Appendix D

Deschutes River Bacteria TMDLs Technical Analysis

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
BMP	Best Management Practices
cfs	Cubic Feet per Second
cfu	Colony-forming Unit
cfu/100mL	Colony-forming Units per 100 Milliliters
cfu/day	Colony-forming Units per Day
CV	Coefficient of Variation
CWA	Clean Water Act
DEM	Digital Elevation Model
E. coli	*Escherichia coli*
Ecology	Washington Department of Ecology
EIM	Environmental Information Management System
EMC	Event Mean Concentration
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
GMC	Geometric Mean Criterion
LA	Load Allocation
LDC	Load Duration Curve
mg/L	Milligram per Liter
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
NHD	National Hydrography Dataset
NHDPlus V2	Horizon Systems - National Hydrography Dataset (NHD) plus National Elevation Dataset and Watershed Boundary Dataset Version 2
NLCD	National Land Cover Dataset

Acronyms/Abbreviations	Definition
NPDES	National Pollutant Discharge Elimination System
QAPP	Quality Assurance Project Plan
SSC	Single Sample Criterion
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
WEF	Water Environment Federation
WLA	Waste Load Allocation
WQS	Water Quality Standard
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

1.0 INTRODUCTION

This appendix is based a report prepared by Tetra Tech under contract with the Environmental Protection Agency, Region 10. All work was conducted in accordance with an approved Quality Assurance Project Plan (QAPP; Tetra Tech, 2019). The objectives of the technical analyses presented in this report include identifying and quantifying key sources of bacteria to the impaired tributaries of the Deschutes River and Budd Inlet (Figure 1), ensuring protection of downstream water quality standards, establishing a Total Maximum Daily Load (TMDL), and determining the required percent reductions.

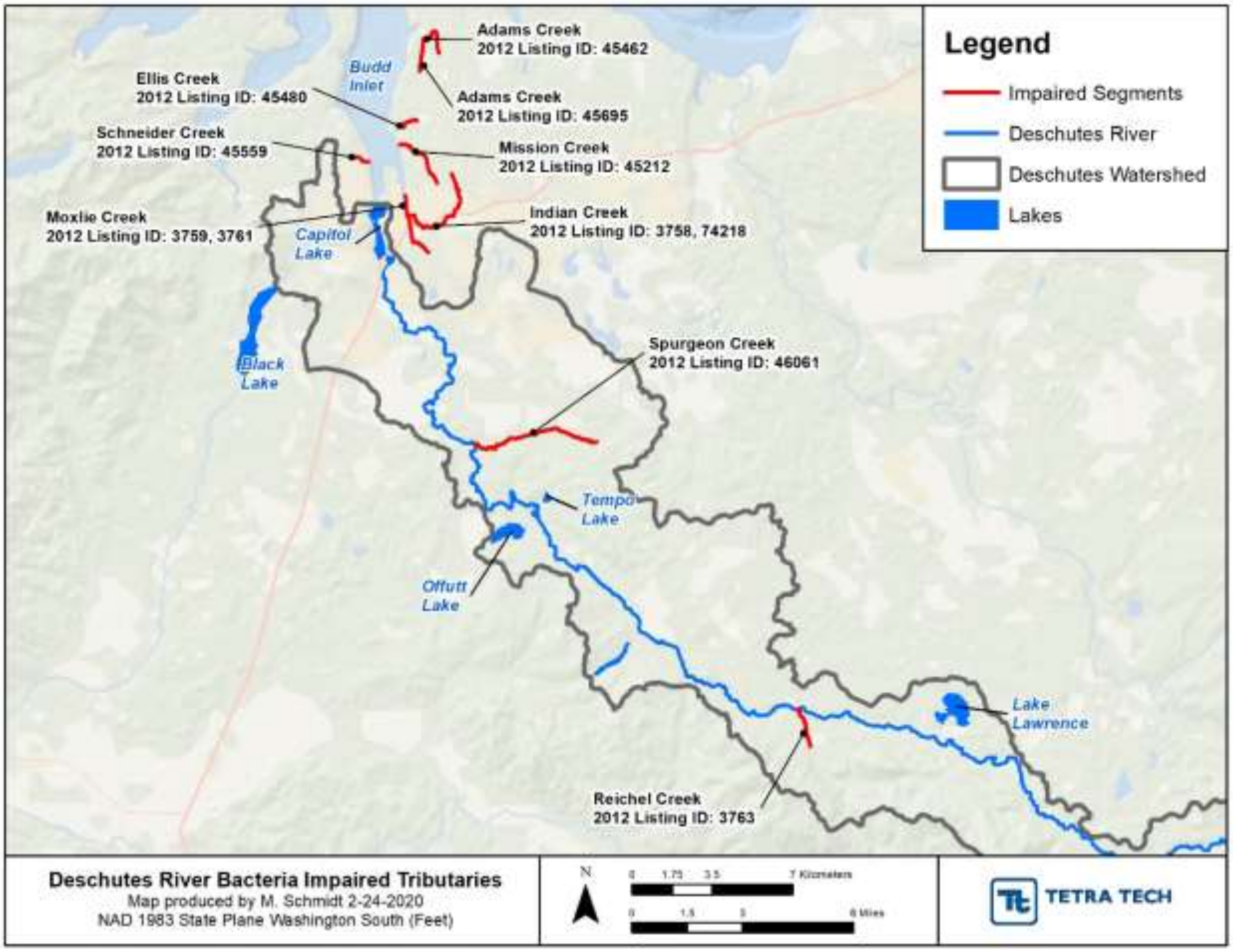


Figure 1. Deschutes River and Budd Inlet Bacteria Impaired Waterbodies

1.1 BACKGROUND

EPA disapproved the bacteria TMDLs in the Washington Department of Ecology (‘Ecology’) 2015 Deschutes TMDL because it determined they lacked a required public participation component, and some of the TMDLs did not demonstrate protection of downstream water quality standards. Because the freshwater quality standards were updated and approved by EPA since the *2015 Deschutes TMDL* was written, EPA developed new TMDLs for all impaired waterbodies based on the revised standards. EPA used the Load Duration Curve (LDC) method to calculate loads (Stiles, 2001, 2002; Cleland, 2002, 2003), which provides both the existing load and the TMDL under all flow conditions. The LDC approach has been used to develop numerous TMDLs throughout the U.S. including in the State of Washington (Washington Department of Ecology, 2008). However, this method differs from the one used in the *2015 Deschutes TMDL*, which was to derive TMDLs using a mass-balance approach at critical flow. EPA determined the LDC method was appropriate in this case because it provides valuable information about the allowable loading under a variety of flow conditions in addition to information about flow conditions where the loading typically exceeds the allowable amount and reductions are most needed.

To derive the LDC, instream flows are translated into percentage points on a cumulative distribution curve based on the percent of time that historic flows exceed a given value. The flows are multiplied by the applicable concentration target, along with appropriate unit conversion factors, to derive the load. By plotting the targeted TMDL with observed data, the LDC shows the flow conditions in which water quality criteria are being exceeded. The LDC is divided into a set of flow regimes – high, moist, mid-range, dry, and low. This provides useful information about which flow regimes have the highest number of deviations from the water quality standards, and potential sources of the water quality problem (U.S. Environmental Protection Agency 'USEPA', 2007). For example, a stream segment could have bacterial excursions during low flow conditions due to leaking septic tanks and illicit discharges, while excursions during wet weather might be due to urban and agricultural runoff. Bacteria die-off instream is considered negligible for the LDC analysis, which provides a high level of confidence that the TMDL will achieve the applicable bacteria criteria.

EPA also evaluated downstream water quality standards to determine the applicable standard for each impaired segment, either the criteria applicable to the impaired waterbody or the downstream waterbody. In the case of freshwaters protected for primary contact recreation flowing into marine waters also protected for primary contact recreation, the freshwater criteria are protective of downstream uses because both were developed using the same illness rates (EPA, 2012; L. Wilcut, personal communication, 7/8/2020). For freshwaters flowing into marine waters protected for shellfish harvesting, EPA compared the two criteria to determine which one should be applied in TMDL development. Because different indicator bacteria apply to fresh and marine waters, EPA performed regression analyses to relate everything to a common indicator, fecal coliform, so comparisons could be made. Fecal coliform was chosen because prior to adoption of the new bacteria standards in 2019, only fecal coliform was monitored with regularity in the impaired segments. Regression relationships were developed using paired bacteria samples (i.e. collected at the same time and location) from waterbodies in the region, all within the State of Washington.

2.0 AVAILABLE DATA

Data used in the technical analysis for the bacteria TMDL include geographic information system (GIS) spatial datasets for drainage areas, land use/cover, permitted urban stormwater boundaries, and Washington State Department of Transportation (WSDOT) operated roadways. In addition, the assessments described in this appendix apply instream water chemistry and flow monitoring data.

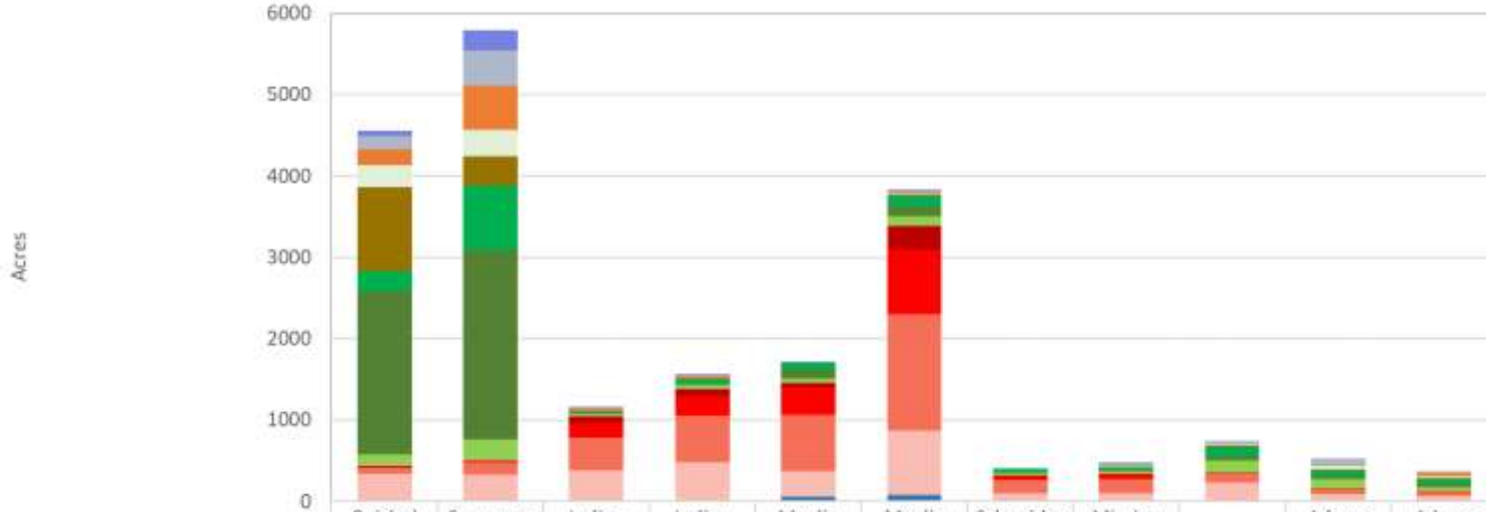
2.1 GIS

EPA used GIS data to develop catchment boundaries for the impaired waterbodies and to differentiate between Municipal Separate Storm Sewer System (MS4) and non-MS4 areas. Sources of GIS data are as shown in Table 1. Both point and nonpoint sources can contribute pollution to the waterbodies, the latter of which can be summarized by land use/cover. The National Land Cover Dataset (NLCD 2011 at a 30-meter resolution) was used to classify land use/cover in each tributary's drainage area (Figure 2). Figure 2 includes the full drainage area for each segment, including the catchments of upstream segments (e.g., lower Indian Creek (# 74218) includes upper Indian Creek (#3758)).

