at the mouths of creeks draining urbanizing subbasins.

There are a number of potential explanations for the observed relationships in the variability of nearshore FC data. First, violations of the Part I WQS (geometric mean is greater than 14 cfu/100 mL) are relatively uncommon, except during storm events, indicating that high bacterial pollution levels are likely transitory and probably dissipate fairly rapidly after the storm event is over. This assumption is supported by research from other regions (Mallin et al., 2000b; Schiff et al., 2001; Schiff et al., 2003). Also, an obvious trend emerges when the data for the Part II WQS (more than 10% of FC samples have greater than 43 cfu/100 mL) are examined (Figures 7-6 and 7-7). This WQS measures the variability or "spikiness" of the FC data and appears to be related to drainage-basin imperviousness, at least to the extent that it indicates a greater likelihood of a WQS violation in subbasins with a %TIA greater than 20%. This level of %TIA lies somewhere in the transition between rural and suburban ranges of development. The relative number of FC WQS violations appears to increase as shoreline development moves from undeveloped or rural to more suburban (Figures 7-6 and 7-7).

With respect to water quality, a critical stage in the urbanization continuum may occur in the suburban range of the development process when the human population often takes a significant jump and housing density increases dramatically. At this time, a large portion of the households can still be served by onsite septic systems, even though sewers are also present. The continued use of septic systems may not be appropriate, depending on housing density or operability of existing systems. Sewers and OWTS each have their limitations that need to be recognized. At some point, if development continues within a drainage basin, a shift from onsite treatment to municipal or community sewage treatment is usually made. In addition, the age (e.g., design and operation and maintenance issues) of OWTS in areas that are transitioning from rural to suburban can become problematic from an operational perspective.

At this range of development, stormwater conveyance systems often shift from those dominated by overland sheet-flow and vegetated roadside ditches to one dominated by curb-and-gutter stormwater collection and piped stormwater conveyance. The best example of this is the Silverdale area at the head of Dyes Inlet. Silverdale is a developed area that includes a significant amount of HD residential (multi-family apartments), suburban residential developments, and a large commercial core (the Silverdale Mall area). The majority of the Silverdale area is served by sanitary sewers, with onsite septic systems common in the less-developed sections. For the most part, stormwater from roads and parking lots is collected in drain inlets and piped to the head of Dyes Inlet or into the lower mainstem of Clear Creek, which also drains into the head of Dyes Inlet. Some stormwater treatment BMP facilities are located in this area, but many of these systems are not at the current level of design for water-quality treatment; many of the older developed areas have little or no stormwater BMP treatment. It can also be hypothesized that "hard" or engineered stormwater systems (e.g., curb-and-gutter, drain inlet collection points, and piping networks) could be a contributing factor to the overall level of bacterial contamination found in nearshore areas adjacent to urbanizing shorelines. Similar results and conclusions have been shown for urbanizing coastal watersheds in other parts of the U.S. In a study by Mallin and others (2000b), a strong correlation was found between the level of watershed imperviousness and associated development characteristics and bacterial contamination levels in tidal creeks and estuaries in North Carolina. Weiskel and others (1996) also found a strong relationship between FC levels in coastal embayments in Massachusetts and the level of shoreline and upland development. These studies also identified stormwater runoff and wet-weather streamflows as significant FC sources.

Another reason that the correlation between upstream development and FC levels at nearshore and estuarine sites is not consistently strong may be that nearshore areas and estuaries, especially those in a relatively natural condition, can naturally reduce bacterial contamination levels. Research in other portions of the country supports this hypothesis (Burkhardt et al., 2000; Weiskel et al., 1996; Mallin et al., 2000b). The effects of sunlight, bacterial predators, and natural die-off are typically strong in natural estuarine environments (Burkhardt et al., 2000).

Based on this data analysis, it can be concluded that microbial pollution of marine waters is not extensive. However, there are several examples of localized bacterial pollution problems in the nearshore-marine waters of Sinclair-Dyes Inlet. The Clear Creek estuary, near Silverdale, in Northern Dyes Inlet is currently a chronic bacterial pollution area. The geometric mean FC level for the sample site located at the mouth of the creek is in violation of WQS (greater than 14 cfu/100 mL). Both WA-DOH (Station 466) and KCHD (DY27) FC data support this characterization. No shellfish harvest is allowed within approximately one mile from the stream discharge point into Dyes Inlet. In addition, a shellfish closure zone has been established around the mouth of nearby Barker Creek (WA-DOH Station 463) as a result of periodic high FC levels detected in the estuary. Stormwater discharges associated with impervious surfaces in and around the Silverdale area contribute to the FC load that enters northern Dyes Inlet from the developed stream watershed. In addition, it is likely that failing OWTS and sewer infrastructure in Silverdale also contribute to the FC pollution in northern Dyes Inlet. Sufficient dilution and dispersion of these polluted discharges likely prevents microbial contamination from reaching the nearest shellfish harvesting areas.

Bacterial pollution has also been periodically detected in Chico Bay at both WA-DOH sampling stations (Stations 469 through 474) and KCHD sampling sites (DY-19 through DY-21). Analysis of KCHD routine sampling data and the Chico PIC project has identified a variety of sources of FC contamination. These sources include failing OWTS, waterfowl, and wildlife. At times, these multiple sources can have a negative effect on the water quality in Chico Bay, which is a shallow embayment bounded on three sides by land and not well flushed by tides or currents. The WA-DOH sample stations in Chico Bay (Stations 469 through 474) generally tend to have higher FC levels during dry-weather conditions as compared with wet-weather samples. The geometric mean and estimated 90th percentile values at each of the six WA-DOH stations are all consistently higher under the relatively dry conditions. In addition, a relay verification study conducted by WA-DOH (2001a) on shellfish from Chico Bay indicates that natural bacterial cleansing of the shellfish is more conducive under wet-weather conditions than in dry, summer conditions. However, based on the most current KCHD data, Chico Bay meets the marine FC WQS, likely because of KCHD PIC program efforts along the shoreline of Chico Bay.

The mouth of Dee Creek in Port Orchard Passage also appears to have a mainly dry-season bacterial pollution problem. KCHD sampling indicates that this station (PO-13) violates Part II of the marine FC WQS. It is believed that input from Dee Creek, a highly urbanized watershed, is the main source of microbial pollution to the nearshore zone. KCHD is working with the City of Bremerton and Kitsap County to bring sanitary sewers to this area. Based on the data currently available, KCHD has determined that failing OWTS are the primary cause of bacterial contamination in Dee Creek and its estuary. If warranted, KCHD may also conduct a PIC program in the Dee Creek watershed in the near future.

Data analysis for all marine stations in the Sinclair-Dyes Inlet watershed generally indicates no strong positive correlation between rainfall (quantity, intensity, and antecedent dry period [ADP]) and bacterial water quality for the stations as a whole. However, a review of WA-DOH FC data indicates that about half of the samples that were greater than 43 cfu/100 mL did occur within a few days of a rainstorm event of greater than 0.50 inches, and about a third of the high FC samples occurred shortly after a rainfall of greater than 0.75 inches. Although no statistically significant trends can be identified between rainfall and FC levels in marine waters, wet-weather periods and storm events can still contribute to bacterial pollution problems. Examples of wet-weather FC pollution problems within the study watershed include the estuaries of several creeks that drain relatively urbanized watersheds, e.g., the mouths of Clear Creek (KCHD DY27 and WA-DOH 466), Blackjack Creek (KCHD SN12), Olney Creek (KCHD SN13), and Sacco Creek (KCHD SN15).

The effect of tidal flushing on bacterial water-quality in Dyes Inlet was investigated for WA-DOH FC sample stations only (WA-DOH 2003c). This investigation indicated that water quality at each of the six stations in Chico Bay (Stations 469 through 474) is more adversely affected by ebb-tide conditions. Three of the six stations (469, 472 and 473) exceeded 43 FC/100 mL, and the three others were very close to this criterion. With the exception of Station 474, the geometric mean and 90th percentile values for each of the six stations were all higher on ebb tides than on flood tides. These findings indicate that future water-quality sampling should emphasize water sample collection on ebb tides in Chico Bay and in other similar low-flushing embayments. However, flood-tide sampling should not be excluded at these stations, because elevated samples have also been collected on flood tides. Data from the FC station at the mouth of Barker Creek (WA-DOH 463) indicate that water quality is more adversely impacted by flood tides as compared with ebb-tide conditions. This result is probably due to a tendency to transport pollution from Barker Creek toward this station on flood tide. In contrast, ebb-tide sampling results tend to produce higher fecal coliform levels at the Chico Bay stations. This result may be due to the more direct influence and/or reduced dilution of Chico Creek flows into the bay. Also, fecal coliform levels in Chico Creek may be higher in dry months than in wet months because of the effect of dilution on fecal coliform loading to the creek's tributaries, a variation in residential occupancy in its drainages, or changes in wildlife patterns in and around Chico Bay. Alternatively, the problems found Chico Bay may be due to shoreline sources not associated with Chico Creek or a combination of both these potential source areas. The ongoing KCHD Chico PIC program should resolve these issues in the near future.

Based on the analysis of Sinclair-Dyes Inlet FC data presented above, there appears to be a relationship between the level of urbanization of the developed shoreline zone (direct runoff) and the contributing drainage area (stream and/or stormwater) that influences the nearshore area. However, no statistically significant relationship was noted between bacterial pollution indicators and LULC metrics at the scale of analysis used in this study. A recent study of Puget Sound (sponsored by PSAT and conducted by the University of Washington [UW]) found a relationship between landscape-level changes in upland watersheds and the decline in water quality in coastal waters when analyzed at a larger scale than was used in this project (Alberti and Bidwell 2004). In the UW-PSAT study, a landscape-scale empirical analysis of several urbanizing basins was conducted. The UW-PSAT study sites represented shellfish growing areas and were selected to span gradients of urban LULC patterns. Dyes Inlet was one of the basins used in this study. Using bacterial contamination as the indicator of nearshore water-quality conditions, a cross-sectional analysis was conducted across the Puget Sound to assess what landscape factors best explain water-quality conditions in shellfish growing areas. For each study area (such as Dyes Inlet), the available FC data were compiled spatially and temporally to obtain a representative pollution index for the entire area. This index value typically was the composite of FC data from several sample sites over a period of a few years. In contrast, the nearshore analysis presented in this report was based on a "finer" scale (that of a nearshore reach or individual stream estuary).

The results from the UW-PSAT research indicate that forest fragmentation in the contributing drainage basin, impervious surface area, and road density are the best predictors of nearshore water-quality conditions (Alberti and Bidwell 2004). Within the more urbanized areas, the amount and connectivity of the impervious surface explained most of the variance in bacterial pollution (Alberti and Bidwell 2004). The UW-PSAT results support the findings of this report with respect to the potential impacts of urbanization on nearshore water quality and microbial pollution.

A number of sources of bacterial pollution are present in the Sinclair-Dyes Inlet watershed, and multiple modes of transport of FC bacteria from sources to nearshore marine waters and shellfish growing areas are also present. In all but a very few locations and under specific conditions, marine water quality in Sinclair-Dyes Inlet meets bacterial WQS. When present, the level of bacterial contamination found in nearshore areas is generally higher in more developed shoreline areas, primarily due to the greater number of potential FC sources typical of higher levels of development. In addition to the level or intensity of development, the type of development practices that are present in upland areas also appears to influence the level of microbial pollution present in marine receiving waters. Developments served by older sewer or OWTS infrastructure have the potential for more bacterial problems related to failing treatment systems. Engineered (catch basin and piped conveyance) stormwater systems also appear to be more efficient in transporting microbial pollution from source areas to receiving waters.

Environmental factors, such as storm-event rainfall quantity, rainfall intensity, storm duration, tidal conditions, salinity, sunlight and natural die-off, and local site conditions all can also influence FC levels in the nearshore. In general, nearshore areas at or near the mouths of streams draining urbanizing watersheds or near stormwater outfalls have a greater chance of bacterial WQS violations. However, elevated nearshore FC levels appear to persist for only a short time after storm events or during extended periods of rainfall with significant stormwater runoff and stormflow inputs. Although transient, the FC levels found during storm-season sampling are an order of magnitude greater than those for non-storm periods, especially for nearshore sites with adjacent highly urbanized drainage subbasins.

The drainage resulting from the various types of human activities and land uses into a nearshore or estuarine area also have the potential to be major factors in determining whether there will be a bacterial contamination problem. For example, agricultural inputs, when present, can be a significant source in rural areas. Failing OWTS, leaking sewer lines, and WWTP spills are all sources found in urbanizing watersheds. Stormwater runoff can also be a significant transport mechanism in these more urbanized areas. When they occur, CSO events can also be a significant source of bacterial pollution into the nearshore environment. Like stormwater outfalls, CSO events are generally transient sources. Although much has been done by the COB to eliminate or mitigate the CSO problem in Sinclair-Dyes Inlet, CSO sources are still present in the study area and are still of concern. Although no data on FC levels in CSO outfalls during CSO events were available for this report, literature values indicate that CSO FC levels are typically an order of magnitude above stormwater outfall FC levels (Ferguson et al., 1996; Vernberg 1997; Pitt 1998; CWP 1999). As a precaution, shellfish harvest is prohibited in areas that could be adversely influenced by possible CSO events, much as it is for areas near WWTP outfalls (WA-DOH 2004). Although CSO events still have the potential to adversely affect water quality in Sinclair-Dyes Inlet, the number and the magnitude of CSO events have been significantly reduced through the efforts of the COB. The on-going CSO reduction and treatment program has been extremely effective in improving water quality in the watershed, as evidenced by the recent opening of shellfish harvest sites in Dyes Inlet by WA-DOH (WA-DOH 2003d) (see Section 5 for details).

In conclusion, because of the effectiveness of several on-going programs, microbial pollution is currently not a widespread or severe problem in the marine waters of the Sinclair-Dyes Inlet watershed. The key efforts include the following:

- KCHD WQ Monitoring
- KC-SSWM Program
- KCHD PIC Projects
- COB CSO Reduction Program
- KCD Farm Management Plans.

In spite of these effective source-control programs, violations of WQS in nearshore-marine waters do still occur, although only rarely. These marine bacterial contamination events appear to be mostly associated with large rainfall events that generate significant quantities of stormwater runoff and/or cause a CSO event. In addition, sewage spills resulting from failures of WWTP infrastructure can also result in high marine-nearshore bacterial levels. These events are generally localized spatially and are usually of a relatively short duration. Nearshore areas with poor natural flushing and areas with a higher density of stormwater outfalls tend to be more susceptible to these transient high-bacterial excursions.

7.3 Freshwater Stream Data Analysis

Research from throughout the U.S. has found that bacterial pollution in streams and other natural waters can usually be correlated with watershed development, as measured by population, the density of development, the %TIA, or the type of land uses present in the watershed (Young and Thackston 1999; Smith et al., 2001; Frenzel and Couvillion 2002; Tuford and Marshall 2002; Alberti and Bidwell 2004). Sources of bacterial pollution in freshwater streams include a variety of human and nonhuman sources that tend to be dependent on a number of factors related to land use. Typical sources found in the built-environment include sanitary sewer system leakage or spills, failing onsite septic systems, illicit wastewater discharges, livestock manure, pet waste, and urban wildlife or waterfowl. In some regions, CSO events can also be a source of bacterial contamination into streams or rivers, but that is not the case for the Sinclair-Dyes Inlet watershed.

Stormwater (NPS) runoff can be a major conveyance path for FC pollution (Pitt 1998; CWP 1999; Pitt et al., 2004). Stormwater runoff can contain human fecal matter from failing septic systems or sanitary sewers, as well as pet or livestock waste and fecal material from urban wildlife. In general, these are the same sources that were discussed in the previous section related to marine water-quality and bacterial pollution. As was pointed out in the previous section, urban streams can be a significant source of bacterial pollution into marine receiving waters.

In relatively undeveloped, rural watersheds (less than 5%TIA), the major sources of bacterial contamination tend to be livestock waste runoff from farms and pastures, wildlife, and failing onsite septic systems. Generally, in low-density suburban watersheds (5% to 15%TIA), the primary sources of bacterial contamination include failing onsite septic systems, stormwater runoff (containing fecal matter from humans, pets, and wildlife), and livestock waste runoff from farms or pastures. In medium-density suburban watersheds (15% to 30%TIA), stormwater runoff, failing onsite septic systems, and sanitary sewer system leakage generally dominate as sources of bacterial pollution, along with pet waste and urban wildlife. In urban watersheds (greater than 30%TIA), stormwater runoff and failing sanitary sewer infrastructure tend to be the primary sources.

Depending on one’s point of view, stormwater runoff could be considered a complex source of microbial pollution or simply a transport mechanism for contamination from a variety of sources. The latter is probably more accurate from the perspective of pollution control, as “source-control” measures that prevent contamination of runoff are generally more effective in reducing microbial pollution than stormwater treatment methods (CWP 1999).

Development in the Sinclair-Dyes Inlet watershed study area is typical of development in the Puget Sound region as a whole, although, in general, the Kitsap Peninsula does not have as much HD urban development as the areas of Seattle, Tacoma, Bellevue, and Everett. In most areas of the Puget Sound, including this study area, imperviousness increases as development increases, at the expense of the loss of native forest cover (Figure 7-8). Roads are ubiquitous in the developed landscape of all regions, including the Puget Sound and the Sinclair-Dyes Inlet watershed. Figure 7-9 shows the very close correlation between subwatershed imperviousness (%TIA) and road density (length of road per basin area).

On the riparian-corridor scale, there is also a close relationship between the loss of native forest cover and the increase in development, as measured by total impervious area within the riparian buffer (50 m) zone (Figure 7-10). As with the overall landscape, roads have a significant effect on the riparian corridor, with fragmentation being the most obvious impact (Figure 7-11).

In line with the national and regional findings, the results from stream sampling in the Sinclair-Dyes Inlet watershed show a discernable relationship between several measures of bacterial pollution in streams and contributing watershed LULC characteristics. Table 7-1 shows the LULC metrics and the measures of bacterial (FC) pollution used in this analysis. For the initial phase of the LULC-FC analysis, stream subwatershed imperviousness (%TIA) was used as an integrative measure of urbanization. As has been discussed, imperviousness generally increases in direct proportion to the magnitude and intensity of watershed development. Based on the analysis of FC data (2000-2003) from the Sinclair-Dyes Inlet (ENVVEST) study, the levels of bacterial pollution tend to increase as watershed imperviousness increases.

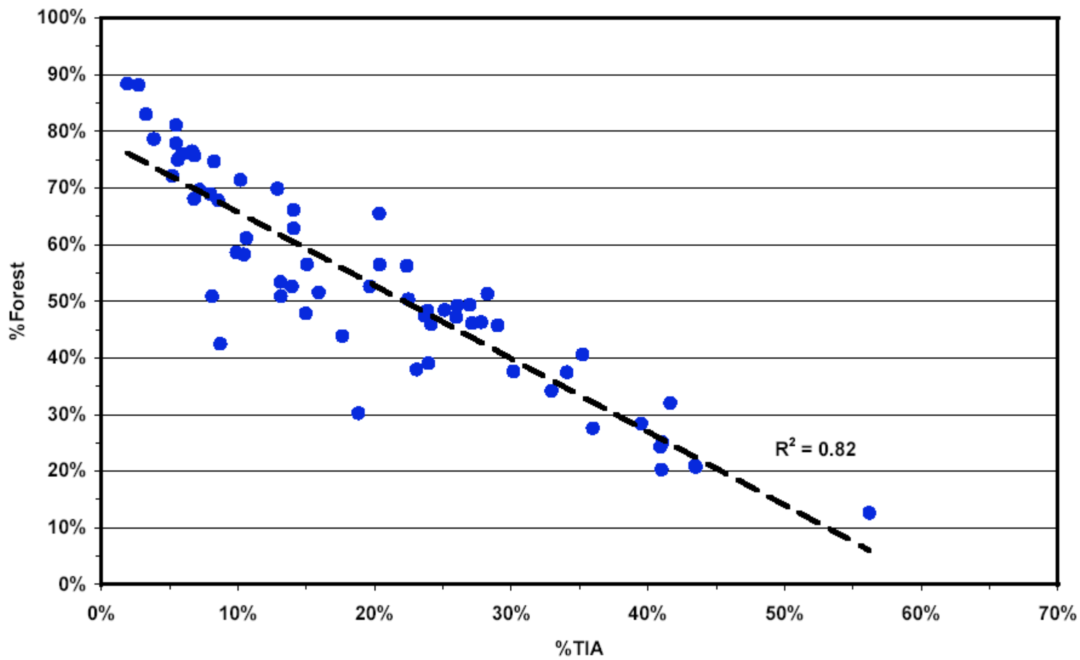


Figure 7-8. The Relationship Between Stream Subwatershed Total Impervious Area and Native Forest Cover in the Sinclair-Dyes Inlet Watershed

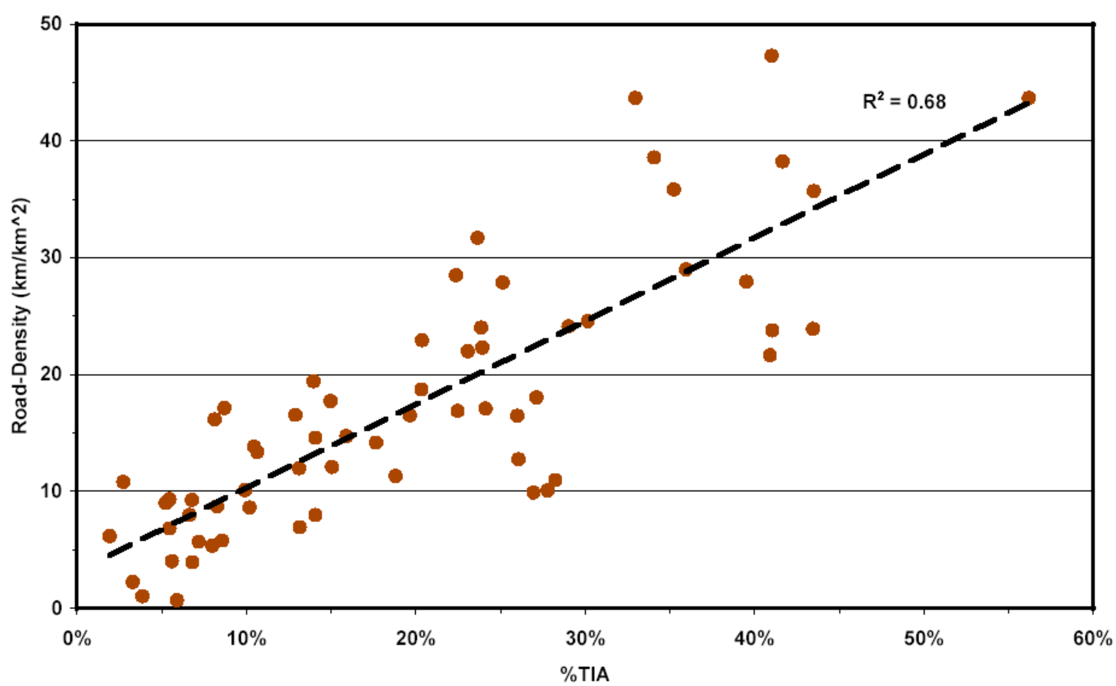


Figure 7-9. The Relationship Between Stream Subwatershed Road-Density and Native Forest Cover in the Sinclair-Dyes Inlet Watershed

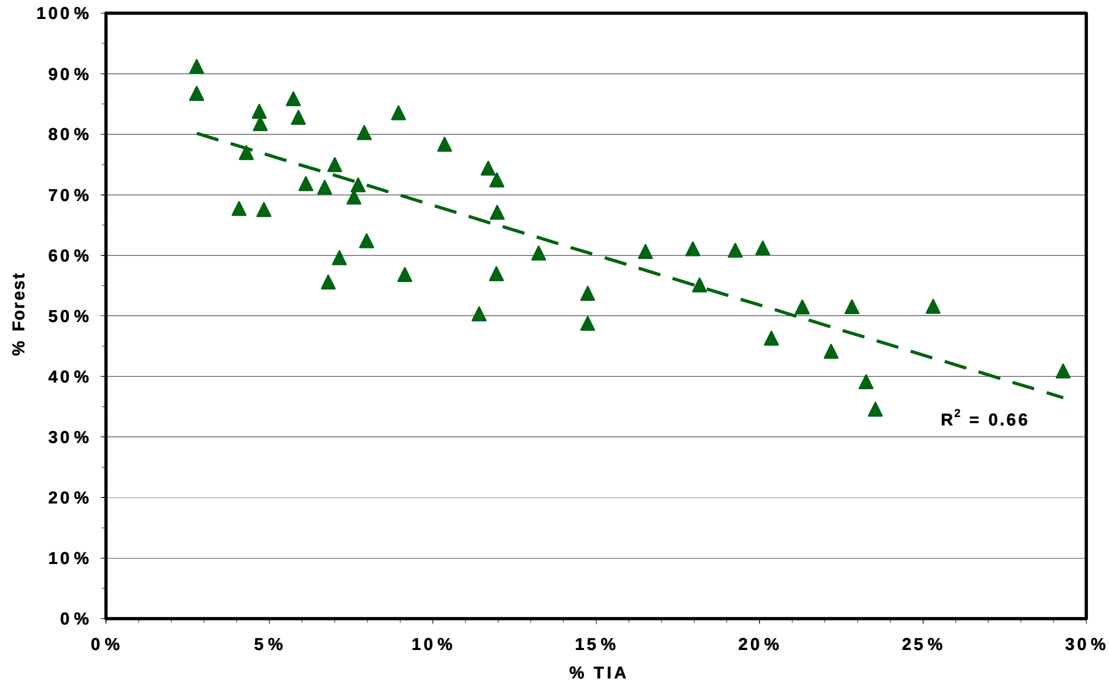


Figure 7-10. The Relationship Between Riparian Corridor Imperviousness and Native Forest Cover, as Measured Within the 50-Meter Buffer Surrounding Streams in the Sinclair-Dyes Inlet Watershed

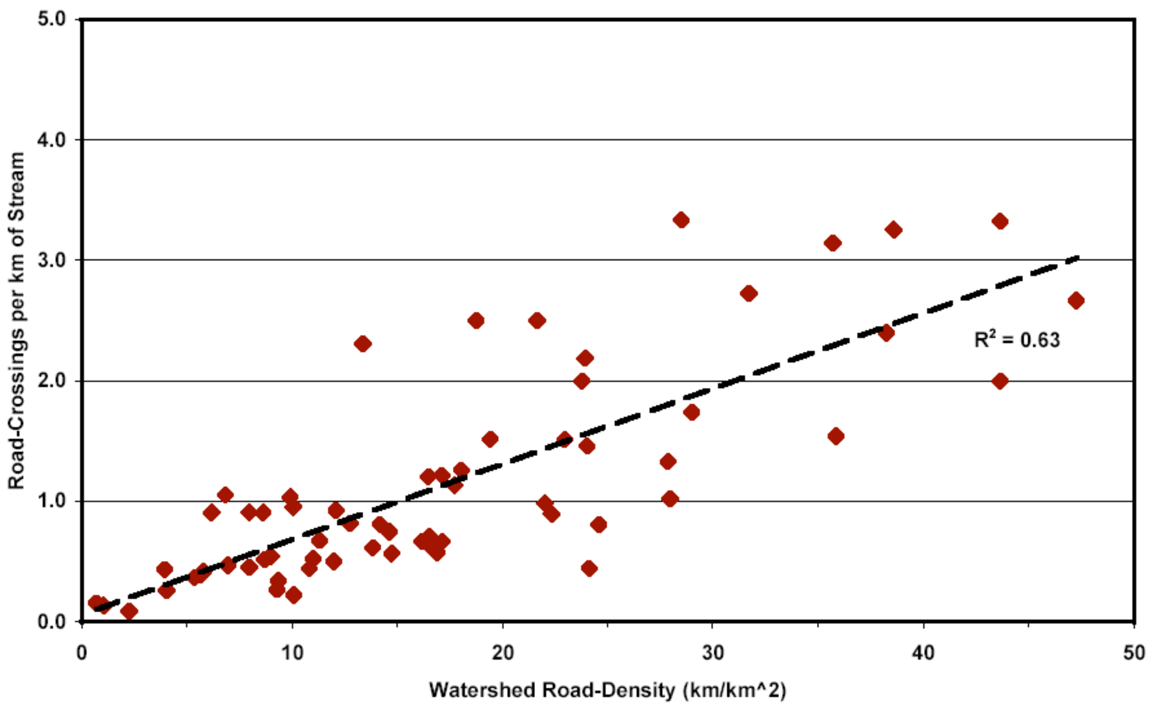


Figure 7-11. The Relationship Between Riparian Corridor Fragmentation (Road-Crossings Per Length of Stream Channel) and Subwatershed Road-Density, as Measured Within the 50-Meter Buffer Surrounding Streams in the Sinclair-Dyes Inlet Watershed

Table 7-1. Descriptive Statistics for Stream Fecal Coliform Sample Sites in the Sinclair-Dyes Inlet Watershed

Variable	N	Mean	Std.Dev.	Median	Minimum	Maximum	25th Percentile	75th Percentile
Basin Area (acres)	44	2500	2650	1374	197	10475	790	2952
Watershed % Mixed Forest	44	0.03	0.04	0.01	0.00	0.25	0.01	0.04
Watershed % Deciduous Forest	44	0.22	0.10	0.20	0.03	0.47	0.16	0.24
Watershed % Coniferous Forest	44	0.30	0.15	0.32	0.02	0.59	0.18	0.42
Watershed % Shrub	44	0.01	0.01	0.01	0.00	0.04	0.01	0.02
Watershed % Natural Vegetation	44	0.56	0.18	0.52	0.21	0.90	0.46	0.71
Watershed % Grass or Turf	44	0.07	0.05	0.07	0.00	0.19	0.04	0.10
Watershed % Rural (LD Residential)	44	0.05	0.07	0.02	0.00	0.26	0.00	0.10
Watershed % Suburban (MD Residential)	44	0.08	0.06	0.07	0.00	0.22	0.05	0.10
Watershed % Urban (HD Residential)	44	0.10	0.10	0.08	0.00	0.37	0.03	0.15
Watershed % Commercial/Industrial	44	0.12	0.11	0.09	0.00	0.41	0.02	0.20
Watershed %TIA	44	0.19	0.12	0.17	0.03	0.43	0.08	0.27
Watershed % Forest	44	0.54	0.17	0.51	0.21	0.88	0.46	0.69
Watershed Road Length (km)	44	115.7	112.4	63.6	2.2	497.8	42.5	169.6
Watershed Road Density (km/km^2)	44	15.7	9.9	14.4	0.7	43.7	9.0	22.6
Watershed Basin Area (sq-km)	44	10.1	10.7	5.6	0.8	42.4	3.2	11.9
Watershed Basin Area (sq-miles)	44	3.9	4.1	2.1	0.3	16.4	1.2	4.6
Watershed Stream Length (km)	44	20.2	23.3	12.8	1.5	97.4	5.4	24.4
Watershed Drainage Density (km / km^2)	44	2.0	0.6	1.9	0.8	3.9	1.6	2.3
Watershed Stream-Road Intersections	44	12.2	11.1	7.0	1.0	41.0	4.0	19.0
Watershed Stream-Crossings/Stream-Length (#/km)	44	0.91	0.73	0.67	0.09	3.26	0.44	1.21
Riparian % Urban (HD Residential)	44	0.06	0.07	0.05	0.00	0.25	0.01	0.10
Riparian % Commercial/Industrial	44	0.05	0.06	0.03	0.00	0.25	0.01	0.08
Riparian % Suburban	44	0.07	0.06	0.06	0.00	0.24	0.03	0.09
Riparian % Rural (LD Residential)	44	0.03	0.04	0.01	0.00	0.12	0.00	0.07
Riparian % Agricultural	44	0.07	0.06	0.07	0.00	0.24	0.03	0.09
Riparian %Developed	44	0.29	0.15	0.28	0.05	0.65	0.17	0.40
Riparian %TIA	44	0.12	0.07	0.10	0.03	0.29	0.06	0.18
Riparian % Deciduous Forest	44	0.38	0.15	0.34	0.04	0.74	0.31	0.46
Riparian % Coniferous Forest	44	0.24	0.14	0.21	0.00	0.57	0.15	0.33
Riparian % Mixed Forest	44	0.03	0.04	0.02	0.00	0.15	0.01	0.03
Riparian % Forest	44	0.65	0.14	0.64	0.35	0.91	0.54	0.76
Cumulative GeoMean FC	38	78.89	77.64	54.01	5.01	351.78	32.20	89.76
Cumulative 25th Percentile	38	30.42	33.05	18.50	2.00	170.00	11.00	36.25
Cumulative 75th Percentile	38	241.75	310.45	146.25	15.50	1600.00	80.00	262.50
Cumulative 90th Percentile	38	521.72	537.01	355.25	27.36	2605.83	210.21	576.79
Storm GeoMean FC	27	104.03	98.02	78.85	11.69	422.66	49.24	113.86
Storm 25th Percentile	27	43.15	39.28	37.00	5.00	193.75	18.50	54.00
Storm 75th Percentile	27	281.66	332.19	173.00	24.00	1425.00	88.00	300.00
Storm 90th Percentile	27	586.33	766.39	361.28	54.07	3227.75	204.16	522.83
Wet Season GeoMean FC	30	52.40	62.49	29.76	2.98	253.21	15.83	52.91
Wet Season 25th Percentile	30	18.45	20.63	10.50	1.85	90.00	5.50	22.00
Wet Season 75th Percentile	30	182.02	273.69	76.75	4.00	1050.00	40.00	147.50
Wet Season 90th Percentile	30	371.22	445.54	163.79	8.58	1563.57	128.28	385.44
Dry Season GeoMean FC	30	138.75	122.44	97.23	10.50	582.18	67.31	179.21
Dry Season 25th Percentile	30	69.61	67.19	47.50	3.50	290.00	30.00	72.50
Dry Season 75th Percentile	30	353.62	354.63	230.00	30.00	1600.00	130.00	500.00
Dry Season 90th Percentile	30	719.95	665.39	550.19	78.42	2948.46	251.65	843.22

Figure 7-12 illustrates the common trend observed with respect to subwatershed imperviousness (%TIA) and the FC geometric mean of individual streams (using the full 2000-2003 data set). As would be expected, stream FC levels tend to be lower where there is greater retention of natural forest cover (percentage of forest) in the upstream watershed (Figure 7-13). Neither of these relationships was found to be statistically significant, but both exhibit a distinct nonlinear trend and both appear to have some interesting relative thresholds of impact with respect to FC WQS. At the lower (undeveloped-rural) end of the development spectrum (%TIA is less than 10%), there are no violations of Part I of the freshwater FC WQS, with the geometric mean for all streams less than 100 cfu/100 mL (Figure 7-12). At the highest (suburban-urban) level of development (%TIA is greater than 40%), all streams are in violation of the WQS (greater than 100 cfu/100 mL). In the middle-range of development (rural-suburban), violations of Part I of the freshwater FC WQS are present, but not common. As has been established, streams draining these moderately developed watersheds have a number of potential bacterial contamination sources associated with a variety of human activities and land uses, but they also have a considerable amount of natural areas (e.g., forests, wetlands, and riparian corridors) still intact. As can be seen from Figure 7-13, retention of natural forest appears to have a mitigating effect on the bacterial pollution levels. In stream watersheds where at least 60% of the native forest is still intact, there were no chronic violations of the freshwater FC WQS (less than 100 cfu/100 mL).

The number of WQS violations is also correlated with the level of development (%TIA) in stream subbasins (Figure 7-14). Using Part II of the freshwater FC WQS as an indicator of water-quality degradation, there appears to be a linear relationship between imperviousness (%TIA) and violations of the WQS (more than 10% of samples have greater than 200 cfu/100 mL). The data indicate that peak violations of WQS are likely in almost all urbanizing watersheds under current development practices.

In summary, it appears that violations of Part I WQS are common when the contributing subbasin imperviousness (%TIA) is greater than 10%, which is typically in the transition zone between rural and suburban land use. Part I WQS violations become almost inevitable when the %TIA is greater than 40%, which is generally thought of as the demarcation between suburban and urban levels of subbasin development. There also appears to be a shift in water quality that corresponds to the loss in native forest cover caused by development. This occurred in the study at a level of approximately 60% forest. These apparent "threshold-ranges" (no distinct thresholds were indicated in the data) are similar to those identified in other studies relating bacterial pollution to watershed land use or development intensity (Young and Thackston 1999; Smith et al. 2001; Frenzel and Couvillion 2002; Tuford and Marshall 2002; Alberti and Bidwell 2004), as well as to research findings related to water quality, biological integrity, and habitat quality in the Puget Sound region (May et al., 1997a, b; Horner and May 1999; Alberti and Bidwell 2004).

Generally, the number of bacterial WQS violations and the level of bacterial contamination in streams are greater as subwatershed development increases. This relationship holds relatively constant for the composite data analysis (using all available data regardless of season) or for the seasonal (wet, dry, or storm event) data analyses (Figures 7-15 and 7-16). Figures 7-17 and 7-18 illustrate these relationships and correlations for storm-event data only. Figures 7-19 and 7-20 show wet-season data and Figures 7-21 and 7-22 show the dry-season data. In addition to the relationship between stream watershed development and bacterial pollution described above, it appears that the level of FC contamination is greater and violations of WQS are more common during the dry season. This conclusion is in agreement with the findings of the most recent KCHD WQ analysis and report (KCHD 2004). Based on past experience, KCHD has found that failing OWTS and/or leaking sewer infrastructure are the most likely FC sources during the dry season. In contrast, stormwater runoff-related sources tend to dominate during wet-weather conditions, and especially during storm events.

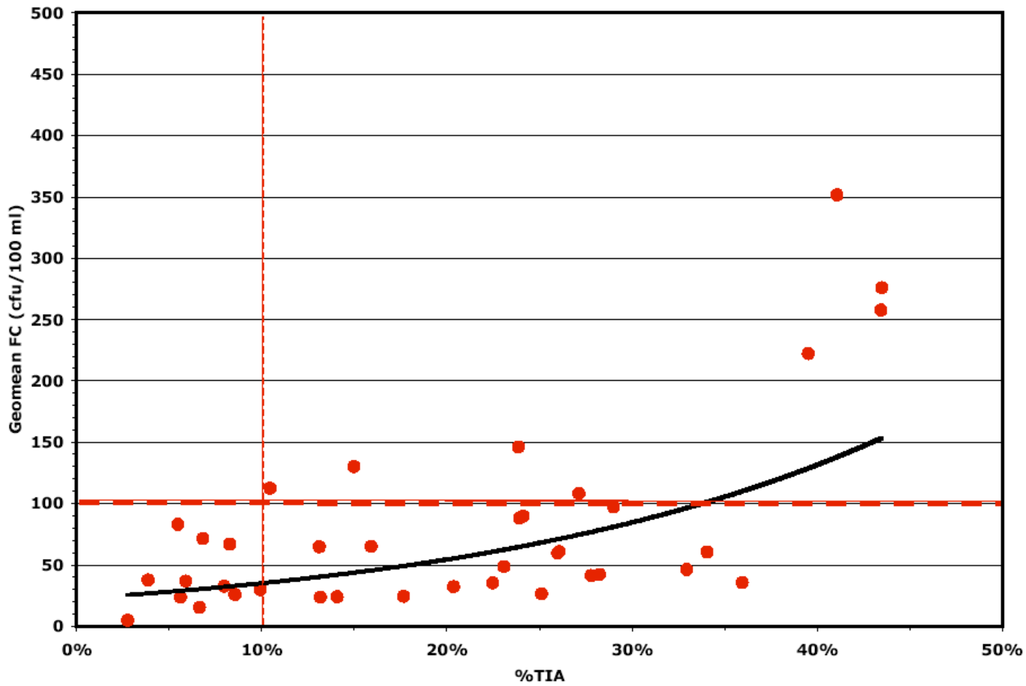


Figure 7-12. The Relationship Between the Level of Watershed Development, as Measured by Total Impervious Area, and Cumulative Stream Fecal Coliform Levels (Geometric Mean) in the Sinclair-Dyes Inlet Watershed. Dataset includes all historical fecal coliform data.

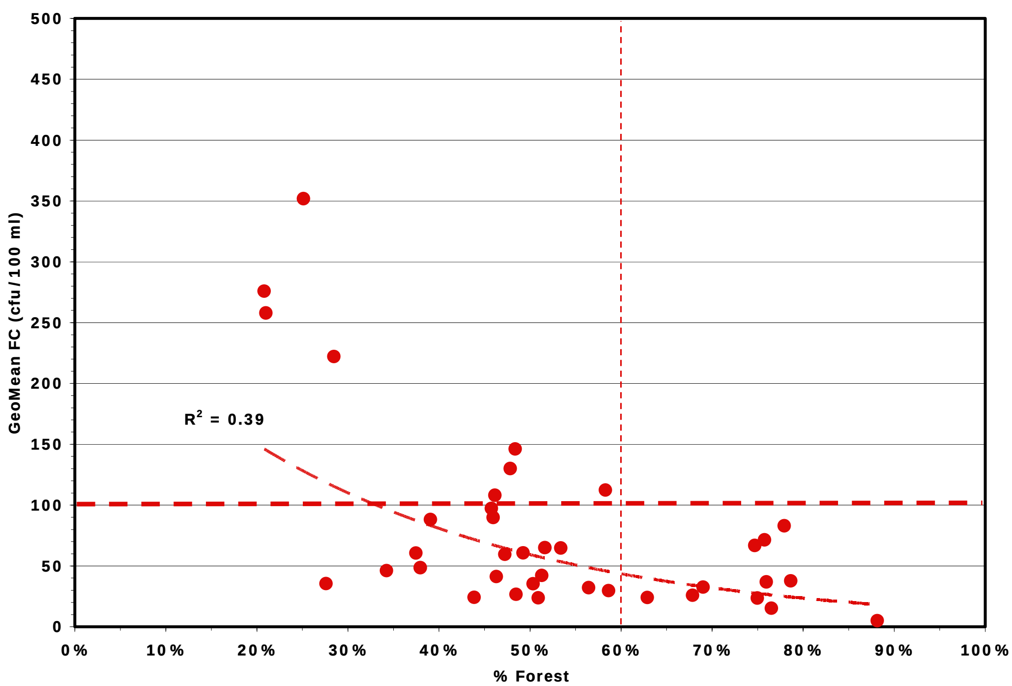


Figure 7-13. The Relationship Between Sub-Watershed Forest Cover and Cumulative Stream Fecal Coliform Levels (Geometric Mean) in the Sinclair-Dyes Inlet Watershed. Dataset includes all historical fecal coliform data.

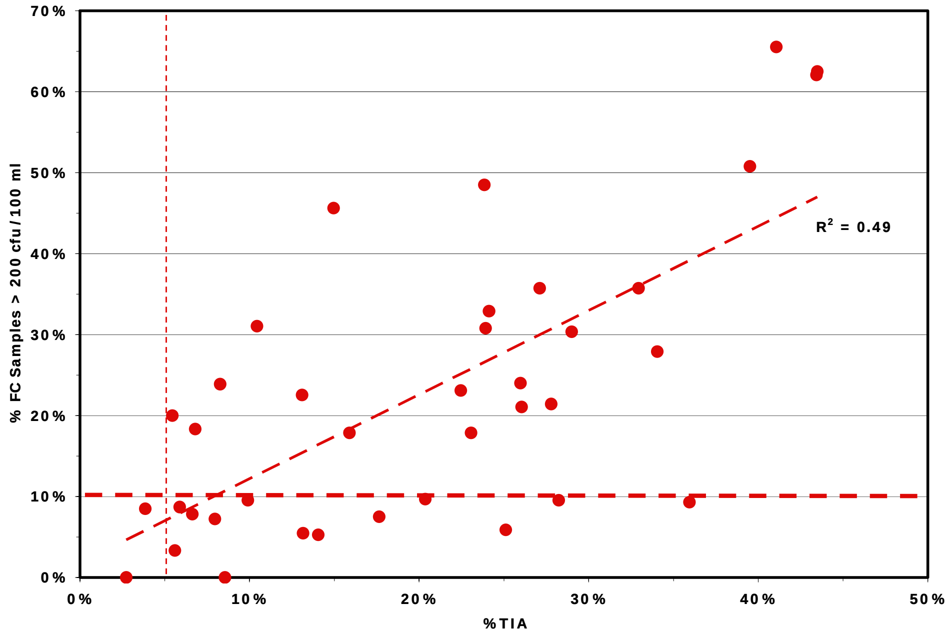


Figure 7-14. The Relationship Between the Level of Watershed Development, as Measured by Total Impervious Area , and Cumulative Water Quality Standard Violations (Percentage of Fecal Coliform Samples Greater than 200 cfu/100 mL) in the Sinclair-Dyes Inlet Watershed. Dataset includes all historical fecal coliform data.

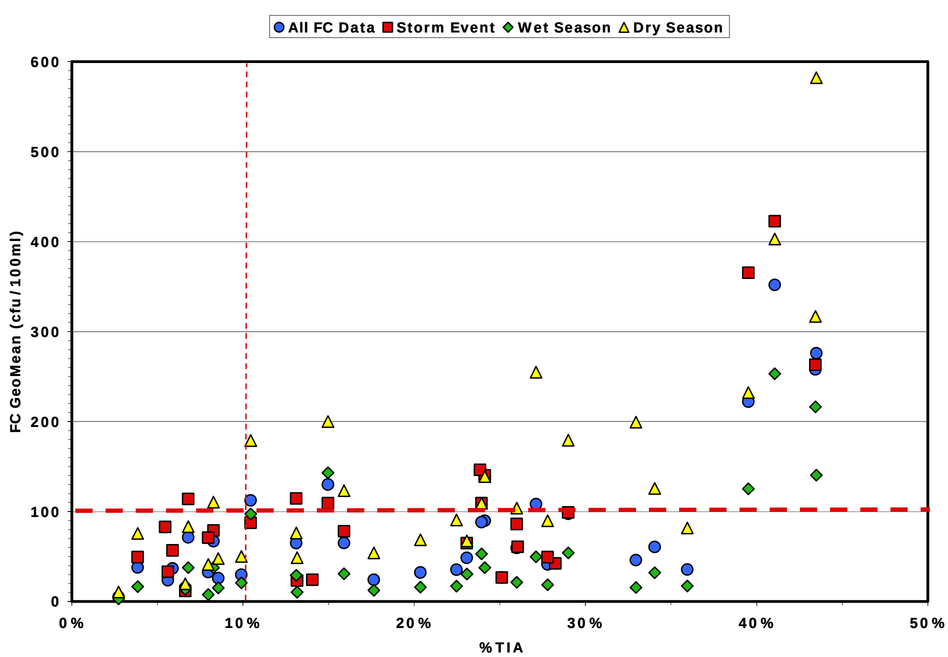


Figure 7-15. The Relationship Between the Level of Watershed Development, as Measured by Total Impervious Area, and Stream Fecal Coliform Levels (Geometric Mean) in the Sinclair-Dyes Inlet Watershed. Dataset is segregated by wet season, dry season, and storm events.

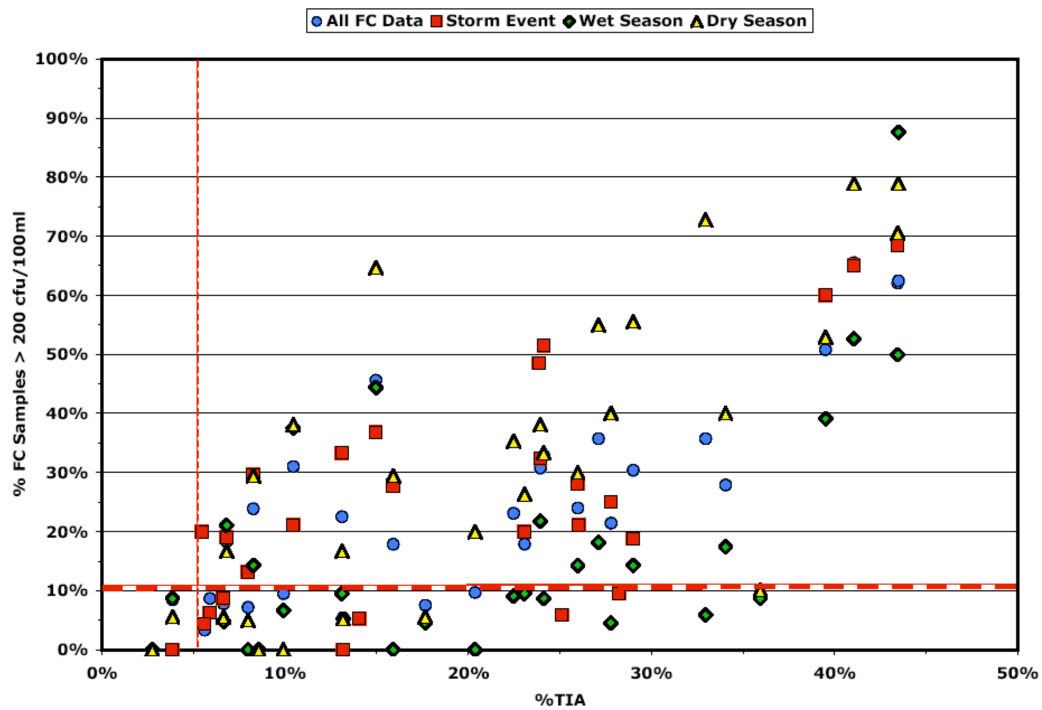


Figure 7-16. The Relationship Between the Level of Watershed Development, as Measured by Total Impervious Area, and Water Quality Standard Violations (Percentage of Fecal Coliform Samples Greater than 200 cfu/100 mL) in the Sinclair-Dyes Inlet Watershed. Dataset is segregated by wet season, dry season, and storm events.

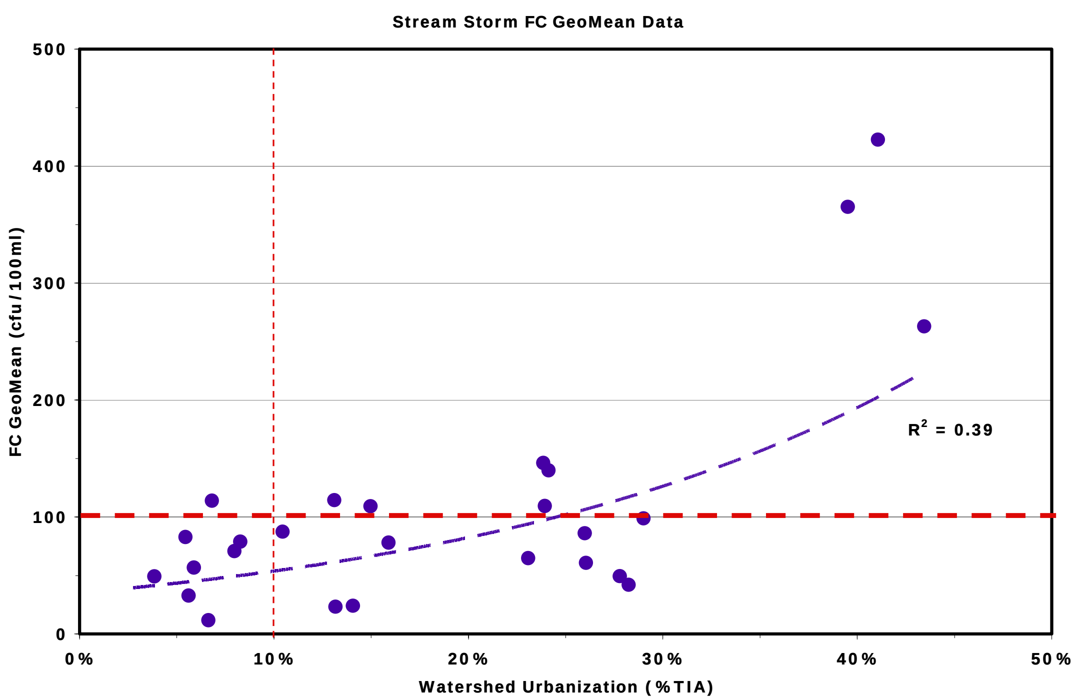


Figure 7-17. Storm-Event Fecal Coliform Geometric Mean Data in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

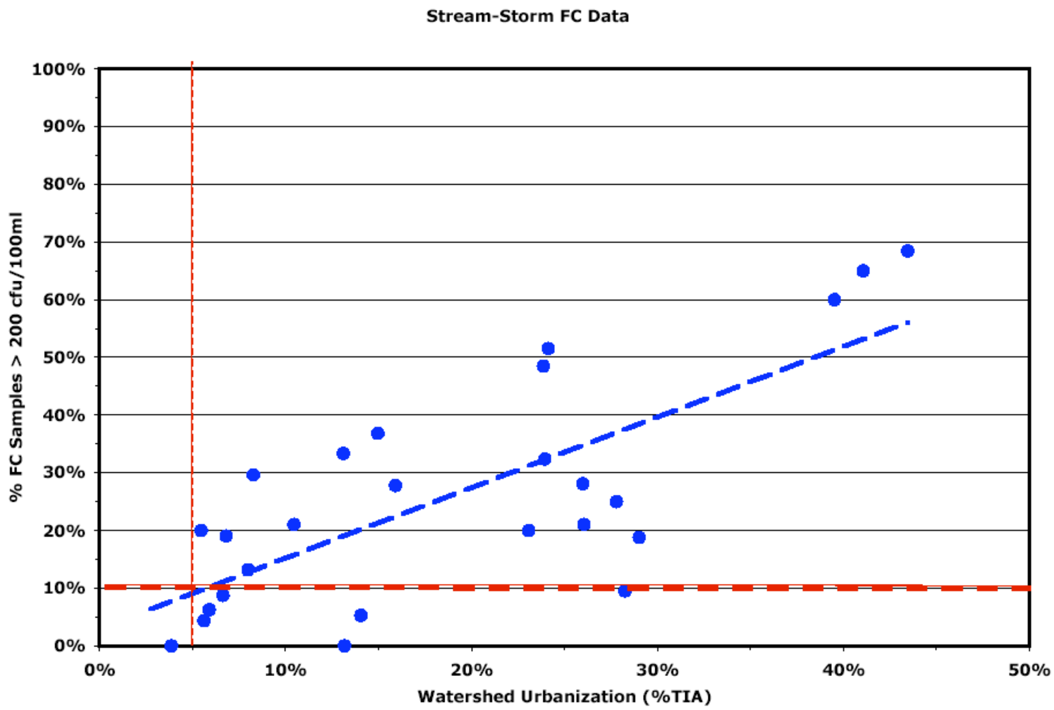


Figure 7-18. Storm-Event Fecal Coliform Water-Quality Standard Violations in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

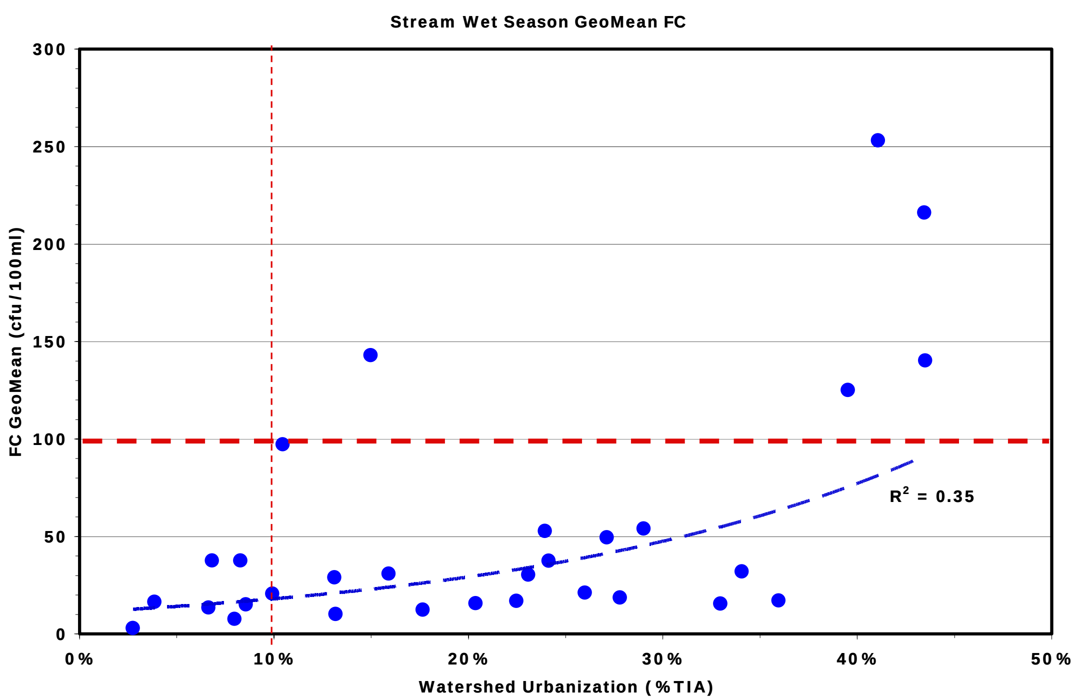


Figure 7-19. Wet Season Fecal Coliform Geometric Mean Data in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

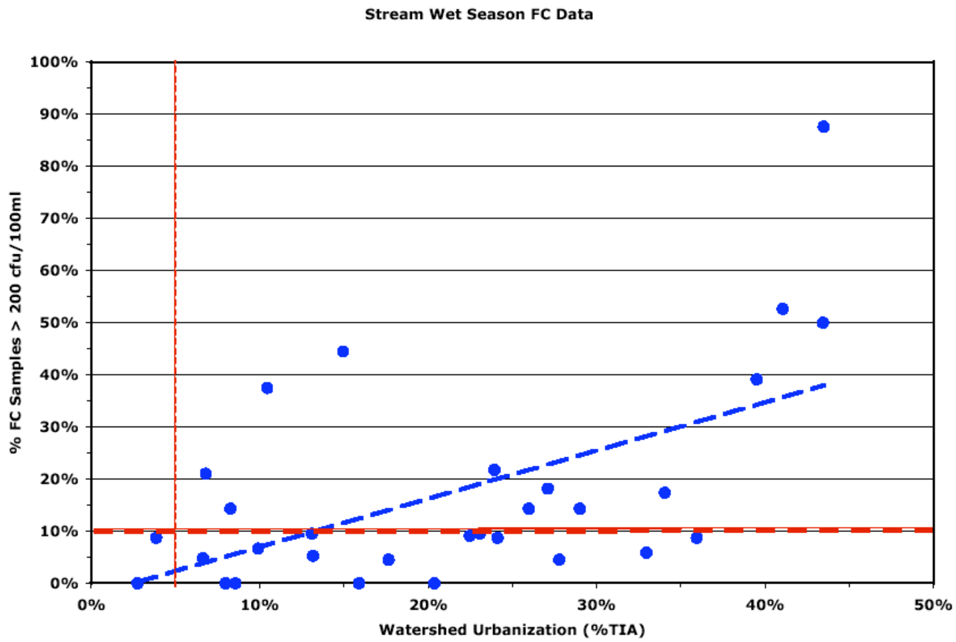


Figure 7-20. Wet Season Fecal Coliform Water-Quality Standard Violations in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

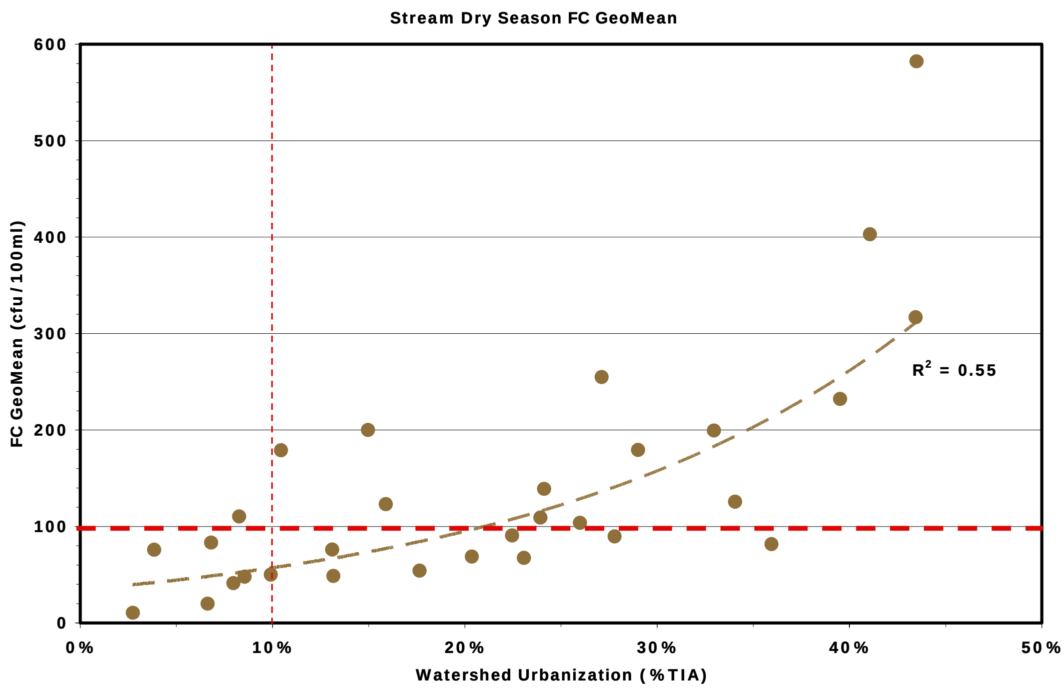


Figure 7-21. Dry Season Fecal Coliform Geometric Mean Data in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

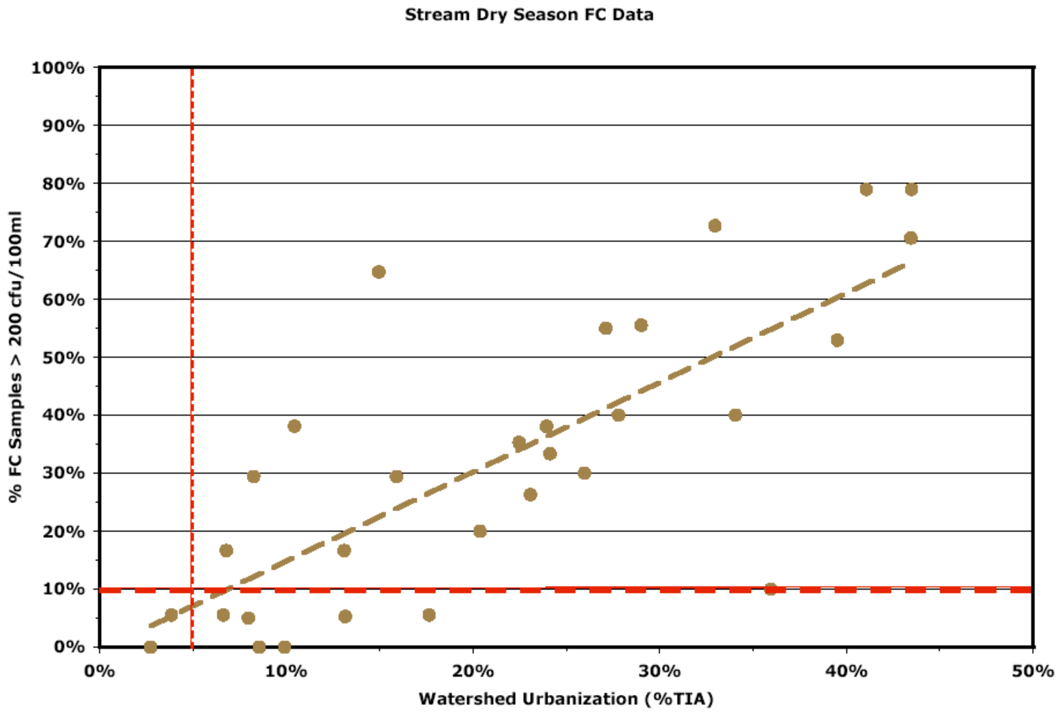


Figure 7-22. Dry Season Fecal Coliform Water-Quality Standard Violations in Comparison to the Level of Stream Subbasin Development, as Measured by Total Impervious Surface Area

Although %TIA is generally a good overall measure of watershed urbanization, it is sometimes too broad in that the individual influences of specific LULC components are not observable. Therefore, based on the previously observed relationships between landscape imperviousness and the FC metrics, an investigation as to what correlations might exist between the level of microbial pollution and individual LULC classes was the next logical step.

Figures 7-23 through 7-26 show the geometric mean FC correlated with land-use classes for all sampled streams in the study area. There are a few strong (direct) correlations (r>0.60) between several measures of overall watershed development, such as total impervious area (%TIA), urban or HD residential development, commercial-industrial development, and road density (total length of roads per basin area). The more urbanized land-use classes (HD residential, commercial, and industrial) show a close relationship with FC levels under all environmental conditions, whereas there is less correlation with less-urbanized land-use categories (suburban and rural). As would be expected, these findings reinforce the conclusions developed in the previous discussion related to imperviousness. However, the correlations between FC level and the individual land-use classes are much stronger than those related to imperviousness. This observation also follows from what is known about the sources of bacterial pollution and how those sources tend to vary as land-use changes.

As would be expected, the fraction of natural, vegetated landscape (e.g., the percentage of forest and coniferous forest) is also strongly (inversely) correlated with FC level in streams. This observed relationship confirms what has been found elsewhere (CWP 1999): natural systems are able to attenuate bacterial pollution much better than can developed watersheds, which reaffirms the benefit of retaining natural vegetative and forest cover in watersheds even when developed. As can be seen from the plots, the FC-LULC relationships hold for wet and dry seasons, as well as for storm events.

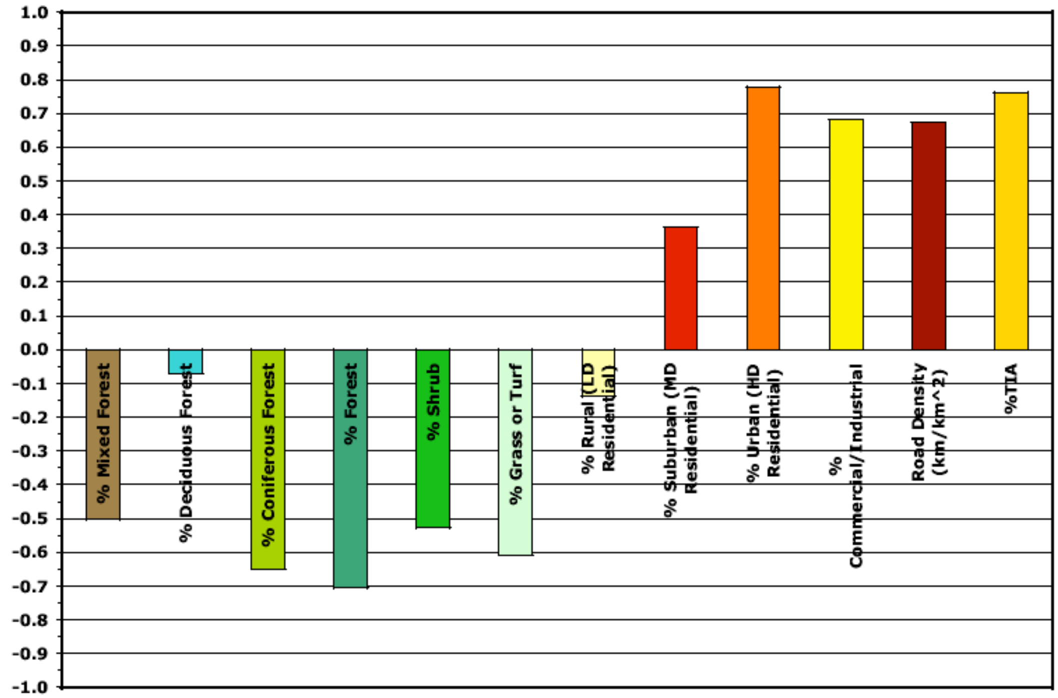


Figure 7-23. Correlation Coefficients for the Cumulative Fecal Coliform Geometric Mean Data in Comparison to Stream Subbasin Land-Use and Land-Cover Metrics

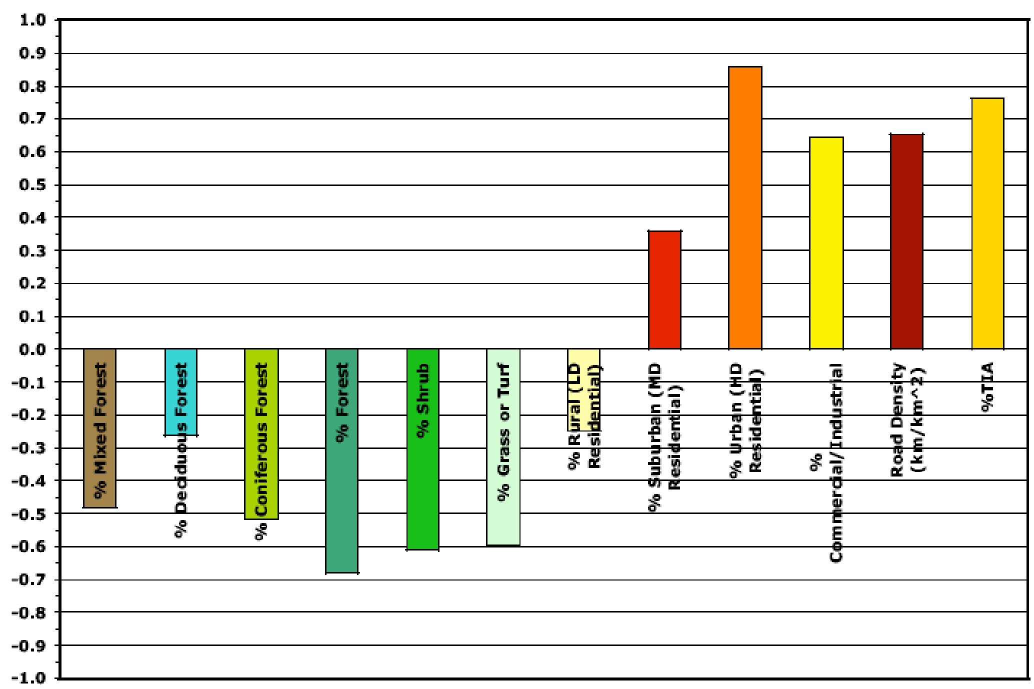


Figure 7-24. Correlation Coefficients for the Storm-Event Fecal Coliform Geometric Mean Data Compared with Stream Subbasin Land-Use and Land-Cover Metrics

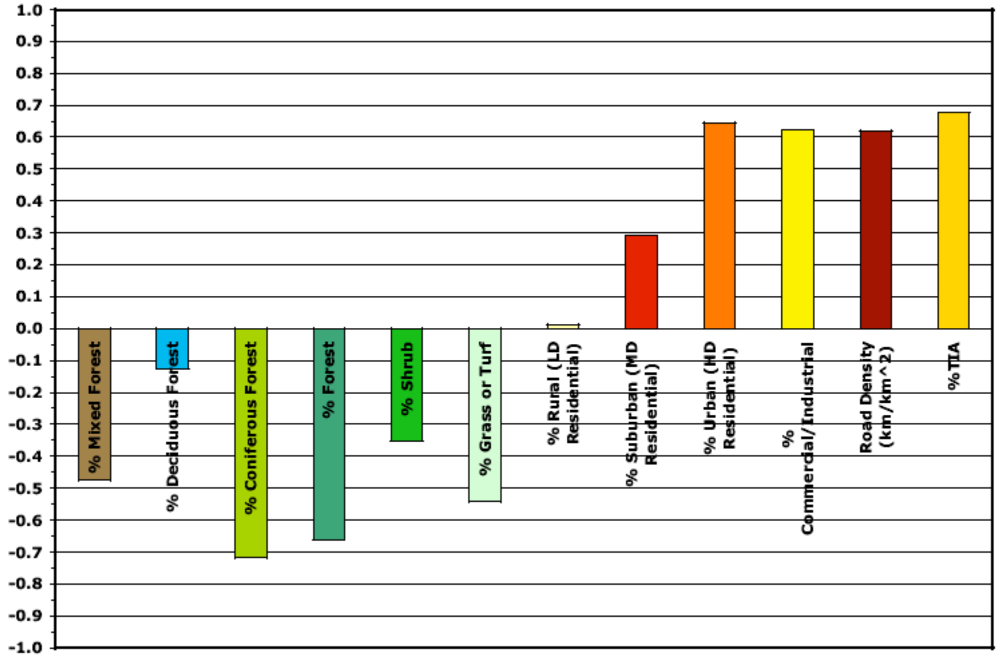


Figure 7-25. Correlation Coefficients for the Wet-Season Fecal Coliform Geometric Mean Data Compared with Stream Subbasin Land-Use and Land-Cover Metrics

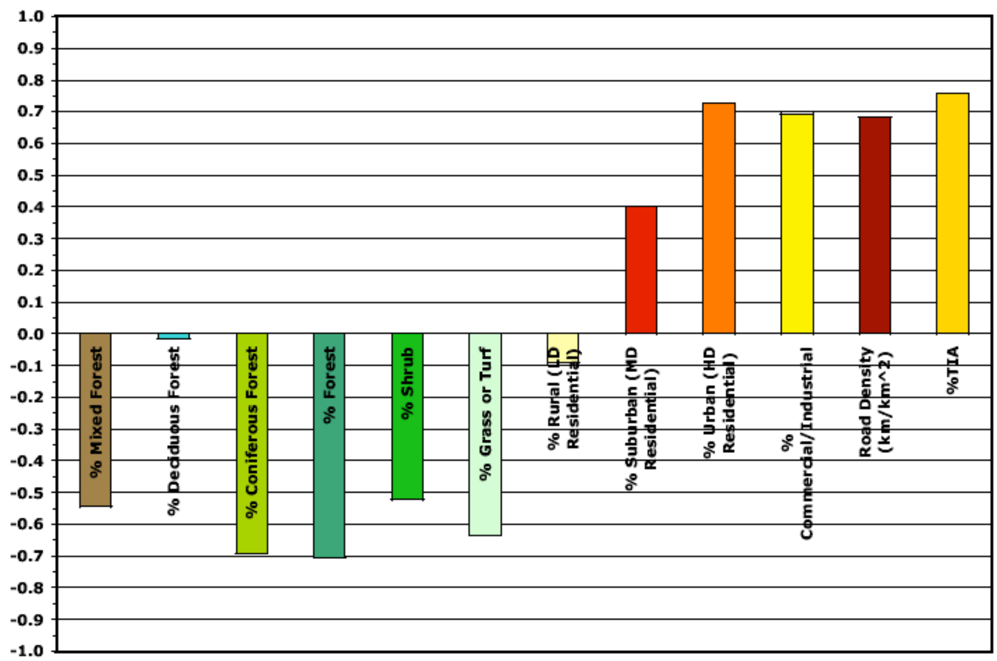


Figure 7-26. Correlation Coefficients for the Dry-Season Fecal Coliform Geometric Mean Data Compared with Stream Subbasin Land-Use and Land-Cover Metrics

In addition to the landscape-scale LULC-FC relationships, there is also a correlation between FC levels and the quality of the riparian buffer zone maintained around streams. Figure 7-27 shows that, in general, FC levels are lower when there is a greater proportion of native vegetation, especially coniferous-dominated forest, within the riparian buffer zone. This same relationship is not as strong for buffers dominated by deciduous or mixed riparian forest, indicating that the quality of the riparian buffer may be as important as the extent (width) in maintaining instream water quality. In the Pacific Northwest, coniferous vegetation provides extensive rainfall interception and evapotranspiration during the fall-winter wet season. This reduces the amount of water that reaches the ground, thus reducing the potential runoff quantity in developing watersheds. In addition, coniferous vegetation in riparian corridors can provide significant, natural year-round filtration of runoff. The lack of a stronger correlation between FC metrics and riparian buffer metrics could also be an artifact of the 30-m resolution of the satellite imagery used to determine vegetation composition. At this resolution, misclassification of pixels is relatively common. The use of a higher resolution LULC dataset may provide a better comparison for future projects.

During the 2002-2003 storm season, TEC conducted in-stream storm sampling in the major stream subbasins of the Sinclair-Dyes Inlet watershed. A total of 11 sampling sites were monitored during 7 discrete storm events during the 2002-2003 storm season. A minimum of three storm events were sampled for each stream sample site. Storm-event criteria specified that rainfall for each "qualifying" storm event was greater than 0.25 inches. A total of 137 FC samples were collected. In addition, 193 composite sample bottles were collected for analysis of other conventional water-quality constituents. For the 2002-2003 storm season, the calculated average storm-event FC concentration (geometric mean) at 7 of the 11 sampling sites (OC, SC, CE, CC, BA, CW, and BL) did not meet bacterial WQS. Conversely, only four sampling sites (AC, GC, CH, and CT) did meet WQS.

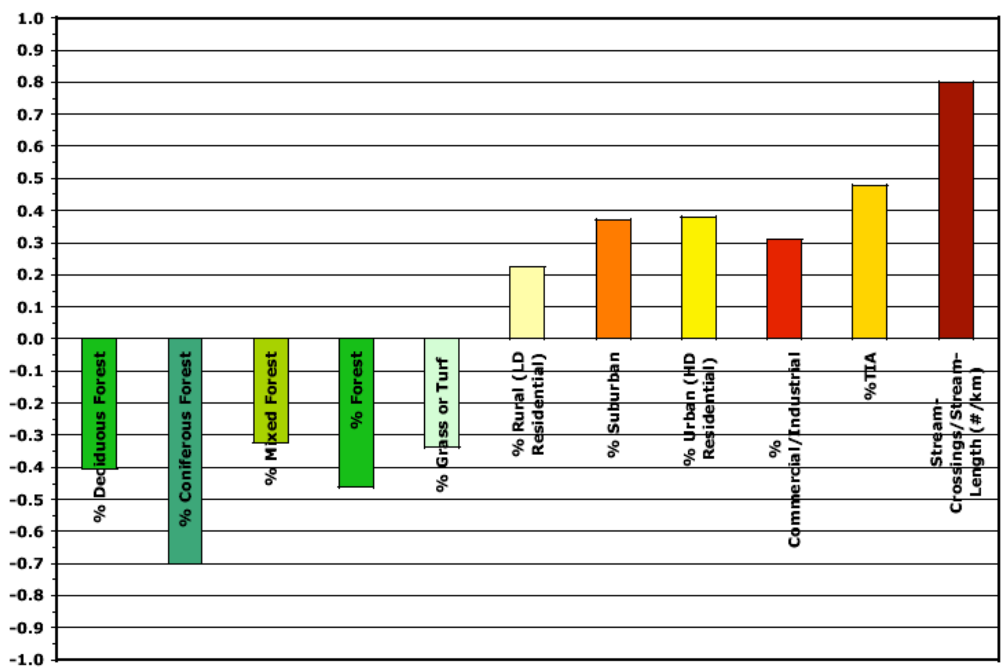


Figure 7-27. Correlation Coefficients for the Cumulative Fecal Coliform Geometric Mean Data Compared with Stream Riparian (50-Meter Buffer) Land-Use and Land-Cover Metrics

In previous research, there has been some indication that FC levels in streams tended to be greatest during the peak in streamflow during storm events (Olyphant et al., 2003). Although this phenomenon was observed in several instances, it was not always the case for storm events monitored during this project. In some cases, FC concentrations displayed a strong first-flush effect during several of the storm events, especially those storms that were preceded by longer between-storm (antecedent) dry periods. However, other sites did not display a first-flush effect and, in some instances, FC concentrations peaked at the end of the storm event. Research in other regions of the U.S. (summarized in Pitt et al., 2004) has shown that FC levels generally do not display a first-flush characteristic except in highly impervious subbasins where source areas are directly connected to stormwater collection and conveyance systems. Based on this information, the timing of the first sample collection may be important. From the limited numbers of storms sampled for this study, it appears that FC concentrations do not rise above wet-season baseflow concentrations until there is greater than 0.10 inch of cumulative rainfall. It is, therefore, recommended that future sampling efforts wait to take the first round of FC samples until this level is reached. This information was factored into the 2004-2005 storm-event sampling scheme. Data from those samples are not included in this study, but will be used for model verification.

In general, for the 2002-2003 storm season in Sinclair-Dyes Inlet streams, FC samples taken during storm events tended to track with turbidity and streamflow (TEC 2003). Research has shown that the turbidity levels can influence storm-event FC levels because of the affinity of bacteria for fine particulate organic matter (Pitt et al., 2004). Heavy streambed scour and streambank erosion could potentially result in higher FC-particulate levels as bacteria is mobilized from sediment and attaches to particulate material entrained in the flow (Sherer et al., 1992; Davies et al., 1995; Francy et al., 2000; Olyphant et al., 2003). Streambank erosion and streambed scour are typically more severe in more urbanized stream subbasins because of higher runoff-driven stormflows created by the greater impervious surface area (May et al., 1997a, b). Also, sediment source areas of bacteria are likely more common in urbanized watersheds because of the greater number and variety of potential sources.

An analysis of rainfall patterns during the 2002-2003 storm season was conducted to determine whether the storm events that were monitored were representative of typical storm seasons for the study area over the long term (Halkola 2004). Rainfall data were available from 13 rain gages located throughout the study area. Rainfall events were classified based on their recurrence interval or probable frequency of occurrence (i.e., 2-, 5-, 10-, 25-, 50-, and 100-yr events), which is common practice for quantifying storm events. Historical rainfall data for the Kitsap Peninsula were then compared with the data for the 2002-2003 storm season. This comparison indicated that the 2002-2003 storm season was within the typical distribution of storms with respect to total rainfall and average storm intensity (Halkola 2004).

Although no statistically significant relationships between rainfall quantity, rainfall intensity, and ADP were found during this study, there were some consistent trends observed (Figures 7-28 and 7-29). Watersheds within the project area appear to reach their maximum storm-flow FC concentrations after an ADP of approximately 7 days, and higher rainfall events (wetter storms) result in higher FC concentrations; therefore, storm-flow FC concentrations appeared to peak from a 24-hour storm producing at least 3 inches of rainfall with an ADP of approximately 7 days (TEC 2003). Figure 7-30 shows sampled storm events and Figure 7-31 summarizes the FC data collected. Figures 7-32 through 7-37 illustrate the typical water quality collected for each storm event.

