Whatcom Creek Fecal Coliform Total Maximum Daily Load Study

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Whatcom Creek Fecal Coliform Total Maximum Daily Load Study

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Abstract

Whatcom Creek is located entirely within the city limits of Bellingham, Washington. Whatcom Creek exceeds state water quality criteria for Class A standards as per Chapter 173-201A WAC. In response to these violations, the City of Bellingham voluntarily conducted a Total Maximum Daily Load (TMDL) study for fecal coliform in the Whatcom Creek watershed from January 2002 through February 2003.

Bacterial (fecal coliform and *Escherichia coli*) samples were collected every two weeks for the duration of the study. The study design included sampling five mainstem locations and each of the four tributaries entering Whatcom Creek.

The hydrology of the basin was assessed by the placement of two continuous gauging stations. One station is located below the outflow dam on Lake Whatcom, approximately 2,000 feet from the headwaters of the watershed (Derby Pond). The other station is downstream, located at Dupont Street 100 feet upstream of Whatcom Falls.

Fecal coliform violations of Class A standards were documented during both wet and dry weather patterns. Data generated during this study support the listing of Whatcom Creek on the state's 303(d) list of impaired waterbodies. Pollution is exclusively from diffuse sources (i.e., not municipal or industrial discharges). Potential nonpoint sources of bacteria and other pathogens within Whatcom Creek watershed include stormwater, hobby farms, wildlife, domesticated-pet waste, homeless camps, septic systems, and illegal sewer connections. There has been no attempt in this study to identify individual sources of fecal coliform.

Geometric means and 90^{th} percentiles for bacteria were calculated from the TMDL data. The Statistical Theory of Rollback (Ott, 1995) was applied to determine the percentage of reduction in bacteria loads needed to bring water quality into compliance with water quality standards. Reductions in bacterial loading for the mainstem ranged from 0% to 62%, while tributary reductions ranged from 58% to 88%.

Acknowledgements

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Introduction

Total Maximum Daily Load Overview

Under the federal Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of three parts: 1) designated uses, such as cold water biota and drinking water supply, 2) numeric criteria to protect those uses, and 3) an anti-degradation policy. When a lake, river, or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the waterbody on a list of impaired waterbodies and to prepare an analysis called a Total Maximum Daily Load (TMDL).

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

The goal of a TMDL is to ensure that an impaired waterbody will meet water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and a list of the pollutant sources that cause the problems. The TMDL determines the amount of a given pollutant that can be discharged to a given waterbody and still meet standards. The amount of the pollutant is called the *loading capacity*, and TMDLs allocate that load among the various sources within the watershed. If the pollutant comes from a discrete (point) source, its share of the loading capacity is referred to as a *wasteload allocation*. If the pollutant comes from a diffuse (nonpoint) source, then its share of the loading capacity is referred to as a *load allocation*. All sources that receive coverage under a permit issued pursuant to the National Pollution Discharge Elimination System (NPDES) are by definition point sources.

The TMDL must consider seasonal variations and include either an implicit or explicit margin of safety that accounts for any lack of knowledge about the causes of water quality problems or the waterbody's loading capacity. The sum of the individual allocations and the margin of safety must be equal to or less than the loading capacity.

Basin Overview

Whatcom Creek is located in northwestern Washington State and runs through the City of Bellingham (Figure 1), originating at Lake Whatcom and draining into Bellingham Bay. This urban stream has been listed under Section 303(d) of the federal Clean Water Act as not meeting Class A water quality standards for fecal coliform and temperature.

Whatcom Creek is the only natural surface water outlet of Lake Whatcom, a glacially formed lake located in Whatcom County. Whatcom Creek is 4.3 miles long with a drainage basin of approximately 5,790 acres (City of Bellingham, 1982) which includes four tributaries: Hanna, Cemetery, Fever, and Lincoln creeks.

Lake Whatcom supplies drinking water for more than 85,000 residents in Bellingham and Whatcom County, as well as process water for several industries. The City of Bellingham diverts flow from river mile 7 of the Middle Fork of the Nooksack River into Lake Whatcom. Water is diverted through a tunnel under Bowman Mountain to Mirror Lake. Water from Mirror Lake flows to Lake Whatcom via Anderson Creek. The City of Bellingham operates a control dam at the outfall of Lake Whatcom as it enters Whatcom Creek. Operational considerations include: minimization of downstream flooding, utility storage for water quantity and water quality considerations, and maintaining lake level within the legal limitation to prevent lakefront properties from flooding.

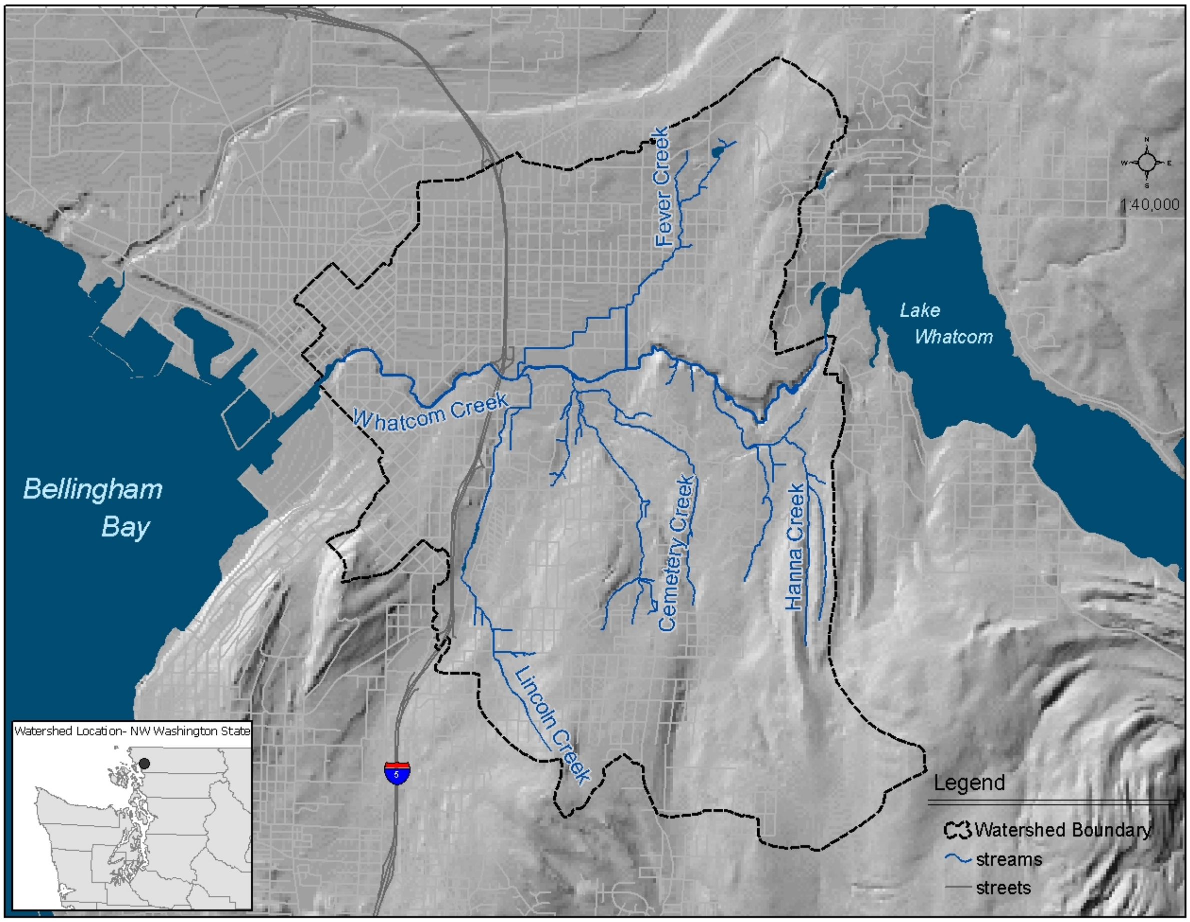

Figure 1. Study area map showing the Whatcom Creek watershed.

Like many municipalities, the City of Bellingham employs Whatcom Creek and its tributaries as part of the stormwater conveyance system. Watershed and resource managers are challenged by the encroachment of development and associated pollutant loads. In areas with a high percentage of impervious surfaces, stormwater runoff is a major source of bacteria pollution in streams. Currently 23.6% of the total Whatcom Creek watershed area is covered with impervious surface.

The flow regime of Whatcom Creek has been heavily impacted by development in the basin and by flood management of Lake Whatcom. The impacts to the creek include channelization and flood control projects, loss of riparian vegetation, channel restrictions from road crossings, and the addition of many point sources of stormwater runoff. A control dam used to regulate Lake Whatcom water levels also regulates the volume of the headwaters entering Whatcom Creek. The creek's artificial flows are managed as a channel for stormwater, flood control, and to maintain desired operational storage in the Lake Whatcom reservoir per utility operational protocols.

Fever and Lincoln creeks are *flashy* due to the basin topography and soil conditions. These conditions are compounded by the increase in imperious surfaces and loss of riparian buffer strips associated with development in these watersheds. Cemetery Creek is comprised of four tributaries that drain residential areas and small wetlands. Fever, Lincoln, and Cemetery creeks are perennial streams that have summer flows with less than one cubic foot per second. Hanna Creek is an intermittent stream that usually goes dry during August and September.

Water Quality Standards

Whatcom Creek and its tributaries are classified as Class A waters as outlined in Chapter 173-201A of the Washington Administrative Code (WAC). Class A waters are considered *excellent*. The water quality standards also designate beneficial uses within classes that water quality criteria are intended to protect. Beneficial uses that apply to Whatcom Creek include water supply, fish and shellfish, wildlife habitat, and recreation. The pertinent fecal coliform criterion is as follows:

Shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10% of samples exceeding 200 organisms/100 mL.

Appendix A contains the freshwater quality portion of the standards for a Class A waterbody, including the characteristic uses and water quality criteria.

Historical Data

Since 1990, the City of Bellingham's Urban Streams Monitoring Program has monitored water quality of Whatcom Creek and its tributaries (City of Bellingham, 2002). The City monitors Whatcom Creek in three locations and has one sampling station on each of the tributaries: Cemetery, Lincoln, Fever, and Hanna creeks. Sampling parameters include temperature dissolved oxygen, pH, conductivity, turbidity, and fecal coliform. Sampling schedules varied from monthly (1990 to 1995) to four times per year (1998) to monthly (2001 to present).

Problem Description

Whatcom Creek is a polluted urban stream system; water quality currently is not meeting standards for fecal coliform bacteria and temperature. Data collected since 1990 by the City of Bellingham's Urban Streams Monitoring Program indicate that bacteria levels have exceeded standards both in Whatcom Creek and its tributaries for several years. Between September 1991 and September 1996, Ecology's ambient water quality monitoring found 3 excursions out of 12 samples in the lower reach of Whatcom Creek. These data led to the listing of Whatcom Creek on Washington's 1998 303(d) list (Ecology, 2002). Table 1 lists the waterbody segment identification numbers for the Whatcom Creek watershed.

Table 1. Ecology's 1998 303(d) listing for Whatcom Creek.

	Waterbody		Parameters	
Name	Old segment ID#	New segment ID#	Temperature	Fecal coliform
Whatcom Creek	WA-01-3110	EZ19GC	Yes	Yes

The City of Bellingham and the Washington State Department of Ecology (Ecology) worked together for this Whatcom Creek TMDL study, splitting responsibilities between the two agencies. The City of Bellingham voluntarily took on the lead. This study supports the 303(d) listing, due to the continued exceedance of fecal coliform bacteria (see Results and Discussion).

Project Objectives

The goal of this TMDL study is to develop a water cleanup plan that will allow Whatcom Creek to meet Class A Washington water quality standards for bacteria. This goal will be achieved by assessing the current conditions and developing recommendations to reduce the loading capacity, while fully supporting all beneficial uses. A monitoring strategy will ensure that the implementation measures are meeting the necessary load reductions to obtain compliance with state water quality standards.

The objectives of this study are to:

1. Characterize seasonal loading of bacteria in Whatcom Creek and its tributaries.
2. Determine the need for additional water quality data by analyzing existing data.
3. Identify potential bacteria source areas to Whatcom Creek and its tributaries that may be contributing to the exceedance of Class A water quality standards for bacteria.
4. Provide information to facilitate recommendation of target allocations and reductions for bacteria in Whatcom Creek and its tributaries.

Methods

Study Plan

The objectives of this project were met through a combination of water quality and discharge data collection, analysis of loading scenarios, and resulting water quality. Data collected from January 2002 through February 2003 were used to assess possible sources and seasonal variation of bacterial loading in Whatcom Creek.

Fecal coliform bacteria surveys and discharge measurements were conducted every two weeks from January 2002 through February 2003. The City of Bellingham Environmental Resources Division conducted the field sampling while the City of Bellingham state accredited laboratory (COB-POTW) conducted the bacterial analysis of the samples. Both Ecology's Bellingham Field Office and the City of Bellingham Environmental Resources Division modeled and analyzed loading scenarios.

