Whatcom Creek Fecal Coliform Bacteria Total Maximum Daily Load

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Whatcom Creek
Fecal Coliform Bacteria
Total Maximum Daily Load

Technical Report

by

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Acknowledgments

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Abstract

Whatcom Creek has stream segments that do not meet Washington State water quality criteria for fecal coliform (FC) bacteria. Washington State Department of Ecology (Ecology) selected Whatcom Creek for a total maximum daily load (TMDL) study to address areas with water quality impairements. The City of Bellingham and Ecology published the Whatcom Creek TMDL report in 2004 (Shannahan et al.). Since then, the City of Bellingham's Urban Streams Monitoring Program (USMP) has collected monthly water quality samples throughout Whatcom Creek and its tributaries. This technical report provides a summary analysis of FC based on USMP data from 2004–2018 and includes TMDL element recommendations for an updated Whatcom Creek FC TMDL.

Since 2004, Whatcom Creek FC trends generally display significant improvements in water quality (decreasing FC trends). For the tributaries, Cemetery Creek showed a significantly decreasing FC trend. More recent FC data (2017–2018) were used to calculate FC percent reductions and establish target FC concentrations needed to meet water quality criteria. The tributaries required larger FC reductions in order to meet criteria than mainstem Whatcom Creek sites, with Fever Creek requiring the highest FC reductions (93%). Most Whatcom Creek sites did not require FC reductions, except for a low reduction (10%) at the furthest site downstream (WHA00.2).

Recommendations for updated loading capacities, load allocations, and wasteload allocations were developed using 2017–2018 FC data to be used in the updated TMDL and implementation plan for Whatcom Creek. The TMDL will be written to achieve compliance with Washington State water quality standards for bacteria.

Introduction

Whatcom Creek and its tributaries have areas that exceed (do not meet) fecal coliform bacteria (FC) water quality criteria. The federal Clean Water Act requires that a Total Maximum Daily Load (TMDL) study be developed for each of the water bodies on the 303(d) list of impaired waters. The City of Bellingham and Washington State Department of Ecology (Ecology) completed a TMDL study addressing areas in Whatcom Creek that exceed (do not meet) FC water quality criteria (Shannahan et al., 2004). Since the completion of the TMDL, the City of Bellingham's Urban Streams Monitoring Program (USMP) has conducted routine water quality monitoring in Whatcom Creek and its tributaries. Segments of Whatcom Creek and its tributaries continue to exceed water quality criteria (Table 1) and are addressed in this report.

Table 1. 303(d) listings of bacteria impaired waters in Whatcom Creek and its tributaries.

Listing ID	Medium	Parameter	Waterbody Name
39061	Water	Bacteria	Cemetery Creek
39089	Water	Bacteria	Fever Creek
45565	Water	Bacteria	Hanna Creek
39110	Water	Bacteria	Lincoln Creek
16408	Water	Bacteria	Whatcom Creek

The purpose of this report is to summarize FC data collected since the completion of the 2004 TMDL (Shannahan et al.) and provide recommendations for an updated TMDL. Report objectives:

- Summarize routine USMP FC data since 2004.
- Evaluate FC water quality trends from 2004–2018.
- Compare more recent (2017–2018) FC data with data analyzed in the 2004 TMDL Report.
- Provide updated TMDL elements and recommendations using more recent data.

Watershed Description

Whatcom Creek is an urban stream that flows through the City of Bellingham, beginning as an outflow from Lake Whatcom and draining into Bellingham Bay (Figure 1).

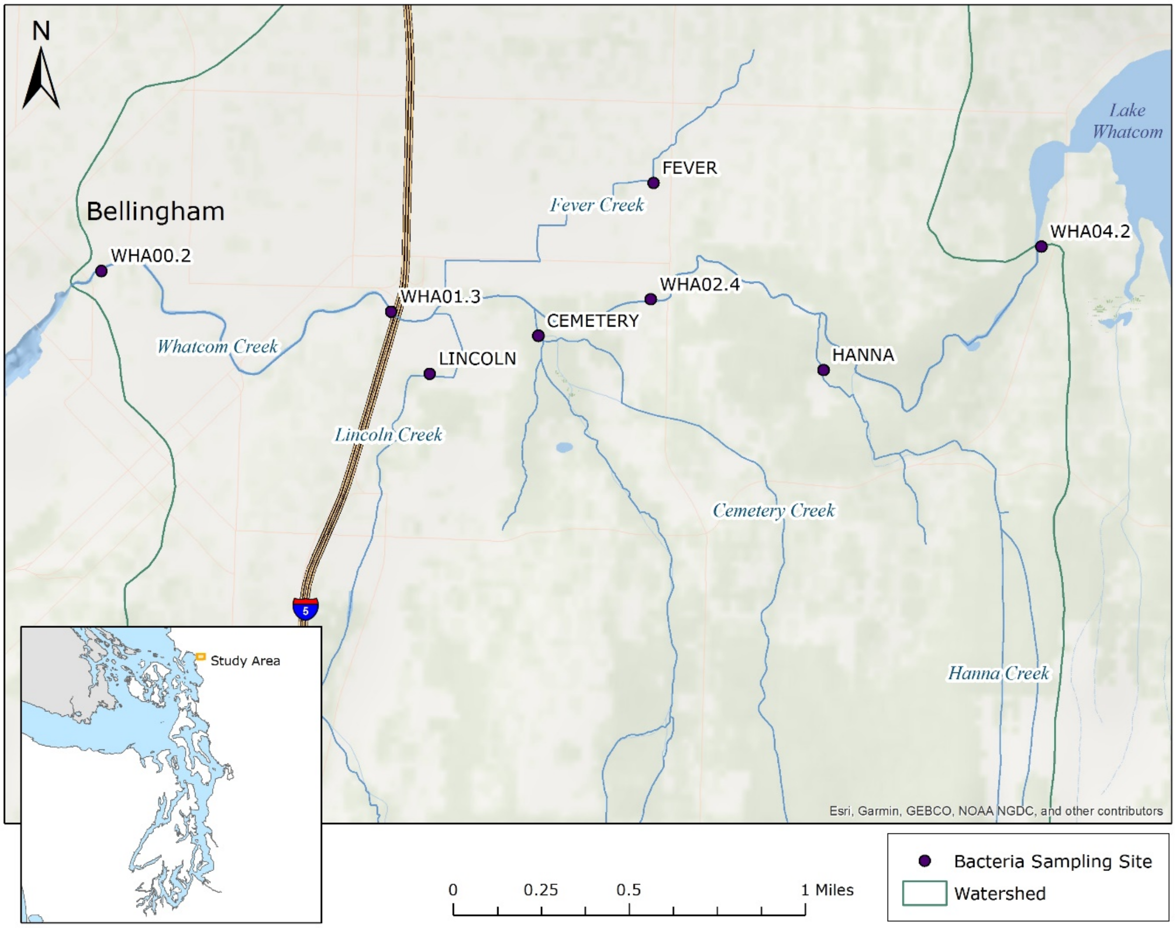

Figure 1. Map of study area and FC sampling sites.

Whatcom Creek is heavily impacted by development in the watershed and by flood management of Lake Whatcom. The watershed is influenced by channelization and flood control projects, loss of riparian vegetation, channel restrictions from road crossings, and the addition of many point sources of stormwater runoff.

Lake Whatcom is the drinking water supply for more than 100,000 Bellingham and Whatcom County residents, as well as the process water supply for several industries. The control dam used to regulate Lake Whatcom water levels also regulates the flow entering Whatcom Creek at its headwaters. These 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. Operational considerations of the control dam 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.

All of the Whatcom Creek watershed is covered under the City of Bellingham or the Whatcom County Phase 2 municipal separate stormwater system (MS4) permits. Washington State Department of Transportation roads are covered under an NPDES stormwater permit. Various industrial stormwater and construction stormwater permits are also located within the watershed. A Washington Department of Fish and Wildlife fish hatchery is the only non-stormwater discharge into Whatcom Creek authorized by an NPDES permit.