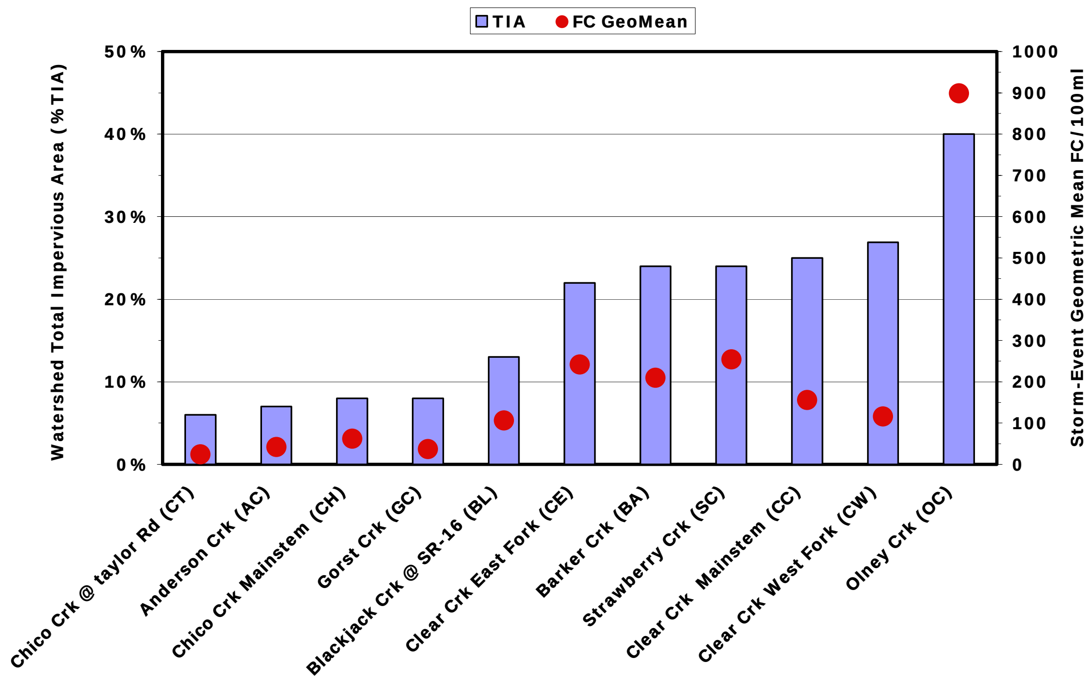


Figure 7-28. The Relationship Between the Level of Watershed Development, as Measured by Total Impervious Area, and the Average Storm-Event Geometric Mean Fecal-Coliform Level Based on Three Individual Storm-Event Samples for Each Stream Site (TEC 2003)

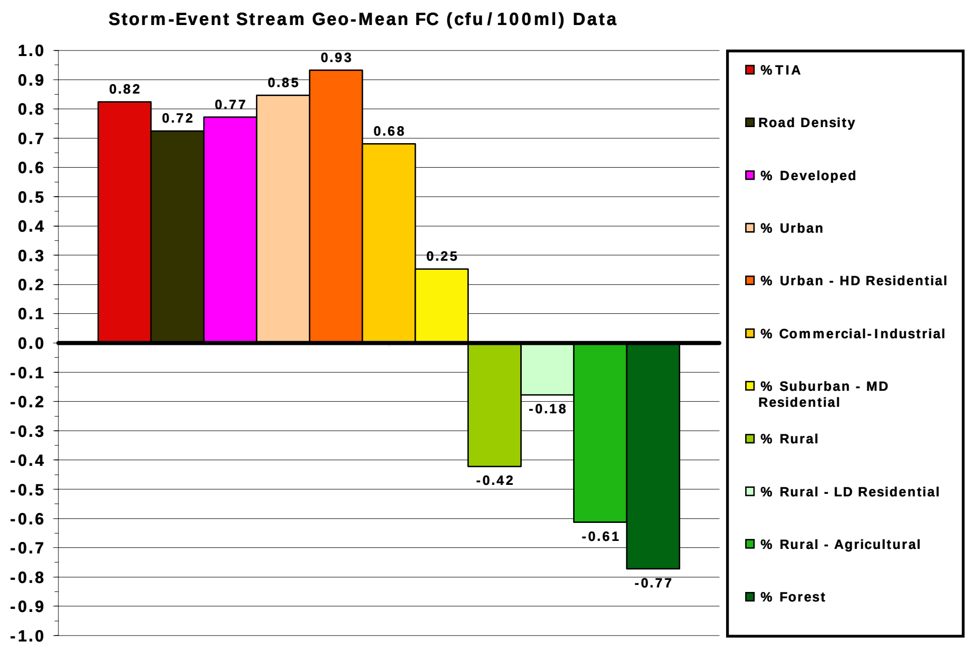


Figure 7-29. Correlation Coefficients for 2002-2003 Storm-Event Stream Fecal Coliform Data and Land-Use and Land-Cover Metrics

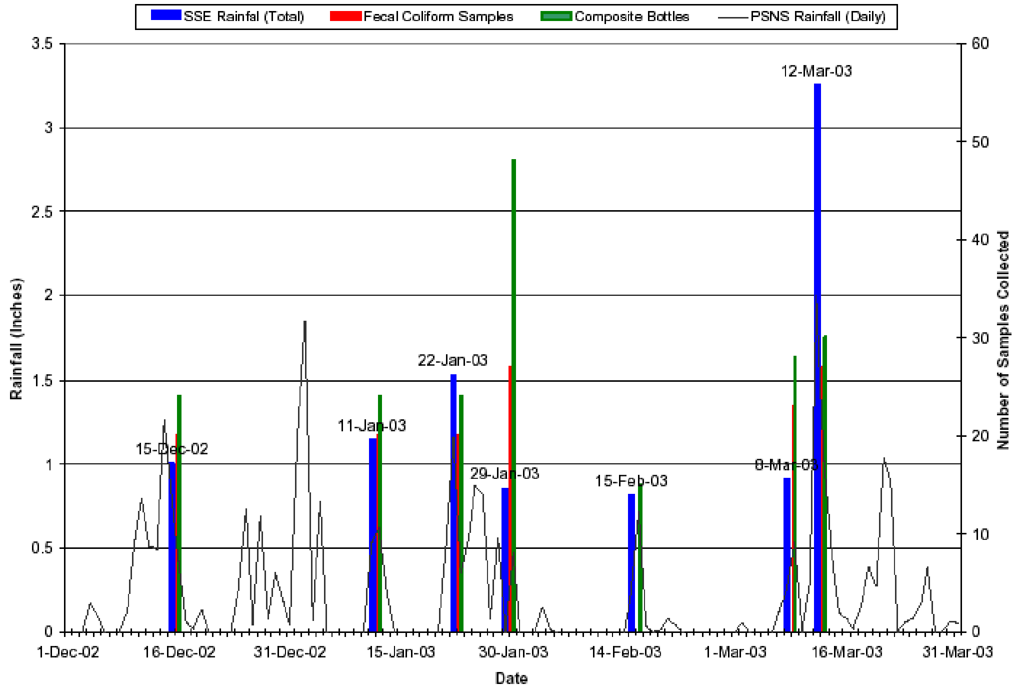


Figure 7-30. 2002-2003 Storm Season Storm-Event Sampling Summary (TEC 2003)

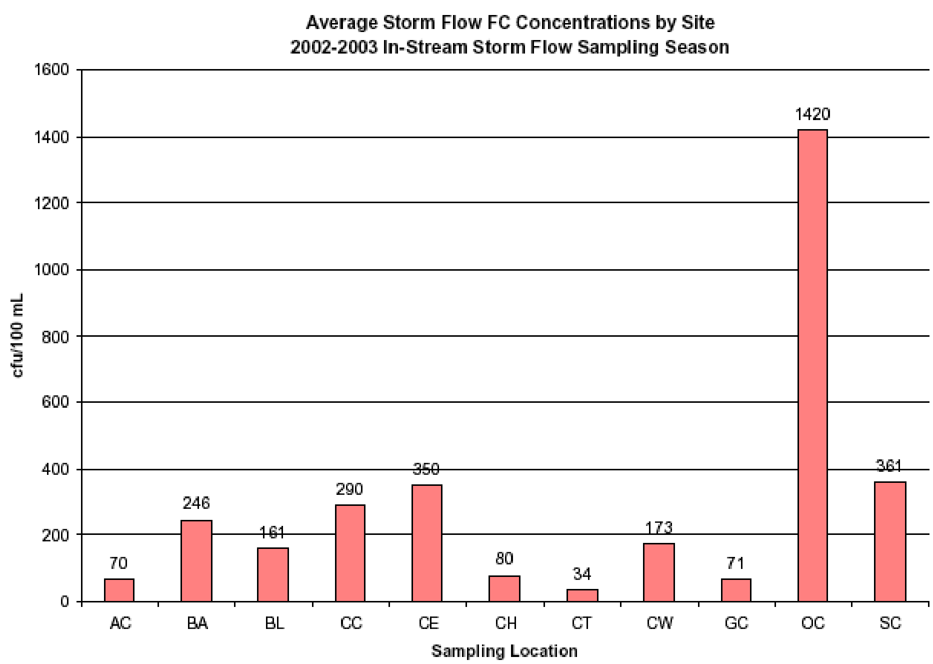


Figure 7-31. 2002-2003 Storm Season Storm-Event Fecal Coliform Data Summary (TEC 2003)

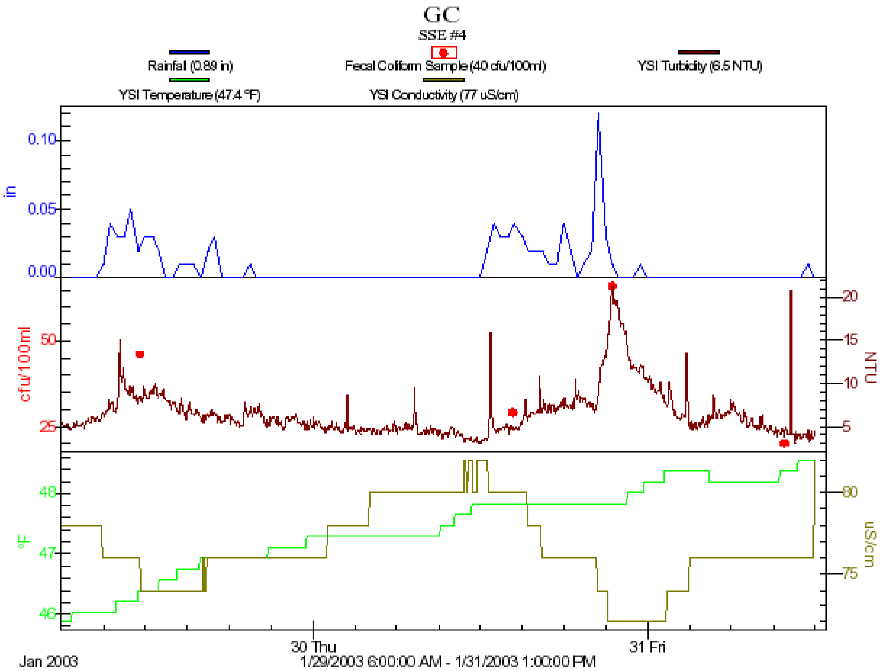


Figure 7-32. Example Storm Event from 2002-2003 Storm Season (TEC 2003)

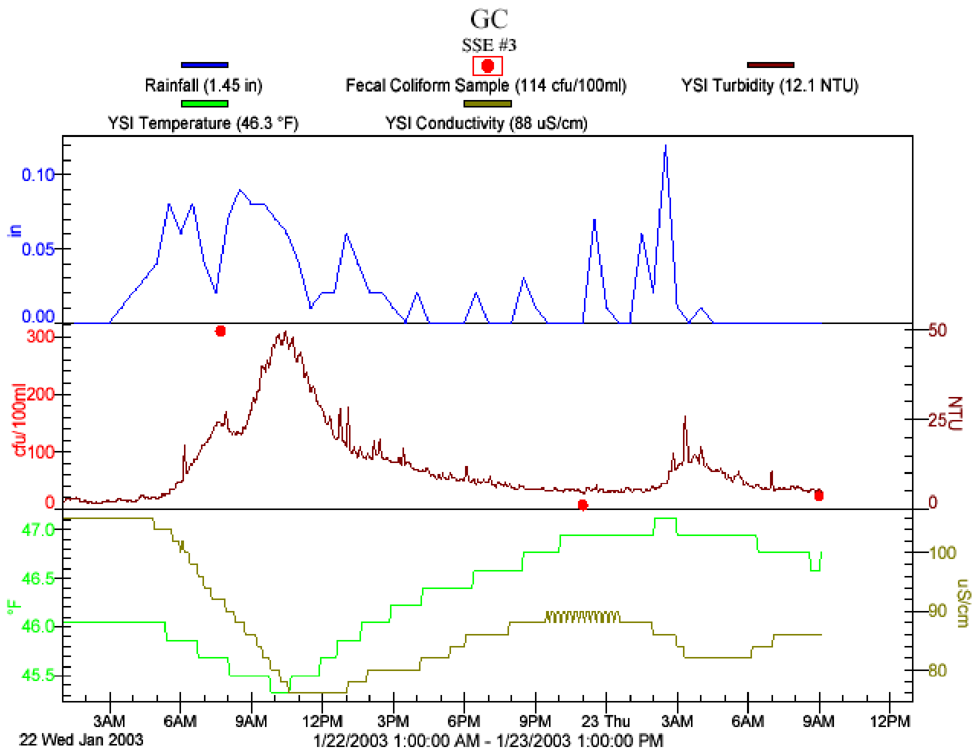


Figure 7-33. Example Storm-Event from 2002-2003 Storm Season (TEC 2003)

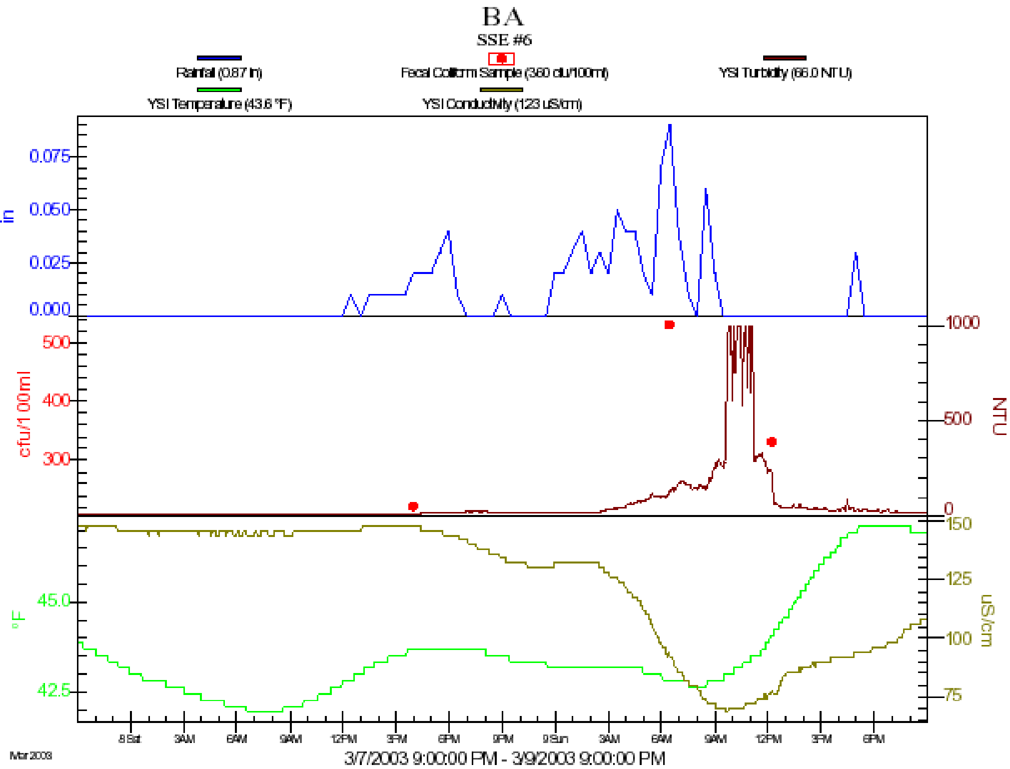


Figure 7-34. Example Storm-Event from 2002-2003 Storm Season (TEC 2003)

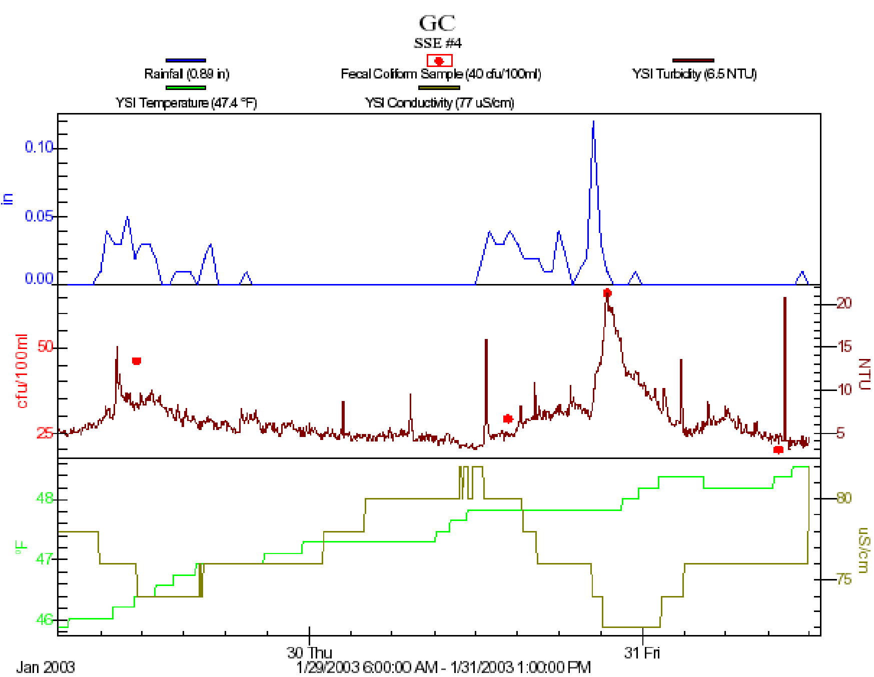


Figure 7-35. Example Storm Event from 2002-2003 Storm Season (TEC 2003)

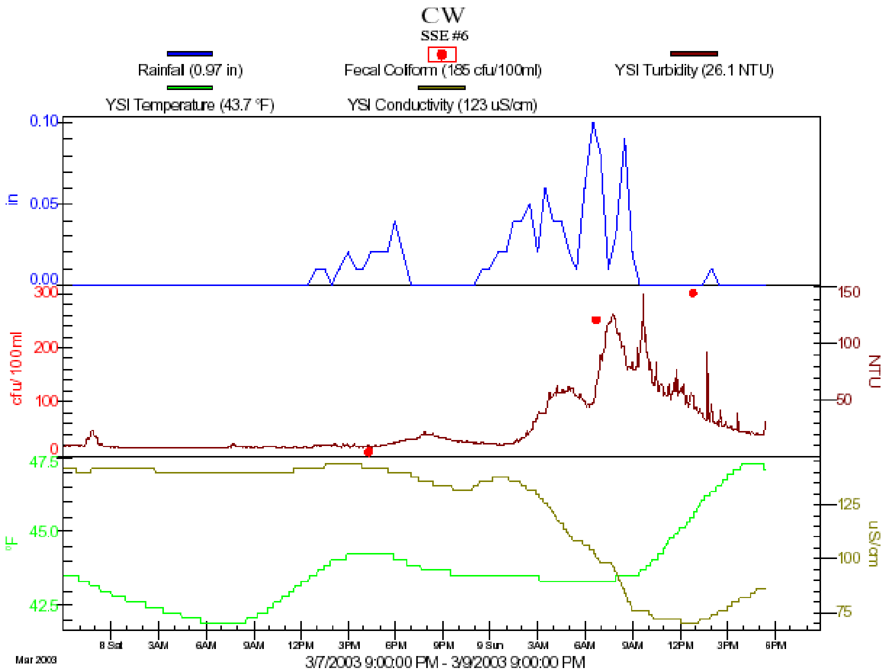


Figure 7-36. Example Storm Event from 2002-2003 Storm Season (TEC 2003)

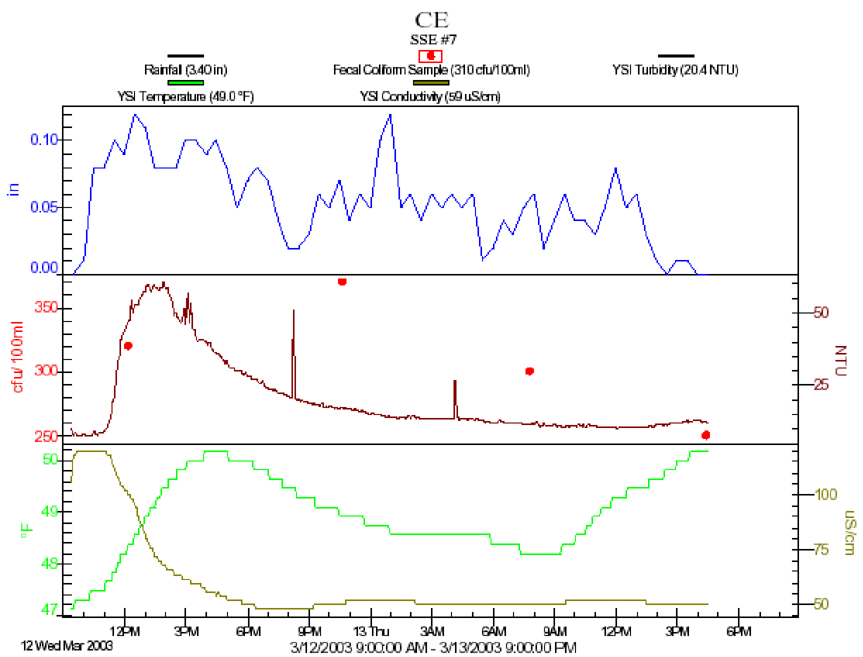


Figure 7-37. Example Storm Event from 2002-2003 Storm Season (TEC 2003)

During this study, FC storm-event concentrations were generally higher a) in more urbanized watersheds (%TIA greater than 40%), b) during larger storm events (greater than 3 inches of rainfall in 24 hours or a 5-year storm event), and c) when the storm was preceded by an extended (5 to 7 days) ADP (TEC 2003). Although the relationships among these factors are not yet completely understood, these conditions could be thought of as "worst-case" scenarios that combine in a complex way to drive bacterial pollution loading in streams. The results of the preceding analysis underscore the earlier findings that link higher FC levels with greater impervious surfaces in more urbanized watershed conditions and their engineered stormwater conveyance systems. Larger rainfall events following a long ADP, falling on highly impervious areas with a piped stormwater network, could very likely result in transient high bacterial loading to streams draining these urbanized areas. As the next section will show, what is true for urban streams can also be true for these engineered stormwater systems as well.

In summary, an analysis of storm-event FC data for the 2002-2003 storm season sampling period shows a relationship between %TIA and other measures of watershed land use (especially HD urban residential land use) and FC levels during the storm event (see Figure 7-24). These findings are similar to those found by researchers in other parts of the U.S. (Young and Thackston 1999; Frenzel and Couvillion 2002; Tuford and Marshall 2002; Olyphant et al., 2003). The typical pattern that is seen with FC levels in highly urbanized stream subbasins is that large storm events following a relatively long (between-storm) ADP tend to generate the highest FC levels in the stream. Bacterial contamination in urbanizing streams can come from a variety of sources, including failing OWTS and sanitary sewer leaks or spills where these systems are present (Weiskel et al., 1996; Frenzel and Couvillion 2002; Olyphant et al., 2003). Other urban FC sources include wash-off of pet waste from turf areas into storm drains, runoff of manure from domestic animals, and urban wildlife.

In conclusion, microbial pollution is currently a problem in several of the streams that drain into Sinclair-Dyes Inlet. Three streams (Olney or Karcher, Oyster Bay, and Dee Creeks) in the watershed have been posted to warn people of the risks involved with water contact (KCHD 2004). Other streams in the watershed do not meet bacterial WQS but are not considered as severely contaminated. Most of these problem streams violate WQS during the dry season, but several are also in violation of WQS during the wet season. Most of these WQS problems are violations of Part II of the WQS (more than 10% of samples have greater than 200 cfu/100 mL), but there are also a number of violations of Part I (geometric-mean is greater than 100 cfu/100 mL) of the bacterial WQS. The storm sampling conducted during this project also indicates that most developed streams in the watershed violate WQS during storm events, some showing very high FC levels.

Based on the FC data collected in the Sinclair-Dyes Inlet watershed, the following observations with regard to the relationship between development and bacterial pollution can be made:

- There were no violations of Part I of the WQS for stream subbasins with less than 10%TIA (Figure 7-12), nor were there any Part I WQS violations for streams subbasins that retained greater than 60% of their native forest cover (Figure 7-13).
- All highly developed (greater than 40%TIA) stream-watersheds had FC geometric-mean levels in violation of the WQS (Figure 7-12).
- There is a solid linear correlation (with no threshold) between the level of stream-watershed development (%TIA) and the frequency of violations of bacterial WQS (Figures 7-14, 7-16, 7-18, 7-20, and 7-22).
- These relationships also hold for seasonal water-quality data, including wet-season (Figures 7-19 and 7-20) and dry-season (Figures 7-21 and 7-22) conditions.

- Storm-event FC data collected during this study also show a similar relationship (Figures 7-17 and 7-18).

The majority of violations of Part II (more than 10% of samples have greater than 200 cfu/100 mL) WQS are found in streams where the subbasin imperviousness (%TIA) is greater than 10%. These levels are typically found in the transition zone between rural and suburban land use. In contrast, Part I (geometric-mean is greater than 100 cfu/100 mL) WQS violations are generally found in the more developed subbasins (%TIA is greater than 40%). This level is found in the transition range of development between suburban and urban. There also appears to be a shift in water quality that corresponds to the loss in native forest cover caused by development, which appears to occur when subbasin forest cover drops below approximately 60%.

In general, the number of bacterial WQS violations and the level of bacterial contamination in streams are greater as subwatershed development increases. This relationship holds relatively constant for the composite data analysis using all available data (Figures 7-15 and 7-16). This relationship also applies to storm-event FC levels (Figures 7-17 and 7-18), wet-season FC levels (Figures 7-19 and 7-20), and for dry-season FC levels (Figures 7-21 and 7-22). For most streams with chronic bacterial pollution problems in the study area, it appears that the level of FC contamination is greater and violations of WQS are more common during the dry season. The main source of dry-season bacterial pollution problems is believed to be failing onsite septic systems and/or leaking sewer infrastructure. Livestock, pet, and wildlife waste also are likely contributing sources. Where there are wet-season and storm-event bacterial WQS violations in stream subbasins, bacterial pollution from these same sources, as well as fecal material washed off of impervious areas, is carried into streams by stormwater runoff.

Although bacterial pollution problems do exist in the streams of the Sinclair-Dyes Inlet watershed, the trend for water quality in most streams is improving, primarily because of the effectiveness of several ongoing programs. The key efforts include

- KCHD WQ Monitoring
- The KC-SSWM Program
- KCHD PIC Projects
- KCD Farm Management Plans.

Although these programs appear to be making a difference, work still needs to be done. More emphasis on source control, enhanced stormwater treatment, improvements in wastewater-treatment systems, and continued monitoring will be necessary to continue to improve the water quality in the streams of the Sinclair-Dyes Inlet watershed.

7.4 Stormwater Outfall Data Analysis

In addition to watershed drainage via natural stream channels, stormwater runoff from the urbanizing landscape can also be collected and conveyed to receiving waters by a network of stormwater drain inlets, catch basins, piping networks, and outfalls. This engineered or "hard" stormwater infrastructure is common in suburban and urban (medium- to high-density) developments throughout the Puget Sound region, as well as in the majority of the country. The typical stormwater infrastructure found in the Sinclair-Dyes Inlet study area consists of various configurations of curb-and-gutter street design, which drain to catch basins or drain inlets spaced throughout the drainage subbasin. A stormwater conveyance piping network draining individual subbasins typically links these collection points. Older developments may not have as much engineered infrastructure. In older areas, street runoff is often directed into vegetated swales or roadside ditches where it is routed to receiving waters. In some cases, stormwater collection and conveyance networks use urban stream channels for routing stormwater runoff. Some of these streams may actually be routed through stormwater piping and may flow into receiving waters via an outfall. In many urbanizing watersheds, stormwater conveyance systems are a combination of all of these pathways.

Stormwater outfalls, whether draining urbanized (piped) stream channels or engineered stormwater piping networks, are a common feature in the developed landscape. There are usually several outfalls of various sizes that serve each urbanized area. A common trait that stormwater outfalls share with streams draining urbanized watersheds is that higher FC levels in stormwater runoff are generated during large storm events that follow a relatively long (between-storm) ADP (CWP 1999). The longer ADP allows for pollutants (including FC) to build up on impervious areas and within the underground stormwater collection and conveyance system. Larger storms tend to flush more pollutants off impervious surfaces and out of stormwater piping and into receiving waters. In some cases, a “first-flush” effect can be observed in which pollutant loading is higher at the start of the storm due to the initial wash-off from impervious surfaces (CWP 1999). However, recent investigations of the first-flush phenomenon indicate that FC is typically not one of the pollutants that consistently exhibit first-flush characteristics, except in the case of small, well-connected, and highly impervious drainage subbasins (Pitt et al., 2004).

The NSQD contains the most current information on stormwater pollutant characteristics (Pitt et al., 2004). Table 7-2 shows a summary of stormwater data from throughout the U.S. The FC data indicate that there is usually a measurable difference in FC levels from different land-use types, with residential having the highest FC levels and highways the lowest. In general, stormwater FC levels are typically in the thousands or even tens of thousands of counts (cpu/100 mL). Figures 7-38, 7-39, and 7-40 show the NSQD FC data ranges for different land-use types, seasons, and rainfall patterns.

During the 2002-2003 storm season, several stormwater outfalls were sampled for FC pollution during multiple storm events. As is the case with urban streams, research from throughout the country has found that bacterial pollution in stormwater is usually related to watershed development, as measured by the density of development, %TIA, and the type of land uses present in the watershed (Pitt et al., 2004). Sources of bacterial pollution in stormwater include a variety of human and nonhuman sources that tend to be dependent on a number of factors related to land use. Stormwater runoff can be a major conveyance path for FC pollution. Stormwater runoff can also contain human fecal matter from failing OWTS or leaking sanitary sewers, as well as pet waste and fecal material from urban wildlife. In general, these are the same sources that were discussed in the previous section related to stream water quality and bacterial pollution. Figures 7-41 and 7-42 show the LULC characteristics of the outfall subbasins monitored in the Sinclair-Dyes Inlet watershed. The monitored outfalls were selected to be representative of the many stormwater outfalls found throughout the study area. The selection of monitored outfalls was based on subbasin area and land-use composition, as well as on outfall size and geographic location.

During the 2003-2004 storm season, flow measurement devices were installed in a subset of the stormwater outfalls that were sampled during the 2002-2003 storm season. These outfalls also had automated water-quality sampling equipment installed for this period. As part of the overall Sinclair-Dyes Inlet watershed monitoring effort, FC samples were also taken for several storm events in 2003-2004 to add to the existing FC database. The FC samples taken at various points in the storm cycle were used to characterize FC levels for different storms and any intra-storm variability. These additional FC data were collected to help refine the stormwater outfall FC level characterization effort and facilitate a more accurate estimation of loading that can be attributed to “typical” stormwater outfalls. Stormwater outfall sampling continues during the 2004-2005 storm season. The data collected during this period will be used for the watershed model verification process.

Table 7-2. Summary of National Stormwater Quality Database Stormwater Data (Pitt et al., 2004)

Parameter	Overall	Residential	Commercial	Industrial	Freeways	Open Space
Area (acres)	56	57.3	38.8	39	1.6	73.5
% Imperv.	54.3	37	83	75	80	2
Precip. Depth (in)	0.47	0.46	0.39	0.49	0.54	0.48
TSS (mg/L)	58	48	43	77	99	51
BOD5 (mg/L)	8.6	9	11.9	9	8	4.2
COD (mg/L)	53	55	63	60	100	21
Fecal Coliform (mpn/100 mL)	5081	7750	4500	2500	1700	3100
NH3 (mg/L)	0.44	0.31	0.5	0.5	1.07	0.3
N02+NO3 (mg/L)	0.6	0.6	0.6	0.7	0.3	0.6
Nitrogen, Total Kjeldahl (mg/L)	1.4	1.4	1.6	1.4	2	0.6
Phos., filtered (mg/L)	0.12	0.17	0.11	0.11	0.2	0.08
Phos., total (mg/L)	0.27	0.3	0.22	0.26	0.25	0.25
Cd, total (ug/L)	1	0.5	0.9	2	1	0.5
Cd, filtered (ug/L)	0.5	ND	0.3	0.6	0.68	ND
Cu, total (ug/L)	16	12	17	22	35	5.3
Cu, filtered (ug/L)	8	7	7.6	8	10.9	ND
Pb, total (ug/L)	16	12	18	25	25	5
Pb, filtered (ug/L)	3	3	5	5	1.8	ND
Ni, total (ug/l)	8	5.4	7	16	9	ND
Ni, filtered (ug/L)	4	2	3	5	4	ND
Zn, total (ug/L)	116	73	150	210	200	39
Zn, filtered (ug/L)	52	33	59	112	51	ND
ND = not detected, or insufficient data to present as a median value.						

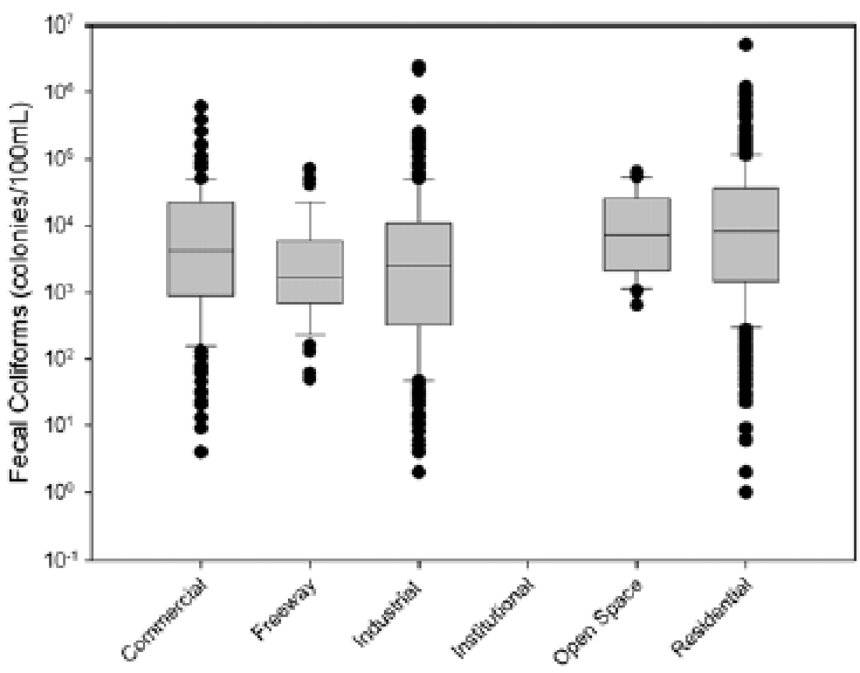


Figure 7-38. National Stormwater Quality Database Fecal Coliform Data for Different Land-Use Types (Pitt et al., 2004).

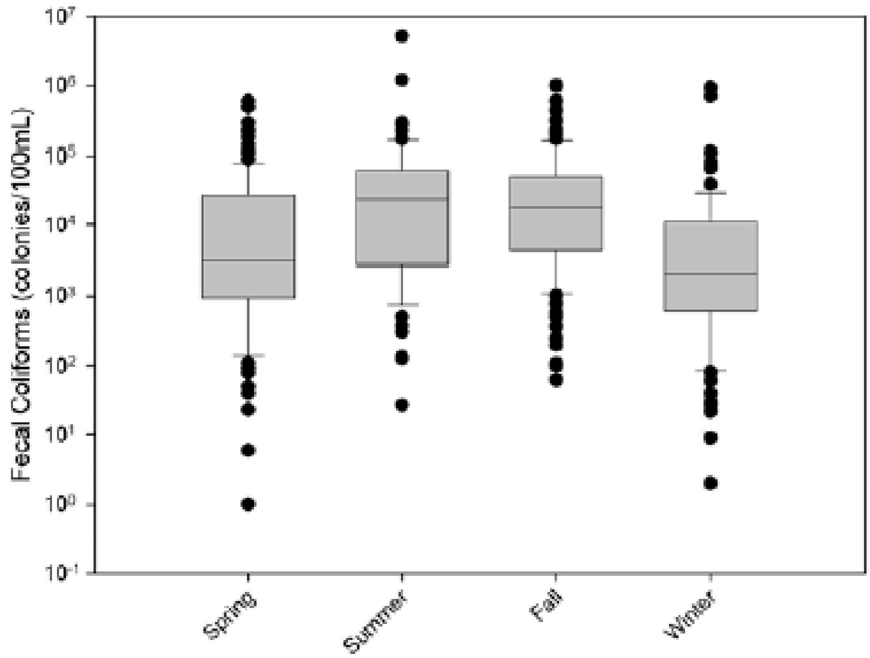


Figure 7-39. National Stormwater Quality Database Fecal Coliform Data for Different Seasons (Pitt et al., 2004)

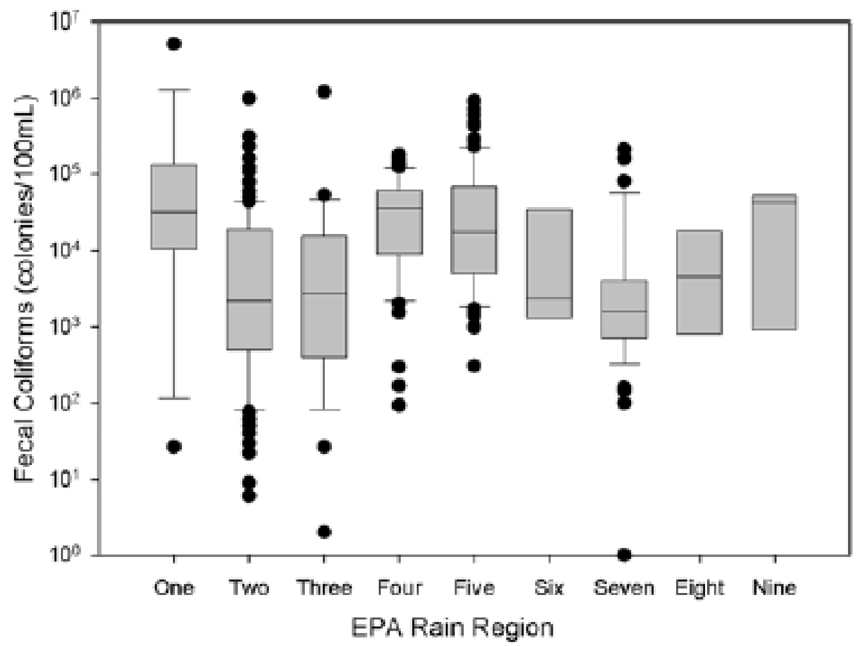


Figure 7-40. National Stormwater Quality Database Fecal Coliform Data for Different Rainfall Patterns (Pitt et al., 2004). The Puget Sound region is in Rainfall Zone 7.

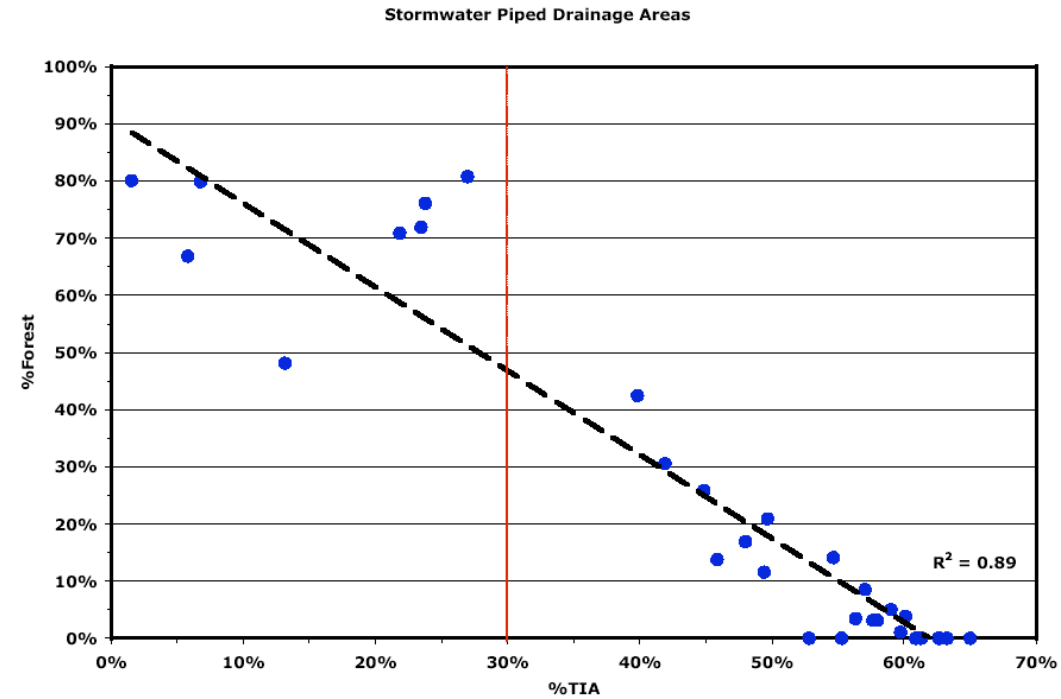


Figure 7-41. Relationship Between Natural Landscape (as Measured by Percentage of Forest) and Developed Land Area (as Measured by Percentage of Total Impervious Area) for Stormwater Outfall Subbasins in the Sinclair-Dyes Inlet Watershed

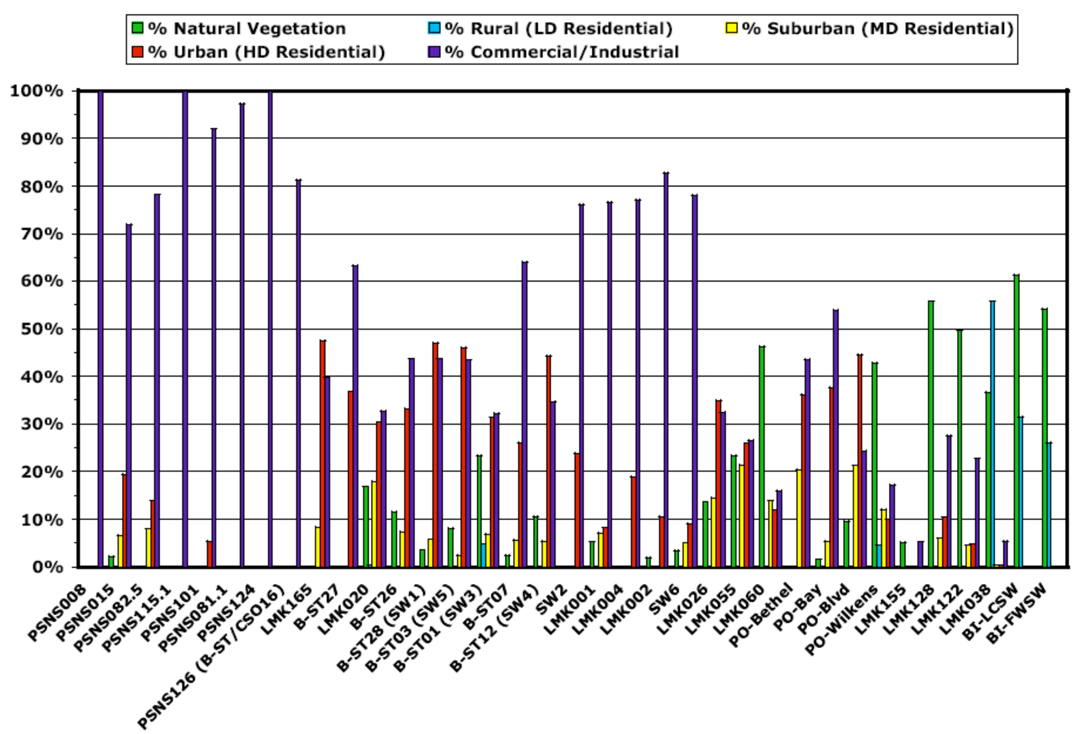


Figure 7-42. Land-Use and Land-Cover Characteristics for Stormwater Outfall Subbasins in the Sinclair-Dyes Inlet Watershed

Based on the data obtained during the 2002-2003 storm season alone, it can be concluded that stormwater outfalls have the potential to be significant sources of bacterial pollution to the Sinclair-Dyes Inlet watershed. The FC levels found during this sampling period were typically an order of magnitude higher than streams with comparable drainage basin development (see Table 7-3 for the summary statistics on stormwater outfalls compared with Table 7-1 for streams). Stormwater outfalls generally only flow during storm events, so the period of time that the immediate water-quality impact is felt on the nearshore environment tends to be relatively brief. However, there may be long-term impacts of the loadings from stormwater outfalls on sediment quality, biological integrity, and other environmental factors.

Stormwater FC concentrations from sampled outfalls in the Sinclair-Dyes Inlet watershed tended to be significantly higher than stream FC levels, but were highly variable (coefficient of variation [CV] was approximately 150%). The sampled stormwater outfalls fell into three general development categories: moderate-density (suburban) residential areas, HD (urban) residential areas, and areas dominated by commercial-industrial development (i.e., PSNS industrial area). Although there is no established WQS for stormwater outfalls, the average geometric mean FC for all three groups was greater than 100 cfu/100 mL.

As with streams, there was a correlation found between %TIA and developed land use for stormwater outfall FC levels; however, the relationships were not nearly as strong as those for streams (Figures 7-43, 7-44, and 7-45). As with the national and regional findings, the results from stormwater outfall sampling in the Sinclair-Dyes Inlet watershed show a relationship between FC levels in stormwater and contributing drainage-basin land use or imperviousness. As would be expected, stormwater FC levels are also inversely related to the amount of natural vegetative cover (e.g., percentage of forest) found in the contributing subbasin.

More important than these relationships, however, is that stormwater outfall bacterial contamination levels can be significant. Although there is not a specific WQS for stormwater outfalls, Figure 7-43 shows that almost all stormwater outfalls were in violation of Part I of the bacterial WQS (geometric mean greater than 100 cfu/100 mL). In addition, Figure 7-44 shows that all sampled stormwater outfalls violated Part II of the stream WQS for FC pollution (more than 10% of FC samples have greater than 200 cfu/100 mL). These WQS levels are used here for relative comparison only and do not imply any regulatory requirements. Typical storm-event FC responses for a sampling of stormwater outfalls are shown in Figures 7-46 through 7-53. Generally, like their urban stream counterparts, FC levels peak, along with turbidity, at higher stormwater flow rates (resulting from larger storm events).

As was the case for urban streams, the highest FC levels and the most WQS violations generally occurred in stormwater outfalls draining highly urbanized drainage basins (Figures 7-43 and 7-44). Typically, these are also the drainage basins with the most “hard” or engineered stormwater infrastructure. Although there are several stormwater treatment BMPs located within the study area, many developments either do not have any structural stormwater treatment BMPs or the BMPs that are present are of an older design. Any attempt to draw conclusions regarding the effectiveness of stormwater BMP treatment, therefore, is difficult. In general, engineered stormwater BMPs, with the exception of infiltration facilities, are not especially effective in removing bacterial pollution. Very few, if any, stormwater treatment (BMP) facilities in the study area were designed to be effective in treating bacterial contamination.

Table 7-3. Descriptive Statistics of Watershed Land-Use Variables and Fecal Coliform Results Used to Characterize the Stormwater Outfall Site Population

Variable	N	Mean	Std.Dev.	Median	Minimum	Maximum	25th Percentile	75th Percentile
Basin Area (acres)	34	188	188	136	9	864	33	284
% Mixed Forest	34	0	0	0	0	0	0	0
% Deciduous Forest	34	0	0	0	0	0	0	0
% Coniferous Forest	34	0	0	0	0	1	0	0
% Shrub	34	0	0	0	0	0	0	0
% Natural Vegetation	34	0	0	0	0	1	0	0
% Grass or Turf	34	0	0	0	0	0	0	0
% Rural (LD Residential)	34	0	0	0	0	1	0	0
% Suburban (MD Residential)	34	0	0	0	0	0	0	0
% Urban (HD Residential)	34	0	0	0	0	0	0	0
% Commercial/Industrial	34	1	0	0	0	1	0	1
%TIA	34	0	0	1	0	1	0	1
% Forest	34	0	0	0	0	1	0	0
Road-Density	34	44	15	45	19	66	33	59
FC/100ml	33	792	1349	424	10	7602	158	952
Min FC	33	84	201	20	1	1100	7	49
Max FC	33	19044	32942	3800	640	133000	2100	19000
25th Percentile	33	379	640	124	1	3200	46	385
75th Percentile	33	2458	3802	1490	16	18000	573	2970
90th Percentile	33	10323	22975	2872	220	124917	1372	10677
N>200	33	10	5	11	2	23	6	12
P>200	33	1	0	1	0	1	1	1

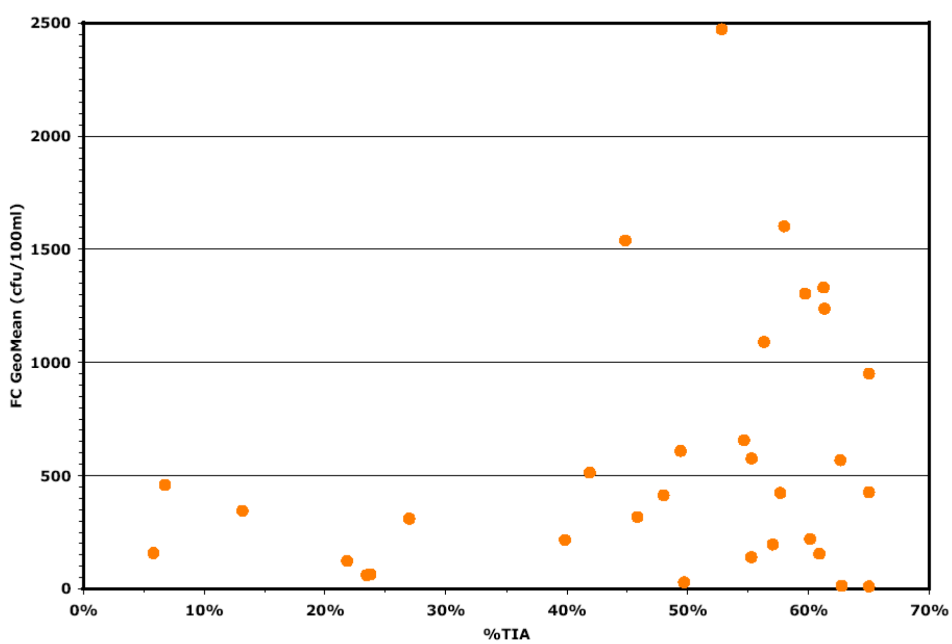


Figure 7-43. Geometric Mean Fecal Coliform Data for Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed for the 2002-2003 Storm Season

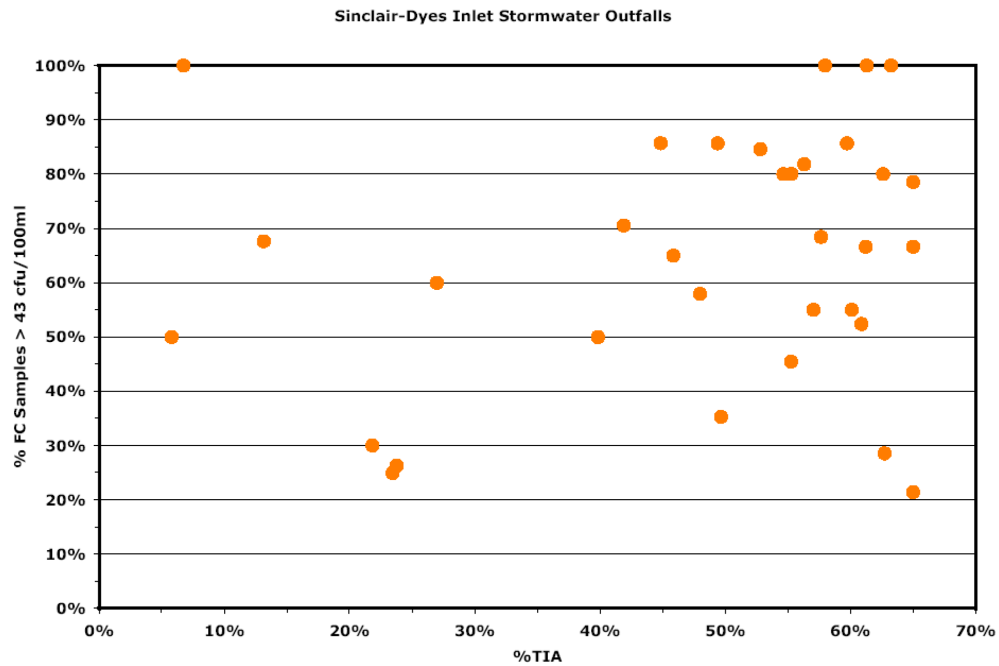


Figure 7-44. Fecal Coliform Water-Quality Data for Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed for the 2002-2003 Storm Season

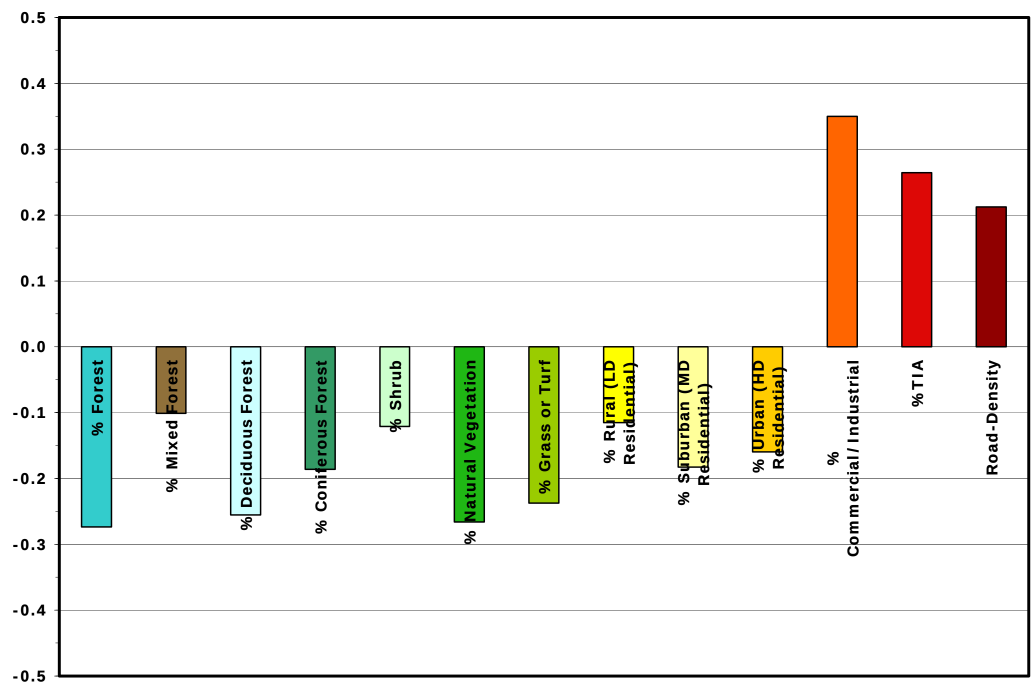


Figure 7-45. Correlations Between Fecal Coliform Geometric Mean Data and Drainage Subbasin Land-Use and Land-Cover Classes for Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed for the 2002-2003 Storm Season

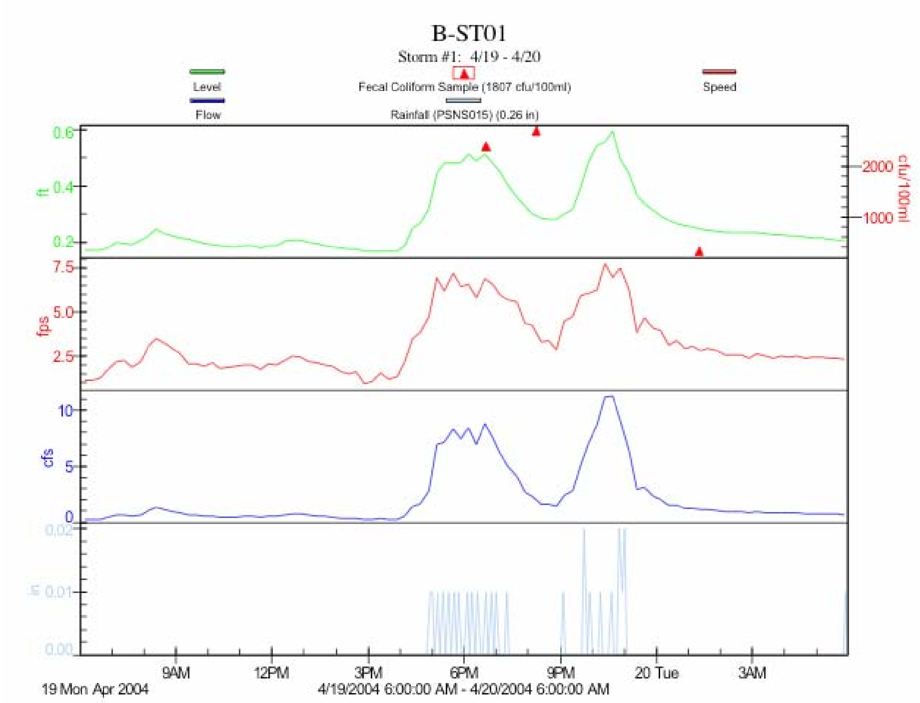


Figure 7-46. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

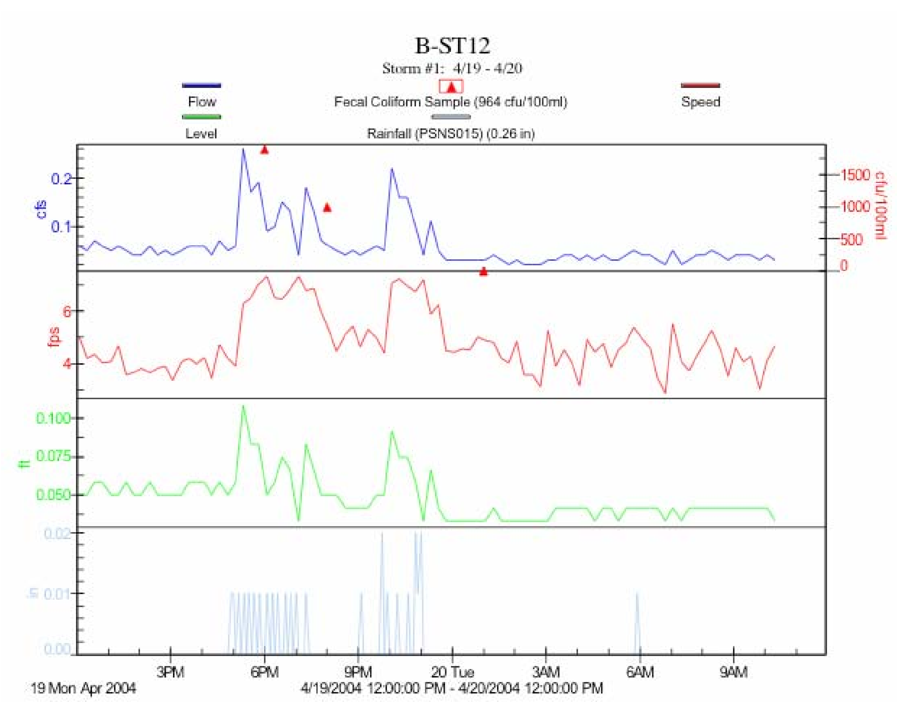


Figure 7-47. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

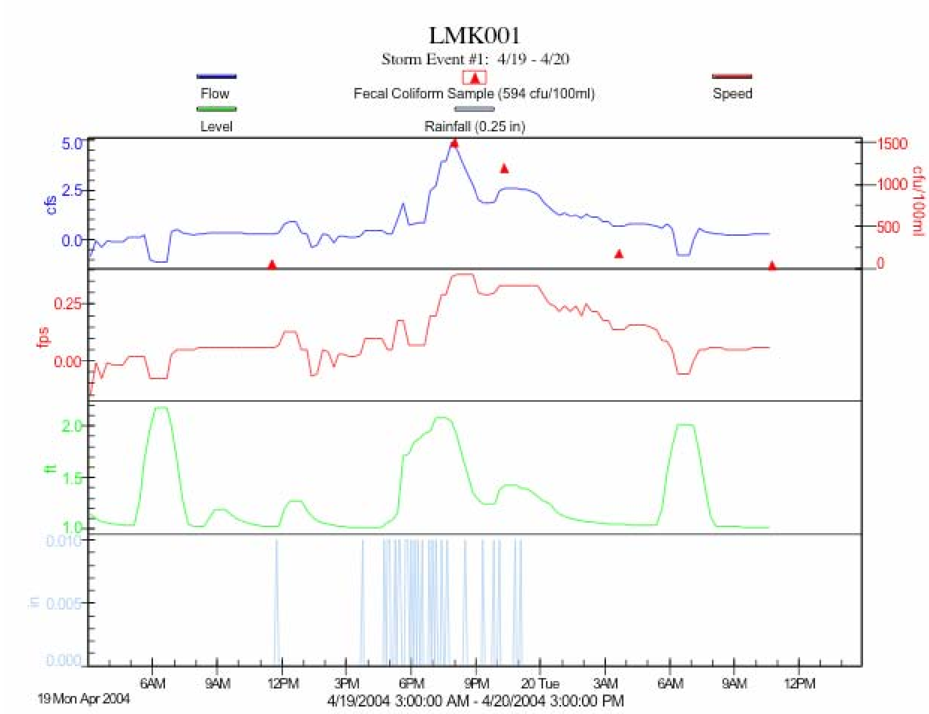


Figure 7-48. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

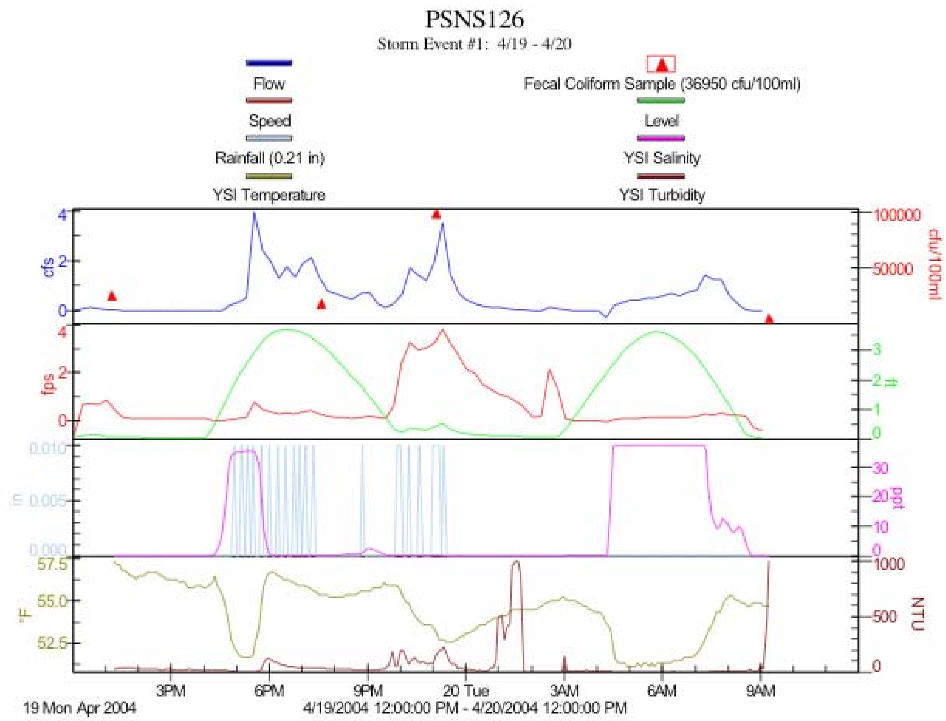


Figure 7-49. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

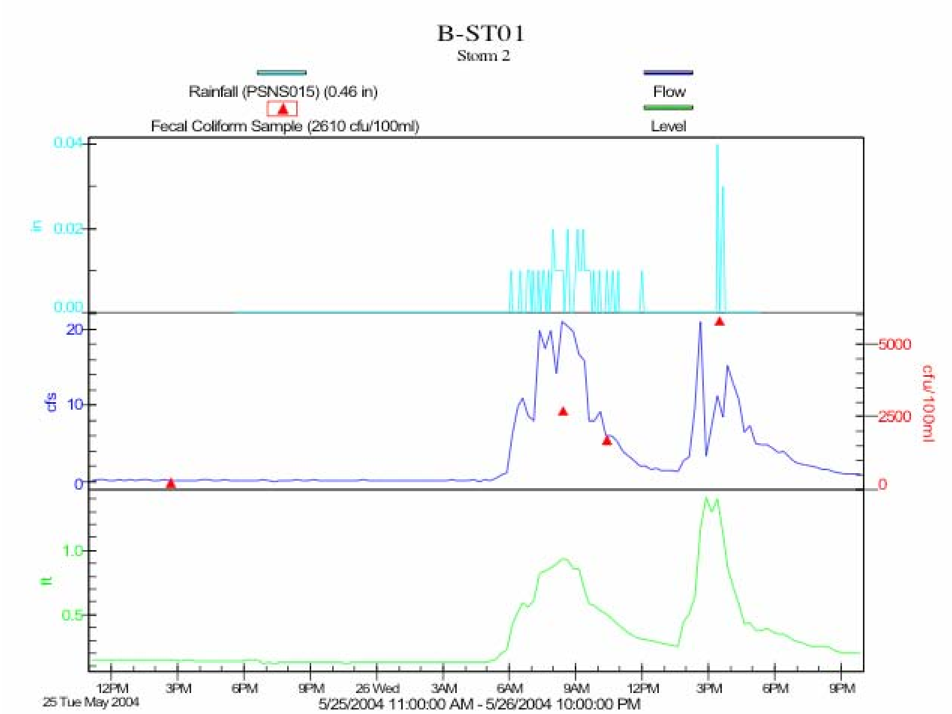


Figure 7-50. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

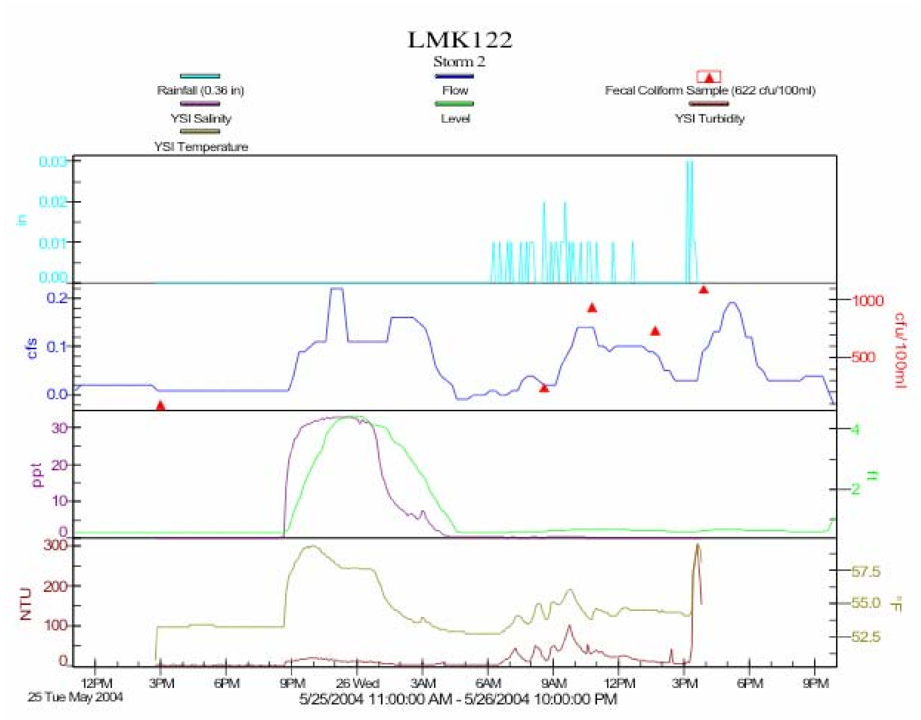


Figure 7-51. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

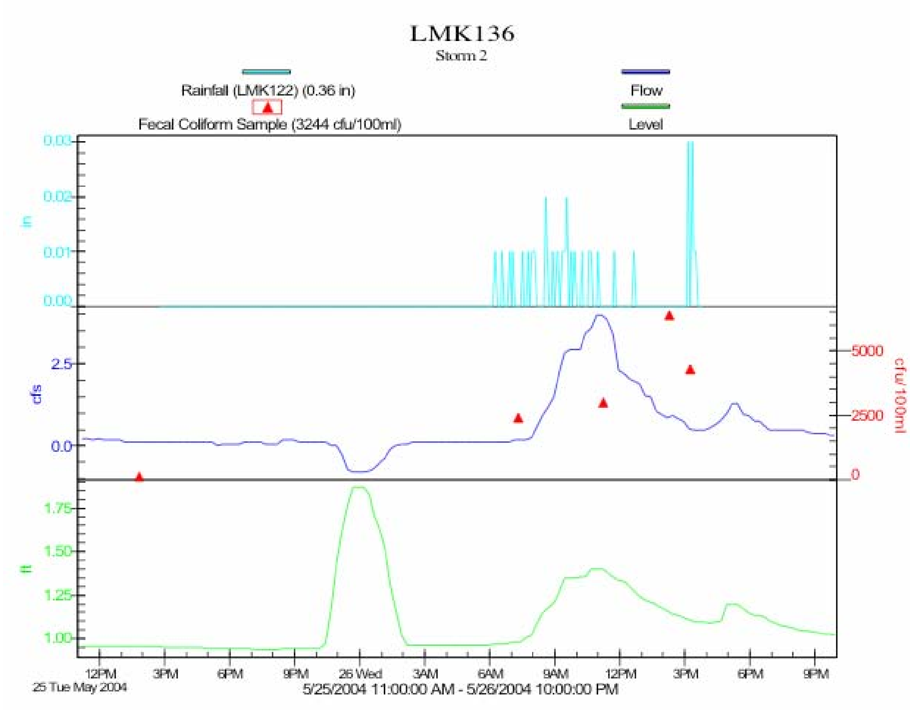


Figure 7-52. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

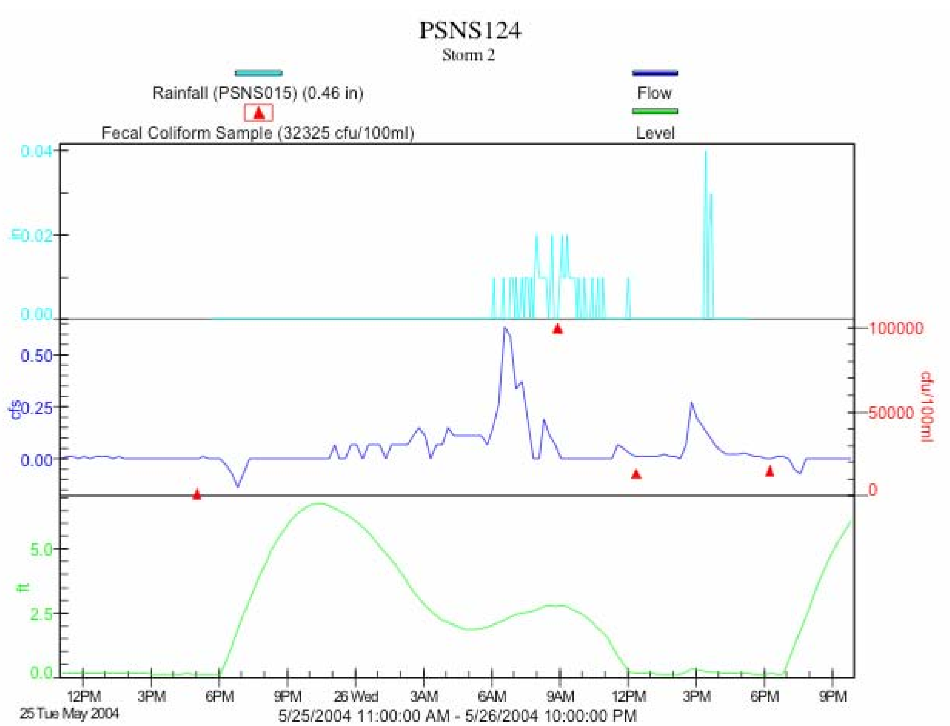


Figure 7-53. Storm-Event Response for Selected Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed During the 2003-2004 Storm Season (TEC 2004)

In summary, data from this study indicate that stormwater outfalls can be a significant source of bacterial pollution to freshwater and marine-nearshore receiving waters. Other researchers have also made this finding (Weiskel et al., 1996; Mallin et al., 2000b; Frenzel and Couvillion 2002). In a study of Buttermilk Bay in Massachusetts (Weiskel et al., 1996), the median FC level in stormwater was found to be approximately 10,000 FC/100 mL and represented about 15% of the total FC inputs to the bay. For the Sinclair-Dyes Inlet watershed, the geometric mean FC level for stormwater outfalls was closer to 1000 FC/100 mL. Although stormwater inputs to Sinclair-Dyes Inlet represent only about 10% of all FC inputs and tend to be transient in duration, they are still a source of bacterial pollution that should to be addressed. Because bacterial contamination enters nearshore areas and embayments via multiple sources, stormwater management efforts alone cannot eliminate FC pollution; however, they can contribute to the remediation of impaired water bodies. As is the case for FC pollution sources in urbanizing streams, source-control measures are the most effective means of reducing bacterial contamination. Efforts such as the KCHD PIC Program and the KC-SSWM Program are examples of the types of activities that can lead to long-term improvements in receiving water quality.

7.5 Quality Assurance / Quality Control Results

Quality Assurance (QA) activities were conducted to ensure that the collected data were of sufficient quality to support the goals of the project. Field duplicate QA samples were collected from each sampling station during the course of the sampling. These samples are very important in reducing sampling error and bias and ensuring the comparability among samples collected by the different stakeholder groups participating in the study. For the FC samples, one field duplicate for every nine samples (10%) was collected during the study period. The field duplicates were labeled and processed by the laboratory in the same manner as the other field samples. Electronic spreadsheets were used to document chain-of-custody information.

Laboratory QA/QC procedures were conducted according to the laboratory-specific standard operating procedures (SOPs) in effect for the project. For each batch of 20 samples, the laboratory included one method blank and one laboratory duplicate analyzed along with the field samples. The laboratory's standard data quality acceptance criteria were used. Acceptance criteria focus on ensuring an appropriate level of data quality to meet the project objectives. Method blanks and laboratory duplicate samples were analyzed to evaluate and monitor analytical results. Throughout this study, acceptance criteria were periodically reviewed for appropriateness and adequacy in meeting the study goals and objectives.

Targets for precision of bacterial analyses are inherently difficult to quantify. The CV for replicate samples for FC has been found to increase as FC levels decrease. For low levels of FC (e.g., less than 10 FC/100 mL), the CV for replicates can approach 50%. For higher FC levels (e.g., greater than 100 FC/100 mL), the CV is typically around 20%. A residual percent difference (RPD) of 25% was established as the target for field duplicates, and an RPD of 40% (logarithmic scale) for laboratory duplicates. The actual values for the project were as follows:

- Field Duplicate Average RPD = 10.5% (14 of 152 samples OOS)
- Laboratory Duplicate Average RPD = 25.7% (12 of 53 samples OOS)

These results are in accordance with the RPD values typically encountered in FC sampling and analysis studies.

8.0 Bacterial Loading Analysis

8.1 Introduction

Fecal coliform (FC) loading can be defined as the mass of bacteria transported to a receiving water body by a stream, stormwater outfall, or other discharge source over a given time period. It can be estimated by multiplying discharge or flow by the estimated concentration of FC (cfu/100 mL) for the given time period. This estimate of FC concentration can be expressed as an average value using the geometric mean or as some range of FC typical levels, such as the 25th and 75th percentiles. The intent of this effort to estimate FC loading is to aid in the development of a watershed-based model that will be used to establish a bacterial TMDL for the study area as part of the Water Cleanup Plan. In addition, this loading analysis and the subsequent modeling effort should assist in the identification and correction of bacterial pollution problem areas.

8.2 Stream Fecal Coliform Loading Estimation

For streams, the load estimation process was conducted for a 24-hour time period. The choice of 24 hours as an appropriate time period has the advantage of smoothing the variability in flow estimates, which were modeled on a 15-minute time-step, and FC measurements, which were typically sampled only once per month for baseflow conditions or up to several times per day during stormflow conditions. Typically, streamflow does not change significantly over the course of a day unless there is a storm event with measurable rainfall. On the other hand, FC variability can be relatively high depending on the sources within a drainage area. Using the FC data compiled during this project and available streamflow data from the Kitsap Public Utilities District (KPUD), an estimate of seasonal (wet and dry season), storm season or storm event, and annual FC loading can be calculated for each source. Several of the streams in the study area have long-term flow gages installed to measure discharge over time. FC loading estimates for streams without installed flow gages were estimated using a simple hydrologic model based on watershed area and LULC characteristics. Streamflow modeling will be discussed elsewhere in this document and was only evaluated here as a potential explanatory variable of FC concentrations and to estimate FC loading.

For this statistical analysis, the modeled and/or observed stream flows from seven streams (CC, CC01, CH, CH01, AC, BA, and OC) within the study area were chosen to compare estimation procedures for FC concentrations and the resulting FC loads (Table 8-1). Between January 2001 and September 2003, FC measurements were taken between 28 and 62 times, depending on the stream. The distribution of modeled stream flows (the closest 15-minute time-step of the FC sampling time period) is shown in Table 8-2 and Figure 8-1. Typically, the modeled and observed flows were well-correlated (Figure 8-2). Finally, the modeled flows from all streams had a consistent pattern associated with the time of year (represented as the number of days elapsed since January 1 divided by 365) (Figure 8-3). High flows were typically associated with the higher rainfall during the winter and spring months.

Within this subset of streams, average FC concentrations were greatest in OC with 25% of the observations greater than 875 cfu/100 mL (Table 8-3). CH01 had 75% of its FC measurements less than 50 cfu/100 mL and no observations greater than 200 cfu/100 mL (Figure 8-4). In general, however, FC measurements were not consistent between streams as a function of the time of year (Figure 8-5), nor as a function of flow (Figure 8-6). FC measurements can be costly in effort and tend to be highly variable both within and between streams (Table 8-3 and Figure 8-4).

Table 8-1. Stream Identification Information for Streams Used to Compare Load Estimation Techniques and for Verification

Streams Used for Model Comparison					
Stream	**Watershed**	**Stream Sub-Watershed**	**Ch3d ID#**	**HSPF ID#**	**Basin Area (acres)**
CC	Dyes Inlet	Clear Crk @ Silverdale Way	54	135	5004.3
CC01	Dyes Inlet	Clear Crk @ Ridgetop Blvd	31 thru 63	2112 thru 2144	5394.6
CH	Dyes Inlet	Chico Crk @ Golf Course	6+7+9+12+13+26+27+28+29	2050+2051+2053+2056+2057+2094+2095+2096+2097	10033.1
CH01	Dyes Inlet	Chico Crk @ Kittyhawk Dr	6+7+9+12+13+26+27+28+29+240000	2050+2051+2053+2056+2057+2093+2094+2095+2096+2097	10475.5
AC	Sinclair Inlet	Anderson Crk	15+640000	2059+2060	1265.9
BA	Dyes Inlet	Barker Crk @ Barker Crk Rd	16+17+18+19+320000	2062+2063+2064+2065+2066	2597.8
OC	Sinclair Inlet	Olney Crk	20+590000	2067+2068	1245.4

Table 8-2. Distribution and Correlation of Modeled Stream Flows Associated with Fecal Coliform Measurements Taken Between January 2001 and September 2003

Stream	N	Mean	Median	StdDev	Minimum	Maximum	First Quartile	Third Quartile	Correlation with Fecal Coliform Measurement
AC	55	4.80	1.46	5.59	0.18	21.3	0.43	10.9	0.10
BA	62	11.7	5.95	13.3	1.05	54.8	2.37	15.3	0.21
CC	28	10.3	6.46	10.6	1.72	40.1	3.80	12.2	-0.20
CC01	33	7.72	4.95	11.3	1.97	67.0	3.05	8.30	-0.18
CH	34	87.7	98.8	48.4	6.27	198	48.2	122	0.05
CH01	33	21.2	11.2	30.3	1.40	141	2.66	27.2	0.31
OC	48	11.5	1.57	19.9	0.08	95.7	0.36	12.1	0.50

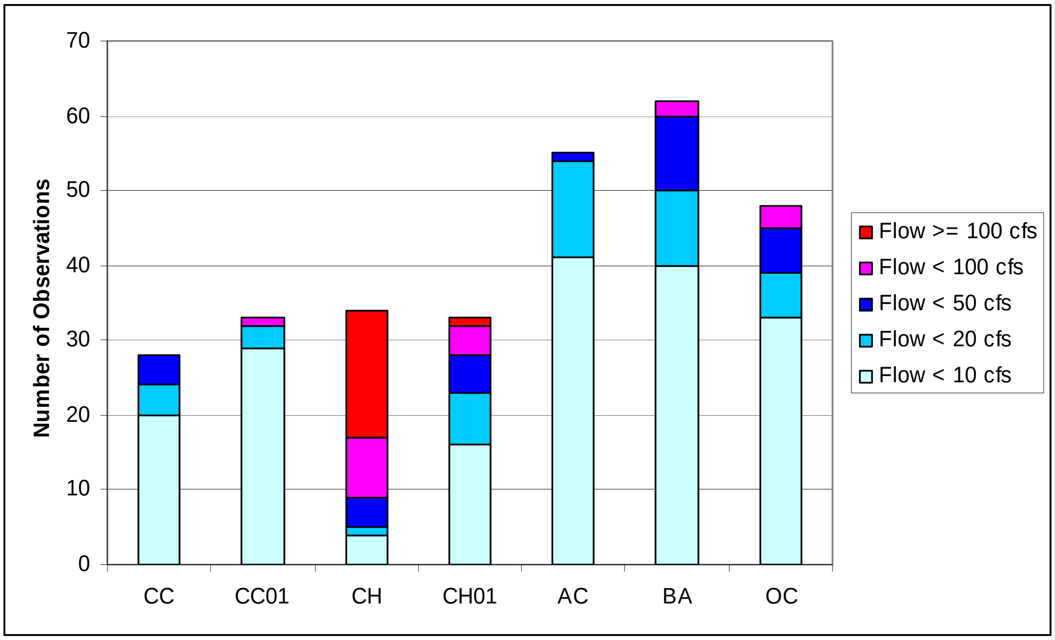


Figure 8-1. Distribution of Modeled Flows Associated with Fecal Coliform Measurements Taken Between January 2001 and September 2003

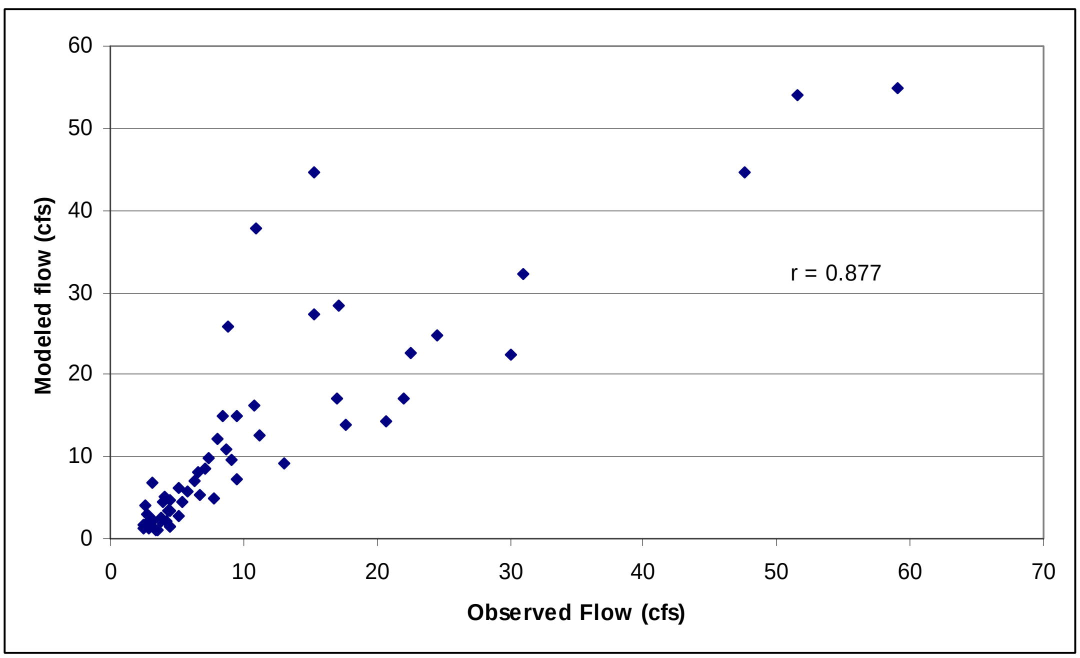


Figure 8-2. Modeled and Observed Flows from Barker Creek (BA) Associated with Fecal Coliform Measurements

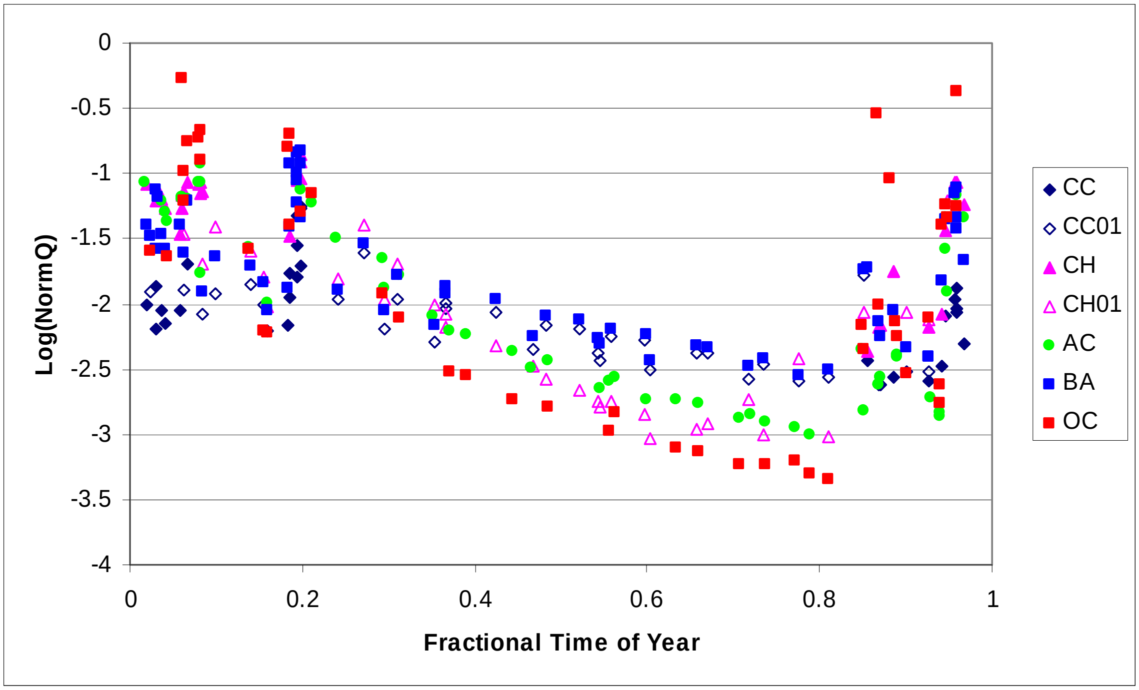


Figure 8-3. Log (Base 10) of the Watershed Area (km) Normalized Modeled Flows (NormQ) Associated with Fecal Coliform Measurements as a Function of the Fractional Time of Year

Table 8-3. Descriptive Statistics of Fecal Coliform Measurements for Selected Streams Taken Between January 2001 and September 2003

Stream	N	Mean	Median	Stddev	Coefficient of Variation	Minimum	Maximum	First Quartile	Third Quartile
AC	55	45.2	20	74.5	165%	1	300	4	49
BA	62	163.5	84	174.6	107%	8	900	49	245
CC	28	194.7	102.5	228.5	117%	6.8	910	42.5	285
CC01	33	416	80	599	144%	13	1601	30	500
CH	34	103.5	51	116.1	112%	1.8	560	37	151
CH01	33	40.24	30	38.73	96%	4	170	12	50
OC	48	754	300	1136	151%	4	5800	106	875

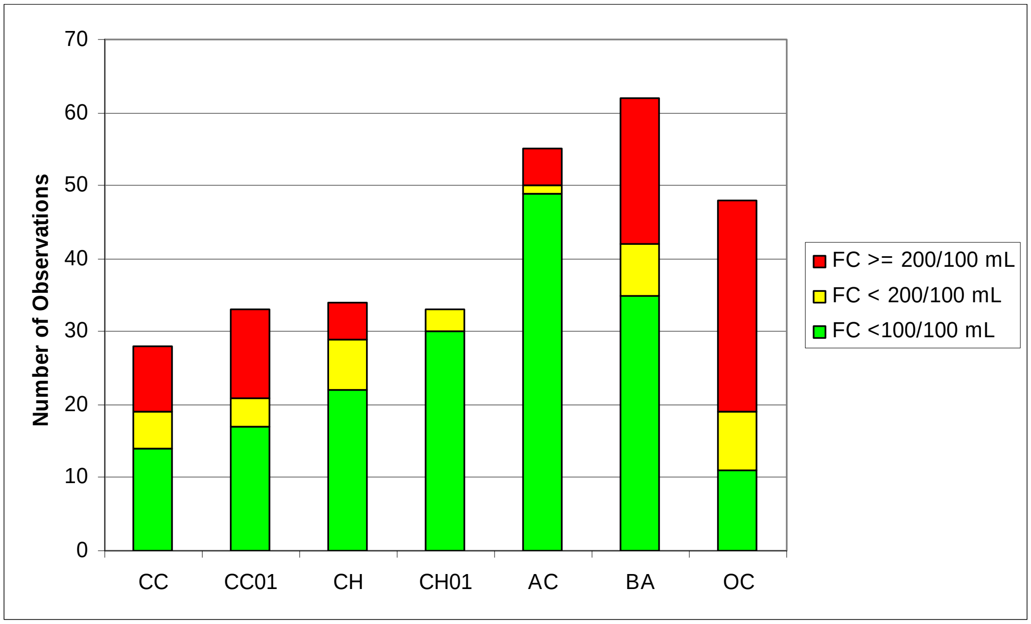


Figure 8-4. Distribution of Fecal Coliform Measurements for Selected Streams Taken Between January 2001 and September 2003.

