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State of Washington

Eastern Padilla Bay Tributaries Fecal Coliform Bacteria Total Maximum Daily Load Study

Water Quality Study Findings

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COVER PHOTO: Eastern Padilla Bay tributary. Photo taken by Renee Fields.

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Eastern Padilla Bay Tributaries
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Total Maximum Daily Load

Water Quality Study Findings

by

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Acknowledgments

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Executive Summary

Relevancy

The freshwater tributaries in the eastern Padilla Bay watershed have listings on the federal Clean Water Act 303(d) list of impaired waters. This water quality study findings report addresses areas in Joe Leary Slough, Big Indian Slough, Little Indian Slough, and No Name Slough that exceed (do not meet) fecal coliform bacteria (FC) water quality criteria.

The goal of this report is to provide the technical analysis necessary to develop a bacteria total maximum daily load (TMDL) for the eastern Padilla Bay tributaries. The TMDL will be written to achieve compliance with Washington State water quality standards for bacteria.

Summary of Technical Approach

- Bacteria and streamflow data were collected throughout the eastern Padilla Bay watershed freshwater tributaries and select outfalls from 2016–2017.
- Data were reviewed in a quality assessment and compared with water quality criteria.
- E. coli bacteria (E. coli) samples were collected at a subset of locations and compared with FC samples.
- Recommendations for loading capacities, load allocations, and wasteload allocations were developed for the eastern Padilla Bay tributaries to guide the TMDL and implementation plan.

Key Findings

- All Joe Leary Slough sites exceeded water quality criteria with typically higher bacteria concentrations during the wet season than during the dry season.
- Little Indian Slough required the highest overall reduction of bacteria (85% reduction of bacteria levels during the wet season) to meet water quality criteria.
- Wet-season average bacteria loads were larger than dry-season loads, as higher flows due to precipitation and runoff contribute to higher loads. Generally, loads increased moving upstream to downstream in all of the sloughs. Joe Leary Slough had the overall highest bacteria loads.
- Comparison of bacteria samples showed that FC concentrations were typically higher than E. coli concentrations. These results can be used to (1) guide implementation activities to improve water quality and (2) help to meet water quality criteria considering the recent rule-change adopting E. coli as the bacterial indicator in place of FC.

Introduction

Tributaries in the eastern Padilla Bay watershed exceed (do not meet) Washington State freshwater quality criteria and designated beneficial uses for fecal coliform bacteria (FC). This report presents the water quality study findings from data collected during 2016–2017. The technical analysis and results from this report will be used to guide a Total Maximum Daily Load (TMDL) report for the eastern Padilla Bay tributaries.

The study area for the eastern Padilla Bay watershed consists of four major tributaries: Joe Leary Slough, No Name Slough, Big Indian Slough, and Little Indian Slough (Figure 1).

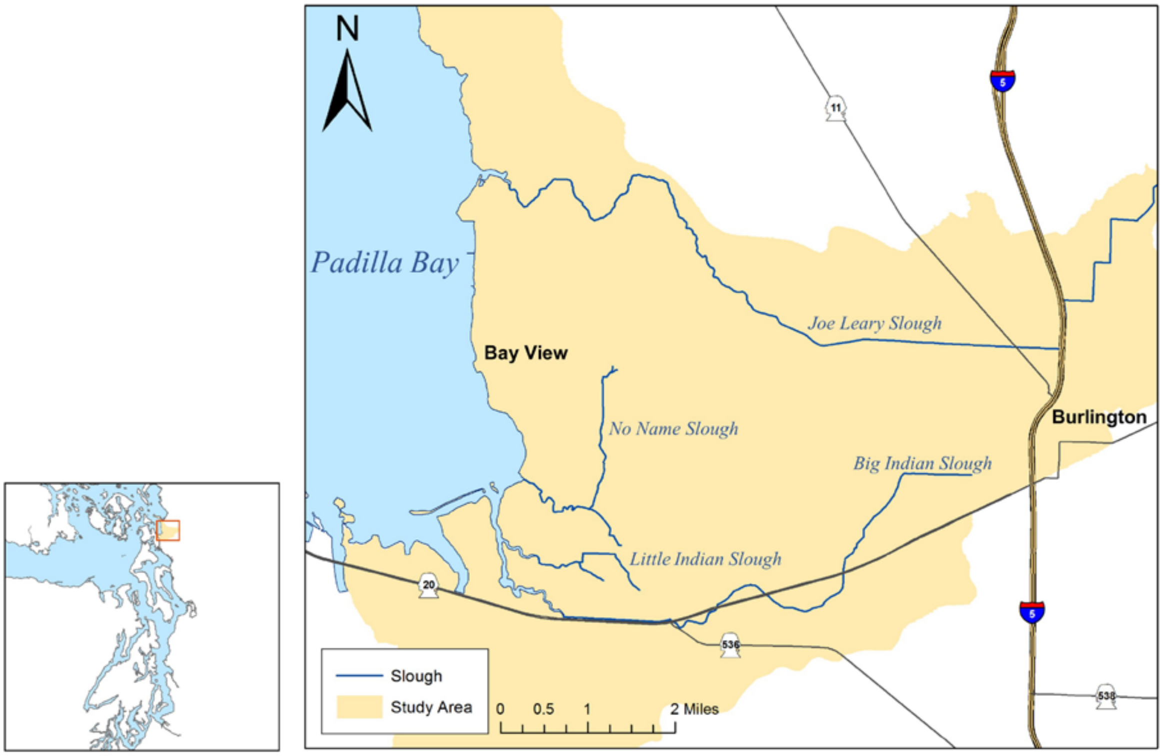


Figure 1. Eastern Padilla Bay watershed study area.

Goals and Objectives

The goal of the eastern Padilla Bay tributaries TMDL is to develop a plan to meet water quality standards for FC. The technical analysis in this water quality study findings report will help accomplish this goal through the following:

- Provide a comprehensive assessment of data.
- Identify and characterize bacteria concentrations and loads throughout the four freshwater tributaries.
- Recommend TMDL strategy including loading capacities, load allocations, and wasteload allocations to meet water quality criteria and protect beneficial uses.

Water Quality Standards and Beneficial Uses

Freshwater 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 the eastern Padilla Bay tributaries are based on the *Primary Contact Recreation* use [WAC173-201A-200(2)(b)]. The freshwater quality standards for this study area are:

1. Geometric mean criterion not to exceed 100 cfu/100mL.
2. Not more than 10% of samples (or any single sample when less than ten samples exist) exceed 200 cfu/100mL (percent exceedance criterion).

The percent exceedance criterion is calculated as the 90th percentile. The 90th 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.

This study addresses impaired freshwaters shown in Figure 2 and listed in Table 1.

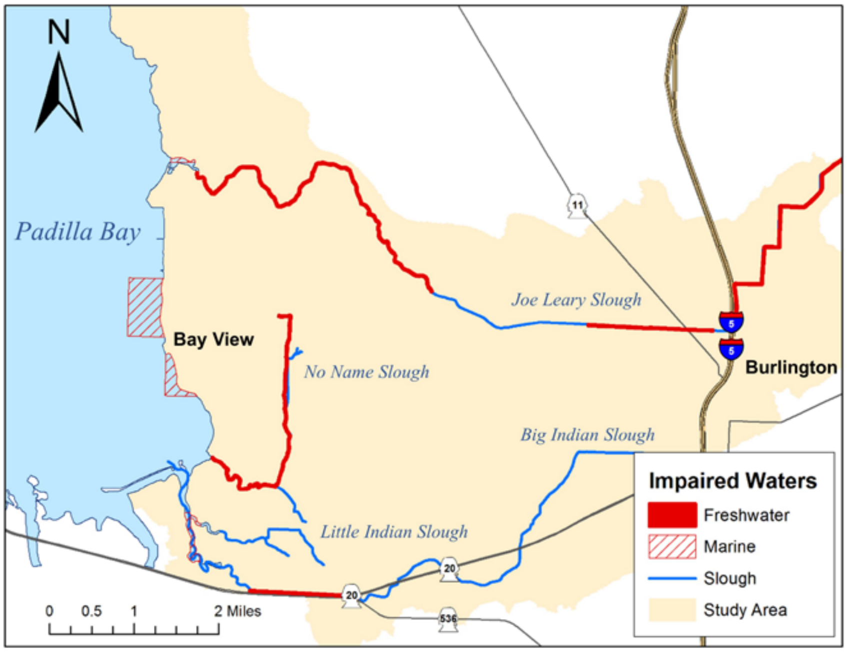


Figure 2. FC 303(d) listings of impaired waters (2014).

Table 1. 303(d) listings, or impaired waters, for FC in the Eastern Padilla Bay Watershed addressed by this study.

Listing ID	Waterbody Name	Pollutant	Medium	Reach Code (Assessment Unit ID)
45711	Big Indian Slough	Bacteria	Freshwater	17110002000331
7158	No Name Slough	Bacteria	Freshwater	17110002000314
39608	Joe Leary Slough	Bacteria	Freshwater	17110002001748
39607	Joe Leary Slough	Bacteria	Freshwater	17110002000523
16410	Joe Leary Slough	Bacteria	Freshwater	17110002000031

In January 2019, the Washington State Department of Ecology (Ecology) adopted amendments to Chapter 173-201A WAC, Water Quality Standards for Surface Waters 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. Data for this study were collected prior to the rulemaking, and this report was completed during the transition period (2020) which allows for the option of using the FC indicator.

If a TMDL is written for both recreational and shellfish harvesting uses, the recreational use will need to meet the updated criteria starting in 2021 (Ecology, 2019). To meet both uses, dual monitoring can be done to determine the attainment of each use (recreation and shellfish) or the facility may wait for effectiveness monitoring to occur using E. coli. Samples collected during effectiveness monitoring may be analyzed for E. coli and compared with water quality standards during the water quality assessment to determine attainment of the recreational use.

Marine Standards

While E. coli will be used to determine future attainment of the recreational use in freshwaters, FC will continue to be used to determine attainment of the shellfish harvesting use in marine waters. The marine water quality standards for shellfish harvesting are:

- FC organism levels must not exceed a geometric mean value of 14 colonies/100 mL, with not more than 10% of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 43 colonies/100 mL. [WAC 173-201A-210(3) (b)].

Study Area

Watershed Description

The eastern watershed draining into Padilla Bay is located within Skagit County in Water Resources Inventory Area (WRIA) 3 Lower Skagit-Samish. Four major freshwater tributaries (Joe Leary Slough, No Name Slough, Little Indian Slough, and Big Indian Slough) drain into Padilla Bay (Figure 3).

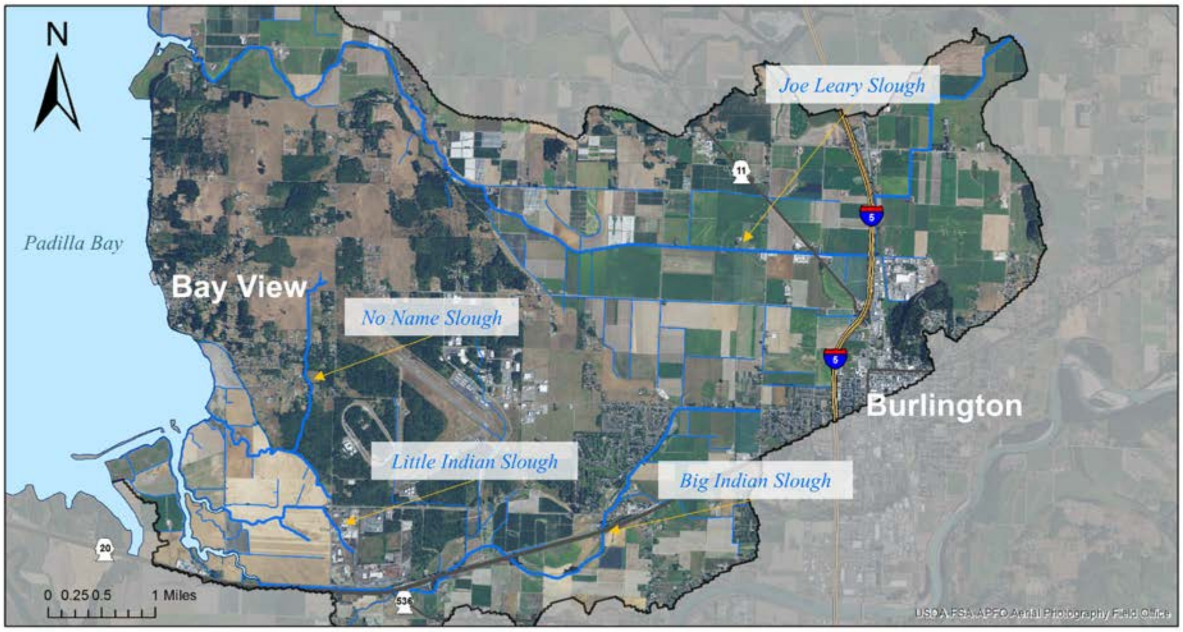


Figure 3. Satellite imagery map of study area.

Maintained drainage ditches run along roads in much of the eastern Padilla Bay watershed. Skagit County Public Works dredges sediment and vegetation from ditches along roadways (Fields, 2016). Many ditches also drain pastures, fields, and forest areas to flow into roadside ditches or directly into sloughs. The main source of sedimentation in the ditches and sloughs on the flats is soil eroded from agricultural fields (Bulthuis, 2013).

Land use within the watershed is primarily agriculture. As of 2010, the average farm size was 99 acres, with most farms under 50 acres (USDA, 2012). Figure 3 shows the relative land use for each slough subbasin. Relative land use for each slough subbasin was estimated using 2010 land-use data (Washington State Parcel Based Land Use). Joe Leary and Little Indian drainage areas are largely agricultural (79% and 86%, respectively), with the remainder mixed land use. No Name and Big Indian drainage areas are both approximately 50% agriculture, followed by roads and transportation, residential, and commercial areas.

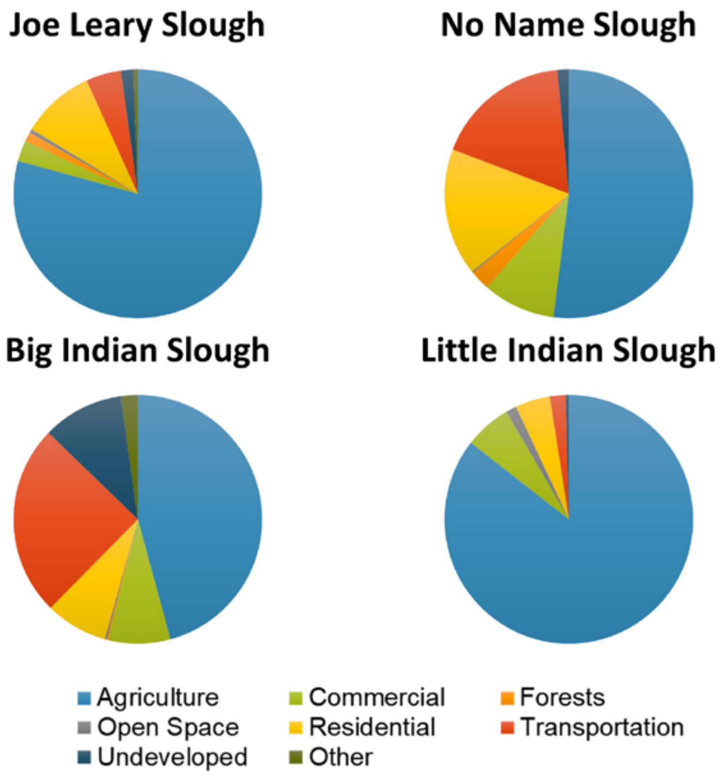


Figure 4. Land use for slough subbasins.

Joe Leary Slough is the largest subbasin, draining about 10,000 acres, and is mainly agricultural (79%). In its upper reaches, Joe Leary Slough drains field and roadside ditches. After flowing under Interstate-5, the slough flows through agricultural fields before discharging into Padilla Bay.

No Name Slough (watershed of 2,500 acres) flows through areas of low intensity agriculture and rural housing. According to the Washington Department of Fish and Wildlife, Coho salmon, cutthroat trout, and resident fish historically used the No Name watershed (Skagit Conservation District and Padilla Bay Estuary Research Reserve, 2005). Coho salmon smolts have been documented as far upstream as Bayview Road (Dugger, 2000).

The smallest subbasin, Little Indian Slough (650 acres), drains a small industrial area of Bay View Ridge and flows through several fields to the same dike as Big Indian Slough.

Big Indian Slough is the southernmost slough in the eastern Padilla Bay watershed, draining approximately 5,200 acres. The drainage area includes a significant part of Bay View Ridge, including industrial and residential areas, a small airport, and a golf course, before flowing through the agricultural floodplain to the dike. Just under half of the drainage area is agricultural land.

Point Sources

Five types of NPDES permits are present in the Padilla Bay watershed: municipal separate stormwater sewer systems (MS4s), sand and gravel stormwater, industrial stormwater, construction stormwater, and individual industrial permits. Figure 5 shows the spatial distribution of these permits, and they are summarized in Table 2.

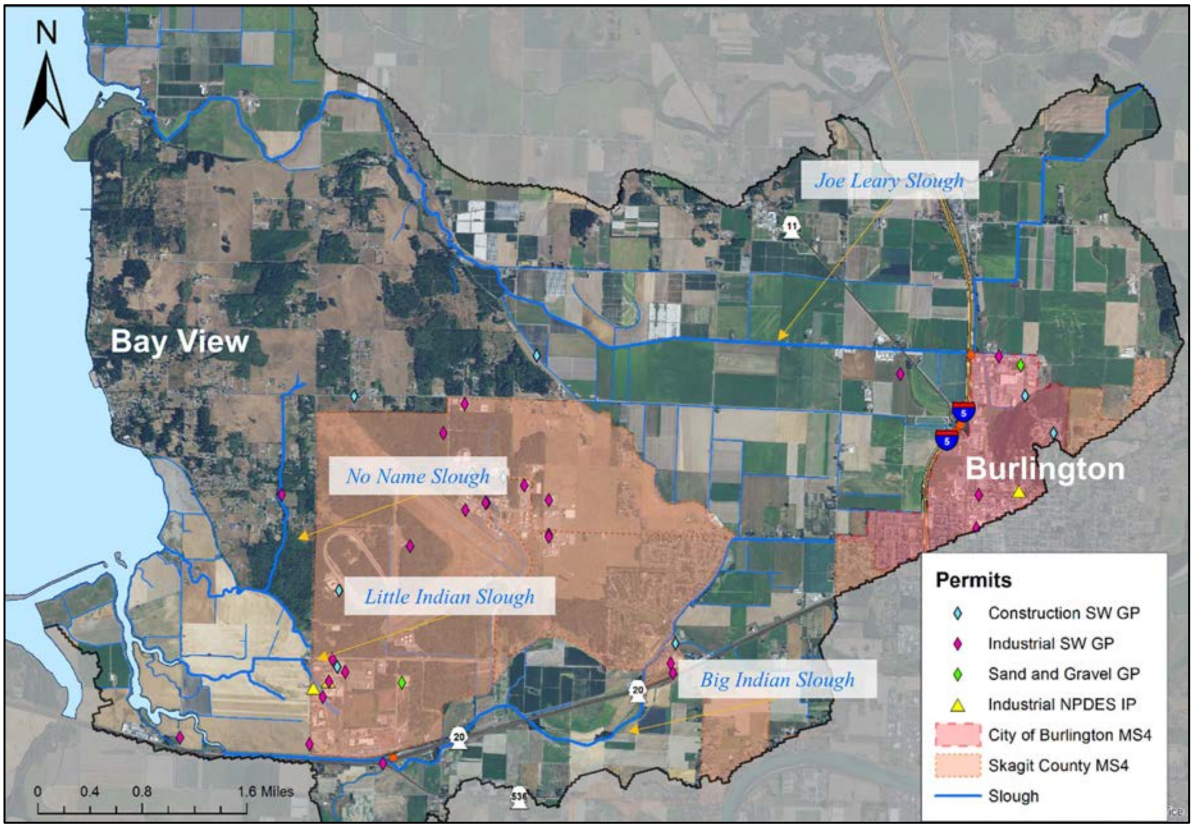


Figure 5. Map of point sources throughout study area.

Table 2. Summary of NPDES and State Waste Discharger permit holders.

Permit Type	Category	Permit Count
MS4	Skagit County	1
MS4	City of Burlington	1
MS4	WSDOT	1
General	Sand & Gravel	4
General	Construction Stormwater	24
General	Industrial Stormwater	26
Individual	Industrial NPDES	2

A full list of point sources and permit holders can be found in Appendix E.

Hydrology

Each of the sloughs maintains a tidegate that pumps high flows over the dikes and into the bay. These gates control freshwater to flow out during low tide and prevent salt-water flow upstream into the sloughs during high tide.

Joe Leary Slough drains to a dike with tidegates. During high tide, the gates close and freshwater collects in a small reservoir that has been dredged. Other tidegates exist at the pump station and at the confluence of ditches and channels with Joe Leary Slough. At low tide, the tidegates open and freshwater flows into the bay. The pump station pumps water during high flows from the channel to the north of Joe Leary Slough. Freshwater from Big Indian Slough flows into Padilla Bay during low tide through six tidegates and two vertical turbine pumps. The pump station operates during peak storm events that coincide with high tides and is controlled by a series of floats. The main tidegate for Little Indian Slough is located at the dike and has no pump station. The main tidegate and pump station for No Name Slough are near the mouth.

The quantity of freshwater discharging into Padilla Bay reflects the seasonal rainfall. Peak discharge is typically from November to February, and the period of low discharge is from July to October (Bulthuis, 2013). Local water quality monitoring groups and farmers have reported that the sloughs often have very little to no flow by the end of the dry period (Fields, 2016). Often during the dry season, water discharging from the tidegates into the bay is marine water that previously leaked through to the freshwater side (Skagit Conservation District and Padilla Bay Estuary Research Reserve, 2005).