Sampling Sites

The monitoring network for fecal coliform surveys consisted of five mainstem sites and four tributary sites (Figure 2). Sites were selected based on hydrological and bacterial significance, with consideration given to long-term monitoring stations. To assess the loading from the entire sub-basin, each of the four tributary sampling sites were located as close as possible to the confluence of Whatcom Creek. Determining the location of stations was based on the criteria described in Ecology's Watershed Assessments Section Protocols (WAS, 1993). Descriptions of sample site locations, latitude and longitude coordinates, and the associated sub-basin land cover breakdowns are presented in Appendix B.

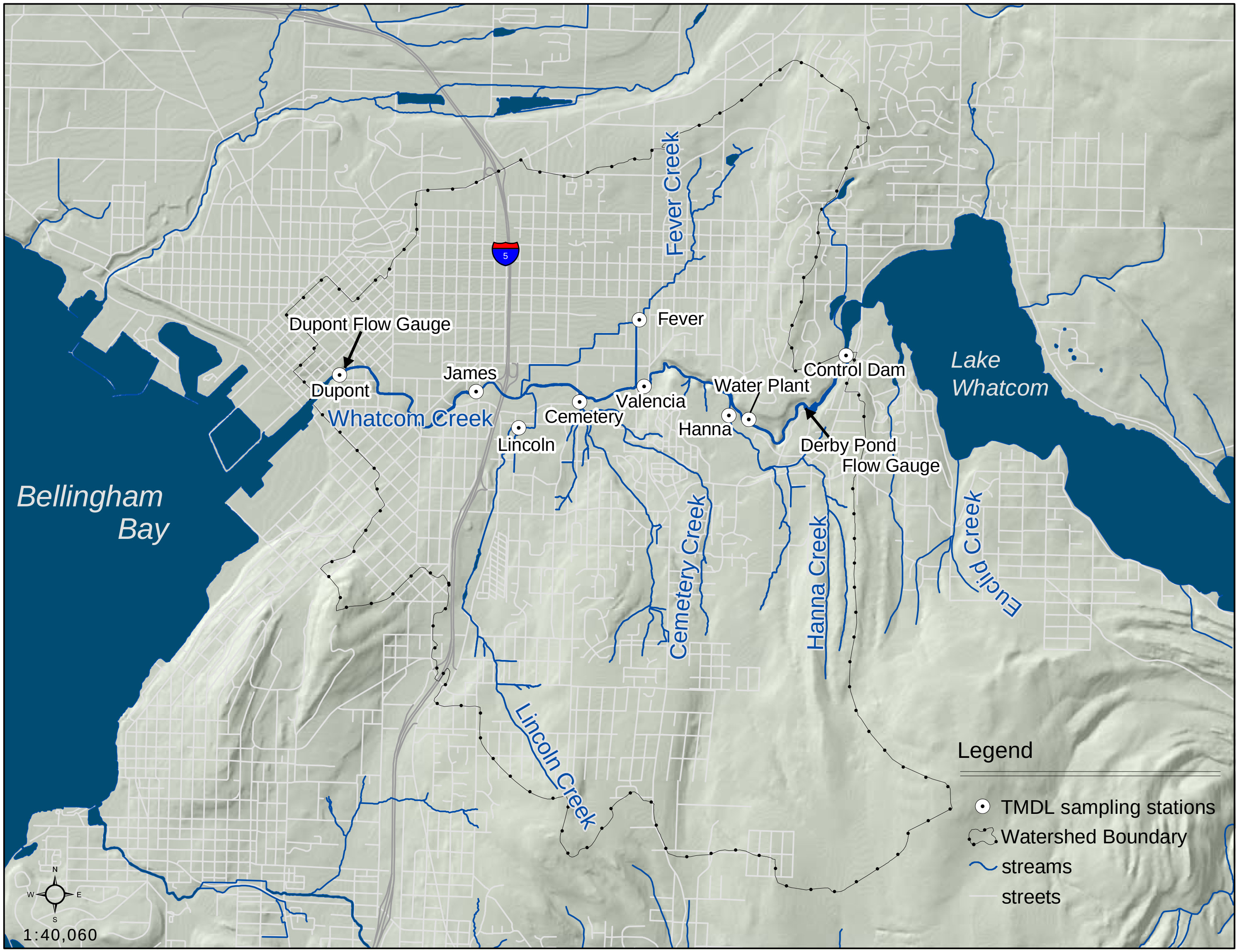

Figure 2. Whatcom Creek fecal coliform TMDL sampling stations and flow gauges.

Data Analysis

Sample measurement and collection followed Ecology's Watershed Assessments Section Protocols (WAS, 1993). The fecal coliform and *E. coli* samples were collected at wrist-depth and placed directly into pre-cleaned, sterile 250-ml bottles. The samples were immediately stored on ice in the dark and were transported to the COB-POTW. The COB-POTW is a state-accredited laboratory that meets the standards for precision and accuracy cited in the reference method for each procedure. Table 2 lists the analytical and preservation methods for fecal coliform field samples as well as field measurement target detection limits and methods. Analysis for fecal coliform and *E. coli* was performed in the event that Ecology changes the bacterial standards from fecal coliform to *E. coli* during this study (WQP, 1999).

Table 2. Analytical and preservation methods for bacterial analysis.

Sample analysis	Sample type	Methods[1,2]	Description	Preservation	Holding times	Detection limit
Fecal coliforms	Grab	SM 9222 D	Membrane filter	Refrigerate (4ºC)	24 hour	1 cfu/100 ml
E. coli	Grab	SM 9223 B	Most probable number	Refrigerate (4ºC)	24 hour	2 MPN/100 ml
E. coli	Grab	SM 9213 D	Membrane filter	Refrigerate (4ºC)	24 hour	1 cfu/100 ml

[1] SM: Standard Methods for the Examination of Water and Wastewater, 20th Edition (SM, 1998)
[2] EPA: EPA/821/R-97/004, March 2000. Improved Enumeration Methods for Recreational Water Quality Indicators: Enterococci and *Escherichia coli*.

Continuous discharge measurements were recorded at two sites on the mainstem, one at the outflow of Lake Whatcom about 2,000 feet down Whatcom Creek (Derby Pond) and one before the estuary above the falls at Dupont Street Bridge (Dupont Street). Sutron data loggers and pressure transducers recorded stage height data at 15-minute intervals. Flow was measured over a range of discharges to allow development of rating curves at both stations.

Stage height was measured from installed staff gauges at all mainstem locations. At monitoring sites where flow measurements were possible, discharge was determined during sampling events. Calculations of discharge followed the protocols described in the WAS manual and USGS protocols (USGS, 1982). The Valencia Street station was the only mainstem location where stage height to streamflow relationships were possible for creating a rating curve.

Daily discharge estimates for tributary sites were accomplished by developing statistical relationships between point-in-time discharge measurements with instantaneous measurements taken on a USGS monitoring station on Euclid Creek. A simple comparison of gross area was used to calculate flow budgets for tributaries in the Whatcom Creek TMDL. The flow measurements from Euclid Creek were extrapolated to the different basins based on the size of the sub-basins compared to the area of Euclid. For instance, Fever Creek flows were estimated by multiplying Euclid flows by 2.393819 (ratio of Fever/Euclid area). Appendix D contains a summary of flow conditions during the study as well as graphical representations comparing tributary measured flow taken at time of sampling to predicted flow (Euclid flow data at the same time).

TMDL survey data were loaded directly into a Microsoft EXCEL workbook. Field data were entered into EXCEL spreadsheets. City of Bellingham staff reviewed all data to ensure internal quality assurance.

Quality Assurance and Quality Control

Bacteria samples have an increased inherent pattern of variability compared with other water quality parameters. Bacterial populations have a patchy distribution in the environment, and discharge rates affect the density in samples. Standardized field sampling, holding times, and handling procedures were used to reduce variability.

To determine acceptable levels of variability between the two bacterial indicator groups used in this study, field and laboratory duplicates were analyzed to determine the precision of the data. Field replicates were collected at a rate of 10% per survey day, and lab duplicates were run at a rate of 10%. All stations were sampled in replicate to assess total variability of the analysis. Field and laboratory duplicate data are summarized in Appendix C. Both field and laboratory duplicates have a root mean square coefficient of variation of 26% (Figures 3 and 4).

Both field and laboratory duplicates met the standards for variability put forth in the Whatcom Creek Watershed Bacterial TMDL Quality Assurance (QA) Project Plan (City of Bellingham, 2001). Other recent fecal coliform TMDL studies by Seiders et al. (2001) and Joy (2000) found similar variability for replicate samples. Therefore the levels of variation found in this study are deemed acceptable based on other TMDL results.

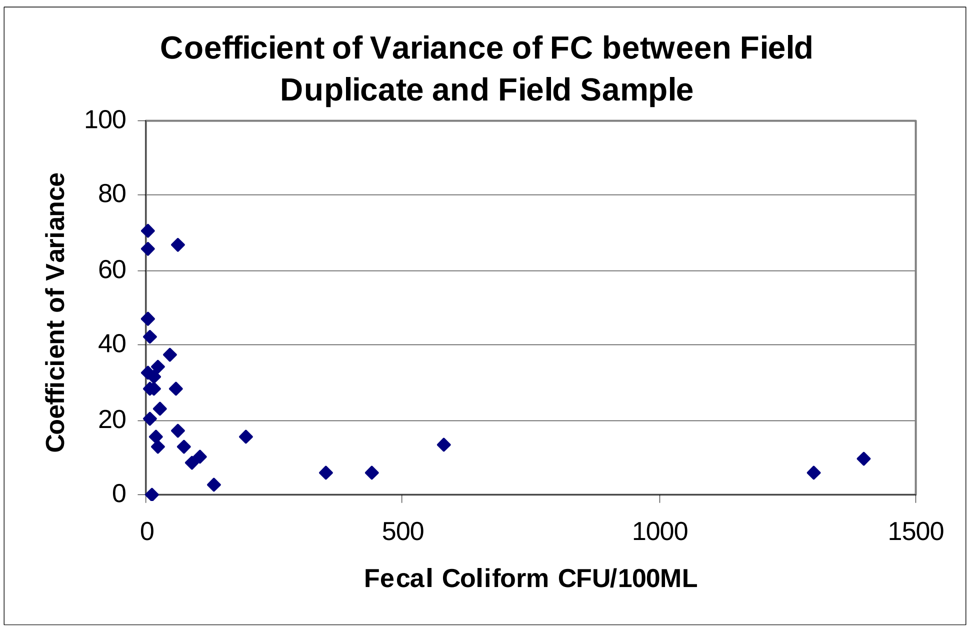

Figure 3. Coefficient of variation for fecal coliform field replicates. Root mean square coefficient of variation (RMSCV) = 26%.

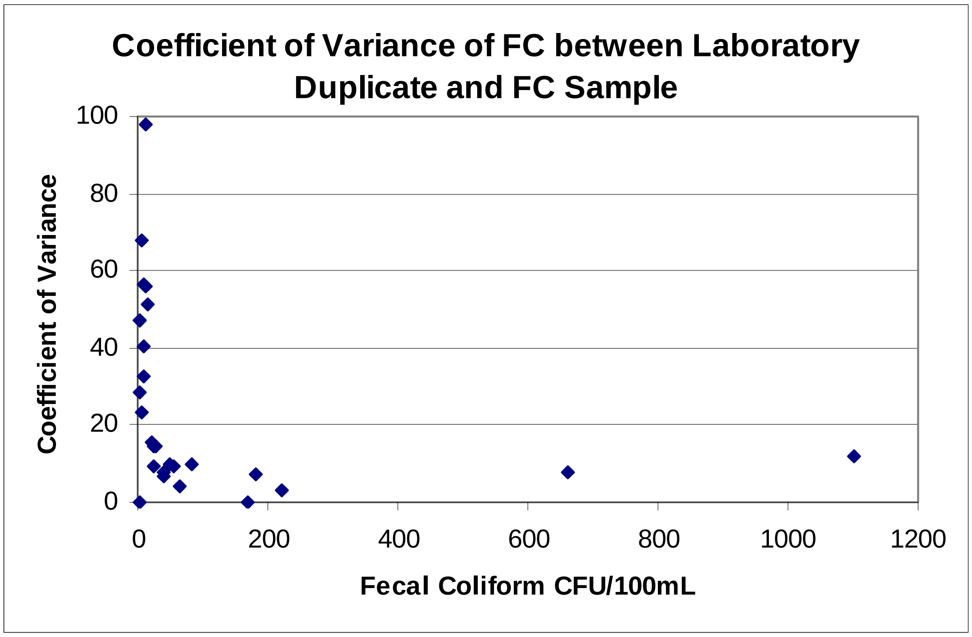

Figure 4. Coefficient of variation for fecal coliform laboratory replicates. RMSCV = 26%.