Table 1. GIS Data Sources

Purpose	GIS Datasets
Develop watershed boundaries and catchment areas	10-meter Digital Elevation Model (DEM) from United States Geological Survey (USGS) National Elevation Dataset
	Catchment boundaries from NHDPlus V2[1]
Definition of MS4 and non-regulated areas	MS4 boundaries from Ecology
	Land use/land cover from National Land Cover Dataset 2011
	National highways from WSDOT

[1]http://www.horizon-systems.com/nhdplus/nhdplusv2_home.php



	Reichel Creek (#3763)	Spurgeon Creek (#46061)	Indian Creek (#3758)	Indian Creek (#74218)	Moxlie Creek (#3761)	Moxlie Creek (#3759)	Schneider Creek (#45559)	Mission Creek (#45212)	Ellis Creek (#45480)	Adams Creek (#45462)	Adams Creek (#45695)
Emergent Herbaceous Wetlands	63.6	241.3	16.5	16.5	2.9	19.3	0.0	6.4	4.2	11.6	0.0
Woody Wetlands	163.5	441.5	13.6	13.6	0.0	13.6	0.0	25.1	29.6	62.3	15.1
Cultivated Crops	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0
Pasture/Hay	198.2	542.2	19.1	19.1	0.0	19.1	0.0	9.1	0.0	15.8	48.7
Grassland/Herbaceous	262.6	322.0	4.0	4.0	4.2	9.6	0.0	3.6	6.4	34.0	17.8
Shrub/Scrub	1034.8	351.6	12.2	12.2	0.0	12.2	0.0	1.1	20.5	16.5	12.2
Mixed Forest	250.0	793.5	11.1	53.4	83.2	136.6	42.0	44.0	106.5	68.7	51.8
Evergreen Forest	2001.8	2334.0	4.7	7.1	102.1	109.2	15.1	14.9	52.9	38.0	46.0
Deciduous Forest	125.4	248.2	35.4	63.6	59.6	123.2	30.7	30.7	154.1	121.2	54.9
Barren	13.8	10.9	0.0	0.0	0.0	2.9	0.2	0.2	0.0	0.0	0.0
Developed, high	9.3	0.0	70.9	82.1	58.9	289.1	4.7	0.7	0.2	0.2	1.3
Developed, medium	16.5	21.3	189.7	241.7	331.8	787.3	46.3	60.9	12.0	7.3	8.7
Developed, low	69.8	150.8	401.2	570.7	688.1	1431.8	165.9	173.2	114.3	51.8	38.7
Developed, open	332.7	329.6	366.5	466.6	316.0	800.0	98.1	101.9	227.1	94.5	72.5
Open Water	11.3	0.0	14.2	14.2	60.9	75.2	0.0	2.7	0.0	0.0	0.0

Figure 2. Land Cover in the Bacteria Impaired Catchments (derived from the 2011 National Land Cover Dataset)

2.2 FLOW

Long-term gaging records were not available for the bacteria impaired segments. Thus, EPA estimated historic flow regimes by scaling daily flows observed at the United States Geological Survey (USGS) Deschutes River at Tumwater gage (USGS 12080010) based on relative drainage area. In the absence of continuous flow data measurements or hydrology simulation models, this is a reasonable method for estimating flows since the catchments have climate and geologic characteristics that are comparable to the broader watershed. The period of record was limited to water year 1998 through water year 2018, coincident with the sampling dates of the bacteria monitoring data summarized in Table 3.

To obtain the ratio of impaired drainage area to the USGS Deschutes River at Tumwater gage drainage area, EPA delineated impaired catchments. Drainage area boundaries for Reichel Creek and Spurgeon Creek were available from the NHDPlus V2 dataset, and the catchments were used directly. However, boundaries were not available for the creeks draining to Budd Inlet, so boundaries were delineated from 10-meter resolution DEMs from the USGS National Elevation Dataset. The TauDEM[1] toolset was used to perform a flow accumulation algorithm contributing to a discharge point, thus providing the drainage areas for each impaired segment. The catchment boundaries are shown in

Figure 3, Figure 4, and Figure 5.

[1] http://hydrology.usu.edu/taudem/taudem5/index.html

Table 2 lists the catchment areas, and it shows cumulative drainage areas for segments with impaired upstream Assessment Units. The area ratio is the impaired segment drainage area divided by the watershed area at the Deschutes River Tumwater gage (162 mi^2 as reported on the USGS gage website). A limitation of the TauDEM method is that it relies on elevation data only, and it cannot account for flow routing alterations associated with road networks and urban stormwater drainage systems. This uncertainty is accounted for by the explicit margin of safety (MOS). The analysis could be adjusted in the future if more accurate drainage boundaries become available.

Table 2. Impaired Watershed Contributing Areas

Waterbody	2012 Listing ID	Area (mi^2)	Area Ratio[1]
Reichel	3763	7.12	0.0439
Spurgeon	46061	9.04	0.0558
Upper Indian	3758	1.81	0.0112
Lower Indian	74218	0.63	0.0151
Upper Moxlie	3761	2.67	0.0165
Lower Moxlie	3759	0.87	0.0369
Schneider	45559	0.63	0.00388
Mission	45212	0.74	0.00457
Ellis	45480	1.14	0.00706
East Adams	45462	0.82	0.00504
West Adams	45695	0.58	0.00356

[1]Relative to USGS Deschutes River at Tumwater gage

2.3 BACTERIA

EPA obtained instream bacteria monitoring data from the impaired waterbodies from the Washington Environmental Information Management System (EIM) online database and from the Thurston County Environmental Health Division. EPA omitted data sampled prior to water year 1998 from the analyses, as it is likely that conditions in the impaired watersheds and degree of development were substantially different more than 20 years ago. All data obtained from EIM were also used in the *2015 Deschutes TMDL*. Data obtained from Thurston County dated 2017 or newer was not used in the *2015 Deschutes TMDL*.

Values reported as less than the detection limit were set equal to the detection limit (1 cfu/100mL for the EIM data and 5 cfu/100mL for the Thurston County data). The detection limits are both much lower than the applicable bacteria concentration standards, so the impact on the LDC analysis is minimal. EPA averaged field duplicates (i.e., observations at a station from the same date and time) and retained separate values for observations taken at different times of day (which generally reflect storm event sampling), as well as observations from all stations taken on the same day (rather than defaulting to the highest concentration). Bacteria data are inherently variable and subject to analytical uncertainty, especially during storm events. Incorporating the range of values across storm events and sites on the same day accounts for variability and allows for more statistical power in the LDC analysis. For example, there were 47 observations available for Indian Creek listing ID 3758; if all daily values were averaged at a site and used, the number of observations would drop to 15. For the same reason, EPA retained data from sites that targeted stormwater conditions. Having more observations during storm event conditions strengthens the TMDL analysis at high flow conditions, which otherwise might not be well reflected from ambient monitoring alone. Table 3 summarizes fecal coliform data availability by monitoring station (following averaging of field duplicates).

Figure 3, Figure 4, and Figure 5 show monitoring station locations and impaired segments.

EPA also used *Escherichia coli* (*E. Coli)* data from EIM to develop the paired regressions. Paired *E. coli*-fecal data were available from the Deschutes Watershed (Water Resource Inventory Area, 'WRIA', 13), but over 20 percent of the paired values were identical, especially at high concentrations. While *E. coli* are a subset of total fecal coliform bacteria, it is unlikely that the concentrations were truly identical. Since the data quality for WRIA 13 could not be verified, EPA used paired data from the Green-Duwamish and Central Puget Sound Watershed (WRIA 9) to develop the *E. coli*-fecal coliform regression. WRIA 9 is primarily in the urbanized area of King County, which is also in the Puget Lowlands. A total of 992 paired observations were available, of which about five percent were identical.

Table 3. Bacteria Sampling Summary for Impaired Segments

Waterbody	2012 Listing ID	Location ID	Source	Water Years	Count
Adams	45462	13-ADA-00.5	EIM	2003 - 2005	39
		Total			***39***
	45695	13-ADA-DS_4446	EIM	2005	1
		13-ADA-DS_4530	EIM	2004 - 2005	4
		13-ADA-HEAD	EIM	2005	1
		13-ADASW-4530	EIM	2005	3
		13-ADA-UNK	EIM	2004 - 2005	27
		13-ADA-US_4446	EIM	2005	1
		13-ADA-US_4510	EIM	2005	3
		13-ADA-US_4530	EIM	2004	1
		ADA-1046_46TH	EIM	2004	1
		Total			***42***
Ellis	45480	13-ELL-00.0	EIM	2003 - 2005	39
		13-ELL-26TH	EIM	2005	2
		13-ELL-33RD	EIM	2005	6
		13-ELL-33RDE	EIM	2005	2
		13-ELL-33RDW	EIM	2005	2
		13-ELL-36THW	EIM	2005	1
		13-ELL-EBAY	EIM	2005	2
		BUDEL0000	Thurston Co.	1998 - 2014	95
		Total			***149***
Indian	3758	13-IND-12TH	EIM	2005	5
		13-IND-BOUL	EIM	2005	6
		13-IND-BOUL-TC	EIM	2008 - 2009	11
		13-IND-DSSBAY	EIM	2008	1
		13-IND-FRED	EIM	2005	6
		13-IND-FRED-TC	EIM	2008	1
		13-IND-MART	EIM	2005 - 2009	8
		13-IND-PAC	EIM	2008	1