Bulthuis (2013) estimated the maximum daily freshwater discharged into Padilla Bay from drainages in the watershed to be less than 1% of daily total exchange in Padilla Bay. Most of the freshwater that enters the bay is exchanged with the Strait of Georgia marine water.

Climate

The climate for the study area is characterized by mild, cloudy, wet winters and relatively dry summers. About 75% of the annual average precipitation occurs from October to April (Fields, 2016). Rainfall is generally continuous and of light-to-moderate intensity, rather than brief heavy rainfall. The driest months of the year are typically during the summer from July to August.

Seasonal variations for this study were determined using historical precipitation records and were compared with rainfall data from the 2016–2017 sampling period. Based on historical precipitation averages, the wet season is defined as October–April, and the dry season is from May–September (Fields, 2016). Daily precipitation data from 2016–2017 were obtained from the National Estuarine Research Reserve System in Padilla Bay. Seasonal variations in rainfall during the two years of this study were typically consistent with historical precipitation patterns. Figure 6 shows the monthly total precipitation (inches) for the Padilla Bay watershed. The main exception was during August 2016, which had unseasonably high rainfall. However, this storm event was not captured during sampling; therefore, the samples collected during the dry season are still representative of typical seasonal conditions.

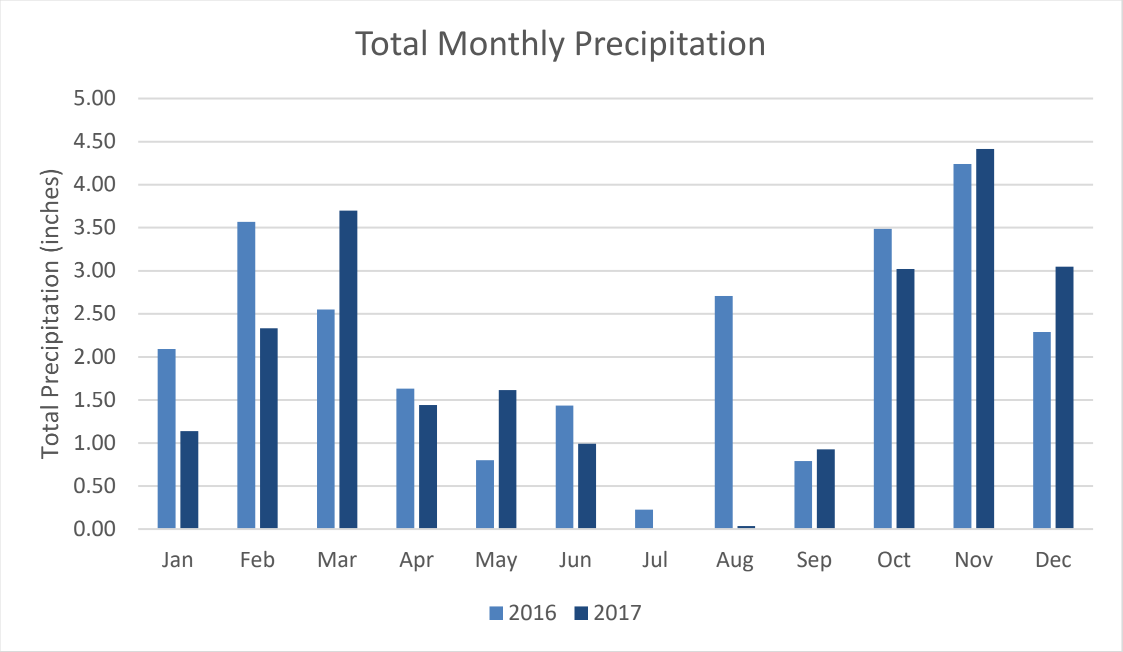


Figure 6. Total monthly precipitation at National Estuarine Research Reserve System in Padilla Bay.

Shellfish Bed Protection

The four freshwater sloughs that are the focus of this study ultimately discharge to Padilla Bay, which has a history of shellfish harvesting. Washington State Department of Health (DOH) collects and analyzes bacteria samples to protect consumers from eating contaminated shellfish. Figure 7 shows the DOH Shellfish Safety Beach Status Map for Padilla Bay. Padilla Bay is closed for butter and varnish clams due to marine biotoxin zones. Both the March Point Recreation Area (western shoreline) and Bay View State Park (eastern shoreline) are closed public shellfish beaches. Both beaches are closed year-round for all species due to shoreline survey information not meeting water quality standards for recreational shellfish harvesting. The restricted area off March Point near Anacortes is classified as “prohibited to shellfish harvesting” due to a wastewater outfall.

The results from this study will help to inform clean-up actions that will ultimately benefit downstream uses. Implementation activities based on the technical analysis completed using FC data are expected to reduce both FC and E. coli levels and to protect downstream beneficial uses.

Beach Status

All areas are closed for the recreational (sport) harvest of scallops due to biotoxins.

Public Shellfish Beaches (click beaches for info.)
✖ Closed (click beach for species)
• Beach End Points

Marine Biotoxin Closure Zones (click area for info.)
▨ Closed for Butter and Varnish Clams only

Water Quality Classification (click area for info.)
🟩 Approved
🟫 Closed Due to Pollution

Figure 7. Washington State Department of Health (DOH) Shellfish Harvesting Map.

Methods

Data Collection

Fecal coliform bacteria (FC) data were collected at (1) a fixed-network of routine sampling sites throughout Joe Leary Slough, Big Indian Slough, Little Indian Slough, and No Name Slough, (2) a subset of outfalls throughout the town of Bay View (Figure 8). Each of the fixed sites were sampled more than five times throughout the field collection duration. Additional sites were added to further pinpoint potential pollutant sources as investigative sites. Although these investigative sites were not used as part of the technical analysis component of this project, they are useful to help identify potential bacterial sources.

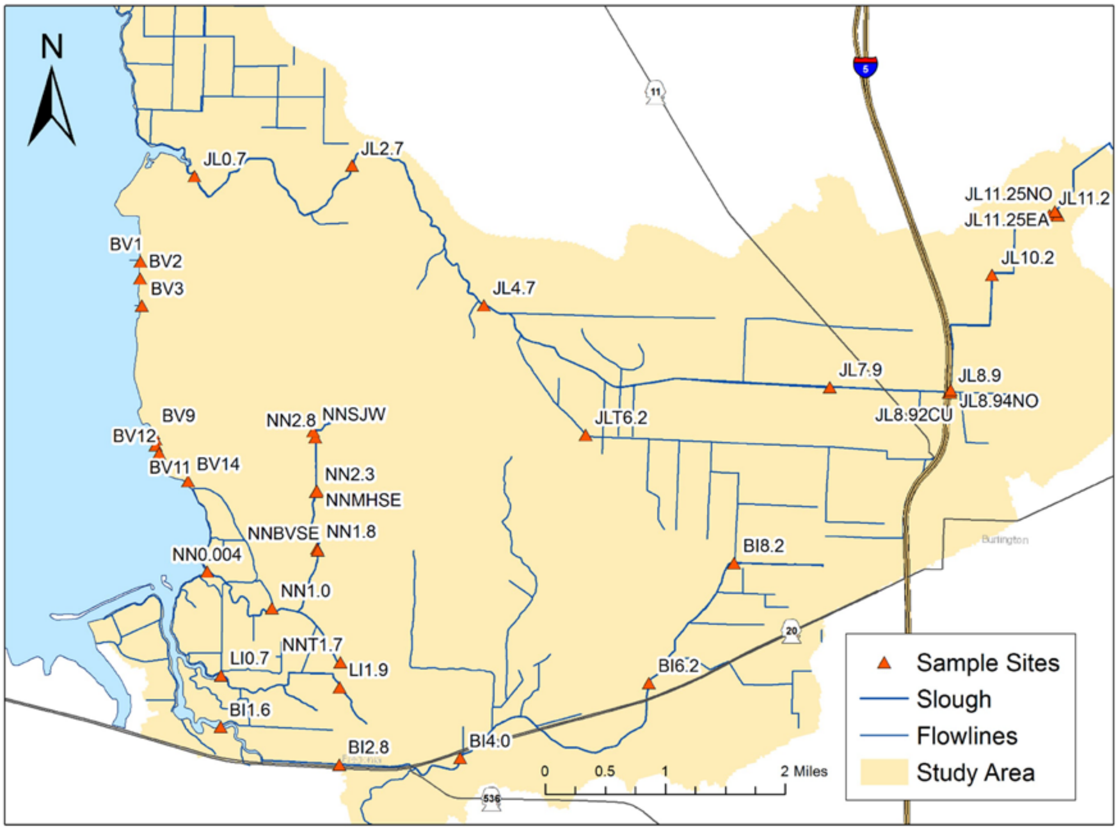


Figure 8. Map of sampling sites.

This study followed the procedures and protocols outlined in the QAPP (Fields, 2016). Bacteria samples were collected at a fixed-network of sites from April 2016–May 2017. Some sites were only able to be sampled intermittently due to low flow levels. Flow measurements were taken along with bacteria samples at select sites throughout both wet and dry seasons. For the site near the tidegate on Joe Leary Slough (JL0.7), flow measurements were taken during low tide, when the tidegate was open.

The QAPP (Fields, 2016) stated the possibility of further investigation of FC concentrations using optical brightener surveys. However, due to limits on staff resources and scheduling constraints, this field sampling method was not used. Shoreline surveys were conducted by sampling Bay View outfall sites.

Bacteria samples were analyzed by Manchester Environmental Laboratory (MEL) according to standard methods outlined in the QAPP (Fields, 2016).

Sites with both FC samples and flow measurements were used to calculate bacteria loads. Fixed sites refer to sites that were sampled routinely, typically biweekly. Intermittent sites were sampled when sampling schedule and flow conditions allowed. Some sites located upstream in a slough (e.g., No Name Slough) or outfalls (e.g., Bay View outfalls) dried up during the dry season; therefore, they were sampled intermittently.

See Appendix A for a summary table of sites, number of bacteria samples and flow measurements, and location descriptions.

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.

The rollback method has been applied by Ecology in many other bacteria water quality studies (Coots, 2002; Fields, 2016; Joy, 2006; Joy and Swanson, 2005; Mathieu and James, 2011; McCarthy, 2018; 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 causing 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 only in place 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 criteria. Any water body with bacteria targets is expected to:

- Meet both the applicable geometric mean and "percent exceedance" criteria.
- Protect designated uses for the category.

The rollback method assumes that the distribution of data follow a log-normal distribution. Bacteria concentrations from each of the sites were tested for log-normality prior to the use of the roll-back method. In all instances, the data sets met the log-normality test. Sites that were not log-normally distributed were not used as part of the statistical rollback analysis. The cumulative probability plot of the observed bacteria data gives an estimate of the geometric mean and 90th percentile which can then be compared to the bacteria concentration standards.

Establishing Critical Seasons

FC concentrations and loads vary seasonally throughout the Padilla Bay watershed. Critical conditions can be a flow regime or seasonal period when the greatest bacteria problem exists. Due to limited streamflow data, critical seasons (wet and dry) were used for this study. The use of a critical season is consistent with other bacteria TMDLs (Mathieu and James, 2011; Lawrence and Swanson, 2013; Svrjcek, 2006). The critical season for each site was ultimately determined through the Statistical Rollback analysis, based on the season that required the greatest reduction in FC to meet water quality standards.

Data Quality

The QAPP developed for this study describes the procedures used to collect and analyze field measurements and water quality samples (Fields, 2016). Sampling procedures and protocols for this study complied with the procedures outlined in the QAPP. Following the 2016–2017 field collection, data were reviewed according to quality assurance (QA) procedures and were uploaded into Ecology's Environmental Information Management (EIM) database. Ecology assessed all data used in this report for quality and also to determine if the data met the quality objectives from the QAPP.

Field sampling procedures and laboratory analyses inherently have associated uncertainty, which results in data variability. Measurement quality objectives (MQOs) state the acceptable variability for a project (Fields, 2016). All bacteria samples for this study were analyzed in the Manchester Environmental Laboratory (MEL).

Field Measurements

Precision for streamflow field measurements was assessed by taking replicate measurements at streamflow sites throughout the study. The results for streamflow met study field measurement MQOs with a median percent relative standard deviation (%RSD) of 2% (MQO < 10% RSD).

Water quality measurement instruments, Hydrolab MiniSonde® and YSI Exo® multiprobes, were calibrated with certified standards before each sampling trip, following the SOP EAP033 (Swanson, 2007) and manufacturer's recommendations. MQOs for dissolved oxygen, specific conductivity, pH, and temperature post-calibration checks are presented in Table 3. Tables with post-calibration results for the different water quality parameters are in Appendix B.

Table 3. MQOs for Hydrolab MiniSonde or YSI post checks.

Parameter	Accept	Qualify	Reject
Temperature (°C)	≤ ± 0.2 °C	> ± 0.2 and ≤ ± 0.8 °C	> ± 0.8 °C
Specific Conductivity	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%
pH	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%
Dissolved Oxygen	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%

Lab Replicates

Total precision for field sampling and laboratory analysis was assessed by collecting replicate samples, which are two samples taken from the environment at the same time and place using the same protocols. Precision for field replicates is expressed as percent relative standard deviation (%RSD). The RSD, also known as the coefficient of variation, is computed as the standard deviation of two values divided by their average. The value is then converted to percent by multiplying by 100 and referred to as the percent (%) RSD.

The MQOs are described in the QAPP (Fields, 2016). The results for the field replicates precision are in Table 4. Based on these results, the FC samples collected for this study met the MQOs for precision.

Table 4. Lab replicate MQOs.

Parameter	Method	Precision - MQO	% Samples Meeting MQO	Meets MQO criteria?
FC - MF	SM9222D	50% of replicate pairs < 20% RSD	60%	YES
		90% of replicate pairs < 50% RSD	97%	YES
FC - MPN	SM 9221E	50% of replicate pairs < 50%	100%	YES
		90% of replicate pairs < 100%	100%	YES
E. Coli	SM9222G	50% of replicate pairs < 20% RSD	47%	NO
		90% of replicate pairs < 50% RSD³	91%	YES
Enterococci	ASTMD 6503-99	50% of replicate pairs < 20%	57%	YES
		90% of replicate pairs < 50%	86%	NO

Lab Duplicates

Precision for laboratory analysis is measured through analyzing duplicate samples. Duplicate laboratory analysis refers to analyzing duplicate aliquots taken from a single sample container in the lab. MEL routinely duplicates sample analyses in the laboratory to determine laboratory precision. The results for lab duplicates provide an estimate of lab analytical precision, including the homogeneity of the sample matrix (MEL, 2016). Any of the samples that did not meet the MQO for lab duplicates were qualified as estimates.

Comparability, Representativeness, and Completeness.

Based on the methods used and the precision results of the data, the data collected for this study are comparable with other data collected for, and used to develop, TMDLs in the state of Washington (Mathieu, 2006). The data used to calculate geometric means and 90th percentile values were representative, to the extent practical, of the conditions of each water body during the averaging seasonal period applied (wet, dry, or annual).

This met the requirements outlined in the QAPP (Fields, 2016) for completeness (minimum number of samples per site) when developing recommended allocations at specific locations.

Results

Fecal Coliform Results

FC data were analyzed seasonally to identify patterns during the wet season (November–April) and dry season (May–October). Seasonal geometric mean values for sites with sampling during both seasons are compared in Figure 9. There is not a strong seasonal difference in FC concentrations, with ten sites having a higher geometric mean during the wet season and eight during the dry season. The overall highest geometric mean for both seasons was located at JL8.92CU. Sites that did not show a strong seasonal difference in FC levels based on the geometric mean are JL8.9, JL2.7, BI8.2, and LI1.9.

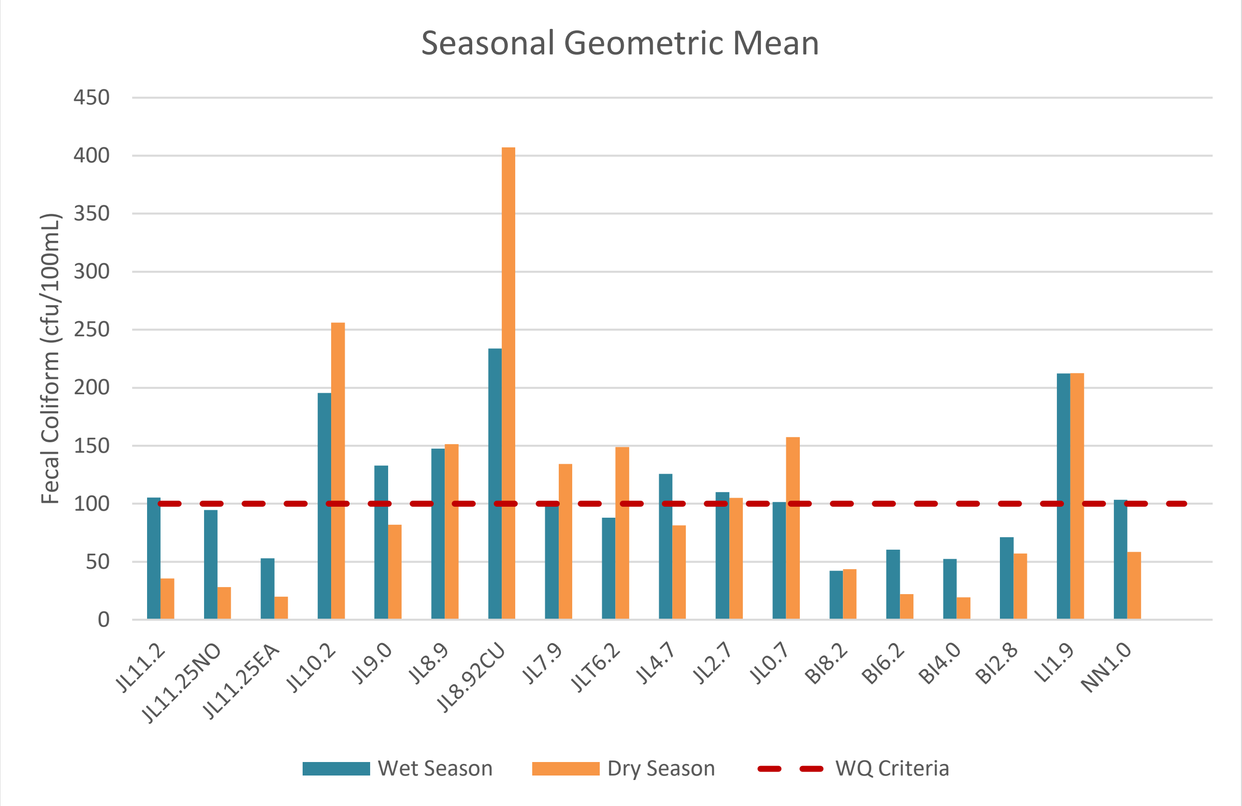


Figure 9. Seasonal FC geometric mean.

Fecal Coliform Loading

Loading patterns are used to observe seasonal variations, where a load represents the amount of bacteria entering a stream during a defined time. Loads were calculated as annual and seasonal averages. Average loads were calculated at sites with five or more flow measurements and FC samples. Average seasonal loads were calculated as the average of individual loads at each site (based on FC sample and flow measurement) for both the wet and dry seasons.

Figures 10 and 11 show the loading patterns at different sloughs during both seasons. All sites had higher loads during the wet season than during the dry season; this is generally due to increased precipitation and runoff. Joe Leary Slough had the highest overall average wet and dry season loads. Big Indian and No Name Sloughs had similar wet-season average FC loads. FC loads were generally the same for both seasons for the Bay View outfalls, although these loads are minimal compared to FC loads that the sloughs bring into Padilla Bay. Generally, FC loading increased from the uppermost sampling sites to the lower reaches of the sloughs. This is consistent with expected patterns, as flow tends to increase moving downstream.

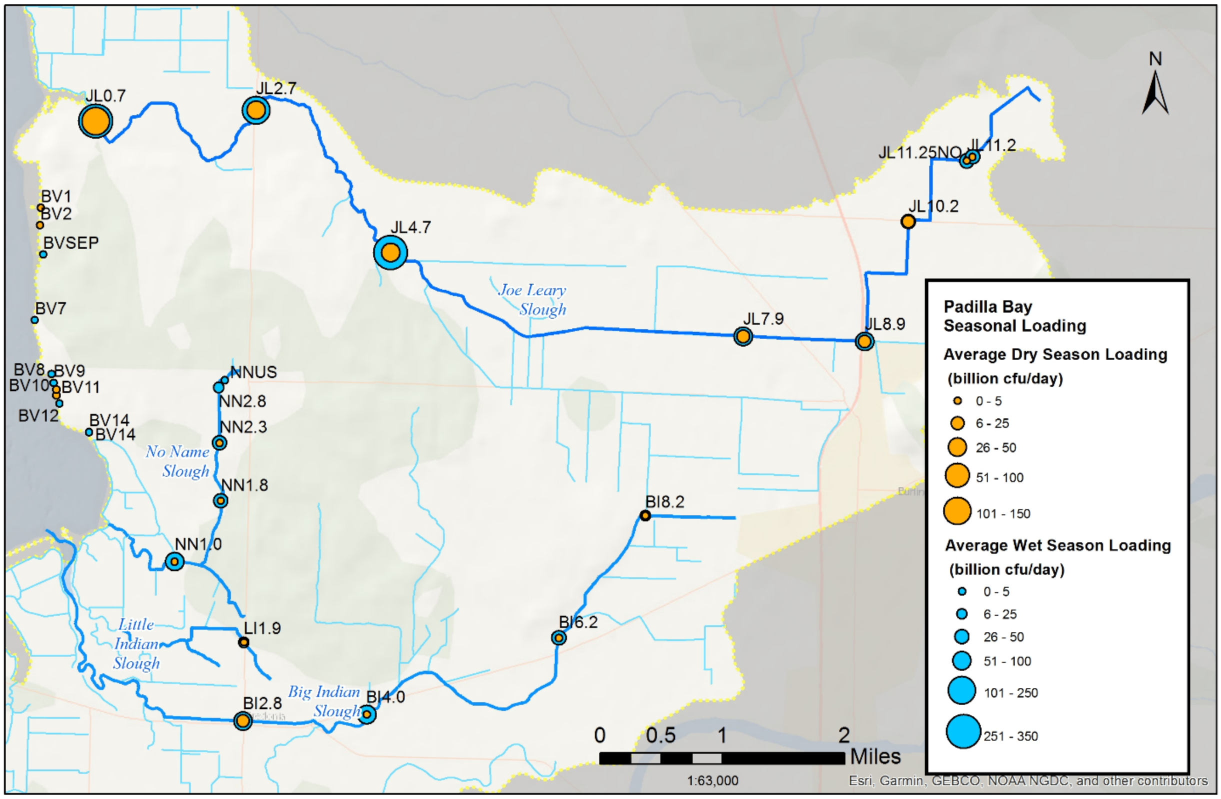


Figure 10. Map of seasonal average FC loading.