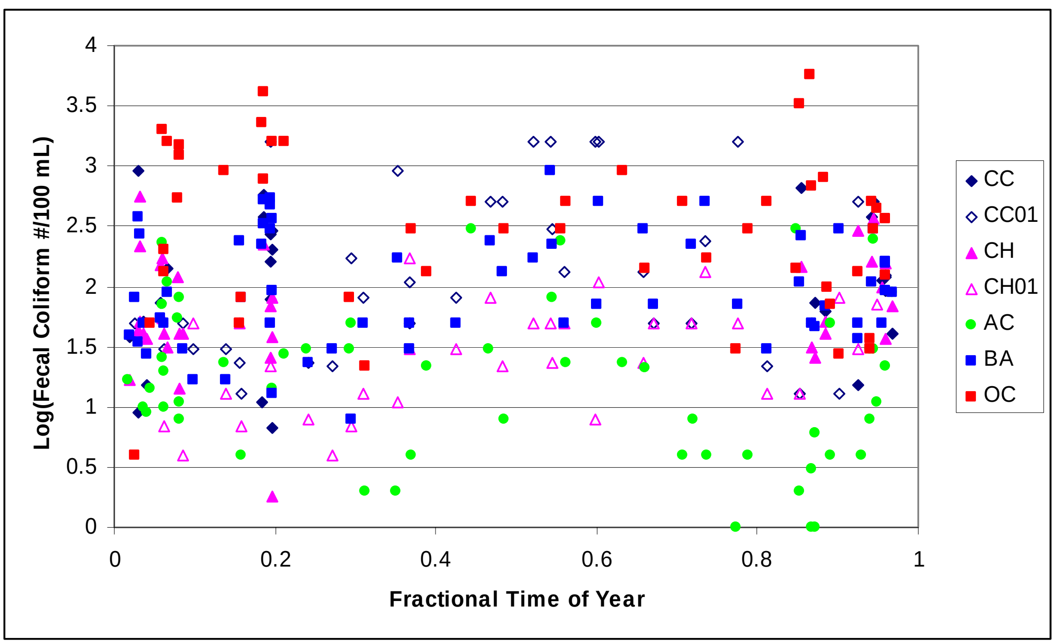


Figure 8-5. Log (Base 10) of the Fecal Coliform Measurements for Selected Streams as a Function of the Fractional Time of Year

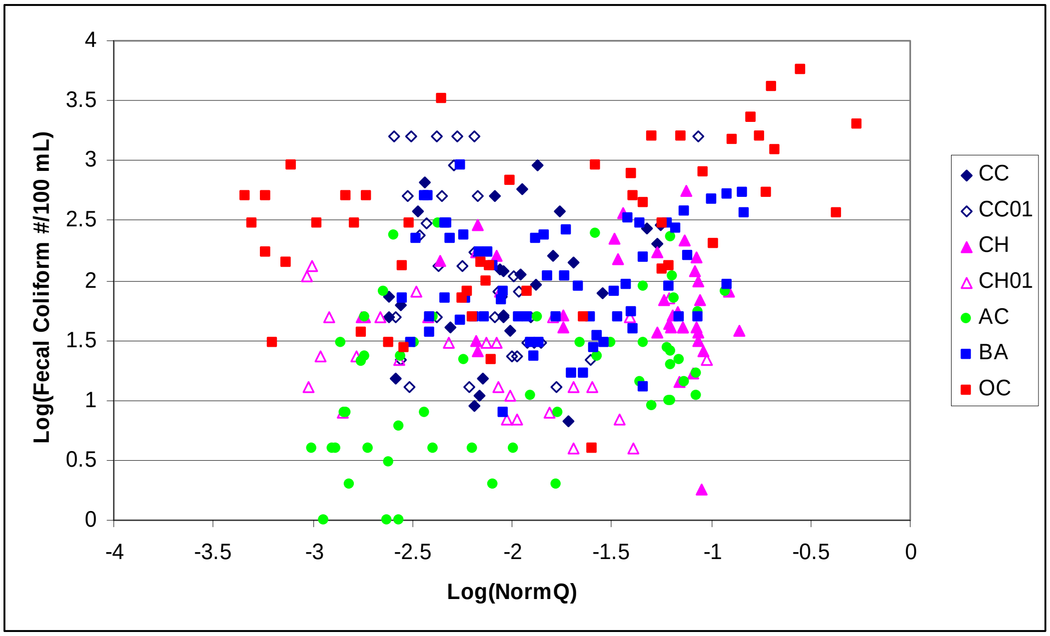


Figure 8-6. Log (Base 10) of the Fecal Coliform Measurements for Selected Streams as a Function of the Log (Base 10) of the Watershed Area (km) Normalized Modeled Flows (NormQ)

As discussed, the high concentrations of FC bacteria in streams are likely a result of some combination of sources, such as pet waste runoff, failing septic systems, overflow or leakage from sewer systems, and runoff from agricultural areas. Further, stormwater runoff and overflow events are a function of rainfall quantity and intensity.

A representative proportion of the streams and outfalls have been sampled within the study area, with 1854 stream and 631 outfall samples collected between January 2000 and September 2003. The specific objective in this section of the study was to compare several different methods of estimating FC concentrations based on measured FC sample sites, and to evaluate the ability to extrapolate to unmeasured sources and predict the loading input into Sinclair-Dyes Inlet. Approximately 88% of the Sinclair-Dyes Inlet study area was covered by actual FC data, based on the monitoring efforts of all the project partners (KC-SSWM, KCHD, WA-DOH, Ecology, and PSNS). Therefore, the portion of the study area that needs to be estimated based on extrapolation of actual data is approximately 12% of the total area of the Sinclair-Dyes Inlet watershed.

Several statistical methods were used to estimate FC loading based on known FC concentration measurements and representative watershed characteristics for several "test" streams selected from the study area. These streams were selected to be representative of those found in the Sinclair-Dyes Inlet watershed and represent the range of development levels typical of subbasins in the ENVVEST study area. The test-streams include Clear (2 sites), Chico (2 sites), Anderson (1 site), Barker (1 site), and Olney (1 site) Creeks.

The following statistical methods were used to evaluate the most appropriate method of estimating FC loading for use in the watershed model:

1) Regression analysis of FC concentration measurements using time of year and streamflow (measured and modeled)
2) Bounded analysis using distribution statistics
3) Step-wise regression analysis of FC concentration measurements using watershed LULC characteristics
4) Cluster analysis of FC concentration measurements using watershed LULC characteristics and statistically based bounded FC concentrations
5) Regression analysis of FC concentration measurements using LULC-based cluster scores.

8.2.1 Method 1 – Regression Analysis using Time of Year and Flow

Several authors have used a regression approach to estimate bacteria concentrations in streams as a function of the time of year and flow with varying rates of success (Pelletier and Seiders, 2000; Roberts and Pelletier, 2001; Christensen et al., 2002). All of these authors used a basic log-linear modeling approach (Cohn et al., 1989; Cohn et al., 1992; Roberts and Pelletier, 2001). Resulting adjusted R^2 coefficients for the multiple regression models employed by these authors for bacterial pollution estimation ranged from 0.17 to 0.86. The basic model used to estimate FC concentrations using this approach is as follows:

$$\log(c) = b0 + b1\cdot\log(Q/A) + b2\cdot(\log(Q/A))2 + b3\cdot\sin(2\pi fy) + b4\cdot\cos(2\pi fy) + b5\cdot\sin(4\pi fy) + b6\cdot\cos(4\pi fy)$$

where c = concentration (cfu/100 mL)
Q = streamflow or discharge in cubic meters per second
A = drainage area of the tributary to be monitored (km^2)
fy = year fraction (dimensionless, varies from 0 to 1)
bi = best-fit coefficients calculated for each dataset (i = 0 to 6).

For the data used in this study, the resulting best-fit models for FC concentrations are presented in Table 8-4. Smearing coefficients (the average exponential residuals from the regression [Cohn et al., 1992]) used for back transformation from log (base 10) to FC (cfu/100 mL) ranged from 1.07 to 1.16. The resulting R^2 coefficients for these models ranged from 0.05 to 0.46 (Table 8-5). Four out of the seven streams had significant slopes associated with either the flow or time of year; however, there was little consistency in the major explanatory variable or which slopes were significantly different from zero. The model tended to overestimate low FC concentrations and underestimate high concentrations (Figures 8-7 and 8-8). However, the residuals for all streams ranged only between 0 and 30 (cfu/100 mL), whereas the observed values ranged between 1 and 5800 (cfu/100 mL). The residuals did not show a pattern with either the time of year or the watershed area normalized flow, and all standardized residuals were less than 3.0. The correlation between the observed and predicted log FC concentrations together for all seven streams was 0.78.

Predicted FC loadings were estimated by multiplying the average daily flow (or mean daily discharge) by the predicted concentration of FC back transformed to cfu/100 mL, times the conversion factor (24.46575546), to give millions of FC/day. The conversion factor was derived by multiplying the number of liters equal to 1 cubic foot by the number of seconds per day, times 10^{-5}, to give millions of FC/day. Average daily flow was calculated for each stream by averaging the 96 modeled 15-minute average flows from the Hydraulic Simulation Program FORTRAN (HSPF) watershed model for each date between January 1, 2001 and September 30, 2003.

Table 8-4. Best-Fit Regression Coefficients and Resulting Smearing Coefficient for Selected Streams

Stream	Constant	$\sin(2\pi f_y)$	$\cos(2\pi f_y)$	$\sin(4\pi f_y)$	$\cos(4\pi f_y)$	log(Q/A)	$(\log(Q/A))^2$	Smearing Coefficient
	Regression Parameters							
CC	-8.66	0.35	16.82	-0.68	-6.17	-1.64	-0.88	1.12
CC01	10.28	0.16	-0.54	0.07	0.33	9.06	2.37	1.11
CH	-0.63	1.57	1.95	-0.89	-0.03	-0.48	0.06	1.08
CH01	2.12	-0.26	-0.13	-0.09	0.11	0.65	0.14	1.07
AC	1.58	-0.35	-0.39	0.12	0.28	-0.47	-0.28	1.16
BA	4.62	-0.26	-0.23	0.08	0.04	2.69	0.65	1.08
OC	4.47	-0.45	-0.61	0.11	-0.30	1.16	0.10	1.10

Table 8-5. Summary Regression Results for the Regression with Time of Year and Flow

Stream	Error Degrees of Freedom	Regression Significance	Adjusted R2	Significant Slopes α=0.05	Major Explanatory Variable
CC	21	0.1300	0.165	None	$\cos(2\pi f_y)$
CC01	26	0.0003	0.504	$\cos(2\pi f_y)$ $\cos(4\pi f_y)$ log(Q/A) $(\log(Q/A))^2$	$(\log(Q/A))^2$
CH	27	0.3065	0.046	None	$\sin(2\pi f_y)$
CH01	26	0.1945	0.097	None	$\sin(2\pi f_y)$
AC	48	0.0018	0.262	$\cos(2\pi f_y)$ $\cos(4\pi f_y)$	$\cos(2\pi f_y)$
BA	55	0.0014	0.241	$\sin(2\pi f_y)$ $\cos(2\pi f_y)$ log(Q/A) $(\log(Q/A))^2$	log(Q/A)
OC	41	0.00002	0.457	$\sin(2\pi f_y)$ $\cos(2\pi f_y)$ $\cos(4\pi f_y)$ log(Q/A)	log(Q/A)

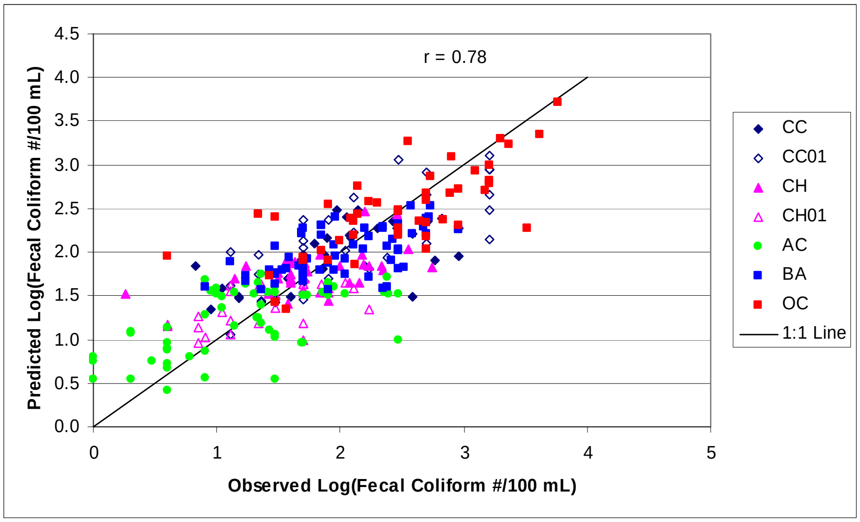


Figure 8-7. Observed and Predicted Log10 of the FC Measurements for Selected Streams from the Regression with Time of Year and Flow

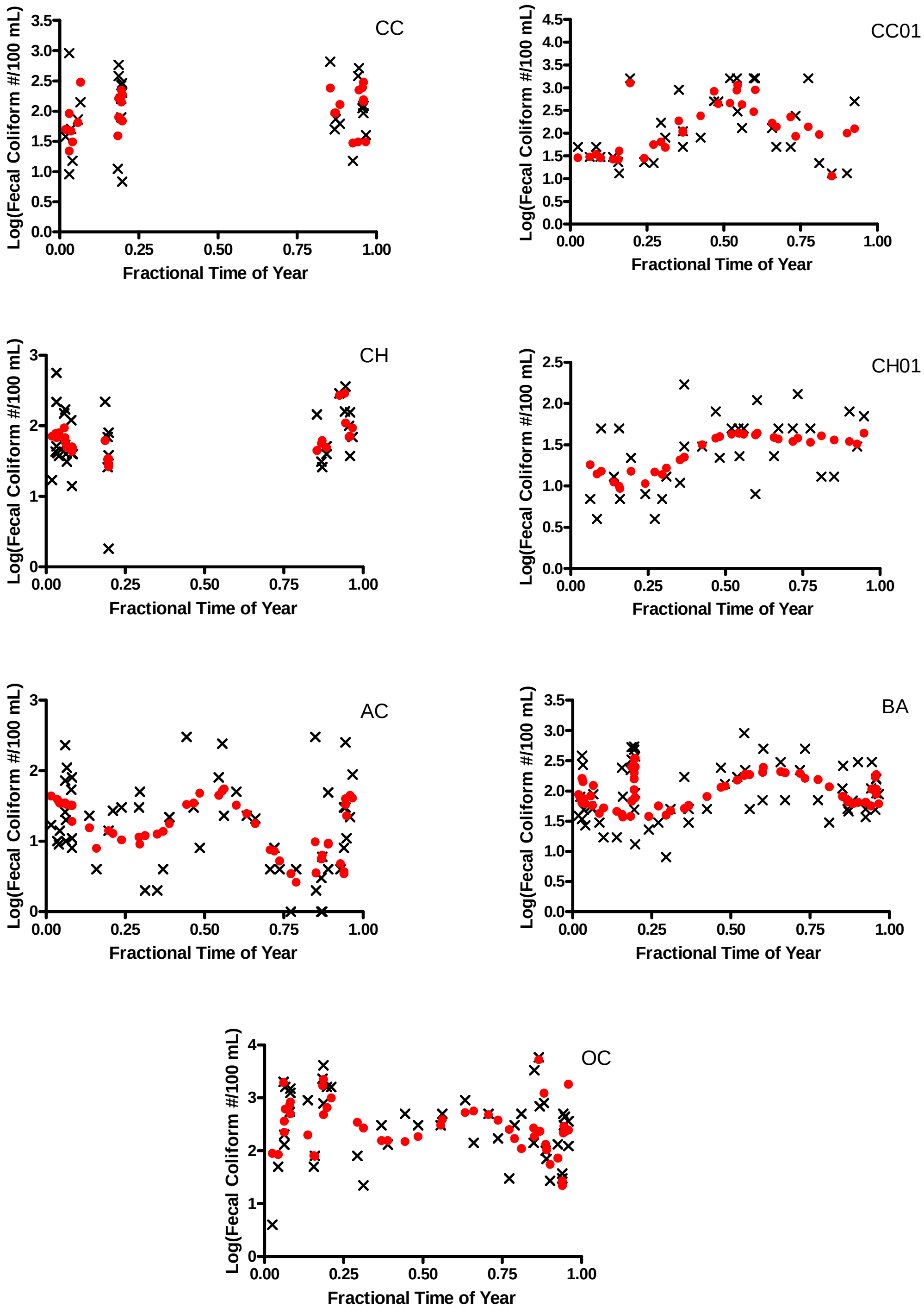


Figure 8-8. Observed (black X) and Predicted (red dot) FC Concentration Based on the Regression with Time of Year and Flow

The minimum, median, and maximum average daily flows (from the HSPF model) for the seven test streams suggests low rainfall during the winter and spring of 2001 compared with those for 2002 and 2003 (Figure 8-9). Observed loadings were calculated by multiplying the observed FC concentration by the same average daily flow used for the predicted loading associated with the date of measurement. All FC concentrations, and thus the resulting loading, were bounded by the highest concentration observed for a given stream. The minimum value was not bounded.

Predicted loadings tended to be between 1000 and 50,000 million FC counts per day except for very low flows observed in the summer months for the following streams: CC (Figure 8-10), CH (Figure 8-11), and less extreme for AC (Figure 8-12). Erratic load behavior was greatest for OC, the most developed test stream (not seasonal dependent), and least for CH, the most undeveloped test stream. Most of the streams had predicted loads that were greatest and more erratic during the winter months when flows tend to be most variable. CC01 had the greatest observed and predicted FC load variation and CH had the least (Table 8-6). CC01 also had the closest match between the observed and predicted percentiles of the loading distribution.

Sampling stations located on the same stream but at different heights in the watershed allow the calculation of differential loads and the evaluation of different bacterial sources. The difference between the predicted loadings from CC01 and CC and also from CH01 and CH allowed an assessment of the contribution of bacterial pollution (FC) from the additional 390 and 442 acres, respectively (Table 8-1 and Figure 8-13). The additional acres in CC01 add a substantial amount of FC pollution during the winter months, most likely because the area between CC and CC01 is the most highly developed section of Clear Creek, which includes multiple known and potential bacterial pollution sources. In the case of Chico Creek, the additional acres in CH01 added very little FC pollution, which was probably within the range of measurement error. In this case, there is little difference in land use between CH and CH01, with few additional bacterial pollution sources.

Using this method, extrapolation of daily FC loads to streams without any actual FC measurements has traditionally been done by matching watershed areas only. This method assumes that similar land areas will produce similar flows and FC concentrations. Thus, the best-fit regression coefficients from one stream are used to estimate the FC concentrations from another of similar area. However, the available LULC data could also be used to further refine this FC loading estimation method.

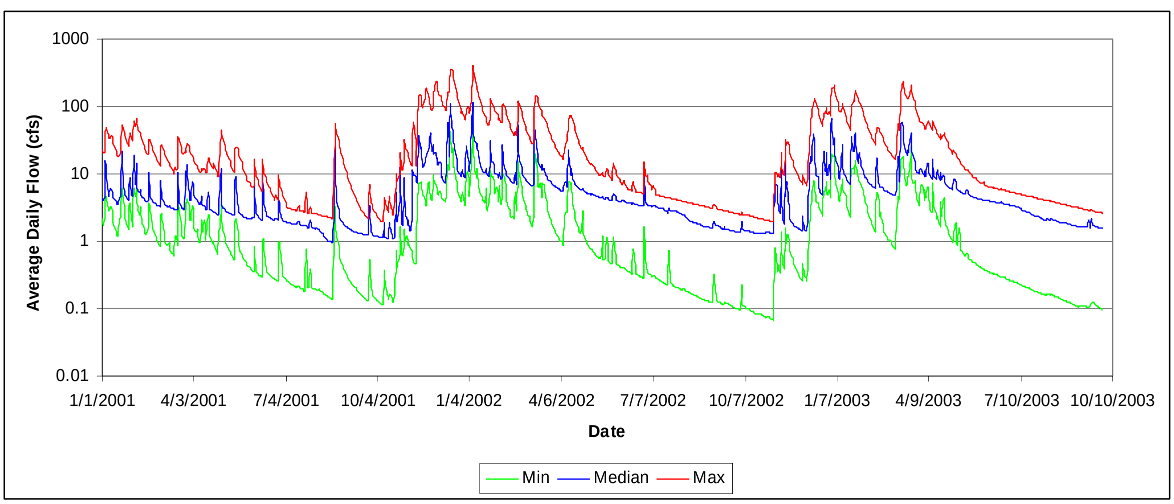


Figure 8-9. Characterization of the Modeled Average Daily Flow from Seven Selected Streams

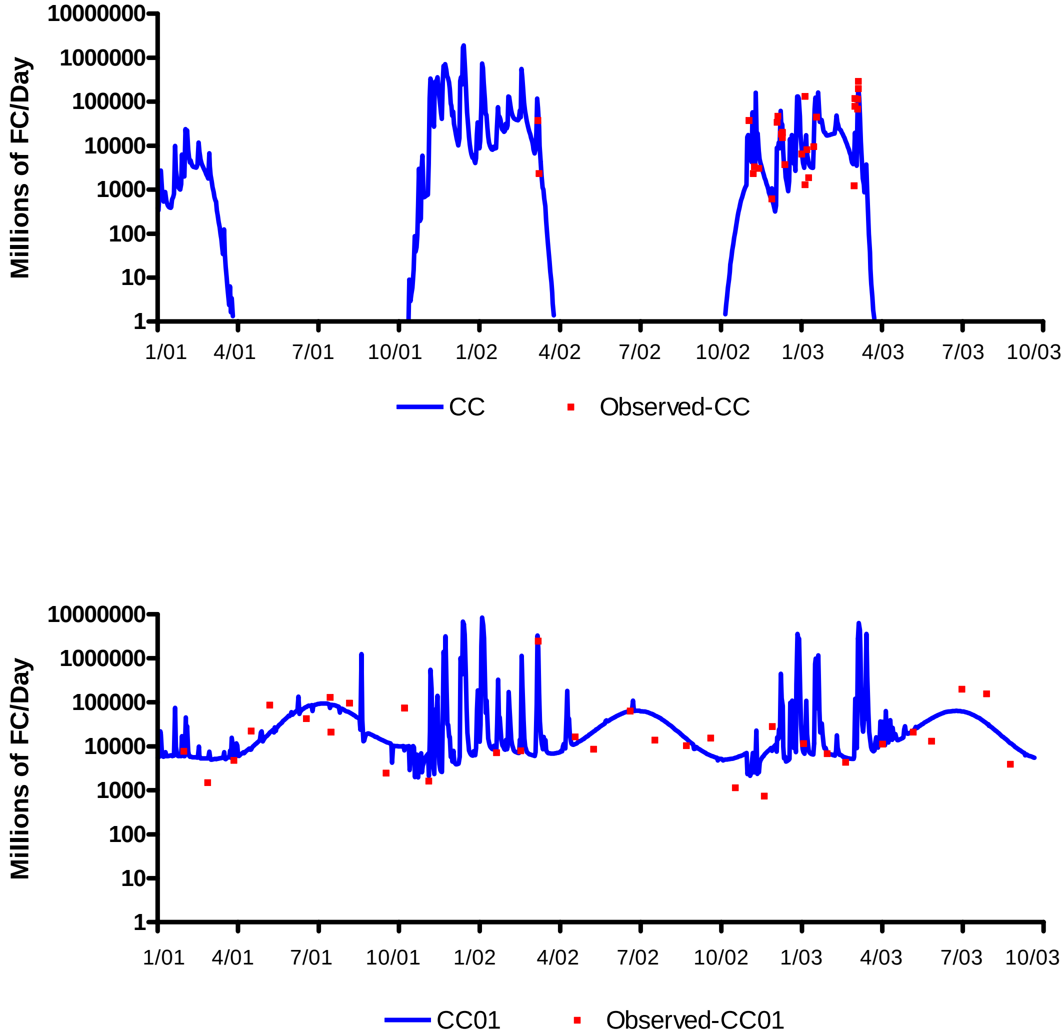
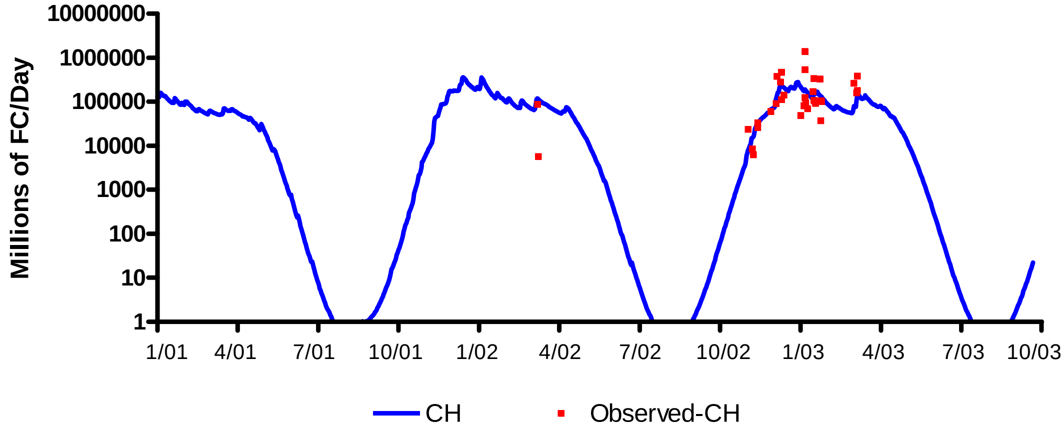


Figure 8-10. Observed and Predicted Fecal Coliform Loadings for CC and CC01



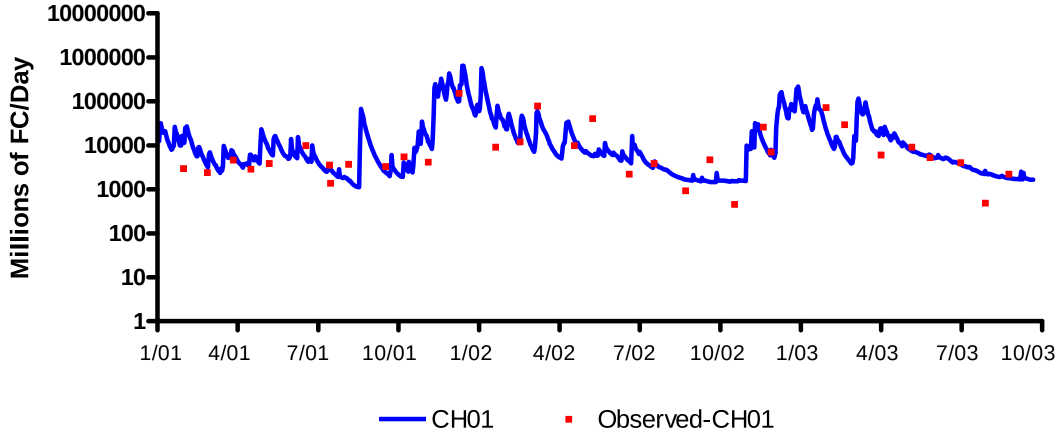


Figure 8-11. Observed and Predicted Fecal Coliform Loadings for CH and CH01

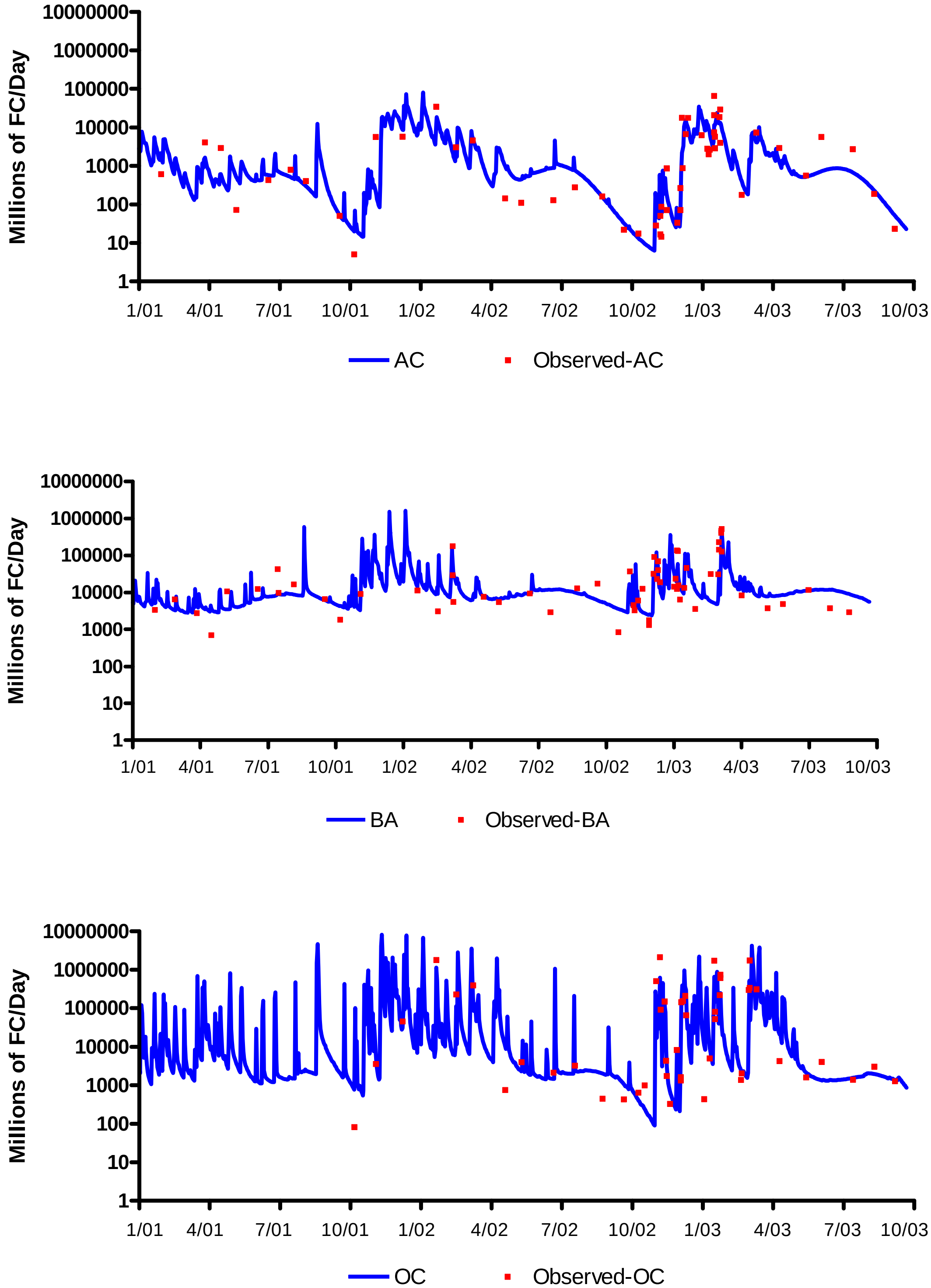


Figure 8-12. Observed and Predicted Fecal Coliform Loadings for AC, BA, and OC

Table 8-6. Distribution of Observed and Predicted Fecal Coliform Loadings (FC/day) for Seven Selected Streams

	Observed Fecal Coliform Loadings						
Statistic	**CC**	**CC01**	**CH**	**CH01**	**AC**	**BA**	**OC**
Mean	46744	107589	188028	15904	5420	51922	252651
Median	18872	12988	104389	4630	866	12440	4652
Standard Deviation	67649	425239	250511	30781	11162	105260	519279
% CV	145%	395%	133%	194%	206%	203%	206%
Minimum	622	750	5654	452	5	702	83
Maximum	285158	2461022	1374950	152791	66264	514926	2119944
25th Percentile	3259	6788	62122	2967	99	5038	1557
75th Percentile	52254	42257	240221	9867	5699	36024	221541

	Predicted Fecal Coliform Loadings						
Statistic	**CC**	**CC01**	**CH**	**CH01**	**AC**	**BA**	**OC**
Mean	21261	108734	48302	26384	2820	21705	118575
Median	0	14656	8592	6579	653	8651	3135
Standard Deviation	107702	582040	67198	62566	6224	81925	563070
% CV	507%	535%	139%	237%	221%	377%	475%
Minimum	0	1953	0	1123	6	2357	89
Maximum	1896148	8331033	357994	646945	80653	1611722	8131918
25th Percentile	0	6961	10	3136	280	5945	1658
75th Percentile	3493	45261	75344	17767	1929	11906	24344

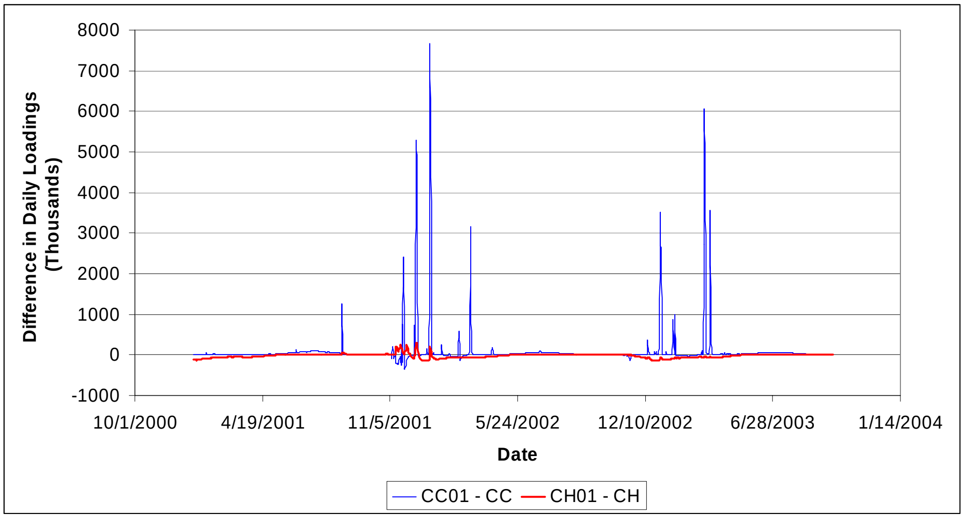


Figure 8-13. Contribution of Non-overlapping Components of CC01 (390 acres) and CH01 (442) to the Predicted Fecal Coliform Daily Loadings

8.2.2 Method 2 – Bounded Analysis Using Distribution Statistics

As the data from this and other studies indicate, FC concentrations tend to be highly variable (Table 8-3). Even with this relatively high variability, an alternative method of estimating FC loading is to estimate a bounded range or interval for the representative FC concentration using the distributional characteristics (e.g., geometric mean, 25th percentile, 75th percentile, and/or 90th percentile) of all the samples taken at a given discharge point. Thus, the estimated FC loading based on the geometric mean, for example, is the sample geometric mean times the daily average flow, corrected for units to give millions of FC/day. The FC concentration intervals can be based on all of the data, selected events (storm events), or on selected seasonal data (wet or dry season). Because there is no need to associate the concentration boundaries with specific flow measurements, more data can be used to better characterize the variability at each stream. Therefore, all data collected between January 2000 and September 2003 were used to characterize the FC concentration distribution by stream (Table 8-7). The estimated interval allows an estimate of the variability in loading to be used in the watershed model, which then can provide an interval estimate of the nearshore FC concentration instead of a single number.

Except for both the low and high extremes, FC concentrations for the test streams were bounded well by the 25th and the 90th percentiles calculated from all of the sampled data (Figure 8-14). Figures 8-15, 8-16, and 8-17 depict the interval estimates when all sample data were used to estimate distribution statistics. CH01 and OC were more often overestimated, but all other streams appeared to be well-bounded by the 25th and 90th percentiles estimated from all of the data. Within the study area, CH01 and OC represent the low and high end of the development spectrum for the test sites, which may explain their lack of fit.

There were no storm-event data for CC01 and CH01 and, therefore, no sample distribution statistics from which to estimate load intervals (Figure 8-18). Storm-event data tended to overestimate loads (Figures 8-19 and 8-20). Wet-season concentration boundaries tended to underestimate loads for CC, CC01, CH, and OC (Figures 8-21 though 8-24). Dry-season concentration boundaries tended to overestimate loads for CC, CC01, CH01, and AC (Figures 8-25 though 8-28). The reasons for this behavior are not well understood.

As with the previous method, extrapolation of daily FC loads to streams without any FC measurements is based on matching watershed areas. Again, this method assumes that similar watersheds will produce similar FC concentrations. Thus, the distribution statistics from one stream would be used to estimate the FC load intervals for another stream of similar watershed area and LULC characteristics.

Table 8-7. Descriptive Statistics for Fecal Coliform Data Collected Between January 2000 and September 2003 Used for Loading Interval Estimation for Seven Selected Streams

All Data

Stream	Geometric Mean of FC/100 mL	N	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	Geometric Mean <100	N>200 FC/100 mL	P>200	Meets WQ Std
CC	59.5	75	2	1600	21.5	185	393	YES	18	0.24	NO
CC01	108	42	4	1600	30.0	450	932	NO	15	0.36	NO
CH	32.6	83	1	560	17.0	80.0	210	YES	6	0.07	YES
CH01	25.9	43	1	170	13.0	50.0	119	YES	0	0.00	YES
AC	15.2	64	1	300	4.00	30.0	101	YES	5	0.08	YES
BA	88.2	78	1	900	49.0	235	473	YES	24	0.31	NO
OC	222	65	4	5800	70.0	540	1504	NO	33	0.51	NO

Storm Events

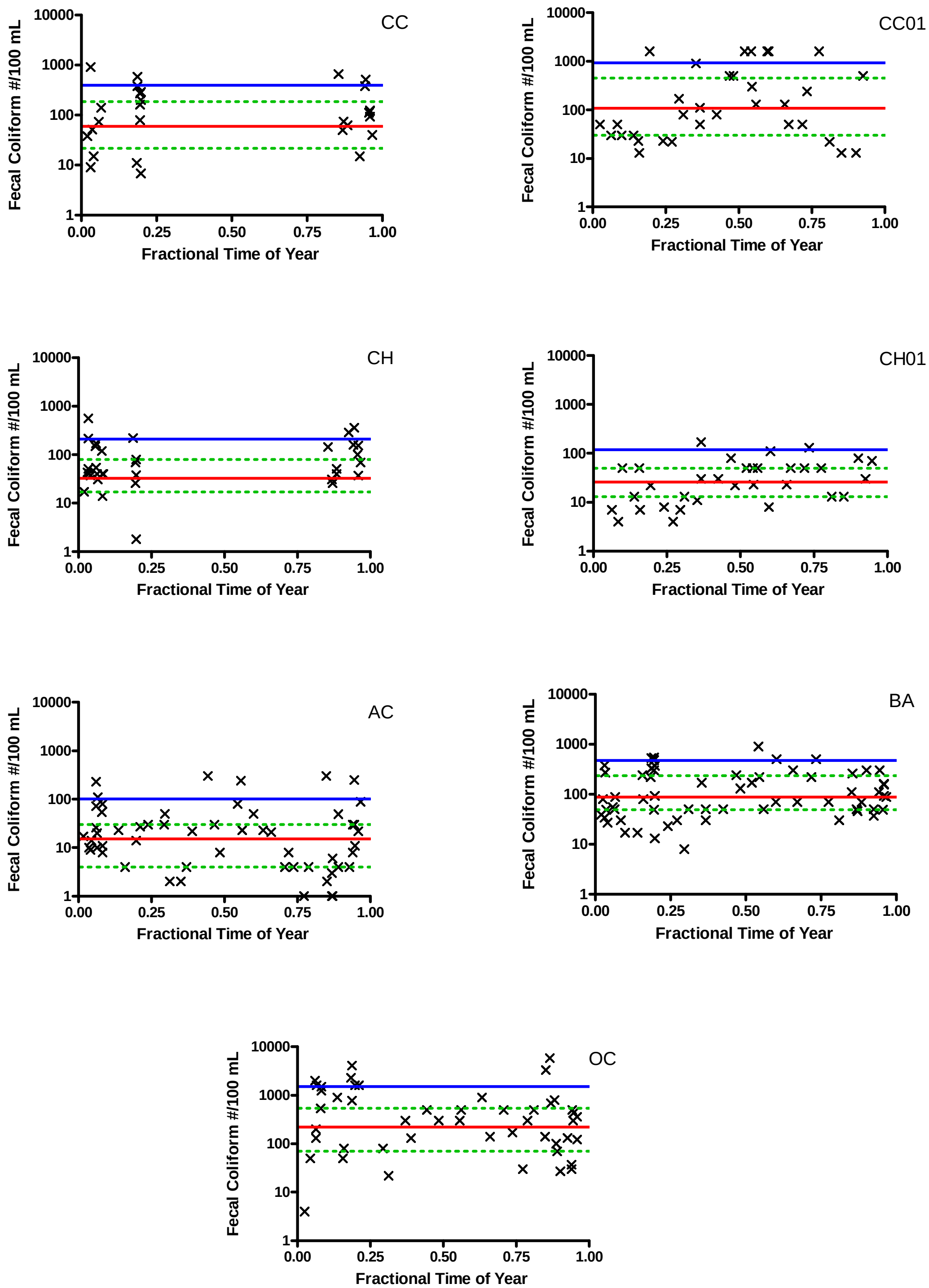
Stream	Geometric Mean of FC/100 mL	N	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	Geometric Mean <100	N>200 FC/100 mL	P>200	Meets WQ Std
CC	86.1	32	9	910	37.8	275	479	YES	9	0.28	NO
CC01											
CH	70.9	38	14	560	38.5	150	223	YES	5	0.13	NO
CH01											
AC	11.7	23	1	250	5.00	24.0	85.5	YES	2	0.09	YES
BA	109	34	8	570	49.0	268	421	NO	11	0.32	NO
OC	365	25	27	5800	123	1233	2840	NO	15	0.60	NO

Wet Season

Stream	Geometric Mean of FC/100 mL	N	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	Geometric Mean <100	N>200 FC/100 mL	P>200	Meets WQ Std
CC	21.3	21	2	300	8	50.0	128	YES	3	0.14	NO
CC01	49.6	22	4	1600	22	148	387	YES	4	0.18	NO
CH	7.77	22	1	110	1.85	25	57.8	YES	0	0.00	YES
CH01	15.2	23	1	80	7	40.0	69.3	YES	0	0.00	YES
AC	13.6	21	1	300	4	30.0	88.1	YES	1	0.05	YES
BA	52.9	23	1	900	26.5	95.0	351	YES	5	0.22	NO
OC	125	23	4	1600	42	400	956	NO	9	0.39	NO

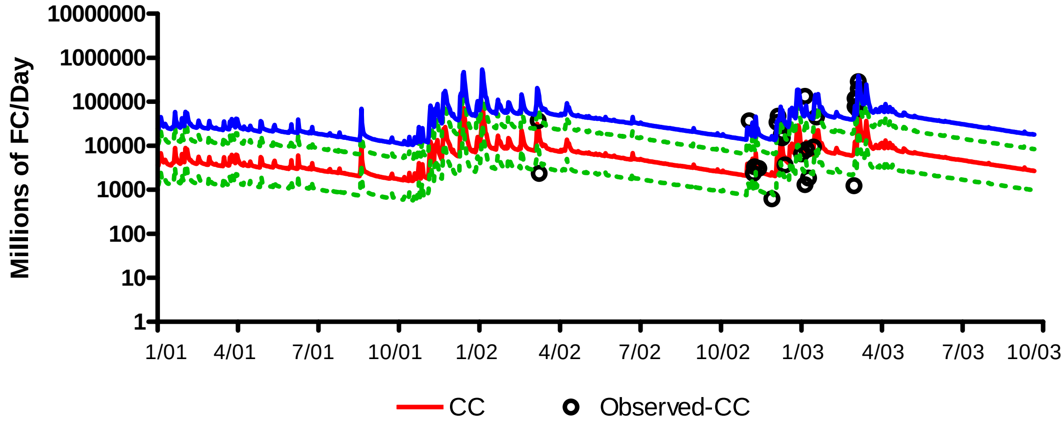
Dry Season

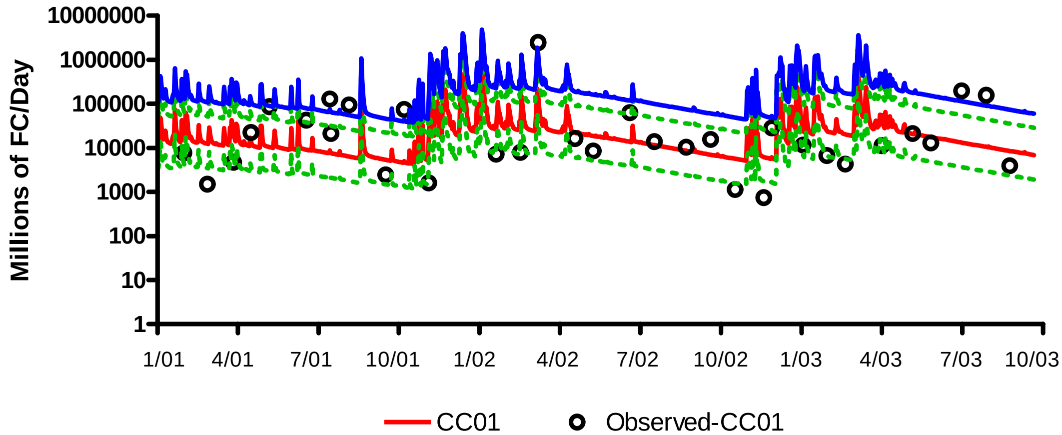
Stream	Geometric Mean of FC/100 mL	N	Min FC	Max FC	25th Percentile	75th Percentile	90th Percentile	Geometric Mean <100	N>200 FC/100 mL	P>200	Meets WQ Std
CC	104	20	8	1600	50	240	552	NO	6	0.30	NO
CC01	255	20	50	1600	72.5	900	1408	NO	11	0.55	NO
CH	41.2	20	4	300	23	72.5	141	YES	1	0.05	YES
CH01	47.8	20	8	170	28.25	87.5	148	YES	0	0.00	YES
AC	19.8	18	2	240	8	45.0	115	YES	1	0.06	YES
BA	109	21	1	900	50	220	656	NO	8	0.38	NO
OC	232	17	50	900	140	500	704	NO	9	0.53	NO



red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

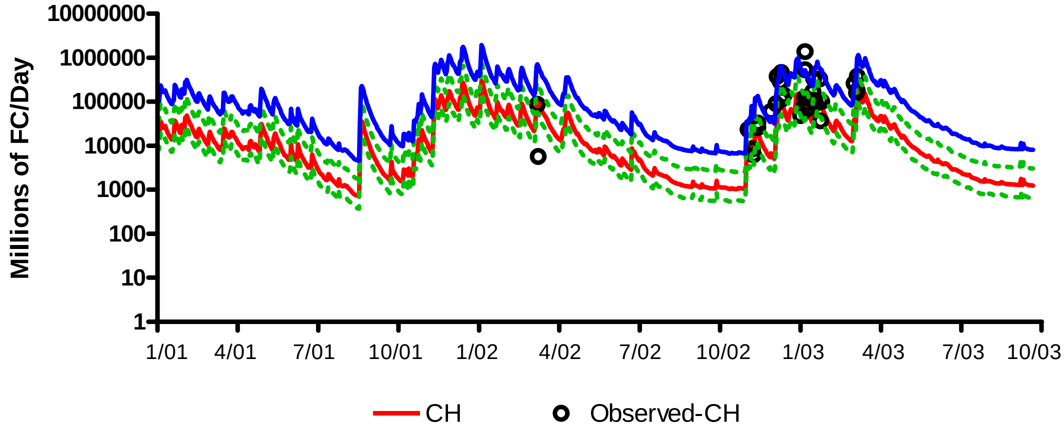
Figure 8-14. Fecal Coliform Concentration Boundaries Based on Sample Distribution Statistics Using All of the Data

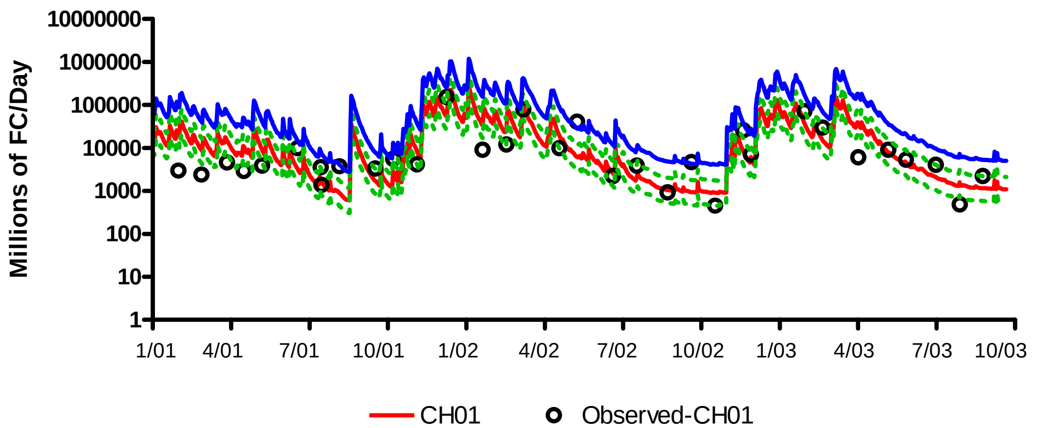




red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

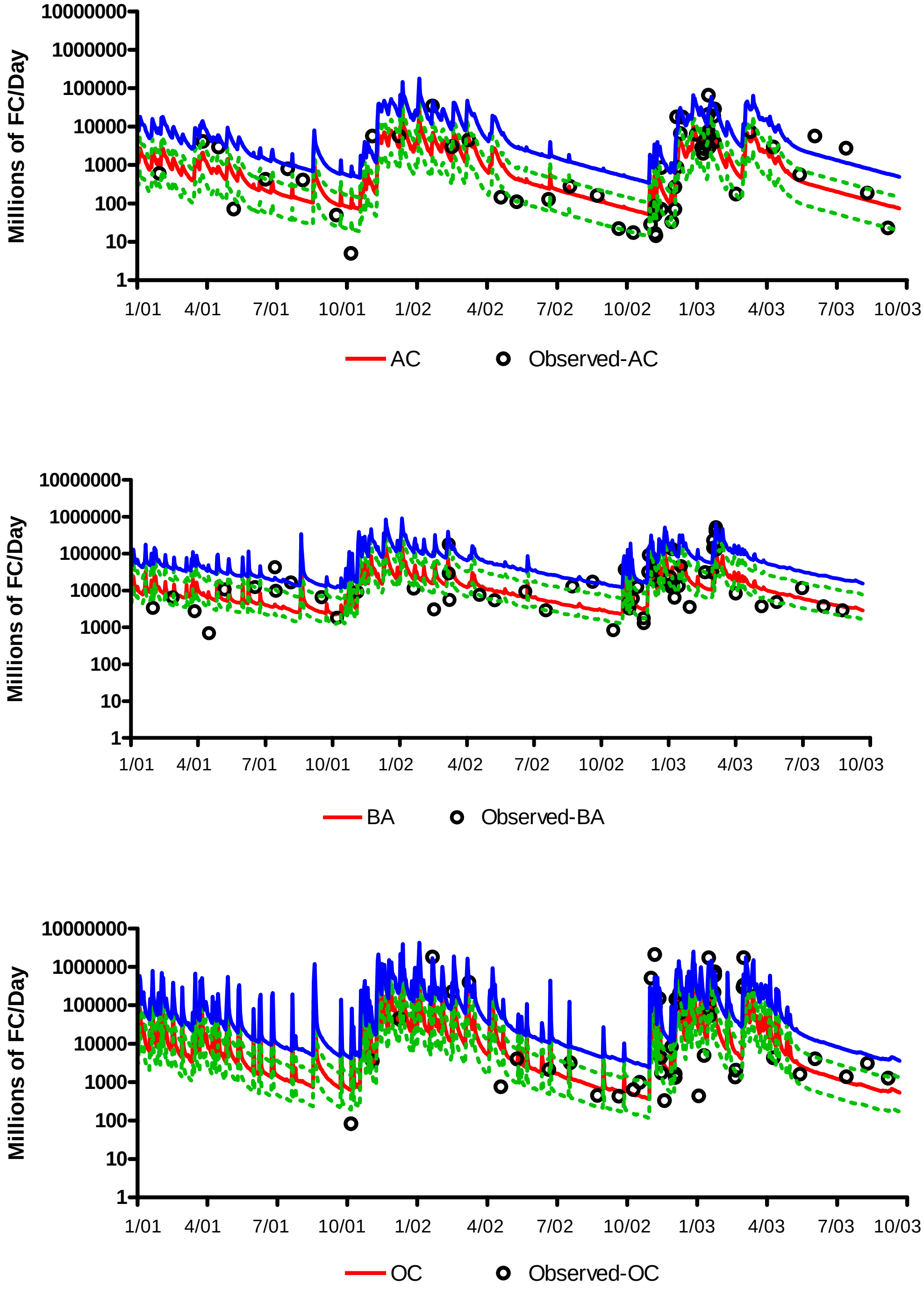
Figure 8-15. Interval Estimates of the Fecal Coliform Load for CC and CC01 Based on Sample Distribution Statistics Using All of the Data





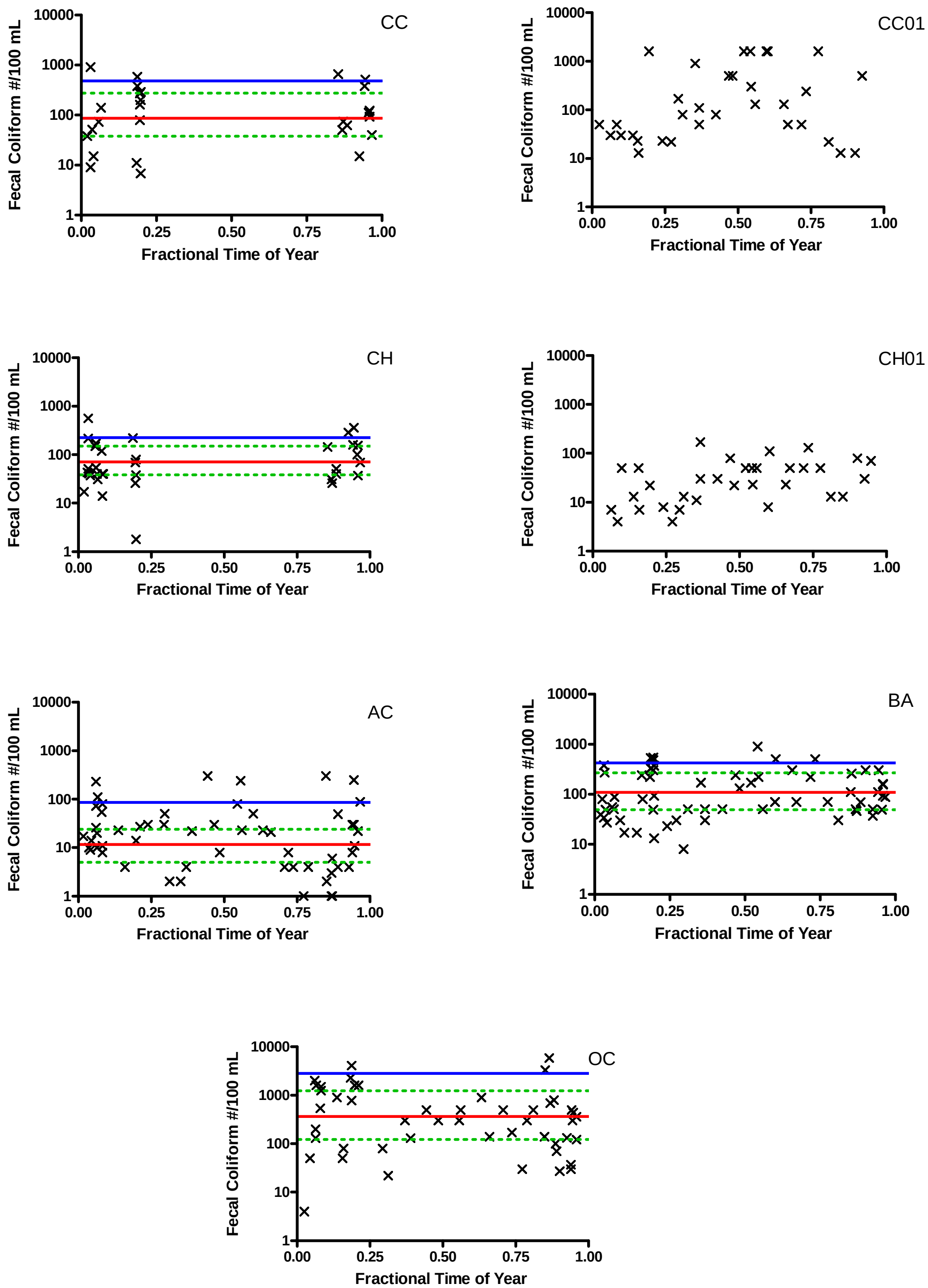
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

Figure 8-16. Interval Estimates of the Fecal Coliform Load for CH and CH01 Based on Sample Distribution Statistics Using All of the Data



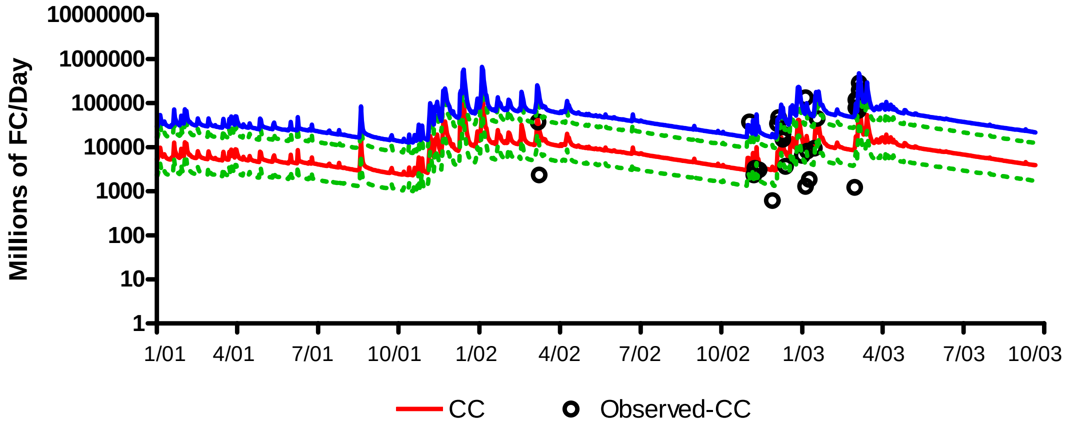
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

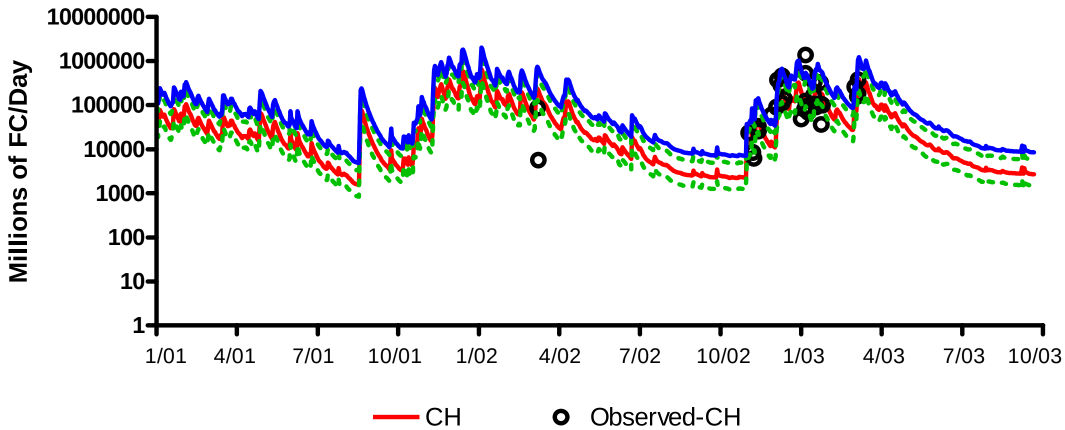
Figure 8-17. Interval Estimates of the Fecal Coliform Load for AC, BA, and OC Based on Sample Distribution Statistics Using All of the Data



red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

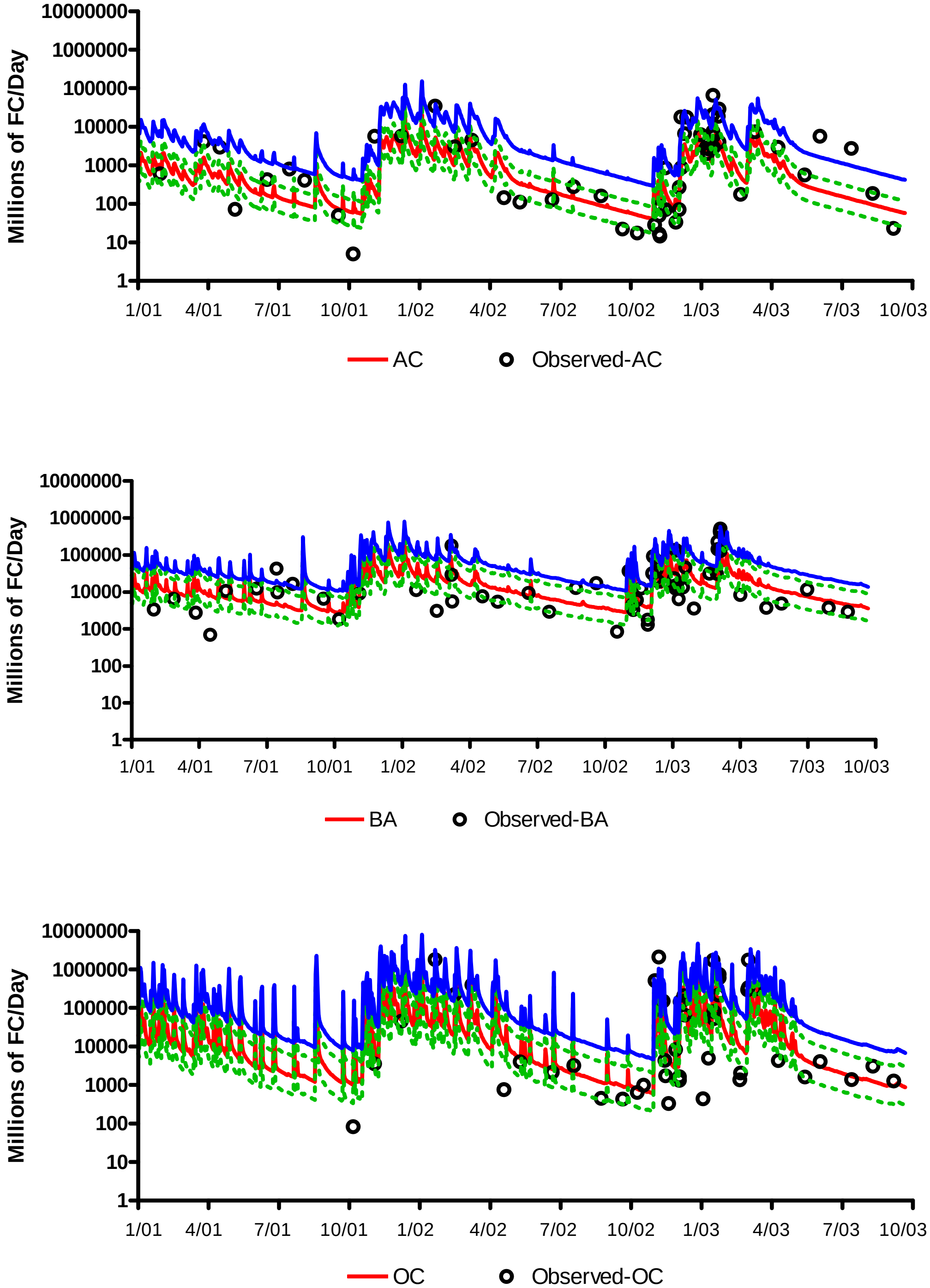
Figure 8-18. Fecal Coliform Concentration Boundaries Based on Sample Distribution Statistics Using Storm-Event Data





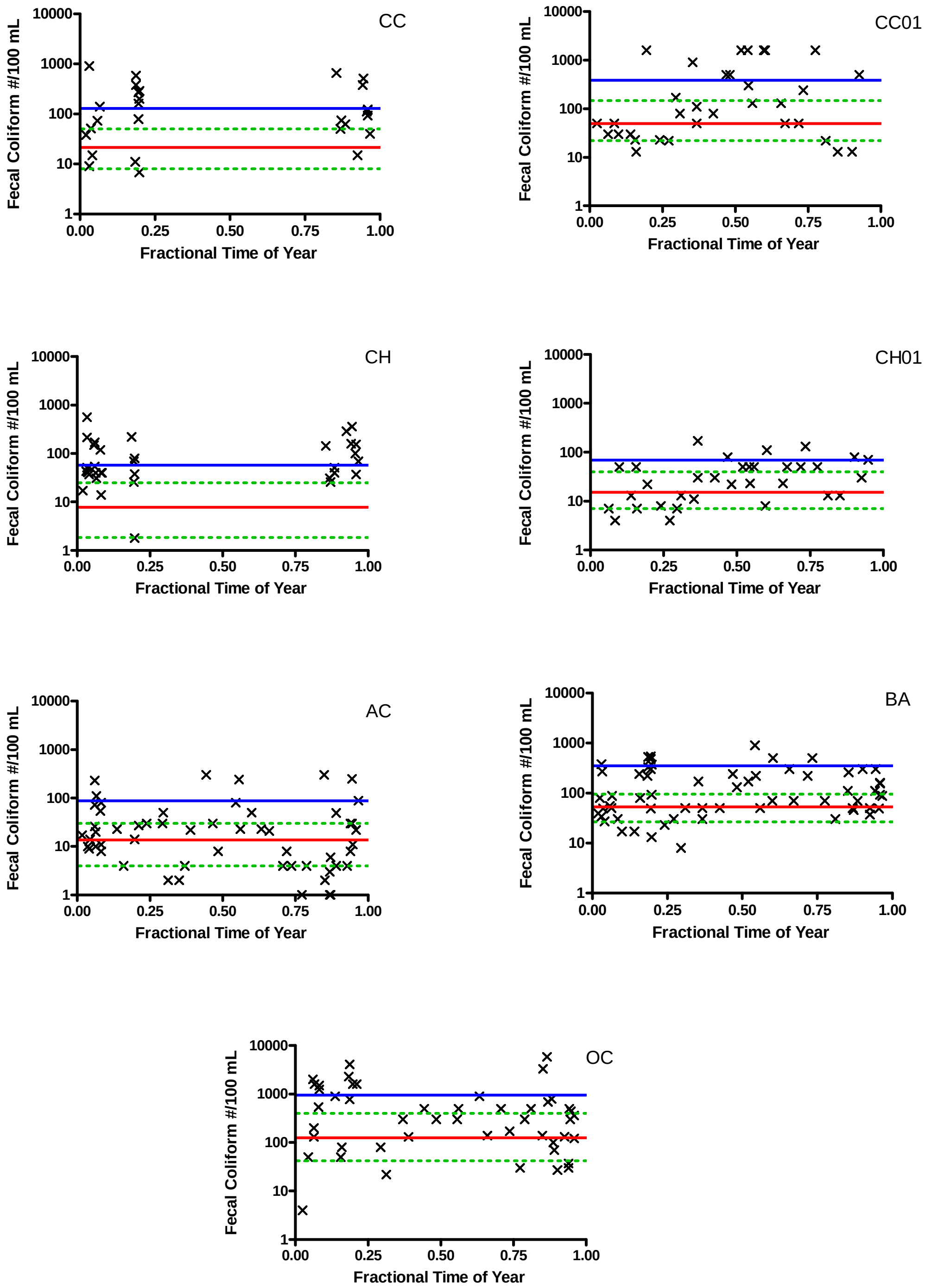
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

Figure 8-19. Interval Estimates of the Fecal Coliform Load for CC and CH Based on Sample Distribution Statistics Using Storm-Event Data



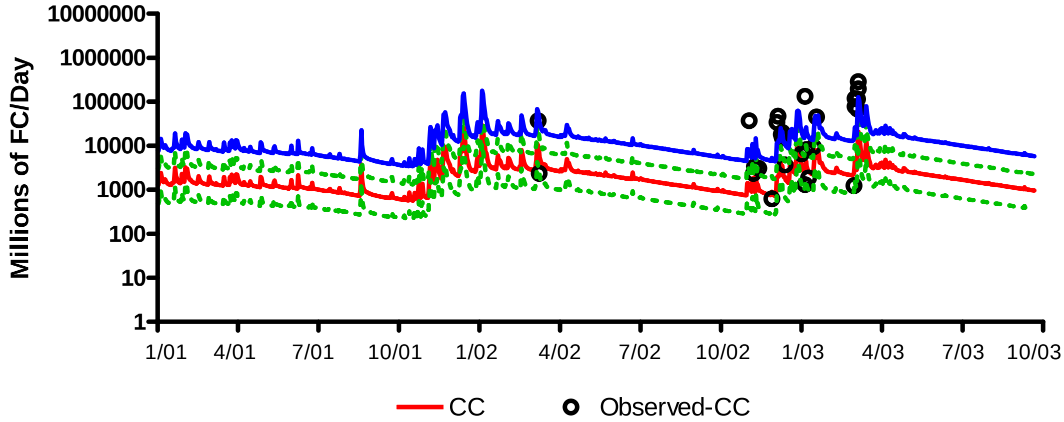
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

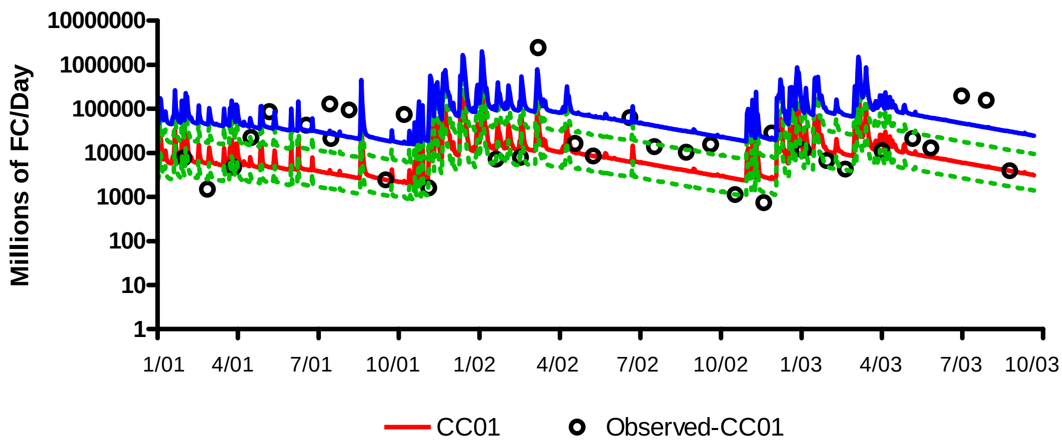
Figure 8-20. Interval Estimates of the Fecal Coliform Load for AC, BA, and OC Based on Sample Distribution Statistics Using Storm-Event Data



red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

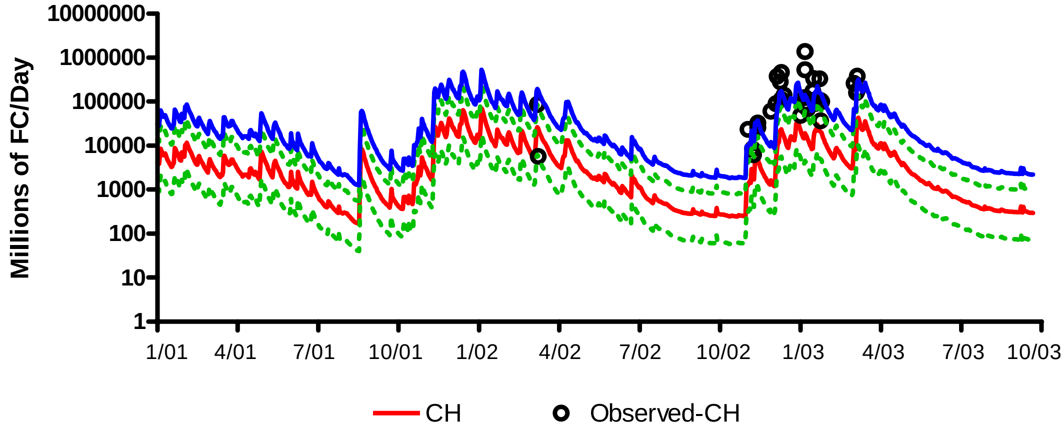
Figure 8-21. Fecal Coliform Concentration Boundaries Based on Sample Distribution Statistics Using Wet-Season Data

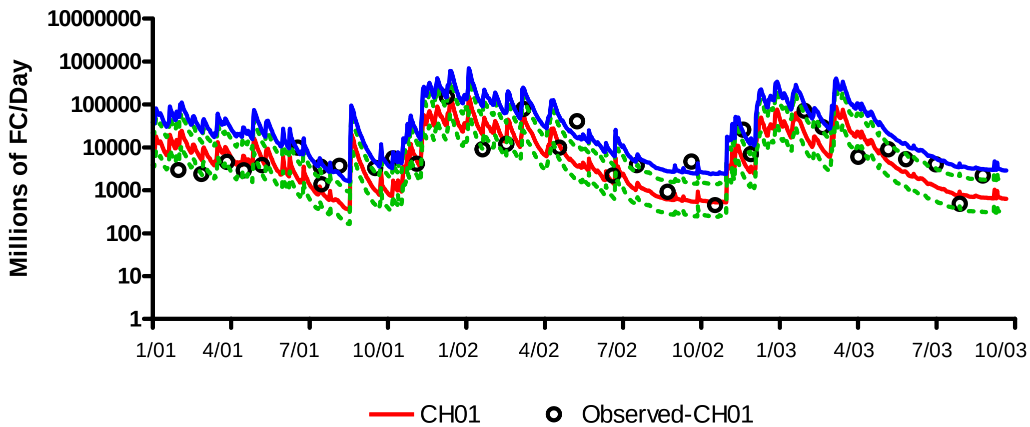




red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

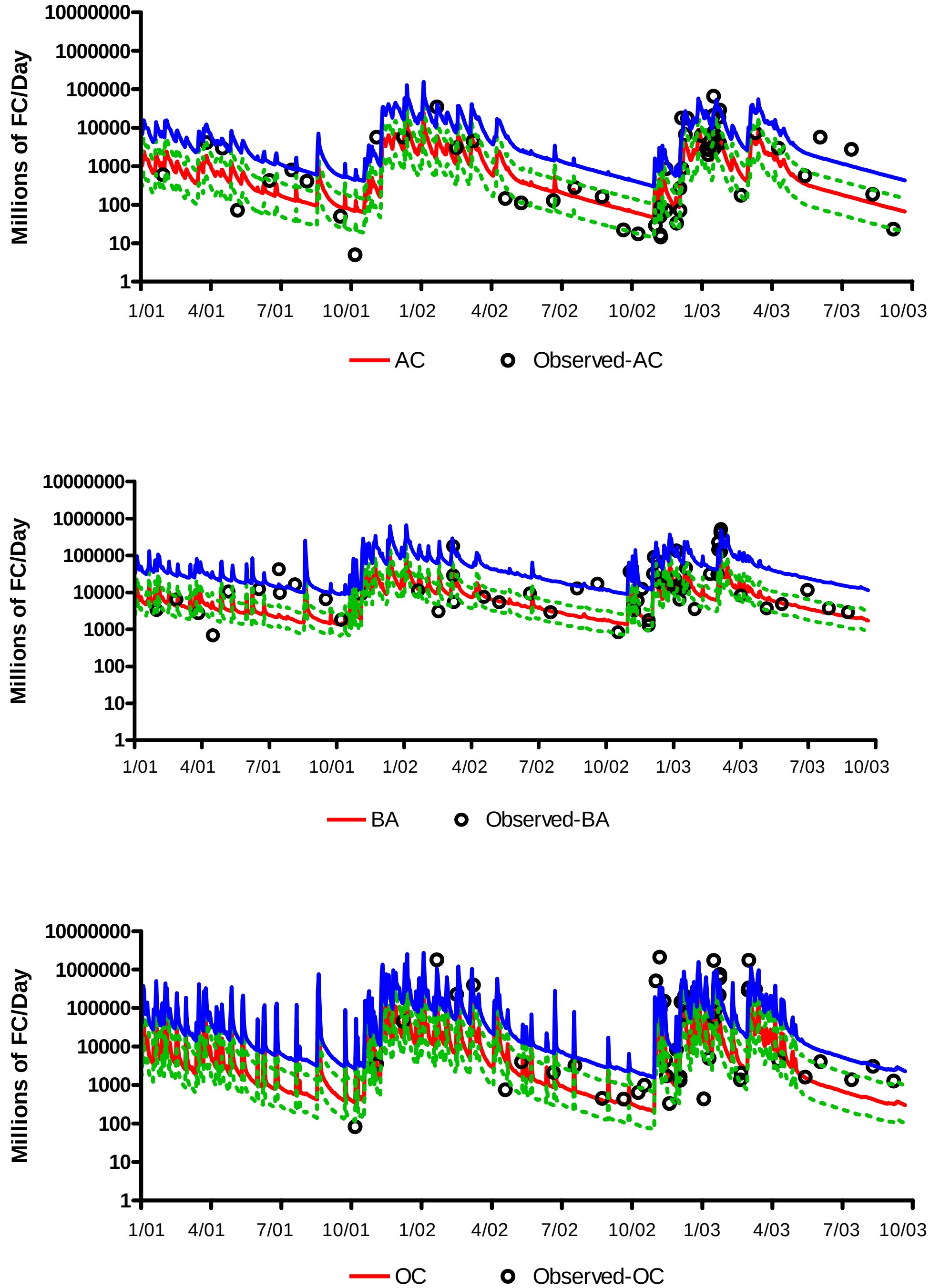
Figure 8-22. Interval Estimates of the Fecal Coliform Load for CC and CC01 Based on Sample Distribution Statistics Using Wet-Season Data





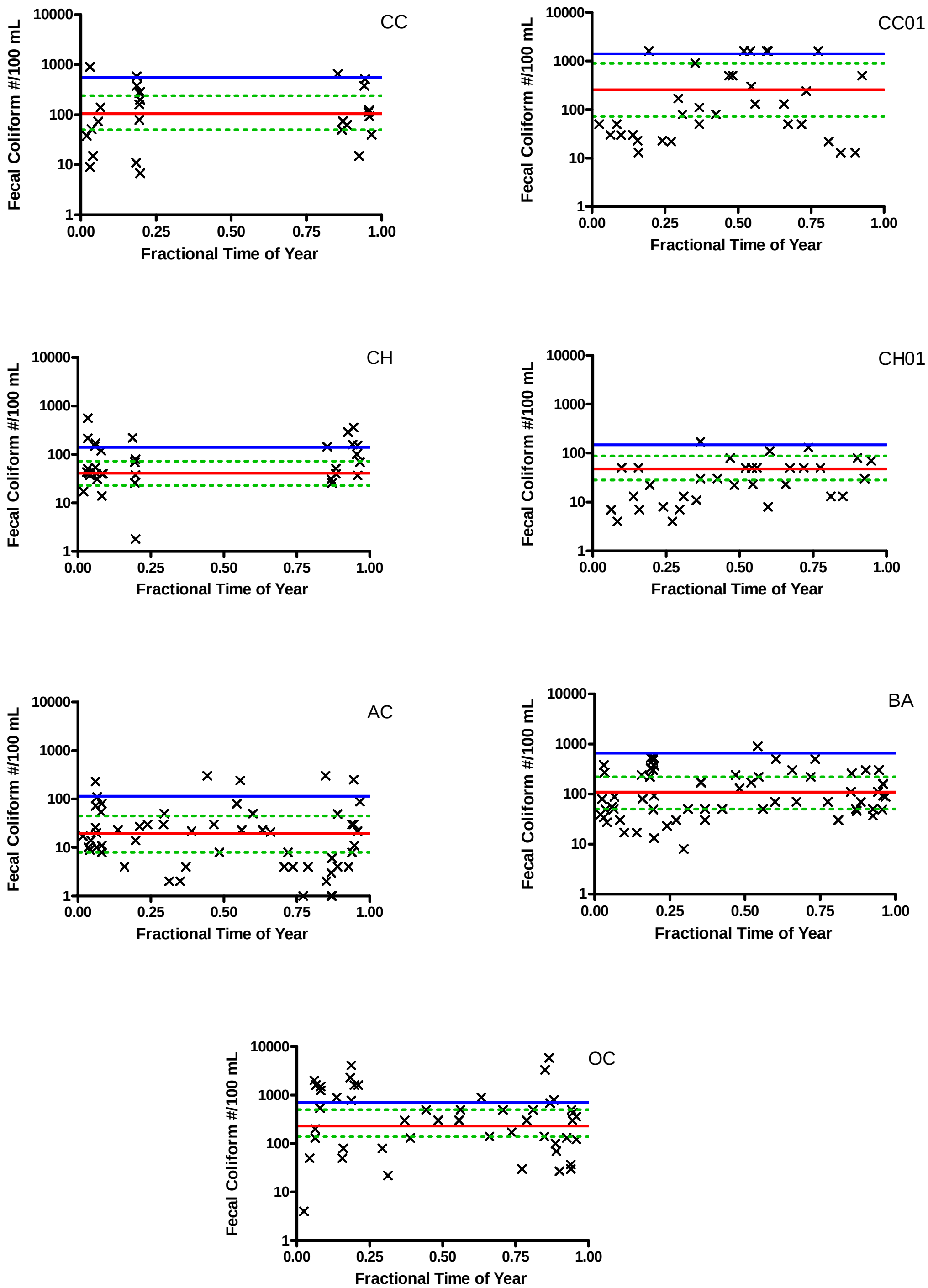
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

Figure 8-23. Interval Estimates of the Fecal Coliform Load for CH and CH01 Based on Sample Distribution Statistics Using Wet-Season Data



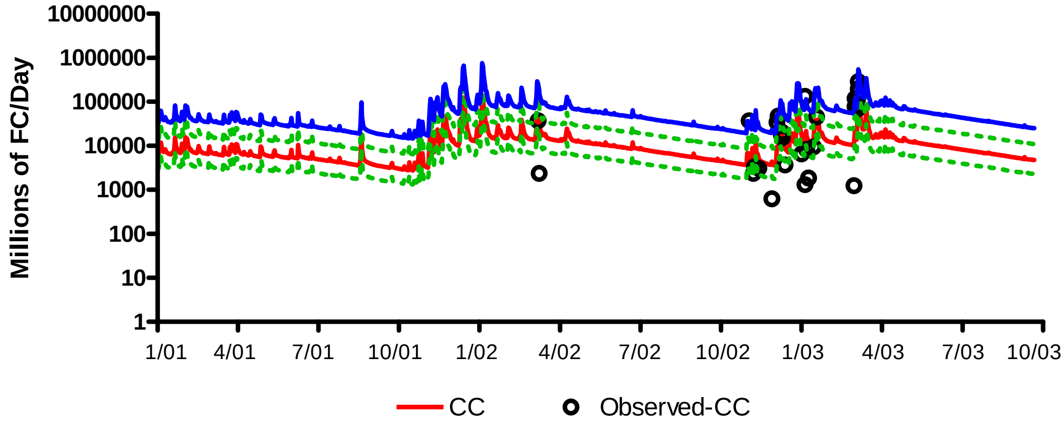
red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

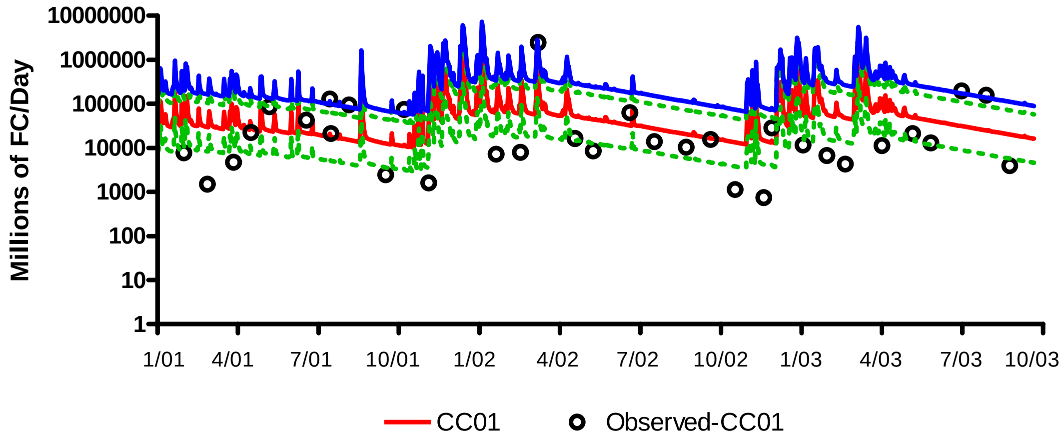
Figure 8-24. Interval Estimates of the Fecal Coliform Load for AC, BA, and OC Based on Sample Distribution Statistics Using Wet-Season Data



red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

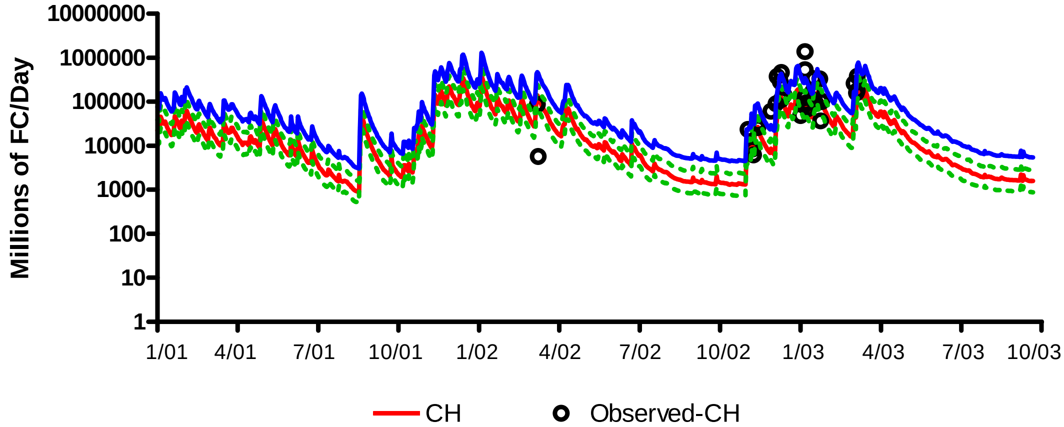
Figure 8-25. Fecal Coliform Concentration Boundaries Based on Sample Distribution Statistics Using Dry-Season Data

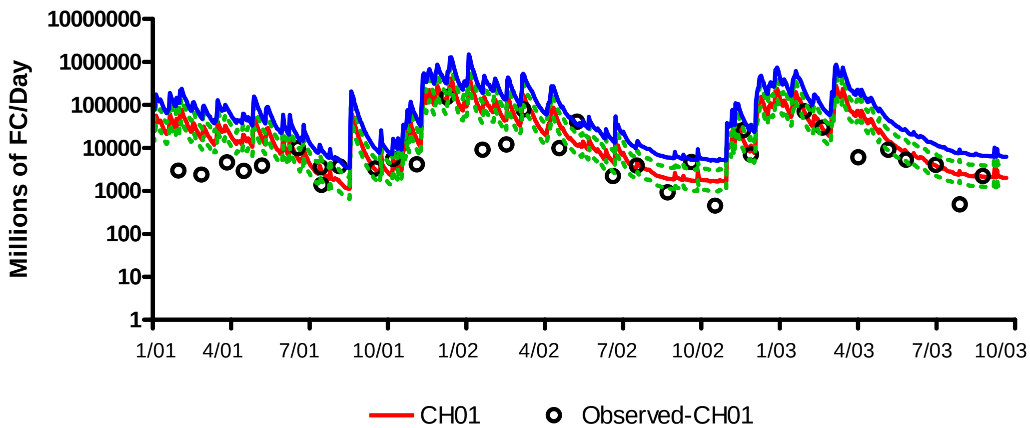




red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

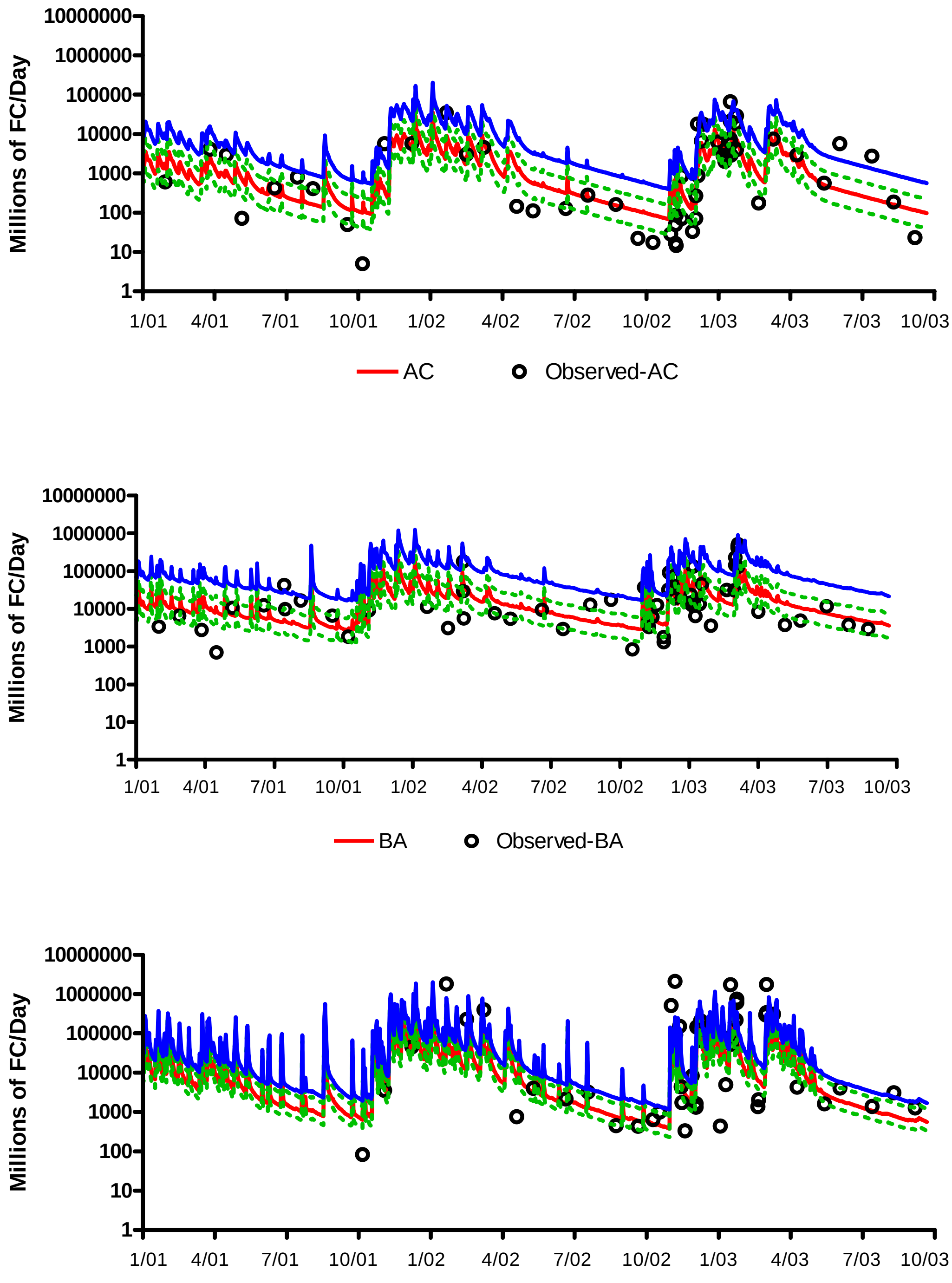
Figure 8-26. Interval Estimates of the Fecal Coliform Load for CC and CC01 Based on Sample Distribution Statistics Using Dry-Season Data





red line = geometric mean
lower and upper green dashed line = 25^{th} and 75^{th} percentiles
blue line = 90^{th} percentile

Figure 8-27. Interval Estimates of the Fecal Coliform Load for CH and CH01 Based on Sample Distribution Statistics Using Dry-Season Data



red line = geometric mean
lower and upper green dashed line = 25th and 75th percentiles
blue line = 90th percentile

Figure 8-28. Interval Estimates of the Fecal Coliform Load for AC, BA, and OC Based on Sample Distribution Statistics Using Dry-Season Data

8.2.3 Method 3 – Step-wise Regression Using Landscape Characteristics

As demonstrated in the data analysis section of this report, sources of FC bacteria tend to vary depending on watershed landscape or LULC characteristics (Chapter 3). Therefore, landscape characteristics can be used to estimate FC concentrations. Available LULC data were collected for stream watersheds in the study area (Table 8-8) along with available FC measurements for the 2000-2003 study period (Table 8-9). Based on these data, a simple regression model was developed using a "step-up" followed by a "step-down" *step-wise regression*. This technique was used to remove redundancies.