Water Quality Standards

Washington State water quality standards are the basis for protecting and regulating the quality of surface waters in Washington State. The standards implement portions of the federal Clean Water Act by specifying the designated and potential uses of water bodies in the state. The water quality standards are established to sustain (1) public health and public enjoyment of the waters, and (2) the propagation and protection of fish, shellfish, and wildlife. The regulatory freshwater designated uses and criteria for FC for Whatcom Creek are based on the Primary Contact Recreation use [WAC 173-201A-200(2)(b)]. The freshwater quality standards for this study area are:

1. Geometric mean criterion not to exceed 100 cfu/100 mL.
2. Not more than 10% of samples (or any single sample when less than ten samples exist) exceed 200 cfu/100 mL (percent exceedance criterion). The percent exceedance criterion is calculated as the 90^{th} percentile. The 90^{th} percentile is a measure of statistical distribution that determines the value for which 90% of the data points are smaller and 10% are higher.

These two water quality criteria ensure that bacteria pollution in a water body will be maintained at levels that will protect human health.

In January 2019, Ecology adopted amendments to Chapter 173-201A WAC of the surface water quality standards of Washington State. This rulemaking updated freshwater quality standards for the protection of water contact recreational uses in state waters. It adopted (1) E. coli as the new bacterial indicator in freshwater, in place of FC, and (2) new numeric criteria to protect water contact recreational uses. The Rule Implementation Plan (Ecology, 2019) includes guidance for the new rulemaking.

Sampling Methods

The USMP conducts routine FC monitoring along Whatcom Creek and its tributaries (Figure 1 and Table 2). The USMP was developed to obtain baseline water quality data for streams in the City of Bellingham. Data are used to detect changes in these streams. The program is conducted by the Public Works Operations and Natural Resources Divisions. Monitoring currently takes place at various sites and streams, including sites along Whatcom, Hanna, Cemetery, Lincoln, and Fever Creeks, which are the focus of this study.

Table 2. City of Bellingham Urban Stream Monitoring Program (USMP) study sites in Whatcom Creek watershed.

Group	Site	Description
Whatcom Creek	WHA00.2	Whatcom Cr at Dupont St
Whatcom Creek	WHA01.3	Whatcom Cr at James St
Whatcom Creek	WHA02.4	Whatcom Cr at Valencia St
Whatcom Creek	WHA04.2	Whatcom Cr at Headwaters/ Control Dam
Tributary	CEMETERY	Cemetery Cr at mouth
Tributary	FEVER	Fever Cr at Valencia St
Tributary	HANNA	Hanna Cr at mouth
Tributary	LINCOLN	Lincoln Cr at Fraser St

Field sampling follows protocols described in the USMP Quality Assurance Project Plan (City of Bellingham, 2012). FC samples are collected six inches below the surface of the water in clean, sterile 250-mL polypropylene bottles. Samples are kept on ice for transportation to the laboratory. In the lab, samples are handled according to SM9060B until analyzed. Analysis for FC (SM9222D) is completed within six hours of collection. All sample analyses are performed by staff of the city of Bellingham's state accredited laboratory.

Analytical Methods

Seasonal Kendall Trend Test

The purpose of the Seasonal Kendall Trend test is to determine monotonic (increasing or decreasing) trends in data over a period of time (Hirsch et al., 1982; Gilbert, 1987; Helsel and Hirsch, 2002). This trend test accounts for both seasonal variations in data over time and outliers in datasets and is also a recommended statistical test for water quality trend monitoring (Meals et al., 2011). This trend test is used to calculate the probability of a relationship between FC and time and discounts seasonal variability by only comparing sample results from the same month. A nonparametric, two-tailed Seasonal Kendall Trend test was performed for each study site using data from 2004–2018.

Loading Summary

A load is defined as the mass of a substance that passes through a particular point of a river or stream (e.g., monitoring site) in a specified amount of time (e.g., daily) (Meals et al., 2013). A load is mathematically defined as the product of water discharge and the concentration of a substance in the water. Load calculations require both FC concentrations and streamflow measurements. Because routine water quality sampling in the Whatcom Creek watershed focuses on collecting FC samples, Ecology was able to calculate FC loads at only one site (WHA00.2) due to its proximity with a continuous streamflow gage (Dupont).

Loads were calculated as seasonal averages by taking the average individual load at WHA00.2 (based on FC sample and daily average flow at the monitoring site) for both the wet and dry seasons each year.

Statistical Rollback Analysis

The statistical rollback method (Ott, 1995) is used to calculate FC reduction targets for stream segments. The rollback method compares monitoring data to standards; the difference is the percentage change needed to meet the standards.

Ecology applied the rollback method in many other bacteria water quality exceedance studies (Coots, 2002; Joy, 2004; Joy and Swanson, 2005; Mathieu and James, 2011; McCarthy, 2020; Pelletier and Seiders, 2000; Swanson, 2009).

Ideally, at least 20 samples taken throughout the year are needed from a broad range of hydrologic conditions to determine an annual bacteria distribution. If bacteria sources vary significantly by season and create distinct critical seasons, seasonal targets may be required. Fewer data provide less confidence in bacteria reduction targets, but the rollback method is robust enough to provide pollutant allocations and targets for planning implementation measures using smaller data sets. Compliance with the most restrictive of the dual bacteria standard criteria determines the bacteria reduction needed at a stream sampling site. The rollback method is applied as follows:

> *The geometric mean (approximate median in a log-normal distribution) and 90th percentile statistics are calculated and compared to the water quality bacteria criteria. If one or both do not meet the criteria, the whole distribution is "rolled-back" to match the more restrictive of the two criteria. The 90th percentile criterion is usually the most restrictive.*

The rolled-back geometric mean or 90th percentile bacteria value then becomes the recommended *target* bacteria value for the site. The term *target* is used to distinguish these estimated numbers from the actual water quality criteria. The degree to which the distribution of bacteria counts is *rolled-back* to the target value represents the estimated percent of bacteria reduction required to meet the bacteria water quality criteria and standards. The bacteria targets are used to assist water quality managers in assessing the progress toward compliance with the bacteria water quality criteria. Compliance is ultimately measured as meeting both parts of the water quality standards criteria.

The rollback method assumes that the distribution of data follows a log-normal distribution. Bacteria concentrations from each of the sites were tested for log-normality prior to the use of the rollback method. In all instances, the data at each site met the log-normality test.

For this study, the statistical rollback analysis was performed using pooled 2017–2018 FC data in order to provide a large enough sample dataset (n >10). Due to this, results are presented non-seasonally and are intended to be applied for the entire year.

Data Quality Assessment

Data quality assessment procedures and measurement quality objectives (MQOs) for the USMP are described in detail in the most recent Quality Assurance Project Plan (QAPP; City of Bellingham, 2012). Additionally, annual water quality monitoring reports provide a review of data quality and are available on the USMP website[1]. Quality control procedures for the City of Bellingham's USMP for FC samples include a laboratory duplicate (one sample, two measurements) and a field replicate (two samples collected from the same sampling site) analyzed monthly along with regular stream samples. The laboratory duplicates serve to check the reproducibility of the instruments and analysis technique. The purpose of the field replicate is to indicate site heterogeneity or to indicate how representative the measurement is for a particular site.

USMP precision MQOs (City of Bellingham, 2012):

1. For values that are greater than 5 times the reporting limit (1 cfu/100 mL), the relative percent difference (RPD) of laboratory and field duplicates will be $\leq$ 30% using the following formula:

$$RPD = \frac{|(C_1 - C_2)|}{(C_1 + C_2)/2} * 100$$

   where C_1 and C_2 correspond with FC sample and replicate.

2. For values that are less than or equal to 5 times the reporting limit, duplicate values will be within ± 2 times the reporting limit.