Waterbody	2012 Listing ID	Location ID	Source	Water Years	Count
		13-IND-PHOX	EIM	2008	1
		13-IND-SBAY	EIM	2005	6
		DEVOESTMWTR	EIM	2008	1
		Total			***47***
	74218	13-IND-00.2	EIM	2003 - 2005	40
		13-IND-CENT	EIM	2008 - 2009	10
		13-IND-QUIN	EIM	2008 - 2009	11
		13-IND-USWHE	EIM	2008	1
		13-IND-WHEE	EIM	2005	6
		BUDIN0010	Thurston Co.	1998 - 2018	161
		Total			***229***
Mission	45212	13-MIS-00.1	EIM	2003 - 2005	40
		13-MIS-BETH	EIM	2005	6
		13-MIS-ETHR	EIM	2005	6
		Total			***52***
Moxlie	3759	13-MOX-00.0	EIM	2003 - 2005	39
		13-MOX-5TH	EIM	2004 - 2005	12
		13-MOX-8TH	EIM	2005	7
		BUDMO0000	Thurston Co.	1998 - 2018	152
		BUDMO0020	Thurston Co.	1998 - 2000	15
		Total			***225***
	3761	13-MOX-00.6	EIM	2003 - 2005	39
		13-MOX-PARK	EIM	2005	6
		13-MOX-PLUM	EIM	2005	6
		BUDMO0030	Thurston Co.	1998 - 2017	40
		Total			***91***
Reichel	3763	13-REI-00.9	EIM	2003 - 2005	35
		DESRE1100	Thurston Co.	2008 - 2018	131
		Total			***166***
Schneider	45559	13-SCH-00.1	EIM	2003 - 2005	30
		BUDSC0000	Thurston Co.	1998 - 2014	95
		Total			***125***
Spurgeon	46061	13-SPU-00.0	EIM	2003 - 2005	40
		13-SPU-EQUU	EIM	2005	6
		13-SPU-LATI	EIM	2005	6
		13-SPU-MOOD	EIM	2005	6
		DESSP0500	Thurston Co.	1998 - 2013	107
		DESSP0510	Thurston Co.	2014 - 2018	60

Waterbody	2012 Listing ID	Location ID	Source	Water Years	Count
		Total			***225***

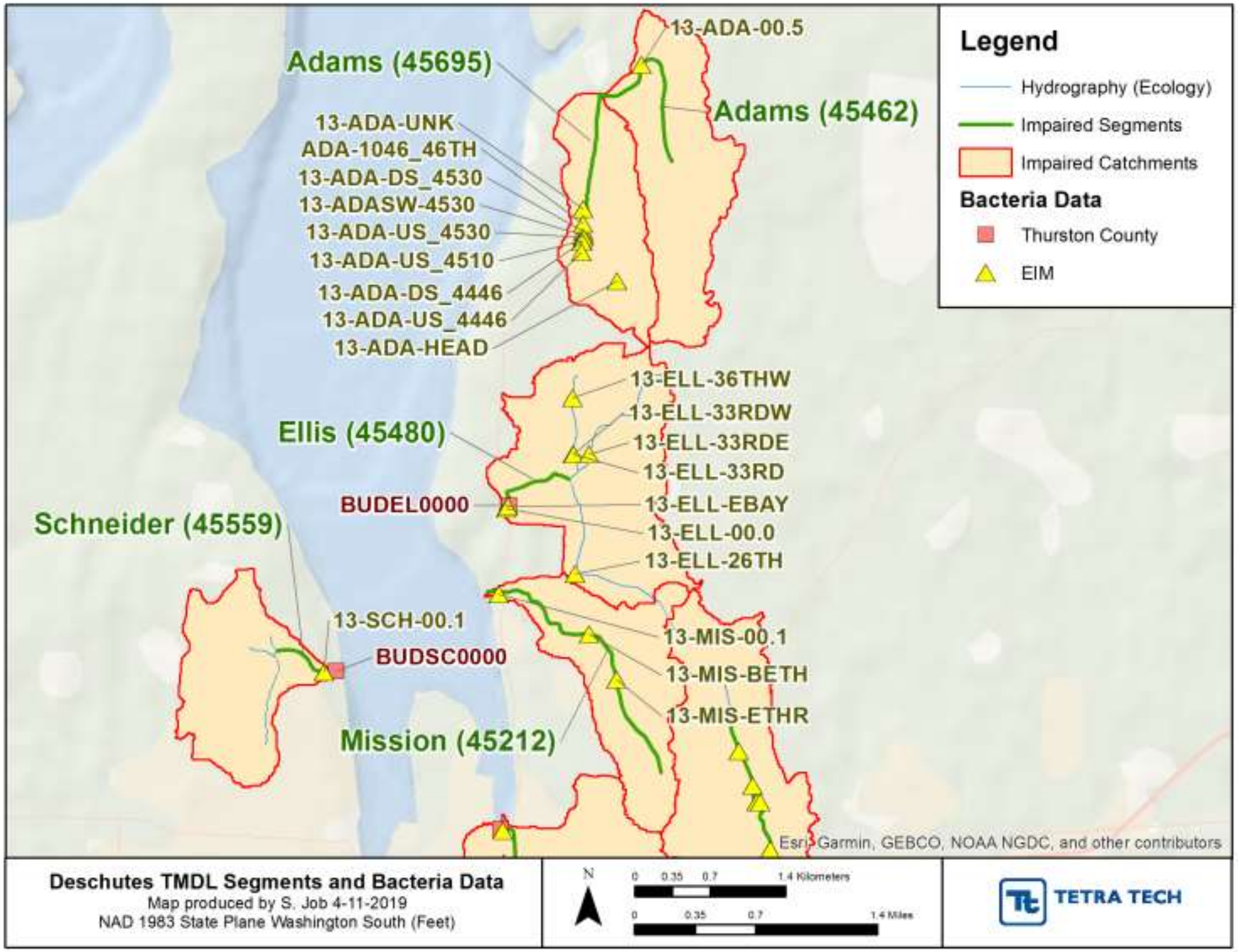


Figure 3. Impaired Waterbody Segments and Bacteria Sampling Locations (Adams, Ellis, Mission, Schneider)

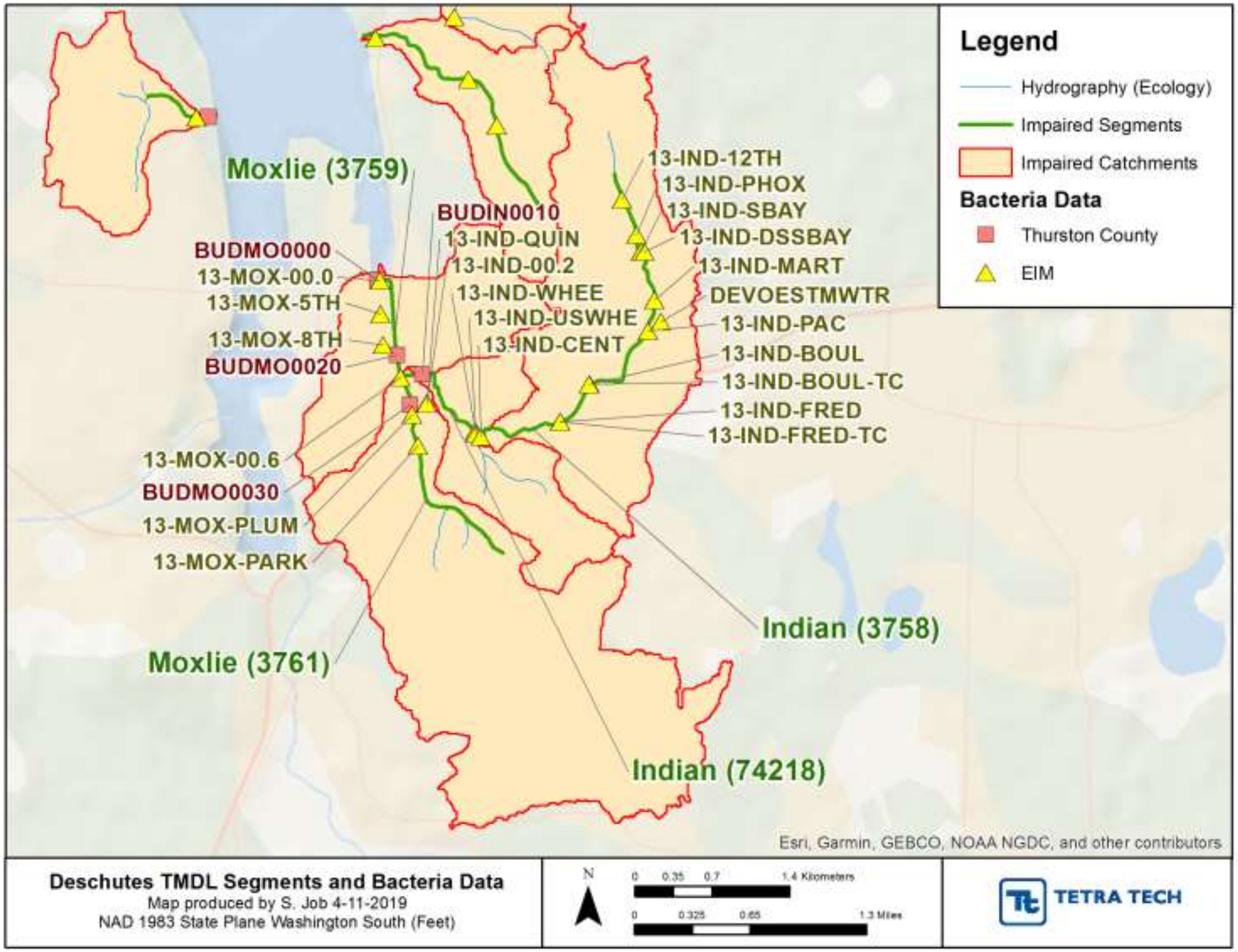


Figure 4. Impaired Waterbody Segments and Bacteria Sampling Locations (Indian, Moxlie)