The LULC analysis used data based on the watershed and riparian spatial scales. As would be expected, the watershed-scale LULC variables were, in general, highly correlated with each other (Table 8-10). In addition, the LULC variables associated with the 50-meter riparian buffer scale were also correlated with each other, but not as well as the watershed-scale variables. Finally, the LULC variables were also correlated with the FC concentration characteristics for both the whole watershed and the 50-meter riparian buffer scales of analysis.

Step-up step-wise regression produced a regression model with eight significant slopes ($\alpha = 0.05$) using 17 explanatory variables (Table 8-11). The overall regression was significant ($F_{17,20} = 11.989$; $p < 0.0001$) and had an overall adjusted R^2 equal to 0.83. Two streams (AC and CH-KC) had predicted FC geometric mean concentrations less than zero (-23 and -9), both streams being mostly undeveloped and having relatively low FC sample measurements. The correlation between all observed and predicted concentrations was 0.95 (Figure 8-29).

In multiple regression analysis, a number of summary diagnostics are used to understand and evaluate the quality of the predicted model, including evaluating *residuals* and *redundancies* in the explanatory variables. Residuals plotted against major explanatory variables should reflect random noise about zero with a constant variance. A lack of significance of the slope suggests that the variable is not needed for prediction. Further, if the dependent variable is standardized (by subtracting the mean and dividing by the standard deviation) before regression analysis, the magnitude of the resulting slopes (*Beta* in Table 8-12) provides an indication of the contribution of each explanatory variable to prediction (Tables 8-11 and 8-12).

The analysis redundancy (Table 8-12) is indicated by the following criteria:

1) The R^2 between the current variable and all other variables in the regression equation closer to 1
2) The partial correlation closer to 0
3) The semi-partial correlation closer to 0.

The partial correlation is defined as the correlation between the residuals resulting from regressing the respective variable and the dependent variable against all other independent variables in the equation. The semi-partial correlation is defined as the correlation between the dependent variable and the residuals resulting from regressing the respective variable against all other independent variables in the equation. The R^2 value between most of the explanatory variables was greater than 0.8, suggesting a high level of redundancy.

Table 8-8. Land-Use Characteristics of Watersheds Associated with Streams in Sinclair and Dyes Inlet

Name	Watershed	Stream Sub-Watershed	Basin Area (acres)	% Mixed Forest	% Deciduous Forest	% Coniferous Forest	% Shrub	% Natural Vegetation[a]	% Grass or Turf
BVR	Yukon Harbor	Beaver Crk	1235.0	1.7%	46.7%	9.9%	1.1%	59.3%	10.6%
SACCO	Rich Passage	Sacco Crk	651.2	0.7%	41.5%	5.6%	1.8%	49.6%	7.3%
SULV	Rich Passage	Sullivan Crk (LMK155)	196.8	0.0%	46.2%	2.3%	2.5%	51.0%	4.3%
OC	Sinclair Inlet	Olney Crk	1245.4	0.3%	11.6%	16.5%	0.0%	28.5%	1.2%
ANNP	Sinclair Inlet	Annapolis Crk (LMK136)	401.6	1.1%	16.4%	3.5%	0.6%	21.5%	1.3%
BL-RBY	Sinclair Inlet	Ruby Crk Tributary	1711.8	0.9%	13.4%	44.3%	1.0%	59.6%	11.5%
BL-HW	Sinclair Inlet	Upper Blackjack Crk	3525.6	1.0%	15.3%	27.6%	0.8%	44.6%	14.5%
BL	Sinclair Inlet	Blackjack Crk @ SR-16	6902.7	1.5%	15.7%	36.2%	0.9%	54.3%	11.6%
BL-KFC	Sinclair Inlet	Blackjack Crk	8347.4	1.4%	17.6%	32.6%	0.9%	52.5%	10.4%
ROSS	Sinclair Inlet	Ross Crk	1273.4	1.8%	28.9%	19.6%	1.0%	51.4%	6.1%
AC	Sinclair Inlet	Anderson Crk	1265.9	4.3%	29.3%	43.0%	1.9%	78.4%	9.3%
GC-HW	Sinclair Inlet	Heins Crk Headwaters	1005.4	14.0%	41.4%	32.8%	2.2%	90.3%	7.1%
GC-PA	Sinclair Inlet	Parish Crk Tributary	1092.0	1.8%	19.8%	41.4%	1.0%	63.8%	5.5%
GC-JAR	Sinclair Inlet	Upper Gorst Crk	3196.9	2.7%	16.9%	56.1%	1.0%	76.7%	13.1%
GC	Sinclair Inlet	Gorst Crk	6142.3	4.3%	22.4%	48.0%	1.1%	75.8%	9.8%
OBC	Dyes Inlet	Ostrich Bay Crk	402.1	1.1%	16.3%	3.4%	0.6%	21.3%	1.4%
CH-DI	Dyes Inlet	Dickerson Crk Tributary	1474.0	4.5%	15.5%	58.7%	1.2%	79.8%	17.2%
CH-KL	Dyes Inlet	Upper Kitsap Crk	777.9	4.7%	35.7%	35.6%	1.5%	77.5%	6.9%
CH-KC	Dyes Inlet	Kitsap Crk Tributary	1968.2	3.0%	23.6%	24.3%	1.1%	52.0%	9.5%
CH-CT	Dyes Inlet	Chico Crk @ Taylor Rd	7516.3	7.2%	22.3%	45.5%	1.8%	76.7%	11.6%
CH	Dyes Inlet	Chico Crk @ Golf Course	10033.1	6.3%	22.1%	40.6%	1.6%	70.6%	10.7%
CH01	Dyes Inlet	Chico Crk @ Kittyhawk Dr	10475.5	6.1%	22.2%	39.6%	1.5%	69.3%	11.0%
SC	Dyes Inlet	Strawberry Crk	1914.2	0.8%	14.4%	30.7%	0.5%	46.4%	3.7%
CC-BSP	Dyes Inlet	Clear Crk West Fork HW	1117.5	0.7%	6.6%	42.0%	2.0%	51.3%	3.7%
CC-BTL	Dyes Inlet	Clear Crk Trident Lakes Tributary	713.2	0.4%	3.0%	47.9%	0.3%	51.6%	0.4%
CC-CW	Dyes Inlet	Clear Crk - West Fork	2706.8	0.9%	9.3%	36.1%	1.2%	47.5%	4.3%
CC-MTV	Dyes Inlet	Clear Crk - East Fork Mountainview Tributary	1217.6	1.4%	22.0%	33.0%	0.5%	56.9%	3.2%
CC-RTP	Dyes Inlet	Clear Crk - East Fork Ridgetop Tributary	344.9	0.5%	16.2%	20.7%	0.0%	37.5%	1.7%
CC-CE	Dyes Inlet	Clear Crk - East Fork	2297.6	0.9%	20.1%	27.4%	0.6%	48.9%	7.2%
CC	Dyes Inlet	Clear Crk @ Silverdale Way	5004.3	0.9%	14.3%	32.1%	0.9%	48.1%	5.0%
CC01	Dyes Inlet	Clear Crk @ Ridgetop Blvd	5394.6	0.8%	14.3%	31.0%	0.9%	47.0%	4.7%
BA-BH	Dyes Inlet	Barker Crk @ Bucklin Hill Rd	2223.9	1.0%	19.5%	17.4%	0.6%	38.5%	8.3%
BA-NN	Dyes Inlet	Barker Crk @ Nils Nelson Rd	373.8	2.0%	23.6%	20.2%	0.0%	45.7%	1.1%
BA	Dyes Inlet	Barker Crk @ Barker Crk Rd	2597.8	1.2%	20.1%	17.8%	0.5%	39.6%	7.3%
PA	Dyes Inlet	Pharman Crk	303.3	0.7%	19.8%	13.7%	0.1%	34.4%	2.4%
MS	Dyes Inlet	Mosher Crk	1096.9	0.8%	15.2%	11.6%	0.5%	28.1%	3.5%
DEE	PO Passage	Dee Crk	396.8	0.7%	17.2%	7.2%	0.3%	25.4%	2.5%
BI-SBC	PO Passage	Springbrook Crk	1539.6	25.0%	19.1%	33.8%	3.7%	81.6%	0.2%

[a] % Natural Vegetation equals the sum of % Mixed Forest, % Deciduous Forest, % Coniferous Forest, and % Shrub

Table 8-8. (contd)

Name	% Rural (LD Residential)	% Suburban (MD Residential)	% Urban (HD Residential)	% Commercial/ Industrial	%TIA[b]	% Forest	Road Density (km/km^2)	Drainage Density (km / km^2)	Stream-Crossings/ Stream-Length (#/km)
BVR	21.6%	1.6%	3.1%	3.5%	10.4%	58.3%	13.8	2.3	0.6
SACCO	26.0%	4.7%	7.8%	4.6%	15.0%	47.8%	17.7	2.0	1.1
SULV	0.1%	10.1%	8.7%	22.8%	25.1%	48.5%	27.9	1.9	1.3
OC	0.4%	9.2%	36.8%	23.6%	39.5%	28.5%	28.0	1.7	1.0
ANNP	0.0%	19.1%	16.7%	41.3%	43.4%	21.0%	23.9	2.0	2.2
BL-RBY	13.5%	7.9%	4.2%	0.8%	9.9%	58.6%	10.1	1.9	0.2
BL-HW	15.6%	6.1%	8.5%	9.1%	17.6%	43.9%	14.2	1.6	0.8
BL	15.3%	6.1%	5.7%	4.9%	13.1%	53.4%	12.0	1.9	0.5
BL-KFC	12.7%	7.2%	8.0%	7.6%	15.9%	51.6%	14.7	1.8	0.6
ROSS	4.7%	7.8%	12.7%	15.8%	22.5%	50.3%	16.9	2.3	0.6
AC	2.8%	6.9%	1.9%	0.5%	6.6%	76.5%	8.0	2.2	0.5
GC-HW	0.0%	0.0%	0.0%	0.0%	2.7%	88.1%	10.8	3.9	0.4
GC-PA	7.5%	10.0%	6.6%	6.4%	14.1%	62.9%	14.6	1.5	0.7
GC-JAR	1.2%	2.1%	2.3%	3.2%	6.8%	75.7%	4.0	2.0	0.4
GC	2.6%	3.3%	3.3%	3.9%	8.3%	74.7%	8.7	2.3	0.5
OBC	0.0%	19.1%	16.7%	41.4%	43.5%	20.8%	35.7	2.2	3.1
CH-DI	0.0%	1.3%	0.2%	0.0%	3.9%	78.6%	1.1	2.5	0.1
CH-KL	11.9%	1.0%	0.5%	1.8%	5.9%	76.0%	0.7	2.0	0.2
CH-KC	5.1%	6.8%	7.0%	6.4%	13.2%	50.9%	7.0	1.9	0.5
CH-CT	1.7%	5.6%	0.9%	0.2%	5.6%	75.0%	4.0	2.4	0.3
CH	2.3%	6.9%	2.7%	1.8%	8.0%	69.0%	5.4	2.3	0.4
CH01	2.2%	7.3%	3.1%	2.2%	8.6%	67.8%	5.8	2.5	0.4
SC	3.2%	22.0%	11.8%	12.7%	24.1%	46.0%	17.1	1.5	1.2
CC-BSP	1.9%	6.9%	13.8%	22.3%	26.0%	49.2%	12.8	0.8	0.8
CC-BTL	0.2%	5.6%	16.1%	25.8%	28.2%	51.3%	11.0	1.3	0.5
CC-CW	0.8%	9.1%	15.6%	22.7%	27.8%	46.3%	10.1	1.2	1.0
CC-MTV	4.6%	12.0%	9.6%	13.5%	20.4%	56.4%	23.0	1.2	1.5
CC-RTP	0.0%	11.8%	28.4%	20.6%	34.1%	37.5%	38.6	1.8	3.3
CC-CE	2.4%	12.2%	13.4%	15.6%	23.9%	48.4%	24.0	1.5	1.5
CC	1.6%	10.5%	14.6%	19.4%	26.0%	47.2%	16.5	1.3	1.2
CC01	1.4%	10.0%	14.2%	21.8%	27.1%	46.1%	18.1	1.3	1.3
BA-BH	17.5%	6.8%	12.7%	14.6%	23.1%	38.0%	22.0	2.6	1.0
BA-NN	0.0%	15.3%	14.8%	22.2%	29.0%	45.7%	24.1	3.0	0.4
BA	15.0%	8.0%	13.0%	15.7%	23.9%	39.1%	22.3	2.7	0.9
PA	0.0%	19.6%	32.3%	11.3%	33.0%	34.2%	43.7	1.6	2.0
MS	0.0%	21.2%	30.7%	16.4%	36.0%	27.6%	29.0	1.0	1.7
DEE	0.0%	10.4%	35.1%	26.5%	41.1%	25.1%	23.8	0.9	2.0
BI-SBC	13.7%	0.0%	0.0%	2.6%	5.5%	77.9%	9.4	2.4	0.3

[b] see chapter 3 for the source of the % TIA estimates

Table 8-8. (contd)

	Within the 50 m Riparian Buffer										
Name	% Urban (HD Residential)	% Commercial/ Industrial	% Suburban	% Rural (LD Residential)	% Agricultural	%Developed	%TIA	% Deciduous Forest	% Coniferous Forest	% Mixed Forest	% Forest
BVR	1.6%	2.2%	1.1%	10.1%	14.1%	29.0%	8%	60.5%	8.3%	0.8%	69.6%
SACCO	8.0%	4.7%	1.8%	7.6%	2.3%	24.5%	12%	71.0%	2.6%	0.9%	74.4%
SULV	2.0%	1.0%	4.0%	3.0%	0.0%	10.0%	7%	55.0%	10.0%	1.0%	66.0%
OC	5.5%	1.3%	7.0%	0.0%	0.0%	13.8%	9%	74.2%	9.2%	0.2%	83.6%
ANNP	13.9%	19.4%	8.9%	0.0%	3.3%	45.4%	25%	47.1%	4.5%	0.0%	51.6%
BL-RBY	1.3%	0.4%	4.2%	10.6%	18.1%	34.6%	7%	18.6%	37.0%	0.0%	55.6%
BL-HW	1.6%	3.6%	2.6%	10.0%	22.3%	40.1%	9%	25.6%	29.8%	1.5%	56.8%
BL	1.0%	1.9%	2.4%	10.0%	17.4%	32.7%	7%	25.0%	33.3%	1.4%	59.6%
BL-KFC	1.9%	2.7%	2.8%	8.4%	15.2%	31.1%	8%	30.3%	30.5%	1.6%	62.4%
ROSS	7.0%	5.7%	5.7%	2.4%	4.6%	25.4%	12%	42.8%	21.0%	3.4%	67.1%
AC	2.3%	0.7%	5.8%	0.5%	3.9%	13.2%	6%	26.2%	56.8%	2.9%	85.9%
GC-HW	0.0%	0.0%	0.0%	0.0%	5.4%	5.4%	3%	53.6%	19.9%	13.3%	86.7%
GC-PA	4.0%	6.3%	5.6%	1.3%	2.9%	20.1%	10%	38.9%	38.0%	1.5%	78.3%
GC-JAR	0.0%	0.0%	0.0%	0.0%	5.4%	5.4%	3%	53.6%	19.9%	13.3%	86.7%
GC	2.1%	2.7%	1.5%	0.4%	6.4%	13.1%	6%	39.5%	37.6%	5.7%	82.8%
OBC	16.0%	20.8%	19.0%	0.0%	1.1%	56.9%	29%	33.7%	5.6%	1.6%	40.9%
CH-DI	21.4%	0.0%	15.4%	0.0%	0.0%	36.8%	18%	4.3%	56.8%	0.0%	61.1%
CH-KL	0.0%	0.0%	2.5%	5.4%	9.1%	16.9%	5%	62.2%	16.3%	3.2%	81.8%
CH-KC	8.8%	2.2%	8.1%	2.2%	8.0%	29.3%	11%	31.9%	16.5%	2.0%	50.3%
CH-CT	0.2%	0.3%	4.2%	0.8%	6.9%	12.5%	4%	37.9%	32.8%	6.3%	77.0%
CH	2.0%	0.8%	5.4%	0.9%	8.4%	17.5%	6%	34.8%	32.2%	4.9%	71.9%
CH01	2.3%	1.4%	5.7%	0.9%	8.4%	18.5%	7%	35.2%	31.4%	4.7%	71.3%
SC	9.3%	11.0%	20.4%	0.6%	6.6%	47.9%	21%	31.1%	19.2%	1.2%	51.5%
CC-BSP	5.1%	6.9%	8.8%	4.0%	2.4%	27.2%	12%	23.3%	47.9%	1.3%	72.5%
CC-BTL	24.9%	25.4%	7.1%	0.0%	0.0%	57.4%	23%	8.1%	29.8%	1.3%	39.1%
CC-CW	12.3%	12.2%	8.7%	0.0%	2.8%	36.0%	19%	25.8%	32.5%	2.5%	60.9%
CC-MTV	20.4%	9.2%	3.5%	0.0%	0.6%	33.8%	20%	36.2%	24.9%	0.1%	61.2%
CC-RTP	13.2%	9.9%	18.5%	0.0%	23.5%	65.1%	24%	31.3%	3.3%	0.0%	34.6%
CC-CE	7.4%	4.1%	7.7%	6.6%	12.9%	38.7%	13%	40.3%	17.7%	2.4%	60.4%
CC	10.1%	8.5%	8.3%	3.0%	7.4%	37.2%	17%	32.4%	25.7%	2.5%	60.6%
CC01	11.2%	9.7%	8.3%	2.2%	11.4%	42.9%	18%	32.6%	20.6%	2.0%	55.1%
BA-BH	5.3%	7.4%	4.9%	4.1%	4.8%	26.5%	12%	35.9%	20.9%	0.1%	57.0%
BA-NN	6.1%	8.4%	5.3%	11.5%	11.2%	42.6%	15%	31.0%	17.0%	0.8%	48.8%
BA	6.2%	8.3%	7.0%	9.0%	8.8%	39.3%	15%	33.4%	18.8%	1.5%	53.7%
PA	10.1%	11.2%	17.4%	0.0%	2.8%	41.5%	20%	32.1%	13.4%	0.9%	46.4%
MS	13.3%	8.7%	24.1%	0.0%	2.3%	48.4%	23%	31.8%	17.4%	2.3%	51.5%
DEE	17.2%	4.7%	20.0%	10.0%	1.4%	53.3%	22%	44.1%	0.1%	0.0%	44.2%
BI-SBC	0.0%	0.0%	15.0%	10.0%	0.0%	25.0%	7%	40.0%	20.0%	15.0%	75.0%

Table 8-9. Fecal Coliform Data for Watersheds Associated with Streams in Sinclair and Dyes Inlet

	All Available FC Data										
Name	Geometric Mean FC/100 mL	Count (N)	Minimum FC	Maximum FC	25th Percentile	75th Percentile	90th Percentile	Geometric Mean FC < 100	N > 200	P > 200	Meets Water Quality Standard
BVR	112	58	8	1600	56	263	532	NO	18	31%	NO
SACCO	130	57	4	1600	50	420	761	NO	26	46%	NO
SULV	27	17	4	560	10	55	154	YES	1	6%	YES
OC	222	65	4	5800	70	540	1504	NO	33	51%	NO
ANNP	258	58	23	3700	115	500	1311	NO	36	62%	NO
BL-RBY	30	21	2	1600	11	50	273	YES	2	10%	YES
BL-HW	24	40	2	300	10	70	134	YES	3	8%	YES
BL	65	71	4	1100	30	179	344	YES	16	23%	NO
BL-KFC	65	56	1	900	23	148	355	YES	10	18%	NO
ROSS	35	39	1	900	11	120	355	YES	9	23%	NO
AC	15	64	1	300	4	30	101	YES	5	8%	YES
GC-HW	5	34	1	80	2	16	27	YES	0	0%	YES
GC-PA	24	19	1	460	9	69	159	YES	1	5%	YES
GC-JAR	71	60	2	1600	30	147	397	YES	11	18%	NO
GC	67	67	1	1600	25	170	398	YES	16	24%	NO
OBC	276	40	8	1600	73	1600	2606	NO	25	63%	NO
CH-DI	38	59	1	1600	13	109	313	YES	5	8%	YES
CH-KL	37	23	2	590	19	92	212	YES	2	9%	YES
CH-KC	24	55	1	900	10	50	136	YES	3	5%	YES
CH-CT	24	30	1	330	11	61	150	YES	1	3%	YES
CH	33	83	1	560	17	80	210	YES	6	7%	YES
CH01	26	43	1	170	13	50	119	YES	0	0%	YES
SC	90	76	4	1600	30	275	577	YES	25	33%	NO
CC-BSP	61	19	3	680	19	173	435	YES	4	21%	NO
CC-BTL	42	21	9	460	11	88	221	YES	2	10%	YES
CC-CW	41	70	2	900	12	145	254	YES	15	21%	NO
CC-MTV	32	31	1	1600	8	120	360	YES	3	10%	YES
CC-RTP	61	43	4	1601	14	220	533	YES	12	28%	NO
CC-CE	146	33	16	1680	54	380	722	NO	16	48%	NO
CC	59	75	2	1600	22	185	393	YES	18	24%	NO
CC01	108	42	4	1600	30	450	932	NO	15	36%	NO
BA-BH	49	56	1	1600	23	145	347	YES	10	18%	NO
BA-NN	97	56	1	1600	36	300	715	YES	17	30%	NO
BA	88	78	1	900	49	235	473	YES	24	31%	NO
PA	46	28	1	1601	8	255	843	YES	10	36%	NO
MS	36	43	1	900	13	110	268	YES	4	9%	YES
DEE	352	58	14	5700	170	1200	2008	NO	38	66%	NO
BI-SBC	83	5	43	231	51	88	192	YES	1	20%	NO

Table 8-10. Correlation Matrix (r) for Sinclair-Dyes Inlet Landscape Characteristics and Fecal Coliform Concentrations

Variable	Basin Area (acres)	% Mixed Forest	% Deciduous Forest	% Coniferous Forest	% Shrub	% Natural Vegetation	% Grass or Turf	% Rural (LD Residential)
Basin Area (acres)	1.00	0.42	-0.20	0.47	0.27	0.38	0.41	0.03
% Mixed Forest	0.42	1.00	0.14	0.66	0.57	0.80	0.61	-0.29
% Deciduous Forest	-0.20	0.14	1.00	-0.33	0.45	0.24	0.21	0.65
% Coniferous Forest	0.47	0.66	-0.33	1.00	0.39	0.83	0.66	-0.40
% Shrub	0.27	0.57	0.45	0.39	1.00	0.69	0.60	0.24
% Natural Vegetation	0.38	0.80	0.24	0.83	0.69	1.00	0.81	-0.05
% Grass or Turf	0.41	0.61	0.21	0.66	0.60	0.81	1.00	0.26
% Rural (LD Residential)	0.03	-0.29	0.65	-0.40	0.24	-0.05	0.26	1.00
% Suburban (MD Residential)	-0.24	-0.41	-0.37	-0.39	-0.52	-0.62	-0.78	-0.36
% Urban (HD Residential)	-0.37	-0.64	-0.39	-0.57	-0.70	-0.83	-0.79	-0.27
% Commercial/Industrial	-0.39	-0.61	-0.42	-0.60	-0.67	-0.86	-0.85	-0.34
%TIA	-0.41	-0.71	-0.40	-0.68	-0.73	-0.93	-0.90	-0.26
% Forest	0.38	0.80	0.24	0.84	0.67	1.00	0.81	-0.06
Road Density (km/km^2)	-0.40	-0.75	-0.07	-0.81	-0.73	-0.89	-0.82	0.13
Drainage Density (km / km^2)	-0.02	0.40	0.37	0.09	0.02	0.32	0.32	0.26
Stream-Crossings/Stream-Length (#/km)	-0.39	-0.64	-0.18	-0.69	-0.39	-0.81	-0.72	-0.08
% Urban (HD Residential)-Buffer	-0.48	-0.18	-0.32	-0.15	-0.16	-0.33	-0.22	-0.36
% Commercial/Industrial-Buffer	-0.31	-0.52	-0.27	-0.48	-0.37	-0.64	-0.67	-0.13
% Suburban-Buffer	-0.34	-0.15	-0.43	-0.08	-0.31	-0.33	-0.32	-0.47
% Rural (LD Residential)-Buffer	-0.04	-0.37	0.41	-0.49	-0.26	-0.29	-0.10	0.56
% Agricultural-Buffer	0.52	0.01	0.23	0.02	-0.04	0.14	0.23	0.41
%Developed-Buffer	-0.31	-0.47	-0.22	-0.45	-0.46	-0.59	-0.44	-0.07
%TIA-Buffer	-0.48	-0.45	-0.35	-0.41	-0.40	-0.62	-0.55	-0.29
% Deciduous Forest-Buffer	-0.26	-0.39	0.41	-0.56	-0.14	-0.35	-0.36	0.31
% Coniferous Forest-Buffer	0.38	0.65	-0.21	0.83	0.50	0.74	0.60	-0.26
% Mixed Forest-Buffer	0.35	0.41	-0.07	0.61	0.28	0.58	0.39	-0.23
% Forest-Buffer	0.21	0.38	0.24	0.43	0.48	0.58	0.36	0.03

Table 8-10. (contd)

Variable	% Suburban (MD Residential)	% Urban (HD Residential)	% Commercial / Industrial	%TIA	% Forest	Road Density (km/km^2)	Drainage Density (km / km^2)	Stream-Crossings/ Stream-Length (#/km)
Basin Area (acres)	-0.24	-0.37	-0.39	-0.41	0.38	-0.40	-0.02	-0.39
% Mixed Forest	-0.41	-0.64	-0.61	-0.71	0.80	-0.75	0.40	-0.64
% Deciduous Forest	-0.37	-0.39	-0.42	-0.40	0.24	-0.07	0.37	-0.18
% Coniferous Forest	-0.39	-0.57	-0.60	-0.68	0.84	-0.81	0.09	-0.69
% Shrub	-0.52	-0.70	-0.67	-0.73	0.67	-0.73	0.02	-0.39
% Natural Vegetation	-0.62	-0.83	-0.86	-0.93	1.00	-0.89	0.32	-0.81
% Grass or Turf	-0.78	-0.79	-0.85	-0.90	0.81	-0.82	0.32	-0.72
% Rural (LD Residential)	-0.36	-0.27	-0.34	-0.26	-0.06	0.13	0.26	-0.08
% Suburban (MD Residential)	1.00	0.45	0.70	0.70	-0.61	0.57	-0.24	0.60
% Urban (HD Residential)	0.45	1.00	0.76	0.90	-0.82	0.78	-0.46	0.68
% Commercial/Industrial	0.70	0.76	1.00	0.96	-0.86	0.75	-0.30	0.81
%TIA	0.70	0.90	0.96	1.00	-0.93	0.85	-0.38	0.83
% Forest	-0.61	-0.82	-0.86	-0.93	1.00	-0.88	0.32	-0.81
Road Density (km/km^2)	0.57	0.78	0.75	0.85	-0.88	1.00	-0.06	0.68
Drainage Density (km / km^2)	-0.24	-0.46	-0.30	-0.38	0.32	-0.06	1.00	-0.53
Stream-Crossings/Stream-Length (#/km)	0.60	0.68	0.81	0.83	-0.81	0.68	-0.53	1.00
% Urban (HD Residential)-Buffer	0.28	0.36	0.44	0.41	-0.33	0.11	-0.30	0.46
% Commercial/Industrial-Buffer	0.77	0.32	0.80	0.68	-0.65	0.52	-0.15	0.71
% Suburban-Buffer	0.54	0.44	0.36	0.43	-0.33	0.17	-0.44	0.45
% Rural (LD Residential)-Buffer	-0.05	0.12	0.02	0.11	-0.29	0.41	0.17	0.04
% Agricultural-Buffer	-0.07	-0.39	-0.29	-0.30	0.14	-0.08	0.22	-0.37
%Developed-Buffer	0.62	0.37	0.57	0.56	-0.59	0.44	-0.25	0.55
%TIA-Buffer	0.68	0.47	0.73	0.68	-0.62	0.42	-0.33	0.71
% Deciduous Forest-Buffer	-0.05	0.39	0.19	0.30	-0.35	0.45	-0.13	0.36
% Coniferous Forest-Buffer	-0.33	-0.58	-0.55	-0.63	0.74	-0.69	0.23	-0.65
% Mixed Forest-Buffer	-0.35	-0.41	-0.39	-0.47	0.58	-0.55	0.00	-0.37
% Forest-Buffer	-0.55	-0.30	-0.50	-0.49	0.58	-0.38	0.12	-0.42

Table 8-10. (contd)

Variable	% Urban (HD Residential)-Buffer	% Commercial / Industrial-Buffer	% Suburban-Buffer	% Rural (LD Residential)-Buffer	% Agricultural-Buffer	%Developed-Buffer
Basin Area (acres)	-0.48	-0.31	-0.34	-0.04	0.52	-0.31
% Mixed Forest	-0.18	-0.52	-0.15	-0.37	0.01	-0.47
% Deciduous Forest	-0.32	-0.27	-0.43	0.41	0.23	-0.22
% Coniferous Forest	-0.15	-0.48	-0.08	-0.49	0.02	-0.45
% Shrub	-0.16	-0.37	-0.31	-0.26	-0.04	-0.46
% Natural Vegetation	-0.33	-0.64	-0.33	-0.29	0.14	-0.59
% Grass or Turf	-0.22	-0.67	-0.32	-0.10	0.23	-0.44
% Rural (LD Residential)	-0.36	-0.13	-0.47	0.56	0.41	-0.07
% Suburban (MD Residential)	0.28	0.77	0.54	-0.05	-0.07	0.62
% Urban (HD Residential)	0.36	0.32	0.44	0.12	-0.39	0.37
% Commercial/Industrial	0.44	0.80	0.36	0.02	-0.29	0.57
%TIA	0.41	0.68	0.43	0.11	-0.30	0.56
% Forest	-0.33	-0.65	-0.33	-0.29	0.14	-0.59
Road Density (km/km^2)	0.11	0.52	0.17	0.41	-0.08	0.44
Drainage Density (km / km^2)	-0.30	-0.15	-0.44	0.17	0.22	-0.25
Stream-Crossings/Stream-Length (#/km)	0.46	0.71	0.45	0.04	-0.37	0.55
% Urban (HD Residential)-Buffer	1.00	0.39	0.78	-0.16	-0.60	0.66
% Commercial/Industrial-Buffer	0.39	1.00	0.31	-0.05	-0.14	0.63
% Suburban-Buffer	0.78	0.31	1.00	-0.16	-0.44	0.69
% Rural (LD Residential)-Buffer	-0.16	-0.05	-0.16	1.00	0.59	0.40
% Agricultural-Buffer	-0.60	-0.14	-0.44	0.59	1.00	0.06
%Developed-Buffer	0.66	0.63	0.69	0.40	0.06	1.00
%TIA-Buffer	0.85	0.77	0.77	-0.02	-0.39	0.87
% Deciduous Forest-Buffer	-0.30	-0.03	-0.34	0.10	-0.17	-0.33
% Coniferous Forest-Buffer	-0.06	-0.37	-0.04	-0.38	0.04	-0.30
% Mixed Forest-Buffer	-0.48	-0.34	-0.42	-0.36	0.04	-0.64
% Forest-Buffer	-0.55	-0.56	-0.58	-0.41	-0.16	-0.92

Table 8-10. (contd)

Variable	%TIA-Buffer	% Deciduous Forest - Buffer	% Coniferous Forest - Buffer	% Mixed Forest - Buffer	% Forest - Buffer
Basin Area (acres)	-0.48	-0.26	0.38	0.35	0.21
% Mixed Forest	-0.45	-0.39	0.65	0.41	0.38
% Deciduous Forest	-0.35	0.41	-0.21	-0.07	0.24
% Coniferous Forest	-0.41	-0.56	0.83	0.61	0.43
% Shrub	-0.40	-0.14	0.50	0.28	0.48
% Natural Vegetation	-0.62	-0.35	0.74	0.58	0.58
% Grass or Turf	-0.55	-0.36	0.60	0.39	0.36
% Rural (LD Residential)	-0.29	0.31	-0.26	-0.23	0.03
% Suburban (MD Residential)	0.68	-0.05	-0.33	-0.35	-0.55
% Urban (HD Residential)	0.47	0.39	-0.58	-0.41	-0.30
% Commercial/Industrial	0.73	0.19	-0.55	-0.39	-0.50
%TIA	0.68	0.30	-0.63	-0.47	-0.49
% Forest	-0.62	-0.35	0.74	0.58	0.58
Road Density (km/km^2)	0.42	0.45	-0.69	-0.55	-0.38
Drainage Density (km / km^2)	-0.33	-0.13	0.23	0.00	0.12
Stream-Crossings/Stream-Length (#/km)	0.71	0.36	-0.65	-0.37	-0.42
% Urban (HD Residential)-Buffer	0.85	-0.30	-0.06	-0.48	-0.55
% Commercial/Industrial-Buffer	0.77	-0.03	-0.37	-0.34	-0.56
% Suburban-Buffer	0.77	-0.34	-0.04	-0.42	-0.58
% Rural (LD Residential)-Buffer	-0.02	0.10	-0.38	-0.36	-0.41
% Agricultural-Buffer	-0.39	-0.17	0.04	0.04	-0.16
%Developed-Buffer	0.87	-0.33	-0.30	-0.64	-0.92
%TIA-Buffer	1.00	-0.21	-0.30	-0.56	-0.75
% Deciduous Forest-Buffer	-0.21	1.00	-0.74	0.09	0.39
% Coniferous Forest-Buffer	-0.30	-0.74	1.00	0.19	0.31
% Mixed Forest-Buffer	-0.56	0.09	0.19	1.00	0.57
% Forest-Buffer	-0.75	0.39	0.31	0.57	1.00

Table 8-10. (contd)

	All Data						
Variable	**Geometric Mean FC/100 mL**	**Minimum FC**	**Maximum FC**	**25th Percentile**	**75th Percentile**	**90th Percentile**	**P>200**
Basin Area (acres)	-0.43	-0.37	-0.42	-0.40	-0.42	-0.45	-0.48
% Mixed Forest	-0.50	-0.35	-0.45	-0.45	-0.49	-0.51	-0.65
% Deciduous Forest	-0.07	0.01	-0.25	-0.02	-0.06	-0.13	-0.01
% Coniferous Forest	-0.65	-0.58	-0.48	-0.65	-0.60	-0.62	-0.73
% Shrub	-0.53	-0.27	-0.60	-0.47	-0.48	-0.58	-0.52
% Natural Vegetation	-0.71	-0.58	-0.64	-0.67	-0.66	-0.71	-0.76
% Grass or Turf	-0.61	-0.45	-0.56	-0.53	-0.57	-0.64	-0.71
% Rural (LD Residential)	-0.14	-0.11	-0.29	-0.08	-0.11	-0.19	0.00
% Suburban (MD Residential)	0.36	0.43	0.27	0.31	0.30	0.37	0.46
% Urban (HD Residential)	0.78	0.41	0.86	0.70	0.79	0.84	0.74
% Commercial/Industrial	0.68	0.67	0.63	0.64	0.58	0.68	0.73
%TIA	0.76	0.61	0.74	0.70	0.70	0.78	0.80
% Forest	-0.71	-0.58	-0.64	-0.67	-0.65	-0.71	-0.76
Road Density (km/km^2)	0.67	0.43	0.62	0.62	0.63	0.70	0.77
Drainage Density (km / km^2)	-0.39	-0.32	-0.40	-0.36	-0.46	-0.37	-0.35
Stream-Crossings/Stream-Length (#/km)	0.80	0.81	0.66	0.80	0.75	0.75	0.85
% Urban (HD Residential)-Buffer	0.38	0.38	0.39	0.38	0.43	0.39	0.33
% Commercial/Industrial-Buffer	0.31	0.55	0.14	0.31	0.21	0.26	0.48
% Suburban-Buffer	0.37	0.29	0.39	0.37	0.47	0.41	0.29
% Rural (LD Residential)-Buffer	0.22	0.05	0.01	0.31	0.33	0.20	0.25
% Agricultural-Buffer	-0.34	-0.20	-0.48	-0.27	-0.34	-0.39	-0.30
%Developed-Buffer	0.40	0.45	0.22	0.46	0.46	0.38	0.43
%TIA-Buffer	0.48	0.56	0.37	0.49	0.48	0.47	0.53
% Deciduous Forest-Buffer	0.52	0.32	0.51	0.44	0.43	0.52	0.59
% Coniferous Forest-Buffer	-0.70	-0.55	-0.57	-0.69	-0.65	-0.67	-0.76
% Mixed Forest-Buffer	-0.32	-0.29	-0.29	-0.30	-0.33	-0.34	-0.36
% Forest-Buffer	-0.26	-0.32	-0.11	-0.33	-0.32	-0.23	-0.24

Highlighted cells have absolute values greater than 0.7.

Table 8-11. Step-Up Step-Wise Regression Summary for Estimating the Geometric Mean of the Fecal Coliform Concentration Using All of the Data (n = 38)

Variable	B	Std.Err.	t(20)	p-level
Intercept	-291.76	141.56	-2.06	0.05
% Commercial/Industrial	44.73	198.70	0.23	0.82
% Deciduous Forest-Buffer	1029.15	413.93	2.49	0.02
%Developed-Buffer	516.22	277.87	1.86	0.08
% Commercial/Industrial-Buffer	242.48	344.17	0.70	0.49
Road Density (km/km^2)	-4.09	1.65	-2.48	0.02
% Agricultural-Buffer	-906.84	234.80	-3.86	0.00
Stream Length (km)	0.27	0.31	0.87	0.39
% Grass or Turf	618.61	328.70	1.88	0.07
% Forest-Buffer	-445.76	363.44	-1.23	0.23
%TIA-Buffer	-752.99	566.22	-1.33	0.20
Drainage Density (km / km^2)	41.56	13.96	2.98	0.01
% Deciduous Forest	-354.99	150.41	-2.36	0.03
Stream-Crossings/Stream-Length (#/km)	105.89	28.09	3.77	0.00
% Rural (LD Residential)-Buffer	1481.40	413.59	3.58	0.00
% Shrub	-797.41	2078.47	-0.38	0.71
% Rural (LD Residential)	-516.49	222.35	-2.32	0.03
% Coniferous Forest-Buffer	619.41	328.22	1.89	0.07

Highlighted variables do not have slopes significantly different from zero (α = 0.05).

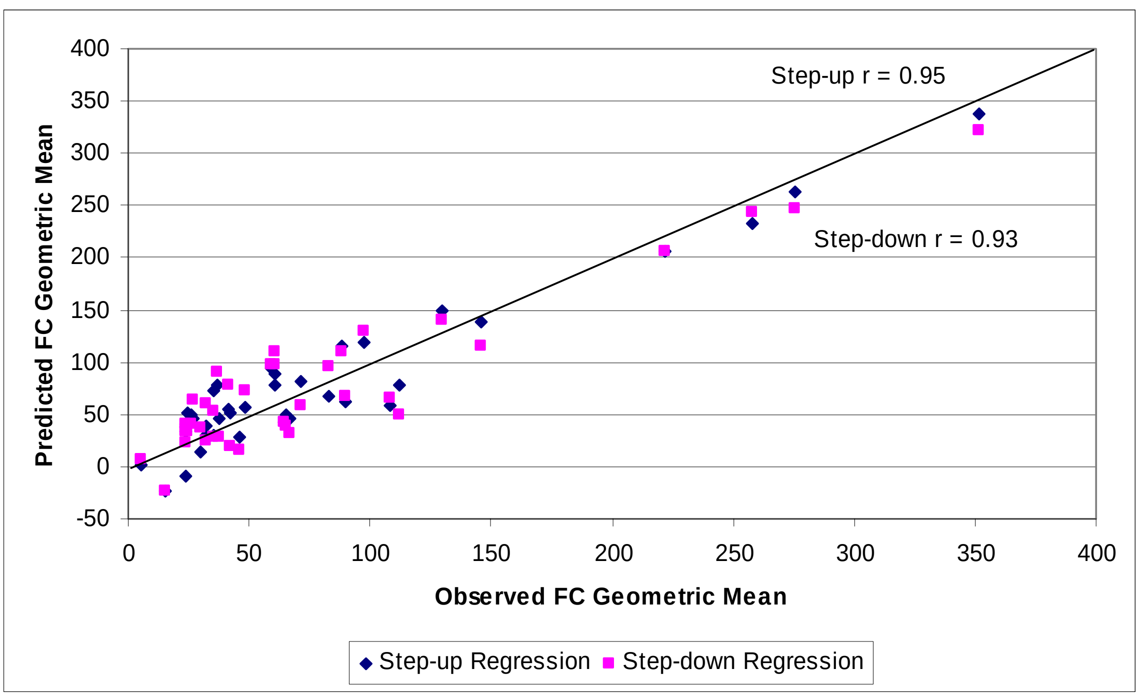


Figure 8-29. Correlation of the Observed and Predicted Fecal Coliform Geometric Mean from the Step-Up and Step-Down Step-Wise Regression

Table 8-12. Summary of Each Variables Contribution to Prediction (Magnitude of *Beta*) and Redundancy of Variables in the Step-Up Step-Wise Regression Model

Variables	*Beta*	Partial Correlation	Semi-partial Correlation	R-square
% Commercial/Industrial	0.063255	0.050272	0.015047	0.943413
% Deciduous Forest-Buffer	1.956544	0.485908	0.166194	0.992785
%Developed-Buffer	1.000065	0.383629	0.124182	0.984581
% Commercial/Industrial-Buffer	0.190596	0.155621	0.047094	0.938946
Road Density (km/km^2)	-0.538401	-0.484613	-0.165615	0.905379
% Agricultural-Buffer	-0.731099	-0.653607	-0.258163	0.875308
Stream Length (km)	0.084987	0.191174	0.058223	0.530665
% Grass or Turf	0.345567	0.387885	0.125802	0.867470
% Forest-Buffer	-0.811732	-0.264487	-0.081984	0.989799
%TIA-Buffer	-0.692436	-0.285030	-0.088893	0.983519
Drainage Density (km / km^2)	0.323559	0.554207	0.199035	0.621600
% Deciduous Forest	-0.456590	-0.466737	-0.157763	0.880614
Stream-Crossings/Stream-Length (#/km)	1.028758	0.644479	0.251966	0.940013
% Rural (LD Residential)-Buffer	0.779323	0.625135	0.239425	0.905615
% Shrub	-0.078119	-0.085474	-0.025645	0.892230
% Rural (LD Residential)	-0.469960	-0.460939	-0.155270	0.890843
% Coniferous Forest-Buffer	1.099940	0.388790	0.126148	0.986847

A step-down step-wise regression using the 17 variables in the final step-up model was conducted to reduce the level of redundancy. This model had 10 explanatory variables with all 10 slopes significantly different from zero and an R^2 value of 0.81 ($F_{10,27} = 17.040$; $p < 0.0001$; Table 8-13). The two models were not significantly different ($p = 0.27$), and thus, the simpler model (10 explanatory variables) was preferred. Redundancy was still high for four of the variables ($R^2 > 0.8$; Table 8-14), but all of the partial correlations had magnitudes greater than 0.55. This model had only one stream (AC) with a predicted FC geometric mean concentration less than zero (-23; Figure 8-29). The correlation between all observed and predicted concentrations was 0.93 (Table 8-14).

For three of the seven selected streams, the predicted FC geometric mean concentration appears reasonable (Figure 8-30). The predicted value for AC was negative (-23) for both the step-up and the step-down models. The concentration was overestimated for CH01 and underestimated for CH and CC01. Estimated loadings tended to follow the same pattern that was observed for the predicted concentrations (Figures 8-31, 8-32, and 8-33).

Extrapolation of daily FC loads to streams without any FC measurements would be based on the step-down regression model. Land-use information is available for all of the watersheds within the study area.

Table 8-13. Step-Down Step-Wise Regression Summary for Estimating the Geometric Mean of the Fecal Coliform Concentration Using All of the Data (n = 38)

Variable	B	Std.Err.	t(27)	p-level
Intercept	-44.748	57.8488	-0.77353	0.445931
% Deciduous Forest	-458.811	86.4674	-5.30618	0.000013
% Rural (LD Residential)	-409.298	117.5875	-3.4808	0.001716
Road Density (km/km^2)	-5.785	1.1739	-4.92764	0.000037
Drainage Density (km / km^2)	49.465	13.0071	3.80294	0.000744
Stream-Crossings/Stream-Length (#/km)	115.678	18.2241	6.34755	0.000001
% Rural (LD Residential)-Buffer	1555.882	222.9355	6.97907	0.000001
% Agricultural-Buffer	-518.7	106.5385	-4.86867	0.000043
% Deciduous Forest-Buffer	1116.89	228.0111	4.8984	0.00004
% Coniferous Forest-Buffer	751.092	213.6853	3.51495	0.001572
% Forest-Buffer	-759.251	201.2836	-3.77204	0.000806

Table 8-14. Summary of Each Variable's Contribution to Prediction (Magnitude of *Beta*) and Redundancy of Variables in the Step-Down Step-Wise Regression Model

Variables	*Beta*	Partial Correlation	Semi-partial Correlation	R-square
% Deciduous Forest	-0.59013	-0.714475	-0.377662	0.590445
% Rural (LD Residential)	-0.37242	-0.556547	-0.247742	0.557484
Road Density (km/km^2)	-0.76077	-0.688110	-0.350720	0.787471
Drainage Density (km / km^2)	0.38514	0.590599	0.270670	0.506103
Stream-Crossings/Stream-Length (#/km)	1.12390	0.773796	0.451781	0.838415
% Rural (LD Residential)-Buffer	0.81850	0.802100	0.496729	0.631705
% Agricultural-Buffer	-0.41818	-0.683737	-0.346523	0.313346
% Deciduous Forest-Buffer	2.12335	0.685951	0.348639	0.973041
% Coniferous Forest-Buffer	1.33378	0.560299	0.250173	0.964819
% Forest-Buffer	-1.38261	-0.587461	-0.268472	0.962295

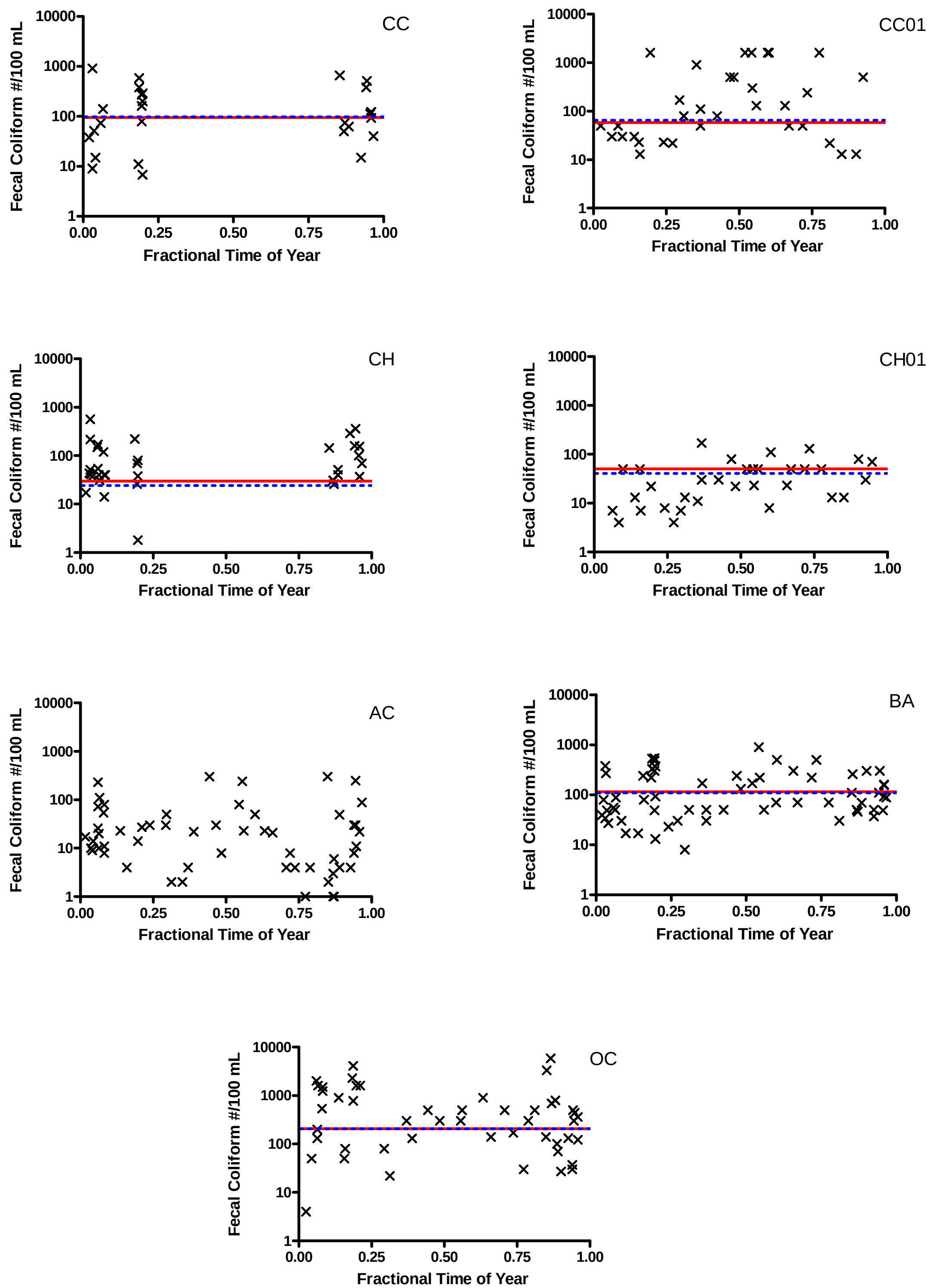
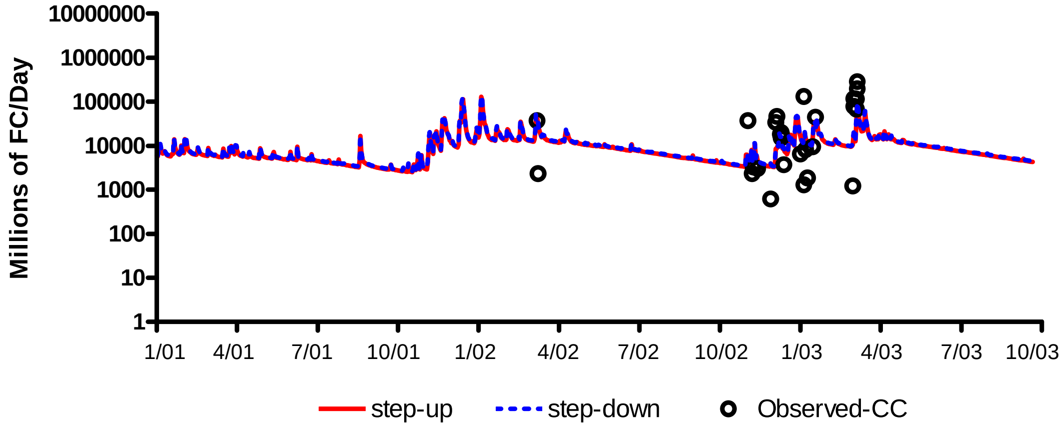


Figure 8-30. Predicted Geometric Mean of the Fecal Coliform Concentration Based on the Step-Up (red line) and Step-Down (blue line) Step-Wise Regression Using the Landscape Characteristics



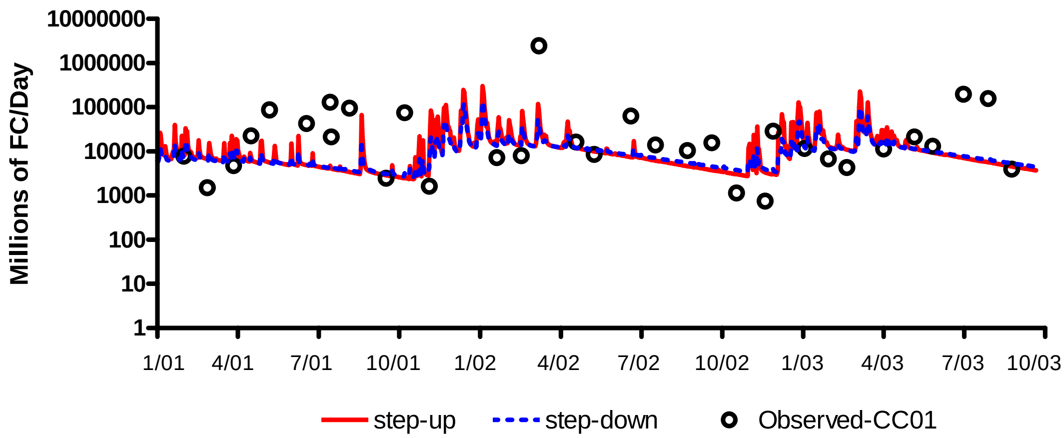


Figure 8-31. Predicted Fecal Coliform Loading Based on the Step-Up Step-Wise Regression for CC and CC01

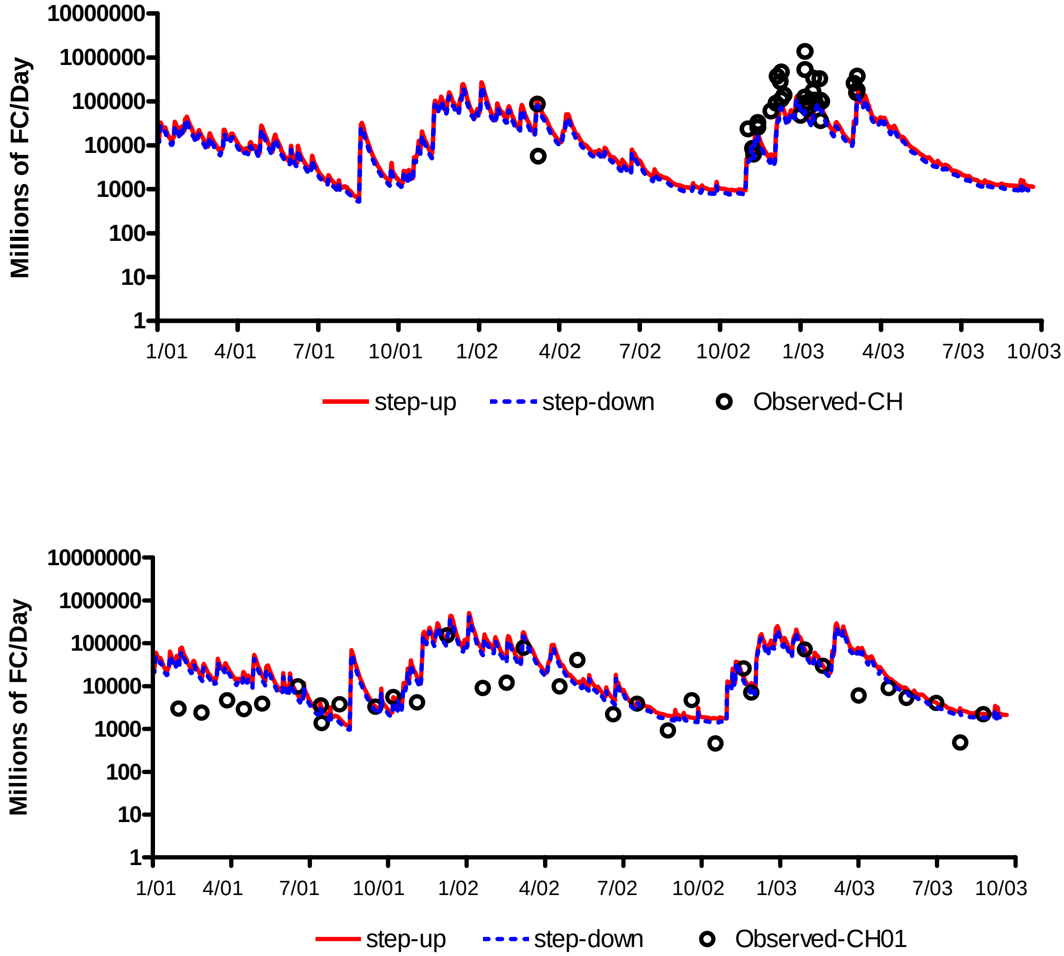


Figure 8-32. Predicted Fecal Coliform Loading Based on the Step-Up Step-Wise Regression for CH and CH01

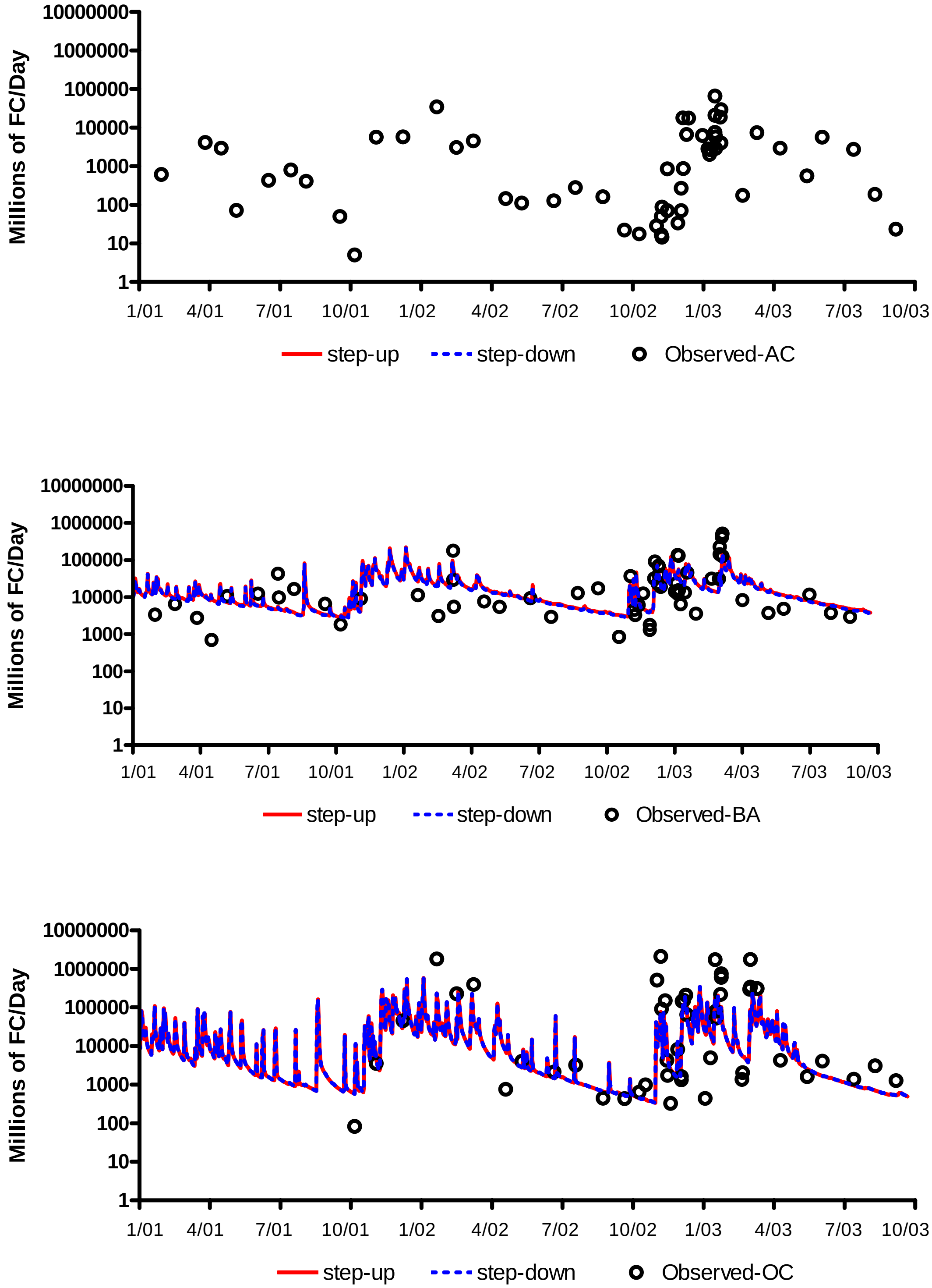


Figure 8-33. Predicted Fecal Coliform Loading Based on the Step-Up Step-Wise Regression for AC, BA, and OC. Note: predicted loadings are less than zero for AC.

8.2.4 Method 4 – Cluster Analysis using Landscape Characteristics

Also used to estimate FC loading was *cluster* analysis, a method that groups landscapes according to similarities and then uses the sample distribution attributes of each cluster to "bound" (interval estimation) the FC concentration. This approach is similar to the descriptive statistics approach discussed above, except that instead of using individual watershed attributes, the cluster attributes are used.

For all sample sites (Table 8-8 and Table 8-15), nine variables were selected for cluster analysis based on their variability, correlation with FC concentration characteristics (Table 8-10), and a minimum of redundancy (i.e., that they not be overly correlated with each other). In general, variables were chosen that had a high coefficient of variation (CV), wide inter-quartile ranges (Table 8-16), and that represented the variety of factors that influence water quality and bacterial pollution, e.g., the natural landscape, human development, and riparian conditions. The %TIA was not used because it is a function of many of the LULC variables in the pool of variables (%TIA is a cumulative attribute) and requires assumptions that could change, whereas the raw variables are not dependent on assumptions (Figure 8-34).

Hierarchical tree clustering based on Euclidean distance was used to determine the number of clusters, followed by k-means clustering to determine the members of each cluster. The k-means clustering analysis was conducted on standardized data (value-mean/standard deviation) so that all variables would be centered at zero and have a standard deviation of 1. There were five clusters indicated at 20% of the maximum linkage distance (Figure 8-35). The value of 20% was chosen before the analysis with the intention of maximizing the number of clusters that would be significantly different. Thus, the number of clusters for the k-means clustering was set to five, which produced well-separated clusters with all variables significantly different between clusters (Table 8-17 and Figure 8-36).

Clusters can be described by their level of human development from least to most using a selection of the LULC variables measured as a percent (Figures 8-37, 8-38, and 8-39). Note that clusters have not been renamed to reflect this order. Thus, Cluster 4 can be characterized as the most developed with an average of 26% urban (HD residential) and 25% commercial/industrial development. Cluster 5 has slightly less development with an average of 14% urban and 19% commercial development. Clusters 2 and 3 have similar amounts of urban and commercial development (9%), but Cluster 2 has 19% rural and 5% suburban development, whereas Cluster 3 has 2% rural and 9% suburban development. Cluster 1 has the least development with less than 5% urban, commercial, and suburban development and only 6% rural development.

The variability in FC concentrations within a cluster did not allow a complete separation of clusters. Only Cluster 1 (least developed) and Cluster 4 (most developed) had significantly different mean FC concentrations ($p < 0.01$; Figure 8-40). The descriptive statistics associated with FC concentrations can be used, however, to bound FC concentrations for those streams within a cluster (Table 8-18). The 25th and 75th percentiles for the cluster geometric mean are not as wide as those for the cluster 25th and 75th stream percentiles (Figure 8-41). The FC concentrations for CC01 were slightly underestimated, but all of the remaining streams are well-represented by the cluster percentiles.

Interval estimates of FC loadings appear to bound the observed data quite well (Figures 8-42 through 8-44). Again, CC01 was slightly underestimated. Extrapolation to streams without FC measurements is not necessary because all streams in the study area have been assigned to a cluster whether they have FC measurements or not. Thus, the cluster statistics in Table 8-18 are used for all streams. Further, the cluster assignment can be used to determine which set of streams can be used to match watershed areas for loading extrapolation using Method 1 (Regression with Time of Year and Flow) and/or Method 2 (Stream Descriptive Statistics).

Table 8-15. Stream Segments Landscape Characteristics for Streams without Fecal Coliform Measurements

Variable	BL-SQR	GC-HNS	WC	CH-WCT	CH-LST	ILL
Watershed	Sinclair Inlet	Sinclair Inlet	Sinclair Inlet	Dyes Inlet	Dyes Inlet	PO Passage
Stream Sub-Watershed	Square Crk Tributary	Heins & Jarstad Crk Tributaries	Wright Crk	Wildcat Crk Tributary	Lost Crk Tributary	Illahee Creek
Basin Area (acres)	1665.3	848.0	725.9	3950.2	1912.6	801.7
% Mixed Forest	3%	2%	1%	7%	11%	1%
% Deciduous Forest	19%	24%	35%	19%	34%	33%
% Coniferous Forest	46%	44%	21%	44%	39%	19%
% Shrub	1%	1%	2%	2%	2%	1%
% Natural Vegetation	69%	71%	59%	71%	85%	54%
% Grass or Turf	6%	6%	19%	9%	13%	10%
% Rural (LD Residential)	17%	5%	0%	3%	1%	1%
% Suburban (MD Residential)	4%	3%	6%	10%	0%	13%
% Urban (HD Residential)	1%	7%	3%	2%	0%	15%
% Commercial/Industrial	0%	8%	13%	0%	0%	6%
%TIA	7%	13%	15%	7%	3%	20%
% Forest	68%	70%	57%	70%	83%	53%
Road Density (km/km^2)	9.3	16.6	12.1	5.7	2.3	16.5
Drainage Density (km / km^2)	2.2	2.5	1.8	2.1	2.9	1.9
Stream-Crossings/Stream-Length (#/km)	0.3	0.7	0.9	0.4	0.1	0.6
% Urban (HD Residential)-B	0%	1%	0%	0%	0%	2%
% Commercial/Industrial-B	0%	2%	5%	0%	0%	3%
% Suburban-B	1%	1%	2%	7%	0%	6%
% Rural (LD Residential)-B	9%	0%	0%	2%	0%	0%
% Agricultural-B	9%	9%	17%	7%	7%	7%
%Developed-B	19%	13%	24%	15%	7%	18%
%TIA-B	4%	5%	8%	5%	3%	8%
% Deciduous Forest-B	30%	33%	60%	30%	49%	69%
% Coniferous Forest-B	36%	48%	11%	33%	33%	10%
% Mixed Forest-B	2%	3%	1%	4%	9%	1%
% Forest	68%	84%	72%	68%	91%	80%

Table 8-16. Descriptive Statistics for the Landscape Variables for All Watershed Segments (n = 44) Sorted by the Coefficient of Variation

Variables in the Cluster Model	Mean	Std.Dev.	Minimum	Maximum	Lower Quartile	Upper Quartile	CV	Inter-Quartile Range
% Rural (LD Residential)	5%	7%	0%	26%	0%	10%	129%	0.095
% Urban (HD Residential)	10%	10%	0%	37%	3%	15%	93%	0.120
% Commercial/ Industrial	12%	11%	0%	41%	2%	20%	92%	0.176
Stream-Crossings/Stream-Length (#/km)	0.91	0.73	0.09	3.26	0.44	1.21	80%	0.773
% Suburban (MD Residential)	8%	6%	0%	22%	5%	10%	67%	0.053
% Grass or Turf	7%	5%	0%	19%	4%	10%	64%	0.069
Road Density (km/km^2)	15.7	9.9	0.7	43.7	9.0	22.6	63%	13.64
% Coniferous Forest-Buffer	24%	14%	0%	57%	15%	33%	58%	0.179
% Coniferous Forest	30%	15%	2%	59%	18%	42%	50%	0.235

Variables Not in the Cluster Model	Mean	Std.Dev.	Minimum	Maximum	Lower Quartile	Upper Quartile	CV	IQR
% Mixed Forest	3%	4%	0%	25%	1%	4%	146%	0.028
% Mixed Forest-Buffer	3%	4%	0%	15%	1%	3%	125%	0.024
% Rural (LD Residential)-Buffer	3%	4%	0%	12%	0%	7%	121%	0.071
% Commercial/Industrial-Buffer	5%	6%	0%	25%	1%	8%	111%	0.077
% Urban (HD Residential)-Buffer	6%	7%	0%	25%	1%	10%	104%	0.088
% Suburban-Buffer	7%	6%	0%	24%	3%	9%	87%	0.060
% Agricultural-Buffer	7%	6%	0%	24%	3%	9%	83%	0.063
% Shrub	1%	1%	0%	4%	1%	2%	69%	0.010
%TIA	19%	12%	3%	43%	8%	27%	62%	0.185
%TIA-Buffer	12%	7%	3%	29%	6%	18%	60%	0.117
%Developed-Buffer	29%	15%	5%	65%	17%	40%	51%	0.225
% Deciduous Forest	22%	10%	3%	47%	16%	24%	45%	0.083
% Deciduous Forest-Buffer	38%	15%	4%	74%	31%	46%	40%	0.148
% Natural Vegetation	56%	18%	21%	90%	46%	71%	32%	0.245
% Forest	54%	17%	21%	88%	46%	69%	32%	0.235
Drainage Density (km / km^2)	1.97	0.59	0.81	3.88	1.57	2.31	30%	0.738
% Forest-Buffer	65%	14%	35%	91%	54%	76%	22%	0.216

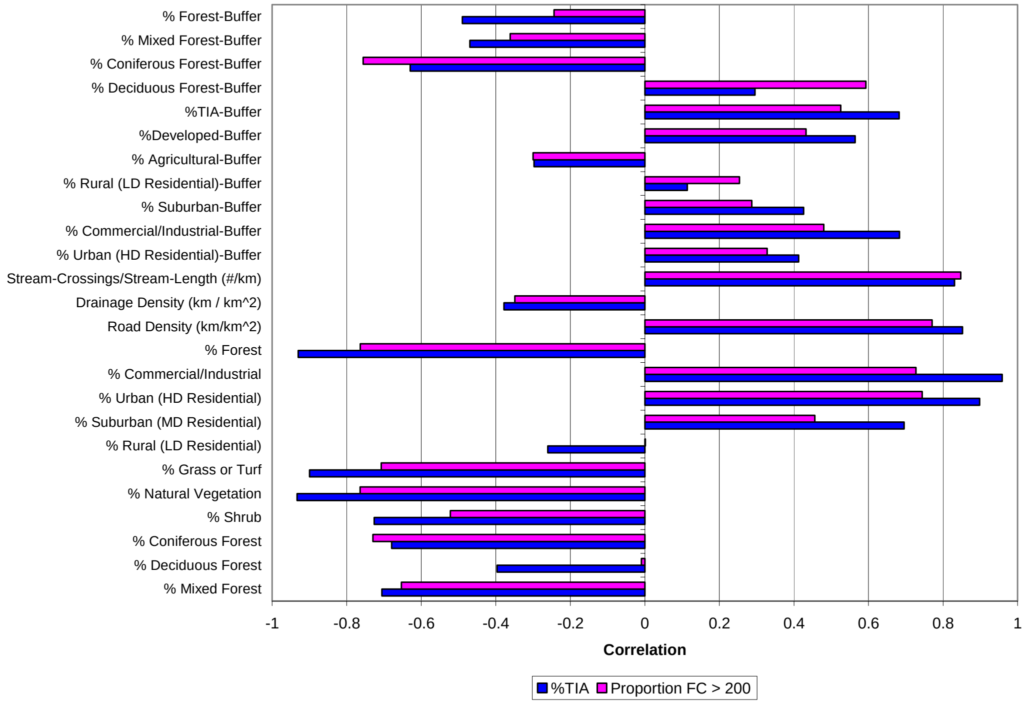


Figure 8-34. Correlation of Landscape Characteristics with Percentage of Total Impervious Surface Area and the Proportion of Fecal Coliform Measurements Greater than 200 cfu/100 mL

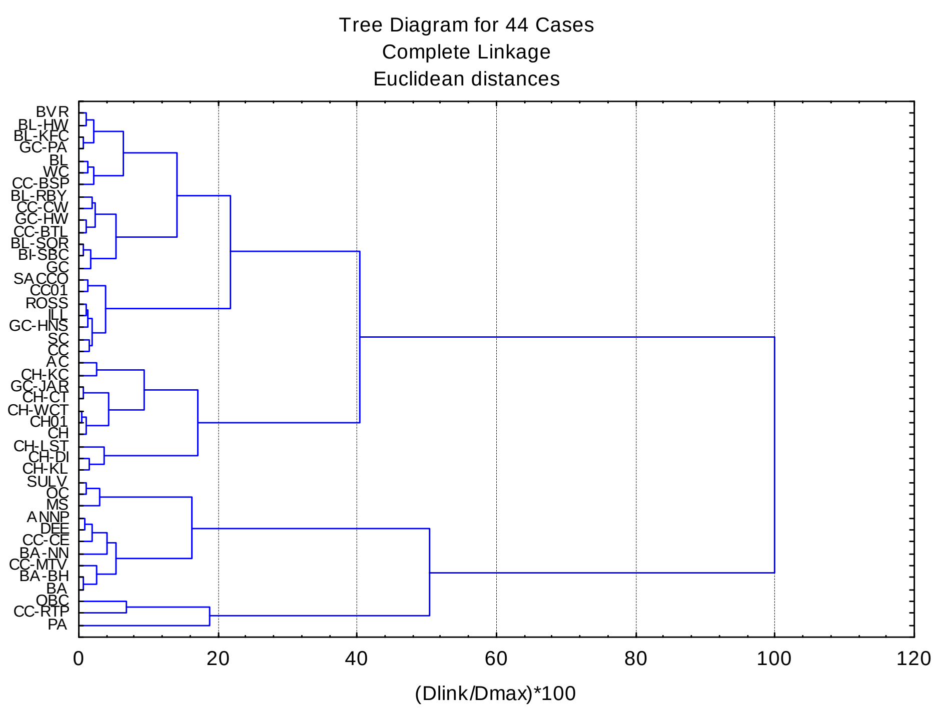


Figure 8-35. Hierarchical-Tree Dendogram of 44 Watershed Segments. Five clusters are indicated at 20% of the maximum linkage distance.