Because the USMP monitors a network of water bodies, FC data quality records are reported with all sites collectively. Therefore, although this study is focused on Whatcom Creek sites, the data quality results are presented for the full dataset for 2017–2018, the focus years for the analysis.

Samples with field replicates were collected for at least 1 out of 10 samples (average of 13% for both 2017 and 2018) meeting the USMP MQO (10%). The levels of bacterial variation were similar to those reported in the 2004 TMDL. The average coefficient of variation (CV) in the 2004 TMDL was 26%, and the CV for 2017–2018 FC dataset was 29%. Further FC data quality results are reported in Appendix A.

[1] City of Bellingham Urban Streams Monitoring Program webpage: https://www.cob.org/services/environment/water-quality/pages/urban-streams-monitoring.aspx

Results

Fecal Coliform Trends

The annual FC geometric mean from 2002–2018 is compared with water quality criteria (100 cfu/100 mL) for each study site (Figure 2).

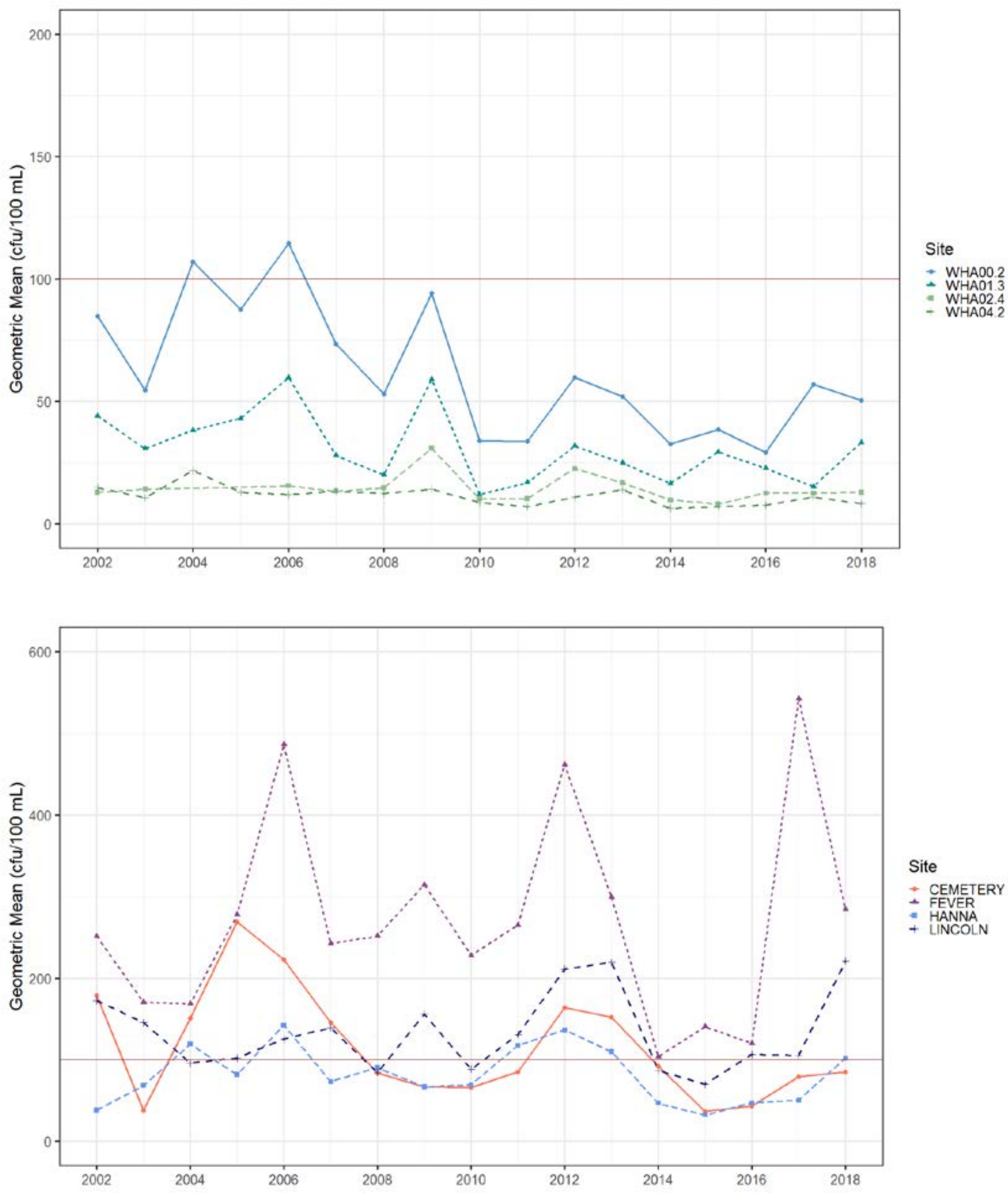

Figure 2. Annual FC geometric mean at Whatcom Creek and tributary sites from 2002-2018.

For the Whatcom Creek sites, WHA00.2 showed the greatest temporal variation and exceeded 100 cfu/100 mL during 2004 and 2006. The annual geometric means at the remainder of the Whatcom Creek sites fell below criteria through the 2002–2018 duration. Both WHA02.4 and WHA04.2 showed consistently low geometric mean concentrations from 2002 through 2018. The annual FC geometric mean at each of the tributaries are typically higher than the Whatcom Creek sites with all sites exceeding 100 cfu/100 mL at some point during 2002–2018. Fever Creek had the overall highest annual geometric mean and exceeded criteria every year.

Seasonal Kendall Trend Test

A Seasonal Kendall Trend test was performed for each site using 2004–2018 data to determine any significant trends in FC concentrations since the original field collection period. The seasonal trend test takes into account monthly FC variability.

Results from the Seasonal Kendall Trend test are presented in Table 3. Positive Z-scores indicate an increasing trend of FC, and negative Z-scores indicate a decreasing trend of FC (improving water quality). The greater the slope, the higher the rate of change over time. Trends are considered significant if the p-value < 0.05 (95% confidence).

All Whatcom Creek sites showed a significant decreasing trend in seasonal FC concentrations (2004–2018), except for WHA02.4 that showed no significant trend. Cemetery Creek also showed a significant decreasing trend.

Table 3. Seasonal Kendall Trend Test summary for FC concentrations.
Significant trends are in bold.

Site	Tau	Slope Estimate	Z-Score	p-value	Trend	Significant?
WHA00.2	-0.169	-2.000	-3.028	0.002	**Decreasing**	**Yes**
WHA01.3	-0.125	-0.667	-2.239	0.025	**Decreasing**	**Yes**
WHA02.4	-0.085	-0.286	-2.239	0.159	Decreasing	No
WHA04.2	-0.133	-0.333	-2.401	0.016	**Decreasing**	**Yes**
Cemetery	-0.135	-4.310	-2.161	0.031	**Decreasing**	**Yes**
Fever	0.007	0.000	0.015	0.988	Increasing	No
Hanna	-0.091	-1.708	-1.326	0.383	Decreasing	No
Lincoln	0.050	1.437	0.872	0.185	Increasing	No

Tau = Kendall's tau coefficient is a statistic used to measure the association between two measured quantities.
Z-score = test statistic used to compare subsequent time period values where a positive value indicates increasing trend and a negative value indicates decreasing value.
Bold = significant trend

Fecal Coliform Loading

FC loads were calculated at WHA00.2 due to the availability of flow measurements from the nearby Dupont continuous flow gage. FC loads are presented as seasonal loads in billion colony-forming units per day (b. cfu/day) to allow for an easier comparison of large load numbers.

Figure 3 shows the overall average FC load and flow at WHA00.2 for each month from 2002–2018. The highest FC loads are observed in the fall during September through December (642–953 b. cfu/day). Despite high flows in January and February, FC loads are lower than in the fall months. The months with the lowest FC loads are April and August (100 and 129 b. cfu/day, respectively).