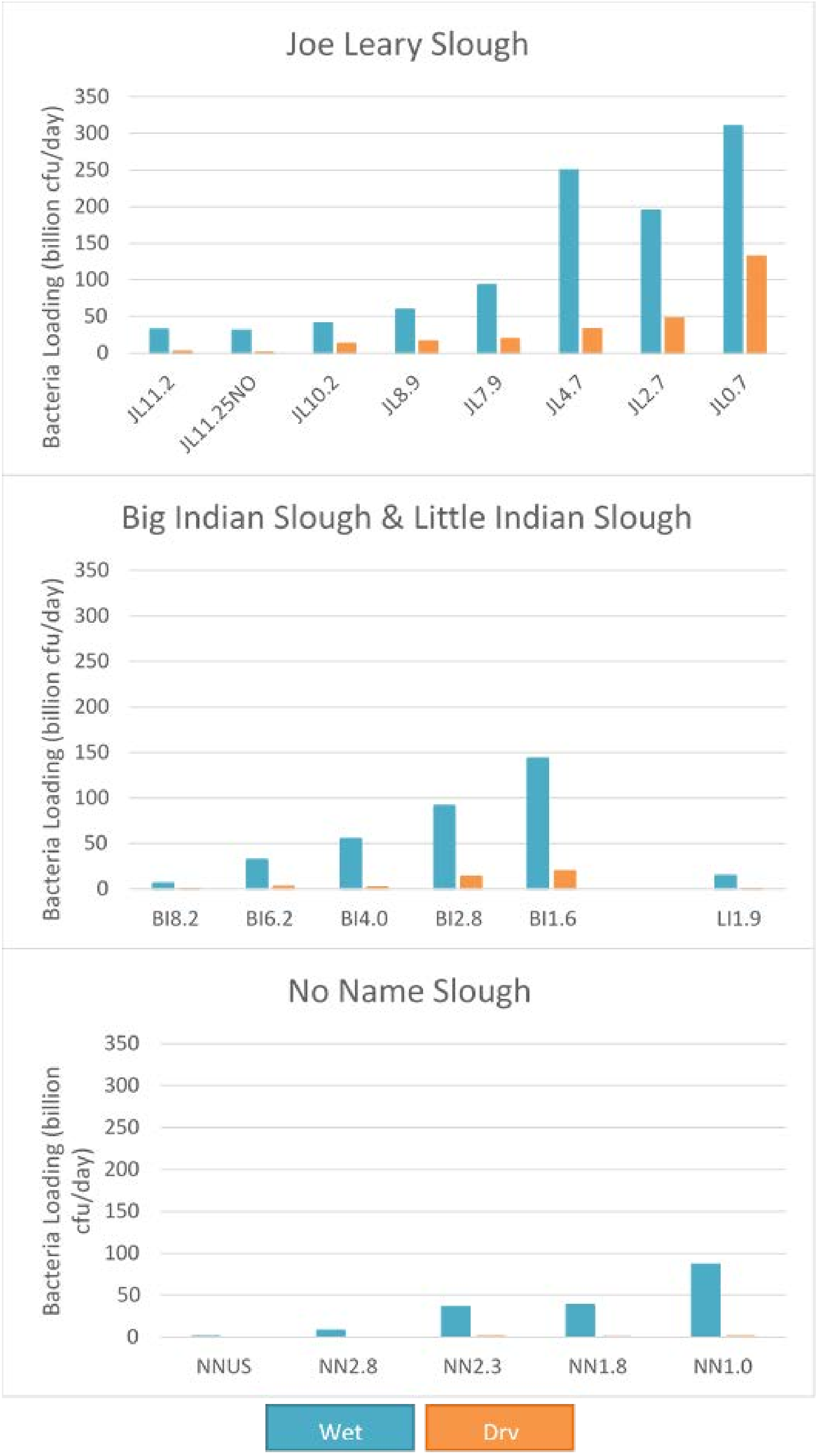


Figure 11. Seasonal average bacteria loads.

Storm Event

The QAPP planned for sampling of two storm events (Fields, 2016). Due to staffing and schedule constraints, Ecology staff were unable to two full storm events. Figure 12 shows total daily precipitation throughout the entire study period (lines), precipitation during sample dates (points), and sampling events that occurred during days with high precipitation (arrows). Generally, sampling occurred during periods with low precipitation.

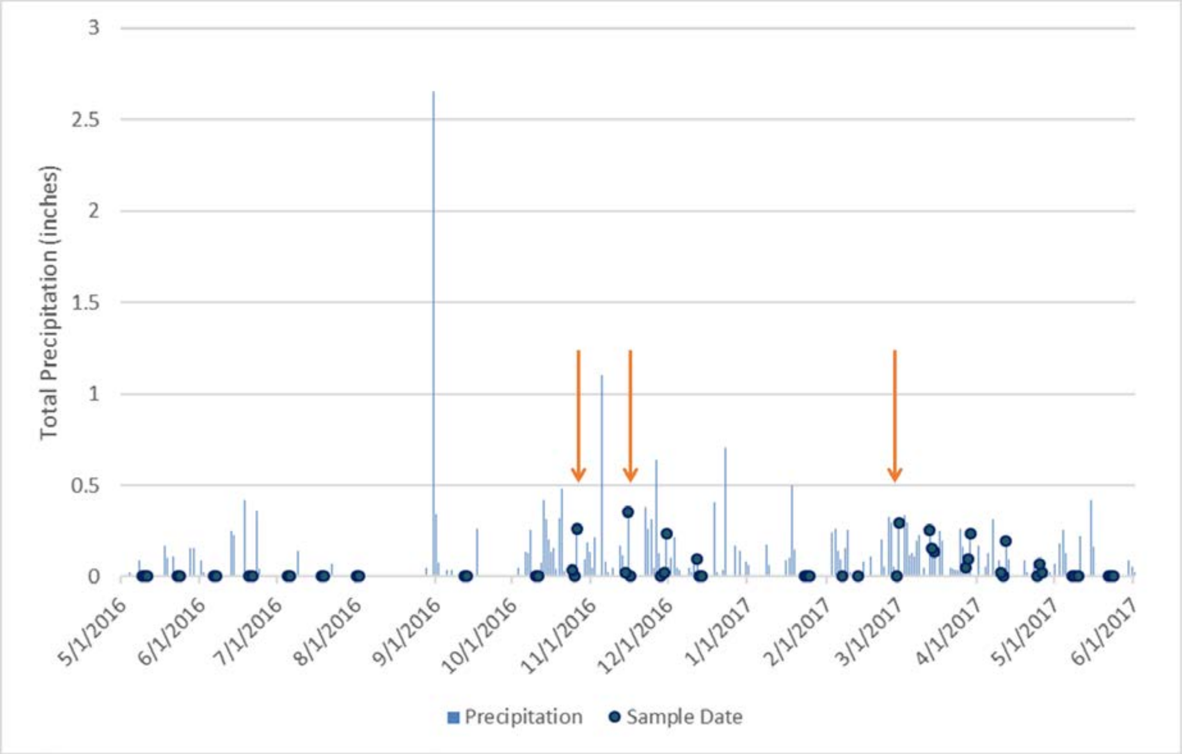


Figure 12. Daily rainfall accumulation during study period.

Points mark sampling dates. Arrows mark high precipitation events that coincided with sampling dates (10/26/16, 11/15/16, 3/1/17).

The sampling date with the highest precipitation (11/15/05) qualified as a storm event (0.35 inches of rain). However, the timing of sampling did not coincide with the period of heavy rainfall; therefore, results from this day are representative of light-moderate rainfall during the wet season.

The rain accumulation on October 26, 2016 (0.26 inches) was less than a full storm event (>0.30 inches). The day prior had no precipitation. Sampling occurred during the time period with heavy rainfall; therefore, the samples are representative of a heavy rainfall event. Sampling results show that sites with the highest bacteria concentrations were the culvert leading into Joe Leary Slough (JL8.92CU) and Bay View outfall (BV10) (960 and 840 cfu/100 mL, respectively) (Figure 13). Other notable sites with high bacteria concentration (>200 cfu/100 mL) were JL8.9 (indicating influence by JL8.92CU), the middle reach of No Name Slough (NN1.8) and one of its small tributaries (NNT1.7), and all of the Bay View outfalls.

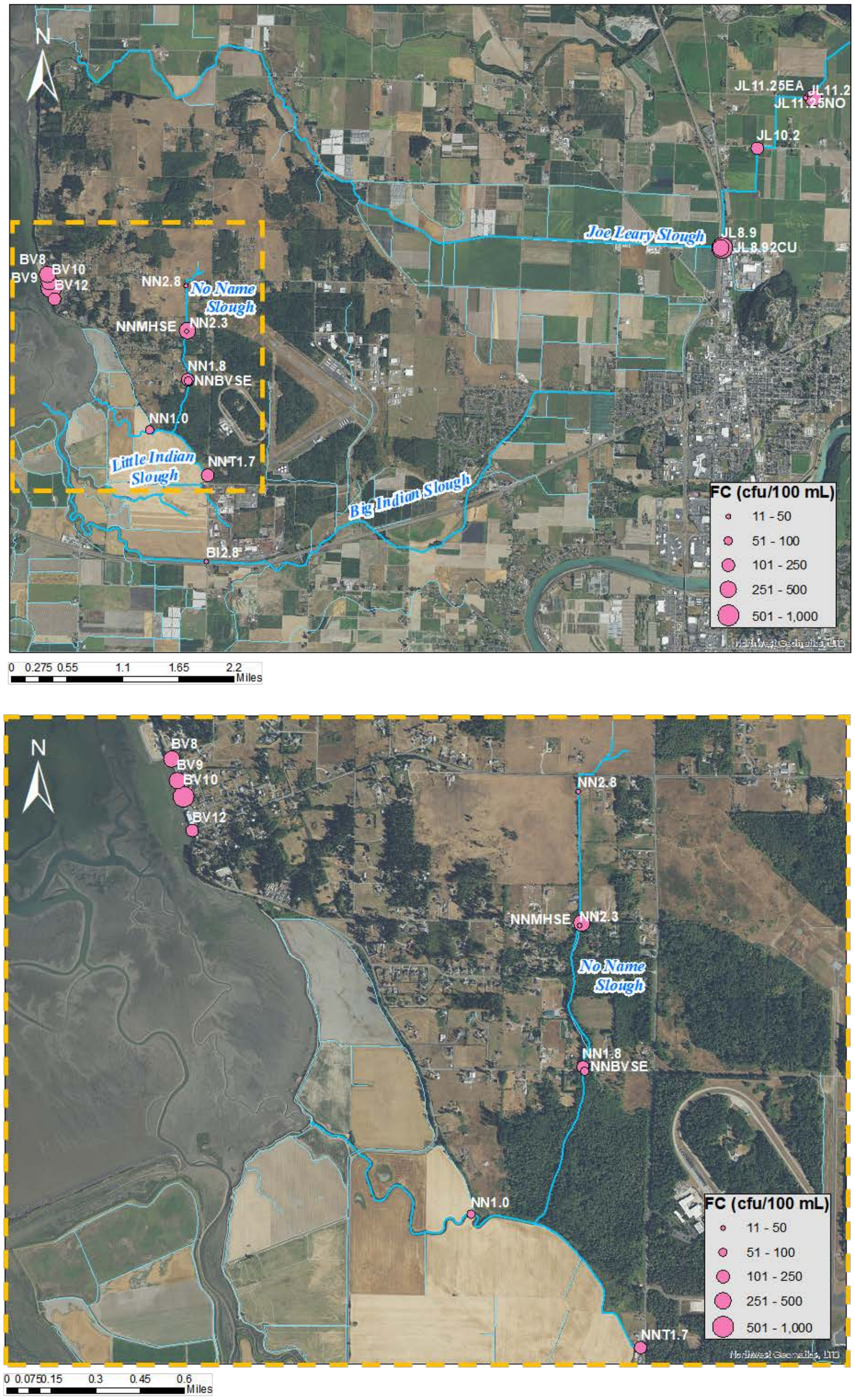


Figure 13. Map of bacteria concentrations from October 26, 2016 heavy rainfall event.

March 1, 2017 also had high precipitation (0.29 inches); bacteria sampling coincided during heavy rainfall (Figure 14). For this sampling date, No Name Slough was sampled in detail. Concentrations were highest at the ditches discharging near NN1.8 and NN2.3, NNBVNW (800 cfu/100 mL) and NNMHNW (680 cfu/100mL), respectively (Figure 14). High FC concentrations were found at sites furthest downstream (NN1.0 and NN0.004).

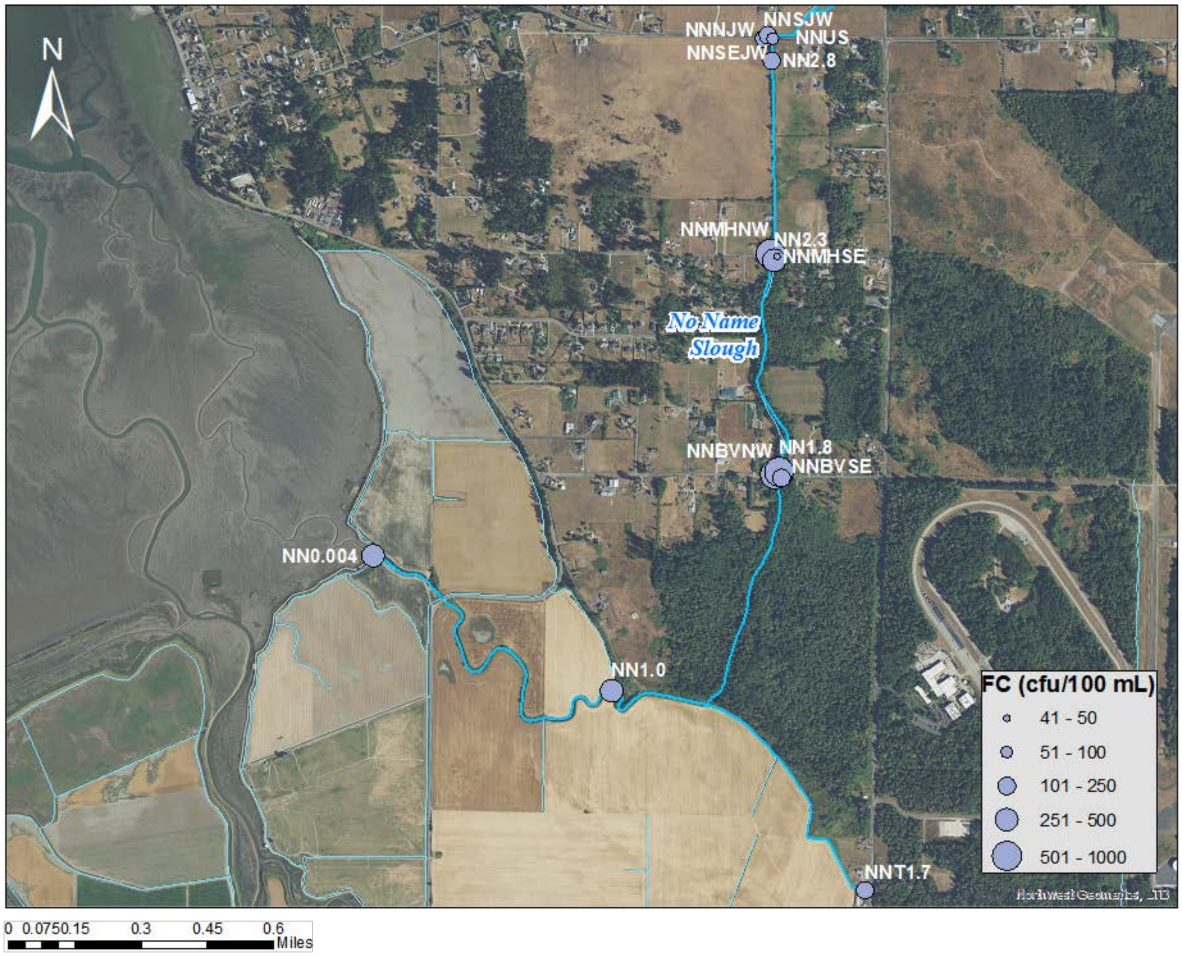


Figure 14. Map of bacteria concentrations from March 1, 2017 heavy rainfall event.

Although these events did not qualify as an official storm event (based on a recommended precipitation >0.30 inches), the high accumulation of rain during and right before bacteria sampling is nevertheless useful for understanding bacteria concentrations in response to heavy rainfall — particularly when identifying areas that are transporting high levels of FC, such as the culvert discharging into upper Joe Leary Slough (JL8.92CU), Bay View outfalls, and ditches discharging into No Name Slough (NNBVNW and NNMHNW).

A summary table of bacteria concentrations during these events is in Appendix C.

Statistical Rollback Analysis

Results from the statistical rollback analysis are presented as FC 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) either the geometric mean or 10% exceedance water quality criteria. Table 5 shows the percent reduction needed to meet water quality criteria annually and seasonally (for sites with 5 or more seasonal samples). FC reduction targets are set for geographic areas upstream of each study site.

Table 5. Results from statistical rollback analysis showing the percent reduction needed to meet water quality criteria annually and seasonally.

Site	n	Annual %Reduc	Wet %Reduc	Dry %Reduc	Greatest %Reduc	Critical Season
JL11.25EA	17	0%	13%	0%	13%	Wet
JL11.25NO	17	56%	71%	0%	71%	Wet
JL11.2	23	64%	72%	40%	72%	Wet
JL10.2	23	72%	75%	67%	75%	Wet
JL9.0	20	53%	61%	36%	61%	Wet
JL8.92CU	22	79%	77%	80%	80%	Dry
JL7.9	23	40%	28%	53%	53%	Dry
JLT6.2	19	55%	50%	64%	64%	Dry
JL4.7	23	32%	52%	0%	52%	Wet
JL2.7	23	18%	27%	8%	27%	Wet
JL0.7	23	34%	14%	50%	50%	Dry
NNBVSE	6	0%	NA	NA	0%	NA
NN2.8	12	43%	43%	NA	43%	Annual
NN2.3	13	83%	78%	NA	83%	Annual
NN1.8	14	70%	74%	42%	74%	Wet
NN1.0	17	61%	70%	28%	70%	Wet
LI1.9	18	81%	85%	69%	85%	Wet
BI8.2	19	27%	0%	66%	66%	Dry
BI6.2	21	40%	63%	0%	63%	Wet
BI4.0	21	0%	7%	0%	7%	Wet
BI2.8	23	7%	23%	0%	23%	Wet
BV1	7	0%	NA	NA	0%	NA
BV2	8	11%	NA	NA	11%	Annual
BV3	6	0%	NA	NA	0%	NA
BV10	11	82%	56%	NA	82%	Annual
BV11	6	35%	NA	NA	35%	Annual
BV12	9	0%	NA	NA	0%	NA
BV14	4	0%	NA	NA	0%	NA

For the majority of sites, the greatest seasonal reductions occurred during the wet season. Typically, critical seasons for nonpoint sources occur during high-rainfall periods, particularly during the start of a rainfall event when bacteria are “flushed” from surface soils into the streams (Ahmed and Rountry, 2007). Some sites did not have enough samples collected during the dry season due to low flow, so an annual critical season was assigned to them (Bay View outfalls and upper No Name Slough sites).

Select Joe Leary Slough sites (JL8.92CU, JL7.9, JLT6.2, and JL0.7) and one Big Indian Slough site (BI8.2) require greater reductions during the dry season than during the wet season.

Despite each site being assigned a critical season based on the rollback analysis, some sites show stronger seasonal differences in FC levels than others. Recognizing this will be useful when targeting seasonal and annual sources of FC during implementation work.

See Appendix F for more detailed statistical rollback results.

Subbasin Summary

The following sections present bacteria results summarized by major subbasin and the Bay View shoreline outfalls. Figure 15 shows the spatial distribution of seasonal bacteria geometric means at sampling sites.