Table 8-17. Univariate Analysis of Variance Between Clusters for Each Variable in the Model

Variable	Between Sum of Squares	Degrees of Freedom	Within Sum of Squares	Degrees of Freedom	F-test	Significance
% Coniferous Forest	33.0	4	10.0	39	32.0	0.000000
% Grass or Turf	24.6	4	18.4	39	13.1	0.000001
% Rural (LD Residential)	27.9	4	15.1	39	18.0	0.000000
% Suburban (MD Residential)	23.1	4	19.9	39	11.3	0.000003
% Urban (HD Residential)	32.1	4	10.9	39	28.9	0.000000
% Commercial/Industrial	31.9	4	11.1	39	28.0	0.000000
Road Density (km/km^2)	31.9	4	11.1	39	27.9	0.000000
Stream-Crossings/Stream-Length (#/km)	30.6	4	12.4	39	24.1	0.000000
% Coniferous Forest-B	23.8	4	19.2	39	12.1	0.000002

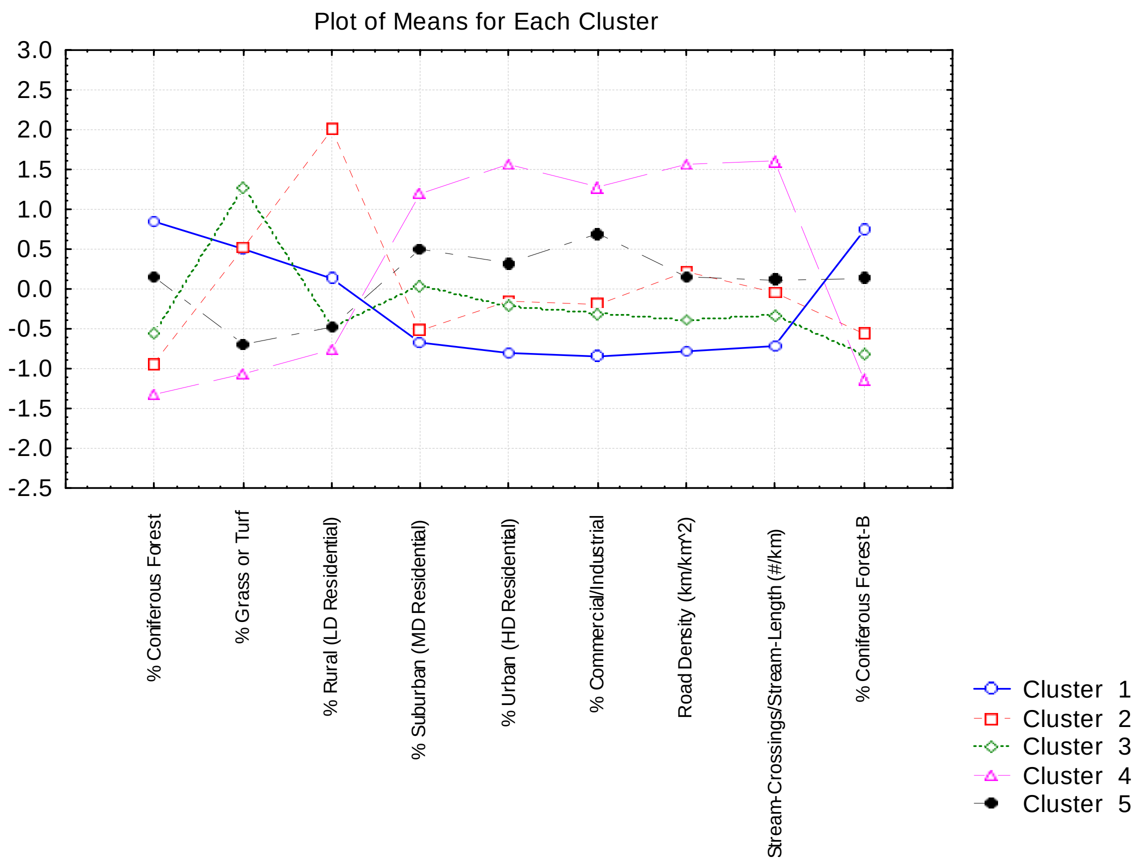
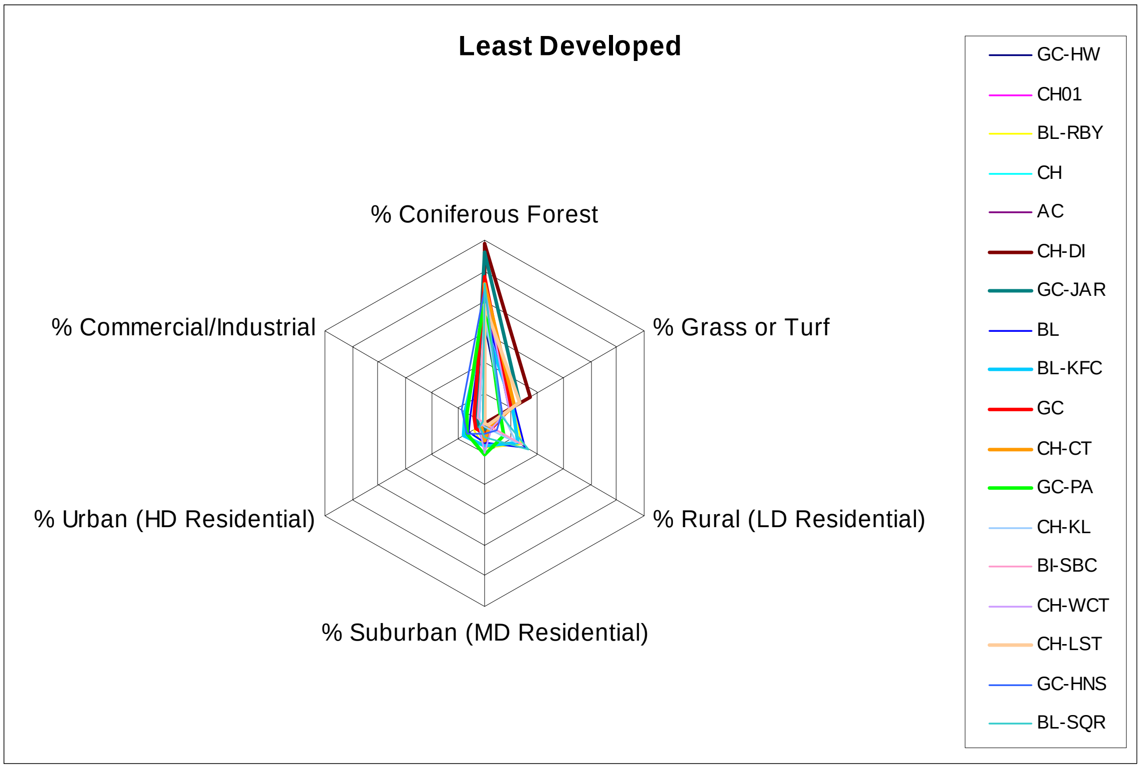


Figure 8-36. Standardized Cluster Mean for Each Cluster and Variable in the Model



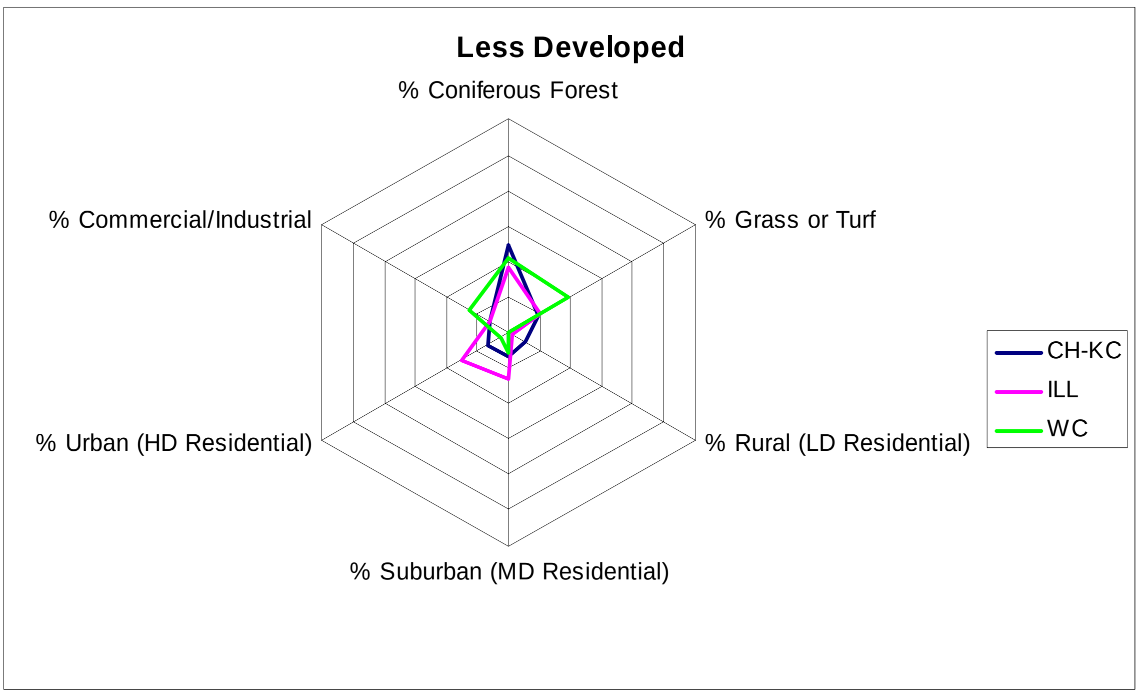
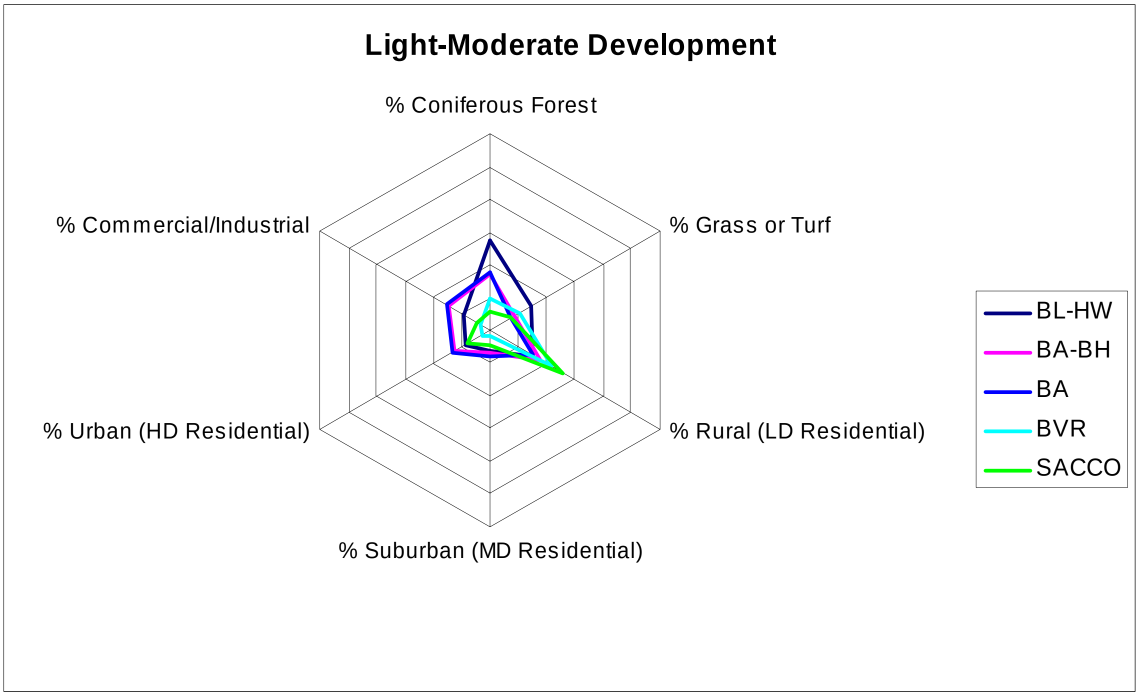


Figure 8-37. Web Plot and Membership of the Two Less-developed Clusters (Clusters 1 and 3)



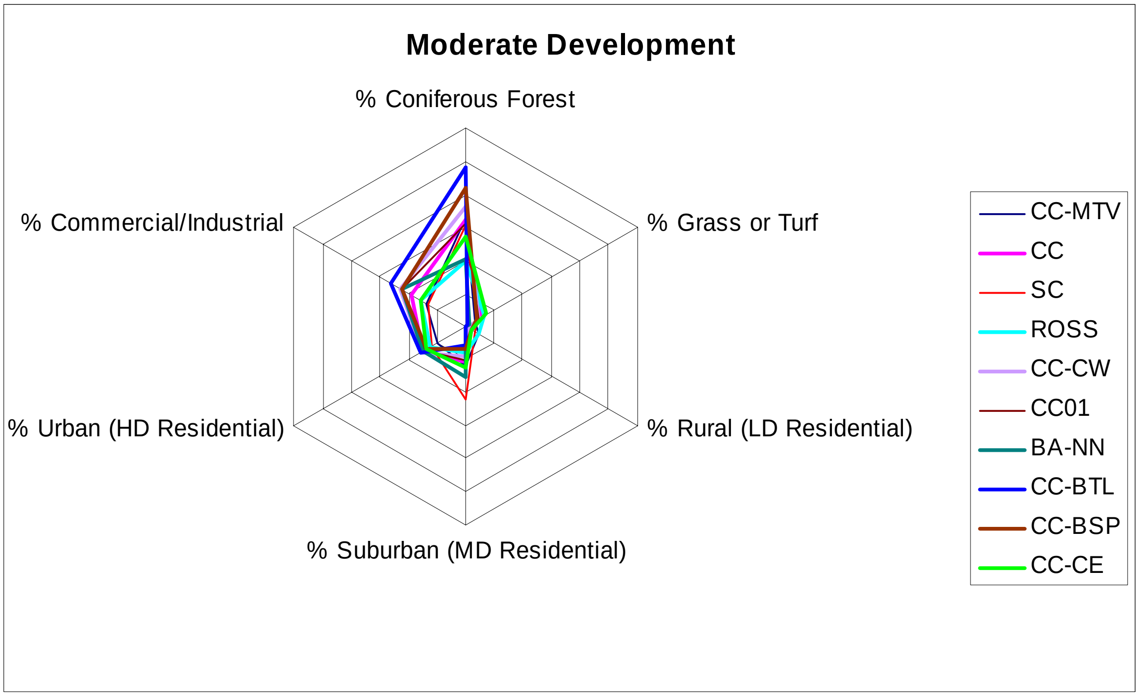


Figure 8-38. Web Plot and Membership of the Two Moderately Developed Clusters (Clusters 2 and 5)

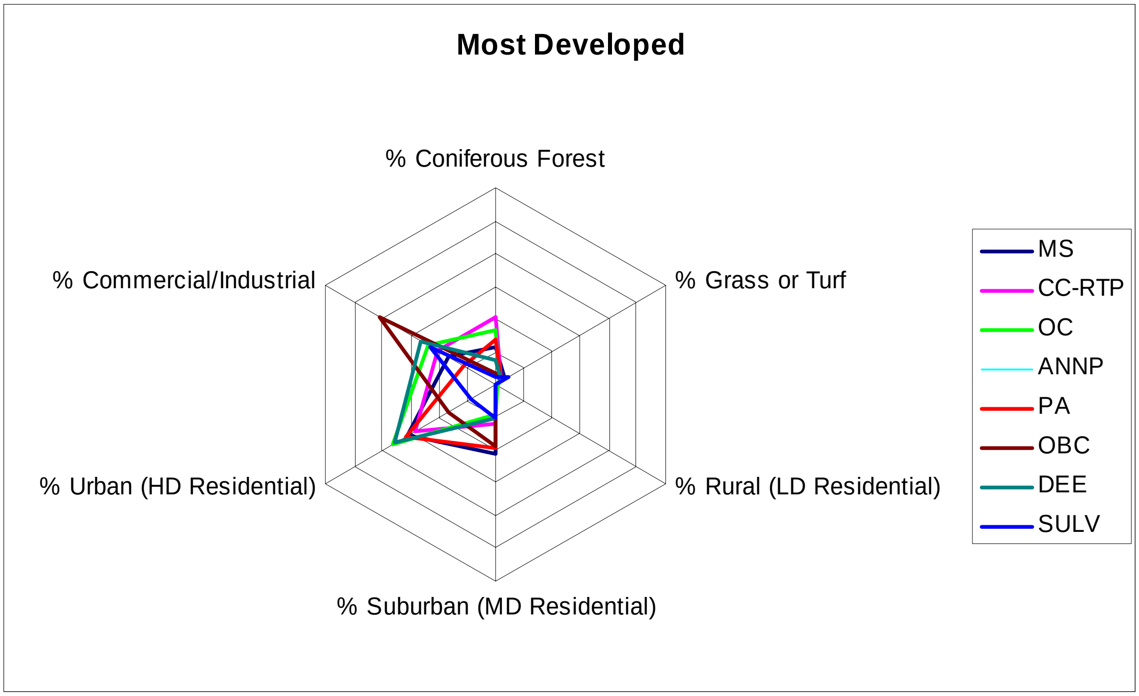


Figure 8-39. Web Plot and Membership of the Most-developed Cluster (Cluster 4)

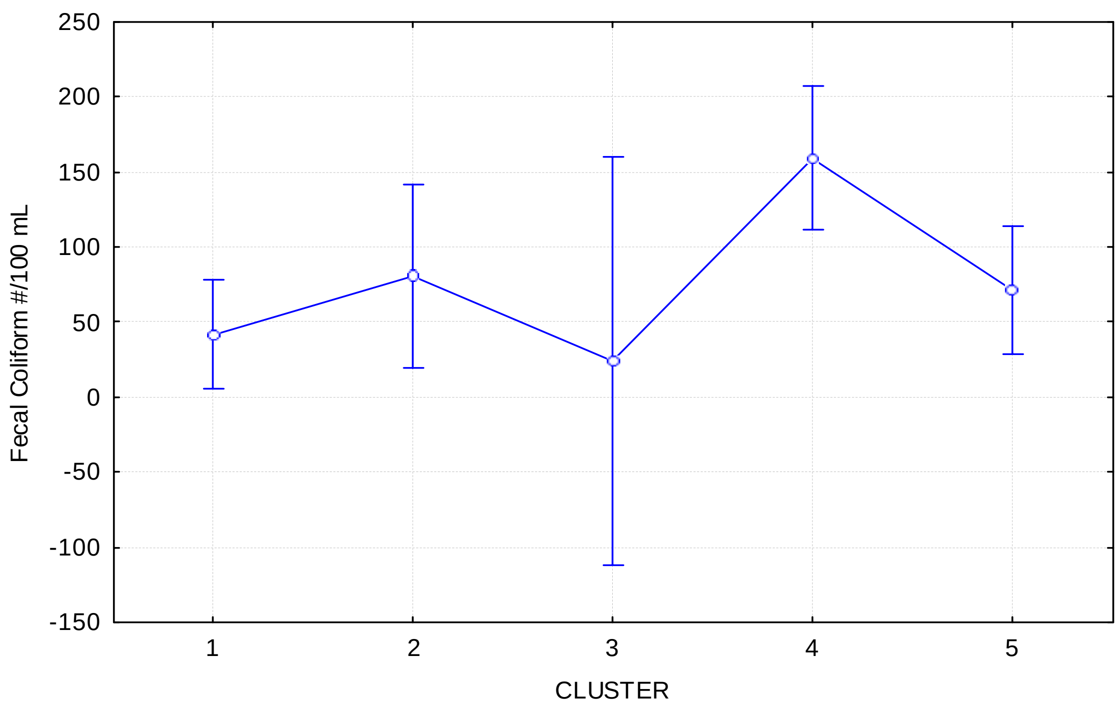


Figure 8-40. Mean and 95% Confidence Intervals for Fecal Coliform Concentrations by Cluster

Table 8-18. Descriptive Statistics for Fecal Coliform Concentrations by Cluster

Cluster	Percentile (Within Cluster)	All Available Data			
		Geometric Mean FC (cfu/100mL)	25th Percentile (Within Stream)	75th Percentile (Within Stream)	90th Percentile (Within Stream)
1	25th	24.5	11.0	52.6	152
1	75th	64.9	24.1	138	337
2	25th	48.6	23.0	145	347
2	75th	112	50.0	263	532
3	25th	23.7	9.50	50.0	136
3	75th	23.7	9.50	50.0	136
4	25th	43.5	12.3	193	467
4	75th	262	83.1	705	1630
5	25th	41.5	11.1	126	356
5	75th	95.5	30.0	294	680

Note: Highlighted cells provide potential boundaries for fecal coliform concentrations for streams within a given cluster.

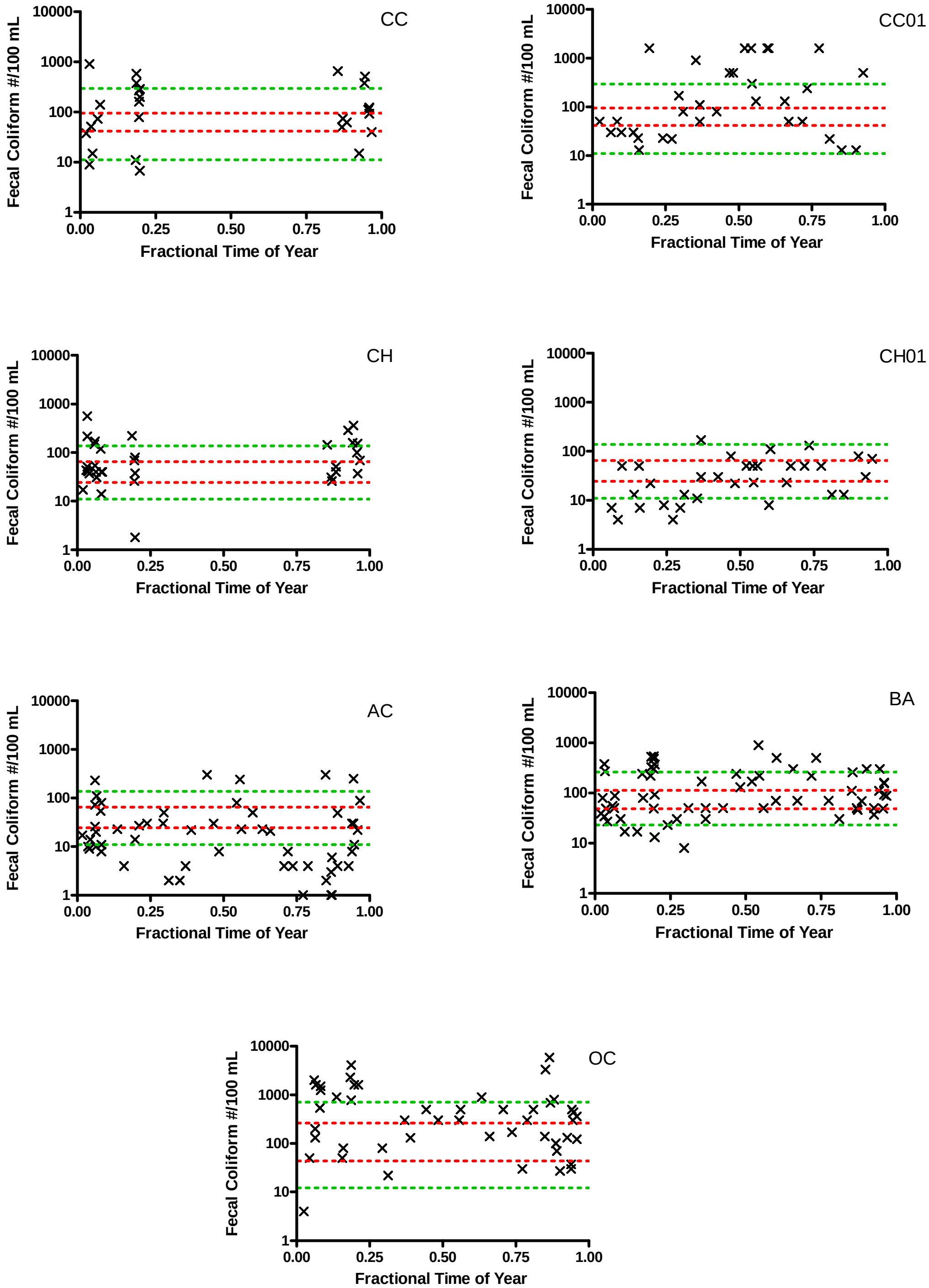
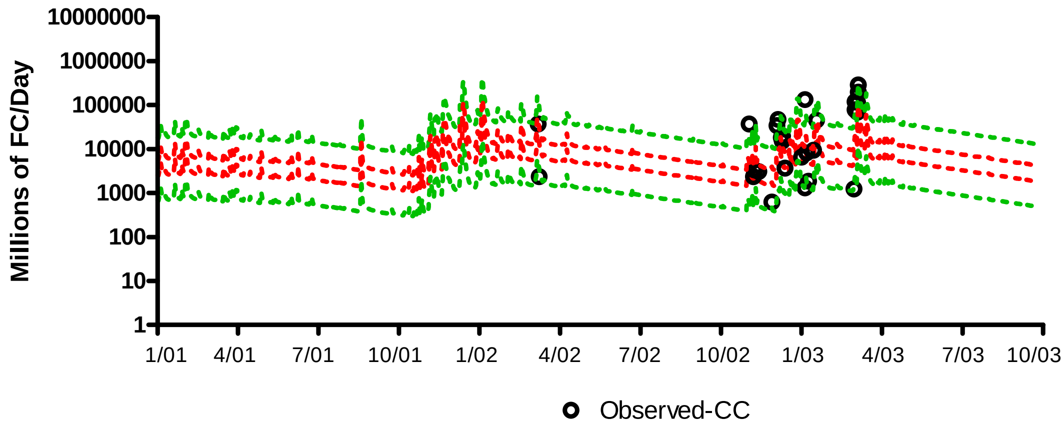


Figure 8-41. Interval Estimates of Fecal Coliform Concentrations Based on the Cluster 25th and 75th Percentile of the Geometric Means (red dashed lines) and the 25th and 75th Cluster Percentile of the 25th and 75th Stream Percentiles (green dashed lines)



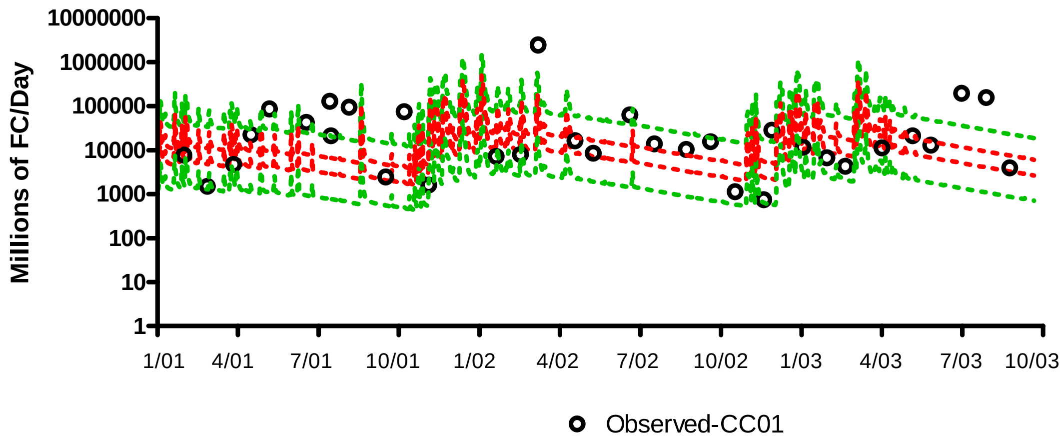


Figure 8-42. Interval Estimates of the Fecal Coliform Loadings for CC and CC01 Based on the Cluster 25^{th} and 75^{th} Percentile of the Geometric Means (red dashed lines) and the 25^{th} and 75^{th} Cluster Percentile of the 25^{th} and 75^{th} Stream Percentiles (green dashed lines)

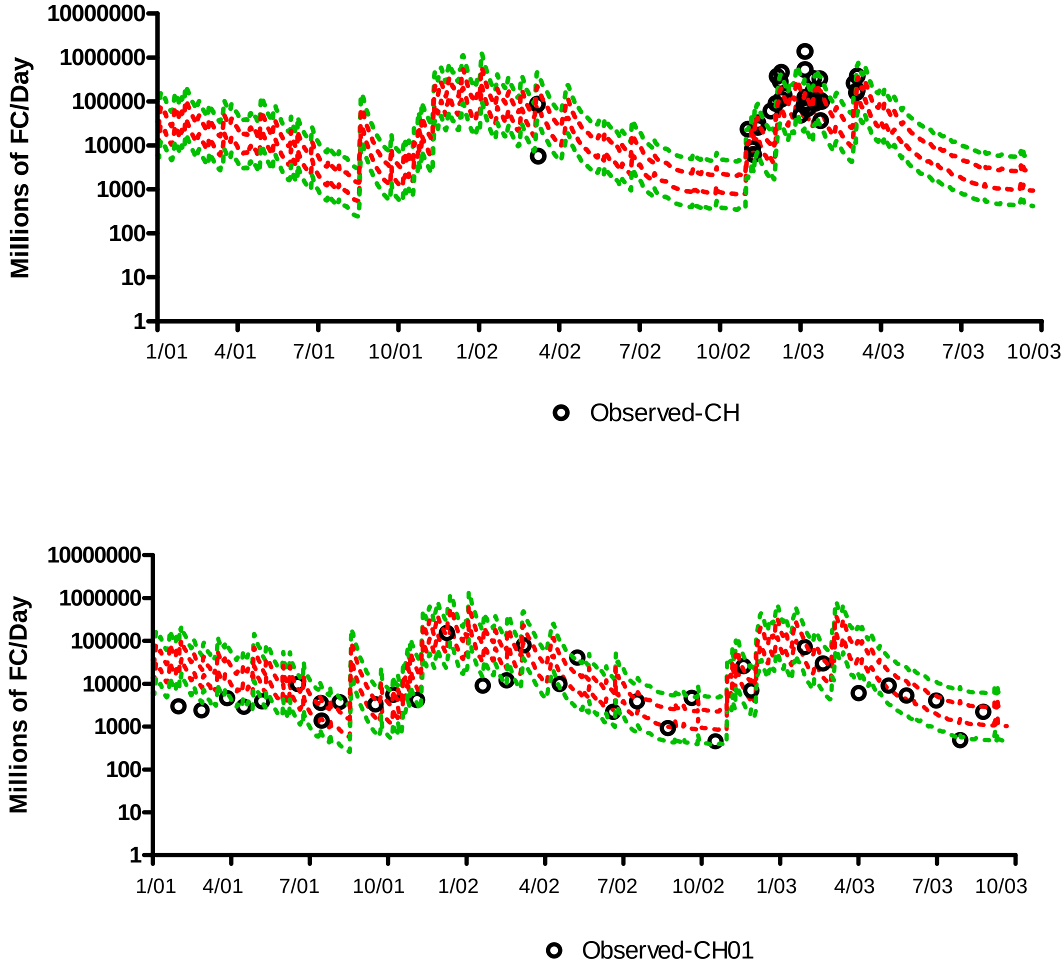


Figure 8-43. Interval Estimates of the Fecal Coliform Loadings for CH and CH01 Based on the Cluster 25th and 75th Percentile of the Geometric Means (red dashed lines) and the 25th and 75th Cluster Percentile of the 25th and 75th Stream Percentiles (green dashed lines)

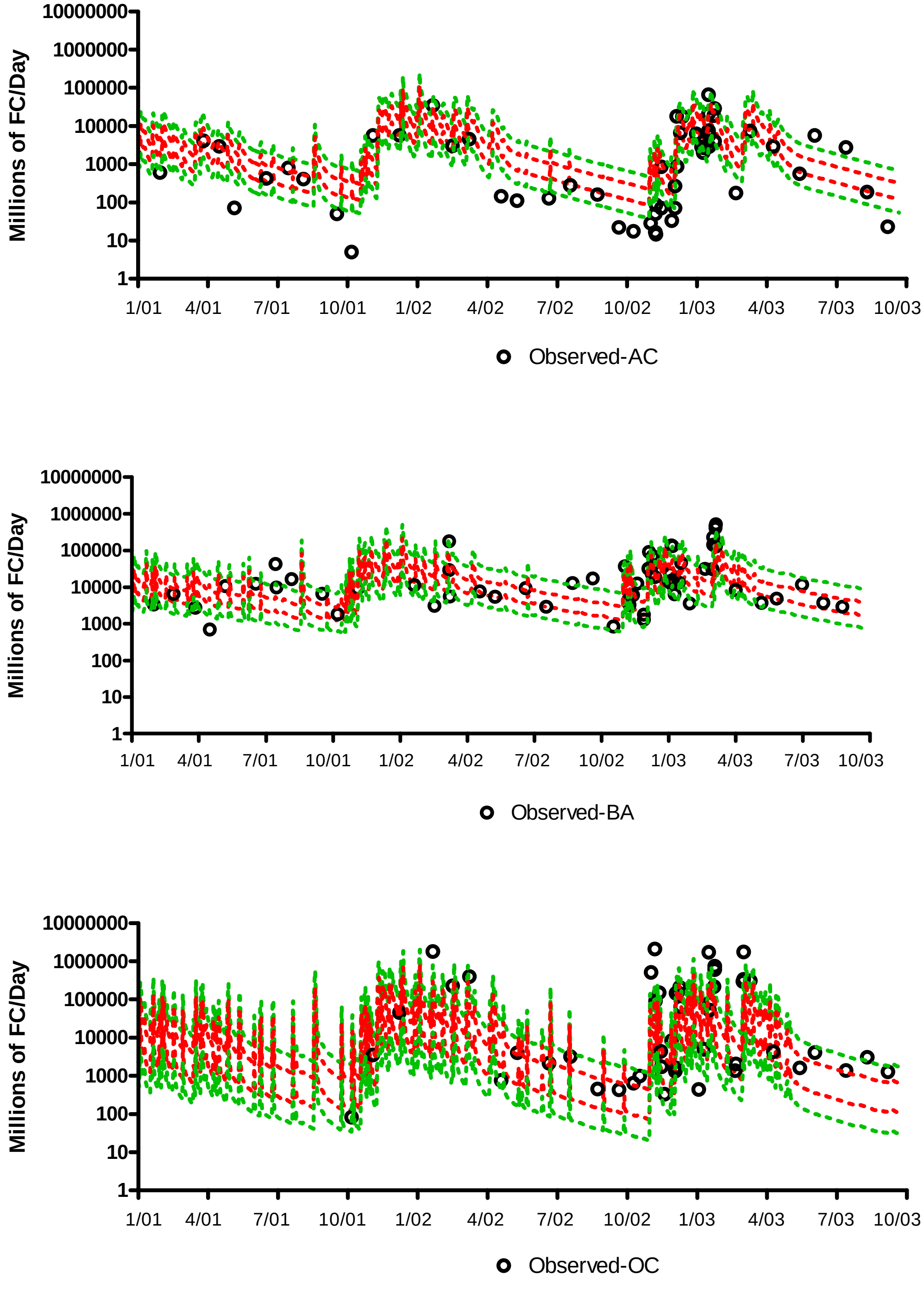


Figure 8-44. Interval Estimates of the Fecal Coliform Loadings for AC, BA, and OC Based on the Cluster 25th and 75th Percentile of the Geometric Means (red dashed lines) and the 25th and 75th Cluster Percentile of the 25th and 75th Stream Percentiles (green dashed lines)

8.2.5 Method 5 – Regression with Cluster Scores

Discriminant analysis of the landscape clusters provided an alternate set of explanatory regression variables (discriminant scores) to estimate FC concentrations (Hand 1981). Discriminant analysis is a technique of deriving classification rules from samples that are already classified into groups. The resulting discriminant scores for each landscape are linear combinations of the standardized LULC variables that were used in the cluster analysis. This method provides a single estimate of the geometric mean for each stream instead of an interval.

Two discriminant scores explained 95% of the variability for discrimination between the landscape clusters (Table 8-19 and Figure 8-45). However, when the FC concentration (the dependent variable) was regressed against the first two discriminant scores, only Score 1 was significant ($p < 0.001$; Table 8-20). The regression was significant ($p < 0.001$) and had an R^2 value of 0.38. The magnitudes of the standardized residuals were all less than 3 and had no particular pattern except that the variance was larger for the smaller scores (Figure 8-46). Therefore, for FC concentration and loading estimation, only the first discriminant score was used (Figure 8-47).

Predicted and observed geometric-mean FC concentrations were nearly identical for CC01, CH, and BA (Figure 8-47). The predicted geometric mean concentration for CH01 appears slightly overestimated. The estimated loadings follow the same pattern (Figures 8-48 through 8-50). Extrapolation to those streams without FC concentrations would be conducted by using the same regression equation:

$$FC\ concentration = 74.63 + -12.794(Score\ 1)$$

where *Score 1* is the first discriminant score for the watershed segment of interest.

Table 8-19. Coefficients for Discriminate Scores and the Amount of Variation Explained for Discrimination Between the Five Clusters

Variable	Score 1	Score 2	Score 3	Score 4
% Coniferous Forest	1.36736	1.17194	-0.68649	-0.66055
% Grass or Turf	0.04429	-1.03360	0.60690	-0.58532
% Rural (LD Residential)	0.70682	-1.14035	-1.03820	-0.32338
% Suburban (MD Residential)	0.03757	0.47042	0.10290	-0.75542
% Urban (HD Residential)	-1.36146	-0.43891	0.08835	0.19130
% Commercial/Industrial	-0.68856	0.06703	-0.81187	-1.52808
Road Density (km/km^2)	-0.05594	-0.05806	-0.51462	-0.18861
Stream-Crossings/Stream-Length (#/km)	-0.65018	-0.23722	0.11498	1.60746
% Coniferous Forest-B	0.04226	-0.12863	-0.46959	0.80011
Eigen value	14.74959	2.89276	0.68711	0.30456
Cumulative Variation Explained	79%	95%	98%	100%

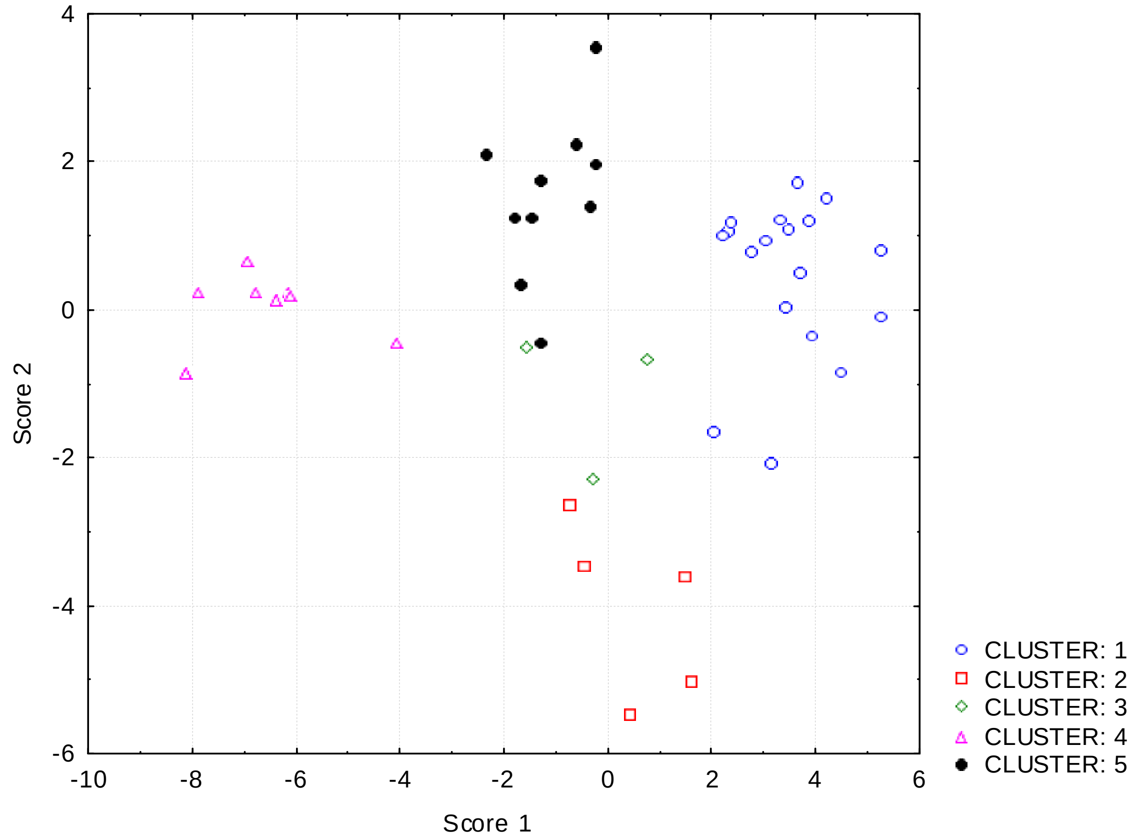


Figure 8-45. Discriminant Scores and Cluster Membership for n = 44 Streams

Table 8-20. Regression Summary for Fecal Coliform Concentrations as a Function of the First Two Discriminant Scores

Explanatory Variable	Coefficient	Standard Error of the Coefficient	t-statistic with 35 Degrees of Freedom	p-value
Intercept	74.6302	9.918171	7.52460	$p < 0.000001$
Score 1	-12.7941	2.598404	-4.92382	0.000020
Score 2	-5.6516	5.109494	-1.10610	0.276230
Source of Variation	**Sums of Squares**	**Degrees of Freedom**	**F-statistic**	**p-level**
Regression	93194.8	2	12.56184	0.000077
Residual	129830.5	35		
Total	223025.4			

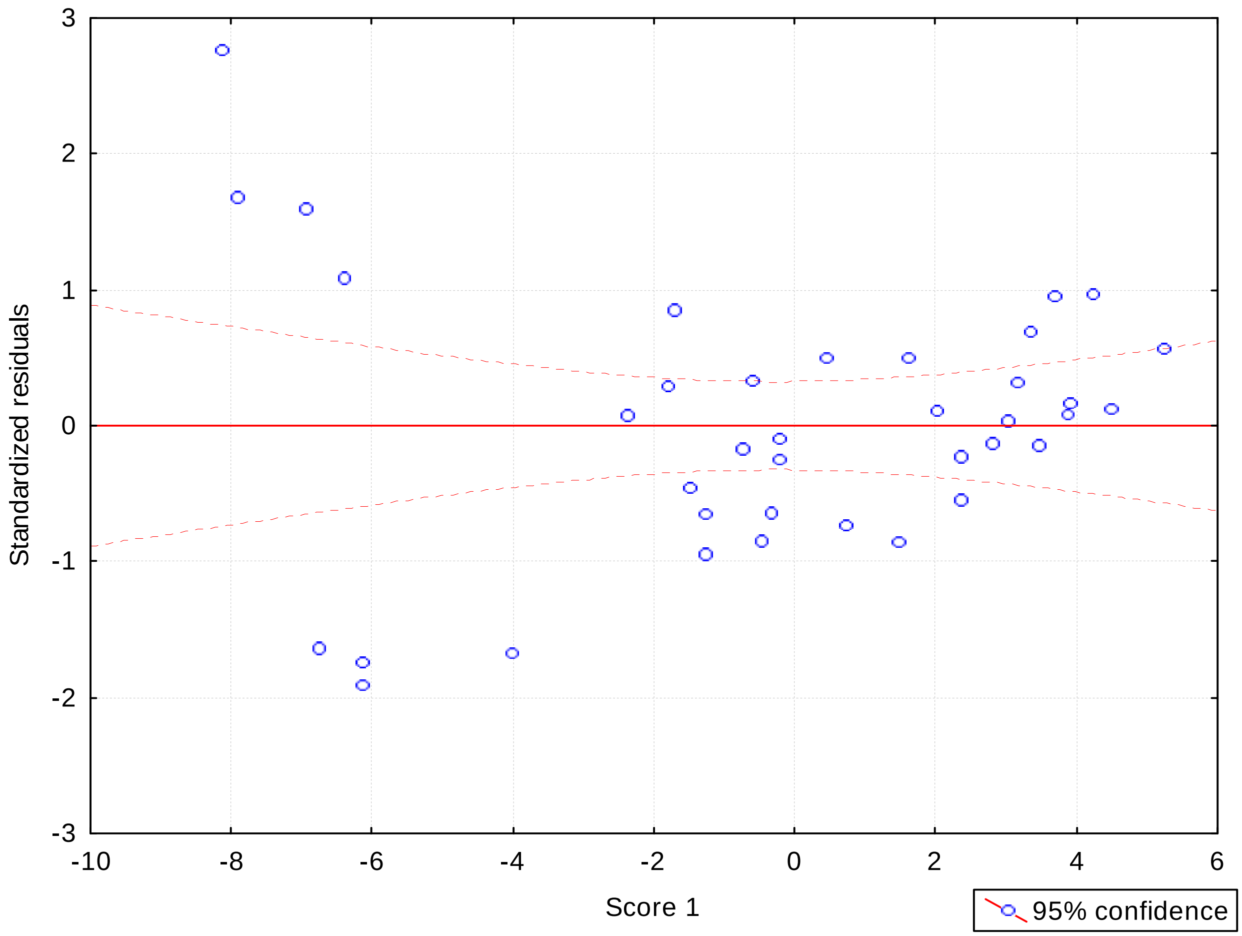


Figure 8-46. Standardized Residuals from Estimating FC Concentration from the First-Discriminant Score (Score 1) Using Linear Regression

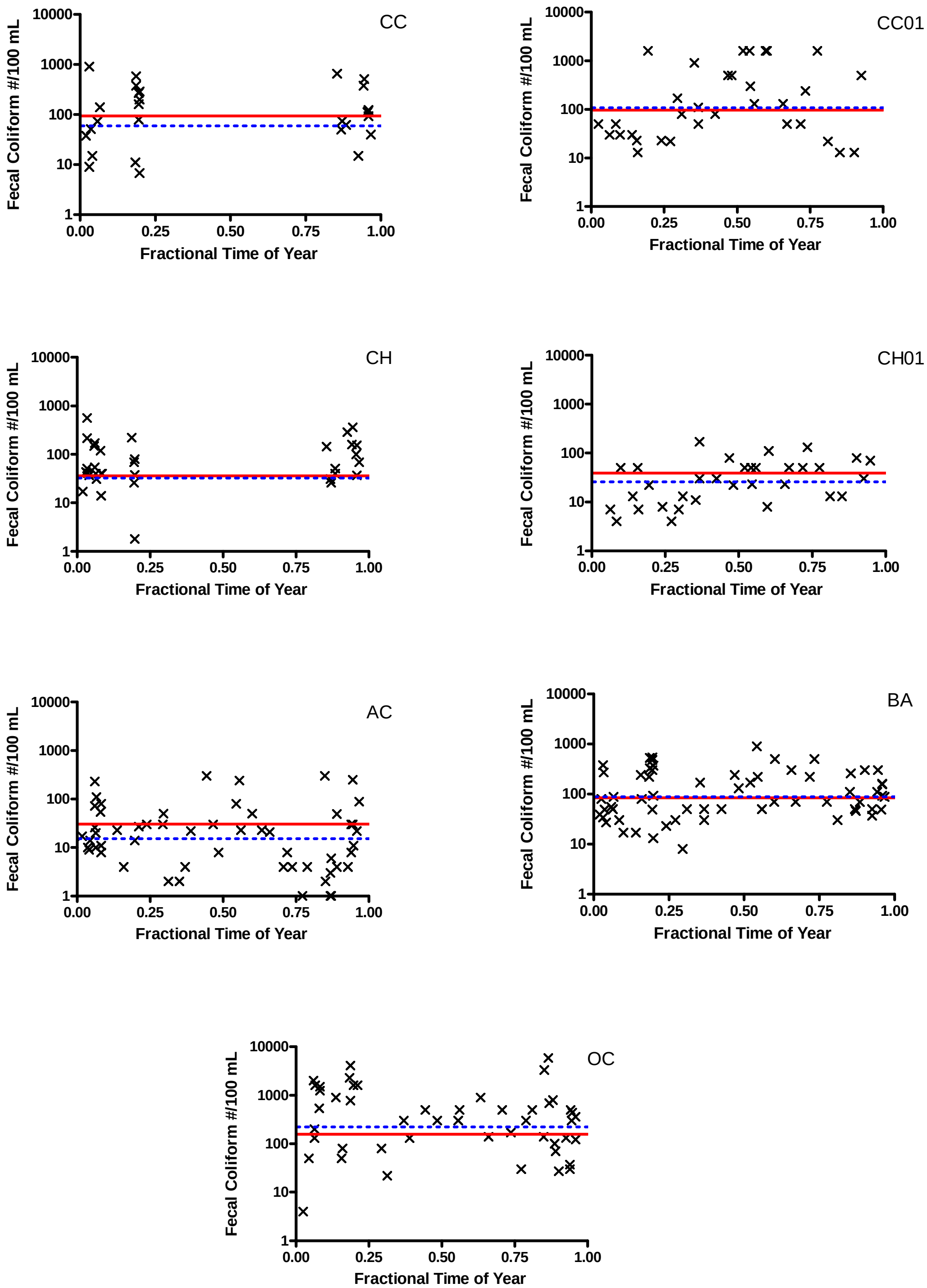
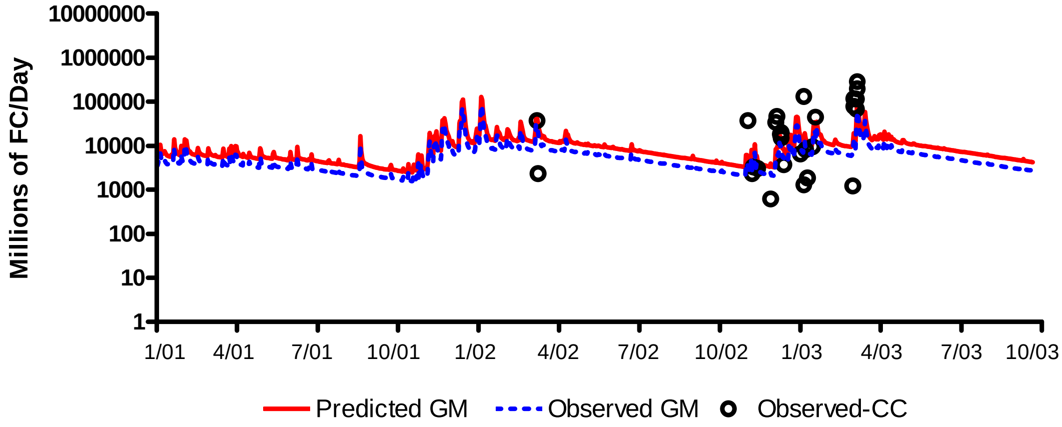


Figure 8-47. Predicted Geometric Mean of the Fecal Coliform Concentrations Based on the Regression Using the First Landscape Cluster Discriminant Score (red line; y = 74.63 + -12.794 [Score 1]) and Actual Geometric Mean of the Fecal Coliform Concentrations (blue dashed line)



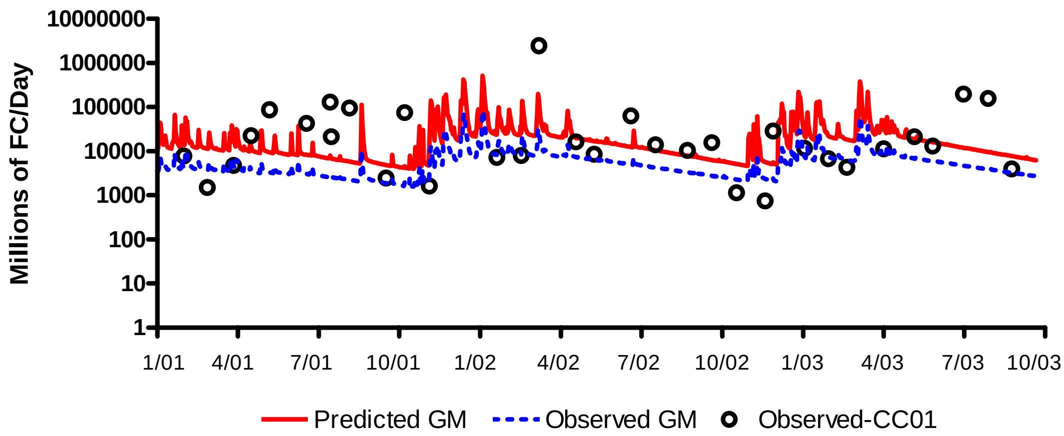
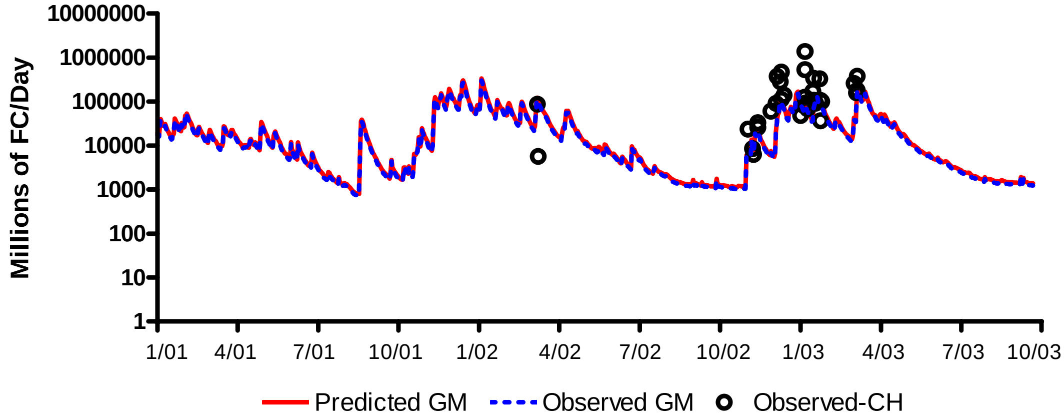


Figure 8-48. Predicted Mean Fecal Coliform Loading for CC and CC01 Based on the Regression Using Cluster Discriminant Scores (red line) and the Observed Based on the Geometric Mean (blue dashed line)



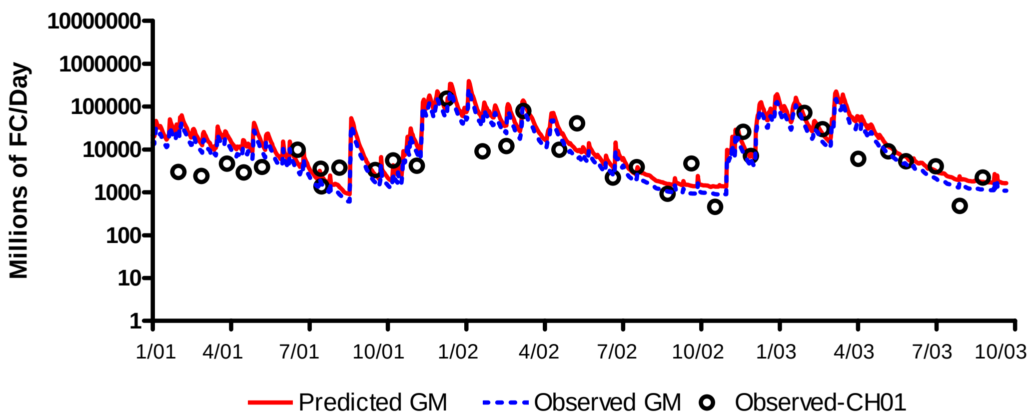


Figure 8-49. Predicted Mean Fecal Coliform Loading for CH and CH01 Based on the Regression Using Cluster Discriminant Scores (red line) and the Observed Based on the Geometric Mean (blue dashed line)

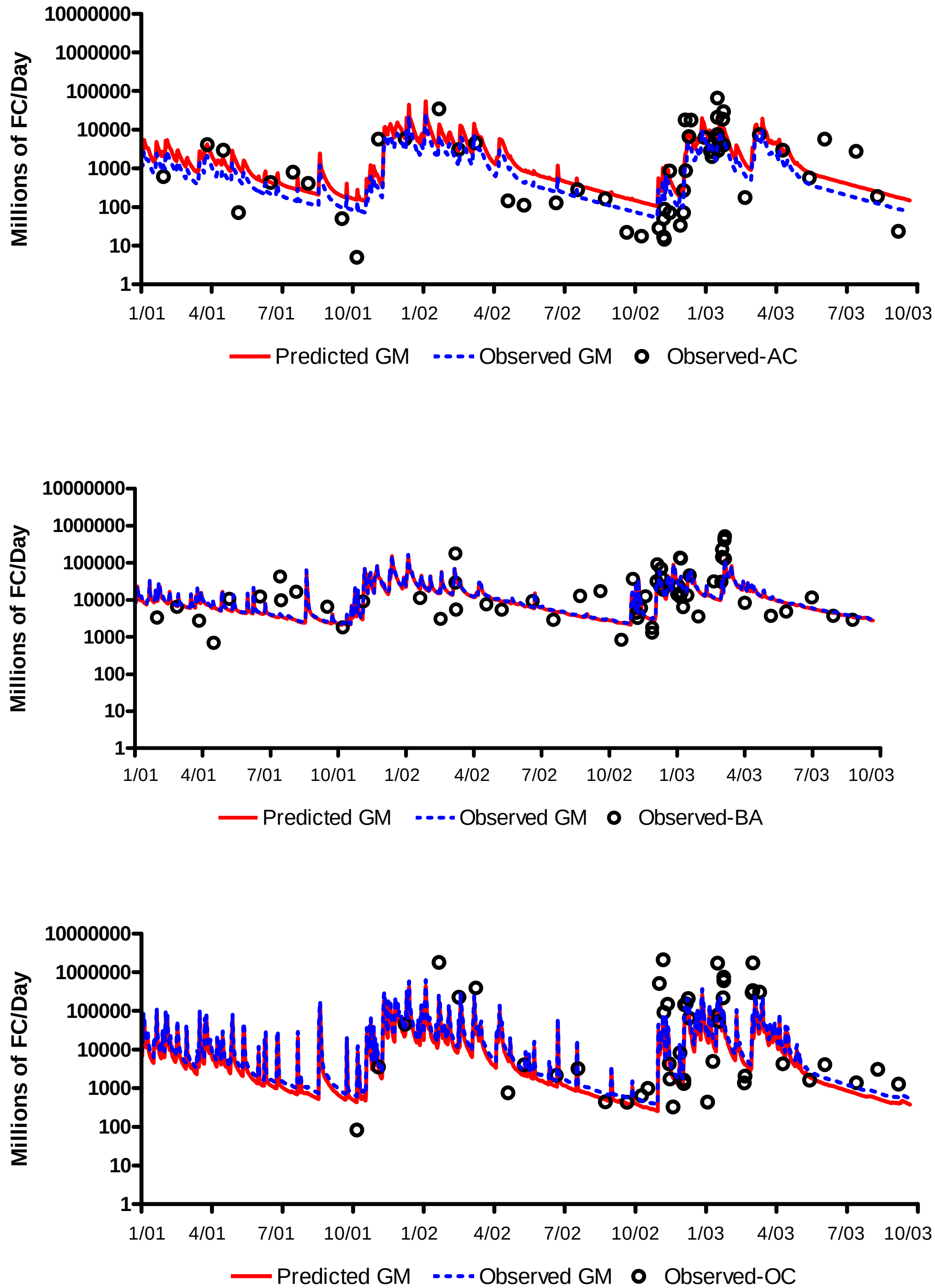


Figure 8-50. Predicted Mean Fecal Coliform Loading for AC, BA, and OC Based on the Regression Using Cluster Discriminant Scores (red line) and the Observed Based on the Geometric Mean (blue dashed line)

8.3 Comparison of Estimators

To determine which method to use for the FC loading analysis, the results from the methods for estimating FC concentration described above were compared by evaluating the residual mean squares derived by estimating the FC concentration for three additional streams: Blackjack Creek, Gorst Creek, and Strawberry Creek (Table 8-21). For each method, the observed FC concentrations were compared with the predicted concentration derived by the method and by extrapolation when the FC data did not exist. Residual mean squares from methods that produced interval estimates were calculated as the difference in the observed FC concentration from the halfway point between the estimated interval boundaries (i.e., low boundary + [high – low boundary] / 2). Extrapolation was not necessary for those methods involving landscape characteristics, because all streams in the study area had land-use data and were used in model development.

Extrapolation was based on two methods: 1) similar basin area to test streams, and 2) similar LULC characteristics and basin area to test streams. Streams within the same LULC cluster determined by Method 4 (Table 8-22) were used to select the potential set of streams that could be used for extrapolation based on LULC characteristics and basin area. The difference in the basin areas from each of the test basins suggested that BL-KFC was closest in area to CH, GC was closest to CC01, and SC was closest in area to AC (Tables 8-1 and 8-21). Thus, for extrapolation purposes, the parameters from CH, CC01 and AC were used to estimate the concentrations of FC for the comparison streams. When both landscape information based on the clustering results (Table 8-22) and basin area were considered, BL and GC were closest in LULC and area to CH, and SC was closest in LULC and area to CC. Thus, for extrapolation purposes, the parameters from CH and CC were used to estimate the concentrations of FC in the comparison streams. In all cases, the estimated log-FC concentrations were restricted to values between 0 and 10.

Table 8-21. Stream Identification Information for Streams Used to Compare Fecal Coliform Concentration Estimation Techniques

Streams Used for Model Comparison					
Stream	**Watershed**	**Stream Sub-Watershed**	**Ch3d ID#**	**HSPF ID#**	**Basin Area (acres)**
BL-KFC	Sinclair Inlet	Mouth of Blackjack Crk	21+22+30+23+ 610000+ 60011000+ 6100250	208+2073+2074+2207+2209+2214+2215	8347.4
GC	Sinclair Inlet	Gorst Crk	8+10+11+14	2052+2054+2055+ 2058	6142.3
SC	Dyes Inlet	Strawberry Crk	290000	2101	1914.2

Table 8-22. Cluster Membership Based Only on Landscape Characteristics

Cluster	Observation	Watershed	Stream Sub-Watershed	Basin Area (acres)
1	GC-HW	Sinclair Inlet	Heins Crk Headwaters	1005.4
1	CH01	Dyes Inlet	Chico Crk @ Kittyhawk Dr	10475.5
1	BL-RBY	Sinclair Inlet	Ruby Crk Tributary	1711.8
1	CH	Dyes Inlet	Chico Crk @ Golf Course	10033.1
1	AC	Sinclair Inlet	Anderson Crk	1265.9
1	CH-DI	Dyes Inlet	Dickerson Crk Tributary	1474.0
1	GC-JAR	Sinclair Inlet	Upper Gorst Crk	3196.9
1	BL	Sinclair Inlet	Blackjack Crk @ SR-16	6902.7
1	BL-KFC	Sinclair Inlet	Blackjack Crk	8347.4
1	GC	Sinclair Inlet	Gorst Crk	6142.3
1	CH-CT	Dyes Inlet	Chico Crk @ Taylor Rd	7516.3
1	GC-PA	Sinclair Inlet	Parish Crk Tributary	1092.0
1	CH-KL	Dyes Inlet	Upper Kitsap Crk	777.9
1	BI-SBC	PO Passage	Springbrook Crk	1539.6
1	CH-WCT	Dyes Inlet	Wildcat Crk Tributary	3950.2
1	CH-LST	Dyes Inlet	Lost Crk Tributary	1912.6
1	GC-HNS	Sinclair Inlet	Heins & Jarstad Crk Tribs	848.0
1	BL-SQR	Sinclair Inlet	Square Crk Tributary	1665.3
2	BL-HW	Sinclair Inlet	Upper Blackjack Crk	3525.6
2	BA-BH	Dyes Inlet	Barker Crk @ Bucklin Hill Rd	2223.9
2	BA	Dyes Inlet	Barker Crk @ Barker Crk Rd	2597.8
2	BVR	Yukon Harbor	Beaver Crk	1235.0
2	SACCO	Rich Passage	Sacco Crk	651.2
3	CH-KC	Dyes Inlet	Kitsap Crk Tributary	1968.2
3	ILL	PO Passage	Illahee Crk	801.7
3	WC	Sinclair Inlet	Wright Crk	725.9
4	MS	Dyes Inlet	Mosher Crk	1096.9
4	CC-RTP	Dyes Inlet	Clear Crk - East Fork Ridgetop Trib	344.9
4	OC	Sinclair Inlet	Olney Crk	1245.4
4	ANNP	Sinclair Inlet	Annapolis Crk (LMK136)	401.6
4	PA	Dyes Inlet	Pharman Crk	303.3
4	OBC	Dyes Inlet	Ostrich Bay Crk	402.1
4	DEE	PO Passage	Dee Crk	396.8
4	SULV	Rich Passage	Sullivan Crk (LMK155)	196.8
5	CC-MTV	Dyes Inlet	Clear Crk - East Fork Mountainview Trib	1217.6
5	CC	Dyes Inlet	Clear Crk @ Silverdale Way	5004.3
5	SC	Dyes Inlet	Strawberry Crk	1914.2
5	ROSS	Sinclair Inlet	Ross Crk	1273.4
5	CC-CW	Dyes Inlet	Clear Crk - West Fork	2706.8
5	CC01	Dyes Inlet	Clear Crk @ Ridgetop Blvd	5394.6
5	BA-NN	Dyes Inlet	Barker Crk @ Nils Nelson Rd	373.8
5	CC-BTL	Dyes Inlet	Clear Crk Trident Lakes Tributary	713.2
5	CC-BSP	Dyes Inlet	Clear Crk West Fork HW	1117.5
5	CC-CE	Dyes Inlet	Clear Crk - East Fork	2297.6

8.3.1 Method 1 – Regression Analysis using Time of Year and Flow

Initially, a log-linear model was fit to each of the three comparison streams (Table 8-23). The resulting R^2 coefficients for these models ranged from 0.2 to 0.4 (Table 8-24). All of the comparison streams had significant slopes associated with either the flow or time of year; however, there was little consistency in the major explanatory variable or which slopes were significantly different from zero. As with the test streams, the model tended to overestimate low FC concentrations and underestimate high FC concentrations (Figure 8-51). The residuals did not show a pattern with either the time of year or the watershed area normalized flow, and the magnitude of all standardized residuals was less than 3.0. The correlation between the observed and predicted log-FC concentrations for all three streams together was 0.64.

Predictions of FC concentrations based on the two extrapolation-based methods were then compared with the results obtained by Method 1. FC estimates for BL-KFC were the same for both extrapolation methods because the regression parameters for CH were used in both cases (Figure 8-52). The extrapolated estimates underestimated the dry-season concentrations. For GC, during the dry season, concentrations of FC were overestimated by the extrapolation based on basin area and underestimated by the extrapolation based on LULC and basin area. For SC, extrapolation based on LULC and basin area underestimated the FC concentration for three quarters of the year. These patterns were replicated when FC loads were calculated (Figure 8-53). Recall that FC loads were defined by the concentration times the average daily flow. Thus, for a given day, each concentration estimate was multiplied by the same flow value, and the pattern of under- or overestimation is replicated in the load plots. Estimates of either FC concentrations or loads were obviously much better when the method was based on observed FC data than on estimates from extrapolation methods.

Residual means squares were calculated as the difference between the observed log-FC concentration and the log of the predicted concentration based on the method and both extrapolation procedures (Table 8-25). As expected, residual mean squares were the smallest when the FC data from the given stream were used. Both extrapolation procedures produced larger residuals; however, the procedure that incorporated land use tended to have similar or smaller residuals than did the procedure that used basin area alone.

Table 8-23. Best-Fit Regression Coefficients and Resulting Smearing Coefficient for Model Comparison Streams

	Regression Parameters							Smearing Coefficient
Stream	constant	$\sin(2\pi f_y)$	$\cos(2\pi f_y)$	$\sin(4\pi f_y)$	$\cos(4\pi f_y)$	log(Q/A)	$(\log(Q/A))^2$	
BL-KFC	5.287	-0.206	-0.385	-0.004	0.275	3.112	0.660	1.094
GC	2.723	-0.535	-0.056	0.008	0.156	0.654	0.106	1.120
SC	3.722	-0.821	-0.411	0.293	-0.119	0.305	-0.230	1.100

Table 8-24. Summary Regression Results for the Regression with Time of Year and Flow for Model Comparison

Stream	Error Degrees of Freedom	Regression Significance	Adjusted R^2	Significant Slopes α=0.05	Major Explanatory Variable
BL-KFC	41	0.001	0.323	$\cos(2\pi f_y)$ $\cos(4\pi f_y)$ log(Q/A) (log(Q/A))2	log(Q/A)
GC	42	0.013	0.210	$\sin(2\pi f_y)$	log(Q/A)
SC	47	< 0.001	0.401	$\sin(2\pi f_y)$ $\cos(2\pi f_y)$ $\sin(4\pi f_y)$	$\sin(2\pi f_y)$

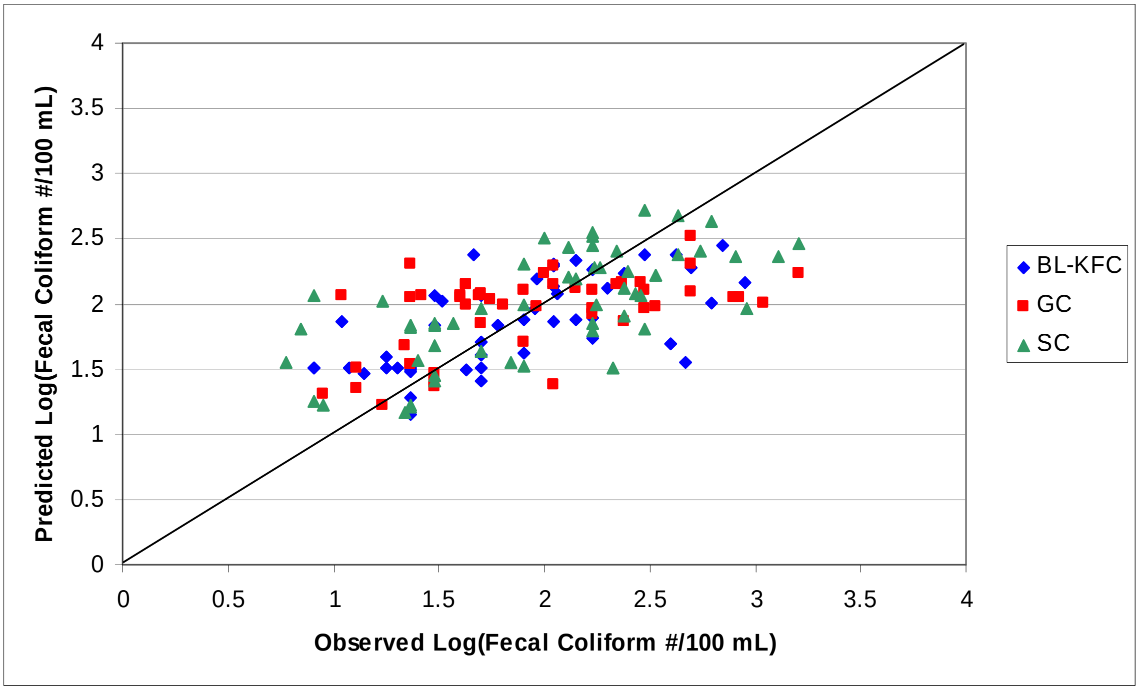


Figure 8-51. Observed and Predicted Log (Base 10) of the Fecal Coliform Measurements for Model Comparison Streams from the Regression with Time of Year and Flow

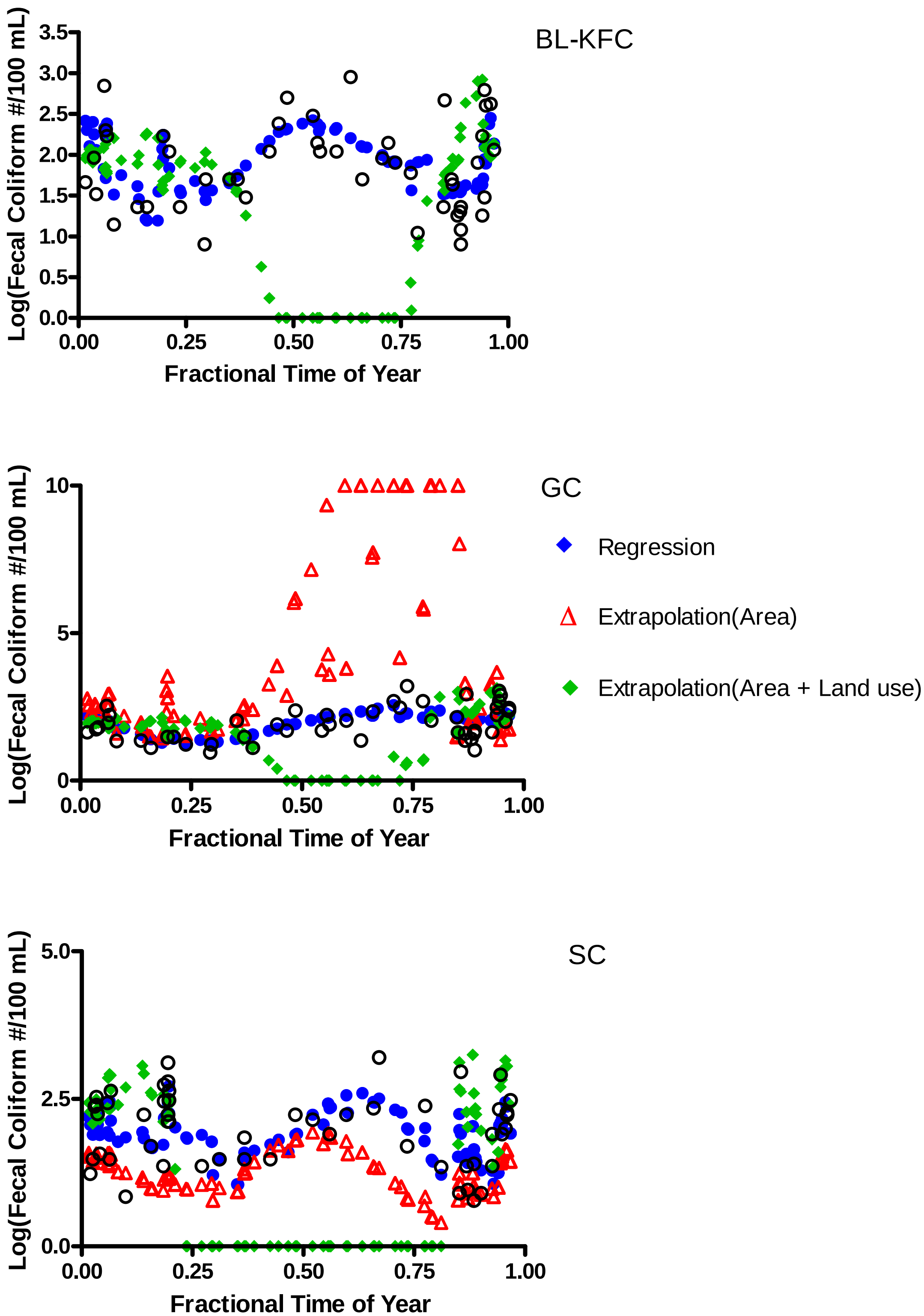


Figure 8-52. Log Observed (o), Predicted by Regression (Method 1), and Extrapolated Fecal Coliform Concentrations for the Verification Streams

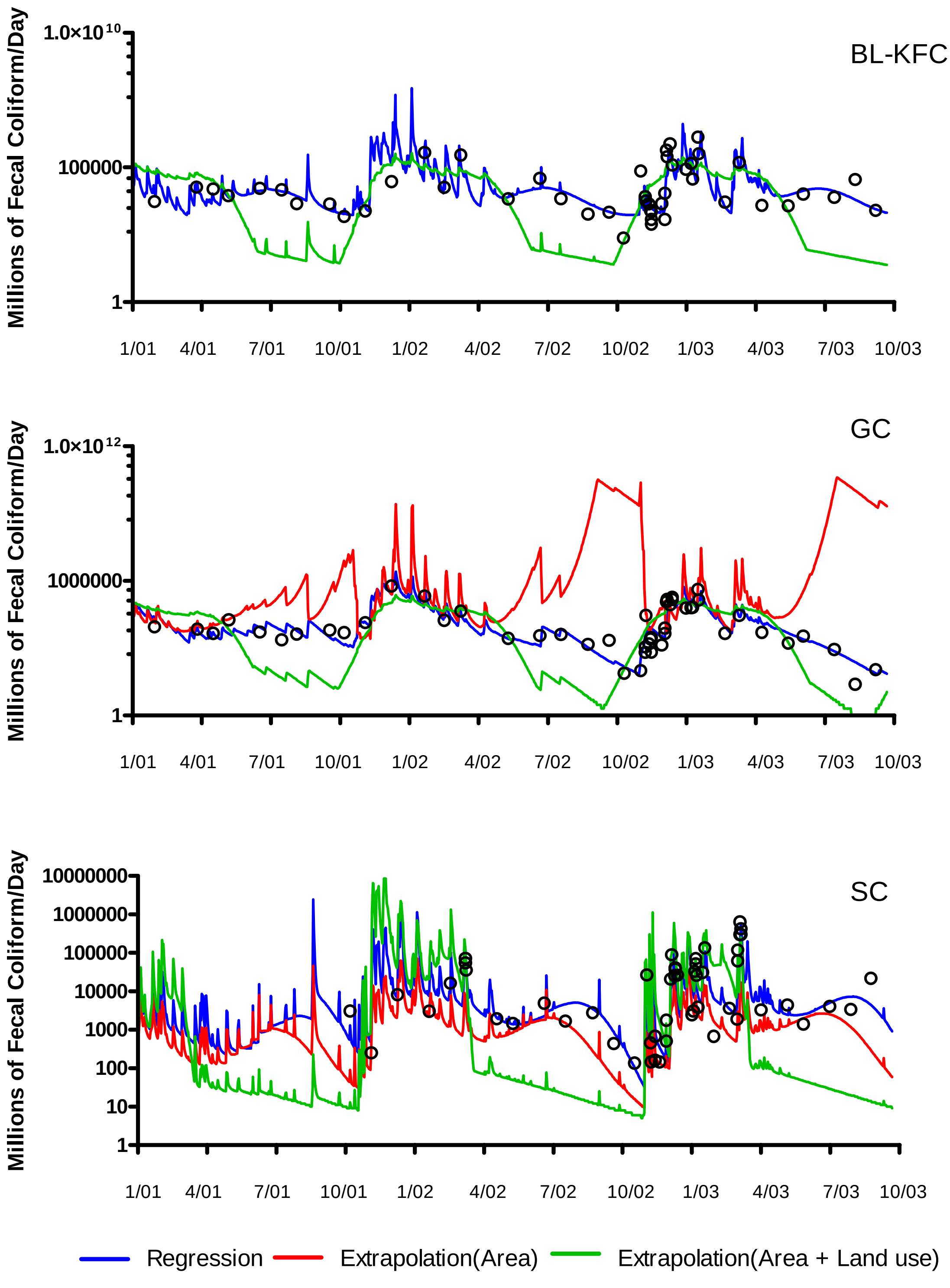


Figure 8-53. Observed (o), Predicted by Regression (Method 1), and Extrapolated Fecal Coliform Loadings for the Verification Streams

Table 8-25. Method 1 Resulting Residual Mean Squares for Comparison Streams Based on the Method and Extrapolation

Method	BL-KFC	GC	SC
Regression using Time of Year and Flow	0.180	0.223	0.201
Extrapolation based on area	1.655	9.397	0.819
Extrapolation based on area+land use	1.655	1.442	1.491

8.3.2 Method 2 – Utilization of Distribution Statistics

The observed 25th and 75th percentiles (descriptive statistics) of the FC concentrations for the comparison streams were not bounded well by the percentiles of the streams used for extrapolation (Table 8-26). Recall that the difference in the basin areas (squared) from each of the test basins suggested that BL-KFC was closest in area to CH, GC was closest in area to CC01, and SC was closest in area to AC. Thus, for extrapolation purposes, the percentiles from CH, CC01, and AC were used to bound the concentrations of FC in the comparison streams. Further, when both LULC information and basin area were considered, BL-KFC and GC were closest in LULC and area to CH, and SC was closest in LULC and area to CC.

As expected, the descriptive statistics (25th and 75th percentiles) from the given stream bounded the observed data better than the percentiles from the streams used for extrapolation (Figure 8-54). Extrapolation using area alone produced boundaries that were too low for SC, whereas extrapolation incorporating LULC produced boundaries that were too low for GC. Both extrapolation procedures produce the same results for BL-KFC. The pattern was repeated for estimated FC loadings (Figure 8-55). The residual mean squares were calculated as the difference from the observed log-FC concentration and the halfway point between each of the interval boundaries (Table 8-27). Extrapolation based on LULC and basin area had equal or smaller residuals than the estimates based on the actual distributional statistics. Further, these residuals were smaller than those resulting from extrapolation using Method 1 (Table 8-25).

Table 8-26. Descriptive statistics of the fecal coliform data for both the comparison streams and the streams used for extrapolation.

	All Fecal Coliform Data								
Name	GM #/100 mL	Count	25th Percentile	75th Percentile	90th Percentile	GM < 100	N > 200	P > 200	Meets WQ Std
BL-KFC	65	56	23	148	355	YES	10	18%	NO
GC	67	67	25	170	398	YES	16	24%	NO
SC	90	76	30	275	577	YES	25	33%	NO
Extrapolation Based on Area Only									
CH	33	83	17	80	210	YES	6	7%	YES
CC01	108	42	30	450	932	NO	15	36%	NO
AC	15	64	4	30	101	YES	5	8%	YES
Extrapolation Based on Area + Land Use									
CH	33	83	17	80	210	YES	6	7%	YES
CC	59	75	22	185	393	YES	18	24%	NO

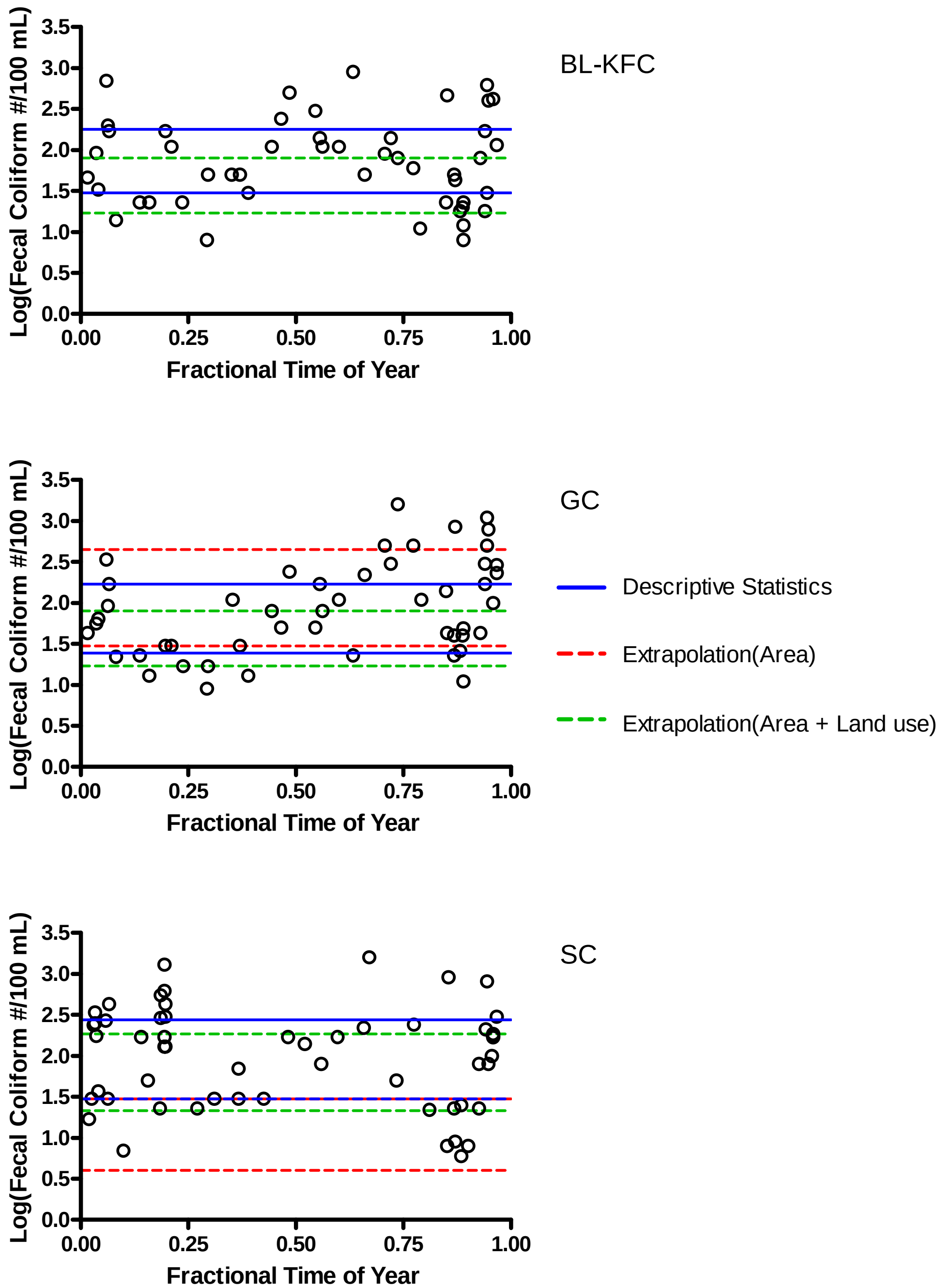


Figure 8-54. Log Observed (o) and Interval Estimates of Concentration Based on Method 2 and Extrapolation Using the 25th and 75th Percentiles of the Observed Fecal Coliform Distribution Using All of the Data

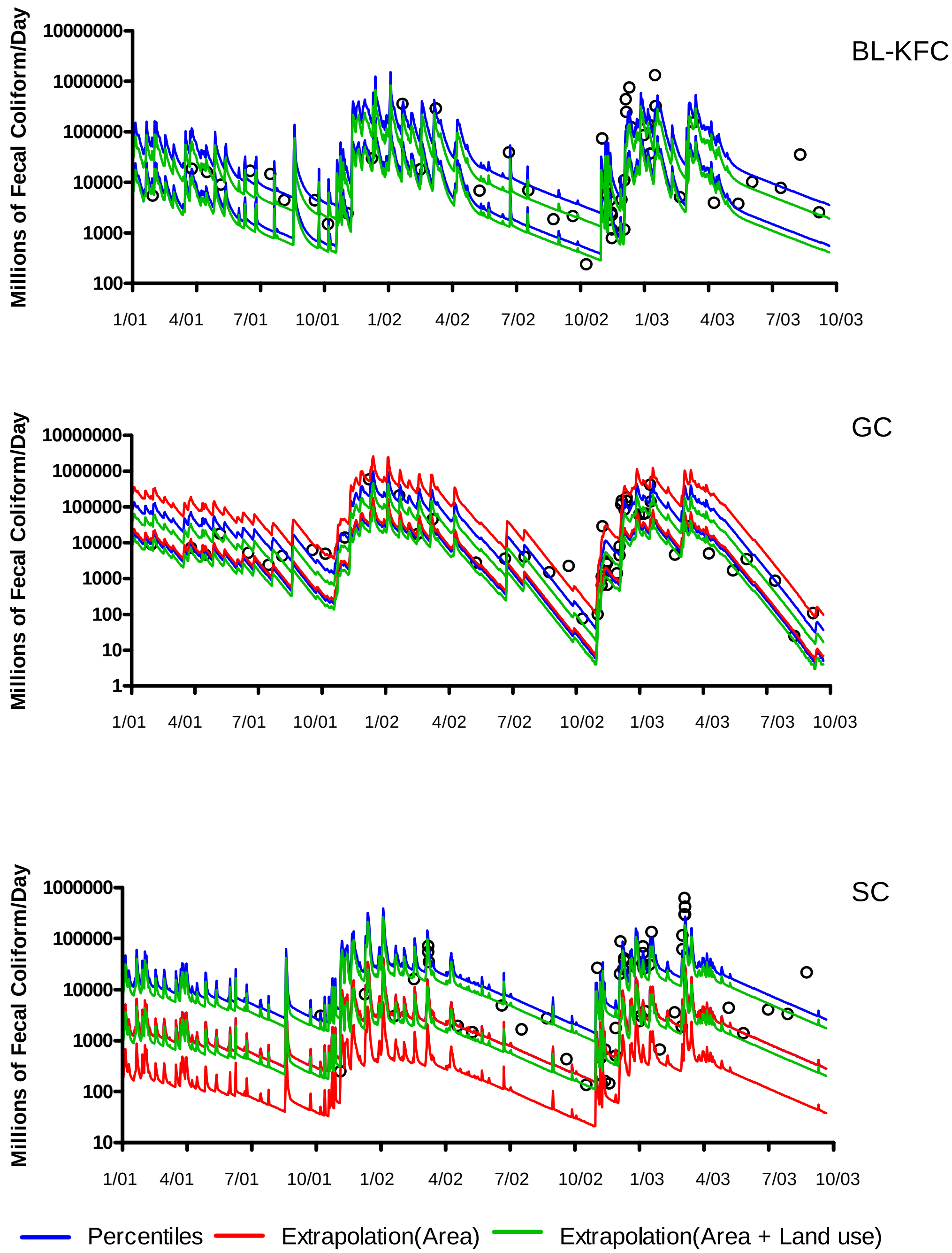


Figure 8-55. Observed (o) and Interval Estimates of Loads Based on Method 2 and Extrapolation Using the 25th and 75th Percentiles of the Observed Fecal Coliform Distribution Using All of the Data

Table 8-27. Method 2 Resulting Residual Mean Squares for Comparison Streams Based on the Method and Extrapolation

Method	BL-KFC	GC	SC
Distributional Statistics	0.291	0.323	0.407
Extrapolation based on area	0.313	0.521	0.936
Extrapolation based on area+land use	0.313	0.380	0.368

8.3.3 Method 3 – Step-wise Regression using Landscape Characteristics

Extrapolation was not necessary to estimate the mean FC concentration for the comparison streams using Method 3 (Table 8-28). The step-down model was developed using all streams that had FC measurements. Thus, the resulting difference in the observed and estimated mean FC concentration for these streams was already presented in Figure 8-29. Even though the step-down land-use model explained 81% of the variation between streams, the predicted mean FC concentration tended to underestimate FC concentrations for the comparison streams (Figure 8-56). The FC loadings followed the same pattern (Figure 8-57).