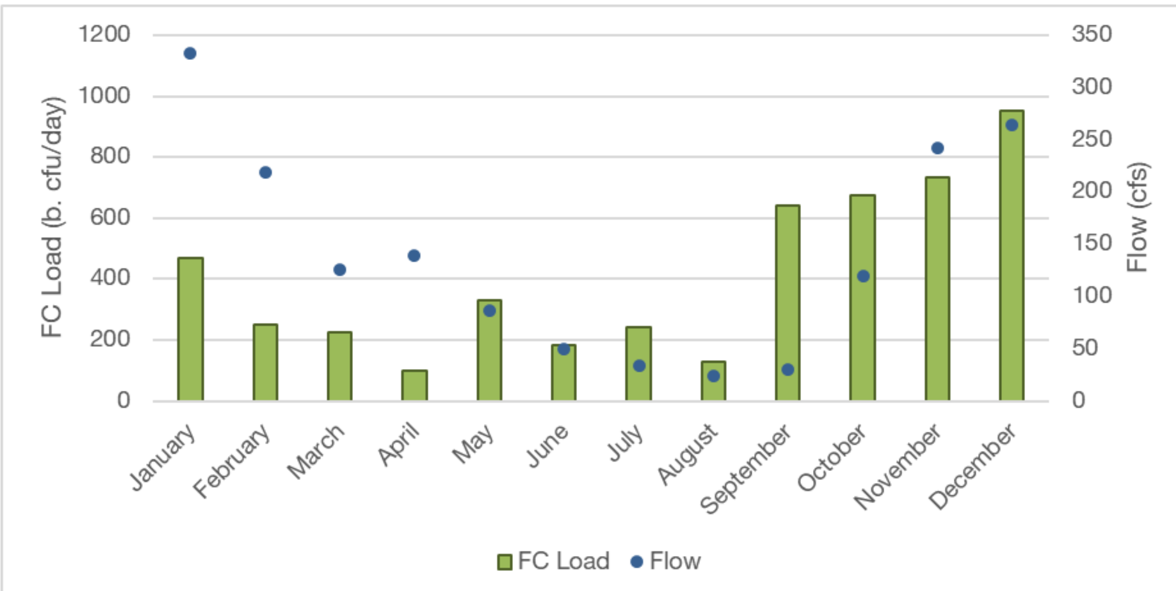

Figure 3. Average monthly FC loading and flow at WHA00.2 (2002-2018).

FC loads were also summarized for Whatcom Creek (WHA00.2) as an average seasonal load for each year from 2002–2018 (Table 4), where the wet season is October through April and the dry season is May through September.

Table 4. Seasonal average FC loads (billion cfu/day), average flow (cfs), and count (n).

Year	Dry Season (n)	Dry Season FC Load	Dry Season Flow	Wet Season (n)	Wet Season FC Load	Wet Season Flow
2002*	13	333	63	7	937	121
2003*	4	201	59	11	260	200
2004	5	226	59	7	656	224
2005	5	158	41	7	1128	172
2006	5	65	26	6	2005	242
2007	5	127	63	7	225	193
2008	5	185	87	7	797	148
2009	5	644	59	7	129	257
2010	5	81	100	7	207	174
2011	5	434	77	7	83	237
2012	5	600	91	7	512	334
2013	5	1107	64	7	249	201
2014	5	124	64	6	166	267
2015	5	48	17	6	66	222
2016	5	48	41	7	67	221
2017	5	183	48	7	495	203

*2002 and 2003 data collected for 2004 TMDL report.

While higher loads may be expected during the wet season due to increased flow, there is not a strong seasonal pattern in FC loads when comparing years. Annual variation includes some years (2002, 2004–2006, 2008, 2017) with much higher wet season FC loads and other years (2009, 2011, and 2013) with higher FC loads during the dry season. The remaining years do not show a strong seasonal difference in FC loads.

The 2004 TMDL noted that Lake Whatcom water level management highly influences flow in Whatcom Creek (Shannahan et al., 2004). Therefore, bacterial loading in terms of seasonal weather patterns is often masked by the anthropogenic control of creek volumes.

Recent (2017-2018) Fecal Coliform Data

This analysis used more recent (2017-2018) FC data to evaluate more recent water quality conditions in the Whatcom Creek watershed and to compare with results presented in the 2004 TMDL. FC data from 2017 and 2018 were pooled to allow for a more robust dataset (n=173 total, 19 to 23 samples per site). Data were summarized seasonally dependent on monthly precipitation to evaluate seasonal variations of FC concentrations. The dry season is defined as May through September and the wet season as October through April. A storm event is when rainfall was equal to or greater than 0.5 inches in 24 hours. Figure 4 shows the total daily precipitation and corresponding sampling dates. One storm event (March 29, 2017) coincided with FC sampling.

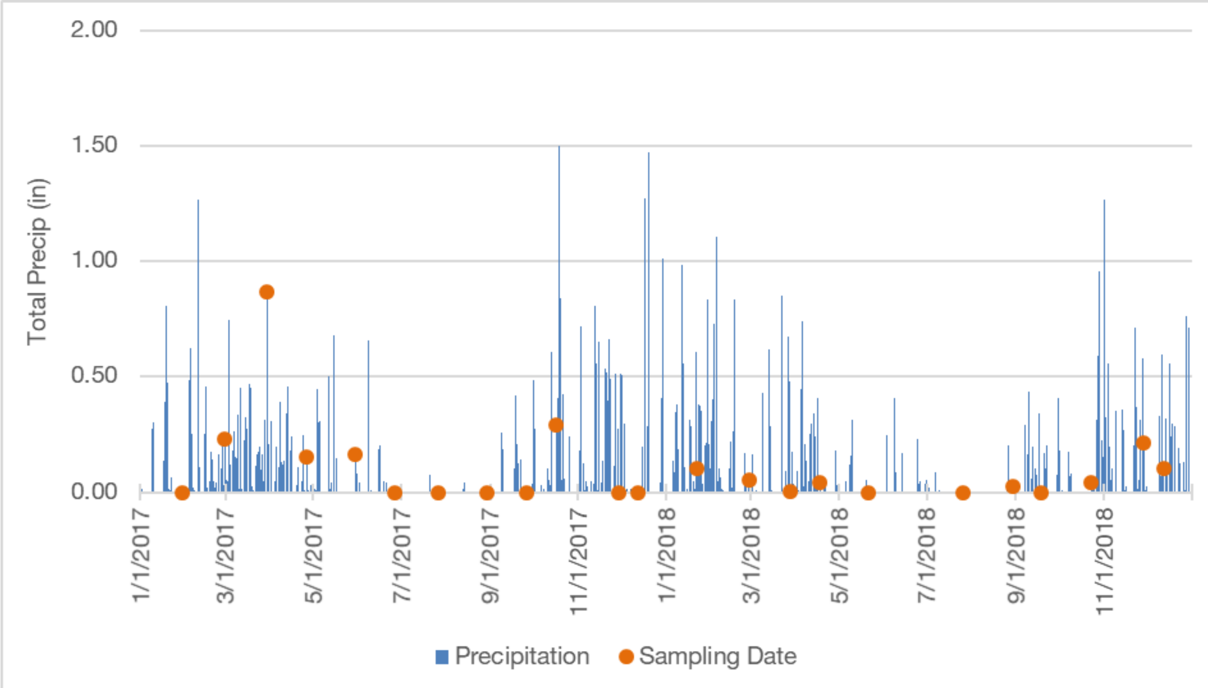

Figure 4. Total daily precipitation and sampling dates (2017-2018).

FC distributions are compared between the dataset used in the TMDL (2002–2003) and more recent data (2017–2018) in Figure 5. These boxplot distributions represent the maximum, 90th percentile, geometric mean, 10th percentile, and minimum in order to compare with water quality criteria.