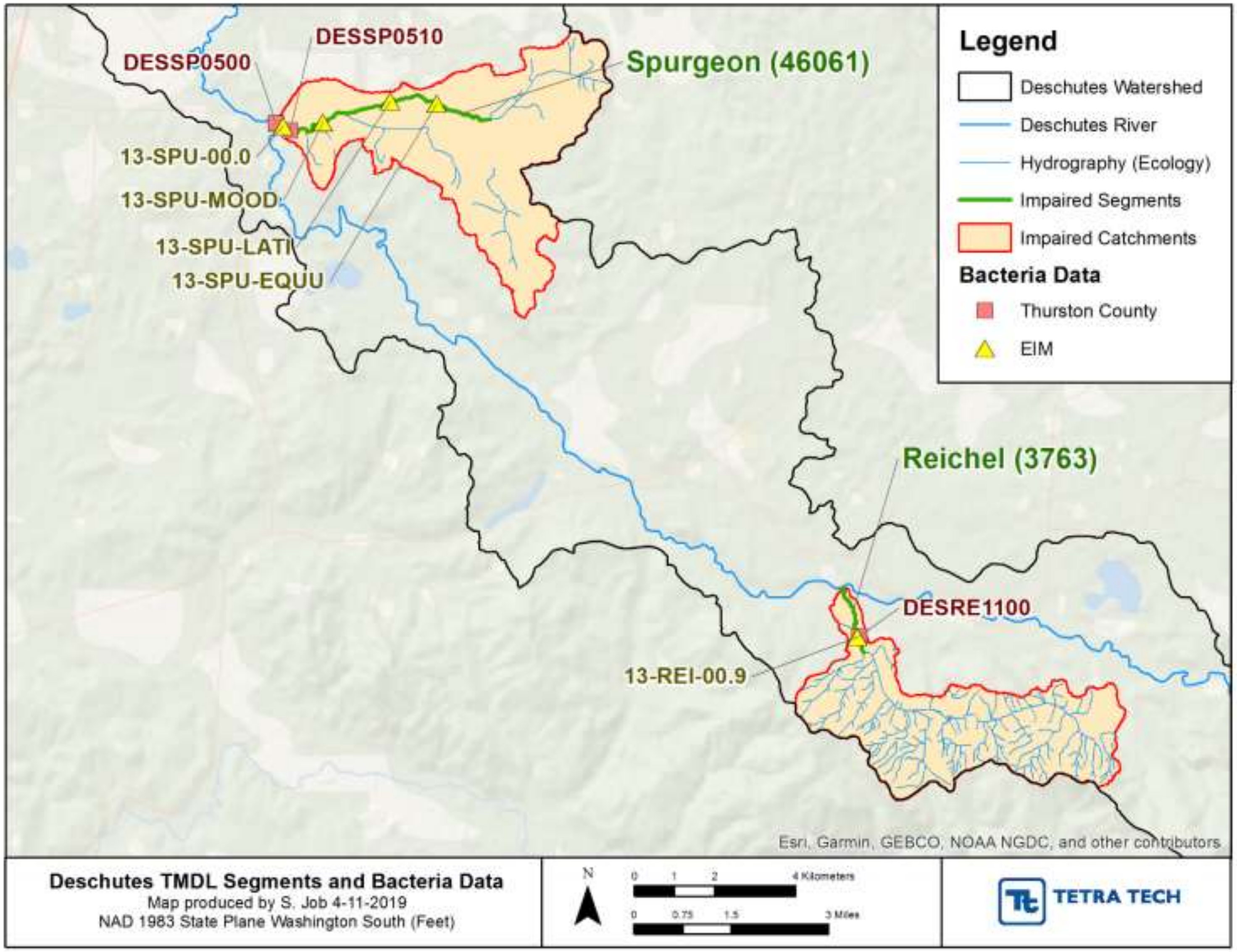


Figure 5. Impaired Waterbody Segments and Bacteria Sampling Locations (Reichel, Spurgeon)

3.0 NUMERIC TARGET SELECTION

EPA used regressions to translate *E. coli* criteria to equivalent fecal coliform criteria using paired data from monitoring locations in other freshwater streams in urban areas of the Green-Duwamish watershed[2]. This allowed for comparison of the criteria to find the most stringent criterion. The regression must allow for two-way translation (e.g., convert *E. coli* criteria to fecal coliform equivalents to determine the applicable TMDL target, while also allowing translation of existing fecal coliform data back to *E. coli* equivalents). Simple linear regression accounts for errors in the dependent variable only (typically plotted on the y-axis). As a result, the regression parameters should not be used to calculate the independent variable from the dependent variable. In other words, a simple linear regression does not provide a two-way relationship.

To address this limitation, EPA used a Deming regression to develop the translators. A Deming regression differs from simple linear regression in that it accounts for errors in observations in both the x- and y-axis, and the resulting relationship can be used translate the x variable to the y variable, and the y variable back to the x variable. A Deming regression attempts to minimize the squared distances from the regression line in both the x and y variables, rather than minimizing only the squared deviations in the predicted variable (Deming, 1943; Glaister, 2001). This makes the relationship invertible, unlike a simple linear regression.

3.1 *E. COLI* – FECAL COLIFORM TRANSLATOR

The Deming regression was performed on $\log_{10}$ transformed data. The resulting regression, once converted to arithmetic space, has the following forms (Equation 1 and Equation 2):

Equation 1. $$Fecal\ coliform = 10^{(1.00000\ [log_{10}\ E.coli]\ -\ 0.01061)}$$

Equation 2. $$E.coli = 10^{(1.00000\ [log_{10}\ Fecal\ coliform] + 0.01061)}$$

The data and the regression line using Equation 1 are shown in Figure 6. The results of criteria translation are shown in Table 4.

[2] While compliance with the marine primary contact recreation criteria is assessed in Budd Inlet downstream of freshwaters (where differing die-off rates could alter the relationship between *E. coli* and fecal coliform), the translation must be developed using paired measurements in freshwater where the fecal coliform data used in the LDC were collected.

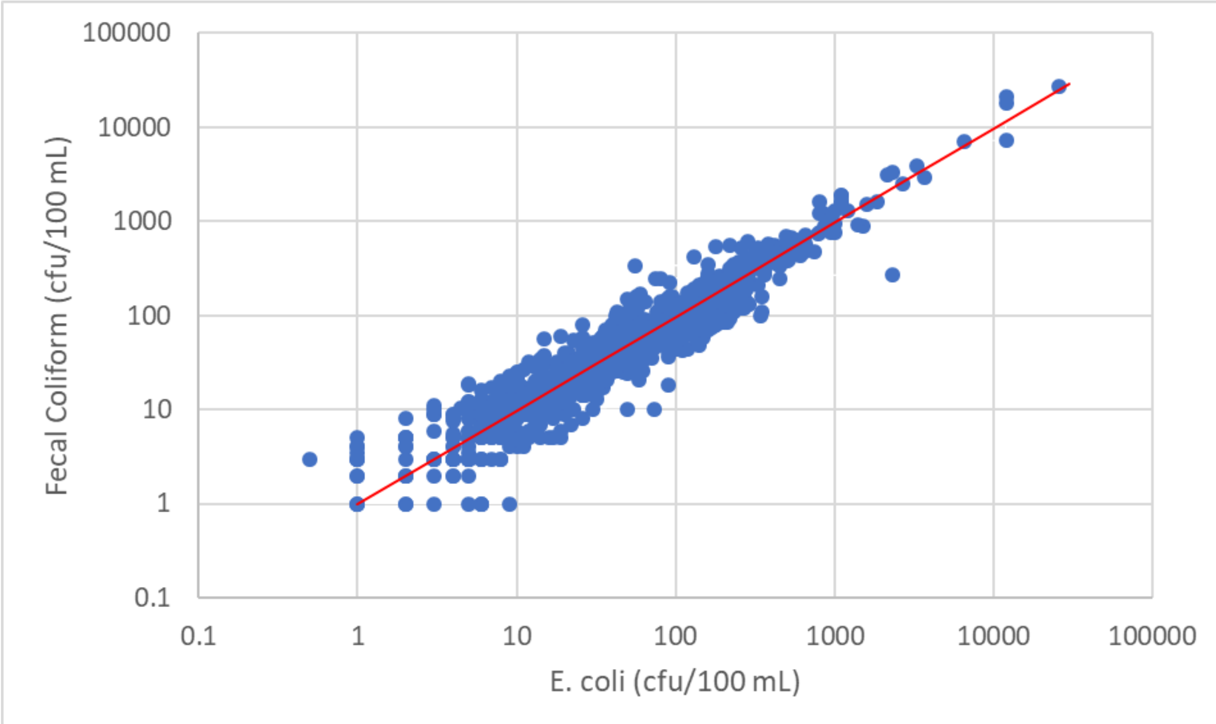


Figure 6. Relationship between *E coli* and Fecal Coliform Concentrations

Table 4. Translation of *E. coli* Criteria to Equivalent Fecal Coliform Criteria

Criterion (colonies/100 mL)	*E. coli*	Translated Fecal Coliform
Geometric mean	100	97.6
Single Sample	320	312.3

The translation yields fecal coliform concentrations that are slightly lower than *E. coli* concentrations in the range of interest. This is counter-intuitive, as *E. coli* are a subset of fecal coliform; however, the results may reflect differential biases in the two test methods. Hamilton et al (2005) report that *E coli*. concentrations frequently exceed fecal coliform concentrations in split samples, depending on the tests used. Different testing methodologies can yield different results depending on the recovery (i.e. reported concentration) ranges of the methods. The test methods are implicitly incorporated in the development of the water quality criteria. The MOS accounts for this uncertainty pertaining to the biases in the two test methods.

3.2 GEOMETRIC MEAN CRITERION TRANSLATION

EPA guidance for the LDC approach (USEPA, 2007) recommends utilizing a linkage analysis to translate between a geometric mean criterion and a daily single sample criterion, using the assumption that bacteria data can be described using a lognormal distribution. The method discussed in EPA guidance assumes use of the 30-day or monthly geometric mean and is not directly applicable to use of an annual geometric mean, which is Ecology's current waterbody assessment approach (Ecology, 2018). However, the U.S. Food and Drug Administration (USFDA) provides an approach for estimating the 90th percentile of lognormally distributed bacteria data for their National Shellfish Sanitation Program Model Ordinance (USFDA, 2017). This can be modified to translate a geometric mean criterion to a daily single sample criterion. Given a data set following the standard lognormal distribution, the 90th percentile can be found using Equation 3:

$$\text{Equation 3. } 90th\ percentile = 10^{(\mu_{log10} + Z\ \sigma_{log10})}$$

where μ_{log10} is the mean of the $\log_{10}$ transformed data, σ_{log10} is the standard deviation of the $\log_{10}$ transformed data, and Z = 1.282 (90th percentile standardized normal score). What is needed, though, is the 90th percentile associated with a geometric mean criterion, which is equivalent to a single sample criterion with no more than 10 percent exceedances. Given a bacteria dataset for an impaired segment with an elevated geometric mean, the goal would be to reduce the concentration distribution of the data so the reduced geometric mean equals the geometric mean criterion. If concentrations are reduced, the standard deviation would change as well; however, Ott (1994) theorizes that the coefficient of variation (CV) of the reduced concentration distribution would remain the same as the CV of the original concentration distribution (referred to as the Statistical Theory of Rollback). Mathematically, this can be expressed as:

$$\text{Equation 4 } CV = \frac{\sigma_{log10}}{\mu_{log10}} = \frac{\sigma'_{log10}}{\mu'_{log10}}$$

where μ'_{log10} and σ'_{log10} are the mean and standard deviation of the $\log_{10}$ transformed reduced concentration dataset. Substituting μ'_{log10} and σ'_{log10} into Equation 3 provides the translated single sample criterion (i.e., the 90th percentile of the reduced concentration dataset, allowing for 10 percent exceedances). The geometric mean of the reduced concentration dataset is equal to the geometric mean criterion, so μ'_{log10} equals $\log_{10}$ of the geometric mean criterion. σ'_{log10} can then be found be rearranging Equation 4:

$$\text{Equation 5 } \sigma'_{log10} = \log_{10}(GMC)\frac{\sigma_{log10}}{\mu_{log10}}$$

where *GMC* is the geometric mean criterion. Equation 3 for the reduced concentration dataset can now be written as:

$$\text{Equation 6 } SSC_T = 10^{\left(log_{10}(GMC) + Z\ log_{10}(GMC)\frac{\sigma_{log10}}{\mu_{log10}}\right)}$$

where SSC_T is the translated single sample criterion derived from the geometric mean criterion. Note that SSC_T depends on the CV of the segment's monitoring data, so SSC_T will vary by segment, even if the same geometric mean criterion is used.