The residual mean squares were calculated as the difference between the observed log-FC concentration and the log of the observed and predicted geometric-mean FC concentration (Table 8-29). Residuals were not greatly different between estimates based on the observed or the predicted geometric-mean FC concentration and were comparable with those produced by Method 2.

Table 8-28. Landscape Characteristics and Resulting Estimated Mean Fecal Coliform Concentration Based on Method 3 for Comparison Streams

Variable	BL-KFC	GC	SC
% Deciduous Forest	17.6%	22.4%	14.4%
% Rural (LD Residential)	12.7%	2.6%	3.2%
Road Density (km/km^2)	14.7	8.7	17.1
Drainage Density (km / km^2)	1.8	2.3	1.5
Stream-Crossings/Stream-Length (#/km)	0.6	0.5	1.2
% Rural (LD Residential)-Buffer	8.4%	0.4%	0.6%
% Agricultural-Buffer	15.2%	6.4%	6.6%
% Deciduous Forest-Buffer	30.3%	39.5%	31.1%
% Coniferous Forest-Buffer	30.5%	37.6%	19.2%
% Forest-Buffer	62.4%	82.8%	51.5%
Estimated Geometric Mean Fecal Coliform Concentration	41.5	31.0	67.5
Observed Geometric Mean Fecal Coliform Concentration	65.0	66.9	89.8

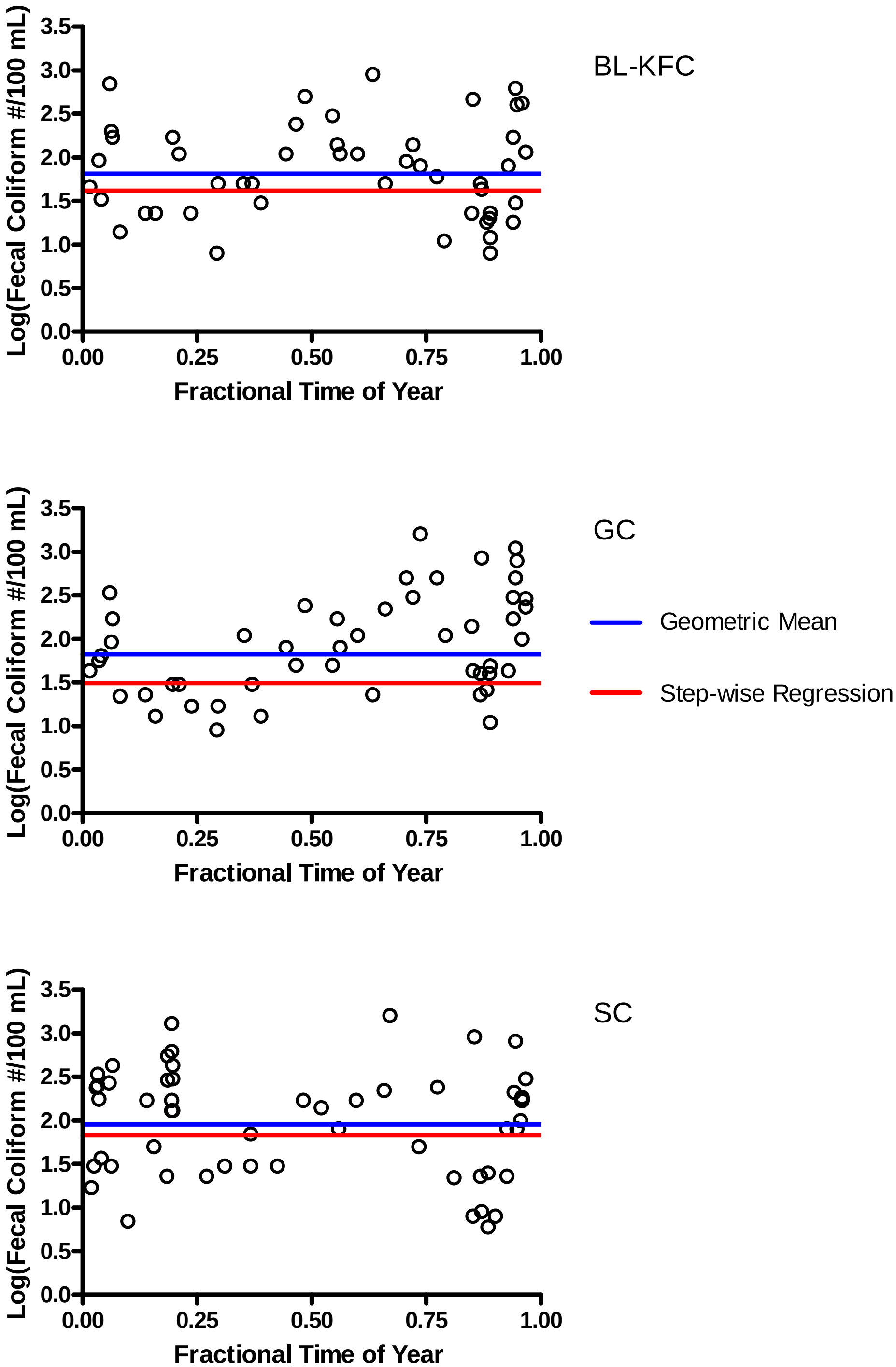


Figure 8-56. Log Observed Fecal Coliform Concentrations (o) and the Log Observed and Predicted Geometric Mean Using the Step-Down Step-Wise Regression Model (Method 3)

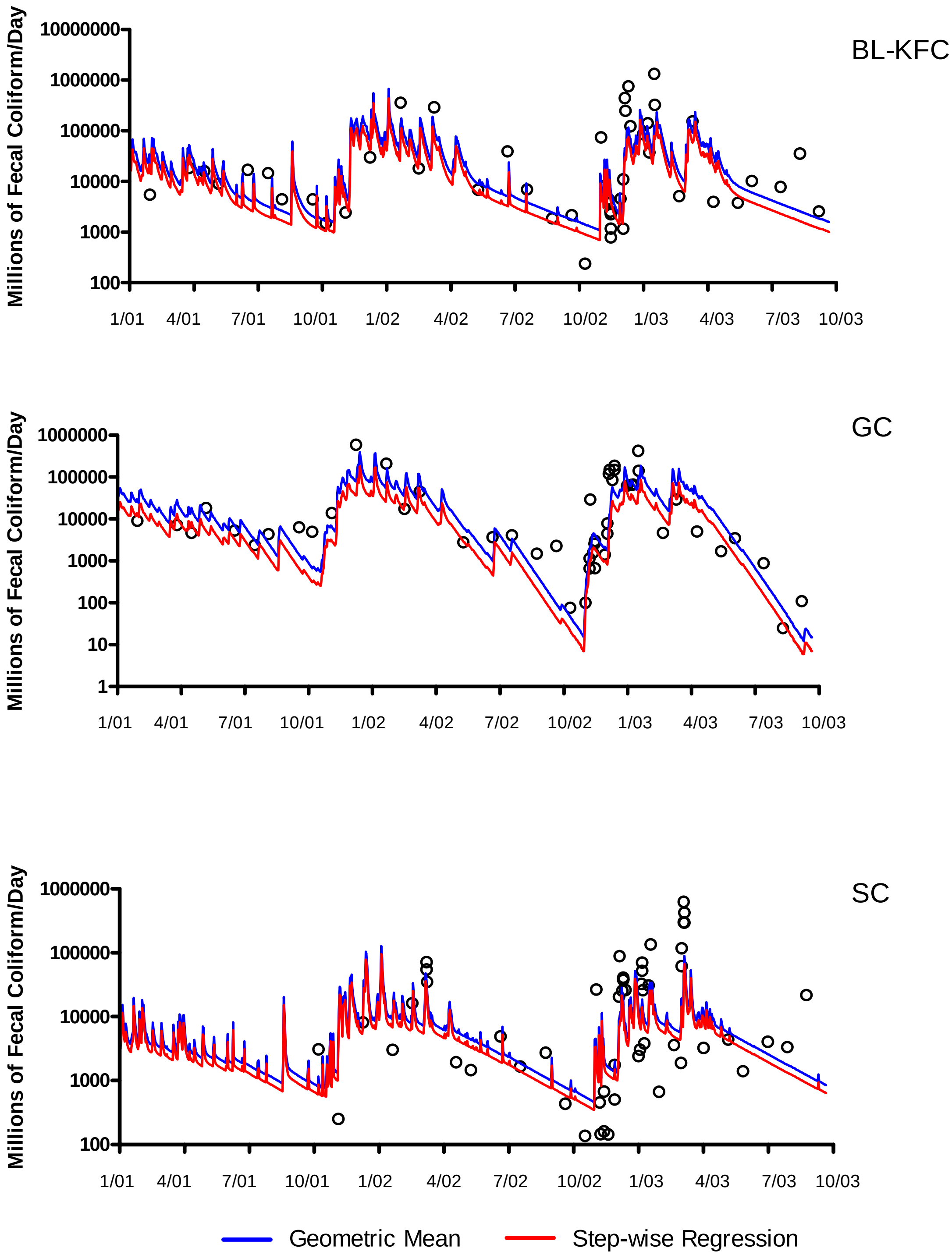


Figure 8-57. Observed Fecal Coliform Loadings (o) and the Predicted Mean Loadings Based on the Observed and Predicted Geometric Mean Using the Step-Down Step-Wise Regression Model (Method 3)

Table 8-29. Method 3 Resulting Residual Mean Squares for Comparison Streams Based on the Observed and Predicted Geometric Mean Fecal Coliform Concentration

Method	BL-KFC	GC	SC
Observed Geometric Mean	0.287	0.331	0.368
Predicted Geometric Mean	0.341	0.513	0.391

8.3.4 Method 4 – Cluster Descriptive Statistics

Again, extrapolation was not necessary to estimate the intervals to bound the FC concentrations for the comparison streams using Method 4. The cluster analysis was conducted using all streams that had LULC data. BL-KFC and GC were both assigned to Cluster 1, and SC was assigned to Cluster 5 (Table 8-22). Thus, the 25th and 75th cluster percentiles of the 25th and 75th stream percentiles were used as interval boundaries for the given cluster (Table 8-30 and Figure 8-58). For comparison, interval boundaries were also estimated by the 25th and 75th percentiles of the given stream's FC distribution.

As expected, the cluster intervals were wider than the stream intervals, but they tended to underestimate the upper boundary for both the FC concentration and loading estimates (Figures 8-58 and 8-59). The residual mean square was calculated as the difference between the observed log-FC concentration and the log of the halfway point between the interval boundaries based on the stream percentiles and the cluster percentiles (Table 8-31). SC and Cluster 5 percentiles had the same log halfway point at three decimal places, and thus, they had the same residual mean square. Residuals were basically the same using the stream percentiles or the cluster percentiles and were slightly better or comparable to those produced by Method 1, Method 2, and Method 3.

Table 8-30. Descriptive Statistics for Clusters Associated with the Comparison Streams and Their Observed Descriptive Statistics

All Available Fecal Coliform Data					
Cluster	**Cluster Percentile**	**Geometric Mean #/100 mL**	**25th Stream Percentile**	**75th Stream Percentile**	**90th Stream Percentile**
1	**25th**	24.5	11.0	52.6	152.4
1	**75th**	64.9	24.1	137.7	336.5
5	**25th**	41.5	11.1	126.3	356.4
5	**75th**	95.5	30.0	293.8	680.3
BL-KFC		65	23	148	355
GC		67	25	170	398
SC		90	30	275	577

Highlighted cells were used as interval boundaries for the given cluster.

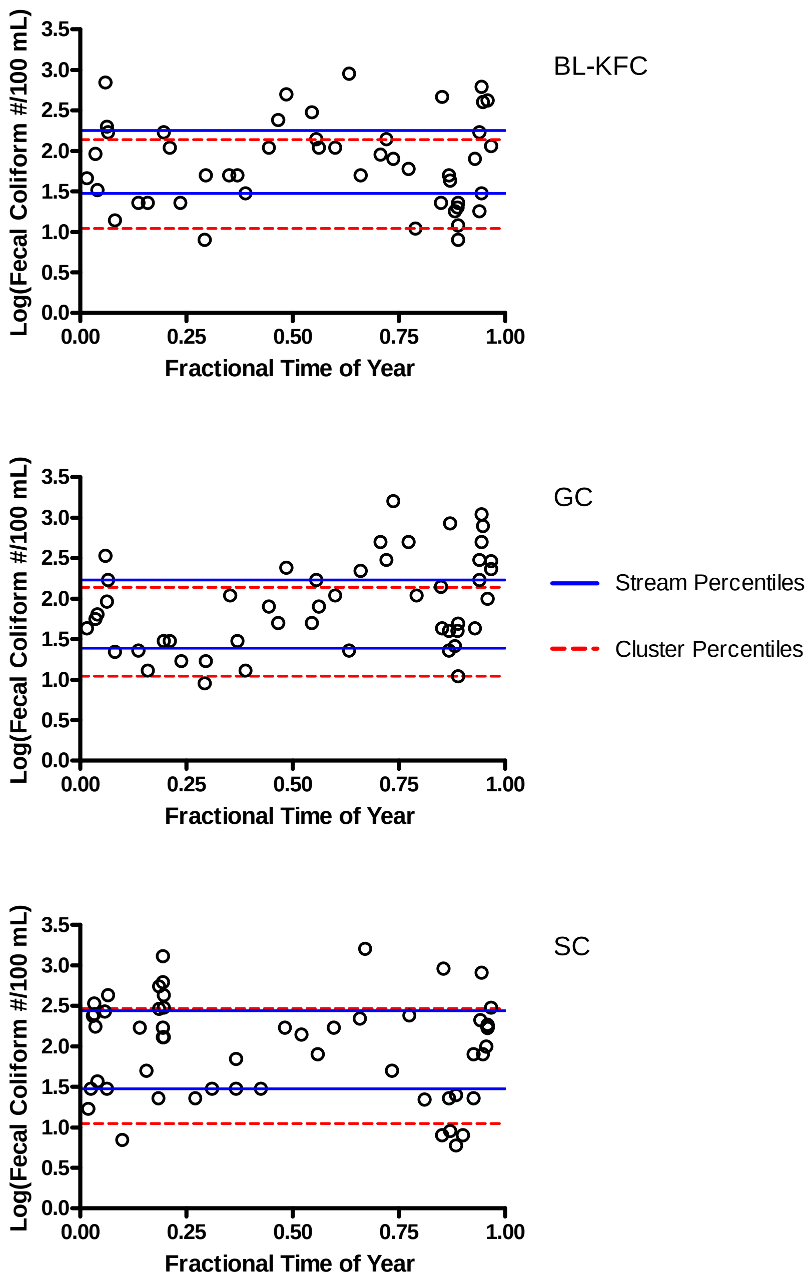


Figure 8-58. Log Observed (o) and Interval Estimates of the Log Fecal Coliform Concentrations for Comparison Streams Based on the Stream 25th and 75th Percentile (blue lines) and the 25th and 75th Cluster Percentile of the 25th and 75th Stream Percentiles (red dashed lines)

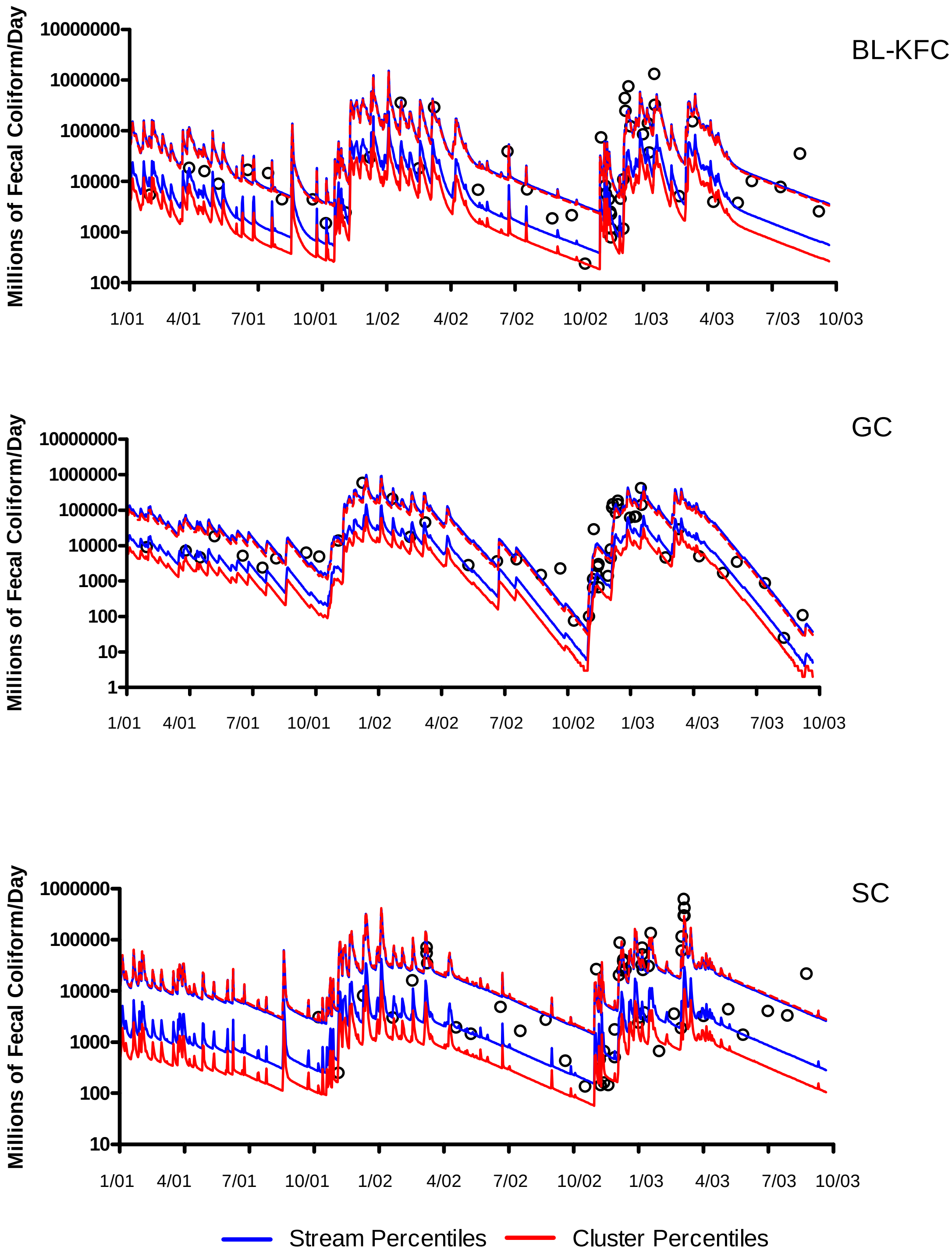


Figure 8-59. Observed (o) and Interval Estimates of the Log Fecal Coliform Concentrations for Comparison Streams Based on the Stream 25th and 75th Percentile (blue lines) and the 25th and 75th Cluster Percentile of the 25th and 75th Stream Percentiles (red dashed lines)

Table 8-31. Method 4 Resulting Residual Mean Squares for Comparison Streams Based on the Observed and Predicted Interval Boundaries About Fecal Coliform Concentrations.

Method	BL-KFC	GC	SC
Stream Percentiles	0.291	0.323	0.407
Cluster Percentiles	0.285	0.324	0.407

8.3.5 Method 5 – Regression with Cluster Scores

Extrapolation was not necessary to estimate the mean FC concentration for the comparison streams using Method 5 (Table 8-32). The discriminant scores between clusters were developed using all streams. The predicted geometric-mean FC concentration was calculated using the equation:

$$y = 74.63 - 12.794(Score\ 1).$$

The resulting standardized residuals between the observed and predicted geometric-mean FC concentration for these streams was already presented in Figure 8-46. Recall that the discriminant score model explained only 38% of the variation in FC geometric means between streams. The predicted mean FC concentration and loadings underestimated the observed geometric-mean FC concentration for BL-KFC and GC more than SC (Figures 8-60 and 8-61).

The residual mean squares were calculated as the difference between the observed log-FC concentration and the log of the observed and predicted geometric-mean FC concentration (Table 8-33). Residuals were not greatly different between estimates based on the observed or the predicted geometric mean and were comparable to those produced by Method 3.

Table 8-32. Cluster Membership, Score 1 Value, and the Observed and Predicted Geometric-Mean FC Using Method 5 for Model Comparison Streams

Observation	Cluster	Score 1	Observed Geometric Mean	Predicted Geometric Mean
BL-KFC	1	2.00	65.0	49.0
GC	1	3.35	67.0	31.8
SC	5	-0.60	90.0	82.4

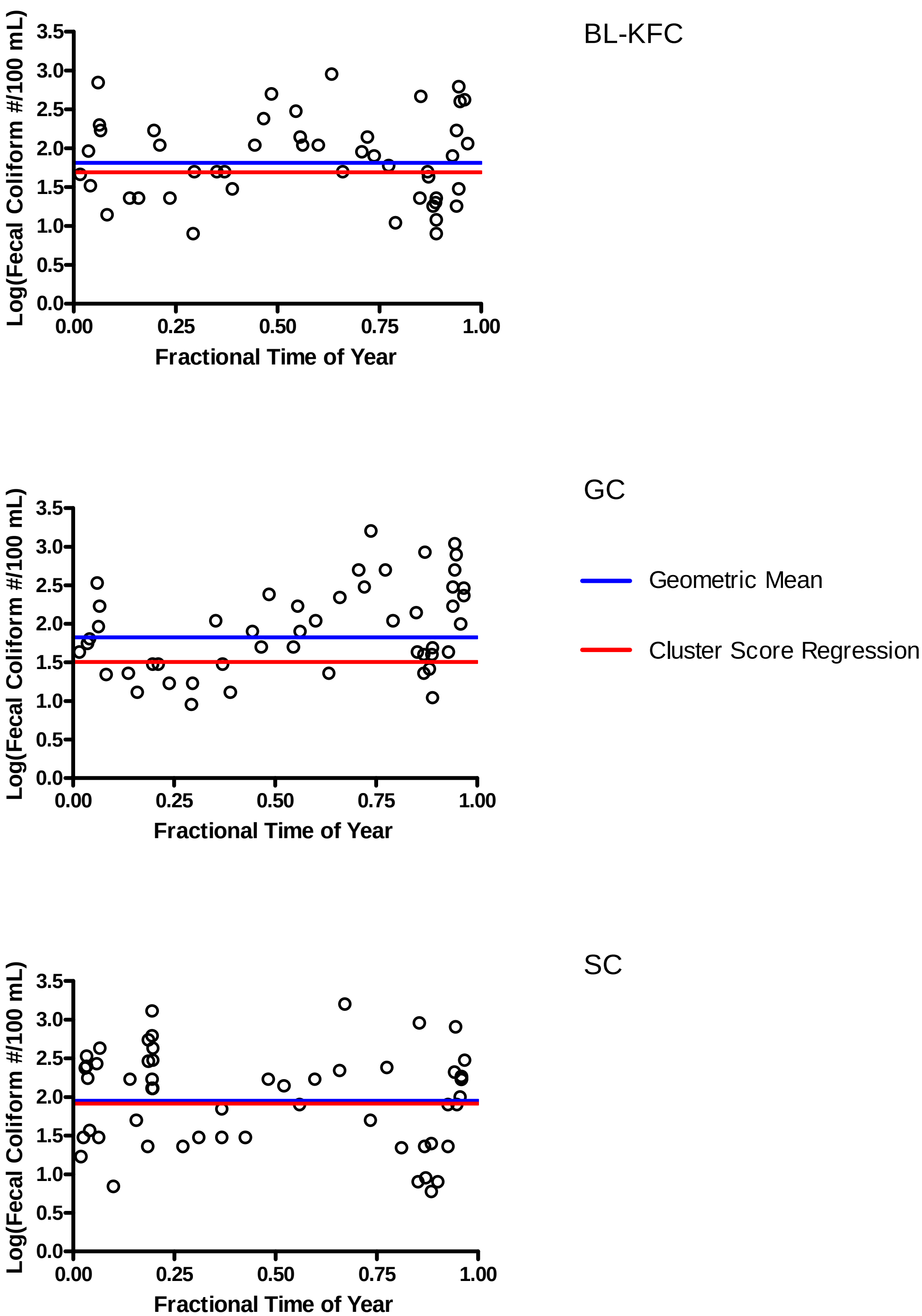


Figure 8-60. Log Observed Fecal Coliform Concentrations and the Log Observed and Predicted Geometric Mean Fecal Coliform Concentration Using the Cluster Score Regression Model (Method 5)

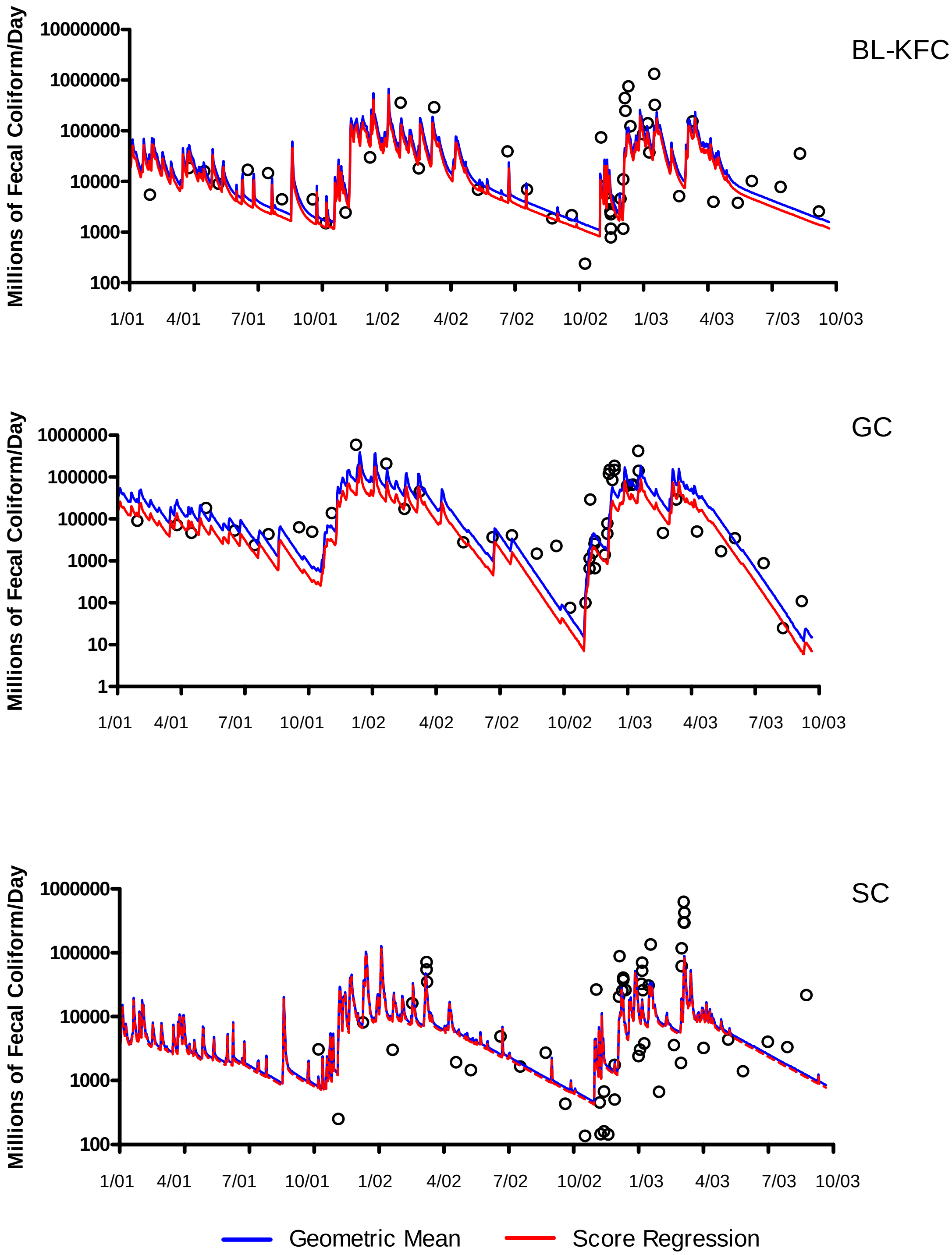


Figure 8-61. Observed Fecal Coliform Loadings and the Predicted Loads Based On the Observed and Predicted Geometric Mean Fecal Coliform Concentration Using the Cluster Score Regression Model (Method 5)

Table 8-33. Method 5 Resulting Residual Mean Squares for Comparison Streams Based on the Observed and Predicted Geometric Mean Fecal Coliform Concentration

Method	BL-KFC	GC	SC
Observed Geometric Mean	0.287	0.331	0.368
Predicted Geometric Mean	0.312	0.504	0.372

8.4 Stream FC Loading Estimation Summary

From a statistical perspective, the estimation method selected for use in this project should provide minimum FC concentration residuals for all streams, minimize the need for extrapolation, and provide an estimate of variance in FC load. Recall that residuals were based on the log concentration; thus, the raw residual would be determined by taking 10 to the power of the obtained residual. For streams without FC measurements, methods that do not require extrapolation have an advantage over those that do, because they use more available information. Also, interval estimators have an advantage because they provide a measure of variance on the FC load estimates going into Sinclair and Dyes Inlet. These intervals allow the estimation of extremes in the shoreline concentrations resulting from the circulation model, and ultimately allow the estimation of the variability in outcomes from future scenario model runs.

None of the above methods met all of these criteria (Table 8-34). Method 1 had large residual mean squares, required extrapolation, and did not allow for an estimate of variability in FC load. Method 2 had small residual mean squares for BL-KFC and GC, allowed for estimation of variability in FC load, but required extrapolation. Extrapolation using both land-use and basin area did better for all three comparison streams than did extrapolation based on basin area alone. Method 3 and Method 5 had similar low residual mean squares, did not require extrapolation, but did not allow an estimate of variability in FC load. Method 4 had the lowest residual mean squares for BL-KFC and GC and a low residual mean square for SC. Further, Method 4 did not require extrapolation and allowed for an estimate of variability in FC load. The best estimator of FC concentration and loading was a combination of Methods 4 and 5. Method 4 provided an interval estimate and, thus, an estimate of variance to the final shoreline concentrations of FC in Sinclair and Dyes Inlet. Method 5 provided a slightly better estimate of the geometric-mean FC loadings than did Method 3. Based on this analysis, it was decided that a combination of Methods 4 and 5 was most appropriate for extrapolating FC loading estimates to areas that were not sampled for this project.

Combining Methods 4 and 5 allows estimation of a mean and range of FC loading. For modeling purposes, only the cluster assignment and cluster percentiles from Table 8-30 are required to determine the extreme values of FC concentration. Table 8-35 lists the cluster assignment and Score 1 for all streams. Finally, the predicted geometric-mean FC concentration is calculated using the following equation to support the estimation of a mean FC load for all streams:

$$y = 74.63 - 12.794(\text{Score } 1).$$

In the results section (Section 6), differences were observed for FC data between the wet and dry seasons, as well as for storm season and storm-event data. Distinct differences were noted in some geometric means, as well as in the 25^{th} and 75^{th} percentile values and in the number of violations of WQS. Based on these findings, the FC data were analyzed at three different temporal scales (wet, dry, and storm), and also in a data set that combined all FC data.

Table 8-34. Comparison of Methods by Their Resulting Residual Mean Squares, Need for Extrapolation, and Ability to Estimate the Variance in FC Load

Method	Estimation/ Extrapolation	Residual Mean Square			Need for Extrapolation	Allows Estimate of Variability in FC Load
		BL-KFC	GC	SC		
Actual Data	Regression using Time of Year and Flow	0.18	0.223	0.201	--	--
Actual Data	25th and 75th Percentiles of the FC Concentration	0.291	0.323	0.407	--	--
Actual Data	Observed Geometric Mean	0.287	0.331	0.368	--	--
Method 1	Extrapolation based on area	1.655	9.397	0.819	Yes	No
Method 1	Extrapolation based on area + land use	1.655	1.442	1.491	Yes	No
Method 2	Extrapolation based on area	0.313	0.521	0.936	Yes	Yes
Method 2	Extrapolation based on area + land use	0.313	0.38	0.368	Yes	Yes
Method 3	Predicted Geometric Mean	0.341	0.513	0.391	No	No
Method 4	Cluster Percentiles	0.285	0.324	0.407	No	Yes
Method 5	Predicted Geometric Mean	0.312	0.504	0.372	No	No

Highlighted cells represent the minimum residual mean square between methods.

Table 8-35. Cluster Assignment and Score 1 for all Stream Segments

Watershed	Stream Sub-Watershed	WQ ID	Cluster	Score 1
Sinclair Inlet	Blackjack Crk	BL-KFC	1	2.0028
PO Passage	Gazzam Crk		1	2.0574
Sinclair Inlet	Jarstad & Heins Crk Tributaries		1	2.1970
Sinclair Inlet	Heins Crk Tributary		1	2.3414
Sinclair Inlet	Parish Crk	GC-PA	1	2.3766
Dyes Inlet	Woods Crk		1	2.5257
Sinclair Inlet	Spring Crk		1	2.5526
Dyes Inlet	Chico Crk @ Kittyhawk Dr	CH01	1	2.7924
Dyes Inlet	Chico Crk @ Golf Course	CH	1	3.0195
Sinclair Inlet	Blackjack Crk @ SR-16	BL	1	3.1697
Sinclair Inlet	Gorst Crk	GC	1	3.3480
Dyes Inlet	Lower Kitsap Crk		1	3.3630
Dyes Inlet	Lost Crk Tributary		1	3.4369
Sinclair Inlet	Anderson Crk	AC	1	3.4639
Dyes Inlet	Wildcat Crk Tributary		1	3.6359
PO Passage	Springbrook Crk	BI-SBC	1	3.7045
Dyes Inlet	Chico Crk @ Taylor Rd	CH-CT	1	3.8700
Dyes Inlet	Upper Kitsap Crk	CH-KL	1	3.9353
Sinclair Inlet	Upper Gorst Crk	GC-JAR	1	4.2159
Sinclair Inlet	Ruby Crk Tributary	BL-RBY	1	4.4914
PO Passage	Shel Schelb Crk		1	4.7824

Table 8-35. (contd)

Watershed	Stream Sub-Watershed	WQ ID	Cluster	Score 1
Dyes Inlet	Dickerson Crk Tributary	CH-DI	1	5.2499
Sinclair Inlet	Square Crk Tributary	BL-SQR	1	5.2517
Yukon Harbor	Duncan Crk		2	-0.7535
Dyes Inlet	Barker Crk @ Barker Crk Rd	BA	2	-0.7423
Dyes Inlet	Barker Crk @ Bucklin Hill Rd	BA-BH	2	-0.4753
Rich Passage	Sacco Crk	SACCO	2	0.4413
Sinclair Inlet	Upper Blackjack Crk	BL-HW	2	1.4884
Yukon Harbor	Beaver Crk	BVR	2	1.6193
Rich Passage	Rich Cove Crk		2	3.5521
Rich Passage	Wilson Crk		2	4.3024
Dyes Inlet	Erlands Crk		3	-2.6611
Dyes Inlet	Kitsap Lake		3	-1.9144
PO Passage	Illahee Crk	ILL	3	-1.5581
Sinclair Inlet	Wright Crk	WC	3	-0.2660
Dyes Inlet	Kitsap Crk Tributary	CH-KC	3	0.7509
Dyes Inlet	Clear Crk – Lower Mainstem		4	-8.9608
PO Passage	Dee Crk	DEE	4	-8.1301
Dyes Inlet	Ostrich Bay Crk	OBC	4	-7.8846
Sinclair Inlet	Annapolis Crk	LMK136	4	-6.9556
Dyes Inlet	Clear Crk - East Fork Ridgetop Tributary	CC-RTP	4	-6.7679
Dyes Inlet	Koch Crk		4	-6.6247
Sinclair Inlet	Olney Crk	OC	4	-6.4112
Dyes Inlet	Stampede Crk		4	-6.3690
Dyes Inlet	Pharman Crk	PA	4	-6.1620
Dyes Inlet	Mosher Crk	MS	4	-6.1157
Dyes Inlet	Clear Crk - Mainstem		4	-5.8337
Rich Passage	Sullivan Crk	LMK155	4	-4.0286
Dyes Inlet	Jackson Park Crk		4	-4.0040
PO Passage	State Park Crk		4	-3.8092
Dyes Inlet	Clear Crk - Middle Mainstem		5	-4.0525
Dyes Inlet	Clear Crk - Lower West Fork		5	-3.1347
Dyes Inlet	Crystal Crk		5	-2.3851
Dyes Inlet	Barker Crk @ Nils Nelson Rd	BA-NN	5	-2.3569
Dyes Inlet	Clear Crk @ Ridgetop Blvd	CC01	5	-1.7918
Dyes Inlet	Clear Crk - East Fork	CC-CE	5	-1.6974
Dyes Inlet	Clear Crk @ Silverdale Way	CC	5	-1.4962
Sinclair Inlet	Ross Crk	ROSS	5	-1.2875
Dyes Inlet	Clear Crk - West Fork	CC-CW	5	-1.2792
Dyes Inlet	Clear Crk - Upper West Fork		5	-0.6865
Dyes Inlet	Strawberry Crk	SC	5	-0.6037
Dyes Inlet	Clear Crk - East Fork Mountainview Tributary	CC-MTV	5	-0.3491
Dyes Inlet	Clear Crk Trident Lakes Tributary	CC-BTL	5	-0.2228
Dyes Inlet	Clear Crk West Fork HW	CC-BSP	5	-0.2208

Despite the differences between observed wet and dry seasons and storm events (Section 6), the final statistical model is based on the distribution of all the FC data for a given cluster. Not only were the number of observations used in the cluster statistics reduced when seasons were evaluated separately, but as seen in Method 2, the uncertainty in prediction was not reduced significantly. FC concentrations for the test streams were bounded well by the 25th and the 75th percentiles calculated from all sampled data (Figure 8-14). Wet-season concentration boundaries tended to underestimate loads (Figures 8-21 though 8-24), and dry-season concentration boundaries tended to overestimate loads (Figures 8-25 though 8-28). Combining all the FC data together produced a more accurate model of FC distributions on all temporal scales of analysis. Therefore, it is recommended that the combined data be used to estimate FC loading factors for all unmonitored sites. If desired, this estimation method could also be used for monitored sites as well. If long-term FC data exist, the actual data could be used instead of an estimated set of data.

8.5 Estimation of FC Loading to Sinclair-Dyes Inlet

Streams, outfalls, and direct runoff from nearshore areas were modeled as major sources of FC to Sinclair-Dyes Inlet. The estimation of FC loadings from streams was discussed extensively above. Cluster membership and descriptive statistics for estimation of FC concentrations in stream segments that empty directly into the inlets are repeated for clarity in Tables 8-36 and 8-37 respectively. As discussed, in addition to streams, other FC source areas include stormwater outfalls that drain urbanized areas served by engineered stormwater collection and conveyance networks, and shoreline areas that have direct runoff into marine receiving waters. FC loadings from stormwater outfalls and direct runoff areas can be estimated from stream modeling analysis. However, because flows for outfalls and direct runoff were not available at the time of this analysis, only the FC concentrations were estimated.

The FC concentrations from outfalls tended to be highly variable, with CVs averaging 150%. Outfalls tended to fall into three developmental categories: urban (HD residential) with commercial/industrial development, rural development, and light suburban development (Table 8-38). However, the average geometric-mean FC concentration was greater than 100 FC/100 mL for all three groups (Table 8-39). Because outfalls tend to flow only during storm events, an alternative to estimating FC loads is required that incorporates a function of the time of year and flow. Further, landscape characteristics do not correlate well with the outfall FC concentrations (Table 8-40). Thus, descriptive statistics associated with the level of development were used to provide a boundary or interval estimate on the FC concentration. The estimate of FC loading based on the FC geometric mean, for example, is the sample geometric mean times the daily average flow (using streamflow as a worst-case scenario), corrected for units to give millions of FC/day. Concentration intervals can be based on the 25^{th} and 75^{th} percentile of the developmental group's distribution or the percentiles from all outfalls (Table 8-41). An estimated interval allows an estimate of the variability in loading to enter the inland waters circulation model, which then can provide an interval estimate (instead of a single number) of the nearshore concentration of FC.

Measurements of FC concentrations from direct runoff from nearshore areas were not available for this analysis. FC concentrations were assumed to be similar to stream FC concentrations and related to the land-use characteristics. Thus, the LULC cluster analysis (Method 4) was applied to nearshore areas, and cluster membership was determined by discriminant function analysis (Table 8-42). The FC concentrations associated with runoff would then be estimated by the cluster descriptive statistics presented in Table 8-37. Treating shoreline direct-runoff areas the same as streams may underestimate the actual FC concentrations for these direct runoff areas, especially for heavily developed shoreline areas, but it is a better comparison than treating them as stormwater because, for the most part, they lack an engineered collection and conveyance system. In general, they are more "stream-like" in source-type and runoff behavior. The 75^{th} and 90^{th} percentiles of the stream cluster FC concentration distribution might provide a more protective estimate of the FC concentrations from direct runoff.

Table 8-36. Cluster Membership and Score 1 for Streams that Empty Directly into Sinclair-Dyes Inlet

Watershed	Stream Sub-Watershed	WQ ID	Ch3d ID#	HSPF ID#	Cluster	Score 1
Sinclair Inlet	Blackjack Crk	BL-KFC	610000	2207	1	2.0028
PO Passage	Gazzam Crk		510000	2089	1	2.0574
Dyes Inlet	Woods Crk		270000	2070	1	2.5257
Sinclair Inlet	Spring Crk		650000	2029	1	2.5526
Dyes Inlet	Chico Crk	CH01	240000	2093	1	2.7924
Sinclair Inlet	Gorst Crk	GC	14	2058	1	3.3480
Sinclair Inlet	Anderson Crk	AC	15	2059	1	3.4639
PO Passage	Springbrook Crk	BI-SBC	198	63005000	1	3.7045
PO Passage	Shel Schelb Crk		520000	2090	1	4.7824
Yukon Harbor	Duncan Crk		9570750	2925	2	-0.7535
Dyes Inlet	Barker Crk	BA	320000	2062	2	-0.7423
Rich Passage	Sacco Crk	SACCO	24	2082	2	0.4413
Yukon Harbor	Beaver Crk	BVR	540000	2087	2	1.6193
Rich Passage	Rich Cove Crk		550000	2086	2	3.5521
Rich Passage	Wilson Crk		560000	2085	2	4.3024
Dyes Inlet	Erlands Crk		250000	2069	3	-2.6611
PO Passage	Illahee Crk	ILL	500000	2080	3	-1.5581
Sinclair Inlet	Wright Crk	WC	10000	2160	3	-0.2660
PO Passage	Dee Crk	DEE	480000	2003	4	-8.1301
Dyes Inlet	Ostrich Bay Crk	OBC	220000	2157	4	-7.8846
Sinclair Inlet	Annapolis Crk	LMK136	600000	2199	4	-6.9556
Dyes Inlet	Koch Crk		280000	2071	4	-6.6247
Sinclair Inlet	Olney Crk	OC	20	2067	4	-6.4112
Dyes Inlet	Stampede Crk		330000	2078	4	-6.3690
Dyes Inlet	Pharman Crk	PA	340000	2079	4	-6.1620
Dyes Inlet	Mosher Crk	MS	350000	2098	4	-6.1157
Rich Passage	Sullivan Crk	LMK155	580000	2037	4	-4.0286
Dyes Inlet	Jackson Park Crk		230000	2077	4	-4.0040
PO Passage	State Park Crk		490000	2081	4	-3.8092
Dyes Inlet	Crystal Crk		260000	2072	5	-2.3851
Dyes Inlet	Clear Crk	CC01	63	2144	5	-1.7918
Sinclair Inlet	Ross Crk	ROSS	630000	2100	5	-1.2875
Dyes Inlet	Strawberry Crk	SC	290000	2101	5	-0.6037

Table 8-37. Descriptive Statistics for FC Concentrations by Cluster.

Cluster	Percentile (Within Cluster)	All Available Data			
		Geometric Mean FC (cfu/100mL)	25th Percentile (Within Stream)	75th Percentile (Within Stream)	90th Percentile (Within Stream)
1	25th	24.5	11.0	52.6	152
1	75th	64.9	24.1	138	337
2	25th	48.6	23.0	145	347
2	75th	112	50.0	263	532
3	25th	23.7	9.50	50.0	136
3	75th	23.7	9.50	50.0	136
4	25th	43.5	12.3	193	467
4	75th	262	83.1	705	1630
5	25th	41.5	11.1	126	356
5	75th	95.5	30.0	294	680

Highlighted cells provide boundaries for FC concentrations for streams within a given cluster.

Table 8-38. Outfall General Land-Use Characteristics

Name	Location	Ch3d ID#	HSPF ID#	Basin Area (acres)	% Natural Vegetation	% Rural	% Suburban	% Urban and Commercial
PSNS008	PSNS	70000	2175	29.80	0.0%	0.0%	0.0%	100.0%
PSNS015	PSNS	71000	2176	103.41	2.2%	0.0%	6.7%	91.2%
PSNS082.5	PSNS	73000	2178	22.46	0.0%	0.0%	7.9%	92.1%
PSNS115.1	PSNS	74000	2179	14.23	0.0%	0.0%	0.0%	100.0%
PSNS101	PSNS	76000	2181	16.68	0.0%	0.0%	0.0%	97.3%
PSNS081.1	PSNS	81000	2186	16.46	0.0%	0.0%	0.0%	97.3%
PSNS124	PSNS	82000	2187	9.34	0.0%	0.0%	0.0%	100.0%
PSNS126 (B-ST/CSO16)	PSNS	80002	2185	17.79	0.0%	0.0%	0.0%	81.3%
LMK164	National Ave	30000	2161	122.54	0.0%	0.0%	8.3%	87.5%
B-ST27	Evergreen	80001	2170	43.59	0.0%	0.0%	0.0%	100.0%

Table 8-38 (contd)

Name	Location	Ch3d ID#	HSPF ID#	Basin Area (acres)	% Natural Vegetation	% Rural	% Suburban	% Urban and Commercial
LMK020	Phinney Bay	190000	2151	331.37	16.8%	0.5%	18.0%	63.1%
B-ST26	Oyster Bay	210000	2159	210.61	11.6%	0.0%	7.4%	77.0%
B-ST28 (SW1)	Callow	65+66+67 +40000	2164+2165 +2166+2167	454.58	3.5%	0.0%	5.7%	90.8%
B-ST03 (SW5)	Stephenson	3+380000	2002+2006	283.55	8.1%	0.0%	2.4%	89.5%
B-ST01 (SW3)	Pine Road	1+2 +360000	2000+2001 +2004	863.78	23.3%	4.9%	6.8%	63.6%
B-ST07	Campbell	400000	2008	221.73	2.4%	0.0%	5.7%	90.1%
B-ST12 (SW4)	Trenton	470000	2013	156.34	10.5%	0.1%	5.4%	79.1%
SW2	Pacific Ave	70+60000	2173+2174	140.11	0.0%	0.0%	0.0%	100.0%
LMK001	Silverdale (Bayshore)	300000	2146	237.30	5.2%	0.0%	7.0%	84.7%
LMK004	Silverdale	290500	2106	32.91	0.0%	0.0%	0.0%	95.9%
LMK002	Silverdale (Sandpiper)	310000	2111	46.26	1.9%	0.0%	0.0%	93.3%
SW6	Combined LMK001+002	300000 +310000	2111+2146	283.56	3.3%	0.0%	5.0%	87.0%
LMK026	Silverdale	310500	2107	533.75	13.6%	0.0%	14.5%	67.4%
LMK055	Tracyton	15501550	2211	279.77	23.4%	0.0%	21.4%	52.5%
PO-Bethel	Port Orchard	600500 +6100500	2205+2206	32.69	0.0%	0.0%	20.4%	79.6%
PO-Bay	Port Orchard	610500	2032	100.30	1.6%	0.0%	5.3%	91.6%
PO-Blvd	Port Orchard	620000 +62007500	2203+2204	86.96	9.5%	0.0%	21.2%	68.8%
LMK038	Manchester	9520000	2190	131.66	36.7%	55.7%	0.3%	5.7%
BI-LCSW	BI Lynwood Center	520500	2046	91.85	61.3%	31.5%	0.0%	0.0%
BI-FWSW	BI Fort Ward	530333	2047	469.70	54.1%	26.0%	0.0%	0.0%
LMK060	Tracyton	22002200	2210	336.26	46.2%	0.0%	13.9%	28.0%
PO-Wilkens	Port Orchard	620500	2031	143.22	42.7%	4.7%	12.1%	27.2%
LMK128	Gorst	650333	2027	173.69	55.7%	0.0%	6.0%	37.9%
LMK122	Gorst	650666	2197	346.27	49.8%	0.0%	4.4%	27.5%

Highlighted cells reflect the major component in each developmental category.

Table 8-39. Outfall Fecal Coliform Characteristics

Name	Location	Group	FC/100 mL	(N)	Min. FC	Max. FC	25th Percentile	75th Percentile	90th Percentile	FC<100	N>200	P>200	WQ Std
PSNS008	PSNS	Urban/Industrial	428	12	1	6100	130	2970	11570	NO	8	67%	NO
PSNS015	PSNS	Urban/Industrial	1304	14	31	13000	601	5158	12178	NO	12	86%	NO
PSNS082.5	PSNS	Urban/Industrial	1331	3	170	6600	1135	4350	14606	NO	2	67%	NO
PSNS115.1	PSNS	Urban/Industrial	952	14	1	39000	385	5025	40974	NO	11	79%	NO
PSNS101	PSNS	Urban/Industrial	14	14	1	90000	1	194	1676	YES	4	29%	NO
PSNS081.1	PSNS	Urban/Industrial	7602	13	1100	99000	3200	18000	44528	NO	13	100%	NO
PSNS124	PSNS	Urban/Industrial	10	14	1	1300	2	16	220	YES	3	21%	NO
PSNS126 (B-ST/CSO16)	PSNS	Urban/Industrial	2473	13	1	133000	1733	14000	124917	NO	11	85%	NO
LMK164	National Ave	Urban/Industrial	576	15	23	11000	270	1650	4678	NO	12	80%	NO
B-ST27	Evergreen	Urban/Industrial	1239	9	290	4752	650	2200	4294	NO	9	100%	NO
LMK020	Phinney Bay	Urban/Industrial	1539	21	69	19000	770	3200	10677	NO	18	86%	NO
B-ST26	Oyster Bay	Urban/Industrial	609	14	54	2200	255	1550	2872	NO	12	86%	NO
B-ST28 (SW1)	Callow	Urban/Industrial	1091	11	30	32000	315	2500	12956	NO	9	82%	NO
B-ST03 (SW5)	Stephenson	Urban/Industrial	657	20	100	3800	303	1490	2888	NO	16	80%	NO
B-ST01 (SW3)	Pine Road	Urban/Industrial	513	17	37	79200	108	1714	6281	NO	12	71%	NO
B-ST07	Campbell	Urban/Industrial	1603	11	290	5500	1013	3254	5505	NO	11	100%	NO
B-ST12 (SW4)	Trenton	Urban/Industrial	29	17	1	3600	3	450	910	YES	6	35%	NO
SW2	Pacific Ave	Urban/Industrial	568	10	10	2376	538	1575	4874	NO	8	80%	NO
LMK001	Silverdale (Bayshore)	Urban/Industrial	196	20	8	1300	61	603	1351	NO	11	55%	NO
LMK004	Silverdale	Urban/Industrial	155	21	5	2904	33	500	1542	NO	11	52%	NO
LMK002	Silverdale (Sandpiper)	Urban/Industrial	221	20	20	2500	59	650	1470	NO	11	55%	NO
SW6	LMK001+002	Urban/Industrial	--	0	--	--	--	--	--	--	--	--	--
LMK026	Silverdale	Urban/Industrial	318	20	40	2640	121	718	1372	NO	13	65%	NO
LMK055	Tracyton	Urban/Industrial	215	20	23	2100	71	645	1409	NO	10	50%	NO

Table 8-39. (contd)

Name	Location	Group	FC/100 mL	(N)	Min. FC	Max. FC	25th Percentile	75th Percentile	90th Percentile	FC<100	N>200	P>200	WQ Std
PO-Bethel	Port Orchard	Urban/Industrial	140	11	10	1100	46	376	881	NO	5	45%	NO
PO-Bay	Port Orchard	Urban/Industrial	424	19	1	31000	64	3050	12443	NO	13	68%	NO
PO-Blvd	Port Orchard	Urban/Industrial	413	19	20	21000	146	2084	5757	NO	11	58%	NO
LMK038	Manchester	Rural	345	34	16	4000	169	670	2080	NO	23	68%	NO
BI-LCSW	BI Lynwood Center	Rural	158	4	31	820	45	573	1272	NO	2	50%	NO
BI-FWSW	BI Fort Ward	Rural	459	4	300	1056	90	580	1440	NO	4	100%	NO
LMK060	Tracyton	Light suburban	61	20	8	980	12	157	478	YES	5	25%	NO
PO-Wilkens	Port Orchard	Light suburban	64	19	7	640	19	260	430	YES	5	26%	NO
LMK128	Gorst	Light suburban	310	20	49	2900	124	658	1398	NO	12	60%	NO
LMK122	Gorst	Light suburban	123	20	14	2100	41	301	738	NO	6	30%	NO

Table 8-40. Correlation Matrix of Land Use Characteristics and Fecal Coliform Concentrations (n=33)

	Basin Area (acres)	% Mixed Forest	% Deciduous Forest	% Coniferous Forest	% Shrub	% Natural Vegetation	% Grass or Turf	% Rural (LD Residential)	% Suburban (MD Residential)	% Urban (HD Residential)	% Commercial/ Industrial	%TIA	% Forest	Road-Density
% Mixed Forest	0.66	0.31	0.27	0.14	0.37	0.30	0.06	0.26	0.27	-0.50	-0.37	0.37	-0.27	-0.17
% Deciduous Forest	0.31	0.33	0.28	0.52	0.41	0.26	0.48	-0.05	-0.10	-0.41	-0.47	0.40	-0.24	-0.10
% Coniferous Forest	0.27	0.28	0.37	0.33	0.86	0.69	0.26	0.22	-0.23	-0.68	-0.79	0.94	-0.45	-0.26
% Shrub	0.14	0.52	0.33	0.52	0.78	0.21	0.63	-0.03	-0.27	-0.65	-0.80	0.67	-0.45	-0.19
% Natural Vegetation	0.37	0.41	0.86	0.78	0.53	0.20	0.90	-0.15	-0.25	-0.55	-0.67	0.47	-0.43	-0.12
% Grass or Turf	0.30	0.26	0.69	0.21	0.20	0.57	0.53	0.10	-0.31	-0.79	-0.96	0.98	-0.54	-0.27
% Rural (LD Residential)	0.06	0.48	0.26	0.63	0.90	0.53	0.14	0.02	-0.23	-0.44	-0.56	0.63	-0.39	-0.24
% Suburban (MD Residential)	0.26	-0.05	0.22	-0.03	-0.15	0.10	0.02	-0.25	-0.34	-0.51	-0.68	0.45	-0.43	-0.12
% Urban (HD Residential)	0.27	-0.10	-0.23	-0.27	-0.25	-0.31	-0.23	-0.34	0.48	-0.43	-0.13	0.16	-0.08	-0.18
% Commercial/ Industrial	-0.50	-0.41	-0.68	-0.65	-0.55	-0.79	-0.44	-0.51	-0.43	-0.26	0.25	-0.28	0.22	-0.16
%TIA	-0.37	-0.47	-0.79	-0.80	-0.67	-0.96	-0.56	-0.68	-0.13	0.25	0.87	-0.79	0.48	0.35
% Forest	0.37	0.40	0.94	0.67	0.47	0.98	0.63	0.45	0.16	-0.28	-0.79	-0.94	0.59	0.26
Road-Density	-0.27	-0.24	-0.45	-0.45	-0.43	-0.54	-0.39	-0.43	-0.08	0.22	0.48	0.59	-0.53	-0.27
FC/100 mL	-0.17	-0.10	-0.26	-0.19	-0.12	-0.27	-0.24	-0.12	-0.18	-0.16	0.35	0.26	-0.27	0.21

Highlighted cells have absolute values greater than 0.7

Table 8-41. Descriptive Statistics for Outfall FC Loading Estimation

Group	N	Mean FC/100 mL	Minimum Geometric Mean FC/100 mL	Maximum Geometric Mean FC/100 mL	25th Percentile of the Geometric Mean FC/100 mL	75th Percentile of the Geometric Mean FC/100 mL
Group 1: Urban and Commercial Development	26	947	10	7602	210	1255
Group 2: Rural Development	3	321	158	459	158	459
Group 3: Light Suburban Development	4	140	61	310	62	263
All Outfall Data	**N**	**Mean FC/100 mL**	**Minimum FC/100 mL**	**Maximum FC/100 mL**	**25th Percentile**	**75th Percentile**
FC Geometric Mean	33	792	10	7602	158	952
25th Percentile	33	379	1	3200	46	385
75th Percentile	33	2458	16	18000	573	2970

Table 8-42. Nearshore Landscapes Associated With Direct Runoff Land-Use Cluster Membership and Score 1

Nearshore Drainage	Location	Ch3d ID#	HSPF ID#	Basin Area (acres)	Cluster	Score1
PO Passage-42	Bainbridge West Shore	500666	2042	181.0	1	5.623
PO Passage-43	Bainbridge West Shore	510200	2043	354.9	1	3.822
PO Passage-45	Bainbridge West Shore	510800	2045	187.9	1	5.496
PO Passage-88	Bainbridge West Shore	510400	2088	59.6	1	5.877
PO Passage-91	Bainbridge West Shore	510600	2091	46.7	1	5.450
Rich Passage-39	Rich Passage South Shore	570333	2039	46.7	1	3.682
PO Passage-44	Bainbridge West Shore	510500	2044	328.0	2	6.097
Rich Passage-38	Rich Passage South Shore	570666	2038	75.4	2	6.312
Rich Passage-40	Rich Passage South Shore	560500	2040	207.0	2	4.473
Rich Passage-41	Rich Passage South Shore	550500	2041	63.8	2	7.249
Rich Passage-48	Manchester Point	540500	2048	427.9	2	3.374
Dyes Inlet-2	Dyes Inlet West Shore	250500	2102	241.1	3	-0.358
Dyes Inlet-4	Chico Bay	240500	2104	77.4	3	-0.147
PO Passage-22	Illahee (N)	490500	2022	133.9	3	-1.965
Sinclair Inlet-96	Sinclair Inlet North Shore	6500750	2196	282.2	3	0.062
Dyes Inlet-5	Dyes Inlet West Shore	280500	2105	333.1	4	-4.143
Dyes Inlet-6-7-11	Silverdale	290500/ 310000/ 310500	2106/ 2107/ 2111	625.0	4	-5.882
Dyes Inlet-24	Oyster Bay (East)	210500	2924	50.9	4	-7.270
Dyes Inlet-25	Jackson Park/Earlands Point	230500	2025	800.8	4	-5.425
Dyes Inlet-53	Oyster Bay (West)	200000	2153	111.2	4	-4.426
Sinclair Inlet-34	Port Orchard	590500	2034	13.1	4	-4.621
Yukon Harbor	Manchester Fuel Depot	9570500	2194	82.3	4	-7.953
Dyes Inlet-3	Dyes Inlet West Shore	270500	2103	407.2	5	-2.263
Dyes Inlet-8	Dyes Inlet East Windy Point	320500	2108	262.9	5	-0.805
Dyes Inlet-9	Dyes Inlet East Tracyton	330500	2109	18.9	5	-0.666
Dyes Inlet-10	Dyes Inlet East Tracyton	340500	2110	18.9	5	-1.366
Dyes Inlet-20	Ostrich Bay	220500	2020	77.6	5	-1.778
Dyes Inlet-26	Rocky Point	190500	2026	512.2	5	-3.266
Dyes Inlet-45	Dyes Inlet West Shore	260500	2145	17.1	5	-0.370
Dyes Inlet-47	Phinney Bay	180000	2147	61.8	5	-3.895
PO Passage-18	Illahee (S)	500333	2018	485.9	5	-2.694
PO Passage-23	East Manette	480500	2023	233.7	5	-0.654
Sinclair Inlet-27-97	Gorst	650333/ 650666	2027/ 2197	525.0	5	-1.546
Sinclair Inlet-28	Sinclair Inlet South Shore	640500	2028	84.5	5	-0.599
Sinclair Inlet-30	Sinclair Inlet South Shore	630500	2030	296.5	5	-1.757
Sinclair Inlet-36	Port Orchard	580500	2036	8.7	5	-2.386

8.6 Loading Estimation Uncertainty

The methods used in this analysis were empirical and took full advantage of the available data on FC distribution, time of year, stream flow, and watershed LULC. The FC concentrations were highly variable within and between streams and outfalls, making model development difficult. The correlations between LULC metrics and FC levels discovered during this research (and confirmed by other research efforts elsewhere) enabled this project to develop empirically based relationships between water quality and watershed LULC. Several statistical analyses were used to investigate these relationships, resulting in a model based on cluster analysis. Although the multiple LULC clusters developed increased our ability to bound and estimate the average FC concentrations in streams, they did not produce statistically significantly different classes of FC concentrations. Thus, the model developed is not able to predict the FC concentration in any stream, stormwater outfall, or direct shoreline runoff source without some uncertainty. However, the model results are sufficiently quantified for use in this project. The specific results of this analysis should not be transferred directly to all watersheds, although these results may be applicable to similar watersheds in the Puget Sound region. In addition, the general principles and methods used here are applicable to other landscapes.

This analysis used the observed distributions of FC from data collected from 2001 to 2003; thus, the resulting bounds and estimated mean FC concentrations may not reflect future changes associated with the major sources of FC. Information associated with implementation of BMPs on farmland, removal of failing septic systems, increased public awareness, improved stormwater treatment technologies, and prevention of discharges from marinas has not been incorporated into this analysis. The predictions of FC concentrations made from this analysis, however, will be useful in pinpointing watersheds requiring better pollution source control and in assessing the relative difference between alternative land-use scenarios.

In summary, Method 4 (described above) was used to estimate the bounds for the FC concentration and was based on

1) selecting a number of landscape characteristics to use in the analysis
2) determining the number of clusters to model
3) determining the discriminant function between clusters
4) calculating discriminant scores for cluster assignment for both new and modeled landscapes
5) assigning the cluster.

Once a cluster assignment was determined, the bounds for the FC concentrations were defined as the 25^{th} and 75^{th} percentile of the cluster's 25^{th} and 75^{th} percentile, respectively, of the streams in the cluster in which FC levels were observed. In other words, the stream percentiles determined the percentiles for the cluster.

Method 5 was used to estimate the geometric mean and was based on a regression of mean FC values against the discriminant scores obtained from Method 4. For modeling purposes, when the predicted geometric mean was greater than the cluster within stream 75th percentile, the overall 75th percentile (using all geometric means for streams within a given cluster) was used to estimate the geometric mean. Likewise, when predicted geometric mean was less than the cluster within stream 25th percentile, the overall 25th percentile of the geometric mean was used to estimate the geometric mean.

For the final (2005) loading-estimation data analysis, all landscapes were reassigned a cluster based on the results of the 2004 data analysis. It was assumed that the number of clusters, the variables used to cluster landscape characteristics, the regression of mean FC values as a function of discriminant scores, and the cluster FC characteristics were the same as the 2004 analysis. The only difference between the 2004 and 2005 data was that a small number of subbasins were reclassified as either stormwater or streams, and some were subdivided and redelineated based on more accurate drainage characterization. These changes did not change the FC statistics significantly. Table 8-43 shows the final loading factors estimated for "pour-points" (those subbasins draining into the Sinclair-Dyes Inlet receiving waters) using the methods described in this section of the report.

8.7 Watershed Modeling Overview

The FC analysis described above is primarily being used to aid in modeling FC loading into the marine waters of Sinclair-Dyes Inlet. A watershed model has been developed using the Hydrologic Simulation Program FORTRAN (HSPF). Figures 8-62 and 8-63 show the HSPF model subbasin delineations, along with the location of streamflow and precipitation monitoring stations used in this study. The HSPF model uses landscape-scale characteristics, monitored flow, and measured precipitation data to simulate hydrographic flow from each of the streams, stormwater outfalls, and shoreline segments into the inlets.

Physical watershed–specific data relevant to HSPF model development and calibration (e.g., elevation, channel geometry, soils, vegetation, and LULC, among others) were obtained from available GIS databases and field observations. A 10-meter Digital Elevation Model (DEM) was used to delineate drainage subbasins. GIS software packages were used for mapping and evaluation at multiple scales. The physical watershed–specific data in GIS format were obtained from the USGS LULC and %TIA data for 1999 that were derived from Landsat 7 Thematic Mapper satellite imagery using standard image processing techniques, and from the Soil Survey Geographic (SSURGO) database for the Kitsap County Area, Washington (Skahill 2004). The %TIA data for the ENVVEST project study area is a reclassification of the urban or built-up land denoted in the LULC data for the project study area (Figure 8-64). Channel cross sections were approximated based on field visits and best professional judgment (Skahill 2004).

Meteorological data were collected from local weather stations maintained by the National Weather Service (NWS), the City of Bremerton, and the KPUD. Data associated with the streamflow gage stations maintained by KPUD were collected to develop and determine the HSPF model (Skahill 2004).

Figure 8-65 shows the modeled flow output for several streams in the study area, superimposed on the HSPF LULC map. Figure 8-66 shows an example of modeled flow compared with observed flow for a representative stream in the study area.

For the marine waters, the Curvilinear Hydrodynamics in 3-Dimensions (CH3D) model calculates time-varying three-dimensional numerical flow fields for water surface, velocity, salinity, and temperature to simulate vertical and horizontal mixing (Wang and Richter 1999; Brown 2001; Richter 2004). Figure 8-67 shows a screen shot of the output for the CH3D model. A curvilinear boundary-fitted numerical grid in the horizontal and vertical directions divides the water column into many layers of equal thickness, with number of layers varying for deeper regions. To model the fate of FC in the marine environment, a module to simulate FC die off as a function of salinity, temperature, mixing depth, and sunlight (Mancini 1978) was added to the model code (Wang et al., 2003). Recently, results from the CH3D model assisted in reopening 1500 acres of shellfish beds in Northern Dyes Inlet (WDOH 2003d).

Table 8-43. Final Fecal Coliform Estimates for Input into Loading Model

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_3	Stormwater	East Bremerton-Upper Pine Rd		1	210	947	1255	
DSN_4	Stormwater	East Bremerton-Middle Pine Rd		1	210	947	1255	
DSN_5	Stormwater	East Bremerton-Upper Stephenson		1	210	947	1255	
DSN_6	Stream	Dee Creek	DEE	4	12.3	179.22	705	
DSN_7	Stormwater	East Bremerton-Pine Rd	BST-001 (SW3)	1	210	947	1255	
DSN_8	Stormwater	East Bremerton-Sheridan		1	210	947	1255	
DSN_9	Stormwater	East Bremerton-Stephenson	BST-003 (SW6)	1	210	947	1255	
DSN_10	Stormwater	East Bremerton-East Park		1	210	947	1255	
DSN_11	Stormwater	East Bremerton-Campbell Ave	BST-07 (SW5)	1	210	947	1255	
DSN_12	Shore	East Bremerton-Reid Ave		4	12.3	179.65	705	
DSN_13	Shore	East Bremerton-Cherry St		4	12.3	141.53	705	
DSN_14	Stormwater	East Bremerton-Manette East		1	210	947	1255	
DSN_15	Stormwater	East Bremerton-Manette West		1	210	947	1255	
DSN_16	Stormwater	East Bremerton-Trenton Ave	BST-012 (SW4)	1	210	947	1255	
DSN_17	Stormwater	East Bremerton-Marlowe Ave		1	210	947	1255	
DSN_18	Shore	East Bremerton-Parkside Dr		4	12.3	179.84	705	
DSN_19	Stormwater	East Bremerton-Manette Bridge		1	210	947	1255	
DSN_20	Stormwater	East Bremerton-Upper Trenton		1	210	947	1255	
DSN_21	Shore	North Illahee Shore		5	11.1	119.26	294	

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_22	Shore	Jackson Park Shore		5	11.1	97.43	294	
DSN_23	Shore	Illahee (MESO-NW)		3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used
DSN_24	Shore	Illahee State Park Shore		5	11.1	82.87	294	
DSN_25	Shore	Earlands Point Shore		4	12.3	144.03	705	
DSN_26	Shore	Rocky Point Shore		5	11.1	116.03	294	
DSN_27	Stormwater	Gorst Commercial (Subaru)	LMK-128	3	62	140	263	
DSN_28	Shore	Gorst Elandan Gardens		5	11.1	82.15	294	
DSN_29	Stream	Spring Creek (Gorst)		1	11	36.29	138	
DSN_30	Shore	Ross Point Shore		5	11.1	65.50	294	
DSN_31	Stormwater	Port Orchard Downtown - Wilkens	PO-WILKENS	3	62	140	263	
DSN_32	Stormwater	Port Orchard Downtown - Bay St	PO-BAY	1	210	947	1255	
DSN_33	Shore	Port Orchard Annapolis Point		4	12.3	131.17	705	
DSN_34	Shore	Port Orchard Olney Ave		5	11.1	105.12	294	
DSN_35	Shore	Port Orchard Ahlstrom Rd		5	11.1	110.71	294	
DSN_36	Shore	Port Orchard Lindstrom Hill		2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_37	Shore	Port Orchard Beach Dr		1	11	29.91	138	
DSN_38	Shore	Port Orchard Hillcrest Dr		2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_39	Shore	Port Orchard Waterman Point		2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_40	Shore	BI-Hansen Rd		1	11	24.50	138	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_41	Shore	BI-Crystal Springs		1	11	26.05	138	
DSN_42	Shore	BI-Point White		2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_43	Stream	Schel Chelb Creek (BI)	BI-SC	2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_44	Stormwater	BI-Pleasant Beach		2	158	321	459	
DSN_45	Stormwater	BI-Fort Ward	BI-FW	2	158	321	459	
DSN_46	Shore	Manchester Point Shore		2	23	31.16	263	
DSN_55	Stream	Gorst Creek @ Sam Christopherson	GC-SC	1	11	29.89	138	
DSN_57	Stream	Anderson Creek	AC	1	11	30.34	138	
DSN_58	Stream	Barker Creek	BA	2	23	84.34	263	
DSN_64	Stream	Olney (Karcher) Creek	OC	4	12.3	157.37	705	
DSN_65	Stream	Earlands Creek		3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used
DSN_66	Stream	Woods Creek		1	11	36.30	138	
DSN_67	Stream	Koch Creek	KOCH	4	12.3	145.21	705	
DSN_68	Stream	Crystal Creek		5	11.1	89.84	294	
DSN_71	Stormwater	Jackson Park Creek Stormwater		3	62	140	263	
DSN_72	Stream	Stampede Creek		4	12.3	153.75	705	
DSN_73	Stream	Pahrmann Creek	PHRM	4	12.3	153.42	705	
DSN_74	Stream	Illahee Creek	ILL	3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used
DSN_75	Stream	Illahee State Park Creek	ILL-SP	5	11.1	99.56	294	
DSN_76	Stream	Sacco Creek	SACCO	2	23	69.75	263	
DSN_77	Stream	Sullivan Creek		2	23	55.70	263	
DSN_79	Stream	Waterman Creek		2	23	26.45	263	

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_80	Stream	Rich Cove Creek		2	23	32.40	263	
DSN_81	Stream	Lower Beaver Creek	BE-LOW	2	23	54.41	263	
DSN_82	Shore	BI-Baker Hill West		1	11	24.50	138	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_83	Stream	Gazzam Creek (BI)		1	11	44.94	138	
DSN_84	Stormwater	BI-Lynwood Center	BI-LWC	2	158	321	459	
DSN_85	Shore	BI-Baker Hill East		1	11	24.50	138	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_86	Stream	Islandwood Creek (BI)		2	23	48.60	263	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_87	Stream	Chico Creek Lower	CH01	1	11	36.63	138	
DSN_92	Stream	Mosher Creek	MOSH	4	12.3	152.46	705	
DSN_93	Stream	Ross Creek	ROSS	5	11.1	91.03	294	
DSN_94	Stream	Strawberry Creek	SC	5	11.1	82.67	294	
DSN_95	Shore	Chico Bay Shore North		3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used
DSN_96	Shore	Chico Way Shore		5	11.1	126.33	294	
DSN_97	Shore	Chico Bay Shore South		4	12.3	132.44	705	
DSN_98	Shore	Old Silverdale Shore		4	12.3	129.77	705	
DSN_99	Stormwater	Silverdale Bayview Dr	LMK-004	1	210	947	1255	
DSN_100	Shore	Silverdale Tracyton Blvd		4	12.3	153.66	705	
DSN_101	Shore	Windy Point		5	11.1	105.91	294	
DSN_102	Shore	Tracyton Paxford Ln		5	11.1	85.13	294	
DSN_103	Shore	Tracyton Stampede Blvd		5	11.1	92.00	294	
DSN_104	Stormwater	Silverdale Bucklin Hill Rd	LMK-026	1	210	947	1255	

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_136	Stream	Clear Creek @ Bucklin Hill Rd	CC01	5	11.1	96.60	294	
DSN_137	Shore	West Dyes Inlet Cedar Terrace		4	12.3	142.46	705	
DSN_139	Shore	Phinney Bay East Shore		5	11.1	124.77	294	
DSN_140	Stormwater	West Bremerton Narrows Stevens Dr		1	210	947	1255	
DSN_141	Stormwater	West Bremerton Narrows Snyder Ave		1	210	947	1255	
DSN_142	Stormwater	West Bremerton Narrows Anderson Cove		1	210	947	1255	
DSN_143	Stormwater	Phinney Creek Stormwater	LMK102	1	210	947	1255	
DSN_144	Stormwater	West Bremerton Narrows Thompson Ave		1	210	947	1255	
DSN_145	Shore	Oyster Bay Marine Dr.		4	12.3	131.83	705	
DSN_146	Stormwater	West Bremerton Narrows Chester Ave		1	210	947	1255	
DSN_147	Stormwater	West Bremerton Narrows Park Ave		1	210	947	1255	
DSN_148	Stormwater	West Bremerton Narrows Ohio Ave		1	210	947	1255	
DSN_149	Stream	Ostrich Bay Creek	OBC	4	12.3	175.37	705	
DSN_150	Stormwater	West Bremerton Washington Ave		1	210	947	1255	
DSN_151	Stormwater	Oyster Bay	BST-026	1	210	947	1255	
DSN_152	Stream	Wright Creek	WRT	3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used
DSN_153	Stormwater	National Ave	LMK-164	1	210	947	1255	
DSN_154	Stormwater	West Bremerton Loxie Egans		1	210	947	1255	
DSN_155	Stormwater	West Bremerton Auto Center Way		1	210	947	1255	

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_156	Stormwater	West Bremerton 11th St		1	210	947	1255	
DSN_157	Stormwater	West Bremerton Upper Callow		1	210	947	1255	
DSN_158	Stormwater	West Bremerton Callow Ave	BST-028 (SW1)	1	210	947	1255	
DSN_160	Stormwater	West Bremerton High Ave		1	210	947	1255	
DSN_161	Stormwater	West Bremerton Narrows High Ave		1	210	947	1255	
DSN_162	Stormwater	West Bremerton Narrows Evergreen Park		1	210	947	1255	
DSN_165	Stormwater	West Bremerton Pacific Ave		1	210	947	1255	
DSN_166	Stormwater	PSNS008 Inactive Ships	PSNS008	1	210	947	1255	
DSN_167	Stormwater	PSNS015 McDonalds NavSta	PSNS015	1	210	947	1255	
DSN_168	Stormwater	PSNS FISC		1	210	947	1255	
DSN_169	Stormwater	PSNS081.1 Bldg 455 "R" St.	PSNS081	1	210	947	1255	
DSN_170	Stormwater	PSNS082.5 Bldg 480	PSNS082	1	210	947	1255	
DSN_171	Stormwater	PSNS DD5		1	210	947	1255	
DSN_172	Stormwater	PSNS Bldg 457		1	210	947	1255	
DSN_173	Stormwater	PSNS "N" St.		1	210	947	1255	
DSN_174	Stormwater	PSNS101 Pier 5		1	210	947	1255	
DSN_175	Stormwater	PSNS115.1 Dry Dock 1	PSNS115	1	210	947	1255	
DSN_176	Stormwater	PSNS124 Dry Dock 3	PSNS124	1	210	947	1255	
DSN_177	Stormwater	PSNS126 Bldg 460 Pier 8	PSNS126	1	210	947	1255	
DSN_178	Stormwater	PSNS Main Gate		1	210	947	1255	
DSN_182	Shore	Manchester Fuel Depot Shore		3	9.5	23.70	50	Predicted geometric mean was greater than the Cluster within stream 75th percentile, the overall 75th percentile was used

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_183	Stormwater	Port Orchard Boulevard	PO-POBLVD	1	210	947	1255	
DSN_185	Stormwater	Port Orchard Farragut Ave		1	210	947	1255	
DSN_186	Stormwater	Annapolis		1	210	947	1255	
DSN_187	Stream	Annapolis Creek	ANNP (LMK-136)	4	12.3	180.67	705	
DSN_188	Shore	Port Orchard East Shore		4	12.3	162.34	705	
DSN_189	Stormwater	Port Orchard Cline Ave		1	210	947	1255	
DSN_190	Stormwater	Port Orchard Cline Ave Upper		1	210	947	1255	
DSN_192	Stormwater	Port Orchard Tracy Ave		1	210	947	1255	
DSN_193	Stream	Blackjack Lower Mainstem	BL-KFC	1	11	48.16	138	
DSN_195	Stormwater	Tracyton Boat Dock	LMK-055 & 060	1	210	947	1255	
DSN_196	Stormwater	Manchester Fuel Depot Upland Area		2	158	321	459	
DSN_199	Shore	Tracyton Shore		5	11.1	90.16	294	
DSN_201	Shore	Madronna Point Shore		4	12.3	167.64	705	
DSN_202	Stormwater	Port Orchard Bethel Road	PO-BETH	1	210	947	1255	
DSN_203	Shore	BI Battle Point West		1	11	18.76	138	
DSN_204	Shore	BI Fletcher Shore South		1	11	24.50	138	Predicted geometric mean was less than the Cluster within stream 25th percentile, the overall 25th percentile was used
DSN_205	Stream	Neseii Creek (BI)		1	11	34.30	138	
DSN_206	Shore	BI Fletcher Bay		1	11	23.33	138	
DSN_207	Shore	BI Battle Point E		1	11	43.61	138	
DSN_208	Stream	Fletcher Bay Creek (BI)		1	11	50.47	138	

Table 8-43. (contd)

DSN	Pour-Point Type	Basin Description / Location	WQ ID	Cluster Assignment	Cluster 25th Percentile	Predicted Geometric Mean	Cluster 75th Percentile	Comment
DSN_210	Stream	Lower Springbrook Creek (BI)		5	11.1	58.91	294	
DSN_211	Shore	Manchester South Shore		5	11.1	91.62	294	
DSN_212	Shore	Manchester North Shore		5	11.1	94.06	294	
DSN_213	Stormwater	Manchester	LMK-038	2	158	321	459	
DSN_214	Shore	Gorst North Shore		5	11.1	98.95	294	
DSN_215	Stormwater	Gorst Commercial (Navy City Metals)	LMK-122	2	158	321	459	
DSN_216	Stormwater	Silverdale Mall West	LMK-002	1	210	947	1255	
DSN_217	Stormwater	Silverdale Mall East	LMK-001	1	210	947	1255	
DSN_218	Stormwater	West Bremerton Burwell		1	210	947	1255	
DSN_219	Stormwater	West Bremerton Warren Ave S. of 11th		1	210	947	1255	
DSN_220	Stormwater	West Bremerton Park Ave	BST-CSO-16 (SW2)	1	210	947	1255	
DSN_221	Stormwater	West Bremerton Porter (Callow)		1	210	947	1255	
DSN_222	Stormwater	West Bremerton Chester Ave		1	210	947	1255	
DSN_223	Stormwater	West Bremerton Evergreen Park	BST-027	1	210	947	1255	
DSN_224	Stormwater	West Bremerton Cambrian Ave (Callow)		1	210	947	1255	

pink highlights = stormwater
blue highlights = streams
yellow highlights = shoreline direct-runoff areas

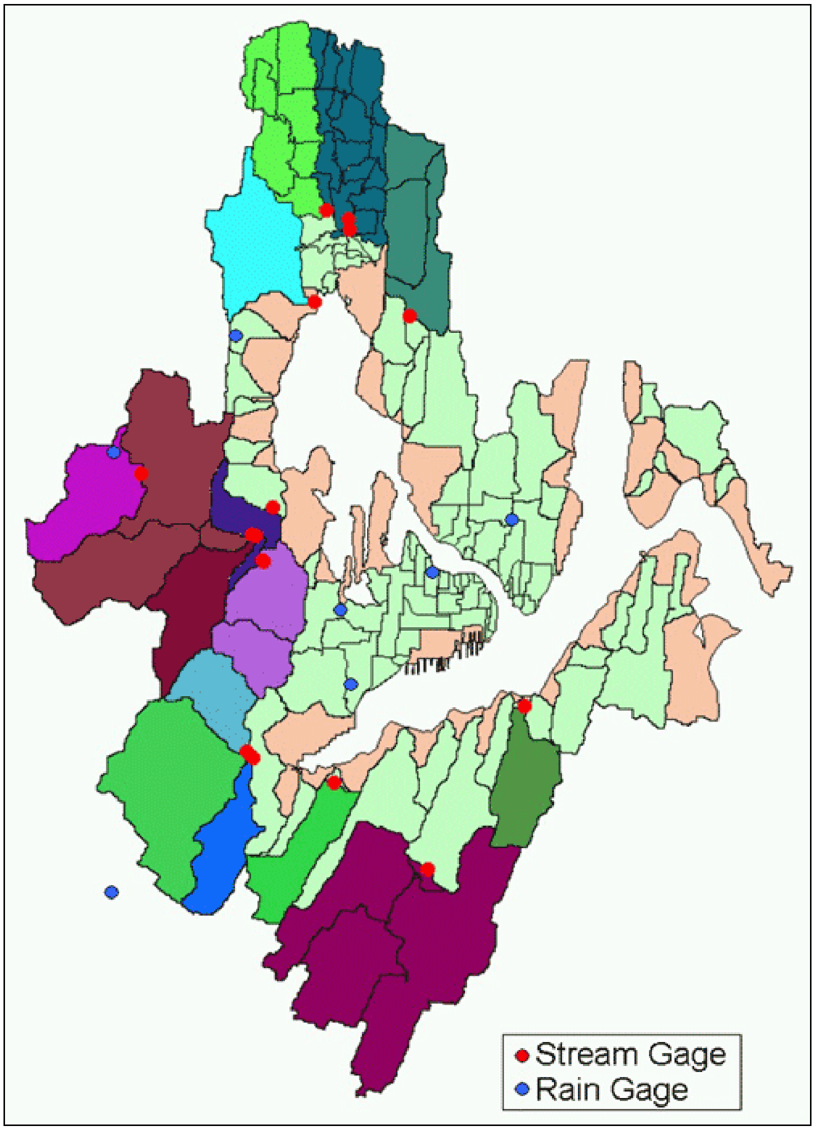


Figure 8-62. Representation of the HSPF Model Developed for the Watershed, Showing Subbasin Delineations

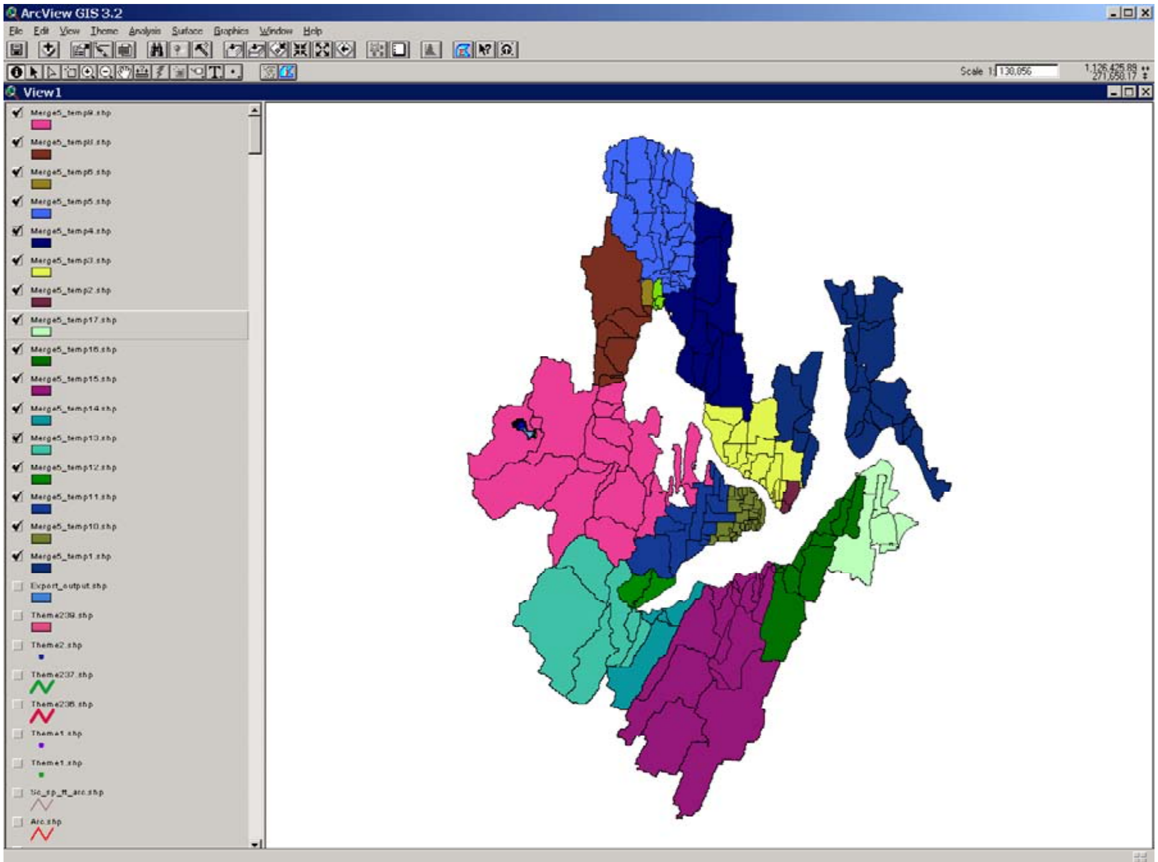


Figure 8-63. Representation of the HSPF model developed for the watershed, showing subbasin delineations.