More recent FC distributions (2017–2018) at the Whatcom Creek sites remain similar or slightly reduced when compared with the 2002–2003 distributions. Geometric means for 2017–2018 are lower at four sites (WHA00.2, WHA01.3,WHA04.2, Cemetery Creek) than the geometric means based on 2002–2003 data. Fever Creek and Hanna Creek had higher geometric means during 2017–2018. Geometric means at Lincoln Creek and WHA02.4 were similar during both time period distributions. A stastical significance test of the difference of these means was not conducted.

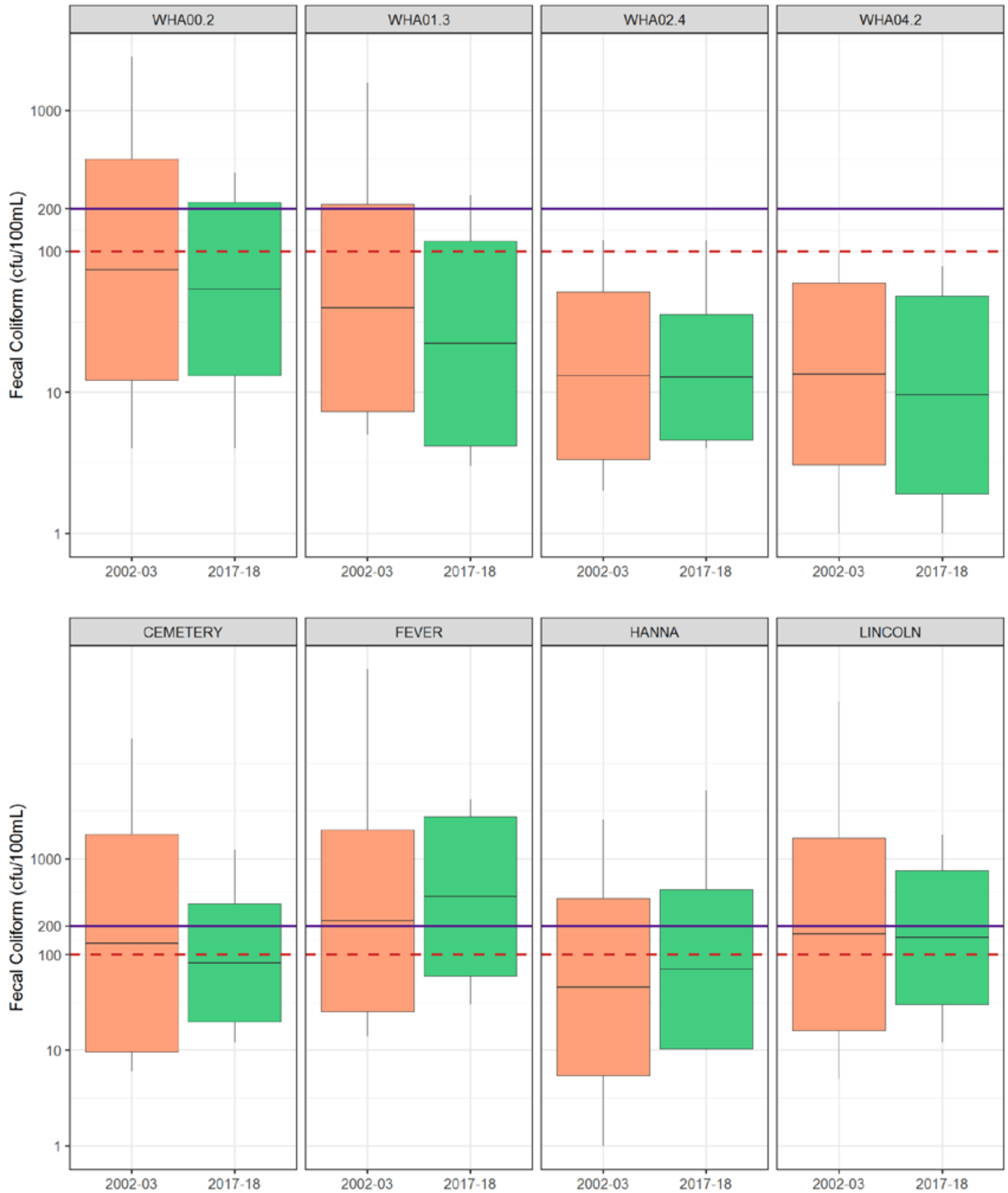

Figure 5. FC distribution during original TMDL period (2002-2003) and more recent data (2017-2018).

Boxplots indicate maximum, 90th percentile, geometric mean, 10th percentile, and minimum and are compared with water quality criteria (solid and dashed lines).

FC results from 2017–2018 are summarized seasonally and non-seasonally (pooled 2017–2018 data) and are compared with water quality criteria (Table 5).

Table 5. Summary of FC results from 2017-2018.

Bolded values exceed water quality criteria.

Site	Non-Seasonal GeoMean	Non-Seasonal % Excd	Dry Season GeoMean	Dry Season % Excd	Wet Season GeoMean	Wet Season % Excd
WHA00.2	54	9%	**128**	**22%**	31	0%
WHA01.3	22	9%	56	**11%**	12	7%
WHA02.4	13	0%	23	0%	9	0%
WHA04.2	10	0%	32	0%	4	0%
CEMETERY	82	**21%**	**116**	**20%**	73	**21%**
FEVER	**406**	**55%**	**1,928**	**100%**	**208**	**36%**
HANNA	70	**26%**	**127**	**40%**	57	**21%**
LINCOLN	**150**	**39%**	**227**	**56%**	**115**	**29%**

% Excd = percent exceedance (10% of samples not to exceed 200 cfu/100 mL)

The Whatcom Creek sites met criteria based on non-seasonal groupings and during the wet season. Both WHA00.2 and WHA01.3 exceeded water quality criteria during the dry season. All of the tributary sites exceeded criteria during both of the wet and dry seasons. Fever Creek had the overall highest FC concentrations and the largest seasonal variation with higher FC concentrations during the dry season. Similar to the results reported in the 2004 TMDL, higher geometric mean concentrations occurred during the dry season for all sampling sites (Shannahan et al., 2004). This may be due to reduced flows that limit the dilution of samples; also this may highlight a FC source that is not stormwater dependent.

Results from the storm event (3/29/17) showed high FC concentrations, although not the overall maximum FC levels (Table 6).

Table 6. FC during 3/29/17 storm event.

Site	FC (cfu/ 100 mL)
WHA00.2	140
WHA01.3	220
WHA02.4	24
WHA04.2	15
CEMETERY	300
FEVER	1,200
HANNA	400
LINCOLN	600

Statistical Rollback Analysis Results

The results of the statistical rollback analysis include target FC concentrations and recommended reductions to meet these targets. Results from the statistical rollback analysis are presented as FC percent reductions, or the percentage necessary for FC concentrations to be “rolled back” in order to meet water quality criteria. These FC reductions were calculated for sites that exceeded (did not meet) water quality criteria. For all sites that exceeded criteria, the 90^{th} percentile (10% of samples not to exceed 200 cfu/100 mL) was the most restrictive. Due to the high values of the 90^{th} percentiles (Table 7), the target geometric means are lower than the geometric mean criteria (100 cfu/100 mL) in order to meet the percent exceedance part of the criteria (200 cfu/100 mL).

Table 7. FC reductions (%) and target geometric mean and 90^{th} percentile to meet water quality criteria (2017-2018).

Site	FC % Reduction	Target GeoMean (cfu/ 100 mL)	Target 90th %ile (cfu/ 100 mL)
WHA00.2	10%	49	200
WHA01.3	0%	22	118
WHA02.4	0%	13	35
WHA04.2	0%	10	48
CEMETERY	41%	48	200
FEVER	93%	30	200
HANNA	58%	29	200
LINCOLN	73%	40	200

The largest FC percent reductions are required upstream of tributary sites Fever Creek (93%) and Lincoln Creek (73%). Moderate reductions are needed at the other tributary sites, Cemetery Creek (41%) and Hanna Creek (58%). A 10% reduction of FC is needed between WHA00.2 and WHA02.3 to meet criteria. The remainder of Whatcom Creek upstream of WHA02.4 is meeting criteria and does not require any FC reductions. As reductions are made in the creeks, particularly Fever Creek and Lincoln Creek, water quality conditions in downstream Whatcom Creek are expected to improve.