Completion

The initial QA Project Plan had identified 14 sampling stations throughout the Whatcom Creek watershed for fecal coliform collection and analysis. Since the characterization of the watershed could be obtained with fewer sampling stations and staff resources were limited, sample stations were reduced to 9 stations. The final project design included five mainstem stations and four tributary stations. The goal of sampling stations twice per month throughout the duration of the study was successfully accomplished. All stations were sampled 31 times. Hanna Creek was dry for three sampling dates, reducing the total samples collected for Hanna Creek to 28. Results from the fecal coliform sampling are shown in Appendix B. All samples met handling and storage guidelines, and all samples were successfully analyzed at the COB-POTW.

The initial Whatcom Creek Watershed Bacteria TMDL Quality Assurance Project Plan (City of Bellingham, 2001) also recommended sampling during five storm events and first-flush events. Due to the El Niño weather patterns and limited staff resources, only three storm events were sampled. Both Fever Creek and Cemetery Creek had additional bacteria samples collected on four separate days to attempt to identify hot spots or sub-basin loading patterns. These studies replaced the *pipe* studies proposed for Fever and Lincoln creeks.

Historical data

The City of Bellingham Urban Streams Program has been collecting water quality data since 1990. Fecal coliform data generated from this program were compiled and analyzed with the TMDL-generated data. Fecal coliform data from 1995 through 2002 were checked for compatibility with TMDL data. Both data sets used the same methodology for analyzing samples (SM 9222 D), and the Urban Streams Monitoring Program sampled six of the nine TMDL stations. Samples collected during historic surveys yielded statistics similar to TMDL monitoring data (Table 3). Graphing a rolling geometric mean of five samples shows that the data generated in the TMDL are to scale with historical data (Figure 5.). Conversely, historical data show that no marked improvements or declines in fecal coliform concentrations have occurred in the watershed.

Table 3. Whatcom Creek TMDL fecal coliform results paired with the City of Bellingham's Urban Streams Monitoring Program's historical fecal coliform data.

Station	Dupont TMDL	Dupont pre-TMDL	James TMDL	Lincoln TMDL	Lincoln pre-TMDL	Cemetery TMDL	Cemetery pre-TMDL	Valencia TMDL
Mean	220	304	111	373	516	1,196	689	23
Median	84	125	42	190	118	88	153	13
Mode	12	13	19	140	800	39	40	4
90 Percentile	647	522	235	1211	931	1,622	1,330	53
Standard deviation	442	607	210	499	1098	3,503	1,688	26
Geometric Mean	93	101	44	138	125	159	174	14
N	31	60	31	31	59	31	60	31

Station	Fever TMDL	Fever pre-TMDL	Water Plant TMDL	Hanna TMDL	Hanna pre-TMDL	Control Dam TMDL	Control Dam pre-TMDL	
Mean	2,001	826	26	129	185	18	56	
Median	230	257	11	42	84	8	30	
Mode	120	14	2	120	120	4	4	
90 Percentile	1,918	1,480	61	361	208	107	106	
Standard deviation	8,558	1,662	41	218	384	24	76	
Geometric Mean	268	276	11	45	59	18	27	
N	31	59	31	28	14	31	60	

Numbers are colony forming units/100mL

Analytical Method = SM 9222 D

Historical data were collected for the City of Bellingham Urban Streams Monitoring Report from January 1995 to December 2002

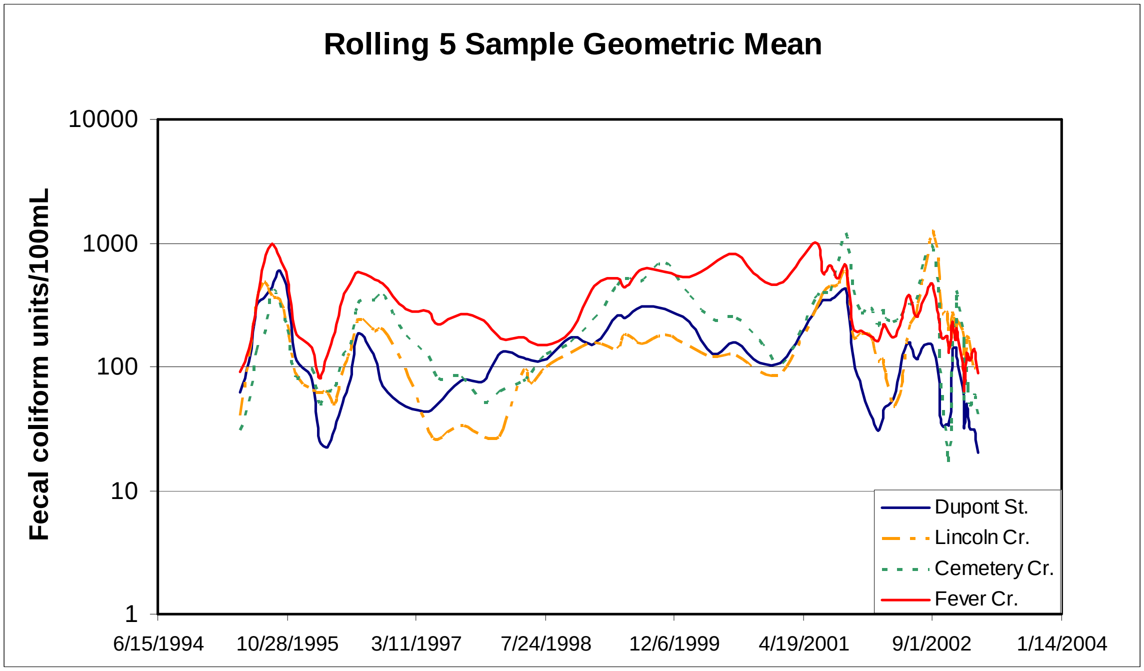

Figure 5. Combined historical fecal coliform data from the City of Bellingham's Urban Stream Report and the Whatcom Creek TMDL study. Lines represent the rolling 5 sample geometric mean values.

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Results and Discussion

Source of Pollution

Potential nonpoint sources of bacteria and other pathogens within the Whatcom Creek watershed include stormwater, hobby farms, wildlife, domesticated-pet waste, septic systems, illegal sewer connections, and homeless camps. Large hobby farms are rare in the watershed, although many residents have a horse, cow, goat, and/or a few chickens. Septic systems can contribute bacterial contamination to streams through surface or groundwater flows when they are improperly installed, improperly located, inadequately sized, and when systems are not maintained or are failing. Pets and waterfowl are primary sources of bacteria conveyed by stormwater runoff in urbanized areas (Glenn, 2001). The watershed does have many older homes, some of which were probably never hooked up to the sanitary sewer and may still be draining directly into creeks. There has been no attempt under this study to identify individual sources of fecal coliform (FC); the goals of the study were to assess loading and to identify potential sources.

The special samples collected on Cemetery and Fever creeks were run to attempt to identify specific hot spots in each of the watersheds. Fever was sampled on two days at four additional sampling locations. The results were inconclusive showing a steady loading of FC concentrations as the sampling went downstream. Cemetery Creek had five additional stations sampled on two days to identify loading hot spots within the sub-basin. The results were also inconclusive, showing a steady loading of FC concentrations as sampling went downstream.

There are four facilities with National Pollution Discharge Elimination System (NPDES) permits discharging into the Whatcom Creek watershed (Table 4). One permit is for industrial discharges and three are for stormwater discharges. Olympic Pipeline's NPDES discharges directly to the sanitary sewer system. There are no permitted wastewater treatment plants in Whatcom Creek or its tributaries.

Table 4. NPDES permits for the Whatcom Creek watershed.

Name Of Facility	Permit No.	Type	Discharges Into	Pollutant
Brooks Manufacturing	WA0030805B	Industrial	Fever Creek via drainage ditch	PCPs, PAHs, oil & grease
Olympic Pipeline Company	ST0007420A	Wastewater	POTW via sewers	BTEX, TPH-G, Pb
WDFW Bellingham Hatchery	WA0031500A	Industrial	Whatcom Creek & POTW	hatchery
Whatcom County Rd. Sewerage Interceptor	SO30003633B	Stormwater	Hanna Creek	sediment
Wholesale Auto	SO3001496B	Stormwater	Whatcom Creek via Fever Creek	petroleum products

Code to permit authority based on first character of permit number:
WA = Federal program; ST = State program; SO = Stormwater

POTW = publicly operated treatment works

Bacterial Comparisons

Fecal coliform (FC) is typically found within the digestive systems of warm-blooded animals. These organisms are indicators of a potential public health risk, as their presence highlights the possibility that other harmful pathogens may be present. During this study, samples were analyzed for both FC and *Escherichia coli* (*E. coli)*. Current numeric criteria exist for FC, but during this study Ecology had proposed changing the bacterial surface water standards from FC to *E. coli*. While awaiting a decision on the proposed changes to surface water bacterial standards, it was hoped that a ratio of FC to *E. coli* could be established. The FC results from this TMDL study are listed in Appendix B. FC samples were analyzed using the membrane filter (MF) method. Duplicate *E. coli* samples were run in conjunction with the FC analysis. *E. coli* samples were analyzed with both most probable number (MPN) and MF methods. On August 27, 2003, the laboratory methods of analysis for *E. coli* samples switched from MPN to MF.

When examining the relationship between *E. coli* and FC, conventional wisdom is that comparison should be done with the similar methodologies. Comparison of the relationship between FC and *E. coli* samples using the two enumeration methodologies found a higher correlation with the MPN method, which is to be expected since the MF method underestimates the number of viable bacteria present in a sample verses the MPN method. Supporting the assumption that the *E. coli* levels would be slightly lower than FC levels because both *E. coli* methods are enumerating one species verses the two additional enteric species represented by FC methodology. Both methods were significantly correlated with their fecal coliform MF companion (MPN *E. coli* r^2 =0.856 and MF *E. coli* r^2 =0.736) and are graphically displayed in Appendix C. Grouping both MPN and MF *E. coli* samples with FC samples showed correlation (Figure 6.). In this study the ratio between FC and *E. coli* is 1: 0.95.

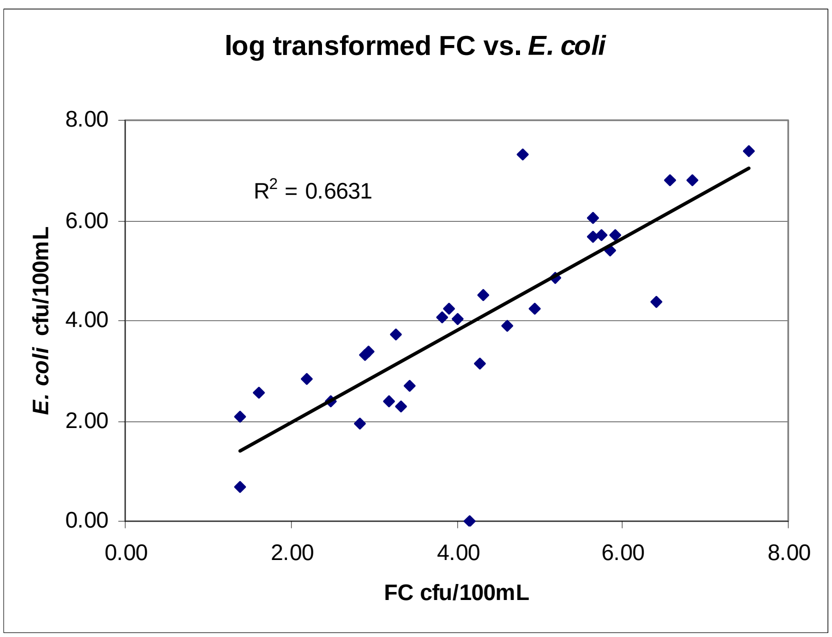

Figure 6. A comparison of paired fecal coliform and *E. coli* sample results collected from various samples during the Whatcom Creek bacteria assessment.

Seasonal Variation

Fecal coliform sample dates and associated concentrations were broken into three climate conditions to assess critical conditions. Dry and wet seasons are clearly defined by average rainfall data. The third climate condition is defined as a storm event when rainfall was equal to or greater than 0.5 inches in 24 hours. The dry season range is from the beginning of May to the end of October, and the wet season range is from the beginning of November to the end of April. Geomean exceedances occur in both wet and dry seasons, with higher geomeans occurring in the dry months. The higher concentrations during the dry season can be explained by reduced flows that limit the dilution of samples, and also highlight a FC source that is not stormwater dependent. Storm event results show the highest FC concentrations. The loading response to rainfall is expected due to the high amount of impervious surface and urban development in the basin. Schueler (1999) found that developed watersheds almost always had greater FC concentrations than underdeveloped watersheds. Increased water velocities can cause the resuspension of bacterial contaminants in detention ponds, catch basins, and creek sediments (Pitt, 1998; Burton *et al*., 1987).