3.3 SELECTION OF APPLICABLE CRITERION

In order to choose the applicable criterion for developing the LDC-based TMDLs, EPA used the following process. It is discussed in detail in the sections that follow:

1. For freshwaters protected for primary contact recreation with downstream waters also protected for primary contact recreation (and not shellfish harvesting), the freshwater primary contact recreation *E. coli* criteria apply.
2. For impaired waterbodies that flow directly into downstream waters with a designated use of shellfish harvesting, the *E. coli* criteria are translated to fecal coliform using the regression equation from Section 3.1. The set of criteria (geometric mean and single sample) with the lowest value is selected.
3. For all of the waterbodies, the geometric mean criterion for the applicable set of criteria for each segment is translated into a single sample criterion, using Equation 6 as discussed in Section 3.2.

4. The geometric mean translated single sample concentration from the previous step is compared to the WQS single sample criterion, and the lowest value of the two is chosen as the applicable criterion. The single sample criterion is the 90th percentile concentration target, which is not to be exceeded at a frequency of more than 10 percent.

3.3.1 Selection of Applicable Criteria (Steps 1 and 2)

Applicable criteria are shown in Table 5 and Table 6, with the applicable set of criteria highlighted for the waterbodies in Table 6. The *E. coli* criteria in Table 6 are expressed in terms of fecal coliform concentrations, using the regression equation and resulting translated criteria described in Section 3.1. This allows for direct comparison to the shellfish harvesting criteria.

Table 5. Applicable Designated Uses and Criteria for Bacteria Impaired Segments with Downstream Primary Contact Recreation (cfu/100mL)

Waterbody	Freshwater Primary Contact (*E. coli*)	
	Geometric Mean	Single Sample
Reichel	100	320
Spurgeon		
Indian		
Moxlie		
Schneider		

Table 6. Applicable Designated Uses and Criteria for Bacteria Impaired Segments with Downstream Shellfish Harvesting (cfu/100mL)

Waterbody	Freshwater Primary Contact (*E. coli* as Fecal coliform)		Downstream Marine Shellfish Harvesting (Fecal coliform)	
	Geometric Mean	Single Sample	Geometric Mean	Single Sample
Mission	97.6	312.3	**14**	**43**
Ellis				
Adams				

3.3.2 Geometric Mean Criterion Translation to Single Sample Criterion (Step 3)

The geometric mean criterion for each segment (as shown in Table 5 and Table 6) were translated into a single sample criterion (90th percentile concentration target, not to be exceeded at a frequency of more than 10 percent), using Equation 6 as discussed in Section 3.2. The results are shown in Table 7.

Table 7. Translation of Geometric Mean Criteria to Statistically Derived Single Sample Criteria

Waterbody	2012 Listing ID	Geometric Mean	Translated Single Sample
***E. coli* (cfu/100mL)**			
Reichel	3763	100	845
Spurgeon	46061	100	781
Upper Indian	3758	100	388
Lower Indian	74218	100	386
Upper Moxlie	3761	100	605
Lower Moxlie	3759	100	384
Schneider	45559	100	2,004
Fecal coliform (cfu/100mL)			
Mission	45212	14	40.3
Ellis	45480	14	41.2
East Adams	45462	14	80.2
West Adams	45695	14	49.0

3.3.3 Selection of Applicable Single Sample Criterion (Step 4)

Table 8 compares the single sample criterion value from the water quality standards (found in Table 5 and Table 6) with the geometric mean translated single sample criterion (found in Table 7). The selected criterion for each impaired segment is highlighted in

Table 8. There are two cases where the geometric mean translated single sample criterion has a lower value.

Table 8. Selection of Applicable Single Sample Criterion

Waterbody	2012 Listing ID	Water Quality Standards Single Sample	Translated Single Sample
***E. coli* (cfu/100mL)**			
Reichel	3763	**320**	845
Spurgeon	46061	**320**	781
Upper Indian	3758	**320**	388
Lower Indian	74218	**320**	386
Upper Moxlie	3761	**320**	605
Lower Moxlie	3759	**320**	384
Schneider	45559	**320**	2,004
Fecal coliform (cfu/100mL)			
Mission	45212	43	**40.3**
Ellis	45480	43	**41.2**
East Adams	45462	**43**	80.2
West Adams	45695	**43**	49.0

4.0 EXISTING BACTERIA SOURCE ASSESSMENT

4.1 MUNICIPAL SEPARATE STORM SEWER SYSTEMS (MS4s) AND NON-POINT SOURCES

Urban areas that collect stormwater runoff in MS4s and discharge it to surface waters are required to have a National Pollutant Discharge Elimination System (NPDES) permit under the Clean Water Act (CWA). Incorporated cities with populations over 100,000 and unincorporated counties with populations over 250,000 are regulated under Phase I MS4 permits, and smaller jurisdictions are regulated under Phase II MS4 permits. Four entities in the study area hold active Western Washington Phase II MS4 Permits and one entity holds a Phase I MS4 permit (Figure 7). The City of Lacey does not intersect any of the bacteria impaired catchments. Interstate 5 (WSDOT) intersects the drainage areas of Moxlie Creek and Indian Creek (Wagner and Bilhimer, 2015). MS4 permittees are required to use available methods of prevention, control, and treatment to prevent and manage pollution to waters of the state to meet the goals of the CWA.

The dynamics and complexity of bacteria in urban streams poses a challenge for quantifying existing MS4 stormwater bacteria loads. Event Mean Concentrations (EMCs) for bacteria were not available for all land uses within MS4 boundaries (e.g., forest, grassland, open space), although EMCs are available for certain urban land uses for Western Washington MS4s (e.g., commercial, industrial – the latter of which are used to estimate loads for industrial stormwater sites). However, factors such as uncertain urban stormwater flow pathways and runoff volumes, and die-off and re-growth in surface and subsurface conveyances (i.e., between monitoring sites and the receiving waterbodies) contribute to general uncertainty that makes quantifying urban stormwater bacteria loads particularly difficult.

As a result, existing MS4 fecal coliform loads were approximated by scaling down the existing load for each catchment using an area-based approach. This approach is described by USEPA as an option for disaggregating stormwater loading (USEPA, 2014). First, the proportion of each impaired catchment area covered by an individual MS4 was determined. All land within MS4 boundaries (Figure 7) was considered to represent MS4 regulated area. Land external to MS4 boundaries was used to approximate the areas not regulated by MS4 permit requirements, which are subject to Load Allocations (LAs). Then, the total existing load was apportioned to individual MS4s and non-MS4 areas according to their contributing area.

WSDOT responsible land (Interstate 5 corridor) had to be estimated separately from the MS4s. Since it is fully contained within the city and county MS4 boundaries, it was differentiated and removed from the underlying city and/or county MS4. A linear coverage from WSDOT[3] was used to approximate WSDOT responsible land. Right-of-way widths were not listed as attributes in the coverage so the linear coverage was buffered and dissolved based on review of aerial imagery to approximate WSDOT responsible land (Figure 8). To span the lanes and shoulders, Interstate on and off ramps were buffered by 15 feet (30 feet total width across the lane and shoulder based on imagery review) and the four-lane, single direction interstate roads were buffered by 60 feet (about 175 feet total width across the eight lanes, shoulder, and median based on imagery review).

[3] NatHwySysState.shp; https://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm

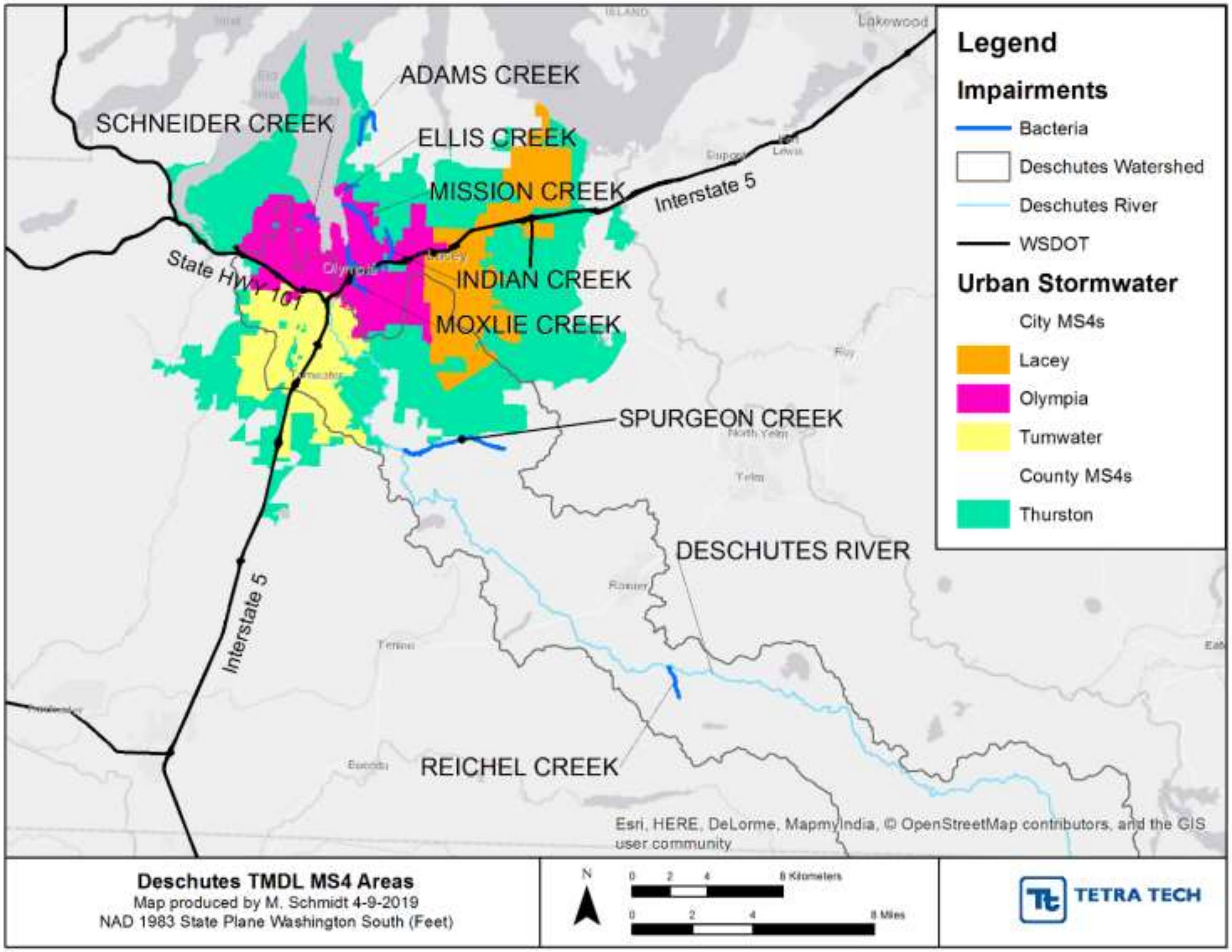


Figure 7. Municipal Separate Storm Sewer System

Figure 8. Washington State Department of Transportation MS4 Boundary

Section 4.3 describes the process for using the load duration curves to estimate existing loads for each catchment, and Section 5.0 includes tables of the existing bacteria loads estimated for individual MS4s and non-MS4 areas using this area-based approach (Table 19 through Table 11).