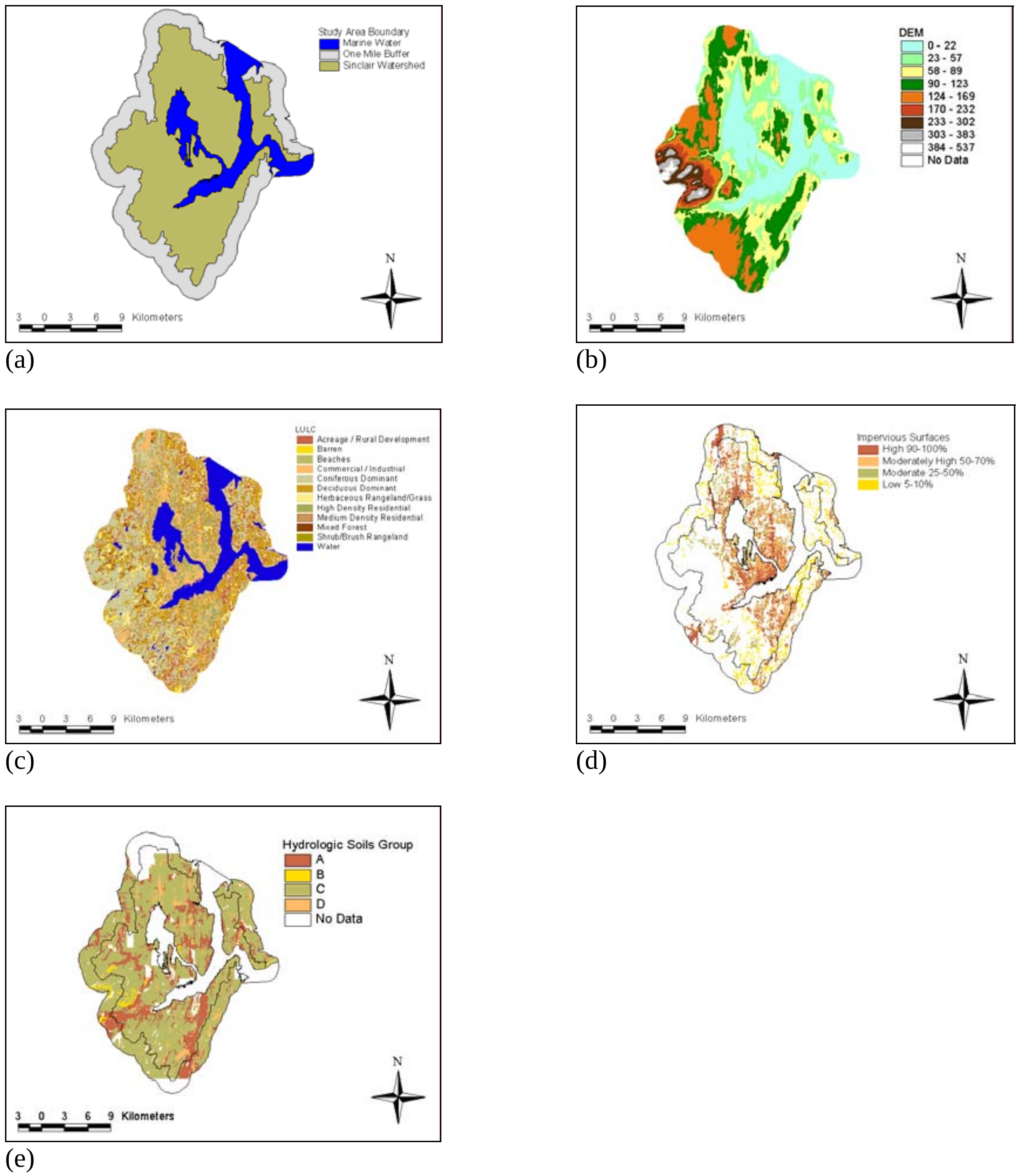


Figure 8-64. HSPF Model Maps a) Model Extent, b) Digital Elevation Model, c) Land Use / Land Cover, d) Imperviousness, and e) Soils Data for the ENVVEST Project Study Area (from Skahill 2004)

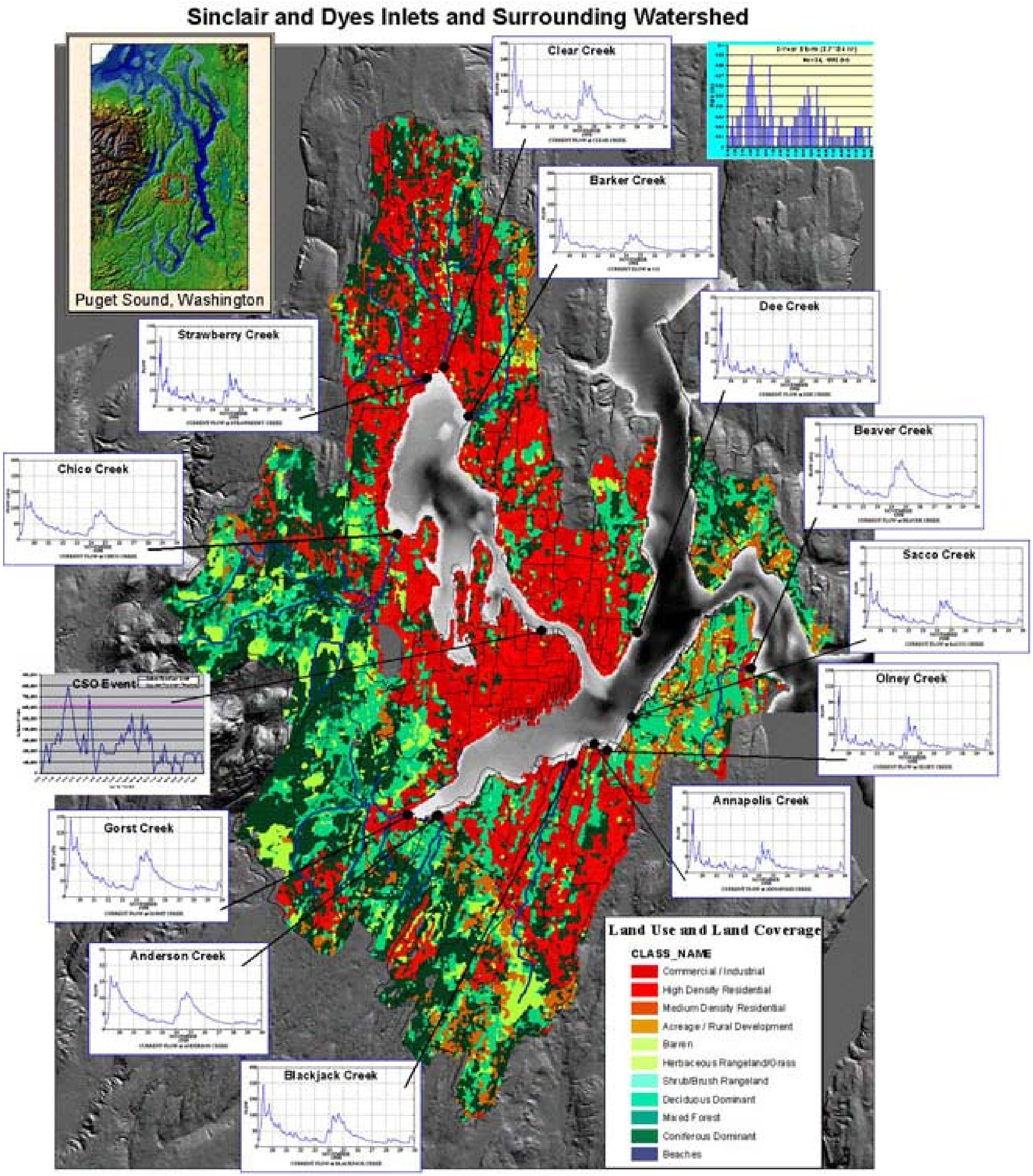


Figure 8-65. Representation of the HSPF Model Developed for the Watershed, Showing Land-Use and Land-Cover Data Along with Modeled Flow Outputs for the Major Streams in the Study Area

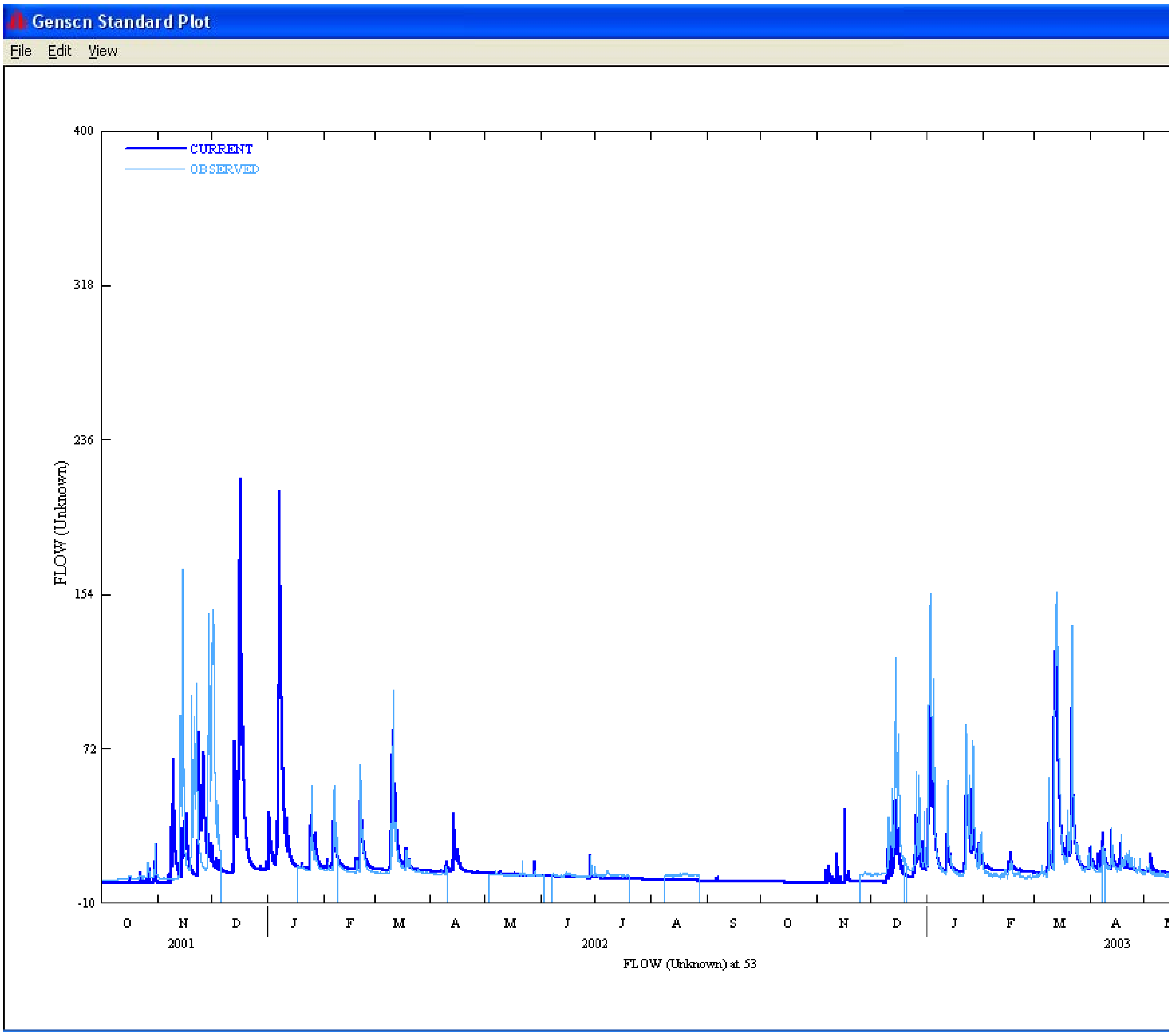


Figure 8-66. Representation of the HSPF Model Output, Showing Modeled and Observed (Actual-Gaged Flow) for a Stream in the ENVVEST Study Area

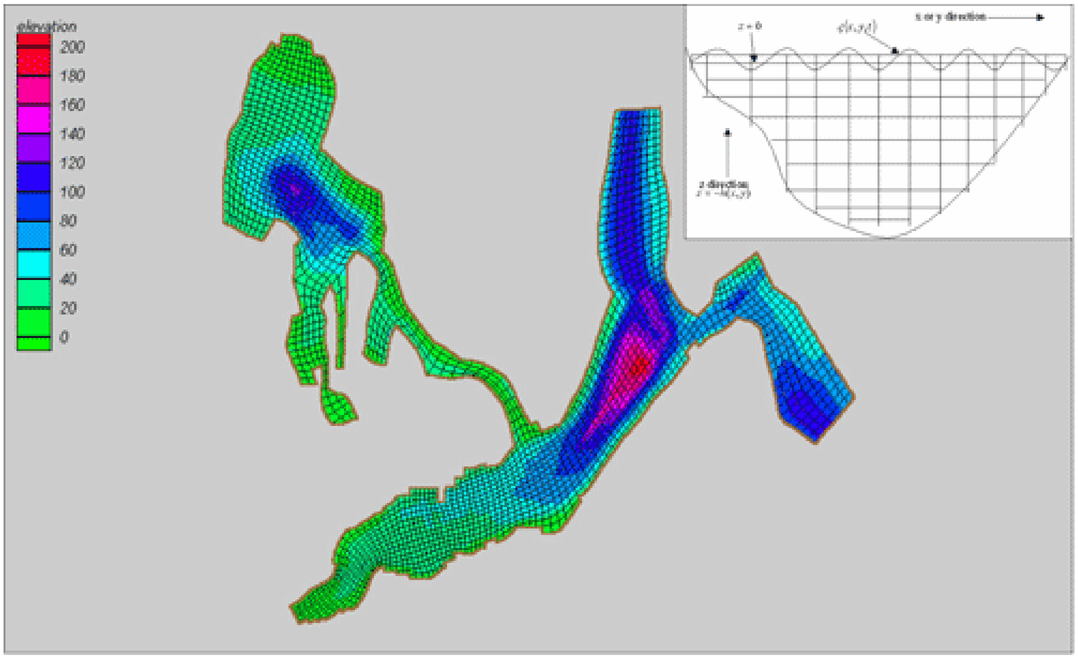


Figure 8-67. The CH3D Model Grid for Sinclair and Dyes Inlet

The HSPF model produces time-varying flows for each of the stream, stormwater, and shoreline drainage basins (cubic feet per second [cfs]) at 15-minute time steps. The loading function developed for each of the pour points is used to calculate the FC concentration as a function of the upstream drainage area, time of year, and hydrologic conditions (wet, dry, or storm event). The estimated FC concentration is then multiplied by the flow rate simulated by HSPF, and the resulting loads are read into CH3D for each cell representing a pour point to simulate total FC loading into Sinclair-Dyes Inlet (Johnston et al. 2003). Figures 8-68 and 8-69 show the pour-point interfaces between the HSPF watershed model and the CH3D receiving-water model. Figures 8-70 through 8-73 show sample results from CH3D model runs.

Currently, a model verification study is being conducted to synoptically sample FC loads from streams, stormwater outfalls, and marine waters during storm events to provide the data necessary to verify the predictions of the integrated watershed-receiving water model (Johnston et al., 2004). Once the model results have been verified, the integrated model will be used to generate a time series from selected model nodes in the study area for the complete Water Year 2003 (WY2003: October 1, 2002 to September 30, 2003) to compare model results with historical data and identify critical periods when WQS are most likely to be exceeded. The WY2003 simulation will include loads from all sources, including WWTP, streams, stormwater outfalls, and nearshore drainages, and will simulate dry and wet periods as well as the storm events that occurred during WY2003. Selection of the critical periods will allow modeling scenarios to be developed that will be the basis for establishing waste load and load allocations and defining water cleanup plans required by the TMDL.

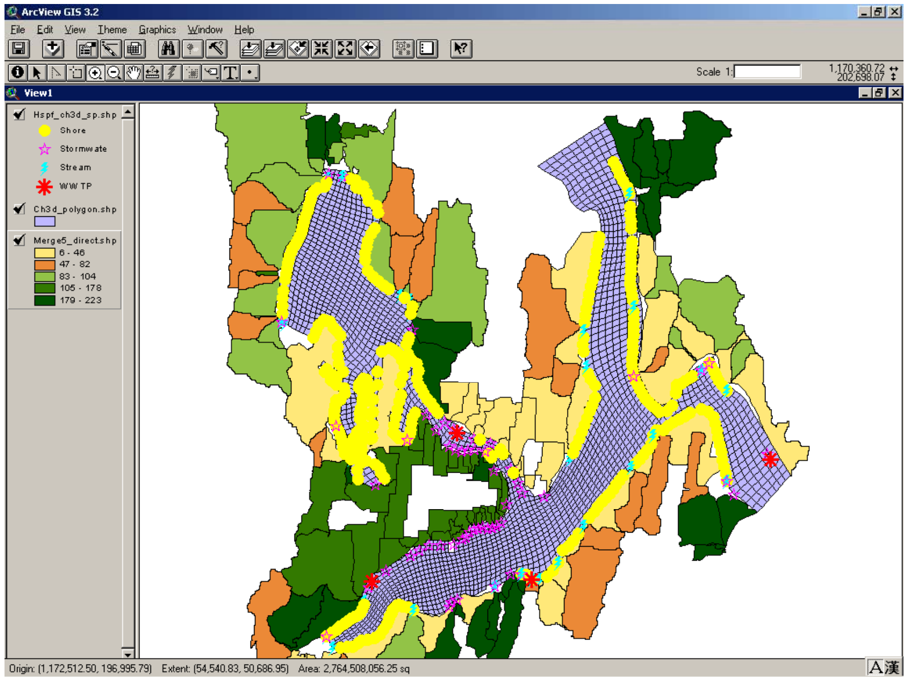


Figure 8-68. The CH3D Model Output for Sinclair-Dyes Inlet Showing Pour-Point Designations

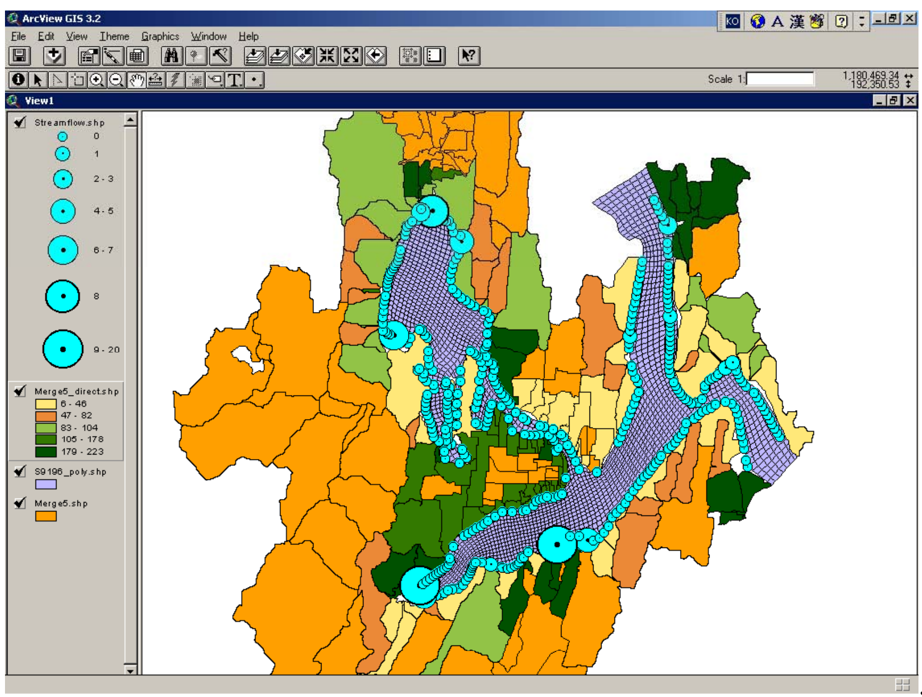


Figure 8-69. The CH3D Model Output for Sinclair-Dyes Inlet Showing Relative Pour-Point Flow Magnitudes

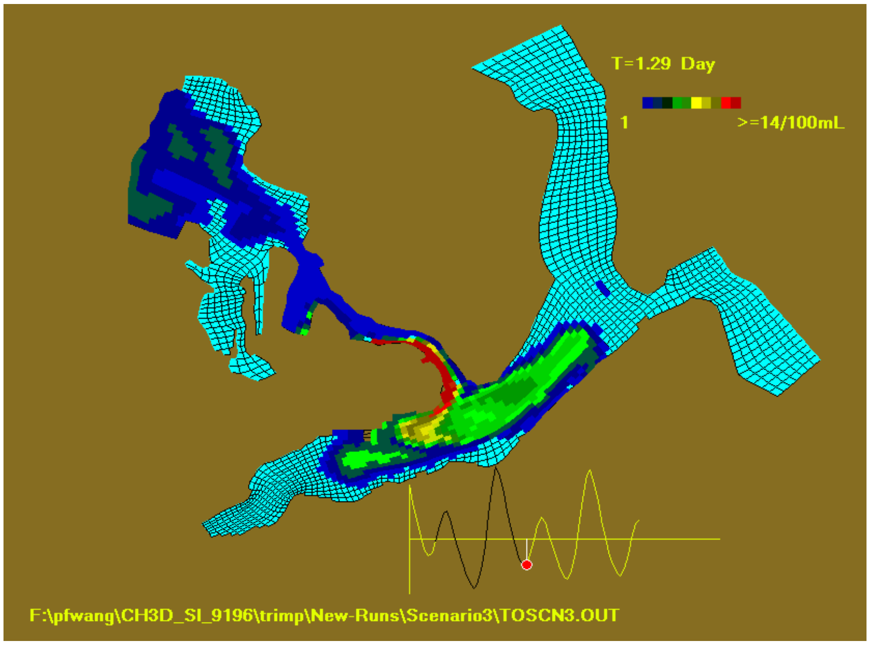


Figure 8-70. The CH3D Model Results for Sinclair-Dyes Inlet Showing the Output from a Simulated Combined Sewer Overflow Event

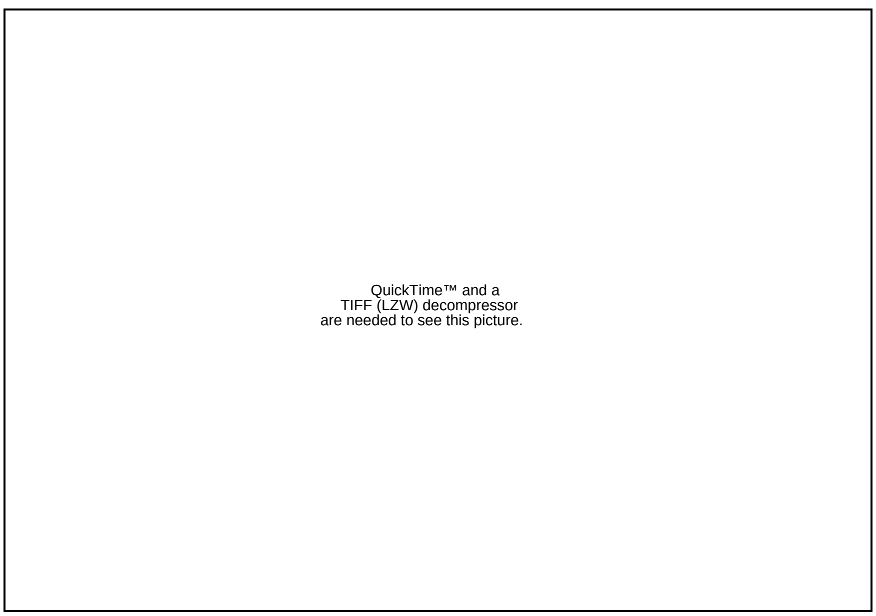


Figure 8-71. The CH3D Model Results For Sinclair-Dyes Inlet Showing the Output from a Simulated Storm Event that Results in Polluted Stream Outflow at Several Locations

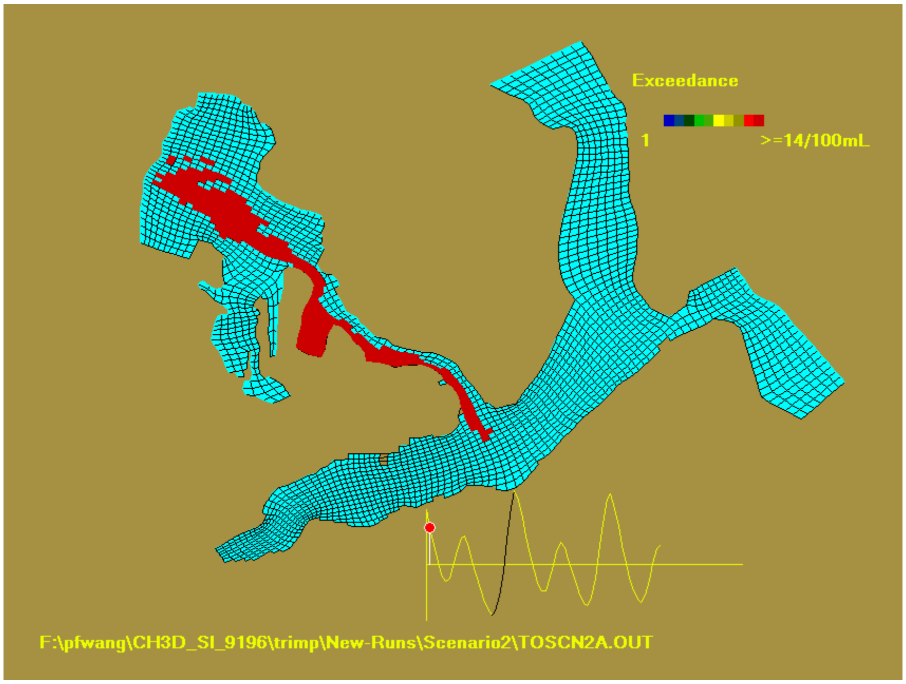


Figure 8-72. The CH3D Model Results for Sinclair-Dyes Inlet Showing the Maximum Extent of Violation of Water-Quality Standards from a Simulated Combined Sewer Overflow Event Without Treatment

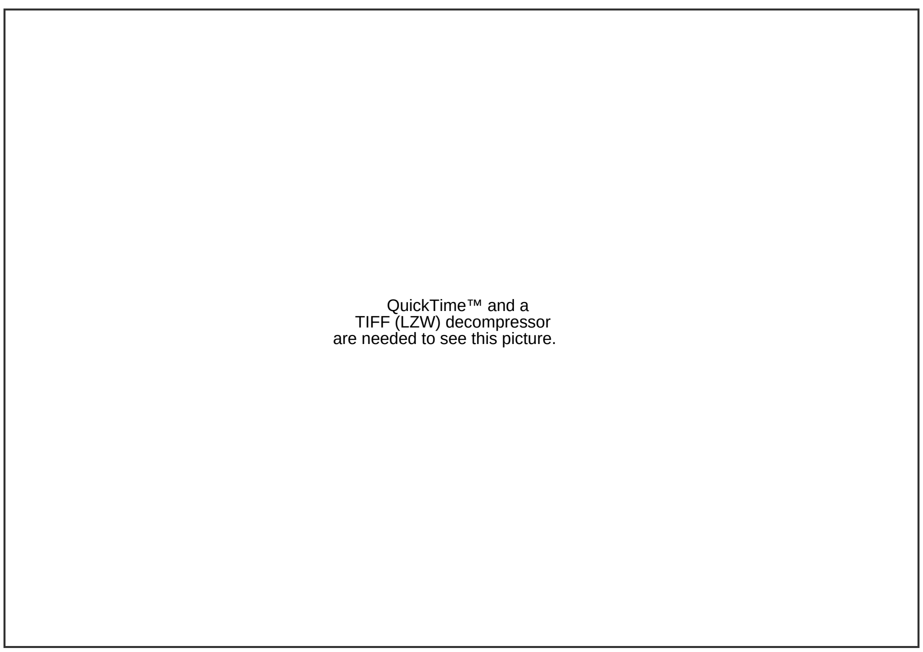


Figure 8-73. The CH3D Model Results for Sinclair-Dyes Inlet Showing the Maximum Extent of Violation of Water-Quality Standards from a Simulated Combined Sewer Overflow Event With Treatment

8.8 Fecal Coliform Loading Estimation

The integrated models just described will be used to determine bacterial loading from the contributing watershed areas, including streams, stormwater outfalls, and shoreline (direct runoff) areas. For the purposes of this report, a rough estimate of this loading would be useful in illustrating the relative contribution of the various sources to the overall bacterial load into the Sinclair-Dyes Inlet watershed. One method of estimating FC loading is to combine the geometric-mean FC concentration for each contributing subbasin and the estimated average daily flow for that subbasin to calculate an estimated daily load (Table 8-44). The drawback of this method of loading estimation is that it is only a 1-day snapshot of the loading generated by an average daily flow. Although this is only a rough estimate for loading, it does illustrate the relative contributions that streams and stormwater outfalls, as well as shoreline runoff areas, make. Table 8-44 indicates that on a daily loading basis, stormwater outfalls and streams tend to dominate as FC source areas.

Focusing on the stream subbasins that were actually monitored for flow allows for a somewhat better estimate of loading. This estimation method is based on using the measured geometric-mean FC concentrations for each time-scale of interest: dry season, wet season, and storm event. The FC data are combined with measured flow data for wet- and dry-season baseflow periods and actual flow data for monitored storm events. Table 8-45 shows the results for eight streams for the dry season, and Table 8-46 shows the same data for the wet season. Similarly, Table 8-47 summarizes the storm-event loading for these eight streams. In general, these data represent conditions at the mouth (or very close to) of each of these streams, showing what is flowing into the nearshore receiving waters of Sinclair-Dyes Inlet. An exception to this is Clear Creek, which was sampled upstream of the major areas of development, such that the results shown here are likely an underestimate of actually loading. A similar set of calculations could be done for stormwater outfalls, but flow data for these systems have not yet been processed.

Figure 8-74 shows the dry- and wet-season and storm-event geometric-mean FC concentrations for the eight streams arrayed in order of increasing watershed development (%TIA). As discussed earlier in this section, there is a general increasing trend in FC concentration as subbasin development (imperviousness) increases. This is certainly true for storm-event FC levels and is generally true for the dry-season and wet-season baseflow concentrations, although there is some variability in those relationships that can be seen in this data. As discussed, this variability is mainly due to the influences of the various FC sources located within each watershed.

Figure 8-75 shows the relative annual loading form each of the eight streams. The loading results are shown on a nondimensional scale for comparison only. The data are again separated into dry-season, wet-season, and storm-event categories. In addition, because flow and, therefore, loading are partially determined by the drainage area of each subbasin, stream-basin areas are also indicated in Figure 8-75. The strong influence of flow volume on loading can be seen for a few of the larger, less-developed creeks (i.e., Chico, Gorst, and Blackjack). Even though their FC concentrations are relatively low (Figure 8-66), the larger flows generated by the larger drainage areas can result in higher FC loading, especially during the wet season or storm events. Those streams with chronic seasonal bacterial problems can have significant seasonal loading factors, such as Clear Creek during the dry season. The effects of impervious surfaces on runoff volume and FC loading can be seen in the case of Olney Creek. This stream has a relatively small drainage area, but is highly developed (%TIA is approximately 40%) and has relatively high FC concentrations, resulting in significant loading levels for both the wet season and storm events. This case can be compared to that of Anderson Creek, which has a comparable drainage area, but little development impact and with very low relative loading factors.

Table 8-44. Loading estimation for Sinclair-Dyes Inlet watershed, calculated using average daily flow and geometric-mean fecal coliform (FC) level.

Pour Point Location	Drainage Basin	Geometric-Mean FC (cfu/100mL)	Average Daily Flow (cfs)	Average Relative Load (Million Counts Per Day)	Pour Point Type
B-ST01 (SW3)	Pine Road	947	2.9	673,743,361	Outfall
LMK026	Silverdale	947	1.8	420,930,858	Outfall
B-ST28 (SW1)	Callow	947	1.7	387,580,638	Outfall
Dyes Inlet	Chico Crk	39	33.3	317,178,345	Stream
LMK020	Phinney Bay	947	1.1	262,256,534	Outfall
LMK055	Tracyton	947	1.1	260,649,937	Outfall
Dyes Inlet	Clear Crk	98	10.1	240,332,468	Stream
B-ST03 (SW5)	Stephenson	947	1.0	239,279,688	Outfall
Sinclair Inlet	Blackjack Crk	49	19.1	229,178,010	Stream
LMK001	Silverdale (Bayshore)	947	0.9	203,717,789	Outfall
B-ST07	Campbell	947	0.8	190,131,521	Outfall
B-ST26	Oyster Bay	947	0.7	167,953,687	Outfall
Dyes Inlet	Mosher Crk	153	4.4	164,686,468	Stream
Sinclair Inlet	Olney Crk	157	4.1	156,804,566	Stream
Dyes Inlet	Jackson Park/Earlands Point	144	3.8	134,632,099	Runoff
Dyes Inlet	Barker Crk	84	6.3	130,396,802	Stream
B-ST12 (SW4)	Trenton	947	0.6	127,890,026	Outfall
SW2	Pacific Ave	947	0.5	125,433,952	Outfall
Sinclair Inlet	Gorst Crk	32	15.6	121,246,575	Stream
BI-FWSW	BI Fort Ward	321	1.3	105,246,595	Outfall
LMK164	National Ave	947	0.4	103,219,000	Outfall
PSNS015	PSNS	947	0.4	90,817,638	Outfall
Sinclair Inlet	Ross Crk	91	3.9	87,453,690	Stream
Dyes Inlet	Ostrich Bay Crk	176	2.0	85,522,044	Stream
PO-Bay	Port Orchard	947	0.4	83,229,859	Outfall
PO Passage	Illahee Crk	95	3.1	71,255,191	Stream
PO-Blvd	Port Orchard	947	0.3	67,237,843	Outfall
Dyes Inlet	Strawberry Crk	82	3.0	60,830,062	Stream
Dyes Inlet	Rocky Point	116	2.1	59,746,348	Runoff
PO Passage	Dee Crk	179	1.3	57,768,594	Stream
PO Passage	Illahee (S)	109	1.9	52,022,278	Runoff

Table 8-44. (contd)

Pour Point Location	Drainage Basin	Geometric-Mean FC (cfu/100mL)	Average Daily Flow (cfs)	Average Relative Load (Million Counts Per Day)	Pour Point Type
Yukon Harbor	Beaver Crk	54	3.7	48,759,787	Stream
Dyes Inlet	Pharman Crk	153	1.2	45,294,533	Stream
LMK060	Tracyton	140	1.2	42,112,680	Outfall
Sinclair Inlet	Annapolis Crk	164	1.0	41,159,312	Stream
LMK002	Silverdale (Sandpiper)	947	0.2	40,282,663	Outfall
B-ST27	Evergreen	947	0.2	38,663,531	Outfall
Sinclair Inlet	Wright Crk	78	2.0	37,490,460	Stream
LMK122	Gorst	140	1.1	36,731,398	Runoff
Rich Passage	Sacco Crk	69	2.0	33,908,818	Stream
Dyes Inlet	Stampede Crk	156	0.9	33,566,062	Stream
LMK038	Manchester	321	0.4	32,920,837	Outfall
Dyes Inlet	Dyes Inlet West Shore	128	1.1	32,857,797	Runoff
Dyes Inlet	Dyes Inlet West Shore	104	1.3	32,750,184	Runoff
Dyes Inlet	Koch Crk	159	0.8	31,699,549	Stream
LMK004	Silverdale	947	0.1	27,847,798	Outfall
PSNS008	PSNS	947	0.1	27,132,707	Outfall
Sinclair Inlet	Anderson Crk	30	3.5	26,024,001	Stream
PO-Bethel	Port Orchard	947	0.1	25,793,165	Outfall
Dyes Inlet	Dyes Inlet West Shore	79	1.1	21,426,689	Runoff
Yukon Harbor	Duncan Crk	84	1.0	21,403,253	Stream
BI-LCSW	BI Lynwood Center	321	0.3	20,919,975	Outfall
Dyes Inlet	Dyes Inlet East Windy Point	85	1.0	19,947,825	Runoff
Sinclair Inlet	Sinclair Inlet South Shore	97	0.8	19,597,395	Runoff
PSNS082.5	PSNS	947	0.1	19,559,969	Outfall
Rich Passage	Sullivan Crk	126	0.6	18,603,862	Stream
LMK128	Gorst	140	0.5	18,349,151	Outfall
PO Passage	East Manette	83	0.9	17,739,369	Runoff
Dyes Inlet	Erlands Crk	109	0.7	17,441,666	Stream
PO Passage	State Park Crk	123	0.6	17,428,277	Stream
PO-Wilkens	Port Orchard	140	0.4	14,983,095	Outfall
PSNS081.1	PSNS	947	0.1	14,579,117	Outfall
Sinclair Inlet	Sinclair Inlet North Shore	74	0.8	14,291,716	Runoff

Table 8-44. (contd)

Pour Point Location	Drainage Basin	Geometric-Mean FC (cfu/100mL)	Average Daily Flow (cfs)	Average Relative Load (Million Counts Per Day)	Pour Point Type
PSNS101	PSNS	947	0.1	13,971,772	Outfall
PO Passage	Springbrook Crk	27	2.0	13,593,246	Stream
PSNS126 (B ST/CSO16)	PSNS	947	0.1	13,161,846	Outfall
PSNS115.1	PSNS	947	0.1	12,959,364	Outfall
Yukon Harbor	Manchester Fuel Depot	176	0.3	12,829,419	Runoff
PO Passage	Illahee (N)	100	0.5	12,306,829	Runoff
Dyes Inlet	Oyster Bay (West)	131	0.3	11,008,595	Runoff
Rich Passage	Manchester Point	31	1.2	9,355,060	Runoff
Dyes Inlet	Jackson Park Crk	126	0.3	8,710,767	Stream
Dyes Inlet	Oyster Bay (East)	168	0.2	8,560,477	Runoff
PSNS124	PSNS	947	0.0	8,504,814	Outfall
Dyes Inlet	Ostrich Bay	97	0.4	8,397,036	Runoff
Sinclair Inlet	Spring Crk	42	0.7	7,263,731	Stream
Rich Passage	Rich Cove Crk	29	1.0	7,262,870	Stream
Dyes Inlet	Woods Crk	42	0.7	7,067,608	Stream
Dyes Inlet	Chico Bay	77	0.4	6,635,677	Runoff
Dyes Inlet	Crystal Crk	105	0.2	6,189,490	Stream
PO Passage	Bainbridge West Shore	26	1.0	6,171,192	Runoff
PO Passage	Shel Schelb Crk	13	1.8	5,852,673	Stream
Sinclair Inlet	Sinclair Inlet South Shore	82	0.2	4,989,179	Runoff
Dyes Inlet	Phinney Bay	124	0.2	4,951,444	Runoff
PO Passage	Gazzam Crk	48	0.3	3,876,815	Stream
Rich Passage	Wilson Crk	20	0.6	2,707,657	Stream
Rich Passage	Rich Pasage South Shore	17	0.6	2,460,971	Runoff
Dyes Inlet	Dyes Inlet East Tracyton	92	0.1	1,494,736	Runoff
Dyes Inlet	Dyes Inlet East Tracyton	83	0.1	1,467,317	Runoff
Sinclair Inlet	Port Orchard	134	0.0	1,395,214	Runoff
Dyes Inlet	Dyes Inlet West Shore	79	0.1	993,013	Runoff
Rich Passage	Rich Pasage South Shore	28	0.1	592,007	Runoff
PO Passage	Bainbridge West Shore	4	0.6	581,383	Runoff
Sinclair Inlet	Port Orchard	105	0.0	532,536	Runoff
PO Passage	Bainbridge West Shore	3	0.5	322,792	Runoff
PO Passage	Bainbridge West Shore	5	0.1	165,568	Runoff

Table 8-45. Dry Season Estimated Annual Fecal Loading for Selected Streams in the Sinclair-Dyes Inlet Watershed

Station ID	Station Location	%TIA	Basin Area (acres)	Annual Dry Season Streamflow Volume (L)	Dry Season FC Geomean	Dry Season FC Min	Dry Season FC Max	Dry Season FC 25th%	Dry Season FC 75th%	FC (GeoMean) Dry Season Load
CH	CHICO CREEK	8.6	10475	2037000960	48	8	170	28	88	9.778E+11
SC	STRAWBERRY CREEK	24	1915	418411008	139	23	1600	55	430	5.816E+11
BA	BARKER CREEK	24	2600	1048780224	109	1	900	50	220	1.143E+12
CC	CLEAR CREEK	27	5395	1602073728	255	50	1600	73	900	4.085E+12
AC	ANDERSON CREEK	6.6	1265	231227136	20	2	240	8	45	4.625E+10
GC	GORST CREEK	8.3	6145	853338240	110	13	1600	240	1600	9.387E+11
BL	BLACKJACK CREEK	16	8350	979962624	123	30	900	50	240	1.205E+12
OC	OLNEY CREEK (KARCHER)	40	1245	291786624	232	50	900	140	500	6.769E+11

Table 8-46. Wet season estimated annual fecal (FC) loading for selected streams in the Sinclair-Dyes Inlet watershed.

Station ID	Station Location	%TIA	Basin Area (acres)	Annual Wet Season Streamflow Volume (L)	Wet Season FC Geomean	Wet Season FC Min	Wet Season FC Max	Wet Season FC 25th%	Wet Season FC 75th%	FC (GeoMean) Wet Season Load
CH	CHICO CREEK	8.6	10475	23528375242	15	1	80	7	40	3.529E+12
SC	STRAWBERRY CREEK	24.1	1915	2144211537	38	4	900	10	105	8.148E+11
BA	BARKER CREEK	23.9	2600	4165565548	53	1	900	27	95	2.208E+12
CC	CLEAR CREEK	27.1	5395	5540178998	50	4	1600	22	148	2.770E+12
AC	ANDERSON CREEK	6.6	1265	2707501703	14	1	300	4	30	3.791E+11
GC	GORST CREEK	8.3	6145	12417882381	38	1	500	17	110	4.719E+12
BL	BLACKJACK CREEK	15.9	8350	11372434378	31	1	170	19	81	3.525E+12
OC	OLNEY CREEK (KARCHER)	39.5	1245	3196613740	125	4	1600	42	400	3.996E+12

Table 8-47. Estimated Storm-Event Fecal Loading for Selected Streams in the Sinclair-Dyes Inlet Watershed

Station ID	Stream	%TIA	Basin Area (acres)	Storm Event FC Geomean	Total Stormflow Volume (L)	FC (GeoMean) Storm Event Load	Average Storm Season Load*
AC	ANDERSON CREEK	6.6	1265	12	4207355	5.049E+08	**5.049E+09**
CH	CHICO CREEK	8.1	10475	71	237098206	1.683E+11	**1.683E+12**
GC	GORST CREEK	8.3	6145	79	157344389	1.243E+11	**1.243E+12**
BL	BLACKJACK CREEK	15.9	8350	78	81313885	6.342E+10	**6.342E+11**
BA	BARKER CREEK	23.9	2600	109	64773605	7.060E+10	**7.060E+11**
SC	STRAWBERRY CREEK	24.1	1915	140	70634620	9.889E+10	**9.889E+11**
CC	CLEAR CREEK	27.1	5395	178	148102081	1.274E+11	**1.274E+12**
OC	OLNEY CREEK (KARCHER)	39.5	1245	365	56626180	2.067E+11	**2.067E+12**

*** Assuming an average of 10 storm events per year**

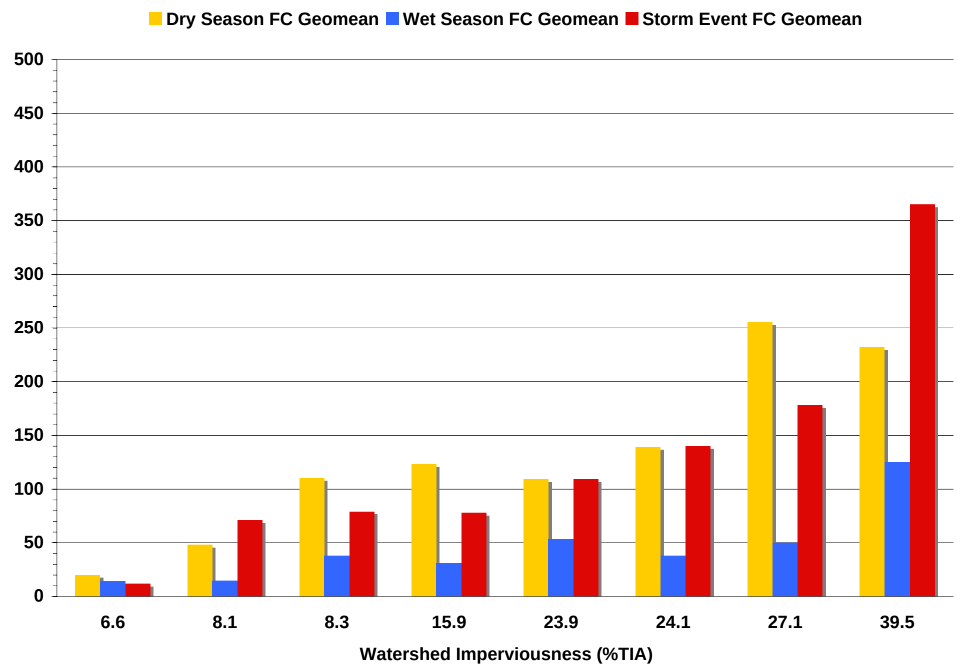


Figure 8-74. Fecal Coliform Levels for Selected Streams in the Sinclair-Dyes Inlet Watershed

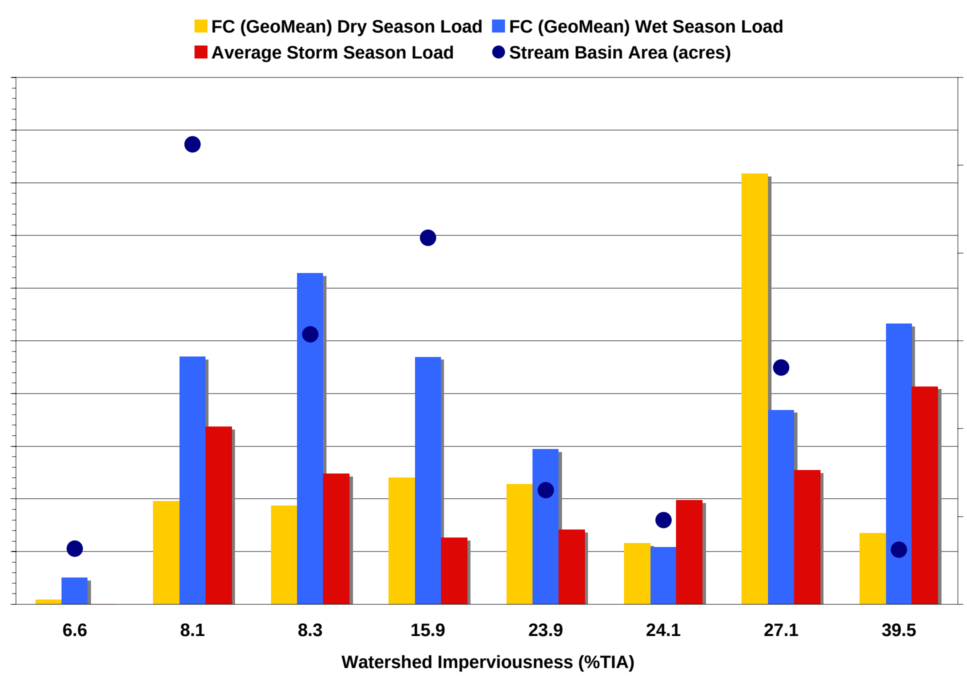


Figure 8-75. Relative Annual Fecal Coliform Loading for Selected Streams in the Sinclair-Dyes Inlet Watershed

9.0 Conclusions and Recommendations

9.1 Conclusions

Based on current research findings, bacterial pollution can be a major concern in coastal areas, often resulting in the degradation of water quality and the loss of beneficial uses, such as shellfish harvesting or contact recreation. In general, urbanization of shoreline areas adjacent to the nearshore and upland areas draining to estuaries via streams and stormwater outfalls can result in significant inputs of bacterial contaminants and other nonpoint source (NPS) pollution to marine receiving waters. During the early stages of development (rural), sources of bacterial pollution (natural and human related) tend to be relatively few and are typically assimilated by the natural soil and vegetation, along with properly designed and operated onsite waste treatment systems (OWTS). As development proceeds, human and animal sources increase and the built-environment (e.g., impervious surfaces) expands. At some point, depending on the characteristics of individual watersheds, the carrying capacity of the environment is exceeded. This point typically occurs somewhere in the suburban-urban transition phase of development. In this range of urbanization, failing septic systems and leaking sewer infrastructure tend to become more probable, as does the potential for sewage spills and combined sewer overflow (CSO) events. Along with the human population density increasing, pet and livestock populations also tend to increase. These factors all contribute to a greater bacterial source potential and more areas likely to be affected by bacterial pollution.

The Sinclair-Dyes Inlet watershed has become increasingly urbanized over the last decade (Figure 9-1). As is the case for most urbanizing coastal embayments, the watershed contains multiple sources of microbial pollution (see conceptual model in Figure 2-1). The main sources of bacterial contamination in this watershed are essentially the same sources that affect developing coastal areas throughout the Puget Sound region and other coastal areas of the country. Human or land-use related sources tend to dominate urbanizing coastal areas (Beach 2002). The primary human land-use and water-based activities that contribute microbial pollution to the Sinclair-Dyes Inlet watershed include (KCHD 2005):

- Failing OWTS (septic systems)
- Sewage spills, CSO events, and failing sanitary sewer infrastructure
- NPS pollution conveyed as stormwater runoff from urbanizing areas
- Improper or ineffective livestock and pet-waste management practices
- Illegal or inadvertent sewage discharges from vessels or marinas.

Although wildlife (waterfowl, birds, marine mammals, and terrestrial mammals) also contribute to bacterial pollution, populations of these organisms do not appear to be out of balance with the natural ecosystem of Sinclair-Dyes Inlet. Therefore, it is assumed that these natural background sources are not the primary cause of violations in water quality standard (WQS) criteria and the degradation of beneficial uses. However, they can be a contributing factor in localized areas. An example of this would be the large concentration of scavenging birds and wildlife that are attracted to the large number of salmon carcasses in the few streams in the watershed that have relatively large spawning runs (e.g., Chico and Gorst Creeks). Concentrations of waterfowl in small embayments that are not naturally well-flushed by tides or currents may also be susceptible to elevated FC levels on a sporadic basis (e.g., Chico Bay and Phinney Bay).

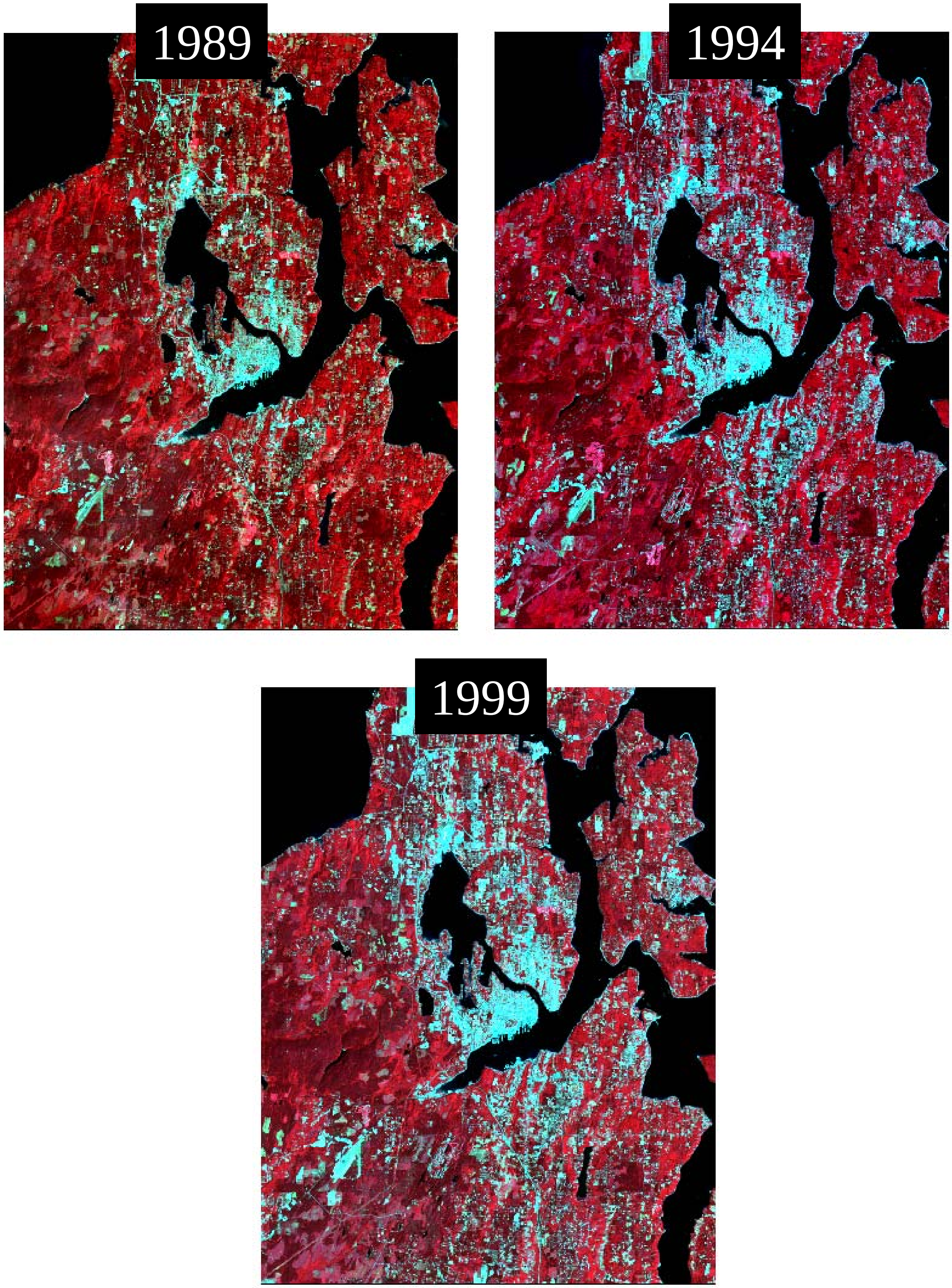


Figure 9-1. Land-Use and Land-Cover Changes Illustrated by Multi-Spectral Satellite Imagery of the Study Area from 1989 to 1999

Based on the findings of this project, it can be concluded that streams draining developing watersheds are more likely to violate bacterial water-quality criteria than are natural stream subbasins, where native forest is still the dominant land-cover feature. As this study demonstrated, urbanizing streams can be significant sources of fecal coliform (FC) loading to nearshore marine waters, especially in nearshore or estuarine waters adjacent to the mouth of the stream itself. Stormwater and CSO outfalls can also be significant localized sources of microbial pollution to nearshore marine waters. Based on the findings of this study and other research, relatively high bacterial levels can be found in the vicinity of stormwater outfalls, although the elevated levels of FC pollution are typically transient. Areas where an urbanized stream and stormwater outfall are collocated appear to particularly prone to elevated FC levels, especially during storm events, and are more likely to violate WQS. The Silverdale area around the mouth of Clear Creek is a prime example of this problem situation.

In addition, analysis of FC data in relation to storm events indicates that higher FC levels are more likely following major storm events that produce significant quantities of stormwater runoff that enter the marine receiving waters via streams and stormwater outfalls. In general, the elevated FC levels observed in nearshore areas around urbanized streams and stormwater outfalls tend to be localized and transient. More developed watersheds generally have higher wet-weather or storm-event-driven FC concentrations than do watersheds that have retained a significant proportion of their native forest vegetation. The findings of this study confirm the conclusions of other studies that have focused on nearshore microbial pollution problems in urbanizing areas on the east and west coasts. A recently completed Puget Sound Action Team (PSAT) study in the Puget Sound region also found that shellfish harvest closures were more common in nearshore areas with contributing watersheds that were urbanized (Alberti and Bidwell 2004). Another study of Puget Sound streams found a similar relationship between bacterial pollution and watershed development and human land-use activities (Embry 2001).

Based on the findings of this study, storm-event streamflow and stormwater runoff can be significant transport pathways for bacterial contamination, especially in urbanizing subbasins. Pet waste, domestic animal manure, and urban wildlife are all contributors to the stormwater fecal load, as are human sources. In addition to stormwater runoff, the major sources of human bacterial pollution in urbanizing areas include failing OWTS and sanitary sewer infrastructures. Sewage spills and periodic CSO events are also important but generally infrequent sources of human bacterial pollution in the built environment.

From a bacterial pollution perspective, current research indicates that it often can be exceptionally difficult to maintain all the beneficial uses of receiving waters as development progresses within a coastal watershed (Beach 2002). In the Puget Sound region, when development moves from the rural-suburban range into the suburban-urban range, degradation in water quality is often observed (Alberti and Bidwell 2004). At that point in the development process, the level of development, the density of the road infrastructure, and the population level typically reach a level at which the natural assimilative capacity of the landscape can become overwhelmed. Also typical at this stage of development, impervious surface area becomes greater than the area of natural forest cover (May et al., 1997a, b). Even at lower levels of development (rural to low-density suburban), bacterial contamination of stormwater runoff is both ubiquitous and periodically occurs at a high enough concentrations (FC "spikes") to have the potential to degrade water quality.

The underlying causes of bacterial pollution problems are complex and often difficult to pinpoint within the development spectrum. For instance, the number of septic systems may become too great for the ambient soil conditions, or the number of domestic and farm animals may reach a level that is high enough to create waste-related bacterial problems. In general, at this stage in the development spectrum, stormwater systems tend to become highly engineered or "hard" (e.g., curb and gutter, drain inlets, and stormwater piping). These systems typically result in less soil infiltration and vegetative filtration of runoff, along with more efficient stormwater conveyance from source areas to receiving waters. The cumulative effect of these factors tends to result in higher overall FC levels in stormwater runoff. Currently, conventional stormwater treatment methods appear to be only partially effective in reducing microbial pollution loads from urbanizing watersheds. Finally, the potential list of bacterial sources in urbanizing and urbanized watersheds is larger and more diverse than in undeveloped or rural areas. Most research indicates that human-related (domestic pets, livestock, sewage overflows, and failed septic systems) sources tend to dominate in the urbanized landscape (CWP 1999). The most recent KCHD water-quality report (KCHD 2005) contains an excellent summary of current bacterial pollution problems in freshwater (streams and lakes) and marine waters within the study area. This report also shows the results of trend analyses for all sampled water bodies in the study area. Dee Creek is the only stream with a significant downward water-quality (FC) trend. All other monitored streams show no significant positive or negative trend for bacterial water quality. Most streams, however, still do not meet WQS. Based on KCHD monitoring results, only Anderson, Ross, and Chico Creeks currently meet bacterial WQS. Conditions have been improving in all marine waters within Sinclair-Dyes Inlet (KCHD 2005).

In comparing the results of bacterial pollution monitoring with the data obtained from biological sampling in the streams of the Sinclair-Dyes Inlet watershed, there are some interesting relationships. Figure 9-2 shows the relationship between biological integrity and watershed development (%TIA) for streams in the study area. Figures 9-3 and 9-4 show the relationship between bacterial (FC) pollution and biological integrity for several streams in the study area. The trends and the correlations are clear. As development increases, under current mitigation standards, both water quality and biological integrity decline significantly. The B-IBI and FC both appear to be strong indicators of the cumulative impacts of watershed development.

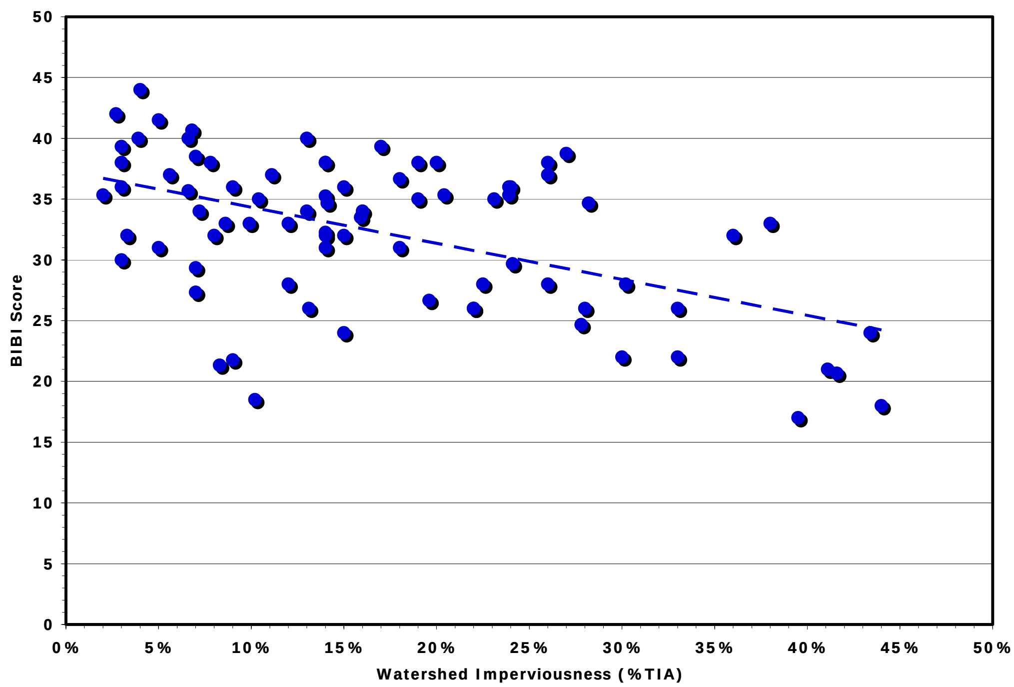


Figure 9-2. The Relationship Between Watershed Imperviousness and Biological Integrity as Measured by the Benthic Index of Biotic Integrity (B-IBI) for Streams in the Sinclair-Dyes Inlet Study Area

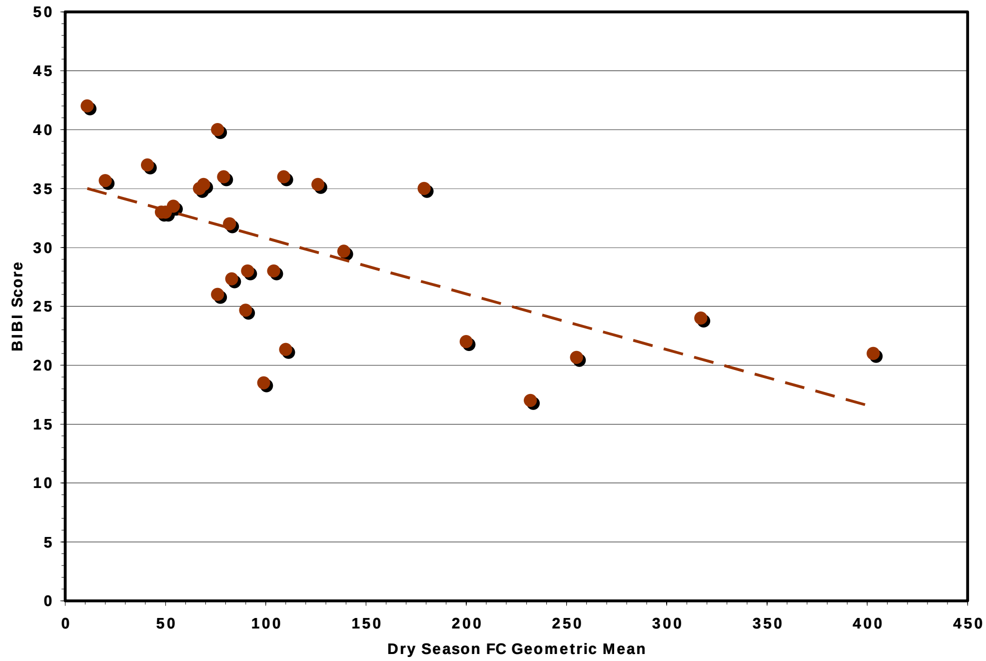


Figure 9-3. The Relationship Between the Benthic Index of Biotic Integrity (B-IBI) and Bacterial Pollution as Measured by the Dry-Season Fecal Coliform (FC) Geometric Mean for Streams in the Sinclair-Dyes Inlet Study Area

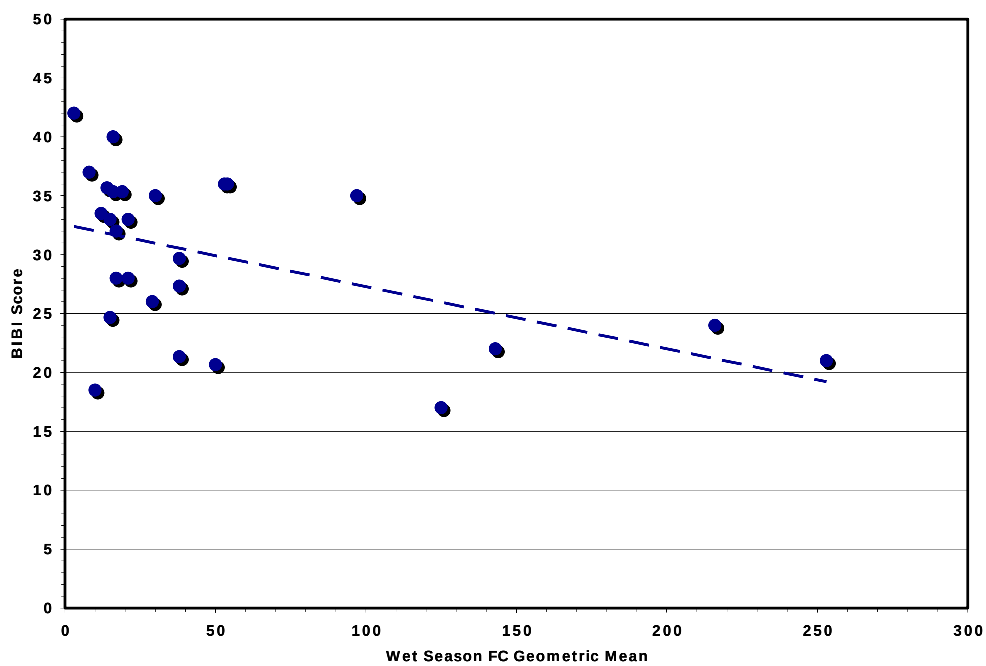


Figure 9-4. The Relationship Between the Benthic Index of Biotic Integrity (B-IBI) and Bacterial Pollution as Measured by the Wet-Season Fecal Coliform (FC) Geometric Mean for Streams in the Sinclair-Dyes Inlet Study Area

One final conclusion that can be drawn from current research and from this study is that best management practices (BMPs), including source controls, need to be optimized to be effective in treating microbial pollution and need to be used throughout the watershed if bacterial contamination is to be controlled. Source control (e.g., prevention) is typically the most effective BMP in dealing with bacterial contamination (CWP 1999). Source control should include an aggressive public education program to make people aware of the sources of bacterial contamination and their ecological and socio-economic impacts. Control of pet and livestock waste should be a very high priority. Routine septic system inspection and maintenance should also be a component of this source-control effort. Exposure to sunlight can also enhance bacterial "die-off" and thus improve water quality. Bacteria can also be effectively removed or reduced by filtering runoff through a natural soil profile. In this regard, vegetated "buffers" surrounding sensitive water resources can be effective in bacterial pollution reduction (Mallin and Wheeler 2000). Few formal studies have been conducted on this type of anti-bacteria BMP, but the combination of vegetative and soil filtration is likely very effective.

Figures 9-5 through 9-21 illustrate the bacterial pollution levels for marine waters, streams, and stormwater outfalls in the Sinclair-Dyes Inlet watershed for the study period of this report. These are map-based presentations of the data that show the location of pollution problems, as well as the level of bacterial pollution found in the study area. These figures illustrate bacterial pollution levels for marine waters, streams, and stormwater outfalls in the Sinclair-Dyes Inlet watershed for data collected from 2000 through 2003. Data sources include the King County Health Department (KCHD), Washington Department of Health (WA-DOH), and the Project ENVironmental InVESTment (ENVVEST) sampling team. Each figure also depicts the underlying land use and land cover (LULC) within the watershed and the sampling locations.

Some figures depict water-quality violations as red points if the geometric-mean FC level is above Part I of the WQS (determined by the ratio of colony forming units [cfu] to water: 14 cfu/100 mL for marine and 100 cfu/100 mL for freshwater) and yellow circles if more than 10% of the samples exceeded Part II of the WQS (43 cfu/100 mL for marine and 200 cfu/100 mL for freshwater). Stations that did not exceed water-quality standards are shown as green points. In other figures, bacterial pollution levels are shown by scaled points representing different levels of FC concentrations (based on geometric mean values). The maps indicating "all data" include all data sources (KCHD, WA-DOH, and ENVVEST) for dry, wet, and storm-season data combined. As discussed earlier in this report, wet-season data include the months of October through April and dry-season data include May through September data collected by WA-DOH and KCHD. These dry- and wet-season data do not include the 2002-2003 storm season data collected by ENVVEST as part of fieldwork conducted for this project. The "storm" maps include only data from the 2002-2003 storm season.