The hydrology of Whatcom Creek is greatly influenced by the management of Lake Whatcom water levels, and assessing bacterial loading in terms of seasonal weather patterns is often masked by the anthropogenic control of creek volumes. Analyzing flow data with FC grab samples shows little or no correlation between concentration and flow. Figure 7 shows an example of FC versus flow for the Dupont sampling site. Graphs showing FC versus flow for the other sites using actual or estimated flows are in Appendix E.

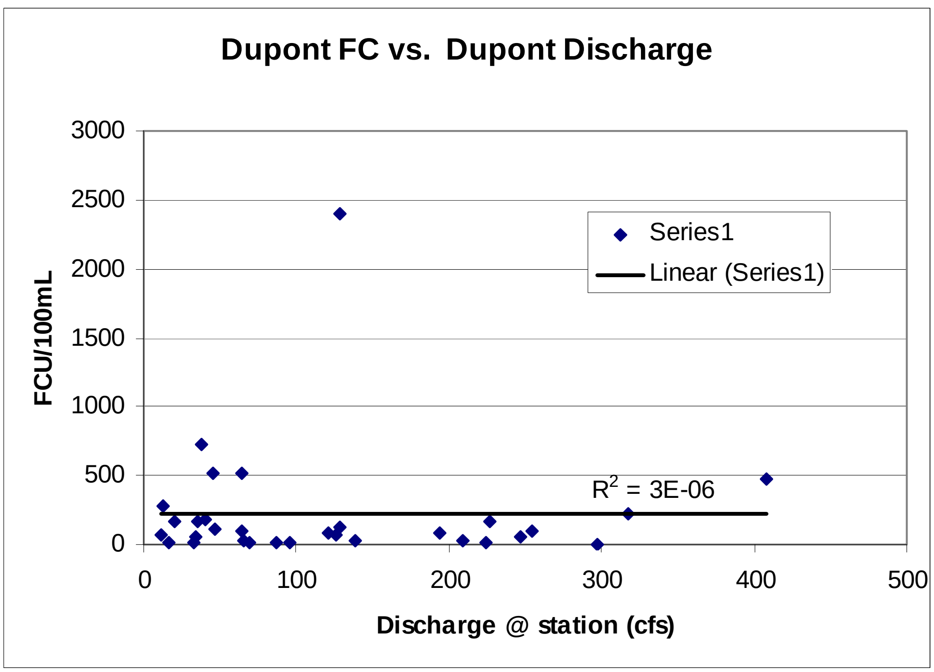

Figure 7. Fecal coliform concentrations compared with discharge at time of sample.

Fecal coliform data collected in the Whatcom Creek watershed do not show a significant pattern of seasonal variation. Fecal coliform violations have been observed in winter and summer months during both wet and dry climate conditions. These results rule out any single climatic season to be considered a critical condition. Therefore, this TMDL loading analysis must encompass the entire year, and address the possibility of multiple bacterial sources with varying delivery and transport mechanisms.

Loading Capacity

One of the objectives for this study is to identify the bacterial load reductions needed to ensure the waterbody meets state standards. Before a loading analysis can be performed, the routing and balance of water must be calculated for the basin. A water balance was calculated to show the average discharge characteristics for the Whatcom Creek watershed during the 2002-2003 TMDL survey period (Figure 8.). Gage records from the mainstem, and simulated hydrographs for the tributaries based on basin area, were developed with the continuous gauge at Euclid Creek (see Data Analysis). Appendix D contains summary statistics for the Dupont Street flows recorded during this study. The Control Dam (Derby Pond flow monitoring station) average flow is based on January 22, 2002 to December 10, 2002 because of limited record due to equipment failure. The major contributor and controlling factor to the basin hydrology is the amount of water released or restricted from the control dam on Lake Whatcom; during this study period, flows from the lake accounted for 93.4% of the total flow.

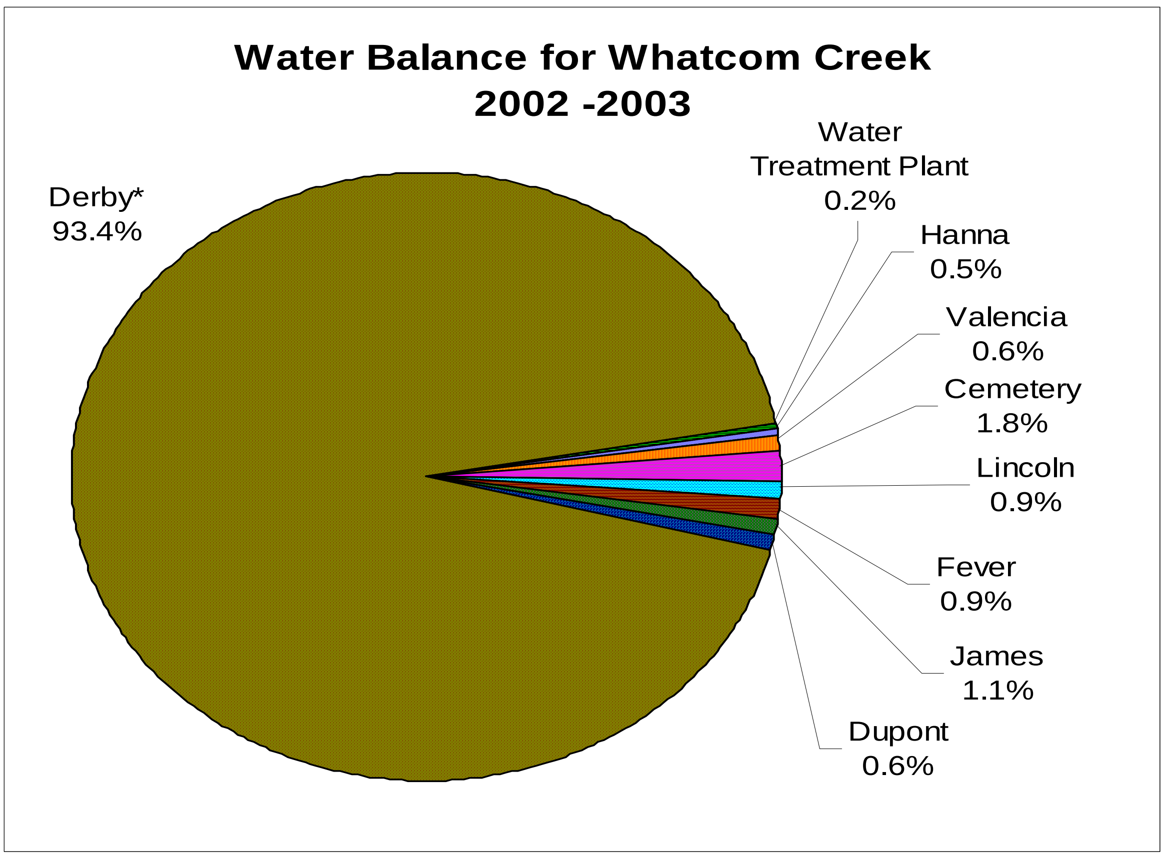

Figure 8. Estimated annual discharge contributions of sub-basins to Whatcom Creek from January 22, 2002 to December 10, 2002.

Fecal coliform densities were multiplied by discharge measurements or estimated flow volumes to determine FC loading. Fecal coliform loads were calculated with the entire TMDL database including routine and storm event sampling. Even though the FC concentration from tributaries were the highest in this study, the resulting loading from the tributaries was relatively minor compared with mainstem loading, which is expected from the limited amount of flow each of the tributaries contributes to the total water balance of the basin. For instance Fever, Lincoln, and Cemetery creeks have the largest geometric means in the study, yet each accounts for less than 3% of the total load for the watershed. The lower basin (below Valencia Street station) accounted for 80% of the total loading. Fecal coliform loads show no correlation with either land area or impervious surface.

Fecal coliform decay rates appear to be minimal or non-existent in the watershed. If FC die-offs were substantial in the watershed, then a reduction in concentrations or loading would be demonstrated moving downstream in the watershed. In contrast, the data indicates very low FC die-off rates or significant FC sources without substantial surface water flow.

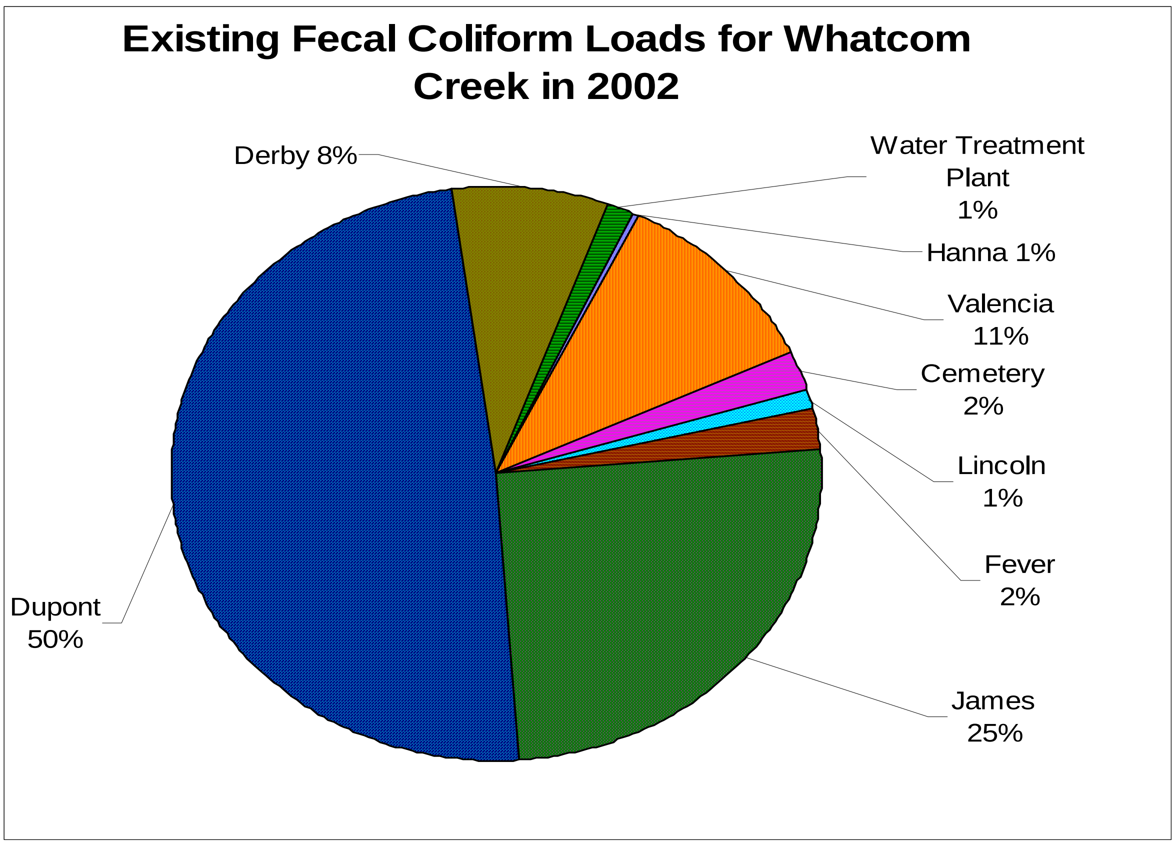

Figure 9. Estimated average percentage of fecal coliform loading for Whatcom Creek from January 2002 to February 2003.

The Statistical Theory of Rollback (Ott, 1995) was used to calculate target geometric means and percentage reductions for this TMDL. The statistical rollback method describes a way to use the statistical characteristics of FC results; to estimate the distribution of future results after abatement processes are applied to sources. To determine the percentage reduction needed for compliance, the more restrictive of the two criteria was selected. The 90th percentile criterion was identified as the most restrictive in this TMDL. Then a target geometric mean was generated for each site. The target geometric mean of future FC data for each station must be equal to or less than the appropriate target value to ensure water quality standards are being met.

Target percentage reduction values range from zero to 88% for the entire watershed. It is apparent that significant FC reductions are needed to meet standards. The statistical rollback method used to establish the target geometric means for the concentration-based allocations provides a more restrictive geometric mean count than the Class A geometric mean criteria. The extremely high values generated under the 90th percentile means that the geometric means of all future sampling must, in turn, be extremely low in order to meet the percent exceedance part of the criteria (200 colonies/100 ml) in the water quality standards. Table 5 shows the needed reductions for each station in the watershed.

Table 5. Whatcom Creek summary statistics for fecal coliform (FC) concentrations and required reductions.