4.2 OTHER NPDES PERMITTED POINT SOURCES

Point sources are direct inflows into a waterway that are subject to NPDES permit limits and effluent requirements (unless illicit or in cases where the point source doesn't meet the qualifications for requiring a permit). There are no permitted domestic wastewater treatment plants that discharge to the bacteria impaired waterbodies. There are two permittees regulated under the NPDES General Permit for Industrial Stormwater and eight permittees regulated under the NPDES General Permit for Construction Stormwater that discharge to the bacteria impaired waterbodies. Existing fecal coliform loads were estimated for the industrial stormwater permittees. As explained in Section 4.2.2, construction stormwater permittees are not expected to be a source of bacteria loading, so existing fecal coliform loads were not estimated.

4.2.1 Industrial Stormwater

Industrial stormwater discharges covered by NPDES permits are subject to regulations defined in Ecology's *Industrial Stormwater General Permit* (as modified, effective January 1, 2020). Depending on the type of industrial activity, stormwater discharges have the potential to contain bacteria that contribute to excursions in receiving waters. All permittees covered by the General Permit for Industrial Stormwater must implement a Stormwater Pollution Prevention Plan that specifies the Best Management Practices (BMPs) used to prevent, control, and treat discharges to comply with water quality standards. Facilities that discharge to bacteria impaired waters have specific BMP requirements.

The two facilities covered under the General Permit for Industrial Stormwater are Pacific NW Bulkhead (NPDES Permit ID: WAR304545) Yard and Olympia Service Center (NPDES Permit ID: WAR304313). Existing bacteria loads for the two facilities covered under the General Permit for Industrial Stormwater were calculated as the product of estimated annual runoff and representative EMCs for fecal coliform in industrial urban stormwater. The Simple Method (Schueler, 1987) was applied to estimate annual runoff. It is an empirical formulation based on data from several dozen sites spanning the range of possible percent imperviousness. It was originally developed as an efficient, yet reasonably accurate, method to estimate stormwater runoff for the purpose of quantifying nutrient loads for urban lands. It has been adopted and adapted by numerous municipalities and agencies since its publication for various purposes, chiefly in relation to compliance with stormwater management criteria. The required information for the Simple Method was readily available in this watershed. Since a mechanistic watershed model was not available to predict annual runoff, the Simple Method was a feasible and appropriate option for approximating runoff-associated loads for these facilities. The form of the equation is:

$$R = 0.9 * P * (0.05 + 0.9\, I_a)$$

where *R* is the runoff depth (inches), *P* is the annual precipitation depth (inches), and I_a is the impervious area fraction (0 to 1).

The average annual precipitation depth, *P,* between 2000 – 2018 at the Olympia Airport (GHCND: USW00024227) was about 50.14 inches. Site footprints were conservatively assumed to be fully impervious because most developed soils have lost some infiltration potential following site disturbance and compaction, so I_a is equivalent to 1. Therefore, solving for *R*, the estimated annual average runoff depth was about 42.9 inches per year, or 3.58 feet per year, for the Industrial Stormwater permittees.

To obtain the annual runoff volume, the runoff depth, *R,* is multiplied by the contributing area. The contributing area for each permit holder was based on facility site footprints provided by Ecology in acres – 0.6 acres for

Pacific NW Bulkhead Yard and 11.4 acres for Olympia Service Center (L. Weiss, personal communication, 9/27/2019).

Site-specific discharge monitoring records were unavailable for the permit holders because the facilities are not required to conduct stormwater bacteria monitoring. Therefore, EPA used the representative median fecal coliform concentration (or event mean concentration, EMC) for industrial land reported for NPDES Phase I Stormwater permittees in Western Washington (Hobbs et al., 2015): 991 cfu/100mL. The median concentration was applied because it is less affected by outliers and small sample sizes compared to the average concentration. Site conditions and activities, such as reduced vegetation on pervious portions of the property, will inherently influence loading dynamics from these facilities. Nevertheless, bacteria loading from these property-owners is anticipated to be a minor component of the overall loading to the segments impaired for elevated bacteria concentrations.

To obtain the existing daily average stormwater loads for the active industrial facilities, average annual runoff depth (*R*), the site area, and the representative event mean concentration (EMC) are multiplied, along with the appropriate conversion factor to correct the units. The resulting estimated existing fecal coliform loads for the two permitted industrial stormwater facilities are shown in

Table 12, Table 13, Table 15, and

Table 16.

4.2.2 Construction Stormwater

Construction stormwater discharges covered by NPDES permits are subject to regulations defined in Ecology's *Construction Stormwater General Permit* (as modified, effective January 1, 2016). The General Permit for Construction Stormwater specifies that permit holders are required to not contribute to violation of surface water and groundwater quality standards and sediment management standards. Facilities covered by the permit must implement all known, available, and reasonable methods of prevention, control, and treatment (Washington Administrative Code WAC 173-218-030 AKART). They must also develop and implement a Stormwater Pollution Prevention Plan and apply stormwater Best Management Practices (BMPs). Active construction stormwater permits discharging to bacteria impaired waterbodies were queried. All eight discharge to Moxlie Creek, and one also lists Lower Indian Creek as a receiving water (

Table 9). All permitted sites are within MS4 boundaries and runoff from the land area is accounted for in the source assessment for MS4s. However, construction stormwater is not expected to be a source of bacteria loading and is not explicitly included in the source assessment.

Table 9. Active NPDES permitted construction stormwater permits.

Permittee	Permit Number	Waterbodies & Listing IDs
Briggs Townhomes	WAR302181	Moxlie Creek (3759 and 3761)
Briggs Town Center	WAR304815	Moxlie Creek (3759 and 3761)
Briggs Village - Copper Leaf	WAR305516	Moxlie Creek (3759 and 3761)
Olympia Courtyard Hotel	WAR305668	Moxlie Creek (3759 and 3761)
Centennial Elementary School	WAR306207	Moxlie Creek (3759 and 3761)
Westman Mill	WAR306771	Lower Moxlie Creek (3759)
Gospel Outreach of Olympia	WAR306803	Lower Indian Creek (74218); Moxlie Creek (3759 and 3761)
Olympia High School Class Modernization	WAR307792	Moxlie Creek (3759 and 3761)

4.3 LOAD DURATION CURVE ANALYSIS

The LDC method plots flow, observed data, and TMDLs to analyze the flow conditions under which excursions of the water quality criteria occur. The LDC method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable TMDLs is represented by the resulting curve. The flow data reflect a range of natural occurrences from extremely high flows to extremely low flows. The drainage area-ratio method was used to scale monitored flows at the USGS Deschutes River Tumwater gage to the locations of the impaired segment outlets. This method likely overestimates long-term flows for the impaired segments, especially for the urban creeks discharging to Budd Inlet. This is because much of the upper Deschutes watershed is at higher elevations and receives more rainfall than areas downstream where most of the bacteria-impaired waterbodies occur. In addition, high flows from small urban catchments are likely to be flashier than high flows on a given day at the Deschutes Tumwater gage. If flow monitoring data become available, or models are developed to represent daily flows for the segments, the TMDLs could be updated. All LDC calculations were performed using the fecal coliform values to maintain monitoring data in its original collection form.

The following steps were used in the LDC analysis. Results of the LDC analysis are shown in Section 5.0.

1. A flow duration curve for each stream segment was developed by generating a flow frequency table and plotting the data points to form a curve.

The flow duration curve was translated into a load duration curve by multiplying each flow value by the applicable single sample criterion (as a 90th percentile concentration target, shown as the highlighted values in

2. Table 8), then multiplying by conversion factors to yield results in the proper units. The resulting points were plotted to create a load duration curve, which represents the daily TMDL across a range of flows.
3. Each observed bacteria concentration was converted to a load by multiplying it by the average daily flow on the day the sample was collected. Then, the individual loads were plotted as points on the load duration curve graph for comparison to the TMDL curve. Points plotting above the curve represent excursions of the water quality target and the daily allowable load. Those plotting on or below the curve represent compliance with the target and the daily allowable load. Based on the bacteria WQS specifications, exceedances can occur up to 10 percent of the time.
4. The stream flows displayed on load duration curves were grouped into various flow regimes (hereafter called "flow intervals") to aid with interpretation of the load duration curves (Cleland, 2002, 2003):
   a. **High Flows** – stream flows that plot in the 0 to 10 percentile exceedance frequency range, related to flood flows.
   b. **Moist Conditions** – flows in the 10 to 40 percentile exceedance frequency range, related to wet weather conditions.
   c. **Mid-range Flows** – flows in the 40 to 60 percentile exceedance frequency range, related to median stream flow conditions.
   d. **Dry Conditions** – flows in the 60 to 90 percentile exceedance frequency range, related to dry weather flows.
   e. **Low Flows** – flows in the 90 to 100 percentile exceedance frequency range, related to drought conditions.
5. An additional graph was produced to show flow ranked concentration instead of load. This allows for visualization of the distribution of the sample concentrations in log-space and comparison to the applicable single sample criterion.

The entire curve depicted in each LDC graph in Section 5.0 represents the flow-varied maximum allowable TMDL (with exceedances allowed 10 percent of the time according to the bacteria standards). The TMDL tables present the midpoints of each flow interval from the LDC (5^{th} percentile for high flows, 25^{th} percentile for moist conditions, 50^{th} percentile for mid-range flows, 75^{th} percentile for dry conditions, and 95^{th} percentile for low flows). A description of the calculations used to derive TMDLs and load reductions are described in the following paragraphs.

The TMDL for each flow interval was calculated as the product of the flow in cubic feet per second at the mid-point flow percentile and the single sample criterion applicable to the segment (cfu/100mL), converted to a daily load (billion cfu/day).

To determine percent reductions, the amount of reduction needed from the observed 90^{th} percentile load to meet the TMDL was determined. Since available data is in terms of fecal coliform, the regression equation from Section 3.1 was used to facilitate comparisons between *E. coli* TMDLs and observed data. The product of the 90^{th} percentile concentration from the monitoring data within each flow interval and the mid-point flow was used to calculate the observed 90^{th} percentile load. The 90th percentile concentration was used since it ensures that no more than 10 percent of the observed fecal coliform distribution would exceed it. This is equivalent to the 10 percent of allowed exceedances for the single sample criterion.