Appendix C provides detailed results and plots from the statistical rollback analysis.

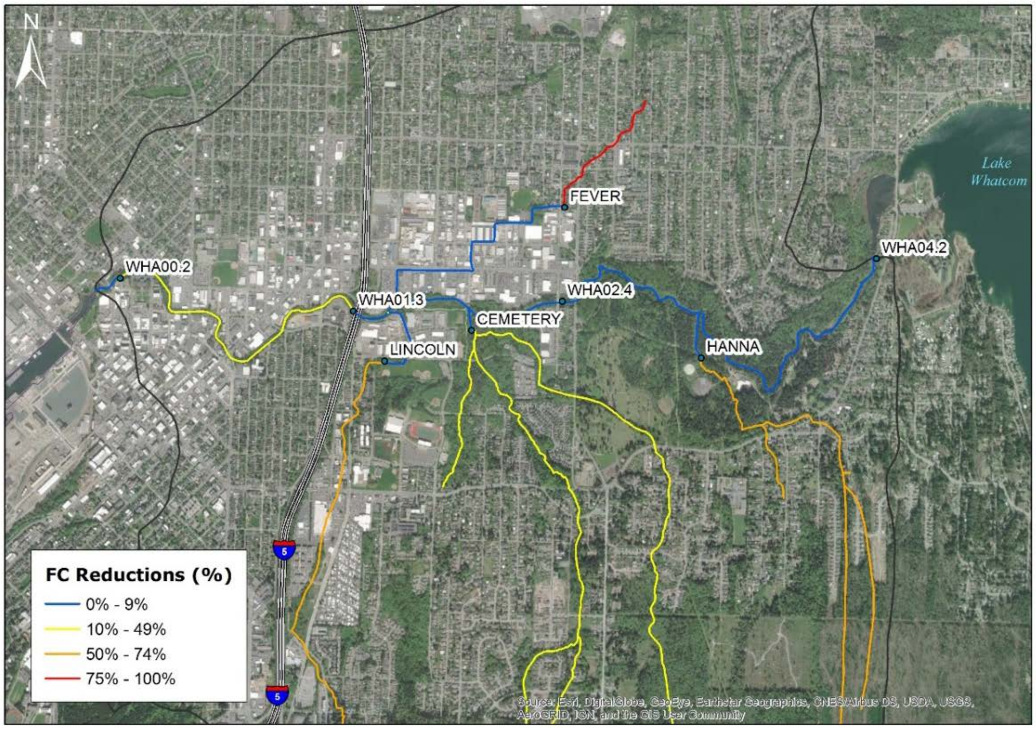

Figure 6. Map of FC reductions (%) to meet water quality criteria (2017-2018 data).

Comparing 2017–2018 results with 2004 TMDL

The 2004 TMDL (Shannahan et al., 2004) included FC percent reductions using 2002–2003 FC data. These reductions from the 2004 TMDL are compared with the updated FC percent reductions (2017–2018) in Table 8. While the 2002–2003 dataset was more robust (n=276) than the more recent 2017–2018 dataset (n=173), the updated FC reductions can still be used to evaluate general changes in water quality since the 2004 TMDL and will be useful to guide implementation and clean-up activities.

Table 8. FC percent reductions needed to meet water quality criteria from 2004 TMDL (2002–2003 data) and updated data (2017-2018).

Site	2002-2003 FC % Reduction	2017-2018 FC % Reduction
WHA00.2	62%	10%
WHA01.3	14%	0%
WHA02.4	0%	0%
WHA04.2	0%	0%
CEMETERY	86%	41%
FEVER	88%	93%
HANNA	58%	58%
LINCOLN	78%	73%

Based on the updated 2017–2018 FC data, smaller FC reductions are needed at the lower Whatcom Creek sites (WHA00.2 and WHA01.3). Similar with the TMDL results, no reductions are required at either WHA02.4 or WHA04.2, indicating that most FC issues in the watershed are focused in the tributaries and in the downstream reaches of the creek. Tributary reductions are similar for both time periods except for at Cemetery Creek, which requires a lower FC reduction to meet criteria based on 2017–2018 data when compared to 2002–2003 data.

Fecal Coliform and E. coli Bacteria Comparisons

During the 2002–2003 field study, both FC and E. coli bacteria samples were collected. The purpose of collecting dual samples was to develop a ratio of FC to E. coli that could be used in the case of updated surface water quality criteria. Since the USMP has continued to only sample FC since 2004, the 2002–2003 collection of dual bacteria samples may be useful for evaluating water quality with Ecology's recent rulemaking in 2019 that updated water quality standards and identified E. coli as the new freshwater bacterial indicator.

Results from the 2004 TMDL indicated correlation between FC and E. coli (Figure 7; Shannahan et al., 2004). The TMDL includes more details about the E. coli sample analysis, including comparisons of the different enumeration methods used for E. coli. From the 2004 TMDL study, the ratio between FC and E. coli is 1:0.95.

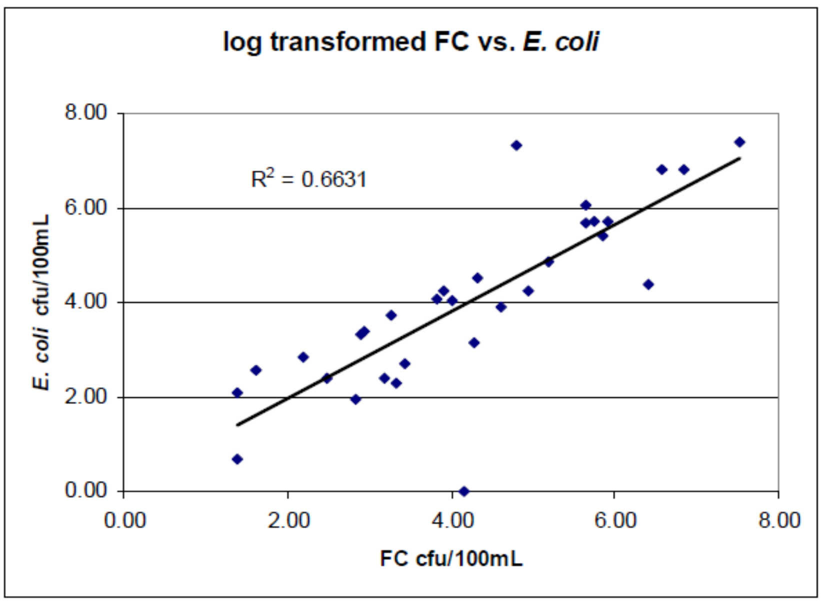

Figure 7. Comparison of paired FC and E. coli results from 2002-2003 samples and published in the TMDL report (Shannahan et al., 2004).

TMDL Elements and Recommendations

The following sections provide recommendations for TMDL elements for the updated Whatcom Creek TMDL report.

TMDL Formula

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load allocation*. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation* (WLA). If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation* (LA).

The TMDL must also consider seasonal variations and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the WLAs and LAs, any margin of safety (MOS), and any reserve capacity. The TMDL must be equal to or less than the loading capacity. The short-hand formula that describes the TMDL is:

$$LC=\sum WLA+\sum LA+MOS$$

Loading Capacity equals Sum of Wasteload Allocations
plus Sum of Load Allocations plus Margin of Safety

Loading capacities, LAs, and WLAs are expressed in terms of daily time increments (mass-per-time). Washington State water quality criteria are expressed as concentration (mass-per-volume). Washington State bacteria TMDLs typically use a combination of loads and statistical percent reductions to define loading capacities and LAs (Lawrence and Swanson, 2013; Lawrence, 2009; Mathieu and James, 2011; McCarthy, 2020; Pickett, 1997; Swanson, 2008).