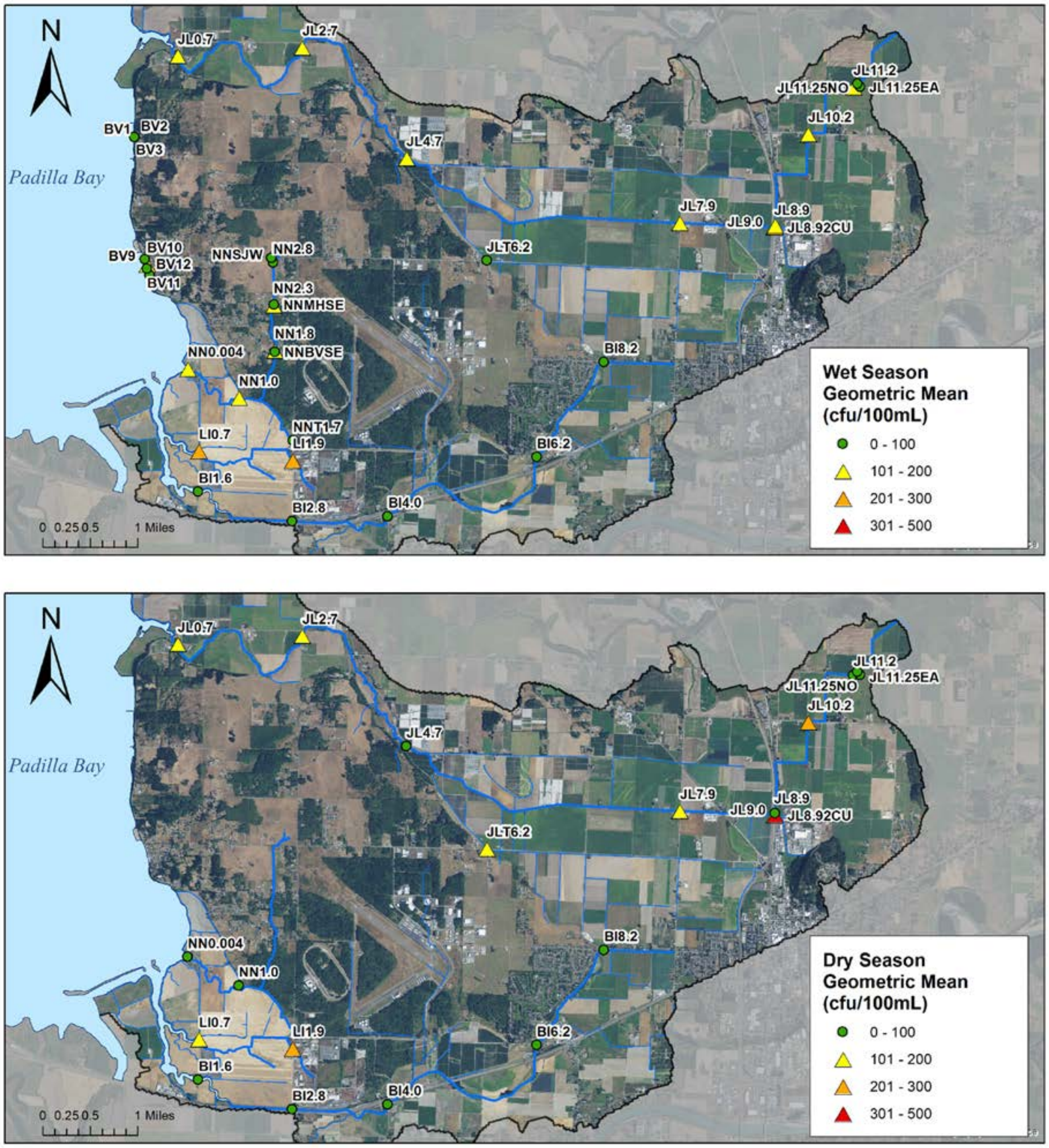


Figure 15. Map of seasonal bacteria geometric means.

Wet season above and dry season below.
Triangles indicate exceedance of water quality criteria.

Joe Leary Slough

Joe Leary Slough is the largest of the sloughs in the eastern Padilla Bay watershed. Joe Leary Slough flows through an agriculture-dominated landscape. Three dairies operate in the upper watershed along with pastures, feed corn, and a wide variety of row crops, including potatoes, blueberries, strawberries, and broccoli (WSDA Cropland Data 2017). The slough also flows through patches of other mixed land use, including flowing along a commercially developed area in northwest Burlington (near JL8.9).

Data results are summarized in Table 6. Water quality exceedances occurred during both the wet and dry seasons for the majority of sites, with all sites exceeding the 90th percentile criterion during the wet season. Three sites (JL7.9, JLT6.2, and JL0.7) had more samples exceed the 90th percentile criteria during the dry season than during the wet season. The highest water quality exceedances overall occurred at JL8.92CU during both seasons, indicating a source of bacteria draining into this culvert that should be further investigated.

Table 6. FC results for Joe Leary Slough.

Bold values indicate water quality exceedance.

Site	Annual (n)	Annual GM	Annual %Exc	Wet	Wet GM	Wet %Exc	Dry	Dry GM	Dry %Exc
JL11.25EA	17	38	**12%**	11	53	**18%**	6	20	0%
JL11.25NO	17	62	**29%**	11	95	**36%**	6	28	**17%**
JL11.2	23	66	**35%**	13	**105**	**38%**	10	36	**30%**
JL10.2	23	**217**	**65%**	14	**196**	**57%**	9	**256**	**78%**
JL9.0	20	**109**	**30%**	12	**133**	**33%**	8	82	**25%**
JL8.92CU**	22	**286**	**77%**	14	**234**	**71%**	8	**407**	**88%**
JL8.9	24	**149**	**38%**	14	**147**	**50%**	10	**151**	**20%**
JL7.9	23	**114**	**22%**	13	**101**	**15%**	10	**134**	**30%**
JLT6.2**	19	**107**	**32%**	12	88	**25%**	7	**149**	**43%**
JL4.7	23	**104**	**30%**	13	**126**	**46%**	10	81	10%
JL2.7	23	**108**	**13%**	13	**110**	**15%**	10	**105**	10%
JL0.7	23	**123**	**22%**	13	**102**	**15%**	10	**157**	**30%**

n=count of samples; GM=geometric mean; %Exc= % of samples exceeding 90th percentile

Due to the large amount of agriculture in the Joe Leary Slough subbasin, potential sources of pollution may include livestock rearing facilities, agricultural operations using livestock manure as an agricultural fertilizer, onsite septic systems located in close proximity to surface waters or drainage systems (MS4 or agricultural drainage), and stormwater runoff.

No Name Slough

No Name Slough flows through an area that is mainly agricultural fields, and smaller areas with rural housing and some commercial areas, including the Skagit County Regional Airport. The downstream reaches of No Name Slough are influenced by tides, and the furthest freshwater site sampled for this study was NN1.0.

Due to low flows in the dry season, Ecology staff were unable to capture FC samples at most No Name Slough sites during the dry season. The furthest downstream site (NN1.0) was sampled during both the dry and wet seasons, and showed larger FC concentrations during the wet season (Table 7). The mainstem sites (NN2.3, NN1.8, and NN1.0) had the highest FC concentrations, compared with tributary and ditches that fed into the slough (NNSJW, NNMHSE, NNT1.7, NNBVSE). No Name Slough was sampled during a heavy rainfall event (March 1, 2017). During this event, FC concentrations were highest at ditches draining into No Name Slough near NN1.8 and NN2.3.

Table 7. FC results for No Name Slough.

Bold values indicate water quality exceedance.

Site	Annual (n)	Annual GM	Annual %Exc	Wet	Wet GM	Wet %Exc	Dry	Dry GM	Dry %Exc
NNSJW	6	80	**17%**	6	80	**17%**	0	NA	NA
NN2.8	12	91	**25%**	12	91	**25%**	0	NA	NA
NN2.3	13	**229**	**69%**	12	**197**	**67%**	1	NA	NA
NNMHSE	6	53	**17%**	6	53	**17%**	0	NA	NA
NN1.8	14	**182**	**64%**	12	**182**	**67%**	2	NA	NA
NNT1.7*	13	56	**15%**	10	89	**20%**	3	NA	NA
NNBVSE	6	80	0%	6	80	0%	0	NA	NA
NN1.0	17	87	**41%**	12	**103**	**50%**	5	58	**20%**

n=count of samples; GM=geometric mean; %Exc= % of samples exceeding 90th percentile

No Name Slough flows mainly through agricultural area, signifying that potential pollutions sources in these areas include livestock-rearing facilities, insufficient exclusion fencing, and potential lack of proper manure management or storage. Bacterial loading may be entering the watercourse from failing onsite septic systems or systems with insufficient drain fields located in close proximity to surface waters.

Little Indian Slough

Little Indian Slough is the smallest of the sloughs in this study. The slough travels through a commercial and developed area in Bay View, and then through agricultural fields, before flowing into the same dike as Big Indian Slough.

Ecology staff were able to sample only one freshwater site (LI1.9) during both the wet season and dry season (Table 8). Although the geometric mean values were equal between seasons (212 cfu/100mL), the dry season had a higher percentage of samples to exceed the percent exceedance criteria. The upstream area that drains into LI1.9 is commercially developed and is within the Skagit County MS4 permit area. This suggests that pollution sources could be coming from nonpoint sources and a stormwater control issue in this area. Ecology will continue to investigate pollutant sources as necessary in this area.

Table 8. FC results for Little Indian Slough.

Bold values indicate water quality exceedance.

Site	Annual (n)	Annual GM	Annual %Exc	Wet	Wet GM	Wet %Exc	Dry	Dry GM	Dry %Exc
LI1.9	18	**212**	**50%**	13	**212**	**46%**	5	**212**	**60%**

n=count of samples; GM=geometric mean; %Exc= % of samples exceeding 90th percentile

Big Indian Slough

Big Indian Slough flows through residential areas, a golf course, and other developed areas. The slough also flows alongside Highway 20, before flowing through agricultural fields and outflowing at the confluence of the dike that drains into Padilla Bay.

Compared to FC concentrations collected at the other major sloughs in the eastern Padilla Bay watershed, concentrations were generally lower throughout Big Indian Slough. One site exceeded water quality criteria during the wet season (BI6.2) and two sites exceeded criteria during the dry season (BI8.2 and BI2.8). Table 9 shows that bacteria concentrations were generally higher during the wet season, with the exception of the furthest upstream site (BI8.2).

Table 9. FC results for Big Indian Slough.

Bold values indicate water quality exceedance.

Site	Annual (n)	Annual GM	Annual %Exc	Wet	Wet GM	Wet %Exc	Dry	Dry GM	Dry %Exc
BI8.2	19	43	**16%**	12	42	8%	7	44	**29%**
BI6.2	21	41	**24%**	13	60	**38%**	8	22	0%
BI4.0	21	36	5%	13	52	8%	8	19	0%
BI2.8	23	65	9%	14	71	7%	9	57	**11%**

n=count of samples; GM=geometric mean; %Exc= % of samples exceeding 90th percentile

The Big Indian Slough subbasin is a mix of agricultural areas and transportation, commercial, and residential developed areas. Potential pollution sources in these areas include livestock rearing facilities, agricultural operations using livestock manure as an agricultural fertilizer, and onsite septic systems located in close proximity to surface waters or drainage systems (MS4 or agricultural drainage).

Bay View Outfalls

Select Bay View outfalls were sampled throughout the study duration. These sites drain areas through the town of Bay View and flow directly into Padilla Bay. Staff were unable to summarize seasonal results due to lack of flows during the dry season causing insufficient sampling data (less than 5 samples. Based on the annual results, high FC concentrations were found primarily in the southern group of outfalls (BV9, BV10, and BV11) (Table 10). These outfalls drain a more developed landscape than the northern outfalls.

Table 10. FC results for Bay View outfalls.

Bold values indicate water quality exceedance.

Site	Annual (n)	Annual GM	Annual %Exc	Wet	Wet GM	Wet %Exc	Dry	Dry GM	Dry %Exc
BV1	7	10	0%	5	7	0%	2	NA	NA
BV2	8	63	0%	6	66	0%	2	NA	NA
BV3	6	5	0%	5	3	0%	1	NA	NA
BV9	9	74	**44%**	9	74	**44%**	0	NA	NA
BV10	11	**201**	**36%**	9	**130**	**22%**	2	NA	NA
BV11	6	85	**17%**	4	NA	NA	2	NA	NA
BV12	9	29	**11%**	7	28	**14%**	2	NA	NA

n=count of samples; GM=geometric mean; %Exc= % of samples exceeding 90th percentile

Ecology sampled select Bay View outfalls (BV8, BV9, BV10, and BV12) during a heavy precipitation event on October 26, 2016. All sites had high FC concentrations (>200 cfu/100 mL), with the highest concentration at BV10 (840 cfu/100 mL), indicating that these outfalls were transporting high levels of FC runoff during times of high flow.

Bacteria Sample Comparison

Fecal Coliform and E. coli

E. coli samples were collected at a subset of fixed-network sites throughout the study period (Table 11). These samples are useful when comparing with the new Washington State water quality standards that adopted E. coli as the new bacterial indicator to protect water contact recreational uses (2019). Because the rulemaking change occurred after the study design and field sampling for this project, E. coli was not sampled routinely at every fixed-network site, and therefore was not used in the analysis.

The revised water quality criteria [WAC 173-201A-200(2)(b)] for E. coli are:

1. Geometric mean criterion not to exceed 100 cfu/100mL.
2. Not more than 10% of samples (or any single sample when less than ten samples exist) exceed 320 cfu/100mL (percent exceedance criterion).

Table 11. E. coli data summary.

Bold values indicate water quality exceedance.

Site	Samples (n)	Minimum (cfu/100 mL)	GeoMean (cfu/100 mL)	% Samples > 320 cfu/100 mL	Maximum (cfu/100 mL)
JL11.2	10	9	59	**11%**	380
JL10.2	9	34.5	**161**	**20%**	360
JL9.0	1	18	18	0%	18
JL8.9	9	18	76	0%	260
JL8.92CU	1	18	18	0%	18
JL7.9	1	48	48	0%	48
JLT6.2	1	400	**400**	**100%**	400
JL4.7	22	27	87	0%	270
JL2.7	3	35	89	0%	260
BI8.2	4	14	23	0%	33
BI6.2	11	2	30	9%	530
BI2.8	24	9	41	0%	133
LI1.9	11	26	96	10%	400
LI0.7*	7	53	**144**	**17%**	350
NNT1.7	1	14	14	0%	14
NN2.8	8	22	88	0%	240
NN1.8	1	140	**140**	0%	140
NN1.0	14	14	57	**18%**	840
NN0.004*	4	22	30	0%	41

*Marine sites

A comparison between FC and E. coli bacteria concentrations shows a good relationship (R^2=0.712) (Figure 16). This supports the use of FC in this report to improve water quality conditions in the Padilla Bay watershed considering the recent adopted rulemaking to change to E. coli as the new bacteria indicator in 2019. FC concentrations are generally higher than E. coli. Therefore, as FC impairments are addressed, water quality conditions are expected to improve and meet new water quality standards using E. coli as the bacteria indicator.

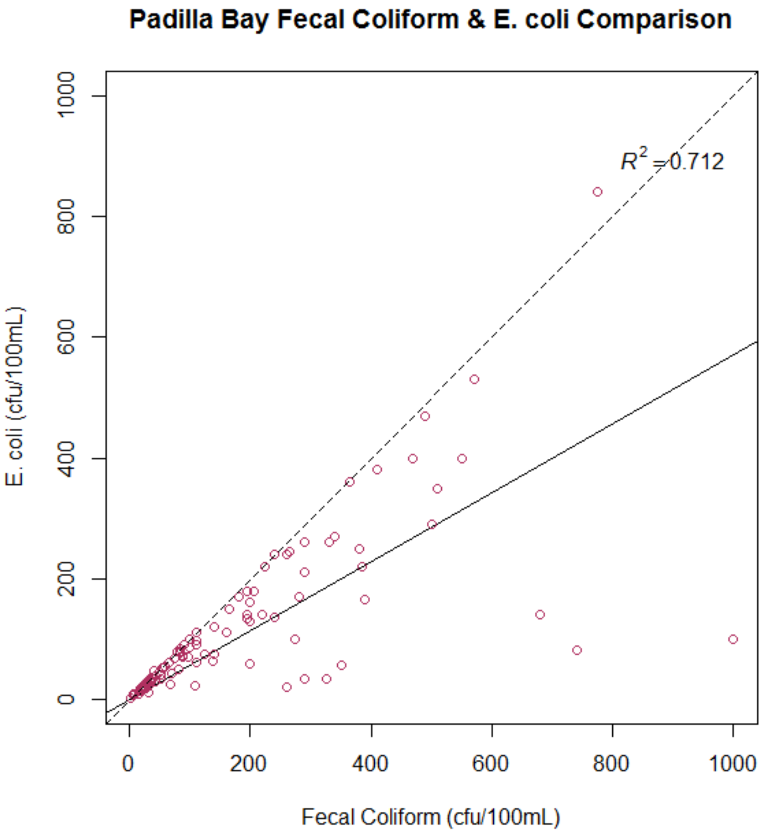


Figure 16. Comparison of FC and E. coli concentrations.

Fecal Coliform and Enterococci

In addition to FC and E. coli, Ecology sampled for enterococci bacteria at the furthest downstream site of each slough that discharges to marine waters. Enterococci bacteria have the ability to survive in saltwater, and EPA recommends enterococci as the best indicator of health risk in marine waters. With the new 2019 rulemaking, Ecology will use enterococci as the bacterial indicator for recreational marine waters; however, FC will continue to be used for shellfish harvesting criteria.

Enterococci bacteria samples (n=13 at each site) were collected at the furthest downstream sites at each of the sloughs (BI1.6, JL0.7, LI0.7, and NN0.004). All of these sites, except Joe Leary Slough, were determined to be marine sites based on salinity measured throughout the study period. Little Indian Slough had the highest geometric mean concentration of enterococci (316 cfu/100mL) (Figure 17).

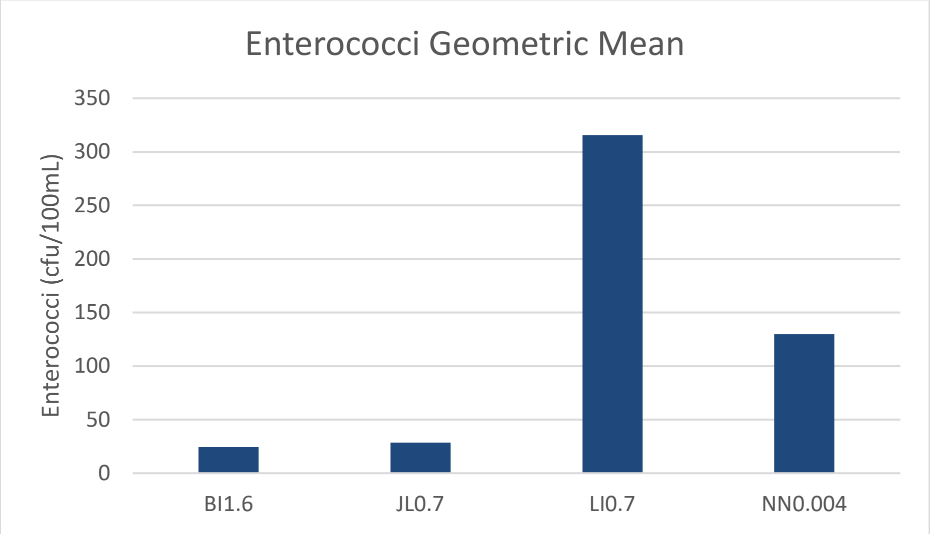


Figure 17. Enterococci geometric mean.

A comparison of FC and enterococci bacteria is shown in Figure 18, and these types of bacteria show a poor correlation (R^2=0.168). Enterococci was adopted to be the only bacterial indicator for recreational marine waters (FC is expiring in 2020), but FC will continue to be used to assess water quality in shellfish harvesting areas.

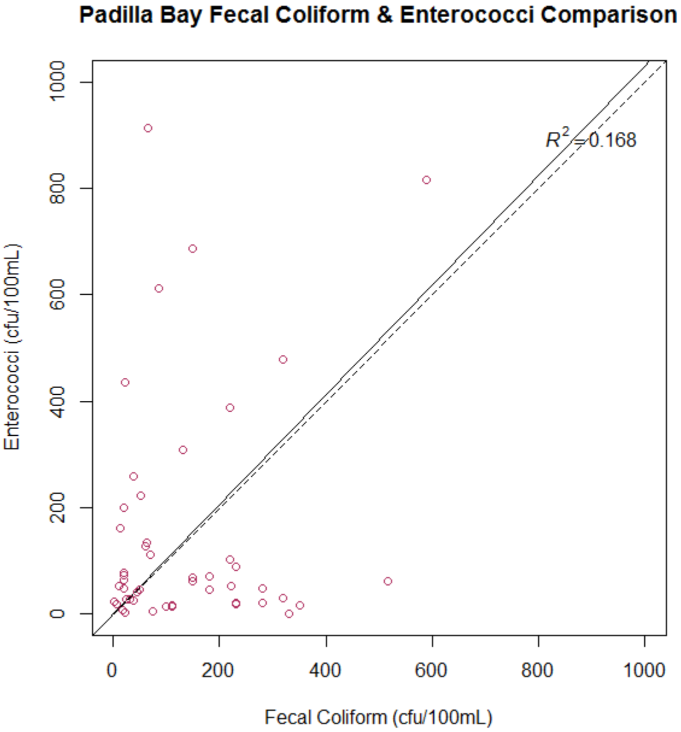


Figure 18. FC and enterococci bacteria comparison.

Other Water Quality Parameters

Dissolved oxygen, pH, specific conductivity, temperature, and turbidity were measured in the field using either a Hydrolab MiniSonde® or YSI Exo® instrument at select sites throughout the study period. These results are used in a general data summary in Tables 12–16.

Table 12. Summary of dissolved oxygen results.

Site	Count (n)	Max (mg/L)	Average (mg/L)	Min (mg/L)
JL11.25EA	1	5	5.4	5.4
JL11.25NO	1	5	4.6	4.6
JL11.2	20	15	5.7	1.5
JL10.2	23	11	6.5	2.5
JL9.0	1	6	5.6	5.6
JL8.9	29	14	6.2	3.6
JL7.9	37	9	6.8	5.0
JL4.7	34	7	5.4	3.7
JL2.7	24	7	4.9	2.6
JL0.7	30	7	4.9	2.9
NNUS	5	14	11.9	10.6
NN2.8	20	14	11.0	6.7
NN2.3	13	14	10.9	7.6
NN1.8	14	99	17.6	7.2
NN1.0	28	12	7.3	1.5
NN0.004	27	15	10.3	6.1
LI1.9	18	9	5.5	1.2
LI0.7	20	14	8.2	3.7
BI8.2	22	13	6.4	0.0
BI6.2	22	9	5.5	0.3
BI4.0	32	10	4.9	0.1
BI2.8	39	9	5.3	1.1
BI1.6	30	12	7.6	5.0

Table 13. Summary of pH results.