Station ID	No. of Samples	Minimum FC cfu/100mL	Maximum FC cfu/100mL	Geo-metric Mean	90th Percentile	Target Geo Mean	Target 90th Percentiles	Required % Reduction
Dupont St.	31	4	2400	93	647	29	200	62
James St.	31	5	1100	44	235	38	200	14
Lincoln Cr.	31	5	2100	138	1211	23	200	78
Cemetery Cr.	31	6	18000	159	1622	20	200	86
Valencia St	31	2	120	14	53	14	50	0
Fever Cr.	31	14	48000	268	1918	28	200	88
Water Plant	31	<1	170	11	61	11	54	0
Hanna Cr.	28	1	740	45	361	25	200	58
Control Dam	31	<1	98	18	107	18	90	0

Load and Wasteload Allocations

An allocation is defined as the portion of the receiving water loading capacity that is attributed either to one of its existing or future sources of pollution, or to natural background sources. The pollutant loading allocation assigned to a particular point source is termed wasteload allocation (WLA), and that assigned to a nonpoint source is termed load allocation (LA). Fecal coliform concentrations are reported in units of “colonies per unit volume”, which does not translate easily into units of mass per unit time. Federal regulations allow TMDLs to be expressed in “other appropriate measures” (40 CFR 130.2(I)). The WLA and LA for fecal coliform in the Whatcom Creek TMDL will be expressed as a percent reduction. The percent reduction allocated will be that necessary to reduce the geometric mean and 90th percentile values by the same percentage such that both will be less than or equal to the numeric criteria.

The method used to split the WLA from the LA will be a unit area allocation. That is, each unit area is assumed to contribute the same quantity of the pollutant and the same quantity of water as other units of area in the watershed. Due to the lack of information discerning point and nonpoint sources, it is recommended that equal allocations be made for each source type based on area.

The TMDL defines sub-basins as that tributary to a particular sampling station. Under the unit area allocation method, it is assumed that each acre in a sub-basin will need the same load reduction as calculated at the sampling station, and so receives the same unit allocation. The mechanism for implementing this allocation is through use of the Target Geometric Mean (see Table 5) as a measure of the loading coming from any individual site. In all cases, the percent reduction required to meet the 90^{th} percentile criterion results in a geometric mean more stringent than the geometric mean criterion in the water quality standards.

As land use analysis is performed that can distinguish point source areas from nonpoint source areas, this information will be incorporated into future allocations. As NPDES permits are written or revised to implement the TMDL, they will be conditioned to implement a target geometric mean as established in this TMDL. By meeting the target geometric mean it is assumed the percentage reduction allocation will have been met. The FC wasteload allocation in the Whatcom Creek TMDL is inherent in the target geometric mean and percent reduction at the station immediately downstream from the site in question. These reductions represent concentrations that will not exceed water quality criteria for fecal coliform bacteria.

The diffuse sources of bacteria in Whatcom Creek would ordinarily be considered nonpoint sources. A memorandum from EPA's Office of Water (EPA, 2002) clarified regulatory requirements stating that all NPDES-regulated stormwater discharges must be addressed by the wasteload allocation component of a TMDL. Further, the United States Supreme Court defined a point source in the South Florida Water Management District, Petitioner v. Miccosukee Tribe of Indians ET AL (No. 02-626). *"Under the Clean Water Act's National Pollutant Discharge Elimination System dischargers must obtain permits to limit the type and quantity of pollutants they can release into the Nations waters."* The act defined a discharge of a pollutant as any addition of any pollutant to navigable waters from any point source, and defined point source as any discernible, confined, and discrete conveyance. Therefore, stormwater runoff that enters City of Bellingham facilities will soon fall under the jurisdiction of the city's Phase II NPDES permits and be given a WLA under this TMDL.

Estimating urban stormwater loads is complicated due to the variability in available data and the costs and uncertainties associated with source identification techniques. As of the 2002 EPA memorandum, all NPDES permits must be given a numeric allocation in a watershed with a TMDL. The numeric WLA and LA can be implemented as a Water Quality Based Effluent Limitation in the NPDES permit in a non-numeric manner, usually expressed in the form of best management practices (BMPs) (40 CFR 122.44(k)). The narrative limitations are most appropriate when there are numerous diffuse, non-continuous sources and when individual contributions are difficult to identify and model, such as in the Whatcom Creek watershed.

Under this approach, EPA suggests that the narrative limitations should require the implementation and enforcement of BMPs, monitoring, and adaptive management. Adaptive management will call for BMP modification if effective monitoring determines that standards are not being achieved. Consistent with this approach, the fecal coliform LA and WLA of Whatcom

Creek is inherent in the target geometric mean at each station in the watershed to ensure loads do not exceed water quality standards for fecal coliform.

Margin of Safety

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

- The statistical rollback method used to establish the target geometric means for the concentration-based allocations provides a more restrictive geometric mean count than the Class A geometric mean criteria. The extremely high values generated under the 90th percentile mean that the geometric means of all future FC counts must, in turn, be relatively low in order to meet the percent exceedance part of the criteria (200 colonies/100 ml) in the water quality standards.

- The loading equations and calculations for the target assume there is no FC decay rate in the watershed (i.e., all FC bacteria entering the river from tributaries or nonpoint sources will stay alive and suspended in the water column to the mouth of the creek).

- The adaptive management process of responding to monitoring results provides an implicit margin of safety because compliance can be determined for each station in the watershed and source control measures will have a cumulative effect downstream.

Adaptive Management

The adaptive management approach is planned for the Whatcom Creek TMDL. As the TMDL process moves forward, the City of Bellingham will continue its ambient water quality monitoring in the watershed. Additional water quality sampling will also be used to identify bacterial sources and specific areas of excessive FC loading. These data will provide the necessary information for developing site-specific source controls and implementation strategies. As information pertinent to the source of FC contamination is identified, it will be corrected through the appropriate control measures and regulatory agencies. This sampling will include all sub-watersheds because little is known beyond the sampling stations set near the confluence with Whatcom Creek. Understanding the loading scenarios in these sub-watersheds will be needed to ensure water quality standards are met for this TMDL

The unit area allocation as defined in the allocation section will also require an adaptive management component. As land use changes in the watershed, the allocation unit will require permitting adjustments to reflect these changes. These changes will need to be regulated until Whatcom Creek meets state water quality standards or meets the necessary reductions set forth in this TMDL.

Monitoring

Another required component of the TMDL process is the development of a monitoring plan. A monitoring program should be designed to provide assurance that source controls are effective at reducing bacterial loads for compliance with water quality standards. The plan needs to include a combination of source identification monitoring, source control and BMP effectiveness monitoring, as well as long-term monitoring. Using this approach, limited resources will be used efficiently to identify the cause of pollution while providing vital information on how to control these sources. The progress of meeting water quality standards can be tracked with ambient and long-term monitoring, and will provide information for the adaptive management process.

Fecal coliform violations occur in all seasons under different climate conditions; therefore, monitoring should occur throughout the year. A monitoring program should also encompass storm events so a complete loading evaluation would be accomplished. Ecology has also ruled that fecal coliform will remain as the bacterial indicator for state standards. Therefore, future monitoring should focus on the collection, identification, and modeling of FC bacteria. If the monitoring data are deemed inadequate, the Bellingham Field Office and Northwest Regional Office need to request additional data collection, or support coordination and collection of additional data.

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Conclusions and Recommendations

Conclusions

- Whatcom Creek violates Class A water quality standards for fecal coliform bacteria and temperature. These fecal coliform violations have been observed in winter and summer months during both wet and dry climate conditions.
- The recommended TMDL reductions are established in the form of fecal coliform target percentage reductions and target geometric means for all watershed stations (see Table 5).

Recommendations

- Continue and expand the current Whatcom Creek watershed nonpoint pollution educational outreach programs.
- Concurrent with the development of the TMDL Summary Implementation Strategy, initiate a bacteria source assessment and control program for septic system failures and illegal sewer connections.
- Identify other potential bacteria loading sources by completing a land-use analysis of the watershed.
- Develop a long-term monitoring strategy for assessing the effectiveness of source control measures at reducing bacteria levels in Whatcom Creek.
- Identify and apply for outside funding sources that can be used to support the watershed cleanup plan and effectiveness monitoring strategy for Whatcom Creek.

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Appendices

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Appendix A

Washington State surface water quality standards for Class A freshwater

Table 1. Surface water quality standards for Class A freshwater (Chapter 173-201A WAC).

Class A (excellent).

General Characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

Characteristic Uses. Characteristic uses shall include, but not limited to, the following:
Stock watering.
Fish and shellfish:

- Salmonid migration, rearing, spawning, and harvesting.
- Other fish migration, rearing, spawning, and harvesting.
- Clam, oyster, and mussel rearing, spawning and harvesting.
- Crustaceans and other shellfish (e.g., crabs, shrimp, crayfish, scallops) rearing, spawning and harvesting.

Wildlife habitat.
Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).
Commerce and navigation.

Water Quality Criteria:

Fecal coliform organisms: Freshwater - fecal coliform organisms levels shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10% of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.

Dissolved oxygen: Freshwater – dissolved oxygen shall exceed 8.0 mg/L.

Total dissolved gas shall not exceed 110% of saturation at any point of sample collection.

Temperature shall not exceed 18.0°C (freshwater) due to human activities. When natural conditions exceed 18.0°C (freshwater), no temperature increases will be allowed which raises the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=28/(T+7) (freshwater). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.

pH shall be within the range of 6.5 to 8.5 (freshwater) with a human-caused variation within the above range of less than 0.5 units.

Turbidity shall not exceed 5 NTU over the background turbidity when the background turbidity is 50 NTU or less, or have more than 10% increase in turbidity when the background turbidity is more than 50 NTU.

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

Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

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Appendix B

Sampling site descriptions and fecal coliform concentration results

Table B-1. Descriptions of Whatcom Creek Bacterial TMDL sampling stations and associated sub-basin land cover breakdowns.

Station_ID	Dupont	James	Lincoln	Cemetery	Fever	Valencia	Hanna	Water Plant	Control D
Waterbody	Whatcom Cr.	Whatcom Cr.	Lincoln Cr.	Cemetery Cr.	Fever Cr.	Whatcom Cr.	Hanna Cr.	Whatcom Cr.	Whatcom Cr.
WRIA #	01-0566	01-0566	01-0567	01-0569	no ID #	01-0566	no ID #	01-0566	01-0566
Samples	31	31	31	31	31	31	28	31	31
Eastings	538229.06	539397.39	539769.47	540283.37	540770.8	540828.88	541557.81	541727.21	542541.93
Northings	5400181.33	5400074.17	5399774.64	5400008.69	5400725.5	5400156.45	5399929.8	5399900.24	5400469.8
Sampling Area/stat	549	944	759	1547	809.47	552	447	160	0.04
Cum.Sampling Area	5768*	5219	NA	NA	NA	1160	NA	160	0.04
Total Basin Area	5788	5788	874	1587	1219	5788	589	5788	5788
Basin Percent IMP	15.0%	15.0%	14.0%	7.0%	19.0%	15.0%	6.0%	15.0%	15.0%
% Impervious/stat	42.4%	15.4%	14.4%	6.8%	19.8%	2.6%	7.9%	4.8%	0.0%
Cum. Road Crossing	88	78	NA	NA	NA	14	NA	0	0
Road Crossing/stat	10	11	15	29	10	1	13	0	0

Area = acres
/stat = includes variables from sampling location upstream to the previous sample location
* = difference between Cum. Sampling Area and Total Basin Area is due to the fact the area downstream is not collected in this sample
Flow accumulation is calculated from USGS 10 meter Digital Elevation Models (DEM)

Table B-2. Fecal coliform results from the 2002 & 2003 Whatcom Creek TMDL.

Date	Dupont ~	James ~	Lincoln Creek	Cemetery Creek	Fever Creek.	Valencia ~	Hanna Creek	Water Plant ~	Control D ~
1/23/02	60	96	340	310	1900	22	120	18	48
2/6/02	56	76	100	120	60	13	44	12	12
2/19/02	164	26	5	88	120	24	21	8	19
2/21/02 *	470	370	360	1400	1650	37	620	47	27
3/5/02	22	32	24	30	140	26	9	12	20
3/18/02	12	72	12	14	48000	4	46	11	8
4/2/02	720	6	17	39	170	2	18	1	3
4/23/02	82	19	130	95	110	9	43	3	3
5/7/02	32	21	180	110	260	22	14	11	5
5/21/02	110	22	140	130	150	15	40	45	4
6/4/02	170	85	420	8400	580	25	11	24	6
6/18/02	520	170	1500	3300	940	79	660	24	33
7/3/02	100	58	350	440	270	67	250	50	27
7/17/02	84	42	460	1300	2400	20	120	9	13
8/7/02	180	140	610	870	1000	12	10	150	4
8/27/02	170	65	2100	80	270	8	0	8	4
9/10/02	280	48	140	68	260	15	0	2	1
9/24/02	75	13	310	38	120	4	0	4	3
10/8/02	20	18	190	50	75	4	46	2	9
10/29/02	55	11	260	6	210	2	1	4	98
11/12/02	520	440	1600	1400	770	13	510	17	28
11/19/02 *	2400	1100	860	18000	1300	120	740	54	90
11/26/02	22	18	54	15	14	10	3	5	2
12/10/02	92	64	170	200	230	31	76	28	26
12/31/02	12	22	280	12	15	4	10	2	5
1/2/03	130	120	67	84	230	48	68	56	28
1/12/03 *	220	230	400	360	500	50	180	61	31
1/14/03	20	14	330	28	200	12	26	4	6
1/28/03	4	5	23	24	54	4	8	5	4
2/11/03	12	7	46	39	42	9	12	3	1
2/25/03	17	19	72	12	23	8	18	1	1

~ = Whatcom Creek mainstem station
* = storm event (> 0.5" within 24 hours)
numbers = colony forming units/100mL
method = Membrane Filter SM 9222

Appendix C
TMDL replicate sample bacterial data and graphs

Table C-1. Field Duplicates for Whatcom TMDL.