Loading Capacity

Loading capacities were estimated as daily loads both seasonally (wet and dry season) and non-seasonally (entire year). The loading capacity was calculated using the following formula:

$$Load\ Capacity\ \left(\frac{cfu}{day}\right) = \ Bacteria\ Concentration\ \left(\frac{cfu}{100mL}\right) * Flow\ (cfs) * Conversion\ Factor\ (2.447 * 10^7)$$

The geometric mean criterion (100 cfu/100 mL) is used for bacteria concentration. By using the more conservative value criterion (geometric mean) the FC distributions are expected to be reduced and meet both water quality criteria. The loading capacity was calculated for the furthest downstream site in Whatcom Creek (WHA00.2) using flow data (2017–2018) from the nearby Dupont flow gage. The loading capacities are expressed as billion cfu per day (total number divided by one billion) in order to effectively communicate very large bacteria load numbers. Seasonal (wet and dry season) and non-seasonal (applied throughout the entire year) loading capacities were calculated.

Table 9. Recommended loading capacity (LC), unit area load allocation (LA), and unit area wasteload allocation (WLA) for Whatcom Creek.

	LC (b.cfu/ day)	LA (b.cfu/ day)	WLA (b.cfu/ day)	Unit Area LA (b.cfu/ day*acre)	Unit Area WLA (b.cfu/ day*acre)
Wet Season	552	276	276	0.05	0.05
Dry Season	90	45	45	0.01	0.01
Non-Seasonal	311	155	155	0.03	0.03

Wasteload and Load Allocations

The updated WLA and LA were developed using methods consistent with those described in the 2004 TMDL report (Shannahan et al., 2004). The WLA and LA are set as unit area allocations (Table 9). 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. The unit area allocations were calculated by the following equations:

1. $LA\ or\ WLA\ \left(\frac{b.cfu}{day}\right) = Loading\ Capacity * \frac{1}{2}$
2. $Unit\ Area\ Allocation\ \left(\frac{b.cfu}{day*acre}\right) = LA\ or\ WLA\ (\frac{b.cfu}{day})\ \div Area\ (acre)$

Consistent with the 2004 TMDL, this approach does not separate point sources and nonpoint sources of bacteria. These equal allocations were developed for each source type based on area due to lack of data for specific point and nonpoint sources. While allocations are set equally for each watershed unit area, implementation efforts should focus on identifying pollutant sources in areas with high FC concentrations, such as Fever Creek and Lincoln Creek.

The primary sources of known contamination in the Whatcom Creek watershed are (1) stormwater runoff directly into the receiving waterways and (2) non-stormwater discharges into the storm drainage system are (Shannahan et al., 2004). These fall into both point source and nonpoint source categories, and therefore, the same WLA and LA apply to discharges from sources covered by an NPDES permit as those sources that are not covered by an NPDES permit. Other potential non-stormwater sources of pollution can include leaking sewer lines and failing septic systems. Detection and elimination of these non-stormwater sources is required under the municipal stormwater permit. It is assumed that all pollutant sources will control stormwater runoff contamination to meet either WLAs or LAs. If an area of land is converted to a use that requires coverage under an NPDES permit, the associated LA is retired and an equal WLA is available to the point source.

The allocations are expressed in terms of loading (billion cfu/day). However, the percent reductions (Table 7) provide a description of reductions in bacteria concentrations needed for the bacteria distribution to be reduced to meet water quality criteria. Therefore, the target geometric mean is the expected concentration when the bacteria distribution has been reduced and can be used to compare with FC sample concentrations.

Recommended Margin of Safety

The federal Clean Water Act requires that TMDLs be established with a MOS. The MOS accounts for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly by setting a specific allocation as a MOS, or as an implicit MOS by using conservative assumptions in the use of data analysis and the effectiveness of proposed management practices.

This TMDL accounts for an implicit MOS by the following:

- The more conservative bacteria concentration (100 cfu/100 mL) value was used to estimate loading capacity, LA, and WLA. This conservative approach will ensure that both water quality criteria are achieved, with a geometric mean less than 100 cfu/100 mL and not more than 10% of samples exceeding 200 cfu/100 mL.
- This conservative approach does not consider bacteria die-off through a decay rate and assumes that FC entering the watershed will stay active and suspended in the water column to the mouth of the water body.
- Updated recreational criteria for E. coli are likely less stringent than the FC criteria. Sites that show improved water quality conditions, based on the WLA and LA determined using FC concentrations, are expected to meet the new water quality standards using E. coli.
- The adaptive management process of responding to monitoring results provides an implicit MOS because compliance can be determined for each station in the watershed, and source control measures will have a cumulative effect downstream.

In addition to the MOS, a reserve capacity for future loads from growth pressures is sometimes included, but is not included in these recommendations. The wasteload from future permitted discharges could potentially replace a portion of the assigned LA based on the portion of land being used.

Protecting Downstream Uses

This technical report addresses bacteria pollution in Whatcom Creek that drains into Bellingham Bay, and the recommended TMDL elements are based on freshwater FC standards. While there are no public shellfish harvesting areas near the outflow of Whatcom Creek, the western shoreline of Bellingham Bay has public shellfish beds that are sensitive to bacteria and are important to the Lummi Nation. The Nooksack River most heavily impacts these shellfish beds and has an established TMDL with target goals that are supportive of shellfish harvest (Joy, 2000). Because of low discharge from Whatcom Creek (average 135 cfs) and its remoteness from shellfish beds (5–10 miles), a separate analysis of Whatcom Creek's effect on the shellfish beds has not been pursued. The developed TMDL recommendations are therefore considered useful and protective of downstream beneficial uses because of increased bacteria die-off in marine waters, low discharge of Whatcom Creek, and distance from shellfish harvesting beds.

Conclusions

The results from this report support the following conclusions:

- FC trends since the completion of the 2004 TMDL (2004–2018) indicate:
  - Whatcom Creek displays improvement in water quality by significantly (probability of at least 95%) decreasing FC trends at all of the Whatcom Creek sites, except at WHA02.4 (not significant trend).
  - Cemetery Creek showed a significantly (probability of at least 95%) decreasing FC trend since 2004.
- Monthly averaged FC loads (2002–2017) at WHA00.2 showed that the highest FC loading occurred during September–December (642–953 billion cfu/day), and the lowest FC loads were during April (100 billion cfu/day) and August (129 billion cfu/day).
- Based on updated FC data (2017–2018), distributions of FC concentrations at the Whatcom Creek sites remain generally similar or had slightly lower dispersion than FC distributions from the 2004 TMDL using 2002–2003 FC data.
- More recent FC data (2017–2018) were used to calculate FC percent reductions and establish target concentrations needed to meet water quality criteria:
  - The tributaries required larger FC reductions in order to meet criteria than mainstem Whatcom Creek sites, with Fever Creek requiring the highest FC reductions (93%).
  - Most Whatcom Creek sites did not require FC reductions, except for a low reduction (10%) at WHA00.2.
  - FC reductions needed to meet water quality criteria were lower at WHA00.2, WHA01.3, and Cemetery Creek than reductions set by the 2004 TMDL. FC reductions were similar to those identified in the 2004 TMDL at Fever Creek, Hanna Creek, and Lincoln Creek sites.
- The FC and E. coli correlation comparison completed for the 2004 TMDL may be used for comparing FC data with new E. coli bacterial freshwater quality standards.
- Recommendations for updated loading capacities, LAs, and WLAs were developed using 2017–2018 FC data to be used in the updated TMDL and implementation plan for Whatcom Creek.