Site	Count (n)	Max (s.u.)	Average (s.u.)	Min (s.u.)
JL11.25EA	3	6.0	6.0	6.0
JL11.25NO	3	6.3	6.3	6.3
JL11.2	71	7.2	6.4	5.5
JL10.2	68	7.3	6.6	6.0
JL9.0	3	8.1	8.1	8.1
JL8.9	69	7.1	6.5	6.0
JL7.9	105	7.1	6.5	6.1
JL4.7	90	7.2	6.6	5.7
JL2.7	68	7.2	6.6	5.9
JL0.7	94	7.0	6.6	5.8
NNUS	17	7.8	7.0	6.7
NN2.8	48	7.8	6.9	5.7
NN2.3	42	7.7	7.1	6.4
NN1.8	43	8.1	7.3	6.7
NN1.0	67	7.6	7.0	6.2
NN0.004	95	8.6	7.3	6.1
LI1.9	69	7.4	6.8	6.2
LI0.7	74	8.3	7.1	6.0
BI8.2	74	7.1	6.5	5.8
BI6.2	65	7.2	6.6	5.7
BI4.0	72	7.4	6.8	6.3
BI2.8	98	8.0	6.8	6.0
BI1.6	81	7.6	6.9	6.4

Table 14. Summary of specific conductivity results.

Site	Count (n)	Max (umhos/cm)	Average (umhos/cm)	Min (umhos/cm)
JL11.25EA	1	186	186	186
JL11.25NO	1	325	325	325
JL11.2	20	381	303	197
JL10.2	21	399	272	208
JL9.0	1	289	289	289
JL8.9	22	386	304	237
JL7.9	53	398	300	247
JL4.7	37	402	313	239
JL2.7	23	395	324	233
JL0.7	23	755	363	218
NNUS	5	76	58	50
NN2.8	16	234	108	69
NN2.3	13	189	109	69
NN1.8	14	157	112	74
NN1.0	23	749	191	83
NN0.004	34	42,215	17,552	445
LI1.9	18	1,050	526	222
LI0.7	19	38,829	10,681	1067
BI8.2	20	346	255	132
BI6.2	21	416	338	209
BI4.0	22	406	304	149
BI2.8	44	399	301	158
BI1.6	22	14,100	2,825	207

Table 15. Summary of temperature results.

Site	Count (n)	Max (°C)	Average (°C)	Min (°C)
JL11.25EA	1	12.3	12.3	12.3
JL11.25NO	1	17.5	17.5	17.5
JL11.2	21	28.4	13.8	6.0
JL10.2	25	20.8	12.6	5.4
JL9.0	1	16.6	16.6	16.6
JL8.9	26	18.7	12.1	5.2
JL7.9	30	19.5	12.1	5.6
JL4.7	31	19.3	11.0	5.3
JL2.7	23	18.2	12.0	5.7
JL0.7	28	20.6	12.4	5.4
NNUS	5	16.3	8.2	1.3
NN2.8	16	15.3	7.7	0.1
NN2.3	16	13.3	7.2	0.3
NN1.8	15	12.7	7.6	0.4
NN1.0	26	15.6	9.2	1.5
NN0.004	24	26.3	12.3	3.1
LI1.9	24	22.8	11.2	4.2
LI0.7	23	30.8	14.9	3.1
BI8.2	24	21.2	12.5	5.1
BI6.2	22	19.6	12.3	4.2
BI4.0	28	20.9	11.3	3.2
BI2.8	32	18.0	11.5	3.8
BI1.6	25	23.8	13.6	3.9

Table 16. Summary of turbidity results.

Site	Count (n)	Max (NTU)	Average (NTU)	Min (NTU)
JL11.2	11	310	100	23
JL10.2	1	90	90	90
JL0.7	21	90	39	9
NNUS	2	11	8	5
NN2.8	4	14	9	6
NN1.0	1	9	9	9
NN0.004	18	39	17	5
LI1.9	9	110	65	20
LI0.7	13	310	90	5
BI8.2	10	400	87	15
BI6.2	1	110	110	110
BI1.6	13	110	36	10

TMDL Recommendations

The technical analysis in this water quality study findings report provides recommendations for loading capacity, load allocations, and wasteload allocations for the eastern Padilla Bay tributaries TMDL. These recommendations were determined through a technical analysis using data collected during the 2016–2017 sampling period.

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. Additionally, the *critical season* that causes the highest water quality standard violation is considered when determining the loading capacity.

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*. 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*.

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 wasteload and load allocations, any margin of safety, 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.

The eastern Padilla Bay tributaries TMDL report will contain the determined loading capacity, wasteload and load allocations, and margin of safety. The next few sections provide the technical analysis and methods for estimating these TMDL elements. The final TMDL report will include the official TMDL requirements.

Recommended Loading Capacity

Loading capacities, load allocations, and wasteload allocations 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 load allocations (Lawrence and Swanson, 2013; Lawrence, 2009; Mathieu and James, 2011; Pickett, 1997; Swanson, 2008).

Loading capacities were calculated as daily loads for both the wet and dry season to inform when FC sources are violating criteria. Seasonal loading capacities also help avoid the potentially erroneous conclusion that when FC loads are met during one season of the year, they are assumed to be met throughout the entire year. The critical season for each site is based on the largest seasonal reduction needed to meet water quality criteria.

The loading capacity was calculated using the geometric mean criterion (100 cfu/100 mL) for bacteria concentration and the average seasonal flow. The recommended 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.

Bacteria sources are quite variable, and different sources can cause water quality violations under different conditions (e.g., poor dilution of contaminated sources during low-streamflow conditions or increased source loading during runoff events). Comparisons of loads along a stream, or between seasons at a site, can be instructive for identifying changes in FC source intensity and for evaluating impacts on marine waters. However, percent reductions are practical for identifying trends and tracking implementation progress. FC load reductions and percent reductions to meet water quality criteria are also included in Tables 17 and 18 (to guide implementation and clean-up efforts).

The percent reduction values in Tables 17 and 18 explain targets for improvement and indicate the relative degree the water body is out of compliance with criteria (i.e., how far it is over its capacity to receive FC source loads and still provide protection of the designated beneficial uses). The percent reduction values were based on the results from the statistical rollback analysis. Sites representing reaches or tributaries currently meeting water quality standards have a minimal reduction needed (<10%). Sites that require aggressive reductions in FC sources have a high percentage reduction value, while sites with minor problems have a low percentage reduction value. These percent reductions are useful to help guide restoration activities.

Recommendations for load reductions include a series of progressive FC reductions needed to meet water quality criteria, as reductions are achieved upstream. FC reductions were calculated using the following steps:

1. Estimate the existing FC load at each site during the wet or dry season (based on existing 90th percentile FC value and average seasonal flow).
2. Calculate the FC reductions as both a percentage and load estimate needed to meet water quality standards.

a. Begin with the furthest upstream site.
b. For the progressive reductions, calculate the adjusted FC reduction needed (in both load and percentage) for the following site moving downstream, if the load reduction is achieved upstream. Continue this method through the furthest downstream freshwater site.
c. As load reductions occur upstream, further downstream sites are expected to require either less or no reduction to meet water quality criteria.
d. If no reductions occur upstream, then the individual reduction values indicate the needed reductions to meet water quality criteria.

Table 17 shows the calculated loading capacities and FC reductions needed at sites at the four sloughs, as both individual and progressive reductions during the wet season and dry season. Individual reductions show how much FC levels need to be reduced when upstream improvements have not yet occurred. Progressive reductions are the amount of FC reduction needed if water quality criteria are met upstream.

This method highlights the effects that reducing pollution sources at upstream sites will have on improving water quality conditions downstream. These reduction estimates assume that bacteria reductions are occurring upstream; therefore, fewer reductions will be required downstream to achieve compliance with freshwater quality standards.

Bay View outfalls were estimated as recommended daily loading capacities for the entire year, due to low flows and inadequate data during the dry season (Table 18). Also, not enough samples allowed for dry season recommendations for most of the No Name Slough sites (NN1.8, NN2.3, NN2.8).

Appendix D provides more description on methods for developing these loading capacities.

Table 17. Recommended daily loading capacities for eastern Padilla Bay tributaries.

Shown in the table are loading capacities estimated from geometric mean criterion (100 cfu/100 mL) and the bacteria load (and percent) reductions needed to meet criteria. Daily loading capacities were estimated for both the wet and dry season. Progressive reductions assume that bacteria loads are reduced upstream. If no reductions upstream occur, then the individual reductions are needed.

Site	Wet Season LC b.cfu/ day	Wet Season Individual Reductions** b.cfu/day (%)	Wet Season Progressive Reductions** b.cfu/day (%)	Dry Season LC (b.cfu/day)	Dry Season Individual Reductions** b.cfu/day (%)	Dry Season Progressive Reductions** b.cfu/day (%)
JL11.25NO	16.5	79.7 (71%)	79.7 (71%)	9.3	0.0* (<10%)	0.0* (<10%)
JL11.2	15.3	78 (72%)	0.0* (<10%)	3.9	5.2 (40%)	5.2 (40%)
JL10.2	16.0	94.0 (75%)	14.4 (11%)	5.0	20.1 (67%)	14.9 (49%)
JL9.0	26.1	81.6 (61%)	67.3 (50%)	12.6	14.4 (36%)	0.0* (<10%)
JL7.9	59.2	46.5 (28%)	0.0* (<10%)	14.8	33 (53%)	18.1 (29%)
JL4.7	121.9	264.4 (52%)	197.1 (39%)	32.3	0.0* (<10%)	0.0* (<10%)
JL2.7	131.0	98.1 (27%)	0.0* (<10%)	52.2	9 (8%)	0.0* (<10%)
JL0.7	197.4	63.2 (14%)	0.0* (<10%)	81.0	161 (50%)	142.9 (44%)
NN2.8	5.3	8.1 (43%)	8.1 (43%)	–	–	–
NN2.3	6.4	44.3 (78%)	36.2 (64%)	–	–	–
NN1.8	7.2	40.0 (74%)	3.8 (7%)	–	–	–
NN1.0	22.1	101.9 (70%)	98.2 (67%)	0.7	0.6 (28%)	0.6 (28%)
BI8.2	4.2	0.0* (<10%)	0.0* (<10%)	0.6	2.2 (66%)	2.2 (66%)
BI6.2	15.1	51.9 (63%)	51.9 (63%)	4.3	0.0* (<10%)	0.0* (<10%)
BI4.0	49.4	7.3 (<10%)	0.0* (<10%)	7.5	0.0* (<10%)	0.0* (<10%)
BI2.8	75.9	44.6 (23%)	0.0* (<10%)	16.4	0.0* (<10%)	0.0* (<10%)
LI1.9	1.8	19.4 (85%)	19.4 (85%)	0.3	1.0 (69%)	1.0 (69%)

b.cfu/day= billion cfu/day; LC= loading capacity;
*0.0 (<10%) indicates minimal reduction needed;
**based on 90th percentile criterion (200 cfu/100 mL)

Table 18. Recommended loading capacities for Bay View outfalls.

Shown in the table are loading capacities estimated from geometric mean criterion (100 cfu/100 mL) and the bacteria load (and percent) reductions needed to meet criteria.

Site	LC b.cfu/day	FC Reductions** b.cfu/day (%)
BV1	0.33	0.0* (<10%)
BV2	0.06	0.02 (11%)
BV3	0.09	0.0* (<10%)
BV9	0.33	0.0* (<10%)
BV10	0.23	2.1 (82%)
BV11	0.29	0.3 (35%)
BV12	0.10	0.0* (<10%)

b.cfu/day= billion cfu/day; LC= loading capacity;
*0.0 (<10%) indicates minimal reduction needed;
**based on 90th percentile criterion (200 cfu/100 mL)

Recommended Wasteload Allocations

Recommended wasteload allocations were calculated for point sources within the study area. Without extensive runoff and stormwater data available, Ecology used a land-use-based approach, the Simple Method, to estimate the relative contribution of point sources to bacteria loads in stormwater runoff in the study area (Schueler, 1987). This method uses estimates of drainage area, impervious cover, stormwater runoff bacteria concentrations, and annual precipitation.

MS4 Permits

Both Skagit County and the City of Burlington have NPDES Phase II municipal separate storm sewer system (MS4) permits within the study area. Big Indian Slough travels through both permit areas, and Little Indian and No Name Sloughs are located downstream of the county permitted MS4 area.

The area that these permits cover was calculated using a spatial dataset for municipal stormwater permit area boundaries (Ecology, 2017). The percentages used for impervious cover specific to each land type (Table 19) were determined based on values from other TMDL studies and reports (Center for Watershed Protection, 2005; Joy, 2004; Lee, 2008; Svrjcek, 2006). The amount of impervious cover strongly correlates with water quality: the more impervious cover, the higher the bacteria levels (PSAT, 2005). Impervious surfaces such as roads, rooftops, and parking lots accumulate contaminants and prevent water from infiltrating as would occur on vegetated grounds. Due to the rush of water off these surfaces, stormwater can carry much of the bacteria directly into a stream, particularly during the wet season.

Table 19. Impervious cover fraction (Ia) for different land use categories.

Land Use Category	Ia
Agriculture	0.30
Commercial/Manufacturing	0.87
Forests/Parks	0.20
Residential	0.40
Transportation	0.80

The impervious fraction for each permit area (Table 20) was then calculated by taking the weighted average of land use cover and impervious fraction for each permit area (Department of Revenue, 2010).

Table 20. Municipal separate storm sewer systems (MS4) permit area and impervious fraction (Ia).

Permit	Category	Permit Holder	Area (acres)	Ia
MS4	County	Skagit County	4,496	0.62
MS4	City	City of Burlington	756	0.63

WSDOT Permits

WSDOT permits cover highway systems in the study area: Interstate Highway 5 (I-5), Washington State Route 11, State Route 20, and State Route 536. This study followed the approach of previous TMDL studies that estimated road cover depending on standard road widths and impervious fraction for major WSDOT roads (Svrjcek, 2006; Lee, 2008). Road width was estimated based on the number of lanes, assuming typical road widths (12 feet per lane). The road width for the different highways accounted for width due to the shoulder and right of way. Aerial photography was used to confirm this approach, by reviewing number of lanes, presence of shoulder area and right of way, and measuring road width distance. The results are summarized in Table 21.

Table 21. WSDOT road area and impervious fraction (Ia).

Road	# Lanes	Width (ft)	Length (ft)	Area (acre)	Ia
I-5	6	172	13,700	54	0.80
Route 11	2	24	9,600	5	0.80
Route 20	4	48	39,600	44	0.80
Route 536	2	24	7,700	4	0.80

General Permits

Major general permits in the study area include sand and gravel, construction stormwater, and industrial stormwater. For this TMDL, the following process was used to estimate wasteload allocations for general permits:

1. Aggregate permit holders by categories and estimate area and impervious cover through GIS spatial analysis, land use data, and permit information.
2. Estimate relative seasonal bacteria loading for permit category to achieve compliance with water quality standards using the Simple Method.
3. Assign wasteload allocations to stormwater permit holders based on permit categories.

The area covered by each general permit was estimated from reviewing current and historical water quality permits from Ecology's Water Quality Permitting and Reporting Information System (PARIS) database. Impervious cover was estimated by viewing sites using aerial photographs, spatial datasets of impervious area and land use cover, and impervious cover fractions from other studies (Table 22).

Table 22. General permit area and impervious fraction (Ia).

Permit	Category	Count	Area (acres)	Ia
General	Sand & Gravel	2	93	0.10
General	Construction Stormwater	20	150	0.70
General	Industrial Stormwater	21	1205	0.90

Precipitation

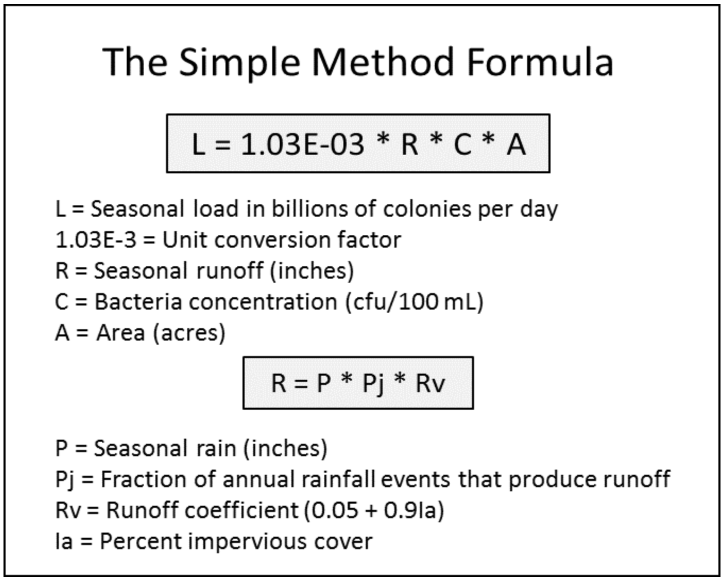
Precipitation during the wet season was estimated based on historical climate records from weather stations near the study area (1931-2005 Anacortes Station 450176; 1931-2005 Sedro Wooley Station 457507; 1956-2005 Mount Vernon 455678) (Fields, 2016). The average of total precipitation at each station during the wet season (October–April) and dry season (May–September) was used: 26.1 inches and 8.8 inches, respectively (Table 23).

Table 23. Total precipitation during wet and dry seasons (inches).

Season	Anacortes	Mount Vernon	Sedro Wooley	Average
Wet	20.1	23.8	34.6	26.1
Dry	6.2	8.5	11.6	8.8

Calculating Wasteload Allocations using the Simple Method

The Simple Method uses available data and assumptions to approximate the seasonal number of bacteria discharged in stormwater from different land use areas. The formula is shown in Figure 19.



The Simple Method Formula

L = 1.03E-03 * R * C * A

L = Seasonal load in billions of colonies per day
1.03E-3 = Unit conversion factor
R = Seasonal runoff (inches)
C = Bacteria concentration (cfu/100 mL)
A = Area (acres)

R = P * Pj * Rv

P = Seasonal rain (inches)
Pj = Fraction of annual rainfall events that produce runoff
Rv = Runoff coefficient (0.05 + 0.9Ia)
Ia = Percent impervious cover

Figure 19. The Simple Method formula.

The Simple Method formula requires certain constants and subbasin-specific values (Table 24):

- Area was estimated based on GIS spatial data, land cover, and permit information.
- The bacteria concentration value was set to achieve compliance the geometric mean criterion (100 cfu/100mL).
- The impervious fraction (Ia) was estimated for each permit area and is used to calculate the runoff coefficient.
- A constant of 0.85 was used for the fraction of annual rainfall events that produce runoff, consistent with other TMDL studies that have used the Simple Method (Svrjcek, 2006; Lee, 2008).
- Seasonal rain was based on a historical (1931-2005) average of total precipitation during the wet and dry season and was obtained from the National Estuarine Research Reserve System (NERRS).
- Seasonal runoff for each permit area was estimated based on precipitation, fraction of annual rainfall events that produce runoff (Pj), and a runoff coefficient (Rv).

Table 24. Values and constants used in Simple Method formula.

Loads are reported in billion cfu/day.

Permit	A (acres)	Ia	Pj	Rv	Wet Runoff (in)	Dry Runoff (in)	Wet Season Daily Load	Dry Season Daily Load
Skagit County	4,496	0.62	0.85	0.61	13.49	4.82	29.5	13.8
City Burlington	756	0.63	0.85	0.62	13.69	4.89	5.0	2.3
WSDOT	107	0.80	0.85	0.77	17.08	6.10	0.9	0.4
GP Sand & Gravel	93	0.10	0.85	0.14	3.11	1.11	0.1	0.1
GP Construction SW	150	0.64	0.85	0.62	13.79	4.92	1.0	0.5
GP Industrial SW	1205	0.87	0.85	0.83	18.48	6.60	10.8	5.1

GP= general permit; SW= stormwater; A= area; Ia= impervious cover fraction;
Pj= Fraction of annual rainfall events that produce runoff; Rv= runoff coefficient

The Simple Method was used to calculate wasteload allocations based on the constants and calculated values in Table 24. The target bacteria concentration was set at 100 cfu/100 mL to achieve compliance with the geometric mean water quality standards.

Individual Permits

There are two individual permits that discharge into surface water within the study area, with the remainder of individual permitted facilities discharging into either groundwater or sewer systems. Based on reviewing associated permit documents using Ecology's Water Quality Permitting and Reporting Information System (PARIS), these facilities currently have no effluent requirements established for FC.

Flow data were obtained from PARIS for the three facilities draining into surface waters; these data were averaged by season as an average flow. Daily wasteload allocations for both the wet and dry seasons were calculated using a bacteria concentration value of 100 cfu/100 mL, consistent with MS4 and other general permits (Table 25).

Table 25. Average seasonal flows used to calculate individual permit wasteload allocations.

Loads are reported as billion cfu/day.

Individual Permit	Dry Season Flow (cfs)	Dry Season Daily WLA (billion cfu/day)	Wet Season Flow (cfs)	Wet Season Daily WLA (billion cfu/day)
Hughes Farms	0.12	0.30	0.14	0.34
Sulex, Inc.	--	--	0.06	0.15

WLA= wasteload allocation

Recommended Wasteload Allocations

Recommended wasteload allocations were calculated for the furthest downstream freshwater site for each major slough (JL0.7, NN1.0, LI1.9, and BI2.8) to account for all point sources located within the watershed. Wasteload allocations estimated using the Simple Method were combined with load estimates for individual permits (Tables 24 and 25). Totaled wasteload allocations were distributed to each slough based on the relative contribution of point-source loading compared to the loading capacity. This approach was used due to the similar distribution of point sources within each slough subbasin and the lack of point-source-specific seasonal flow and bacteria data.

Overall, point sources account for 16% of the loading capacity during the wet season and 24% of the total loading capacity during the dry season. The estimated wasteload allocations were based on these relative contributions for each slough (Table 26).

Table 26. Recommended wasteload allocations.