Date	Location	FC/100mL	FD/ 100mL	Stand D	Ave	CV
2/6/02	Fever Creek	60	90	21.21	75	0.28
2/19/02	Lincoln Creek	5	8	2.12	6.5	0.33
2/21/02	Cemetery Creek	1400	1300	70.71	1350	0.05
3/5/02	Control Dam	20	25	3.54	22.5	0.16
3/18/02	Valencia Street	4	2	1.41	3	0.47
4/2/02	James Street	6	8	1.41	7	0.20
4/23/02	Water Plant	3	1	1.41	2	0.71
5/7/02	Hanna Creek	14	22	5.66	18	0.31
5/21/02	Dupont Street	110	92	12.73	101	0.13
6/4/02	Fever Creek	580	480	70.71	530	0.13
6/18/02	Water Plant	24	20	2.83	22	0.13
7/3/02	Lincoln Creek	350	380	21.21	365	0.06
7/17/02	Cemetery Creek	1300	1200	70.71	1250	0.06
8/7/02	Control Dam	4	11	4.95	7.5	0.66
8/27/02	Valencia Street	8	12	2.83	10	0.28
9/10/02	James Street	48	28	14.14	38	0.37
9/24/02	Dupont Street	75	90	10.61	82.5	0.13
10/8/02	Lincoln Creek	190	240	35.36	215	0.16
10/29/02	Hanna Creek	2	1	0.71	1.5	0.47
11/12/02	James Street	440	480	28.28	460	0.06
11/19/02	Control Dam	90	80	7.07	85	0.08
11/26/02	Cemetery Creek	15	10	3.54	12.5	0.28
12/10/02	James Street	64	23	28.99	43.5	0.67
12/31/02	Fever Creek	15	22	4.95	18.5	0.27
1/2/03	Dupont Street	130	140	7.07	135	0.05
1/12/03	Water Plant	61	48	9.19	54.5	0.17
1/14/03	Hanna Creek	26	36	7.07	31	0.23
1/28/03	Lincoln Creek	23	14	6.36	18.5	0.34
2/11/03	James Street	7	13	4.24	10	0.42
2/25/03	Cemetery Creek	12	12	0	12	0
						25.58

Root mean square coefficient of variation (RMSCV) = 26%

FC = fecal coliform
FD = field duplicate
CV = coefficient of variance

Table C-2. Laboratory duplicate CV for Whatcom TMDL

Date	Sample	FC/ 100mL	LD/ 100mL	Stand D	Ave	CV
2/6/02	Dupont St.	56	64	5.66	60	0.09
2/19/02	Valencia St.	24	21	2.12	22.5	0.09
3/5/02	Valencia St.	26	32	4.24	29	0.15
3/18/02	Water Plant	11	2	6.36	6.5	0.98
4/2/02	Cemetery Creek	39	43	2.83	41	0.07
4/23/02	Control Dam	3	3	0	3	0
5/21/02	Control Dam	4	8	2.83	6	0.47
6/4/02	Control Dam	6	17	7.78	11.5	0.68
6/18/02	Hanna Creek	660	590	49.50	625	0.08
7/3/02	Control Dam	27	22	3.54	24.5	0.14
7/17/02	Water Plant	9	21	8.49	15	0.57
8/7/02	Dupont St.	180	200	14.14	190	0.07
8/27/02	Dupont St.	170	170	0	170	0
9/10/02	James St	48	55	4.95	51.5	0.10
9/24/02	Control Dam	3	2	0.71	2.5	0.28
10/8/02	Dupont St.	20	16	2.83	18	0.16
10/29/02	Valencia St.	2	1	0.71	1.5	0.47
11/12/02	Valencia St.	13	30	12.02	21.5	0.56
11/19/02	James St	1100	1300	141.42	1200	0.12
11/26/02	Valencia St.	10	18	5.66	14	0.40
12/10/02	James St	64	68	2.83	66	0.04
12/31/02	Fever Creek	15	7	5.66	11	0.51
1/2/03	Cemetery Creek	84	73	7.78	78.5	0.10
1/12/03	Dupont St.	220	210	7.07	215	0.03
1/14/03	Water Plant	4	2	1.41	3	0.47
1/28/03	James St	5	7	1.41	6	0.24
2/11/03	Cemetery Creek	39	35	2.83	37	0.08
2/25/03	Valencia St.	8	5	2.12	6.5	0.33
						26.00

Root mean square coefficient of variation (RMSCV) = 26%

FC = fecal coliform
LD = laboratory duplicate
CV = coefficient of variance

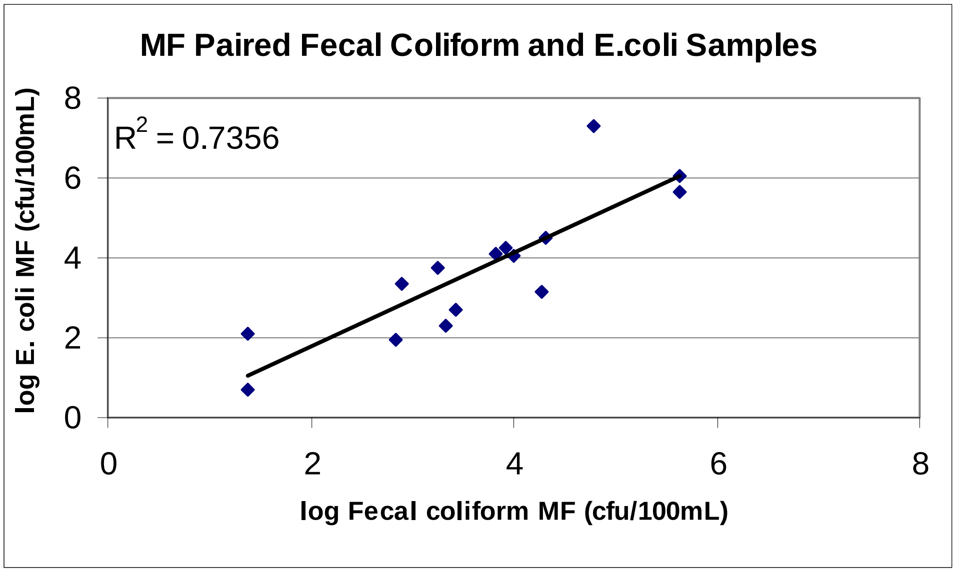

Figure C-1. A comparison of paired fecal coliform and *E. coli* samples that were analyzed using the Membrane Filter (MF) techniques.

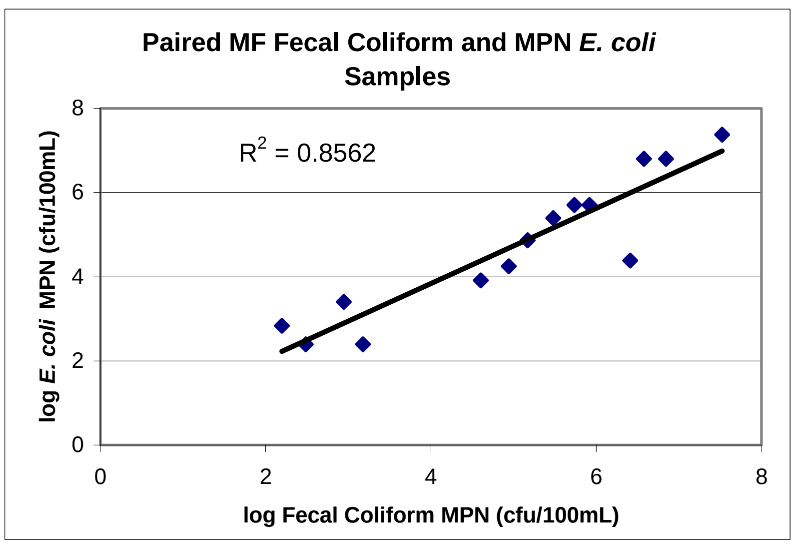

Figure C-2. A comparison of paired fecal coliform samples analyzed with MF techniques to *E. coli* samples analyzed with Most Probable Number (MPN) techniques.

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Appendix D

Summary of discharge conditions during TMDL monitoring

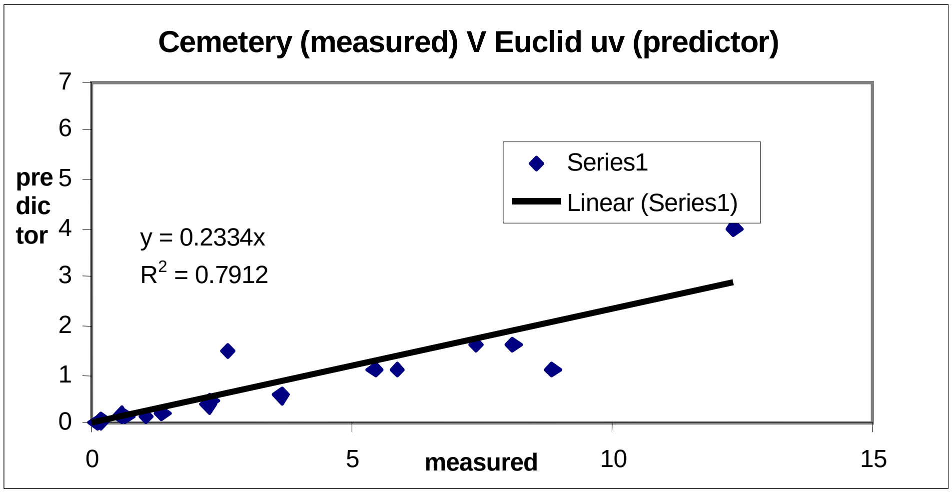

Figure D-1. A flow (measured in CFS) comparison between Cemetery Creek ungauged flow with the continuous flow recorded on Euclid Creek.

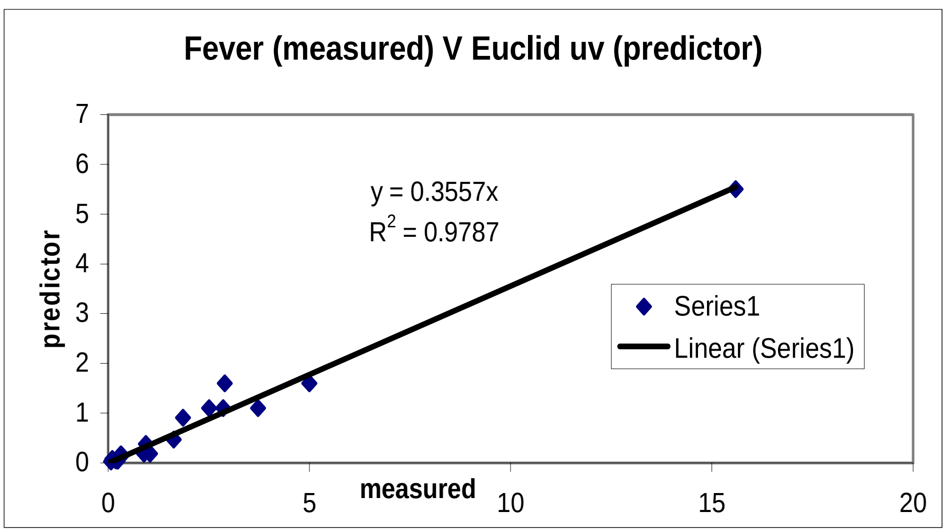

Figure D-2. A flow (measured in CFS) comparison between Fever Creek ungauged flow with the continuous flow recorded on Euclid Creek.