The 90^{th} percentile concentration was calculated using Equation 3 for the sampling data separately within each flow interval. μ_{log10}, the mean of the $\log_{10}$ transformed data, was used in the equation without alteration. However, σ_{log10}, the standard deviation of the $\log_{10}$ transformed data, was modified in certain instances. This was done because there is considerable uncertainty in a standard deviation calculated from a small sample size, which frequently occurred for some flow intervals in certain segments. When this occurred, σ_{log10} was estimated from a weighted pooled CV for the entire segment dataset using the following equation:

Equation 7. $CV_{pooled} = \sqrt{\sum(CV_i^2\ x\ [n_i - 1]) \Big/ \sum(n_i - 1)}$

where i is the flow interval number (i.e., one through five) and n_i is the count of samples within the flow interval. The following rules were used to specify σ_{log10} for each flow interval:

- If n_i was less than five, σ_{log10} was set to the product of CV_{pooled} and μ_{log10} for the flow interval.
- If n_i was greater than twenty, σ_{log10} from the flow interval was used without modification.
- If n_i was between five and twenty, a test was performed to determine whether CV_{pooled} was likely reasonable. The 90 percent confidence interval was calculated for σ_{log10} from the flow interval. If the standard deviation calculated from CV_{pooled} and μ_{log10} for the flow interval fell within the 90 percent confidence interval, then σ_{log10} was set to the product of CV_{pooled} and μ_{log10} for the flow interval. If not, σ_{log10} from the flow interval was used without modification

The observed geometric mean and the final observed 90th percentile concentration are both shown for reference in the flow-ranked fecal coliform concentration graphs (Section 5.0).

5.0 LOAD DURATION CURVE RESULTS

Load duration curves are presented for the tributaries impaired for bacteria in the following subsections. Graphs are shown in terms of the bacteria indicator for the applicable water quality target (i.e. *E. coli* or fecal coliform). For graphs where the TMDL is shown as *E. coli*, the observed data points are translated to *E. coli* using the regression in Section 3.1.

Each load duration curve graph has observation points ("Obs FC as *E. coli*" or "Obs fecal coliform"), the TMDL limit ("90th percentile LC"), the median TMDL load for each flow interval ("Interval 90th percentile LC"), and the median of observed data for each flow interval ("Obs 90th percentile").

Flow ranked fecal coliform concentration plots are also provided for each impaired segment. The observed geometric mean concentration ("Obs geometric mean") and the observed statistical 90th percentile concentration ("Obs 90th percentile") are plotted for each flow interval. The fecal coliform concentration target ("90th percentile target") is shown as a line extending across the range of flow percentiles.

A table is also provided for each segment which divides the current load among sources – individual permittees, MS4s, and the non-MS4 area – as described in Section 4.1. Because permitted MS4s discharge stormwater, they are assumed not to contribute loads during the dry and low flow intervals.

5.1 REICHEL CREEK, LISTING ID 3763

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for Reichel Creek. The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

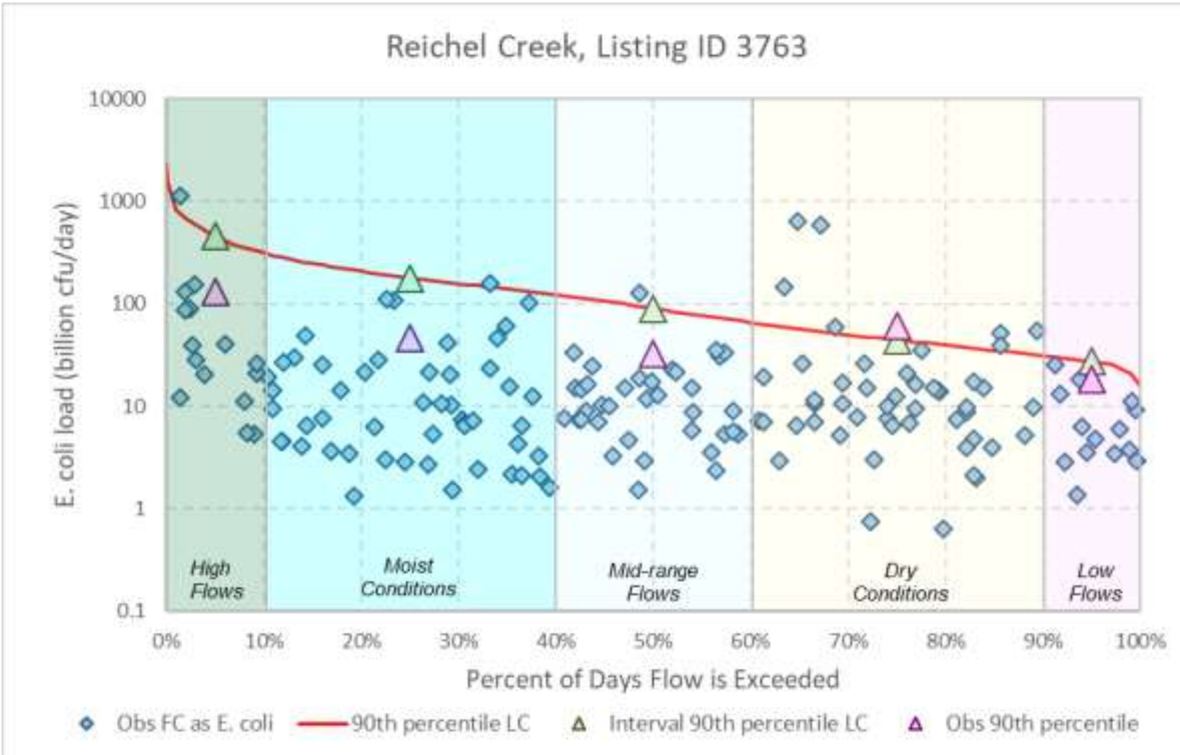


Figure 9. *E. coli* Load Duration Curve for Reichel Creek, Listing ID 3763

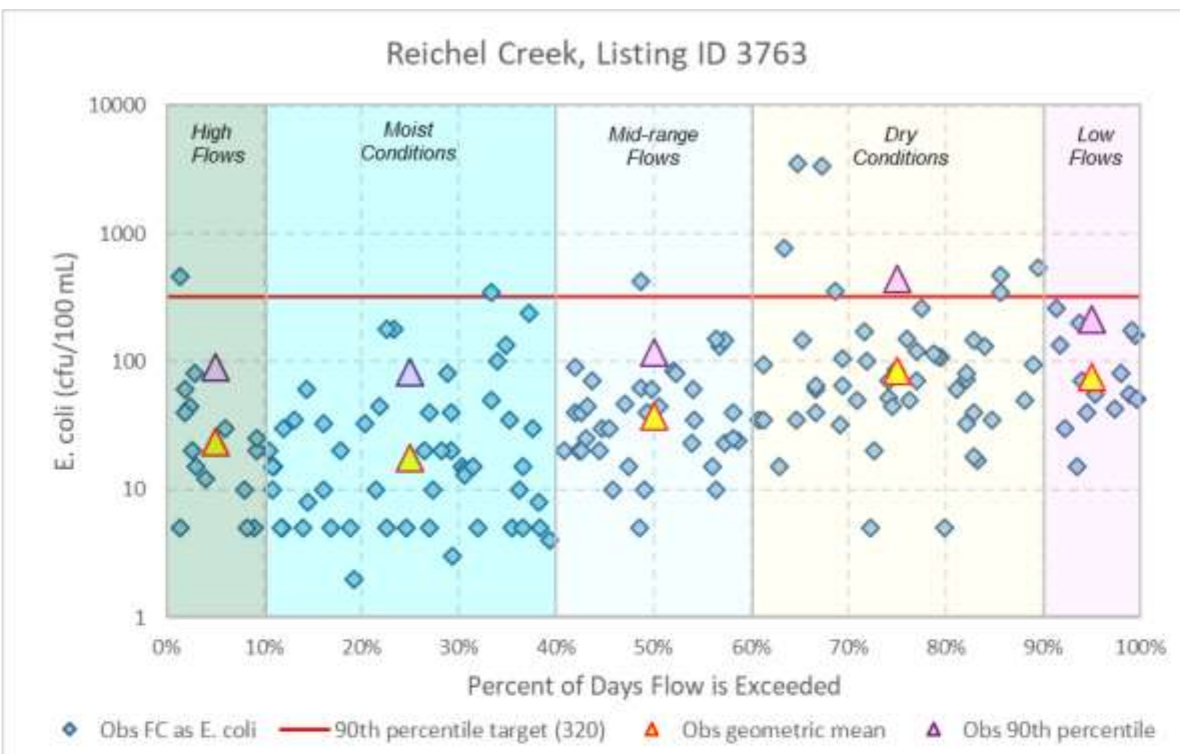


Figure 10. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Reichel Creek, Listing ID 3763

Table 10. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 3763

Source	Current Condition 90th Percentile E. coli Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0	0	0	0	0
Thurston County	0	0	0	0	0
Olympia	0	0	0	0	0
WSDOT	0	0	0	0	0
Non-MS4	130	46	33	61	18

5.2 SPURGEON CREEK, LISTING ID 46061

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for Spurgeon Creek. The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation. For this waterbody, no reductions are necessary based on the 90th percentile observed load and respective 90th percentile load target for each flow interval. While there are individual samples observed in the low, dry, and mid-range flow intervals that exceed the target, these are allowable because the single sample bacteria criteria permit a 10 percent exceedance frequency. This segment was originally assessed as impaired based on the legacy Freshwater Primary Contact Recreation fecal coliform criteria, which were more stringent than the *E. coli* criteria translated to fecal coliform using Equation 1.