Slough	Site	Wet Season Daily WLA (billion cfu/day)	Dry Season Daily WLA (billion cfu/day)
Joe Leary	JL0.7	31.7	18.9
No Name	NN1.0	3.5	0.2
Big Indian	BI2.8	12.2	3.8
Little Indian	LI1.9	0.3	0.1

Recommended Load Allocations

Recommended load allocations were developed for nonpoint sources of FC in the study area for both the wet and dry seasons. These load allocations were calculated by subtracting the relative contribution of point sources to bacteria loading (WLA) from the estimate loading capacity at the furthest downstream freshwater site for the sloughs (JL0.7, NN1.0, BI2.8, and LI1.9) during the wet and dry seasons (Table 27).

Table 27. Recommended load allocations.

Slough	Site	Wet Season Daily LA (billion cfu/day)	Dry Season Daily LA (billion cfu/day)
Joe Leary	JL0.7	165.7	62.1
No Name	NN1.0	18.6	0.5
Big Indian	BI2.8	63.7	12.4
Little Indian	LI1.9	1.5	0.2

Recommended Margin of Safety

The federal Clean Water Act requires that TMDLs be established with a margin of safety (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.

These TMDL recommendations provide implicit MOS by the following:

- The more conservative bacteria concentration (100 cfu/100 mL) value was used to estimate load and wasteload allocations. 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 work did not take into account 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.
- The relatively small size of each of the slough subbasins and the relatively large size of parcels throughout much of the watershed will help ensure the success of local source identification and correction efforts. As sources are corrected in upper subbasins, water quality in downstream areas will become more attainable.
- Updated recreational criteria for E. coli are likely less stringent than the FC criteria used in this analysis, based on the bacteria concentration comparison (Figure 16). Sites that improve water quality conditions based on the recommended load and wasteload allocations determined using FC concentrations are expected to meet the new standards using E. coli.

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 load allocation based on the portion of land being utilized.

Protecting Downstream Uses

This study addresses bacteria pollution in the freshwater tributaries draining into Padilla Bay, and the TMDL recommendations are based on freshwater FC standards. While the marine standards for FC in regards to shellfish harvesting are lower than freshwater criteria, the developed recommendations are still considered useful and protective of downstream beneficial uses due to the characteristics of Padilla Bay.

The recommended cumulative reductions for the loading capacities were developed to focus on reducing bacteria sources in upstream areas. By addressing sources of pollution upstream, water quality conditions downstream are expected to improve. These cumulative reductions will be used to guide an adaptive management strategy and implementation activities where efforts will be targeting upstream sources to protect downstream beneficial uses in the freshwater tributaries as they discharge into Padilla Bay.

Downstream beneficial uses in Padilla Bay will be protected based on the TMDL recommendations for this study because of increased bacteria die-off in marine waters, high mixing zones and low residence times in Padilla Bay, and distance from shellfish harvesting beds (Fields, 2016; Bulthuis, 2013; Sargeant et al., 2006; Mancini, 1978).

Freshwater discharged into Padilla Bay has a short residence time due to high levels of flushing (Bulthuis, 2013). Semidiurnal tides regularly flush the water in Padilla Bay with the estuarine water of north Puget Sound (Bulthuis, 2013). Due to this flushing, most of the freshwater that mixes with marine water in Padilla Bay enters Padilla Bay on the marine (northern and western) sides of the bay and is derived from the Fraser, Skagit, Nooksack, Samish, and other rivers that flow into the Strait of Georgia and north Puget Sound. Bulthuis (2013) estimated the maximum daily freshwater discharged into Padilla Bay from drainages in the watershed to be less than 1% of daily total exchange in Padilla Bay.

Conclusions

Results from the eastern Padilla Bay tributaries study support the following conclusions:

- From April 2016–May 2017, bacteria and streamflow data were collected at (1) a fixed-network of sampling sites throughout the eastern Padilla Bay watershed freshwater tributaries (Joe Leary, No Name, Big Indian, and Little Indian Sloughs) and (2) a set of Bay View outfalls. Due to low-flow conditions during the dry season, Ecology staff were unable to sample sites in upper No Name Slough and Bay View outfalls.
    - All Joe Leary Slough sites exceeded (did not meet) water quality criteria, with generally higher bacteria concentrations during the wet season than during the dry season. Sampling site JL8.92CU, a culvert draining into Joe Leary Slough, had the overall highest bacteria concentrations during both the wet and dry seasons. JL10.2 was the mainstem site with the highest concentrations.
    - No Name Slough had the highest bacteria concentrations in its middle sites (NN1.8 and NN2.3) and had flows too low to sample throughout the dry season.
    - Little Indian Slough (LI1.9) required the highest overall reduction of bacteria (85% during the wet season) to meet water quality criteria. Wet and dry season bacteria levels were similar.
    - Big Indian Slough sites did not show a strong seasonal difference in bacteria levels, and bacteria concentrations were generally lower than the other three major sloughs.
    - A series of outfalls throughout Bay View were sampled during the wet season. The southern outfalls (BV9, BV10, BV11) that drained developed areas had high levels of bacteria that did not meet water quality criteria.
- Wet-season average bacteria loads were much higher than during the dry season, as higher flows due to precipitation and runoff contribute to higher loads. Generally, loads increased moving upstream to downstream in all four sloughs. Joe Leary Slough had the overall highest bacteria loads.
- E. coli bacteria (E.coli) samples were collected at a subset of locations and compared with fecal coliform bacteria (FC) samples. The comparison showed that FC concentrations were typically higher than E. coli concentrations. These results can be used to guide implementation activities to improve water quality and to help meet water quality criteria considering the recent rule-change adopting E. coli as the bacterial indicator in place of FC.

This water quality study findings report provides recommendations for loading capacities, load allocations, and wasteload allocations for the eastern Padilla Bay watershed TMDL. By meeting these recommendations through the TMDL and implementation plan, water quality conditions are expected to improve and meet Washington State water quality standards.

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Glossary, Acronyms, and Abbreviations

Glossary

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.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Critical condition or season: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 (see definition) flow event unless determined otherwise by the department.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Dry season: May through September.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

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.

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

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.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

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.

Riparian: Relating to the banks along a natural course of water.

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.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality based effluent limitation.

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.

Wet season: October through April.

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

DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
E. coli	E. coli bacteria
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
FC	Fecal coliform bacteria
GIS	Geographic Information System software
MEL	Manchester Environmental Laboratory
MOS	Margin of safety
MQO	Measurement quality objective
MS4	Municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System (see glossary)
QAPP	Quality assurance project plan
RPD	relative percent difference
RSD	relative standard deviation
SOP	standard operating procedures
TMDL	Total Maximum Daily Load (see glossary)

WAC	Washington Administrative Code
WQS	Water quality standards
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WWTP	Wastewater treatment plant

Units of Measurement

b.cfu/day	billion colony forming units per day
°C	degrees centigrade
cfs	cubic feet per second
cfu	colony forming units
ft	feet
in	inch
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
m	meter
NTU	nephelometric turbidity units
s.u.	standard units
μmhos/cm	micromhos per centimeter

Appendices

Appendix A. Sampling Locations

Table A-1. Sampling location summary.

Study Site (EIM Site)	Type	FC (n)	Flow (n)	Description
JL11.25NO	Fixed	17	9	Joe Leary Slough on the north side of Dahlstedt Rd 0.7 mile east of Green Rd
JL11.25EA	Fixed	17	0	Ditch discharging into Joe Leary Slough located to the east of the stream gage located on the south side of Dahlstedt Rd 0.8 mile east of Green Rd
JL11.2 (DNMP_SAM-2)	Fixed	23	0	South side Dahlstedt Road, 30 feet west of angled culver confluence
JL10.2	Fixed	23	22	Downstream side of Cook Rd bridge over Joe Leary Slough
JL9.0 (JL8.94NO)	Fixed	20	21	Joe Leary Slough approximately 200 feet upstream of Old Highway 99 bridge and Gear Rd
JL8.92CU	Fixed	22	0	Culvert discharging into Joe Leary Slough at Gear Rd west of the railroad bridge; this culvert enters from the east about 35 feet upstream of Old Highway 99 bridge
JL8.9	Fixed	24	23	Downstream side of Old Highway 99 bridge over Joe Leary Slough; upstream of the I-5 bridge
JL7.9	Fixed	23	22	Joe Leary Slough on downstream side of bridge at Pulver Rd near intersection with Maiben Rd
JLT6.2	Fixed	19	0	Ditch on north side of Josh Wilson Rd at Jensen Ln; 1 mile west of Avon Allen Rd
JL4.7	Fixed	20	23	Joe Leary Slough on downstream side of bridge to Sakuma Brother's housing at 15098 BA Benson Rd; 0.2 mile southeast of Bensen Heights Pl
JL2.7 (03E050)	Fixed	23	23	Ambient station; old 99 to Allen-West Rd. Go west about 5 miles and turn right on the Farm to Market Rd. Sample at bridge.
JL0.7 (JLSBER)	Fixed	23	21	Near Sedro Wooley; Joe Leary Slough on downstream side of Bayview Edison Rd bridge; 0.16 mile south of D'Arcy Rd
NNT1.7	Intermittent	12	0	Tributary of No Name Slough on the west side of Farm to Market Rd, approx. 25 feet north of Ovenell Rd
NNUS	Intermittent	5	5	No Name Slough on north side of Josh Wilson Rd; approximately 170 feet west of intersection with Irene Pl and 0.2 mile west of Farm to Market Rd
NNSEJW	Intermittent	5	0	Ditch on the south side of Josh Wilson Rd flowing from the east; approximately 15 feet east of No Name Slough
NNNJW	Intermittent	5	0	Ditch on the north side of Josh Wilson Rd flowing from the west; approximately 50 feet west of No Name Slough

Study Site (EIM Site)	Type	FC (n)	Flow (n)	Description
NNMHNW	Intermittent	4	0	Ditch on the north side of Marihugh Rd flowing from the west; 35 feet west of No Name Slough
NNSJW	Intermittent	6	0	Ditch on the south side of Josh Wilson Rd flowing from the west; approximately 90 feet west of No Name Slough
NNMHSE	Intermittent	6	0	Ditch on the south side of Marihugh Rd flowing from the east; 40 feet east of No Name Slough
NNBVNW	Intermittent	4	0	Ditch on north side of Bayview Rd flowing from the west; approximately 45 feet west of No Name Slough (upstream of NN1.8)
NNBVSE	Intermittent	6	0	Ditch on south side of Bayview Rd flowing from the east; approximately 15 feet east of No Name Slough (downstream of NN1.8)
NN2.8	Fixed	12	13	No Name Slough approximately 250 feet downstream of Josh Wilson Rd
NN2.3	Fixed	13	13	No Name Slough approximately 65 feet downstream of Marihugh Rd
NN1.8	Fixed	13	15	No Name Slough approximately 40 feet upstream of Bayview Rd
NN1.0	Fixed	16	18	Downstream side of second (downstream) bridge over No Name Slough; approximately 400 feet to west of the first bridge and end of Egbers-Kalso Rd
NN0.004	Marine	32	11	No Name Slough on upstream side of tidegates approximately 20 feet downstream of pumphouse
LI1.9	Fixed	18	16	Little Indian Slough on the west side of Farm to Market Rd; approximately 0.1 mile south of Ovenell Rd
LI0.7	Marine	35	18	Little Indian Slough on west side of Bayview Edison Rd; downstream end of tidegates
BI8.2	Fixed	19	19	Big Indian Slough on Peterson Rd, approximately 215 feet to the east of the intersection with Avon Allen
BI6.2	Fixed	21	21	Big Indian Slough on south side of Ovenell Rd approximately 45 feet downstream of culvert exit
BI4.0	Fixed	21	21	Big Indian Slough on west side of Bradshaw Rd approximately 60 feet downstream of culvert exit
BI2.8	Fixed	23	22	West/downstream side of Farm to Market Rd bridge over Big Indian Slough; approximately 65 feet north of WA-20
BI1.6	Marine	35	18	West/downstream side of Bayview Edison Rd bridge over Big Indian Slough; approximately 175 feet downstream of the tidegates
BV1	Intermittent	7	6	Culvert on west side of Bayview Edison Rd approximately 0.37 mile north of Persons Rd
BV2	Intermittent	8	7	Culvert on west side of Bayview Edison Rd approximately mile 0.22 north of Persons Rd

Study Site (EIM Site)	Type	FC (n)	Flow (n)	Description
BV3	Intermittent	6	5	Culvert of west side of Bayview Edison Rd at the end of Persons Rd; water flowing from north Persons Rd and Bayview Edison Rd
BV9	Intermittent	9	6	Culvert on the west side of Bayview Edison Rd approximately 270 feet south of Farnham St; near mailbox with street number 11043; concrete culvert broken in 2016
BV10	Intermittent	11	9	Culvert of the west side of Bayview Edison Rd across the street from the end of B St
BV11	Intermittent	6	4	Culvert of the west side of Bayview Edison Rd on the south side of the boat launch
BV12	Intermittent	9	8	Culvert next to the bay on the west side of Bayview Edison Rd, approximately 125 feet west of the end of Josh Wilson Rd; near 1146 Bayview Edison Rd
BV14	Intermittent	4	3	Culvert on the west side of Bayview Edison Rd approximately 500 feet east of 2nd St; culvert is on the east side of the Padilla Bay Shore Trail North Trailhead

Appendix B. Data Quality Assessment

Tables B-1 through B-4 show sonde instrument (Hydrolab® or YSI®) post-checks for field-measurement parameters.

Table B-1. Sonde post-calibration checks for dissolved oxygen.

Calibration Date	Post-Check Date	Sonde #	Reference Standard (%)	Post-Check Value (%)	Difference (%)	Check
4/24/2016	4/30/2016	HL#43	100	100.3	0.3	Pass
5/8/2016	5/15/2016	HL#44	100	100.3	0.3	Pass
5/22/2016	6/5/2016	HL#45	100	99.9	-0.1	Pass
6/5/2016	6/10/2016	HL#46	100	101.8	1.8	Pass
6/17/2016	6/22/2016	HL#47	100	100.1	0.1	Pass
7/1/2016	7/7/2016	HL#43	100	99.5	-0.5	Pass
7/17/2016	7/20/2016	HL#43	100	101	1	Pass
9/11/2016	9/14/2016	HL#43	100	99.9	-0.1	Pass
10/9/2016	10/12/2016	HL#25	100	87.4	-12.6	Estimate
11/12/2016	11/17/2016	HL#42	100	99.5	-0.5	Pass
11/27/2016	12/1/2016	HL#42	100	101.8	1.8	Pass
12/11/2016	12/14/2016	HL#42	100	99.2	-0.8	Pass
1/21/2017	1/25/2017	HL#41	100	102.2	2.2	Pass
2/5/2017	2/10/2017	HL#41	100	103.2	3.2	Pass
2/11/2017	2/15/2017	HL#41	100	96.3	-3.7	Pass
2/26/2017	3/3/2017	HL#41	100	98.5	-1.5	Pass
3/12/2017	3/15/2017	HL#42	100	99.2	-0.8	Pass
3/24/2017	3/30/2017	HL#41	100	100.9	0.9	Pass
4/9/2017	4/12/2017	HL#41	100	99	-1	Pass
4/23/2017	4/26/2017	HL#36	100	101.9	1.9	Pass
5/7/2017	5/11/2017	HL#41	100	99	-1	Pass
5/20/2017	5/25/2017	HL#42	100	99.8	-0.2	Pass
5/20/2017	5/26/2017	HL#43	100	100.3	0.3	Pass

Table B-2. Sonde post-calibration checks for specific conductivity.

Calibration Date	Post-Check Date	Sonde #	Reference Standard (uS/cm)	Post-Check Value (uS/cm)	Difference (%)	Check
4/24/2016	4/30/2016	HL#43	50,000	50,309	1%	Pass
5/8/2016	5/15/2016	HL#43	20,000	19,937	0%	Pass
5/22/2016	6/5/2016	HL#43	20,000	20,307	2%	Pass
6/5/2016	6/10/2016	HL#43	20,000	19,898	-1%	Pass
6/17/2016	6/22/2016	HL#43	20,000	20,115	1%	Pass
7/1/2016	7/7/2016	HL#43	50,000	49,877	0%	Pass
7/17/2016	7/20/2016	HL#43	20,000	19,990	0%	Pass
9/11/2016	9/14/2016	HL#43	50,000	49,905	0%	Pass
10/9/2016	10/12/2016	HL#25	50,000	50,185	0%	Pass
11/12/2016	11/17/2016	HL#42	50,000	49,902	0%	Pass
11/27/2016	12/1/2016	HL#42	50,000	50,040	0%	Pass
12/11/2016	12/14/2016	HL#42	50,000	49,959	0%	Pass
1/21/2017	1/25/2017	HL#41	50,000	49,956	0%	Pass
2/5/2017	2/10/2017	HL#41	50,000	49,998	0%	Pass
2/11/2017	2/15/2017	HL#41	50,000	49,998	0%	Pass
2/26/2017	3/3/2017	HL#41	50,000	50,113	0%	Pass
3/12/2017	3/15/2017	HL#42	50,000	50,162	0%	Pass
3/24/2017	3/30/2017	HL#41	50,000	50,173	0%	Pass
4/9/2017	4/12/2017	HL#41	50,000	49,990	0%	Pass
4/23/2017	4/26/2017	HL#36	50,000	49,805	0%	Pass
5/7/2017	5/11/2017	HL#41	50,000	50,021	0%	Pass
5/20/2017	5/25/2017	HL#42	50,000	49,904	0%	Pass
5/20/2017	5/26/2017	HL#43	20,000	20,063	0%	Pass
9/17/2017	9/20/2017	HL#42	50,000	50,085	0%	Pass
10/16/2017	10/20/2017	HL#40	50,000	49,777	0%	Pass

Table B-3. Sonde post-calibration check for pH.

Calibration Date	Post-Check Date	Sonde #	Reference Standard (s.u.)	Post-Check Value (s.u)	Difference (%)	Check
4/24/2016	4/30/2016	HL#43	7.02	7.10	1%	Pass
4/24/2016	4/30/2016	HL#43	10.06	10.20	1%	Pass
4/24/2016	4/30/2016	HL#43	3.96	4.00	1%	Pass
5/8/2016	5/15/2016	HL#43	7.02	7.03	0%	Pass
5/8/2016	5/15/2016	HL#43	10.06	10.15	1%	Pass
5/8/2016	5/15/2016	HL#43	3.94	4.00	2%	Pass
5/22/2016	6/5/2016	HL#43	7.00	7.05	1%	Pass
5/22/2016	6/5/2016	HL#43	10.00	10.00	0%	Pass
5/22/2016	6/5/2016	HL#43	4.02	4.00	0%	Pass
6/5/2016	6/10/2016	HL#43	7.02	6.98	-1%	Pass
6/5/2016	6/10/2016	HL#43	10.06	10.15	1%	Pass
6/5/2016	6/10/2016	HL#43	4.20	4.00	-5%	Pass
6/17/2016	6/22/2016	HL#43	7.01	7.05	1%	Pass
6/17/2016	6/22/2016	HL#43	10.06	10.18	1%	Pass
6/17/2016	6/22/2016	HL#43	4.05	4.00	-1%	Pass
7/1/2016	7/7/2016	HL#43	7.01	6.96	-1%	Pass
7/1/2016	7/7/2016	HL#43	10.03	10.04	0%	Pass
7/1/2016	7/7/2016	HL#43	3.98	4.00	1%	Pass
7/17/2016	7/20/2016	HL#43	7.01	7.13	2%	Pass
7/17/2016	7/20/2016	HL#43	10.03	10.22	2%	Pass
7/17/2016	7/20/2016	HL#43	4.08	4.00	-2%	Pass
9/11/2016	9/14/2016	HL#43	7.01	7.05	1%	Pass
9/11/2016	9/14/2016	HL#43	10.03	10.14	1%	Pass
9/11/2016	9/14/2016	HL#43	4.10	4.00	-2%	Pass
10/9/2016	10/12/2016	HL#25	7.02	6.98	-1%	Pass
10/9/2016	10/12/2016	HL#25	10.05	10.36	3%	Pass
10/9/2016	10/12/2016	HL#25	3.89	4.00	3%	Pass
11/12/2016	11/17/2016	HL#42	7.02	7.16	2%	Pass
11/12/2016	11/17/2016	HL#42	10.05	10.40	3%	Pass
11/12/2016	11/17/2016	HL#42	4.18	4.00	-4%	Pass
11/27/2016	12/1/2016	HL#42	7.02	7.00	0%	Pass
11/27/2016	12/1/2016	HL#42	10.06	10.29	2%	Pass
11/27/2016	12/1/2016	HL#42	3.94	4.00	2%	Pass
12/11/2016	12/14/2016	HL#42	7.02	6.99	0%	Pass
12/11/2016	12/14/2016	HL#42	10.06	10.11	0%	Pass
12/11/2016	12/14/2016	HL#42	3.97	4.00	1%	Pass
1/21/2017	1/25/2017	HL#41	7.02	7.01	0%	Pass
1/21/2017	1/25/2017	HL#41	10.06	10.03	0%	Pass
1/21/2017	1/25/2017	HL#41	3.99	4.00	0%	Pass

Calibration Date	Post-Check Date	Sonde #	Reference Standard (s.u.)	Post-Check Value (s.u)	Difference (%)	Check
2/5/2017	2/10/2017	HL#41	7.02	7.03	0%	Pass
2/5/2017	2/10/2017	HL#41	10.05	10.04	0%	Pass
2/5/2017	2/10/2017	HL#41	4.00	4.00	0%	Pass
2/11/2017	2/15/2017	HL#41	7.01	6.99	0%	Pass
2/11/2017	2/15/2017	HL#41	10.03	9.98	-1%	Pass
2/11/2017	2/15/2017	HL#41	4.01	4.00	0%	Pass
2/26/2017	3/3/2017	HL#41	7.02	7.00	0%	Pass
2/26/2017	3/3/2017	HL#41	10.05	10.01	0%	Pass
2/26/2017	3/3/2017	HL#41	4.00	4.00	0%	Pass
3/12/2017	3/15/2017	HL#42	7.02	7.10	1%	Pass
3/12/2017	3/15/2017	HL#42	10.06	10.19	1%	Pass
3/12/2017	3/15/2017	HL#42	4.10	4.00	-2%	Pass
3/24/2017	3/30/2017	HL#41	7.02	6.99	0%	Pass
3/24/2017	3/30/2017	HL#41	10.06	10.04	0%	Pass
3/24/2017	3/30/2017	HL#41	3.94	4.00	2%	Pass
4/9/2017	4/12/2017	HL#41	7.02	7.36	5%	Pass
4/9/2017	4/12/2017	HL#41	10.06	10.74	6%	Pass
4/9/2017	4/12/2017	HL#41	4.02	4.00	0%	Pass
4/23/2017	4/26/2017	HL#36	7.02	7.45	6%	Estimate
4/23/2017	4/26/2017	HL#36	10.06	8.58	-17%	Reject
4/23/2017	4/26/2017	HL#36	6.73	4.00	-68%	Reject
5/7/2017	5/11/2017	HL#41	7.02	7.04	0%	Pass
5/7/2017	5/11/2017	HL#41	10.06	10.22	2%	Pass
5/7/2017	5/11/2017	HL#41	3.85	4.00	4%	Pass
5/20/2017	5/26/2017	HL#43	7.02	7.05	0%	Pass
5/20/2017	5/25/2017	HL#42	7.02	7.25	3%	Pass
5/20/2017	5/26/2017	HL#43	10.06	10.08	0%	Pass
5/20/2017	5/25/2017	HL#42	10.06	10.08	0%	Pass
5/20/2017	5/26/2017	HL#43	4.07	4.00	-2%	Pass
5/20/2017	5/25/2017	HL#42	3.97	4.00	1%	Pass

Table B-4. Sonde post-calibration checks for temperature.