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Glossary, Acronyms, and Abbreviations

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10- to 10,000-fold over a given period. The calculation is performed by either: (1) taking the n^{th} root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare; (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses; or (3) livestock, wild animals, birds, fish, or other aquatic life.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector, such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FC	Fecal coliform bacteria
LA	Load allocation
LC	Loading capacity
MQO	Measurement quality objective
MOS	Margin of safety
NPDES	National Pollutant Discharge Elimination System (see glossary)
RPD	Relative percent difference
RSD	Relative standard deviation
SRM	Standard reference materials
TMDL	Total Maximum Daily Load (see glossary)
USMP	City of Bellingham' Urban Stream Monitoring Program
WAC	Washington Administrative Code
WLA	Wasteload allocation

Units of Measurement

b. cfu/day	billion colony forming units per day
cfs	cubic feet per second
cfu	colony forming units
mL	milliliters

Appendices

Appendix A. Data Quality Assessment

Table A-1. Field replicate data for USMP FC monitoring data from 2017–2018.
Dataset includes all USMP monitoring sites, not limited to Whatcom Creek.

Date	FC (cfu/100 mL)	Replicate (cfu/100 mL)	StDev	CV (%)	RPD (%)	Meets MQO? (< 30% RPD)
1/30/2017	8	20	8.5	61	35	Estimate
2/28/2017	1*	1	0.0	0	0	Yes
3/29/2017	140	120	14.1	11	8	Yes
4/26/2017	2*	2	0.0	0	0	Yes
5/31/2017	240	180	42.4	20	15	Yes
6/27/2017	34	26	5.7	19	14	Yes
7/26/2017	300	150	106.1	47	40	Estimate
8/29/2017	34	44	7.1	18	12	Yes
9/26/2017	73	73	0.0	0	0	Yes
10/16/2017	22	25	2.1	9	6	Yes
11/29/2017	10	2	5.7	94	100	Estimate
12/12/2017	14	26	8.5	42	26	Yes
1/22/2018	100	100	0.0	0	0	Yes
2/27/2018	22	16	4.2	22	17	Yes
3/28/2018	130	110	14.1	12	9	Yes
4/17/2018	40	60	14.1	28	18	Yes
5/21/2018	30	100	49.5	76	42	Estimate
7/26/2018	250	220	21.2	9	7	Yes
8/29/2018	50	46	2.8	6	4	Yes
9/18/2018	55	240	130.8	89	48	Estimate
10/23/2018	5200	2300	2050.6	55	48	Estimate
11/28/2018	84	130	32.5	30	19	Yes
12/12/2018	2*	3	0.7	28	18	Yes

*FC sample < 5 times the reporting limit (1 cfu/100 mL);
StDev= standard deviation;
CV=coefficient of variation;
RPD = relative percent difference

Appendix B. Additional Data Summaries

Table B-1. Average total monthly and annual precipitation (inches) from the City of Bellingham's City Hall and Bloedel site rain gages.

Month	2003-2018	2017	2018
January	4.8	2.5	6.9
February	3.2	4.8	4.5
March	4.2	6.7	3.8
April	2.7	3.3	3.6
May	2.4	2.7	0.7
June	1.6	1.2	1.3
July	0.7	0.1	0.1
August	0.9	0.1	0.2
September	2.3	2.0	2.6
October	4.1	4.9	2.8
November	6.4	7.4	6.0
December	5.0	5.6	4.8
Annual	38.3	41.3	37.3

Table B-2. Average seasonal flow at Dupont flow gage near WHA00.2.

Year	Wet Season Flow (cfs)	Dry Season Flow (cfs)	Annual Flow (cfs)
2002	121	63	75
2003	200	59	133
2004	224	59	142
2005	172	41	106
2006	242	26	131
2007	193	63	128
2008	148	87	117
2009	257	59	158
2010	174	100	137
2011	237	77	151
2012	334	91	212
2013	201	64	132
2014	267	64	170
2015	222	17	118
2016	221	41	131
2017	203	48	124
2018	251	25	130
Average	216	58	135

Appendix C. Statistical Rollback Results

Figure C-1 shows graphical results from the statistical rollback analysis. Each graph includes:

- Current conditions represented by data points, 90th percentile, and geometric mean (orange).
- Target values for the 90th percentile and target geometric mean (blue).
- Greatest target percent reduction needed to meet water quality criteria (green).
- If the data follows a lognormal distribution and if it passes the Shapiro-Wilk Test (cannot reject H_0 or p value).

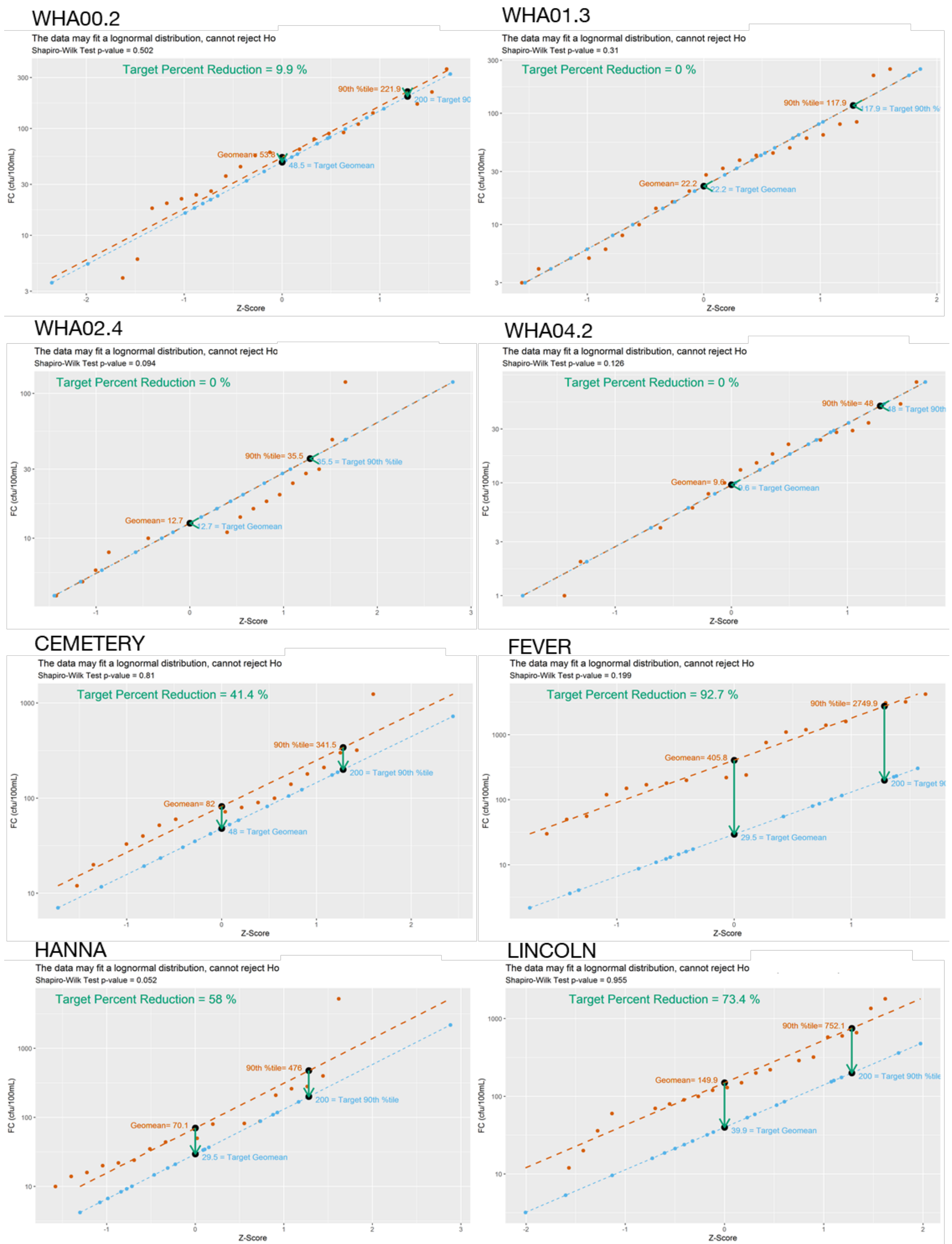

Figure C-1. Statistical rollback results plots for Whatcom Creek and tributary sites (2017-2018).