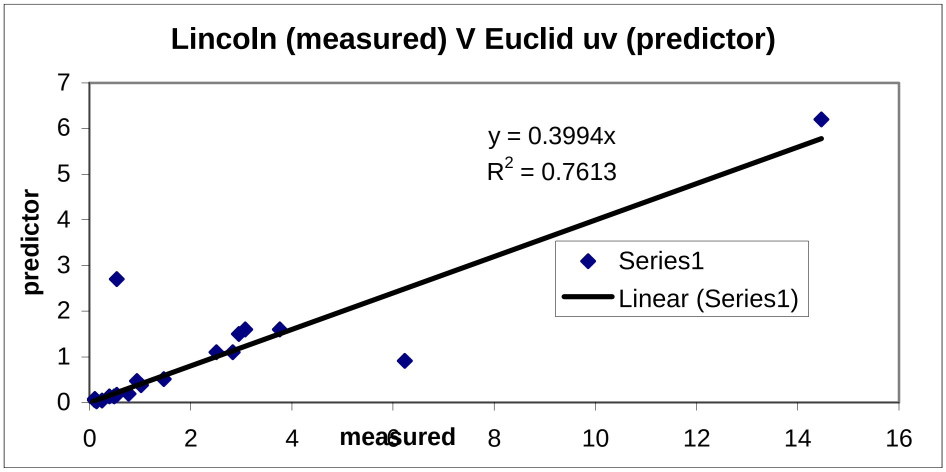

Figure D-3. A flow (measured in CFS) comparison between Lincoln Creek ungauged flow with the continuous flow recorded on Euclid Creek.

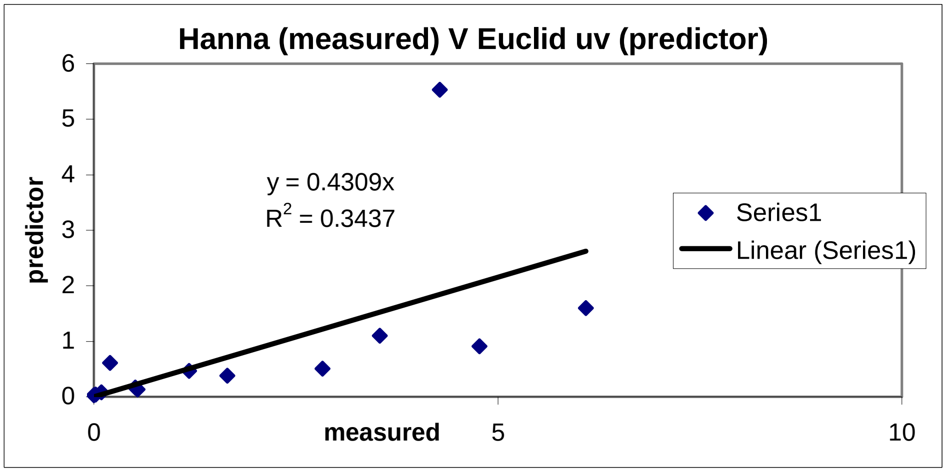

Figure D-4. A flow (measured in CFS) comparison between Hanna Creek ungauged flow with the continuous flow recorded on Euclid Creek.

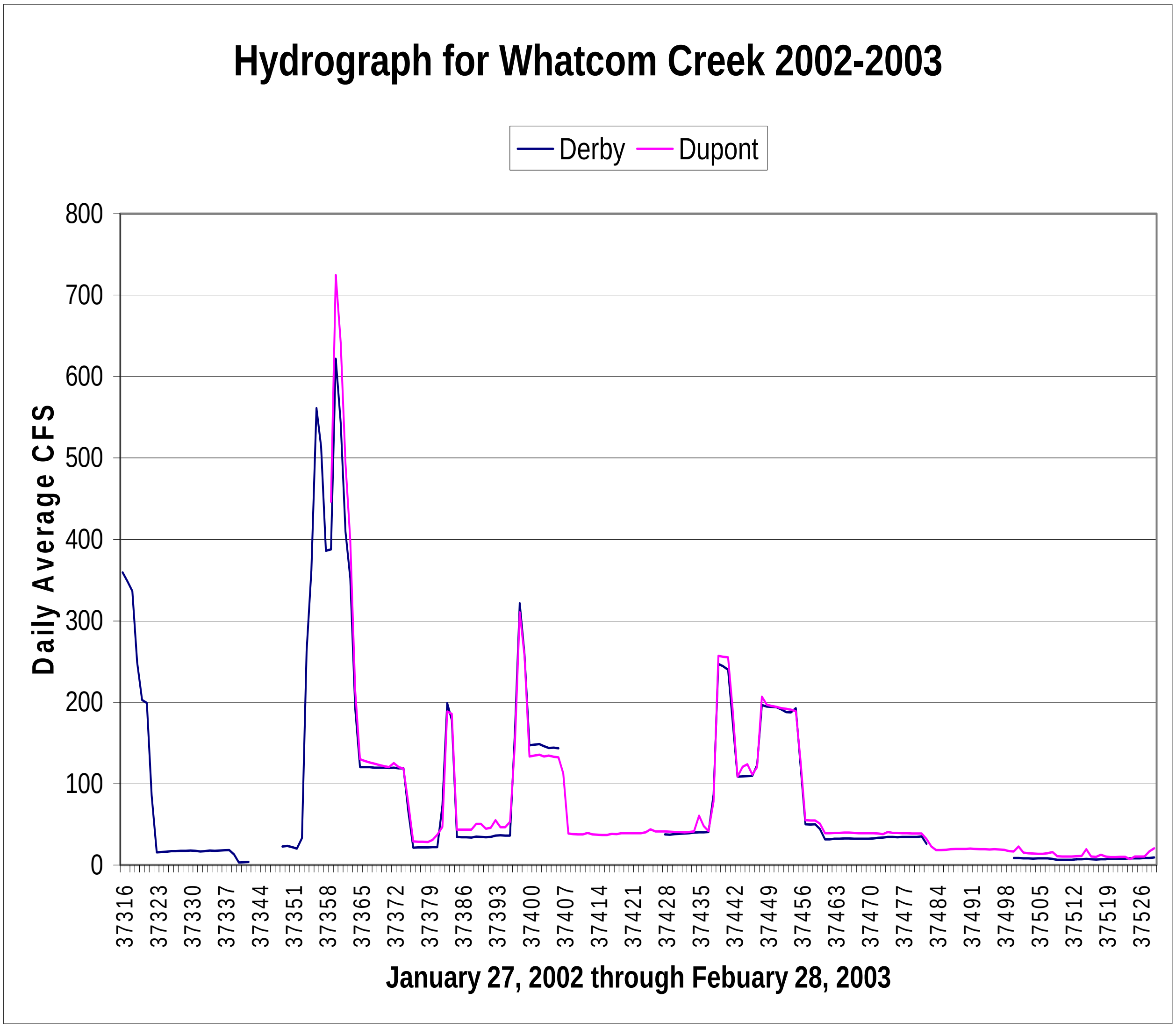

Figure D-5. The hydrograph for Whatcom Creek during the 2002 2003 TMDL Technical study.

Table D-1. Dupont Street discharge summary table.

	April 02			May 02			June 02			July 02			August 02			September 02		
Day	Mean CFS	Max. CFS	Min. CFS	Mean CFS	Max. CFS	Min. CFS	Mean CFS	Max. CFS	Min. CFS	Mean CFS	Max. CFS	Min. CFS	Mean CFS	Max. CFS	Min. CFS	Mean CFS	Max. CFS	Min. CFS
1				29	29	27	39	40	38	78	261	41	39	40	39	17	17	16
2				29	29	27	38	38	37	257	264	250	39	40	38	23	48	16
3				28	29	27	38	38	37	256	261	247	39	39	38	15	16	14
4				31	46	27	38	38	37	255	261	247	39	40	38	15	15	14
5				37	71	29	39	46	38	188	261	107	38	40	38	14	15	14
6				47	146	9	38	38	37	109	111	107	41	53	38	14	14	14
7				189	231	142	37	38	37	121	174	107	40	40	39	14	14	13
8				186	227	44	37	38	37	124	169	111	40	44	39	14	19	13
9				44	45	44	37	38	37	111	113	109	39	40	39	16	62	11
10				44	44	43	38	41	37	120	191	21	39	39	38	11	12	11
11				44	44	43	38	40	37	207	215	194	39	40	38	11	11	11
12				44	44	43	39	41	38	197	203	191	39	40	38	11	12	10
13	446	530	408	51	72	44	39	40	38	195	200	191	39	40	38	11	11	11
14	725	813	514	50	65	45	39	40	38	195	200	191	32	40	22	11	12	11
15	642	784	451	45	46	44	39	39	38	193	197	188	23	24	19	11	12	11
16	494	588	441	46	74	44	39	39	38	192	197	188	19	19	17	20	46	11
17	399	492	237	55	111	46	40	44	37	191	203	188	19	19	17	11	12	10
18	215	247	130	47	48	46	44	51	40	189	194	182	19	24	19	10	11	10
19	130	132	126	47	47	46	41	43	40	127	191	54	20	20	19	13	30	10
20	128	130	126	53	66	47	41	41	40	55	56	54	20	21	20	10	12	10
21	126	130	123	149	321	47	41	41	40	55	57	54	20	20	19	10.0	11	10
22	125	130	121	310	321	301	41	41	40	55	56	54	20	21	20	10.0	11	10
23	123	126	119	257	317	132	41	41	40	51	57	38	20	33	19	10	11	10
24	121	123	119	134	137	130	41	41	40	39	40	37	20	20	20	10	13	10
25	120	123	117	134	139	130	41	41	40	39	40	39	20	20	19	7.0	14	10
26	125	142	119	136	142	132	41	41	40	40	40	39	20	20	19	11	14	9
27	120	123	117	133	137	132	42	61	40	40	40	39	19	20	19	11	12	10
28	118	121	115	135	142	132	61	105	41	40	40	39	20	26	19	11	12	11
29	76	121	29	133	139	130	48	75	41	40	40	39	19	21	19	17	71	11
30	29	30	29	132	135	130	42	45	41	40	40	39	19	20	19	21	82	12
31				113	135	39				39	40	39	17	19	16			
Mean				94			41			124			28			13		
Maximum				310	321		61	105		257	264		41	53		23	82	
Minimum				28		9	37		37	39		21	17		16	7		9

Day	October 02 Mean CFS	October 02 Max. CFS	October 02 Min. CFS	November 02 Mean CFS	November 02 Max. CFS	November 02 Min. CFS	December 02 Mean CFS	December 02 Max. CFS	December 02 Min. CFS	January 03 Mean CFS	January 03 Max. CFS	January 03 Min. CFS	February 03 Mean CFS	February 03 Max. CFS	February 03 Min. CFS
1	13	14	13	31	33	30	62	64	61	127	209	85	336	354	321
2	14	19	13	30	33	29	61	62	61	158	227	111	338	358	325
3	33	65	16	29	33	27	60	62	59	245	290	218	332	345	317
4	16	17	16	28	29	27	63	77	58	267	341	231	243	333	161
5	16	16	15	29	45	27	59	61	58	225	237	218	147	166	98
6	17	17	16	24	33	21	58	59	57	221	231	212	98	101	98
7	16	16	15	24	34	20	57	58	56	218	224	212	98	99	96
8	17	26	15	29	35	25	55	56	54	209	215	203	97	99	94
9	16	17	15	29	40	25	56	66	53	201	209	194	95	98	94
10	17	26	15	26	46	24	62	71	56	190	200	182	94	96	92
11	15	16	14	27	65	15	83	135	58	181	200	172	94	98	92
12	14	14	14	41	68	21	69	113	61	235	363	182	94	96	92
13	14	14	13	18	77	13	68	92	62	217	279	200	93	96	90
14	14	14	14	19	82	9.6	69	96	64	226	261	215	82	94	58
15	14	15	14	10	26	8.5	111	237	75	214	221	206	63	85	58
16	14	14	13	23	44	11	135	282	74	207	218	194	75	132	59
17	14	14	14	13	17	11	118	161	80	194	203	182	88	159	69
18	14	15	14	22	77	12	175	197	156	180	188	172	67	72	62
19	16	25	14	101	166	40	186	191	180	169	180	159	64	74	62
20	14	15	13	20	40	13	179	185	172	155	161	149	82	119	66
21	14	14	13	28	72	9.6	169	177	161	153	174	144	102	161	69
22	14	14	14	71	72	69	159	166	149	162	185	144	79	87	75
23	14	17	14	69	71	68	115	154	79	227	325	164	74	77	71
24	14	15	13	68	68	66	82	99	77	223	244	209	71	72	69
25	14	14	14	67	68	66	90	169	80	223	264	212	70	71	68
26	14	15	13	66	68	64	89	151	80	284	337	254	69	69	66
27	17	31	14	65	66	64	121	247	80	311	389	268	67	68	66
28	19	24	15	64	65	64	92	99	89	306	321	294	70	80	66
29	32	34	24	64	65	62	89	111	85	332	389	297			
30	32	33	31	63	64	62	99	123	89	340	417	309			
31	32	33	30				87	90	85	335	350	321			
Mean	17			40			96			224			117		
Maximum	33	65		101	166		186	282		340	417		338	358	
Minimum	13		13	10		8.5	55		53	127		85	63		58

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Appendix E
Seasonal variation graphs

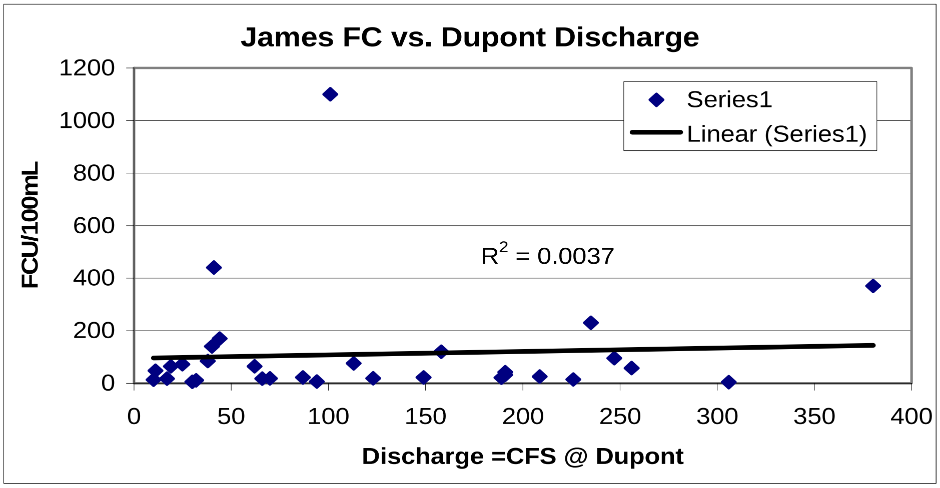

Figure E-1. Relationship between mainstream flow and James St. FC concentrations.