Calibration Date	Post-Check Date	Sonde #	NIST Value (°C)	Post-Check Value (°C)	Difference (°C)	Check
4/24/2016	4/30/2016	HL#43	21.2	21.2	0.0	Pass
5/8/2016	5/15/2016	HL#43	21.3	21.3	0.0	Pass
5/22/2016	6/5/2016	HL#43	23.9	23.8	-0.1	Pass
6/5/2016	6/10/2016	HL#43	21.2	21.2	0.0	Pass
6/5/2016	6/10/2016	YSI30#1	21.2	21.2	0.0	Pass
6/17/2016	6/22/2016	HL#43	22.6	22.6	0.0	Pass
6/17/2016	6/22/2016	YSI30#1	22.6	22.6	0.0	Pass
7/1/2016	7/7/2016	HL#43	22.9	22.9	0.0	Pass
7/1/2016	7/7/2016	YSI30#1	22.9	22.9	0.0	Pass
7/17/2016	7/20/2016	HL#43	22.5	22.6	0.1	Pass
7/17/2016	7/20/2016	YSI30#1	22.7	22.7	0.0	Pass
7/30/2016	8/3/2016	YSI30#1	22.8	22.8	0.0	Pass
9/11/2016	9/14/2016	HL#43	22.7	22.7	0.0	Pass
9/11/2016	9/14/2016	YSI30#1	22.6	22.6	0.0	Pass
10/9/2016	10/12/2016	HL#25	22.7	21.8	-0.9	Reject
10/9/2016	10/12/2016	YSI30#1	22.6	22.6	0.0	Pass
10/9/2016	10/12/2016	YSI30SCT3	22.6	22.6	0.0	Pass
11/27/2016	12/1/2016	HL#42	21.2	21.3	0.1	Pass
11/27/2016	12/1/2016	YSI30#1	21.3	21.3	0.0	Pass
11/12/2016	11/17/2016	HL#42	21.1	21.8	0.6	Estimate
11/12/2016	11/17/2016	YSI30#1	21.8	21.8	0.0	Pass
12/11/2016	12/14/2016	HL#42	20.3	20.3	0.0	Pass
12/11/2016	12/14/2016	YSI30#1	20.3	20.3	0.0	Pass
1/21/2017	1/25/2017	HL#41	20.9	21.0	0.1	Pass
1/21/2017	1/25/2017	YSI30#1	20.7	20.7	0.0	Pass
2/5/2017	2/10/2017	HL#41	20.7	20.7	0.0	Pass
2/4/2017	2/10/2017	YSI30#1	20.4	20.4	0.0	Pass
2/11/2017	2/15/2017	HL#41	21.7	21.7	0.0	Pass
2/11/2017	2/15/2017	YSI30#1	21.6	21.6	0.0	Pass
2/26/2017	3/3/2017	HL#41	21.1	21.1	0.0	Pass
2/26/2017	3/3/2017	YSI30#1	21.0	21.0	0.0	Pass
3/12/2017	3/15/2017	HL#42	21.7	21.7	0.0	Pass
3/12/2017	3/15/2017	YSI30#1	21.6	21.6	0.0	Pass
3/24/2017	3/30/2017	HL#41	22.2	22.2	0.0	Pass
3/24/2017	3/30/2017	YSI30#1	21.1	21.1	0.0	Pass
4/9/2017	4/12/2017	HL#41	21.3	21.4	0.1	Pass
4/9/2017	4/12/2017	YSI30#1	21.3	21.3	0.0	Pass
4/23/2017	4/26/2017	HL#36	21.5	21.5	0.0	Pass
4/23/2017	4/26/2017	YSI30#1	21.5	21.5	0.0	Pass

Calibration Date	Post-Check Date	Sonde #	NIST Value (°C)	Post-Check Value (°C)	Difference (°C)	Check
5/7/2017	5/11/2017	HL#41	21.1	21.2	0.1	Pass
5/7/2017	5/11/2017	YSI30#1	21.0	21.0	0.0	Pass
5/20/2017	5/25/2017	HL#42	22.7	22.7	0.0	Pass
5/20/2017	5/25/2017	YSI30#1	22.7	22.7	0.0	Pass
5/20/2017	5/26/2017	HL#43	22.4	22.4	0.0	Pass
5/20/2017	5/26/2017	YSI30#1	22.4	22.4	0.0	Pass
9/17/2017	9/20/2017	HL#42	21.4	21.4	0.0	Pass
10/16/2017	10/20/2017	HL#40	21.5	21.5	0.0	Pass

Appendix C. Fecal Coliform Results Continued

Figure C-1 describes the box plots (Figures C-2 to C-4) of the seasonal distribution of FC at fixed sampling sites compared with water quality criteria.

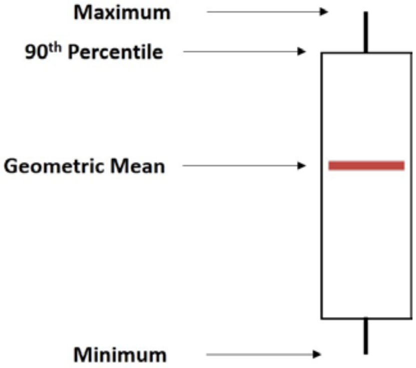


Figure C-1. Box plot descriptions.

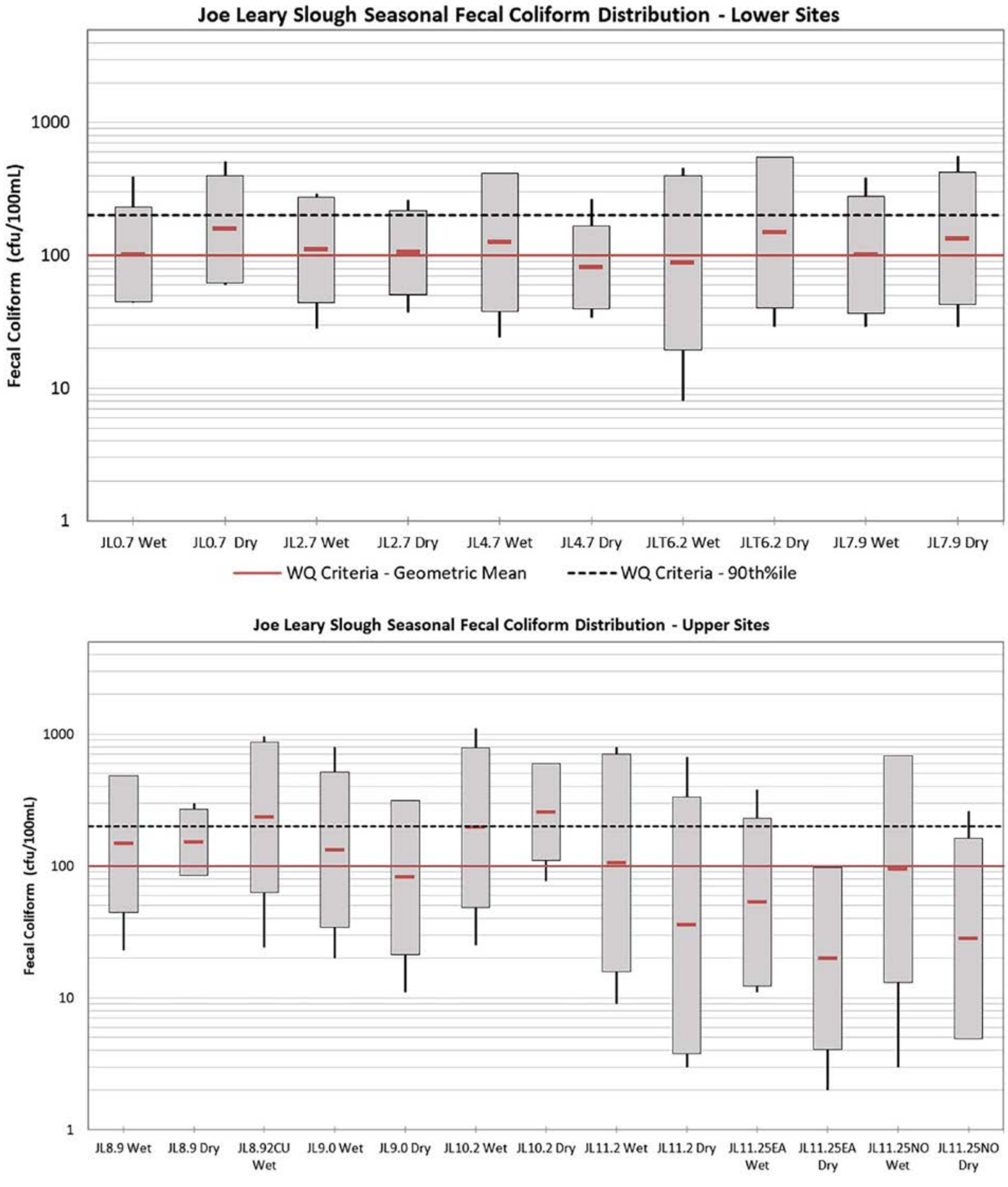


Figure C-2. Seasonal distribution of FC results at Joe Leary Slough sites.

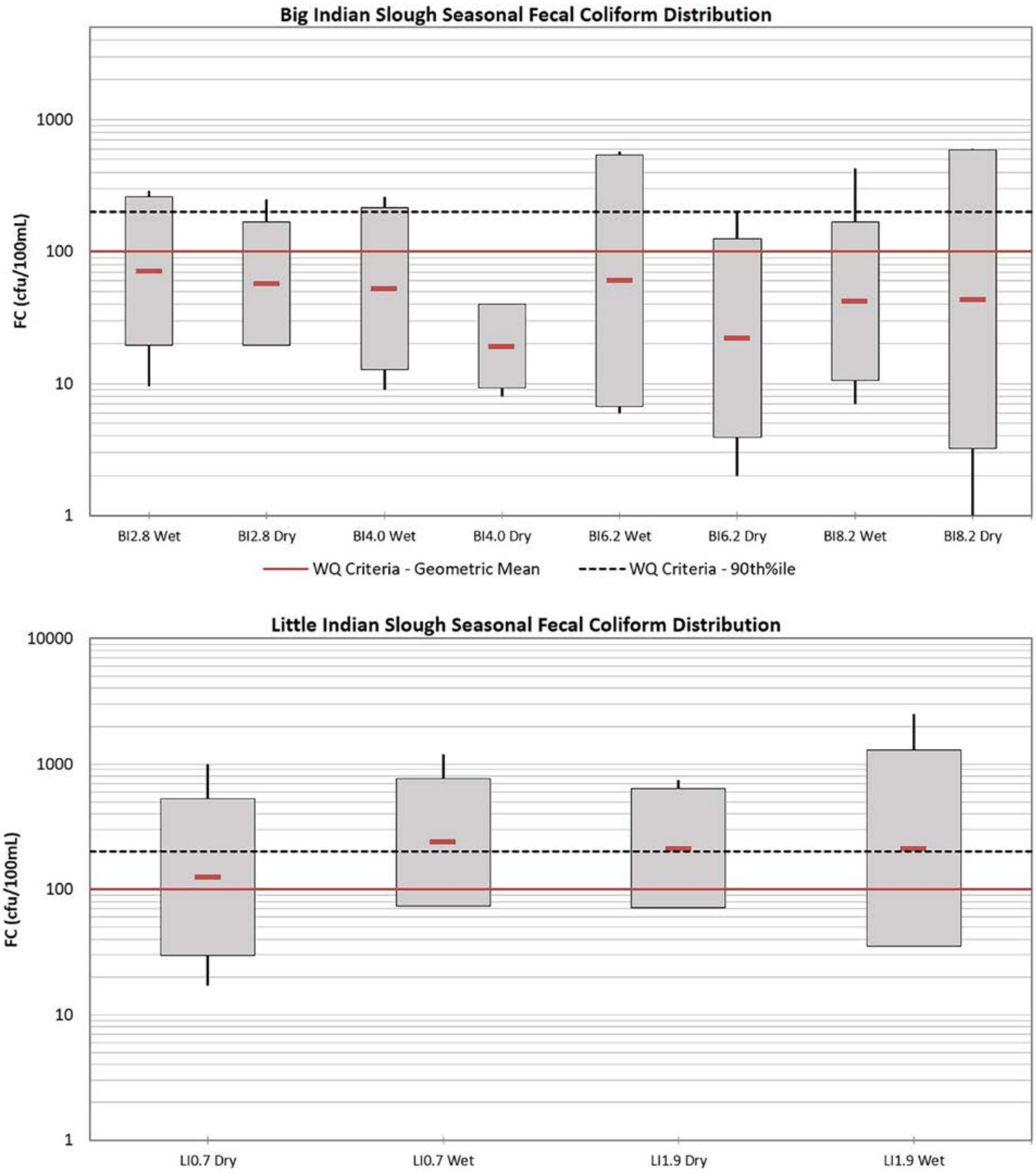
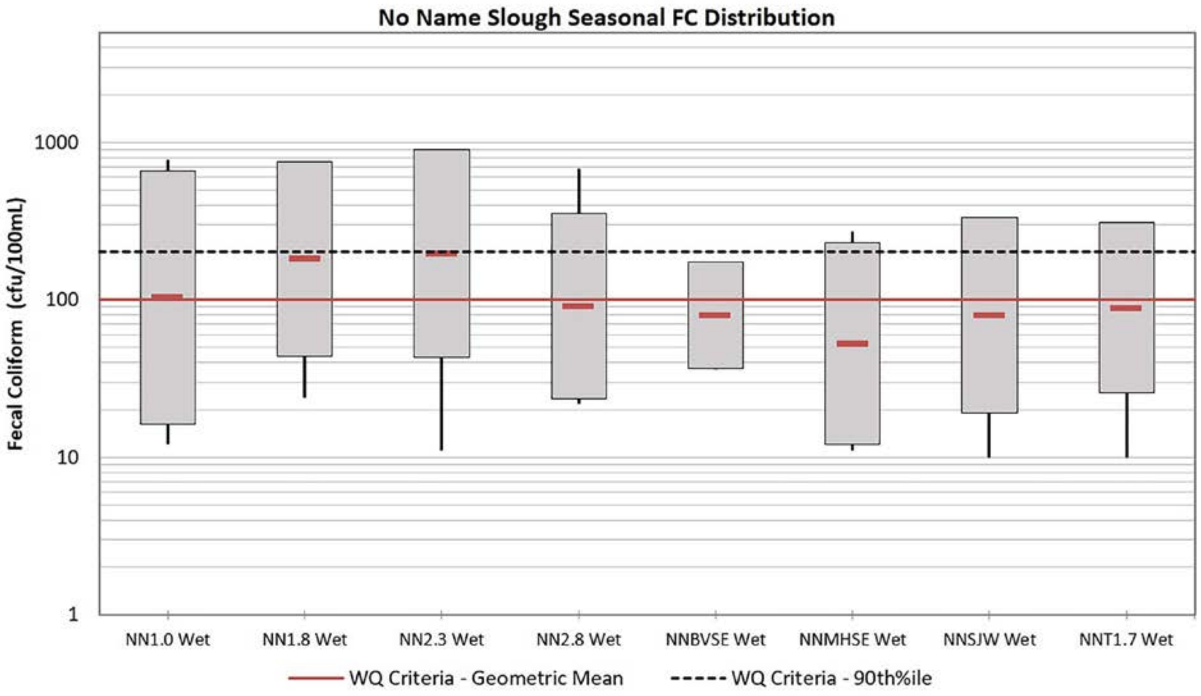


Figure C-3. Distribution of FC results at No Name Slough sites (above) and Bay View outfalls (below).



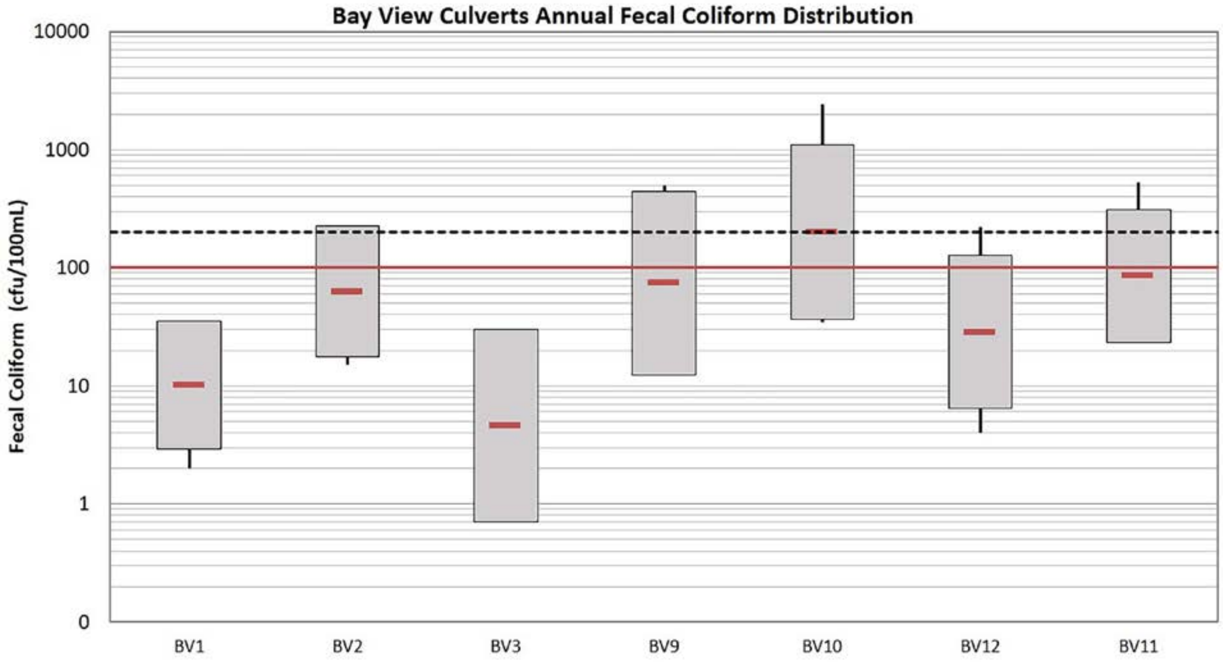


Figure C-4. Seasonal distribution of FC results at Big Indian Slough (above) and Little Indian Slough (below).

Storm Event Results

Table C-1. FC results from high precipitation events.

Waterbody	Site	FC (cfu/100mL) 10/26/2016	FC (cfu/100mL) 3/1/2017
Joe Leary Slough	JL11.25EA	260	NA
	JL11.25NO	32	NA
	JL11.2	40	NA
	JL10.9	64	NA
	JL10.2	130	NA
	JL8.92CU	960	NA
	JL8.9	340	NA
No Name Slough	NNSJW	NA	180
	NNNJW	NA	150
	NNUS	NA	40
	NNSEJW	NA	80
	NN2.8	22	110
	NNMHNW	NA	680
	NNMHSE	270	41
	NN2.3	11	490
	NN1.8	250	740
	NNBVNW	NA	800
	NNBVSE	77	160
	NNT1.7	250	150
	NN1.0	52	490
	NN0.004	NA	480
Big Indian Slough	BIT4.8	170	NA
	BIT4.7	370	NA
	BI4.5	75	NA
	BI2.8	19	NA
Bay View Culverts	BV8	490	NA
	BV9	495	NA
	BV10	840	NA
	BV12	220	NA

Appendix D. TMDL Methods

This section provides further explanation of recommended daily loading capacities (Tables 17 and 18 in this report). Below are details and estimation methods for column values in Tables D-1 and D-2. The daily loading capacity was based on the following formula:

$$\begin{array}{ccccccc} \text{Seasonal} & & \text{Bacteria} & & \text{Conversion} & & \text{Number of} \\ \text{Flow}^{10} & x & \text{Concentration} & x & \text{Factor} & = & \text{Bacteria} \\ (\text{ft}^3/\text{second}) & & \text{Level} & & (2.447 \ x \ 10^7) & & \text{per day} \\ & & (\text{cfu}/100 \text{ mL}) & & & & \end{array}$$

Figure D-1. Loading capacity formula.

The FC concentration was set to the geometric mean criterion (100 cfu/100 mL).