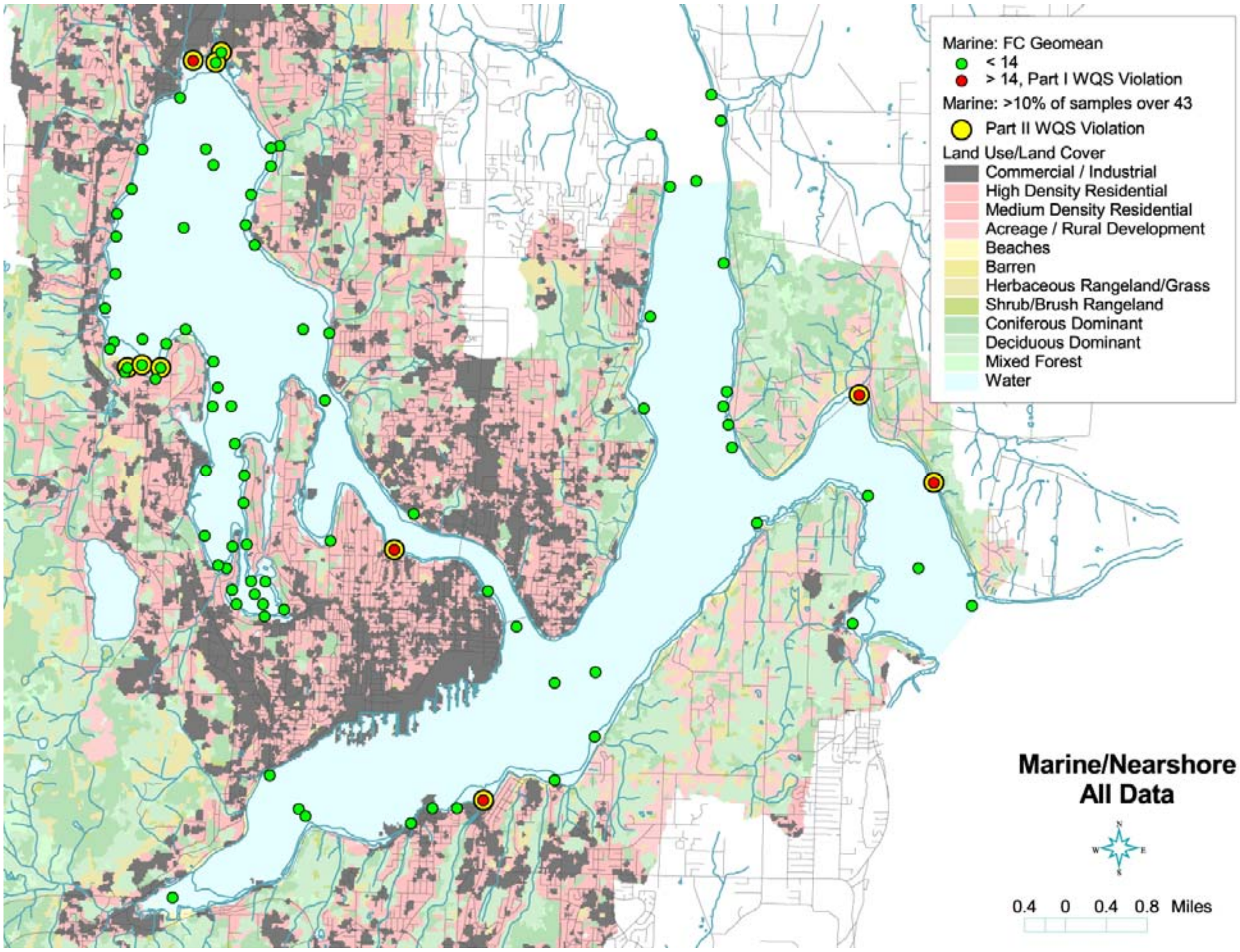


Figure 9-5. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: All Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD, WA-DOH, and ENVVEST Data

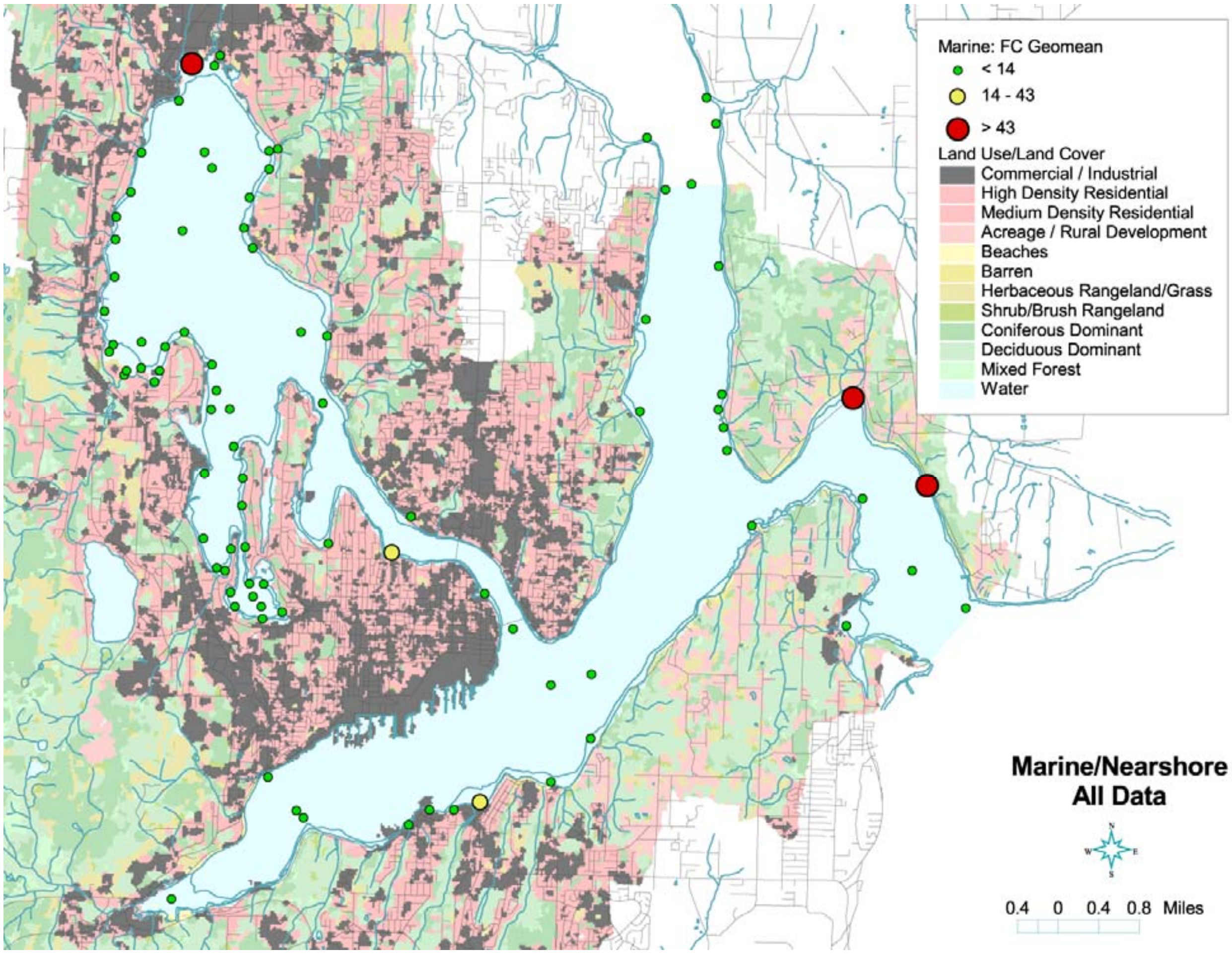


Figure 9-6. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: All Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD, WA-DOH, and ENVVEST Data

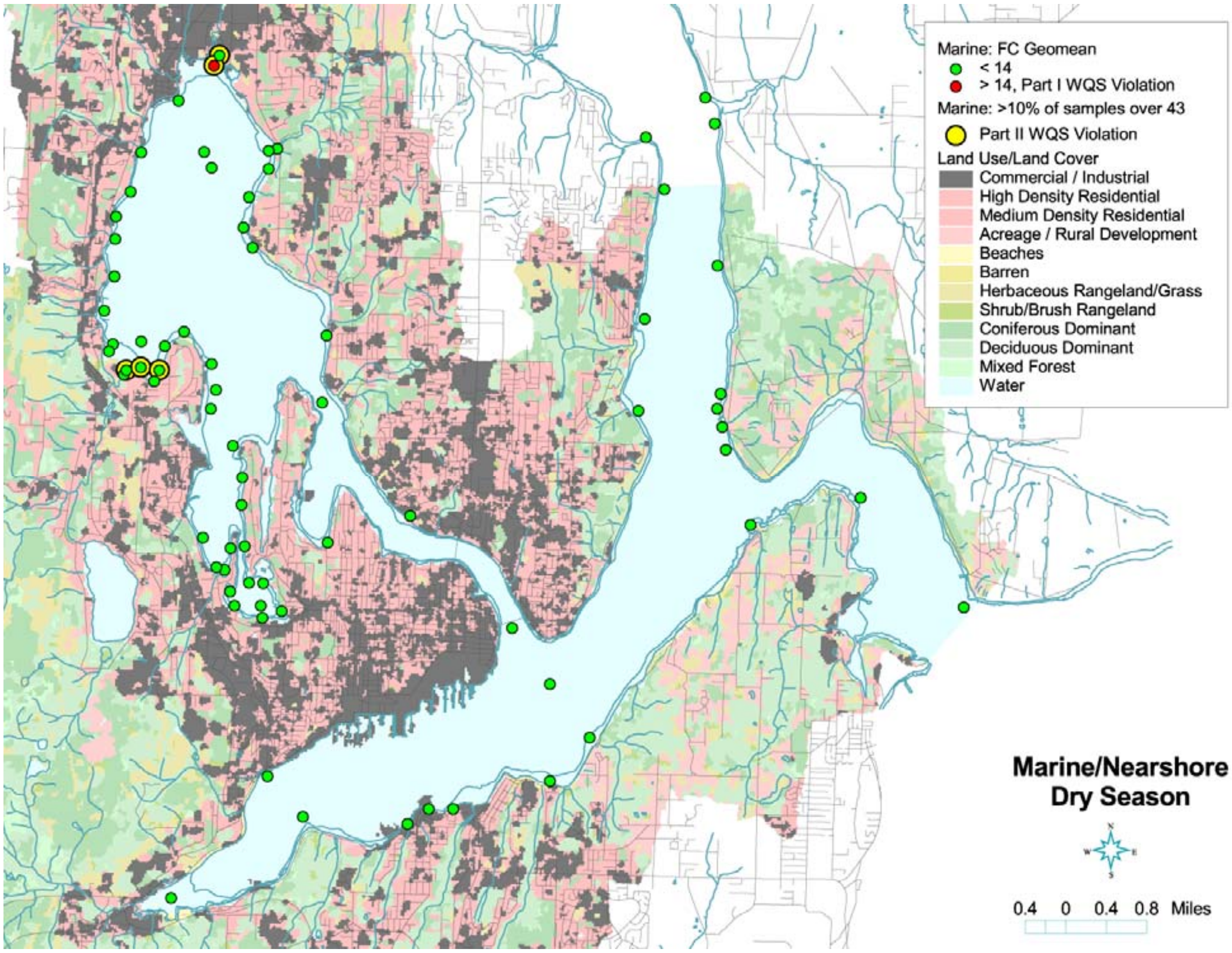


Figure 9-7. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: Dry-Season (May-September) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

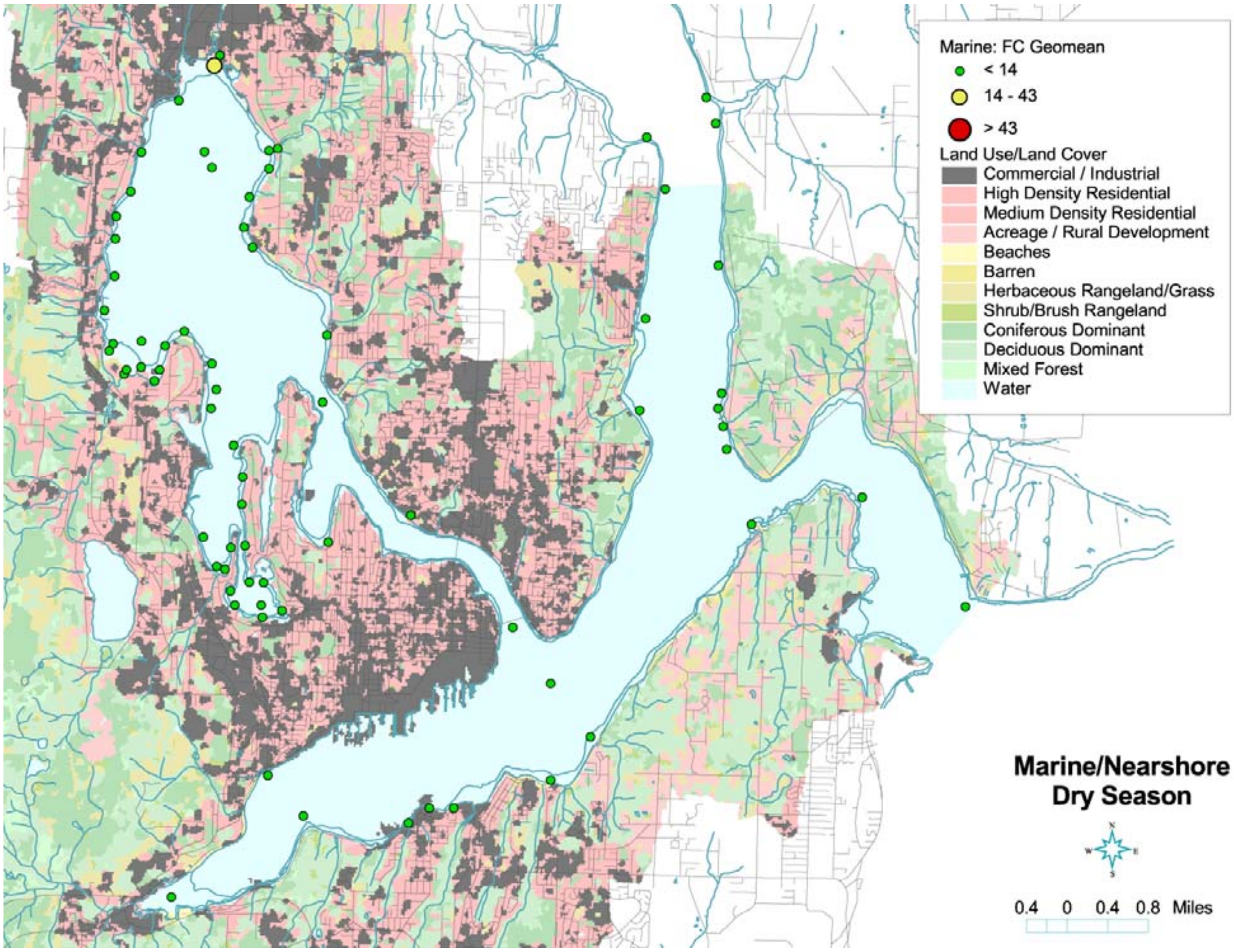


Figure 9-8. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: Dry-Season (May-September) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

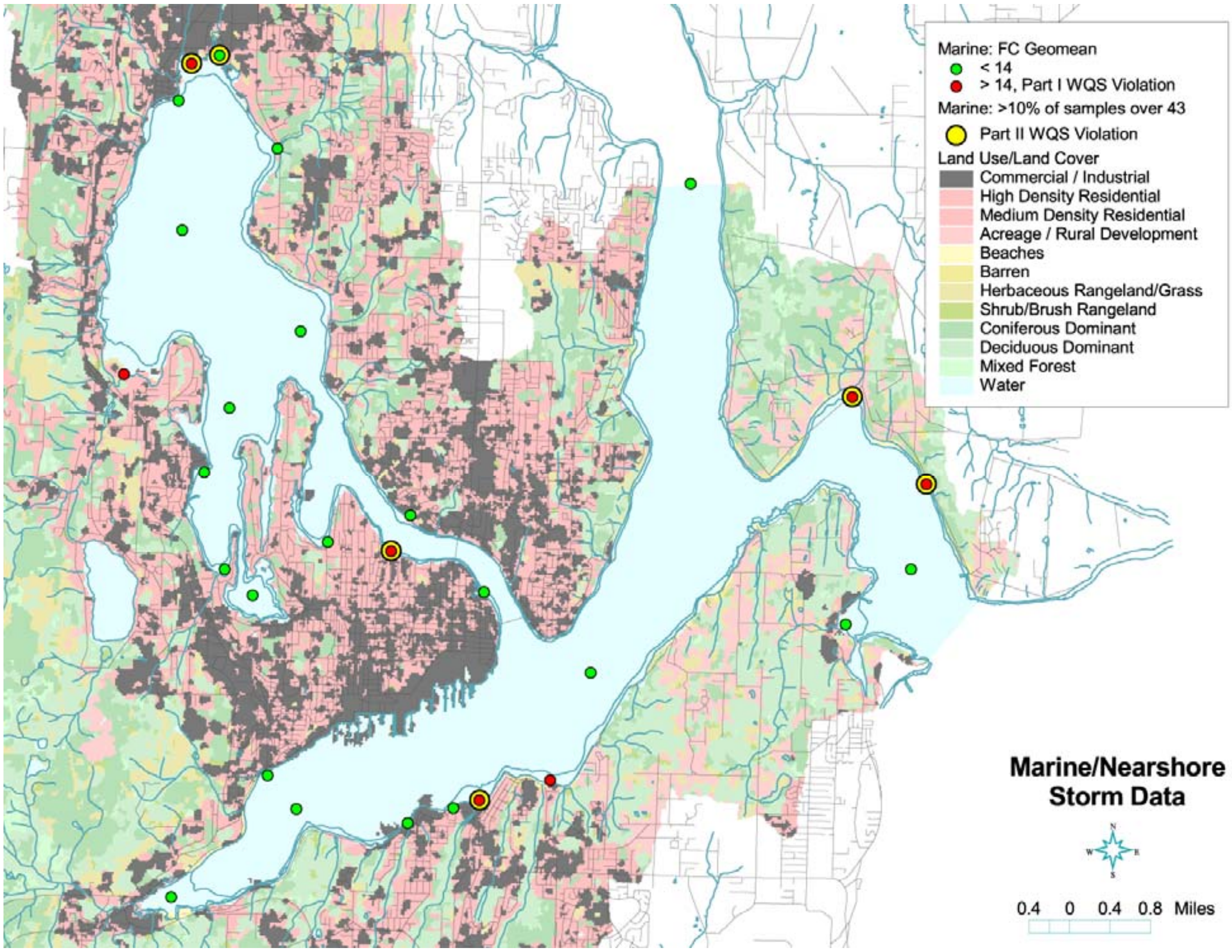


Figure 9-9. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: 2002-20003 Storm-Season ENVVEST Fecal Coliform Sample Data

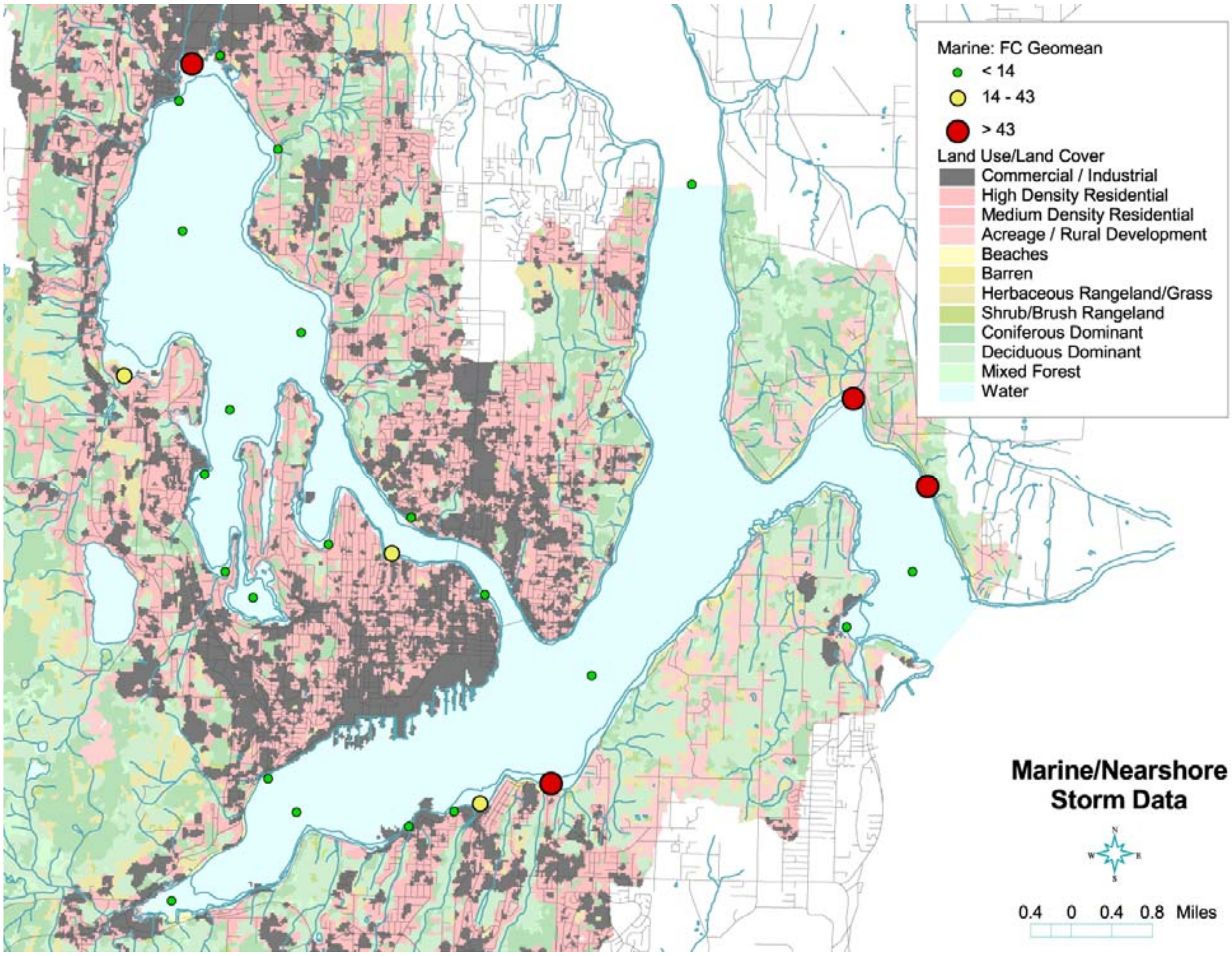


Figure 9-10. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: 2002-20003 Storm-Season ENVVEST Fecal Coliform Sample Data

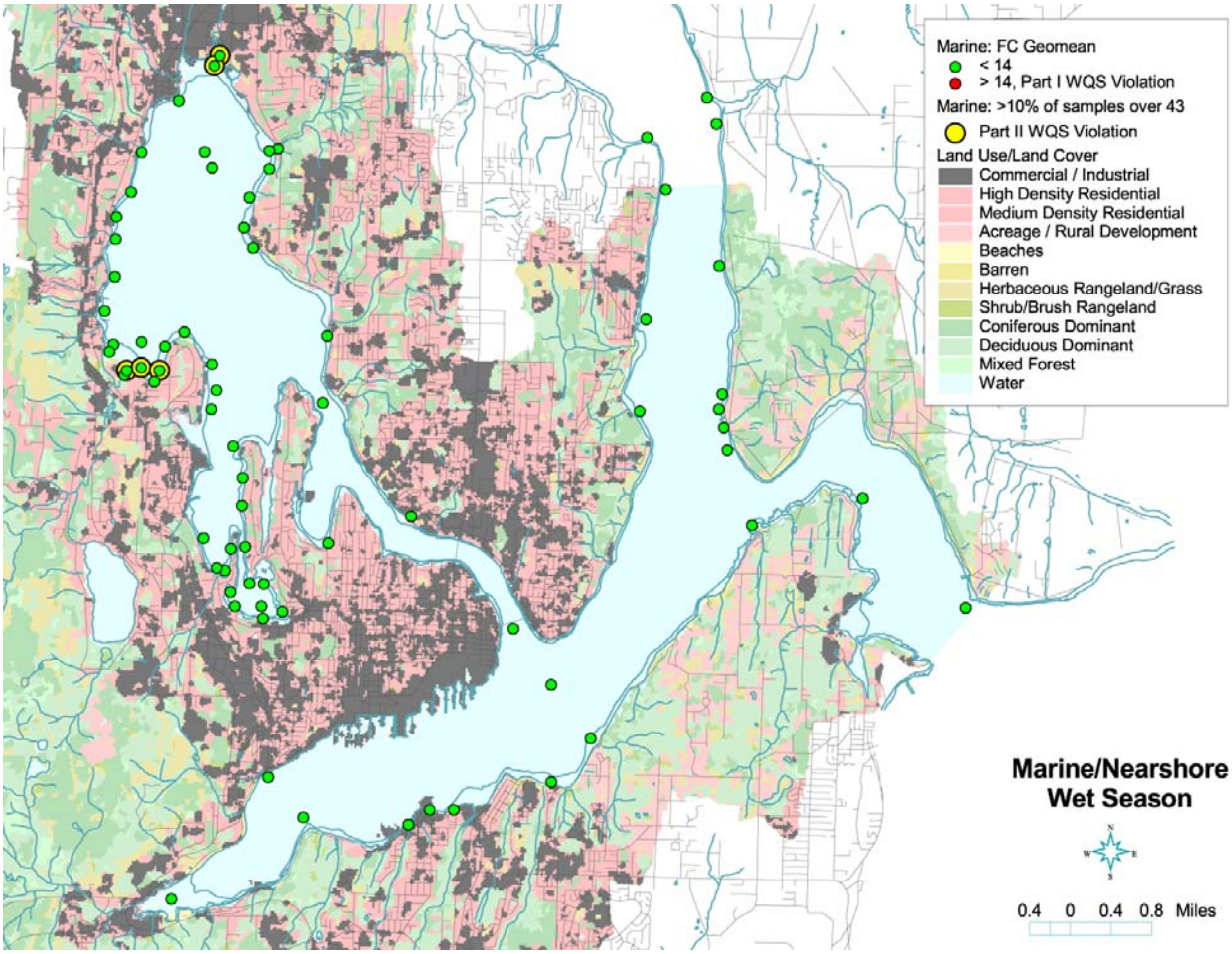


Figure 9-11. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: Wet-Season (October-April) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

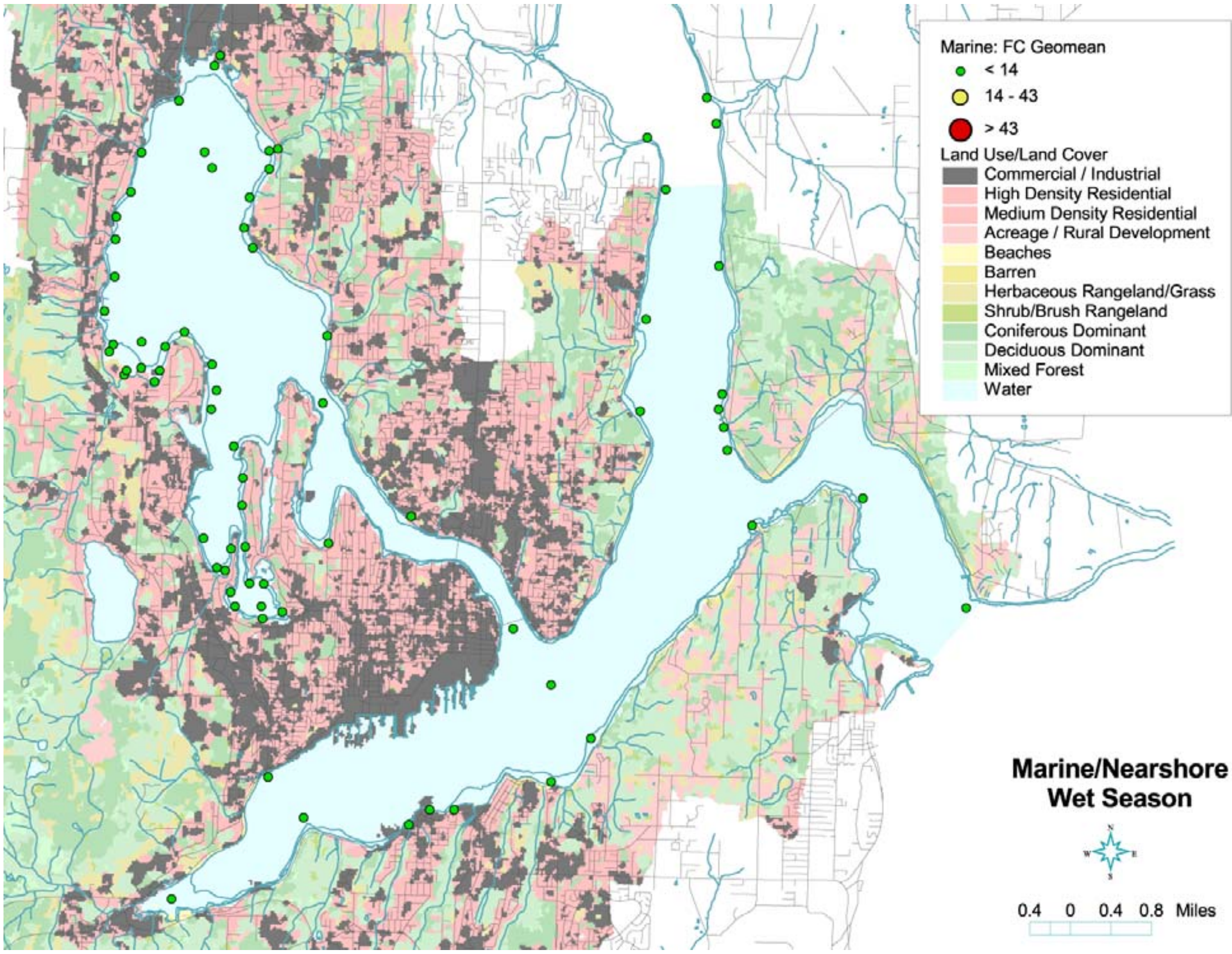


Figure 9-12. Bacterial Pollution Levels and Water-Quality Violations for Marine Waters in the Sinclair-Dyes Inlet Watershed: Wet-Season (October-April) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

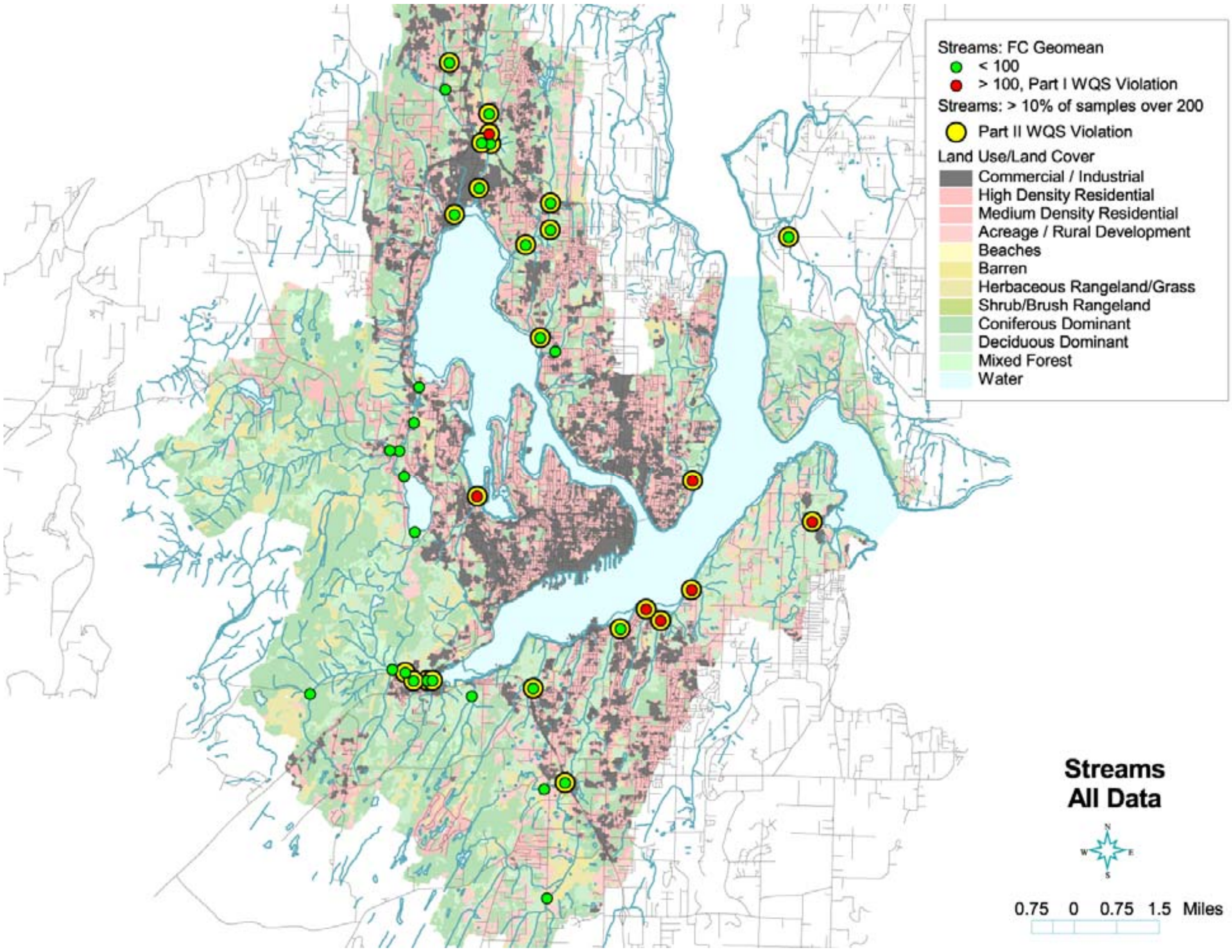


Figure 9-13. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: All Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD, WA-DOH, and ENVVEST Data

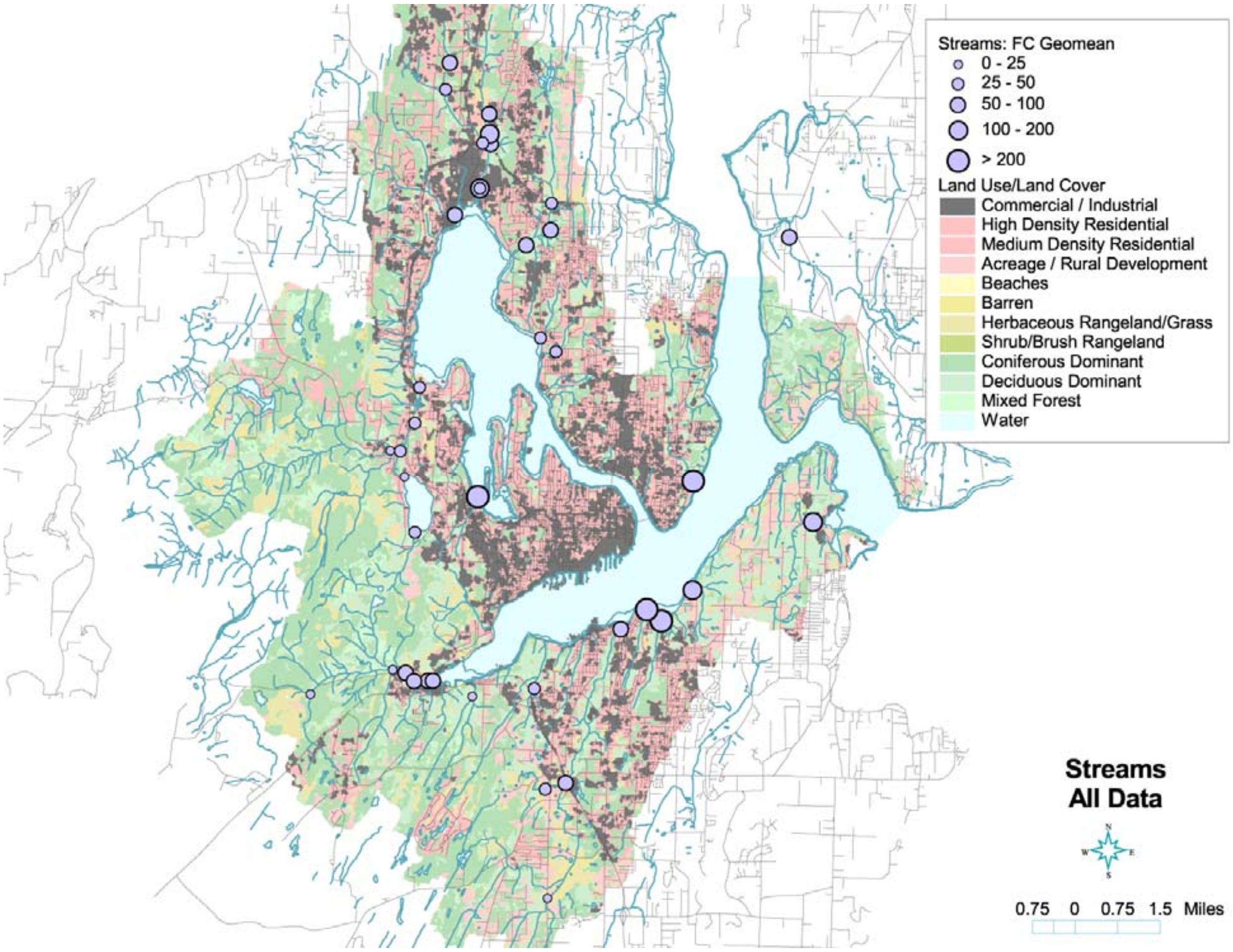


Figure 9-14. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: All Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD, WA-DOH, and ENVVEST Data

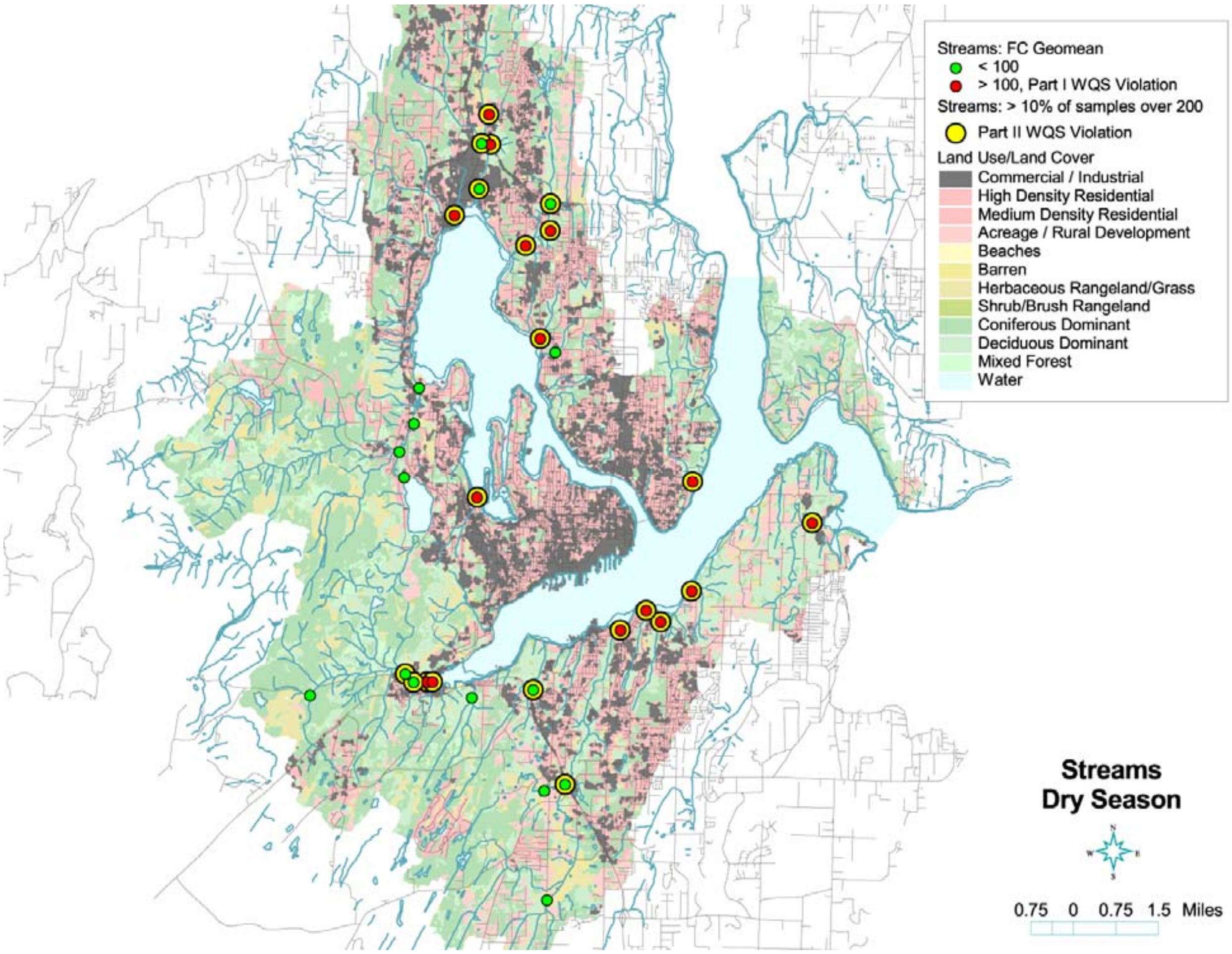


Figure 9-15. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: Dry-Season (May-September) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

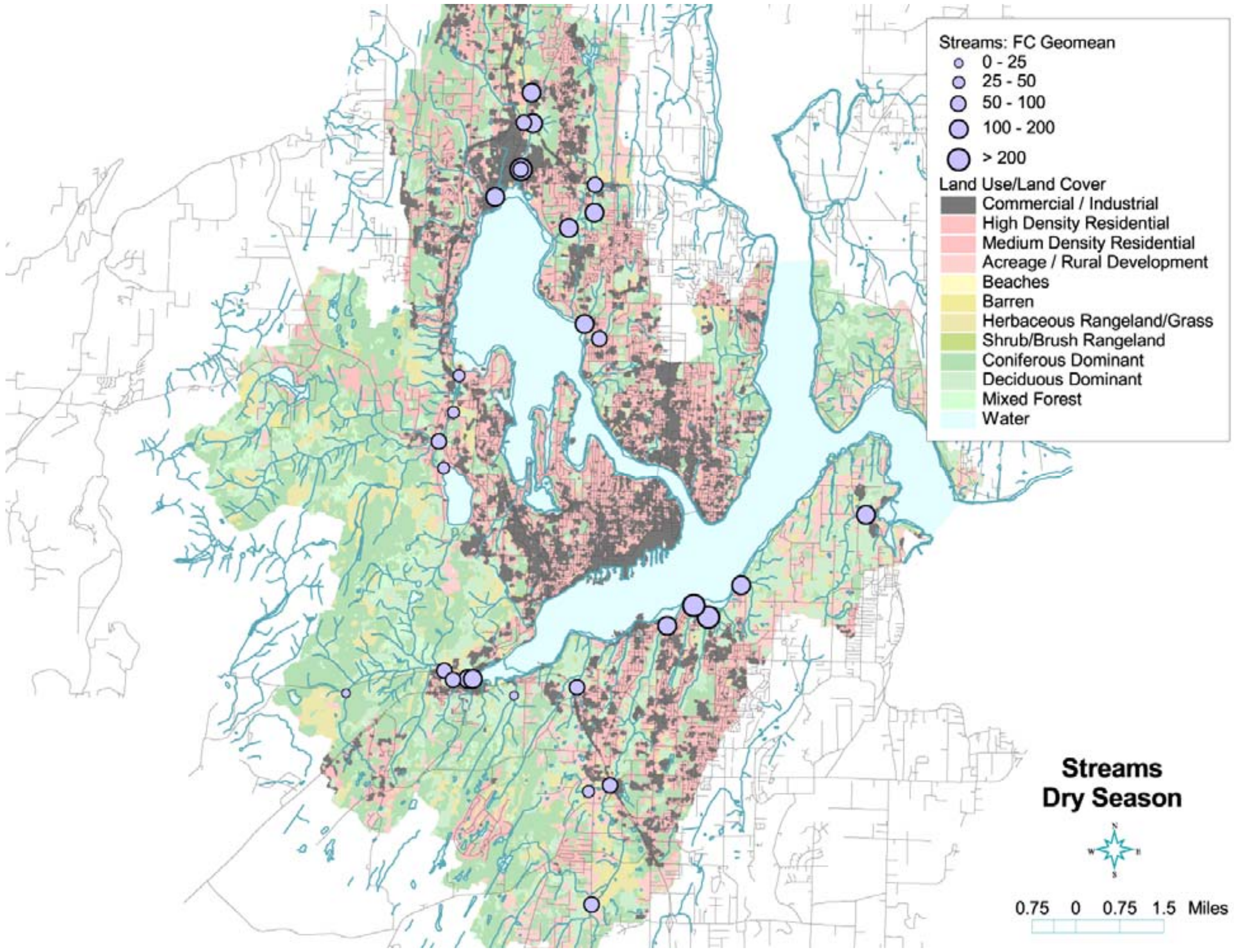


Figure 9-16. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: Dry-Season (May-September) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

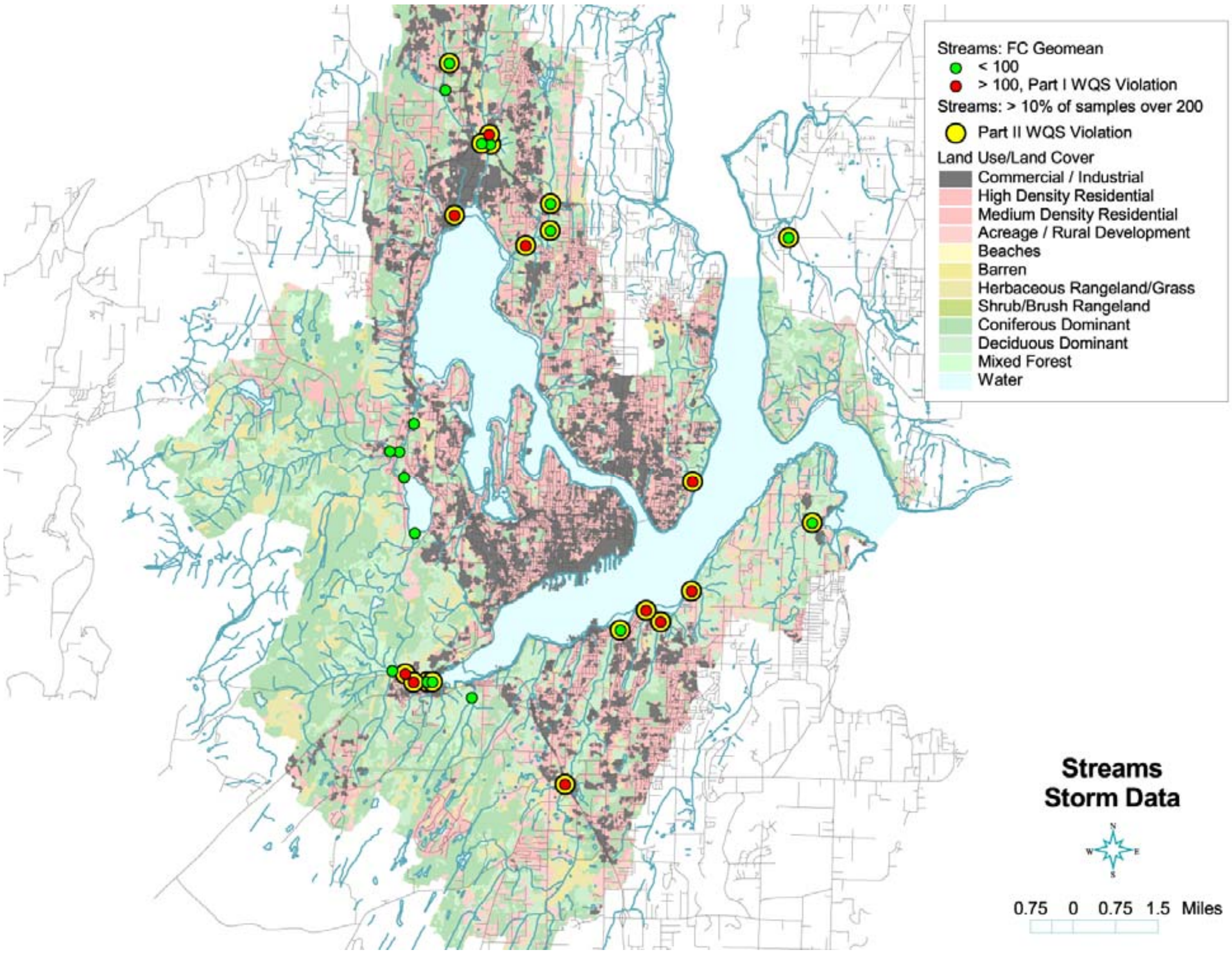


Figure 9-17. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: 2002-2003 Storm-Season ENVVEST Fecal Coliform Sample Data

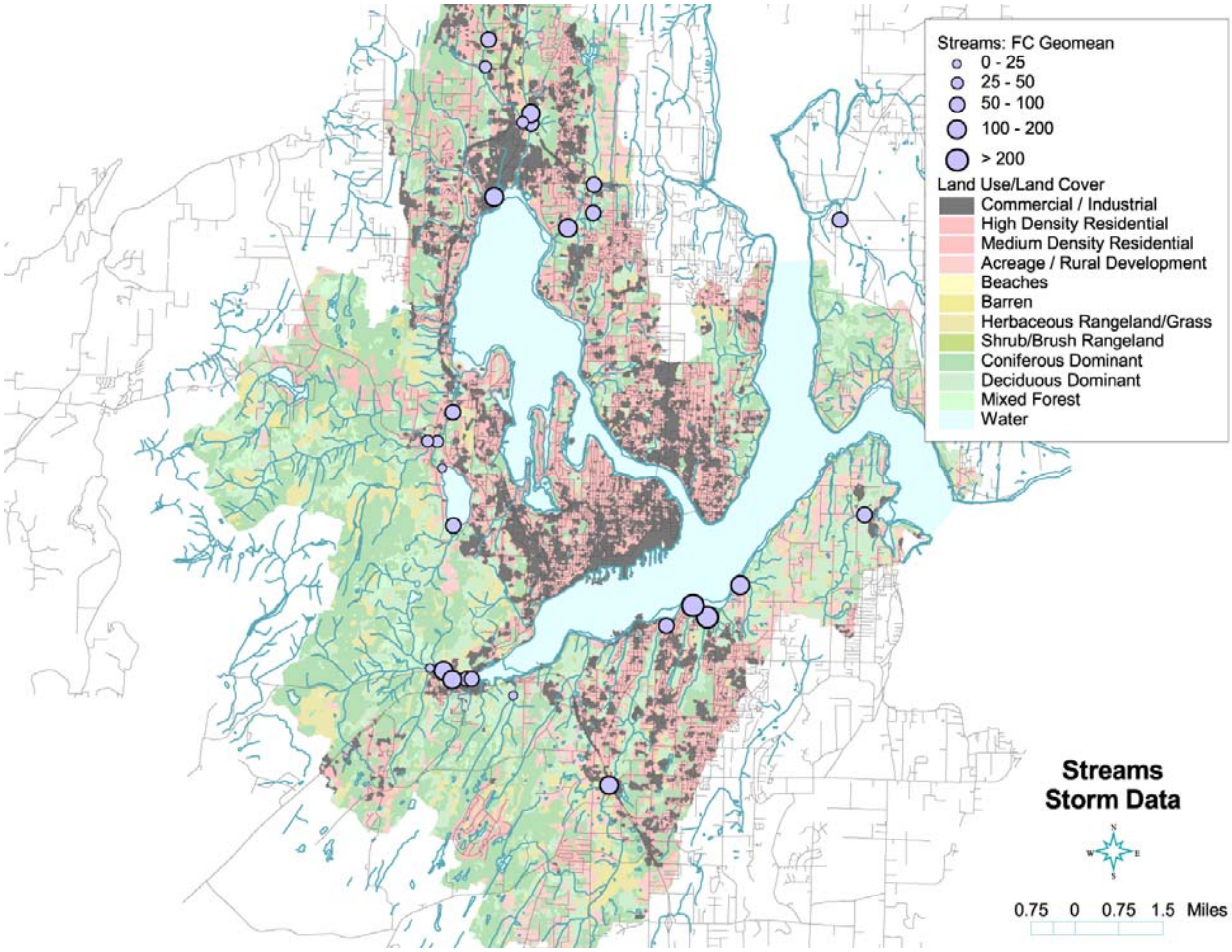


Figure 9-18. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: 2002-2003 Storm-Season ENVVEST Fecal Coliform Sample Data

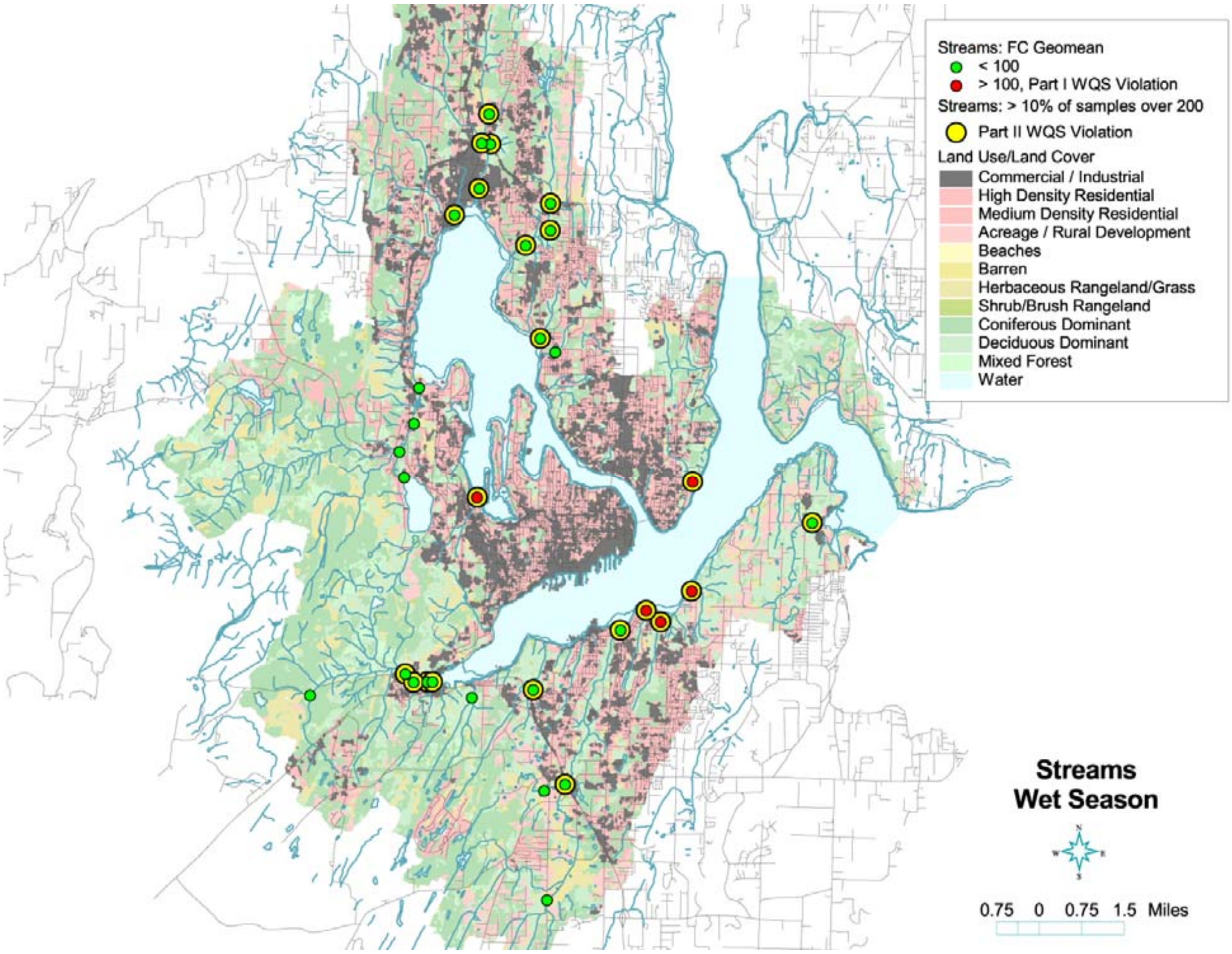


Figure 9-19. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: Wet-Season (April-October) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

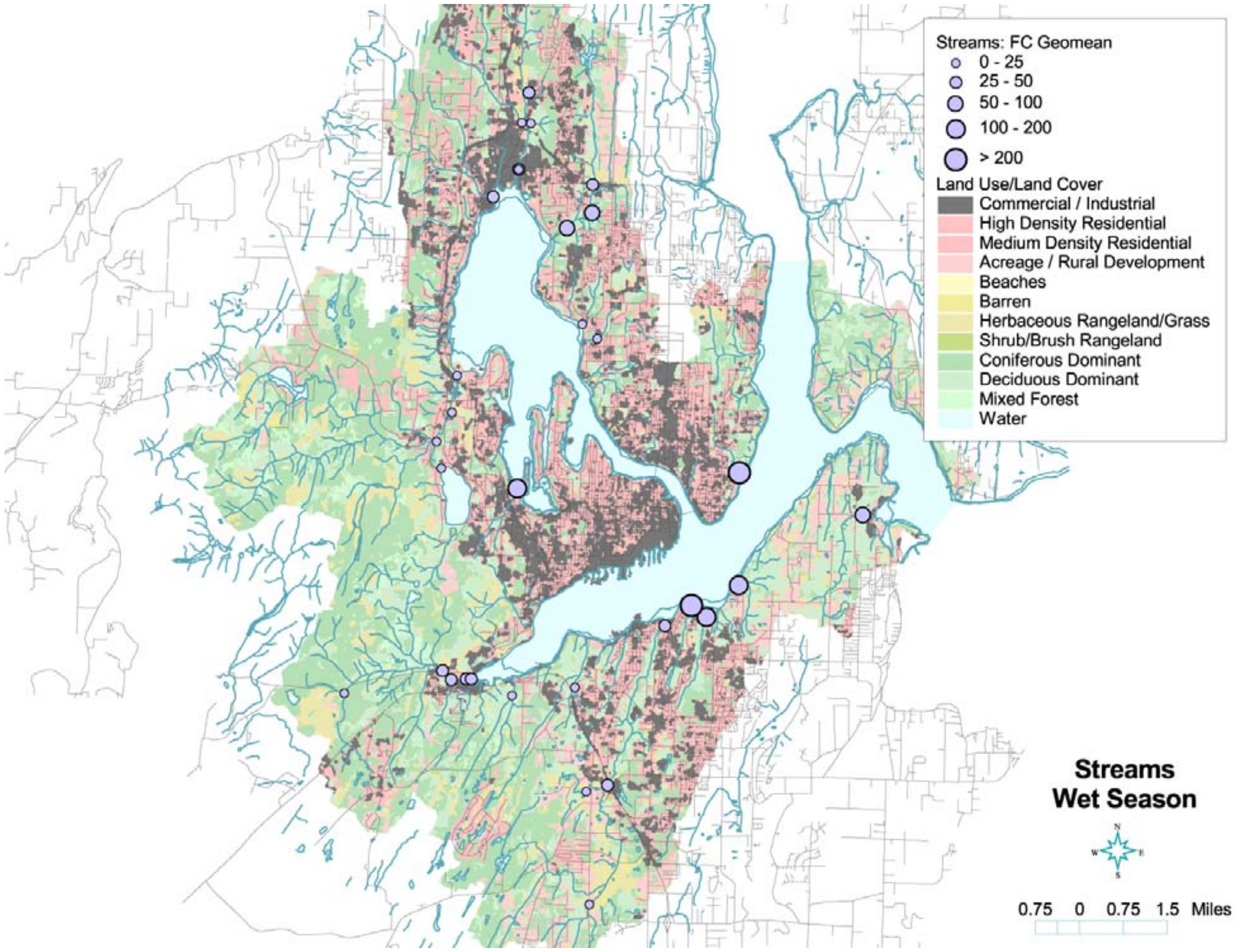


Figure 9-20. Bacterial Pollution Levels and Water-Quality Violations for Streams in the Sinclair-Dyes Inlet Watershed: Wet-Season (April-October) Fecal Coliform Sample Data Available for the 2000-2003 Study Period, Including KCHD and WA-DOH Data

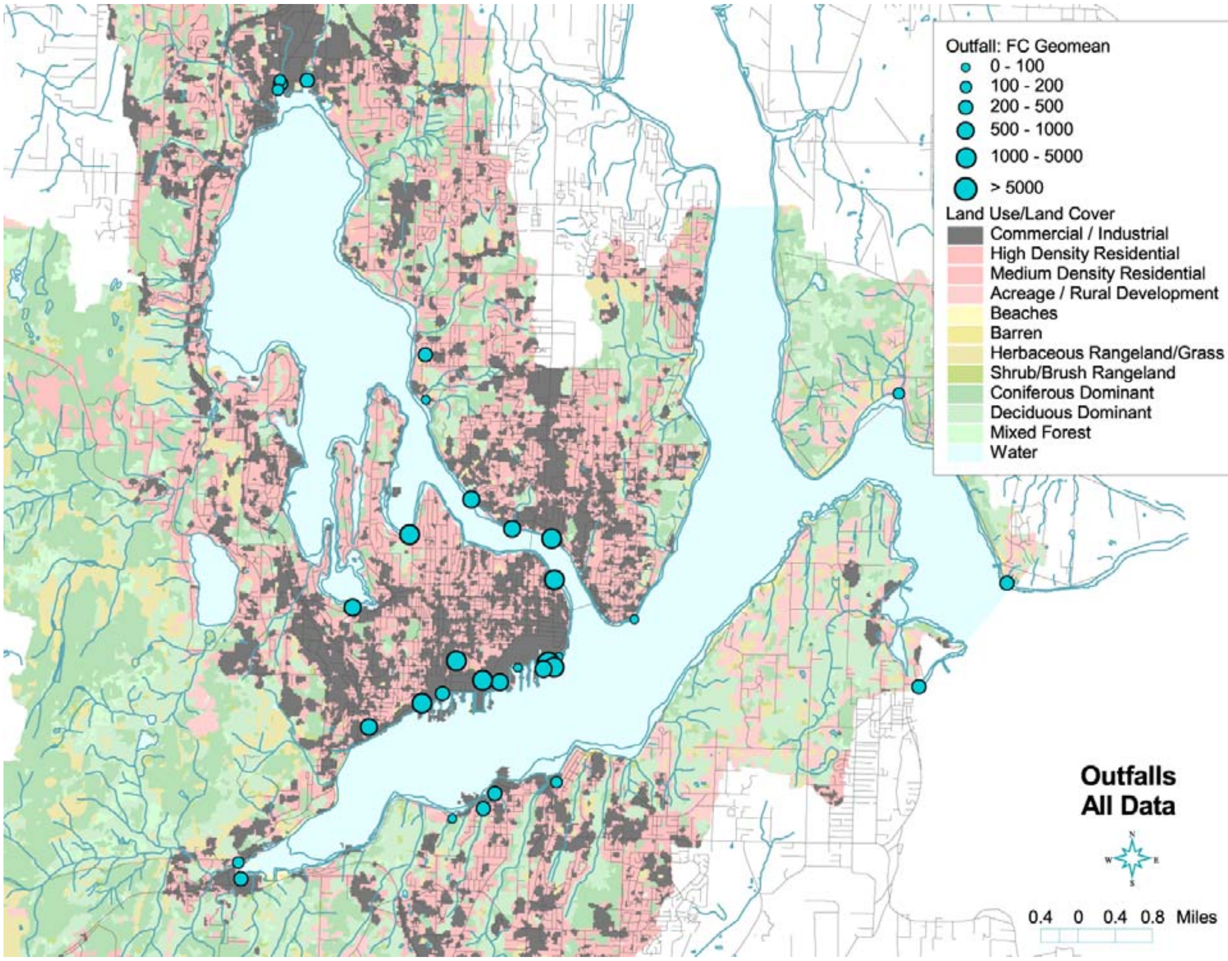


Figure 9-21. Bacterial Pollution Levels and Water-Quality Violations for Stormwater Outfalls in the Sinclair-Dyes Inlet Watershed: Storm-Event ENVVEST Fecal Coliform Sample Data Collected During the 2002-2003 Storm Season

The following is a summary of the main findings of the Sinclair-Dyes Inlet bacterial pollution study:

- The marine and nearshore waters of Sinclair-Dyes Inlet are relatively free of bacterial pollution except in a very few locations and conditions. This desirable condition is largely because of the combined efforts of the KCHD PIC Program, the City of Bremerton CSO Reduction Program, and the KC-SSWM stormwater BMP Program. In addition, monitoring by KCHD, WA-DOH, and Ecology provides timely feedback, which allows for more effective adaptive management efforts in addressing problem areas. As can be seen from the data summarized in Figures 9-5 through 9-12, only a few bacterial pollution problem areas remain in the marine and nearshore waters of the Sinclair-Dyes Inlet watershed.
- The head of Dyes Inlet near Silverdale is affected by stormwater runoff and the discharge of urban creeks (Clear, Strawberry, and Barker). This area has both dry-season and storm-event driven bacterial pollution problems, indicating that both stormwater and failing infrastructure may be the source of the problem. The KCHD has initiated a pollution identification and correction (PIC) study to address this problem. There are also periodic bacterial pollution events in the nearshore waters adjacent to stormwater and CSO outfalls in the City of Bremerton and Puget Sound Naval Shipyard (PSNS). The results of sampling and modeling show that these bacterial pollution events are usually transient and localized in scale. The ongoing CSO Reduction Program, infrastructure upgrades, improvements in stormwater treatment systems, and an increased emphasis on source-control measures should address the majority of these problems.
- Based on the findings of this study, it can be concluded that streams draining developed watersheds are likely to violate Part I (FC geometric mean greater than 100 cfu/100 mL) bacterial WQS when development reaches the medium-density to high-density suburban range or when subbasin forest cover becomes less than 60% of the watershed surface area. Violations of Part II WQS (when more than 10% of FC samples have greater than 200 cfu/100 mL) are much more likely in developing stream watersheds, even at impervious levels (assessed as the percentage of total impervious area, or %TIA) as low as 10%. This development level corresponds to the shift from predominately rural to suburban land use. Under current development practices, when watershed development reaches the urban stage (%TIA greater than 40%), bacterial pollution and WQS violations (Parts I and II) in streams becomes almost a given. In addition, at the higher suburban and urban levels of development, engineered stormwater infrastructure and associated outfalls can become a major bacterial pollution source. These outfalls often drain into urban streams. As a result, streams draining urbanized subbasins can be significant sources of FC loading to nearshore marine waters, especially near the mouth of these developed streams.
- Although not specifically monitored for this study, marinas and marine vessels have the potential to be a significant source of bacterial pollution within the marine waters of Sinclair-Dyes Inlet. Proper operation and good housekeeping measures are the primary means of preventing sewage spills and illicit discharges.
- Figures 9-13 and 9-14 summarize the data applicable to streams in the Sinclair-Dyes Inlet watershed for the entire study period. A relatively small number of streams in the Sinclair-Dyes Inlet watershed have relatively severe bacterial pollution problems (i.e., violation of Part I WQS). Streams with consistently high FC levels include Dee, Olney (Karcher), Annapolis, Oyster Bay, and Clear Creeks. The KCHD has current or planned PIC projects to address these problem areas. On the other hand, numerous streams have chronic bacterial pollution problems (violate Part II WQS), where FC levels are not consistently high, but frequent peak FC levels exceed WQS. These streams include most urbanizing subbasins within the watershed (Strawberry, Barker, Mosher, Blackjack, Ross, Gorst, Springbrook, and Beaver Creeks).

- In many cases, dry-season baseflow FC concentrations (Figures 9-15 and 9-16) are a bit higher than wet-season baseflow FC levels (Figures 9-19 and 9-20), possibly the result of more significant dry-season-related sources or dilution by higher wet-season baseflows. In some cases, however, more developed watersheds have higher wet-season FC concentrations. In addition, analysis of FC data in relation to storm events indicates that higher FC levels are more likely to occur following a major storm event that produces stormwater runoff that enters the marine receiving waters via urbanized streams (Figures 9-17 and 9-18). Experience (KCHD PIC) has shown that dry-season FC loading can be quite high, especially in areas with failing septic systems or leaking sewer infrastructure. In spite of this trend, wet-season loading can also be significant and storm-event FC peaks can also result in bacterial contamination problems in nearshore areas.
- Based on the findings summarized in this study, storm streamflow and stormwater runoff are significant transport pathways for bacterial contamination, especially in urbanizing subwatersheds. Pet waste, domestic animal manure, and urban wildlife are all contributors to the stormwater fecal load, as are human sources. Improperly installed or poorly maintained onsite septic systems, as well as failing sewer infrastructure, are likely significant human sources of bacterial contamination in urbanizing watersheds. Sewage spills and periodic CSO events can also be important sources of human bacterial pollution to marine receiving waters. Clearly, in dealing with bacterial pollution problems from urbanized stream subbasins, multiple sources must be considered. In addition, comprehensive pollution identification and correction efforts must deal with dry- and wet-season sources, as well as storm-event, runoff-driven problems.
- In general, FC levels in streams (both mean-median values and variability "spikes") tend to increase as contributing watershed development increases. This trend holds for nearshore, stream, and stormwater outfall sample data. The level of development can be measured using the %TIA or by delineating land-use patterns. Sources of bacterial contamination in urbanizing watersheds includes failing OWTS, sanitary sewer leakage or spills, CSO events, pet waste, livestock manure, and urban wildlife.

  Although there is almost always a measurable correlation between FC levels and %TIA in urbanizing stream subbasins, it is not a simple cause-effect relationship. There are typically multiple factors, in addition to the overall level of development (as measured by imperviousness), that can influence FC levels found in a watershed. These factors include the type of development, the location of development, the age of development infrastructure, the type and condition of sewage treatment facilities present, the variety of human activities, the presence of pets and livestock, the configuration of the stormwater infrastructure, and the stormwater treatment facilities in place. Watersheds dominated by high-density residential development appear to have the greatest potential for bacterial water-quality violations.

  Under current development and stormwater mitigation practices, local violations of bacterial water-quality criteria are almost certain to occur when watershed development reaches the high-density suburban or urban level (dominated by a mix of HD residential, commercial, and industrial) and when watershed impervious surface area exceeds natural forest cover. Potential FC sources increase as development increases, natural vegetation-soil treatment capacity is lost as impervious surfaces begin to dominate the landscape, and engineered stormwater infrastructures (curb-and-gutter streets, drain-inlet collection points, and piped conveyance networks) are common at the urban level of development.
- Figure 9-21 summarizes the data for bacterial pollution from the monitored stormwater outfalls in the Sinclair-Dyes Inlet study area. Bacterial loading to marine receiving waters from stormwater outfalls can be significant and is on the order of magnitude of streams that drain highly urbanized watersheds. In general, the main difference between urban streams and stormwater outfalls is the

transient (storm-event driven) nature of stormwater outfalls. However, some outfalls are actually piped urban streams, which can flow year-round and can be high FC sources. CSO events are also significant transient FC loading events in the urban environment. The impact of all these upland sources on the nearshore environment appears to be relatively localized (concentrated near the mouth of these streams or outfalls), but can have a cumulative effect on water quality in marine embayments, especially in areas with poor natural flushing capacity.

The value of an integrated watershed approach to water-quality management has been demonstrated during this project. The number and variety of sources for bacterial pollution throughout the study area does not support a conventional "end-of-pipe" approach to pollution control. In addition to ecological concerns related to NPS pollution, the link between human health and water quality is extremely strong in the case of microbial pollution. Therefore, the detection, quantification, and correction of existing sources of microbial pollution should be a high priority for watershed and water resource managers, as should the prevention of future problems.

Based on the findings of this study and others, Figure 9-22 illustrates the linkages between development-related *stressors* at the watershed-scale, the resultant environmental conditions or *exposure*, and the ecological *response* of the aquatic resources in the study area. This conceptual model provides a simple visual representation of the complex linkages between human population-related activities and changes in the environment, such as the degradation of water quality. These changes, in turn, influence the quality of aquatic ecosystems and the biota that inhabit them. This model also provides a framework for assessing the relative risks of watershed development on aquatic resources and beneficial uses. This model can also assist in developing watershed management plans and monitoring programs that will reduce the cumulative impacts of development on aquatic ecosystems and the natural services they provide.

Coastal population growth and associated land-use activities have been identified as one of the most significant threats to natural ecological function in estuarine and nearshore environments (Beach 2002). This is certainly the case for the Puget Sound in general and for Sinclair-Dyes Inlet as well. The coastal zone where much of this development is concentrated is a relatively narrow strip of land that comprises just over 10% of the nations' land area but contains more than 50% of the human population (Beach 2002). This high population density and the associated landscape changes tend to magnify the effects of development and NPS pollution on the nearshore receiving waters. In addition to bacterial pollution, which is the focus of this report, major pollution problems in coastal waters include eutrophication, hypoxia, sediment contamination, habitat modification, and exotic species (NRC 1993; NRC 2000; Beach 2002; PSAT 2002). Aggressive source-control measures, comprehensive stormwater-treatment programs, and adaptive management are key to maintaining beneficial uses through all phases of development.

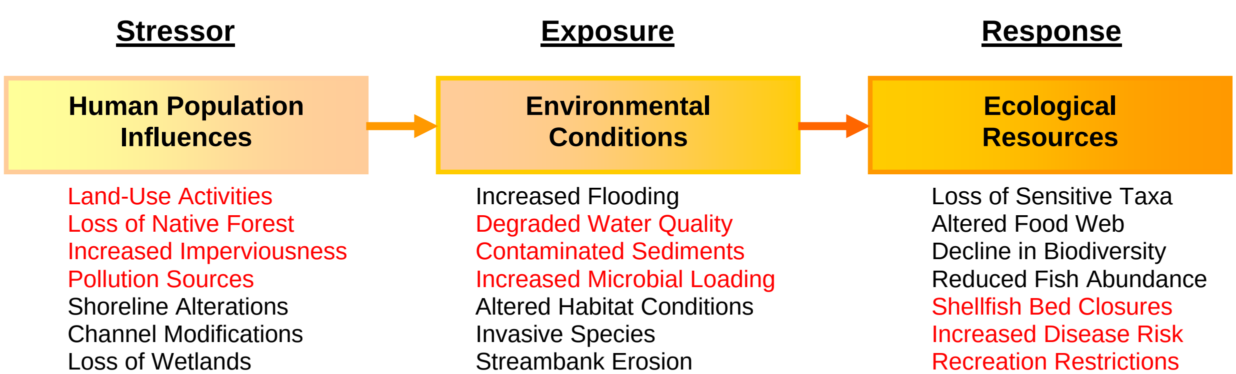


Figure 9-22. Conceptual Model of Linkages Between Human Influences and Ecological Endpoints, with an Emphasis on Bacterial Pollution (modified from Holland et al., 2004). The red text indicates the factors specifically studied as part this project.

9.2 Recommendations

A watershed-based, water-quality cleanup (total maximum daily load, or TMDL) plan should be developed for the Sinclair-Dyes Inlet watershed. The goal of the TMDL plan should be to improve water quality in the watershed such that all designated beneficial uses, including shellfish harvest, contact recreation, and fish and wildlife habitat are fully supported. The water-quality cleanup plan should include adequate monitoring and adaptive management to ensure all implemented actions are effective. The monitoring effort should include biological as well as physio-chemical elements and should cover the entire watershed area, including marine, freshwater (streams, lakes, and wetlands), and stormwater systems (NRC 2001).

A TMDL plan has value on several levels, not the least of which is the structured thinking about source loads and mitigation strategies compelled by the TMDL development process. Incorporation of watershed-specific data is a critical component of a scientifically defensible bacterial TMDL evaluation (NRC 2001). Public education and involvement should also be a major component of the TMDL implementation process, including making information available on the potential water-quality impacts of specific land-use activities common to residential and commercial-industrial communities.

In the case of bacterial water cleanup plans (TMDL), the use of alternative measures of effectiveness instead of assigned "loading" values for sources should be considered (NRC 2001). Assigning specific loading targets to individual streams or stormwater outfalls is problematic from a variety of perspectives. Bacterial levels are notoriously variable and difficult to accurately quantify. The sources of bacterial pollution are also very diverse and often difficult to identify without an extensive, long-term monitoring program and some dedicated detective work. In addition, there are typically multiple pollution sources at work in almost every situation in which bacterial pollution is a problem. Finally, establishing fixed TMDL loading criteria for each source area may be appropriate for some point-source type inputs, such as a wastewater treatment plant, but it may not be the most effective method for dealing with more diffuse, nonpoint sources of pollution, such as stormwater or failing sewage treatment systems. For these types of sources, it may be more effective to take a performance-based approach to bacterial pollution, emphasizing proven PIC techniques and encouraging the application of established BMPs, as well as more innovative approaches to prevention and treatment.

The state of California often uses the frequency of WQS violations as a TMDL target instead of specified bacterial loading levels in several situations. These have been developed by state Water Quality Control Boards (WQCB) and approved by the EPA. An example of this is the Santa Monica Bay TMDL in the Los Angeles area (California Regional WQCB 2002). In these TMDL programs, jurisdictions and agencies emphasize the application of source-control and treatment BMPs, as well as public outreach, education, and involvement. Comprehensive monitoring and adaptive management are also keys to making the TMDL program effective. With multiple sources, such as numerous stormwater outfalls, and highly variable measurements, meeting TMDL loading targets may be difficult and will likely require a high level of monitoring effort. The ultimate goal of a TMDL is not to assign and track allowable loading targets to every single source, but to restore water quality to a level that supports all designated beneficial uses (e.g., shellfish harvest and contact recreation). Therefore, monitoring beneficial-use attainment may be a more efficient use of resources, along with a prioritized approach to address pollution identification and correction of sources. Jurisdictions should be given flexibility in how they achieve the goal of beneficial use attainment (NRC 2001).

The historical KCHD and WA-DOH bacterial pollution monitoring data and the storm-season FC data collected during this study can provide the foundation for watershed-based restoration and water-quality improvement projects. These future restoration and enhancement projects should build upon the efforts of jurisdictions (e.g., Kitsap County and the City of Bremerton), local agencies (e.g., KCHD, Kitsap Conservation District [KCD], and Kitsap County Surface and Stormwater Management [KC-SSWM]), and citizen groups (e.g., Chums of Barker Creek) that are currently underway in the watershed. Several projects have been initiated within the Sinclair-Dyes watershed to specifically address identified bacterial contamination problems. These projects, managed by KCHD, KCD, and KC-SSWM have already improved conditions in several subbasins and nearshore areas. Most notable, the KCHD PIC program is one of the most effective methods of bacterial pollution remediation. These ongoing efforts, along with significant reductions in CSO discharges by the City of Bremerton, have already resulted in the opening of some shellfish areas in Dyes Inlet for harvest and will likely result in the removal of some currently "listed" water bodies from the 303(d) list.

Experience from this area, as well as other parts of the country, have shown that effective mitigation of bacterial pollution based on the most likely sources of contamination, as described in this report, should include the following:

1) Proper operation and maintenance of onsite septic systems and municipal sewage treatment systems
2) Elimination of all illicit and illegal discharges, including land-based sources and boats or marinas
3) Quantity control and water-quality treatment of stormwater runoff draining to receiving waters
4) Implementation of farm and livestock source-control and BMPs
5) Public education to encourage bacterial pollution source control, such as pet-waste management programs.

The findings of this project and other bacterial pollution research efforts throughout the U.S. have significant management implications with respect to maintaining or restoring the water quality of urbanizing watersheds to a more natural condition in support of designated beneficial uses. Multiple approaches have the potential to reduce bacterial contamination; however, most have not been sufficiently researched in terms of quantifying their benefits.

Based on best-available science, recommendations for improving water quality can be grouped according to expanding on current successes, increasing prevention, encouraging public participation in BMPs, enhancing natural systems, and using innovative technologies. The following recommendations are offered as possible focus areas for improving water quality in the Sinclair-Dyes Inlet watershed and are further described in the paragraphs that follow:

Expand on Current Successes

- Increase current KCHD bacterial pollution monitoring and expand the KCHD PIC program
- Consider alternative indicators to better determine bacterial sources.
- Continue to correct of illicit sewage discharge connections
- Support the City of Bremerton CSO elimination and treatment program and infrastructure improvements
- Support the Kitsap County stormwater infrastructure upgrade program
- Support PSNS stormwater and sewer system infrastructure upgrade programs

Increase Prevention and Source Control

- Avoid the creation of bacterial sources or reservoirs within the stormwater conveyance system
- Locate stormwater outfalls away from recreational beaches and shellfish harvesting areas

- Reduce urban wildlife sources
- Control pet waste
- Implement farm BMPs for treatment of livestock waste
- Encourage boaters and marinas to use proper sewage-disposal methods
- Encourage the application of low-impact development (LID) solutions
- Implement or increase maintenance measures, such as street-sweeping coverage and stormwater drain-inlet clean outs

Build or Enhance Natural Systems

- Restore natural structure and functions to streams and wetlands to encourage natural bacterial predation
- Use riparian buffers around water bodies to naturally filter runoff and reduce the level of bacteria populations
- Design stormwater treatment ponds to mimic natural wetland conditions to support vegetative filtration and bacterial predation
- Encourage the use of infiltration BMPs, constructed wetlands, biofiltration swales or vegetative filter strips (VFS), and stormwater-treatment wet ponds (in that order)
- Design stormwater ponds to promote settling of solids and the retention of settled solids within the system
- Enhance bacterial removal in stormwater ponds with flocculation agents
- Consider dredging contaminated sediment to restore shellfish beds in embayments with low natural flushing capacity

Consider the Use of New Technologies

- Consider innovative treatments, such as UV light disinfection, ozone treatment, and antimicrobial coatings on catch-basin inserts

Expand on Current Successes

- Build on the success of current bacterial pollution monitoring and expand the PIC program. For example, consider using microbial source tracking (MST) technologies to identify pollutant sources (Woodruff and Evans 2003) for those situations in which pollution sources cannot be identified using traditional PIC methods. The KCHD PIC program should be a high priority for water-quality cleanup funding. Provide technical assistance and financial support to property owners for the correction of bacterial pollution sources identified during PIC or microbial source tracking (MST) programs.
- Consider the use of alternative indicators to better determine bacterial sources and apply to source-control measures. With regard to bacterial monitoring, under certain conditions, alternative indicators (including molecular or DNA-based approaches) can be used that can differentiate between animal and human pollution sources to improve source identification and aid in source-control measures. A combination of current indicators (e.g., FC and enterococcus) and innovative methods would be more useful than any single indicator in most situations. Support the development of a database of known pollution sources (anthropogenic and natural) to facilitate this method of source tracking. Use new bacterial indicators in conjunction with

existing methods to aid in the development of statistical and GIS-based linkages that allow for the effective use of historical data. This database is particularly important when doing trend analysis and developing relationships based on land-use change. Consider the use of alternative indicators such as viruses to establish pathogen risks.

- Continue to identify and correct all illicit sewage discharge connections to stormwater systems and to natural stream networks. Identify and correct any inadvertent linkages between sanitary sewer systems and stormwater networks, as well as leaking sewer infrastructure or failing septic systems. Dye tests, smoke tests, remote mobile TV inspections of storm sewer systems, flow monitoring, and remote sensing are some of the tools that can be used to detect and eliminate illicit discharges and failing wastewater treatment systems. Optical brightener monitoring (OBM) is an innovative method that can be used detect persistent ultraviolet (UV) man-made dyes common to laundry detergent in storm-sewer systems or downstream of failing septic systems. Wherever the optical brighteners are detected in the environment or storm-sewer system, they indicate the presence of laundry effluent, which is typically a component of sewage or septic-system effluent.
- Continue to support the City of Bremerton CSO elimination and treatment program. This program, which has been very successful, includes infrastructure upgrades and state-of-the-art CSO treatment facilities. Likewise, continue to support stormwater infrastructure improvements within Bremerton, which have also been very influential in reducing pollution into marine receiving waters.
- Expand the stormwater infrastructure upgrade programs currently underway in Kitsap County to specifically address microbial pollution. These programs focus on enhancement of stormwater collection and conveyance networks, as well as stormwater treatment (BMP) facilities.

Increase Prevention and Source Control

- Avoid the creation of bacterial sources or reservoirs within the stormwater treatment and conveyance network. Minimize the use of curb-and-gutter systems with drain inlets, low-gradient piping, and underground vaults. Rather than using engineered or “hard” stormwater-collection and conveyance systems, consider using more natural treatment methods that encourage soil and vegetative biofiltration and infiltration. From a water-quality perspective, biofiltration swales or grass-lined ditches are preferable to unvegetated roadside ditches that retain standing water and create erosional sediment.
- Locate stormwater outfalls away from recreational beaches and shellfish harvesting areas. Provide stormwater treatment for all runoff prior to allowing it to drain via outfalls into receiving waters. Treatment options run from very “low-tech” methods, such as vegetated swales or constructed wetlands, to “high-tech” approaches, such as UV treatment or chemical disinfection.
- Reduce urban wildlife sources of bacterial pollution by humanely decreasing nuisance waterfowl or other wildlife populations. This solution is typically a site-specific integrated program that may include waterfowl egg addling, vegetative barriers around waterbodies, Border collie patrols, goose or duck repellants, and publicly signed and enforced “no feed” zones. Although most wildlife efforts in other areas have focused on strategies specific to nuisance waterfowl populations, the basic concepts may be applicable to invasive species, such as raccoons, nutria, rats, and other animals that have adapted to manmade environments in population densities far greater than would be found naturally (Waye 2004).

Implement BMPs

- Reduce the potential sources of fecal contamination, including controlling pet waste through better enforcement of “pooper-scooper” laws, the creation of dog parks with effective pet-waste

BMPs, and the establishment of controls for urban waterfowl and wildlife. Although most jurisdictions have some sort of legal code banning pet waste in public areas, most put little or no effort into enforcement. Increasing enforcement with an emphasis on public education campaigns and the issuance of warning tickets that explain the problems associated with pet waste can be effective. Dog parks should be sited away from environmentally sensitive areas, and should provide fencing, public education signage, free pet-waste disposal bags, and sanitary trash receptacles. Sponsorship and acceptance of responsibility by a local dog group for each dog park helps ensure accountability and success. The EPA has found that dog parks function as social centers for transferring the conscientious behavior of responsible pet owners who pick up after their pets to less conscientious owners, and thus helping to establish a new social norm (Waye 2004).

- Continue to implement farm BMPs for treatment of livestock waste products for all commercial and rural-residential farms. Proper management and treatment of livestock waste products is an essential element of an effective bacterial source-control program. Include data on farms and livestock operations in the GIS database. Cost-share programs through local conservation districts are often available to assist farmers who are concerned that excluding cattle and other livestock from nearby streams means an end to an inexpensive and convenient source of water for their livestock. Alternative watering systems may be supplied via solar pasture pumps, electric pumps, and even animal-operated pasture pumps. A growing number of states have successfully restored bacteria-impaired streams in agricultural watersheds by fencing out livestock from excessive stream access. Other agricultural BMPs that have been shown to be effective for reducing bacteria runoff include constructing roofs over concentrated feeding areas, stabilizing livestock access areas, and constructing animal-waste storage facilities (Karpiscak et al., 2001).
- Continue efforts to encourage boaters and marinas to use proper sewage-disposal methods with the goal of eliminating all discharges of raw sewage from boats into receiving waters.
- Encourage the application of low-impact development (LID) solutions to increase infiltration and biofiltration and decrease imperviousness runoff, especially in developing watersheds. Consider using a combination of bioretention (rain garden), infiltration, and biofiltration practices that employ soil filtration as a primary pollutant-removal mechanism. Maximize soil infiltration whenever feasible. LID techniques seek to mimic the predevelopment site hydrology by reducing impervious surfaces and taking advantage of opportunities to infiltrate, filter, retain, evaporate, and slow down runoff close to its source. LID techniques can be applied to new and existing developments using decentralized micro-scale or lot-level controls to manage rainfall and runoff. Reducing the volume of runoff decreases the potential for bacteria to be transported into storm drains. One example of how LID can minimize bacteria in streams is from bird waste that runs down a disconnected roof drain or into a rain garden instead of down a driveway to a storm drain. Another is pet waste left on the ground near a rain garden instead of a roadside ditch. Because they incorporate soil and vegetation filtration, bioretention cells are potentially one of the most effective LID BMPs available for dealing with microbial pollution (Waye 2004).
- Implement or increase street-sweeping coverage and frequency. Implement or increase the frequency of stormwater drain-inlet clean outs. Streets and parking lots have been identified as significant sources or conveyance routes for bacteria and other urban pollutants. Bacteria are colonial and likely form bio-films on gutters and sediment that can be swept away. Because bacteria have an affinity for adhering to fine sediment, use sweepers that are efficient at removing the tiniest particles. The new generation of high-efficiency street sweepers are much more effective than conventional broom-type sweepers (Waye 2004).

Build or Enhance Natural Systems

- Restore the natural structure and functions in degraded streams to encourage greater bacteria predation. Research has shown that natural, pristine watersheds with intact headwaters not only have bacteria source loadings lower than those in urban watersheds by several orders of magnitude, but also have balances of predator-prey microbial communities. In the microbial realm, relatively larger microbes like heterotrophic flagellates, paramecia, rotifers, and others, prey on the smaller FC bacteria to help keep their populations in check. These larger predatory microbes are known collectively as bacterivores. In general, urbanized streams with consistently high bacteria levels tend to have a microbial community that is out of balance. Restoring natural structure and function to these areas can augment bacteria predation. Increasing sunlight exposure to microbial impaired waters can also be an effective bacterial management tool. The "day-lighting" of piped urban streams and storm drains is one such technique (Waye 2004).
- Utilize adequate riparian buffers around streams, lakes, wetlands, and nearshore areas. Vegetated or forested riparian zones will provide buffer zones between impacted land uses and water resources in both urban and agricultural areas. Include exclusion (fencing) of livestock from receiving waters where appropriate. Riparian zones have been shown to help in at least two ways. First, they provide a physical separation from species that predominate in human-influenced land uses and the natural waterways. Second, they provide an opportunity for treating animal waste, as long as the riparian zone is directly down-slope, via sheet flow, of the impacted land use (CWP 1999; Mallin and Wheeler 2000; Ensign and Mallin 2001).
- Design stormwater treatment ponds to mimic natural wetland conditions, with shallow areas that support vegetation (pollutant filtration and uptake) and plankton/invertebrates that increase bacterial predation (Barrett et al., 2001; Stenstrom and Carlander 2001; Karathanasis et al., 2003). Create conditions in stormwater ponds that allow for maximum sunlight penetration into the water column. For example, the construction of shallow, multi-cell ponds is preferred to a deep, single-cell pond. Using multiple cells or a fore-bay can also aid in reducing turbidity, which will aid in reducing bacterial levels (Mallin et al., 2002). Reduce waterfowl and wildlife habitat in areas surrounding stormwater treatment BMPs to reduce the input of fecal material from these sources. Forested buffers can be useful in discouraging geese and other large waterfowl from frequenting ponds in comparison to ponds with borders of mown grass, which tend to encourage waterfowl grazing (Waye 2004).
- Encourage the use of infiltration BMPs, constructed wetlands, biofiltration swales or vegetative filter strips (VFS), and stormwater-treatment wet ponds (in that order). Research indicates that these BMPs can be effective in bacteria reduction. Controlling existing wet-pond water-release levels may also provide some benefit, as bacteria counts tend to be higher on pond surfaces. Infiltration BMPs can include trenches, sand filters, porous pavement, permeable pavers, filter strips, bioretention cells, and rain gardens. As well-designed and maintained septic systems have proven, under the right conditions, infiltration can be effective for preventing bacteria from entering surface waterbodies. As long as adequate separation distances exist, bacteria are also not likely to contaminate groundwater resources (Waye 2004).
- Design or retrofit stormwater ponds to allow for additional retention or detention time to promote greater settling of solids, and/or design ponds using a smaller minimum sedimentation particle-size criterion. Design stormwater facility inlet and outlet structures to prevent resuspension of bacteria-rich bottom sediment (Mallin et al., 2002). In general, lakes have significantly lower bacteria levels than do the streams and rivers that feed them. As bacteria levels increase with turbidity, and as bacteria tend to cling to sediment, the more this sediment has a chance to settle, and the more bacteria may be removed from the water. To the extent that BMP ponds promote settling, they may remove significant amounts of bacteria (Waye 2004).

- Enhance bacterial removal in stormwater ponds with the addition of sediment flocculation agents, such as polyacrylamide (PAM), alum, and chitosan, where appropriate. In most cases, PAM is effective at intercepting bacteria, nutrients, and suspended sediment when added to turbid water. Because of the affinity that FC bacteria have for suspended sediment, PAM and other flocculation agents also hold promise for pulling bacteria out of the water column, although more research is needed to verify this. Another flocculation agent is chitosan, a biopolymer typically obtained from chitin in crab shells. Chitosan has been shown to be effective at coagulating fine sediment particles suspended in runoff, which causes them to settle out of the water column. It may be that chitosan also has application as a bacteria-reduction agent in streams with high levels of sediment and bacteria, since bacteria behave similarly to fine sediment particles in the water column. Alum injection has been used successfully in parts of Florida to substantially reduce nutrients, turbidity, and bacteria (Waye 2004).
- Where appropriate, dredge contaminated sediment to restore shellfish beds in embayments with very low natural flushing capacity. Localized dredging of sediment that is highly contaminated with bacteria has been shown to be effective in restoring shellfish beds in areas of low circulation and natural flushing (Mallin et al., 2000b).

Consider the Use of New Technologies

- Consider the use of innovative treatment technologies, such as UV light disinfection, ozone treatment, and antimicrobial coatings on catch-basin inserts. Several applications of UV light disinfection of urban runoff have been installed at several locations in Southern California to treat stormwater runoff prior to discharge in coastal waters used for swimming and surfing (Rasmus and Weldon 2003).

  Another newly emerging technique for bacterial removal from stormwater is electro-coagulation. The vegetation-based techniques tend to be relatively economical, whereas the technology-based treatment systems can be expensive.

  An ozone treatment system for removing bacteria from urban runoff is being constructed by the Southern California Pacific beach community of Dana Point. In this case, the catchment includes baseflow with naturally high concentrations of manganese and iron (Waye 2004). All of these disinfectant systems are very expensive.

  Another innovative treatment system that has been developed is a catch-basin insert with a special antimicrobial coating. It is currently being investigated for its effectiveness at reducing bacteria from runoff entering storm sewers. The sponge-like device was originally designed to trap oil and other hydrocarbons as they enter the urban storm-drain system. The manufacturer has added an antimicrobial coating to the basic catch-basin insert. This coating is an organo-silane that is bonded to the device and acts as an electrically charged plate to attract negatively charged microbes, such as FC bacteria, puncturing their cell membranes and killing them upon contact. Several municipalities in southern California, including Newport Beach, Long Beach, and Manhattan Beach, as well as the state of New Hampshire have recently installed the anti-microbial version of this catch-basin insert device in storm drains and are conducting field monitoring (Waye 2004).

9.3 Additional Data Needs

More FC samples from stormwater outfalls and streams would enhance the accuracy of FC loading estimations. In addition, better rainfall data (quantity, intensity, and timing of storm events) could help clarify the rainfall-runoff relationship in urbanized watersheds.

Further research is needed in the evaluation of alternative indicators of human pathogens, real-time detection methods for microbial contamination, establishing a better linkage between watershed sources and nearshore water-quality, and developing standardized protocols for bacterial source tracking (Long et al., 2003).

More detailed information on stormwater collection, conveyance, and treatment systems would help in the analysis of stormwater FC sources and levels, including more accurate delineation of urban drainage basins served by engineered stormwater infrastructure.

In many cases, detailed information on the characteristics and condition of wastewater treatment systems (both OWTS and WWTP) is lacking. Basic information on the wastewater treatment system applicable to each parcel should be incorporated into the GIS database.

Because of their potential as sources of resuspended bacterial contamination, freshwater, stormwater, and marine sediments could also be sources of bacterial contamination (Marino and Gannon 1991; Sherer et al., 1992; Weiskel et al., 1996). Currently no sampling of marine sediment has been conducted in the Sinclair-Dyes Inlet watershed, but this should be considered for future sampling efforts.

In many cases, the source(s) of bacterial contamination is not clear. In some situations, it may be desirable or necessary to specifically identify the source(s) of microbial pollution, especially if costly corrective action is required. In these cases, the use MST methods may be warranted (Woodruff and Evans 2003).

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