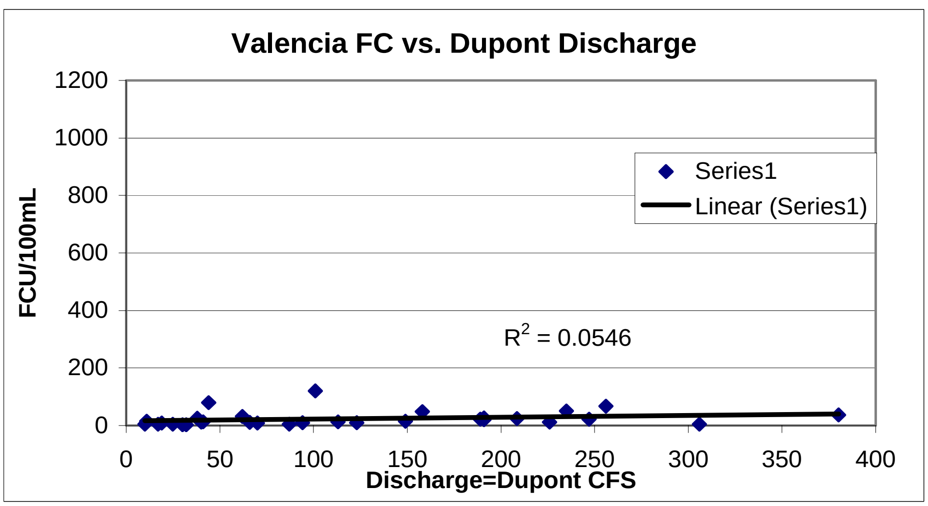

Figure E-2. Relationship between mainstream flow and Valencia St. FC concentrations.

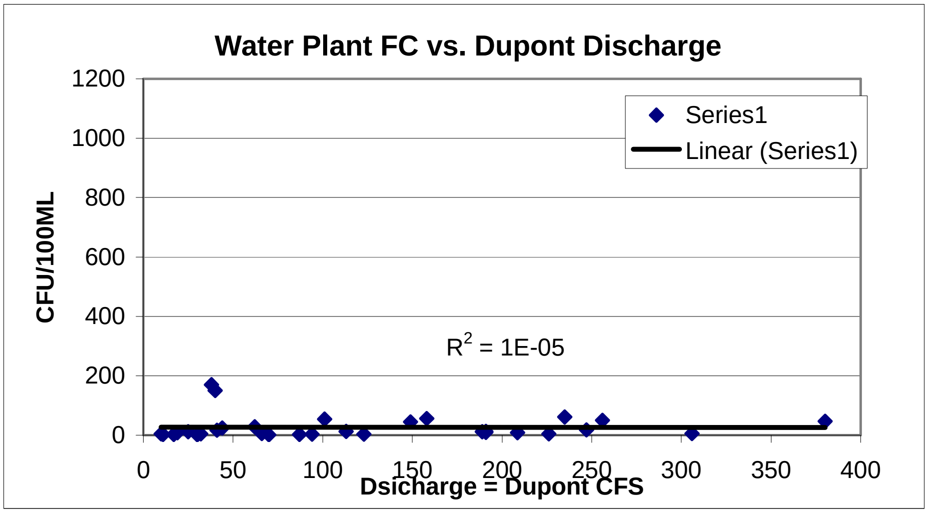

Figure E-3. Relationship between mainstream flow and Water Plant FC concentrations.

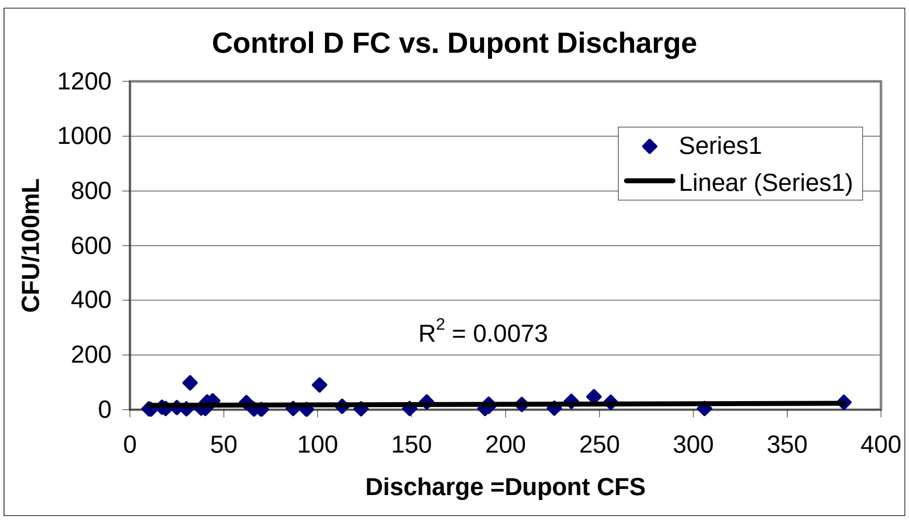

Figure E-4. Relationship between mainstream flow and Control Dam FC concentrations.

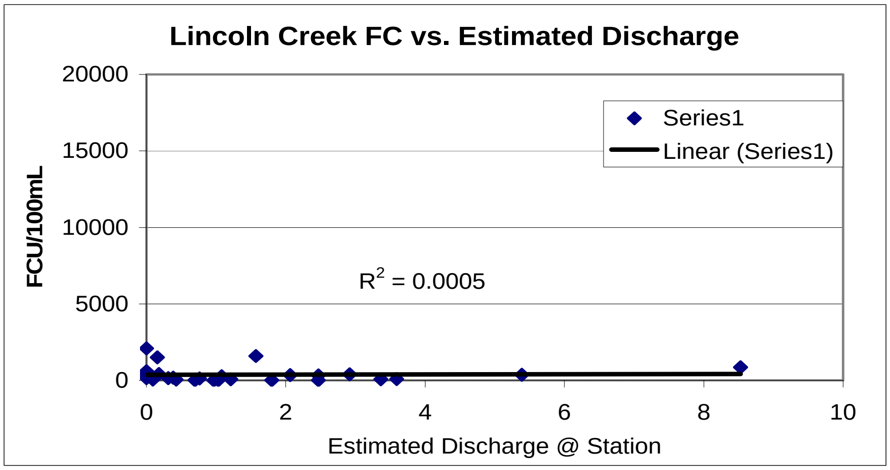

Figure E-5. Relationship between estimated flow and Lincoln FC concentrations.

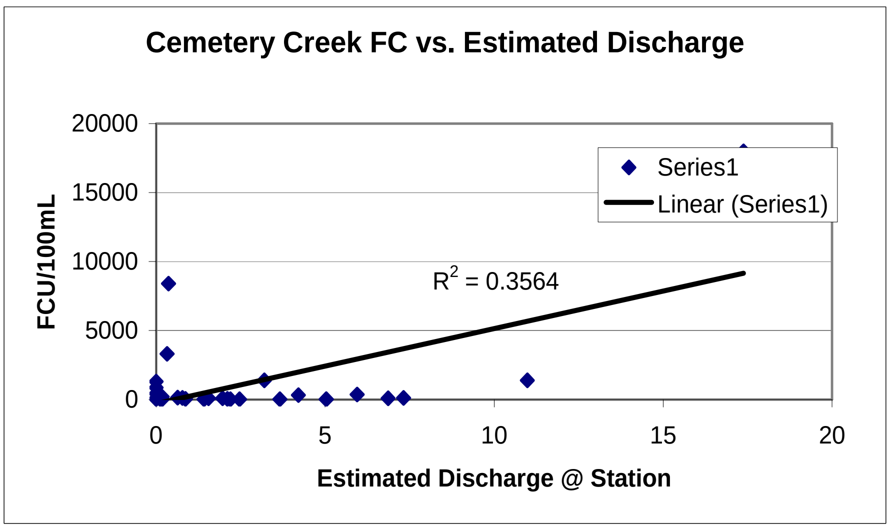

Figure E-6. Relationship between estimated flow and Cemetery FC concentrations.

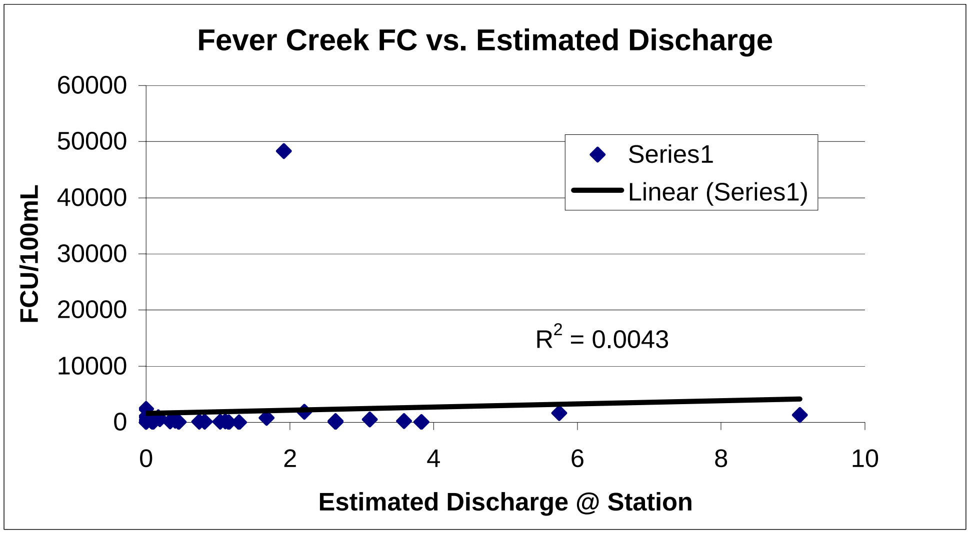

Figure E-7. Relationship between estimated flow and Fever FC concentrations.

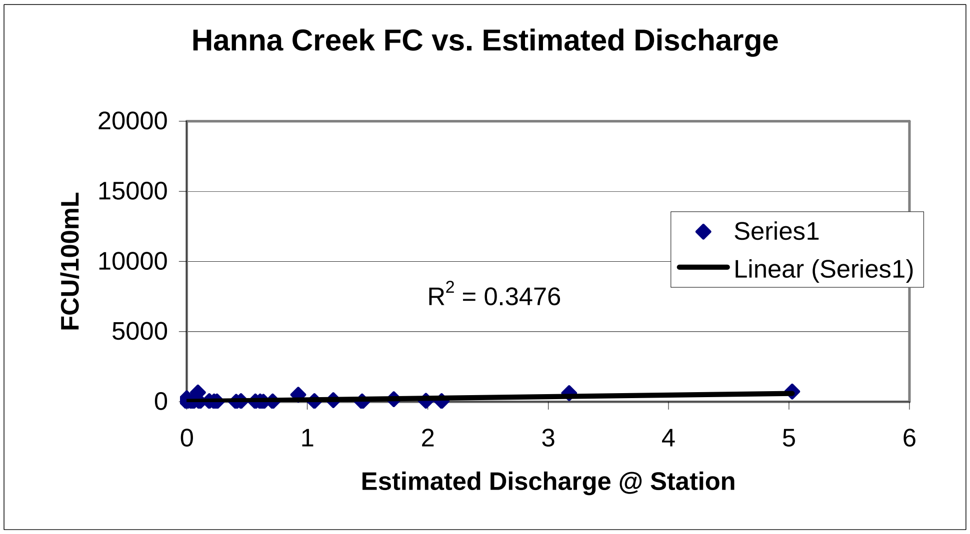

Figure E-8. Relationship between estimated flow and Hanna FC concentrations.