In addition to estimating loading capacities, FC reductions were estimated to provide a more practical basis for identifying trends and implementing restoration activities. FC reduction targets were calculated based on the statistical rollback analysis (Ott, 1997). The rollback method compares monitoring data to standard and calculates the amount of pollutant to be reduced, or "rolled-back" to meet the more restrictive criteria. For this analysis, the statistical threshold value (STV or 90th percentile value) is more stringent. The target loads are calculated based on reducing the whole FC distribution to meet criteria. Therefore, target geometric mean values may be lower than water quality criteria (see Appendix F for graphs that demonstrate this).

The values in Tables D-1 and D-2 were estimated based on the following methods:

- **Loading Capacity** (billion cfu/day): estimated using geometric mean criterion (100 cfu/100 mL) and average seasonal flow.
- **STV (statistical threshold value) Target Load** (billion cfu/day): estimated using 90th percentile criterion value (200 cfu/100 mL) and average seasonal flow.
- **Geometric Mean Target Load** (billion cfu/day): estimated using target load as determined through statistical rollback analysis and average seasonal flow.
- **Existing STV (statistical threshold value) Load** (billion cfu/day): estimated using existing 90th percentile bacteria concentration and average seasonal flow.
- **Individual FC Reductions** (billion cfu/day and percent reduction): estimated FC reduction from statistical rollback analysis needed to meet STV target load allocation.
- **Progressive FC Reductions** (billion cfu/day and percent reduction): if FC reductions occur upstream and meet water quality criteria, the amount of FC reduction still needed to achieve compliance.

Table D-1*.* Daily loading capacities for the Padilla Bay Watershed during the wet season.

Compliance will be demonstrated by direct instream monitoring of water quality. Shown in the table are current loads and the bacteria reductions needed. Segment-based progressive reductions assume that bacteria loads are reduced upstream. If no reductions upstream occur, then the individual reductions are needed.

Site	Loading Capacity (billion cfu/day)	Estimated STV Target Load (billion cfu/day)	Estimated Geomean Target Load (billion cfu/day	Existing STV Load (billion cfu/day)	FC Individual Reductions** (billion cfu/day) (%)	FC Progressive Reductions** (billion cfu/day) (%)
JL11.25NO	16.5	32.9	4.6	112.6	79.7 (71%)	79.7 (71%)
JL11.2	15.3	30.7	4.6	108.6	78 (72%)	0.0* (<10%)
JL10.2	16.0	32.1	8.0	126.1	94.0 (75%)	14.4 (11%)
JL9.0	26.1	52.1	13.5	133.8	81.6 (61%)	67.3 (50%)
JL7.9	59.2	118.3	43.0	164.9	46.5 (28%)	0.0* (<10%)
JL4.7	121.9	243.8	73.5	508.2	264.4 (52%)	197.1 (39%)
JL2.7	131.0	262.1	104.9	360.2	98.1 (27%)	0.0* (<10%)
JL0.7	197.4	394.8	172.8	457.9	63.2 (14%)	0.0* (<10%)
NN2.8	5.3	10.6	2.7	18.6	8.1 (43%)	8.1 (43%)
NN2.3	6.4	12.7	2.8	57.1	44.3 (78%)	36.2 (64%)
NN1.8	7.2	14.4	3.5	54.4	40.0 (74%)	3.8 (7%)
NN1.0	22.1	44.3	6.9	146.2	101.9 (70%)	98.2 (67%)
BI8.2	4.2	8.4	1.8	7.1	0.0* (<10%)	0.0* (<10%)
BI6.2	15.1	30.2	3.4	82.1	51.9 (63%)	51.9 (63%)
BI4.0	49.4	98.7	24.1	106.0	7.3 (<10%)	0.0* (<10%)
BI2.8	75.9	151.7	41.7	196.4	44.6 (23%)	0.0* (<10%)
LI1.9	1.8	3.6	0.6	23.0	19.4 (85%)	19.4 (85%)

*0.0 (<10%) indicates minimal reduction needed;
**based on 90th percentile criterion (200 cfu/100 mL);
STV = statistical threshold value using 90th percentile criterion (200 cfu/100 mL)

Table D-2. Daily loading capacities for the Padilla Bay Watershed during the dry season.

Compliance will be demonstrated by direct instream monitoring of water quality. Shown in the table are current loads and the bacteria reductions needed. Segment-based progressive reductions assume that bacteria loads are reduced upstream. If no reductions upstream occur, then the individual reductions are needed.

Site	Loading Capacity (billion cfu/day)	Estimated GeoMean Target Load (billion cfu/day)	Estimated STV Target Load (billion cfu/day)	Existing STV Load (billion cfu/day)	FC Individual Reductions**	FC Progressive Reductions**
JL11.25NO	9.3	2.6	18.6	15.1	0.0* (<10%)	0.0* (<10%)
JL11.2	3.9	0.8	7.8	13.0	5.2 (40%)	5.2 (40%)
JL10.2	5.0	4.3	10.2	30.1	20.1 (67%)	14.9 (49%)
JL9.0	12.6	6.6	25.3	39.6	14.4 (36%)	0.0* (<10%)
JL7.9	14.8	9.4	29.5	62.5	33 (53%)	18.1 (29%)
JL4.7	32.3	26.2	64.6	53.9	0.0* (<10%)	0.0* (<10%)
JL2.7	52.2	50.5	104.5	113.5	9 (8%)	0.0* (<10%)
JL0.7	81.0	64.0	162.0	322.9	161 (50%)	142.9 (44%)
NN1.0	0.7	0.3	1.4	2.0	0.6 (28%)	0.6 (28%)
BI8.2	0.6	0.1	1.1	3.4	2.2 (66%)	2.2 (66%)
BI6.2	4.3	0.9	8.5	5.4	0.0* (<10%)	0.0* (<10%)
BI4.0	7.5	1.4	15.0	3.0	0.0* (<10%)	0.0* (<10%)
BI2.8	16.4	9.4	32.8	27.4	0.0* (<10%)	0.0* (<10%)
LI1.9	0.2	0.2	0.5	1.4	1.0 (69%)	1.0 (69%)

*0.0 (<10%) indicates minimal reduction needed;
**based on 90th percentile criterion (200 cfu/100 mL);
STV = statistical threshold value using 90th percentile criterion (200 cfu/100 mL)

Appendix E. Permit List

Table E-1. List of permit holders in the study area.

Permit Type	Name
MS4	City Of Burlington, Incorporated UGA
MS4	Skagit County, Bay View Ridge Unincorporated UGA
MS4	Skagit County, Burlington Unincorporated UGA
MS4	Skagit County, Mount Vernon Unincorporated UGA
Construction SW GP	Paccar Technical Center
Construction SW GP	Bay Meadows Subdivision
Construction SW GP	Bay Meadows Subdivision
Construction SW GP	Bay Meadows Subdivision
Construction SW GP	Burlington Arco Fueling Facility
Construction SW GP	Bay View Elementary School
Construction SW GP	Cascade Natural Gas Burlington Pipeline
Construction SW GP	Hughes Farms Construction
Construction SW GP	Pacific Woodtech Corporation Project
Construction SW GP	Bay Meadows Subdivision
Construction SW GP	Cascade Village
Construction SW GP	Lauts Recycle Yard
Construction SW GP	Skagit Valley Farms Raw Product Cooling
Construction SW GP	Skagit Did14 Drainage System Improvement
Construction SW GP	East Ridge Produce Processing Plant
Construction SW GP	Frazier Heights
Construction SW GP	Skagit County Port
Construction SW GP	Port Of Skagit Lots 42-46 51
Construction SW GP	Team Corporation
Construction SW GP	Skagit Valley Malting
Construction SW GP	Wilbur Ellis Company Skagit
Construction SW GP	Poplar Plantation Off Site Mitigation
Construction SW GP	Samish Unit
Construction SW GP	Cook Road Dairy
Industrial SW GP	Fedex Express Odw
Industrial SW GP	Connextion The
Industrial SW GP	Fedex Ground Bay Ridge Dr
Industrial SW GP	The Euclid Chemical Company
Industrial SW GP	Hexcel Corp
Industrial SW GP	Gielow Pickles Nw LLC
Industrial SW GP	Draper Valley Farms Burlington
Industrial SW GP	Americold Corp Burlington
Industrial SW GP	Cargill Animal Nutrition

Permit Type	Name
Industrial SW GP	Nordic Tugs Inc Huggins Airport Way
Industrial SW GP	Edco Inc
Industrial SW GP	Skagit County Port
Industrial SW GP	Rsa Microtech Westar Lane
Industrial SW GP	Tri County Truss Inc
Industrial SW GP	Lindal Building Products
Industrial SW GP	Waste Mgmt Skagit Co Hauling
Industrial SW GP	Burlington Lumber Facility
Industrial SW GP	Washington Alder
Industrial SW GP	Skagit Soils Inc
Industrial SW GP	Rolling Frito Lay Sales Lp Burlington
Industrial SW GP	Skagit Cnty Transfer & Recycling Station
Industrial SW GP	Lautenbach Recycle Park
Industrial SW GP	Bayview Edison Industries Mt Vernon
Industrial SW GP	Pacific Woodtech Corporation
Industrial SW GP	Skagit Soils Inc
Industrial SW GP	Aggregates West Mt Vernon Site
Sand and Gravel GP	Skagit Ready Mix Mcfarland Road
Sand and Gravel GP	Cemex Butler Pit
Sand and Gravel GP	Concrete Norwest Peterson
Sand and Gravel GP	North Hill Resources
Industrial to POTW/ Private SWD	Inman Landfill
Industrial to POTW/ Private SWD	Pse Fredonia
Industrial NPDES IP	Sulex Inc Mount Vernon
Industrial NPDES IP	Hughes Farms

MS4= Municipal Separate Storm Sewer System; SW= stormwater; GP= general permit; POTW= Publically Owned Treatment Works; SWD= State Waste Discharge; NPDES= National Pollutant Discharge Elimination System; IP= individual permit; UGA= urban growth area

Appendix F. Statistical Rollback Results

The following pages show 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 H0 or p value<0.05) (black).

All of the sites required some level of FC reduction to achieve the second water quality criteria, where not more than 10% of samples may exceed 200 cfu/100mL, based on the rollback analysis for the critical season. These reductions were established based on the current conditions of FC in the study area.

Note that the loading capacities developed for this study take into account the effect of improving water quality and reducing FC concentrations upstream. These targets correspond with the amount of FC needed to be reduced in order to meet water quality standards without any upstream reductions.

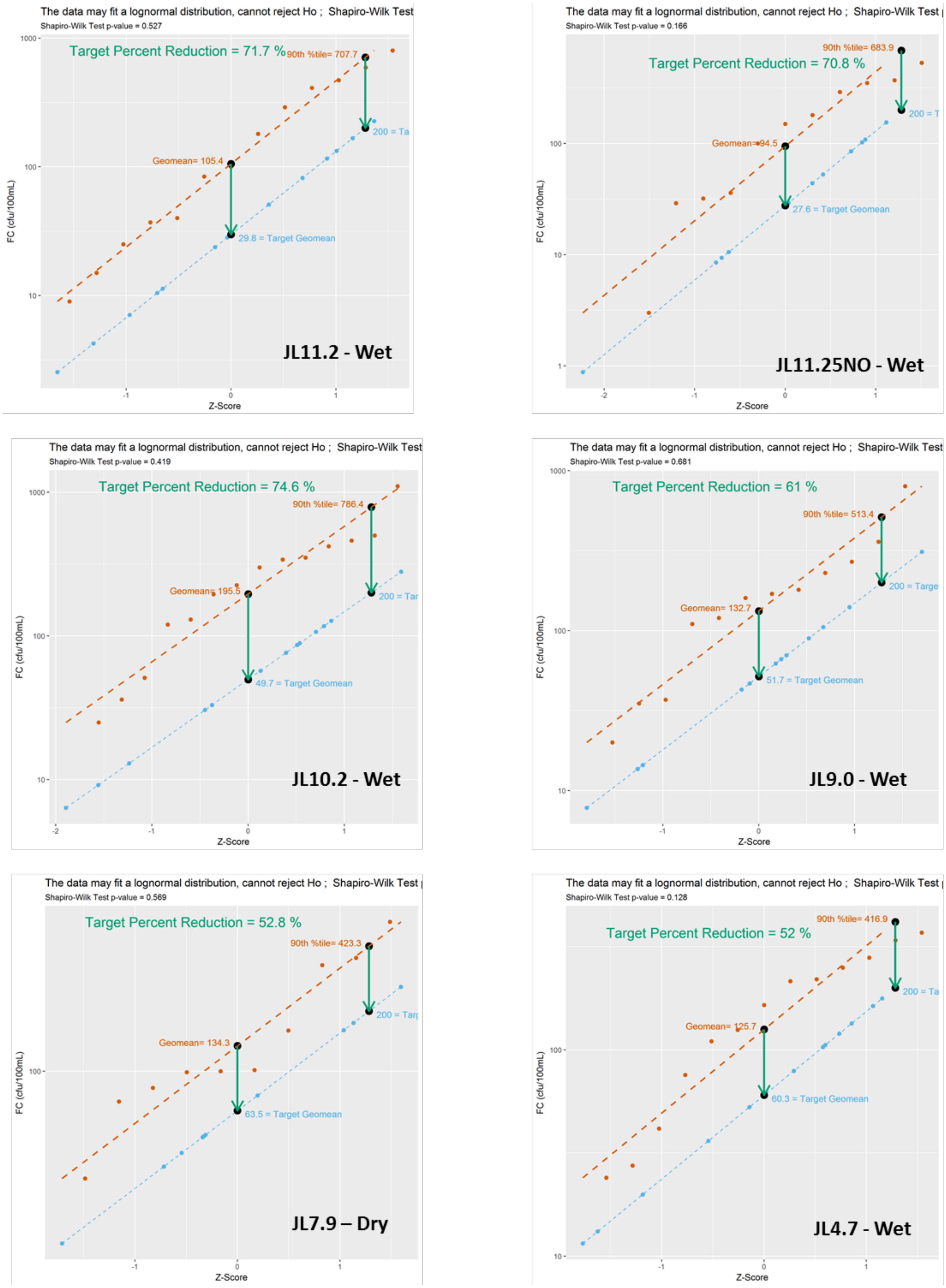


Figure F-1. Statistical rollback analysis reduction results.

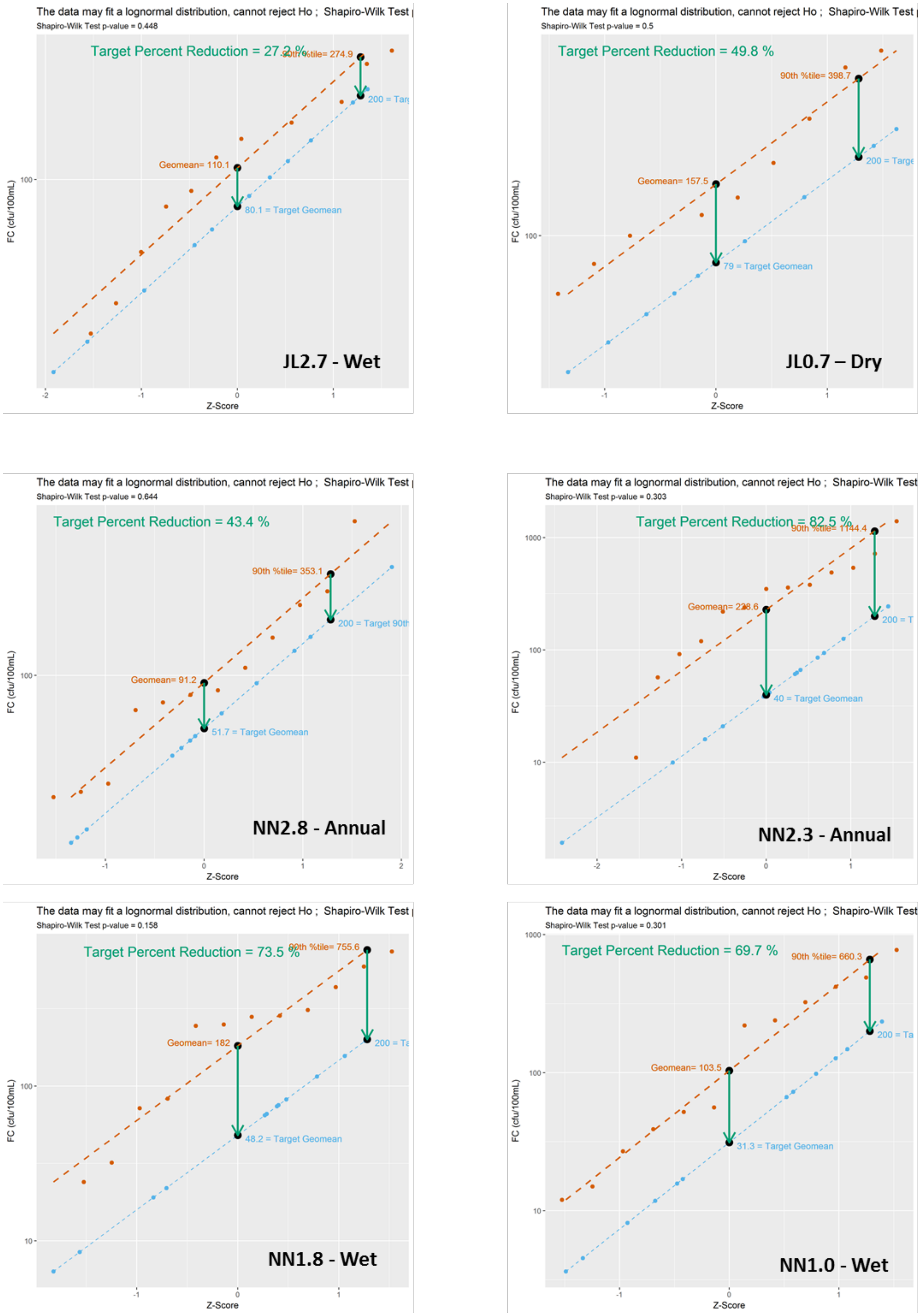
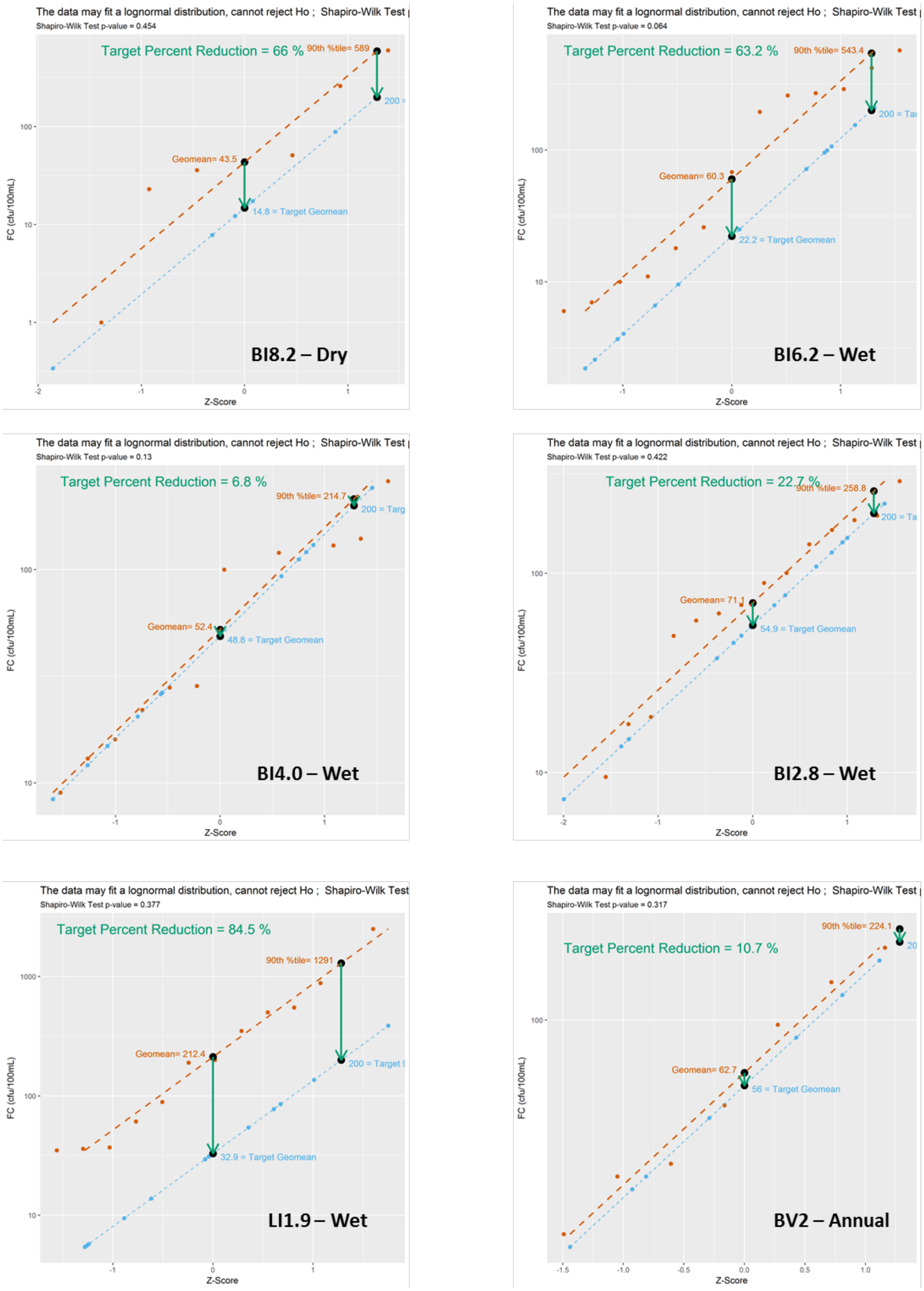


Figure F-2. Statistical rollback analysis reduction results (continued).



FigureF-3. Statistical rollback analysis reduction results (continued).

Figure F-4. Statistical rollback analysis reduction results (continued).