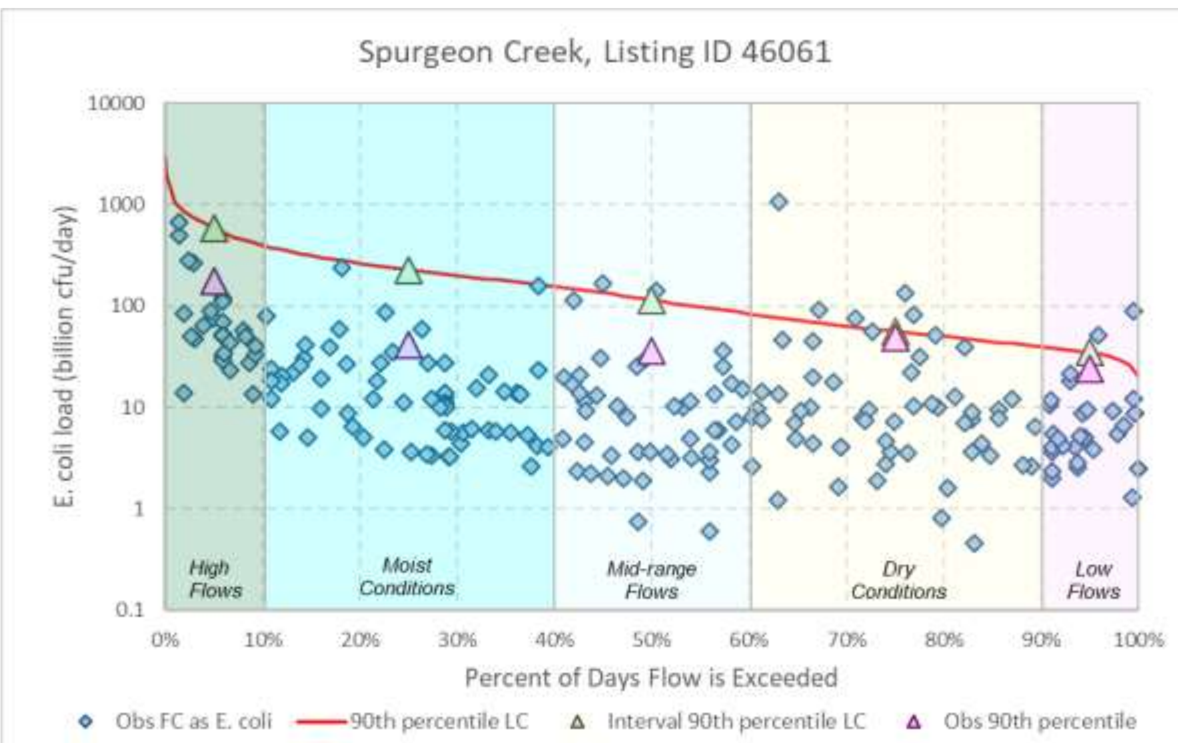


Figure 11. *E. coli* Load Duration Curve for Spurgeon Creek, Listing ID 46061

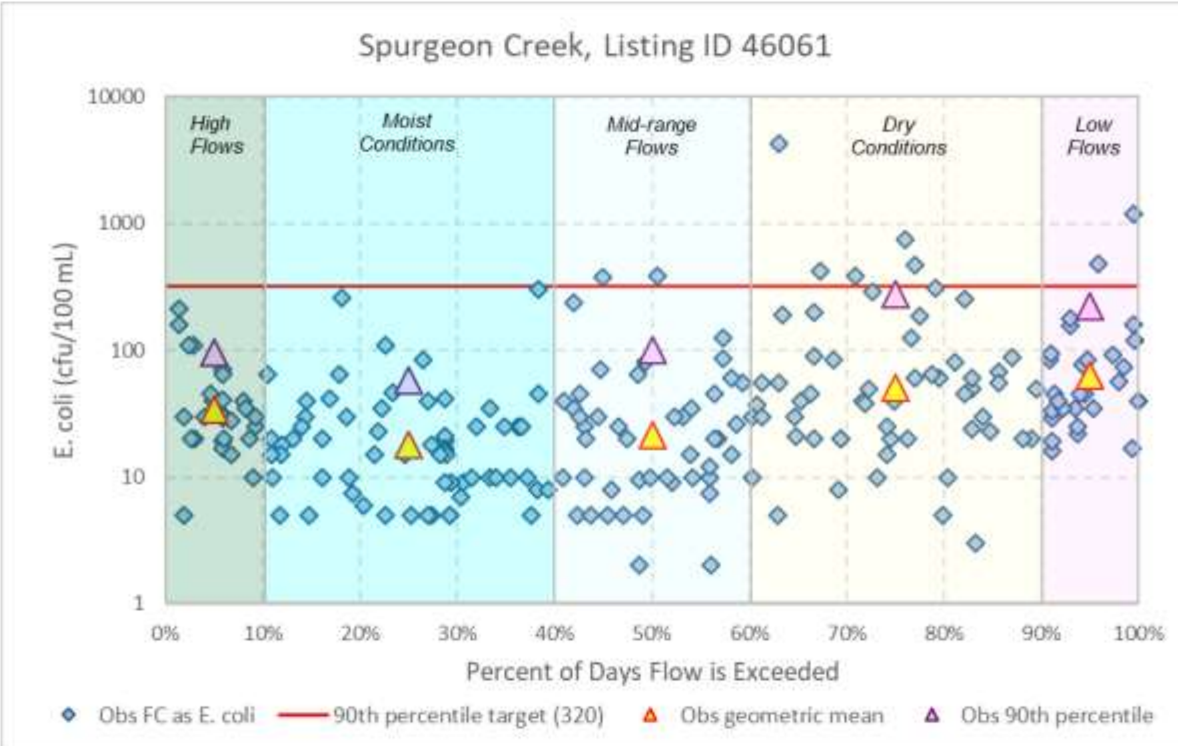


Figure 12. Flow Ranked *E. coli* Concentrations for Spurgeon Creek, Listing ID 46061

Table 11. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 46061

Source	Current Condition 90th Percentile E. coli Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0	0	0	0	0
Thurston County	13	3	3	4	2
Olympia	0	0	0	0	0
WSDOT	0	0	0	0	0
Non-MS4	161	38	33	48	24

5.3 UPPER INDIAN CREEK, LISTING ID 3758

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for the upstream segment of Indian Creek. This segment discharges to lower Indian Creek (listing ID 74218). The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

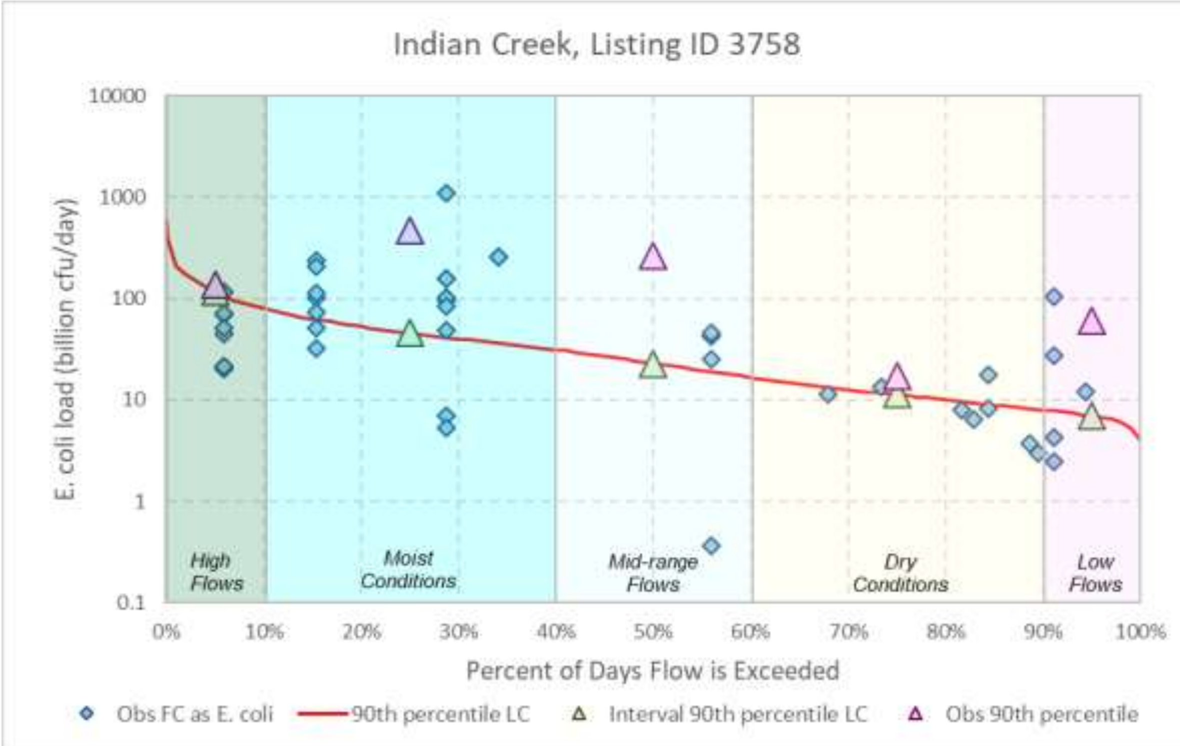


Figure 13. *E. coli* Load Duration Curve for Indian Creek, Listing ID 3758

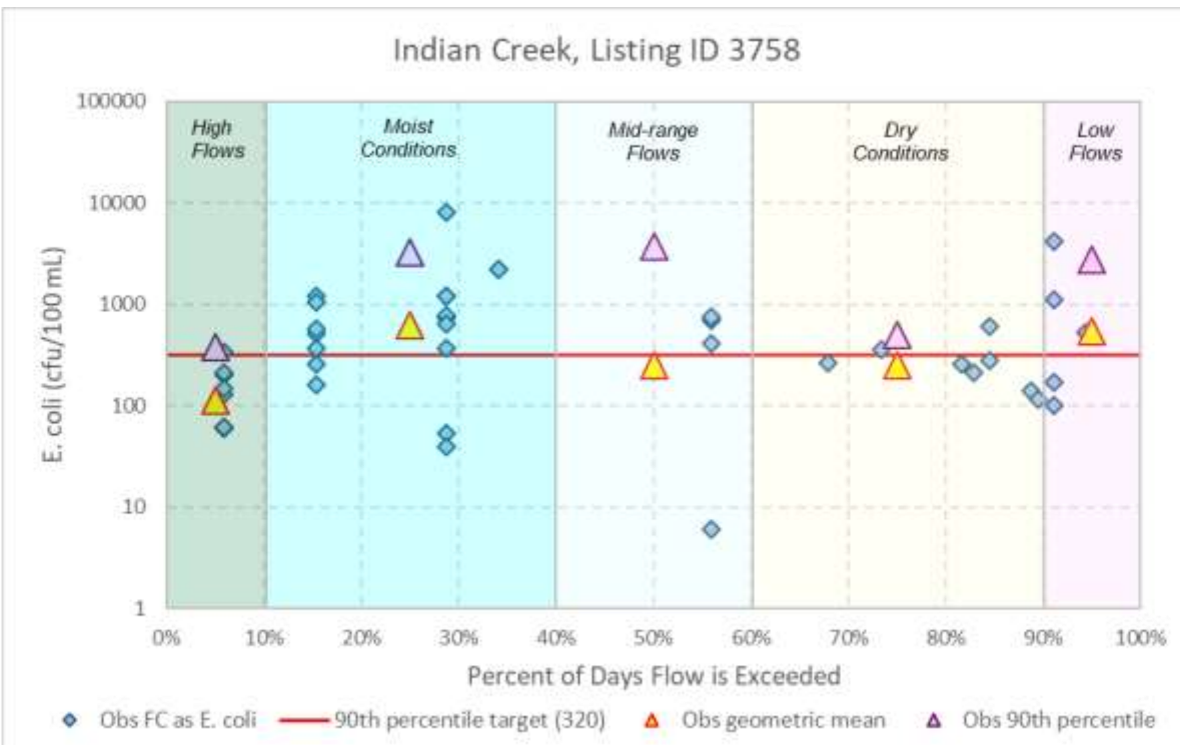


Figure 14. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Indian Creek, Listing ID 3758

Table 12. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 3758

Source	Current Condition 90th Percentile *E. coli* Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Olympia Service Center[1]	1.4	1.4	1.4	0	0
Tumwater	0	0	0	0	0
Thurston County	64	217	122	0	0
Olympia	70	238	135	0	0
WSDOT	3	10	6	0	0
Non-MS4	0	0	0	17	60

[1]The calculation of loads for industrial stormwater permittees are discussed in Section 4.2.1.

5.4 LOWER INDIAN CREEK, LISTING ID 74218

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for the downstream segment of Indian Creek. This segment receives flow from Indian Creek (listing ID 3758), and discharges to the downstream segment of Moxlie Creek (listing ID 3759). The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

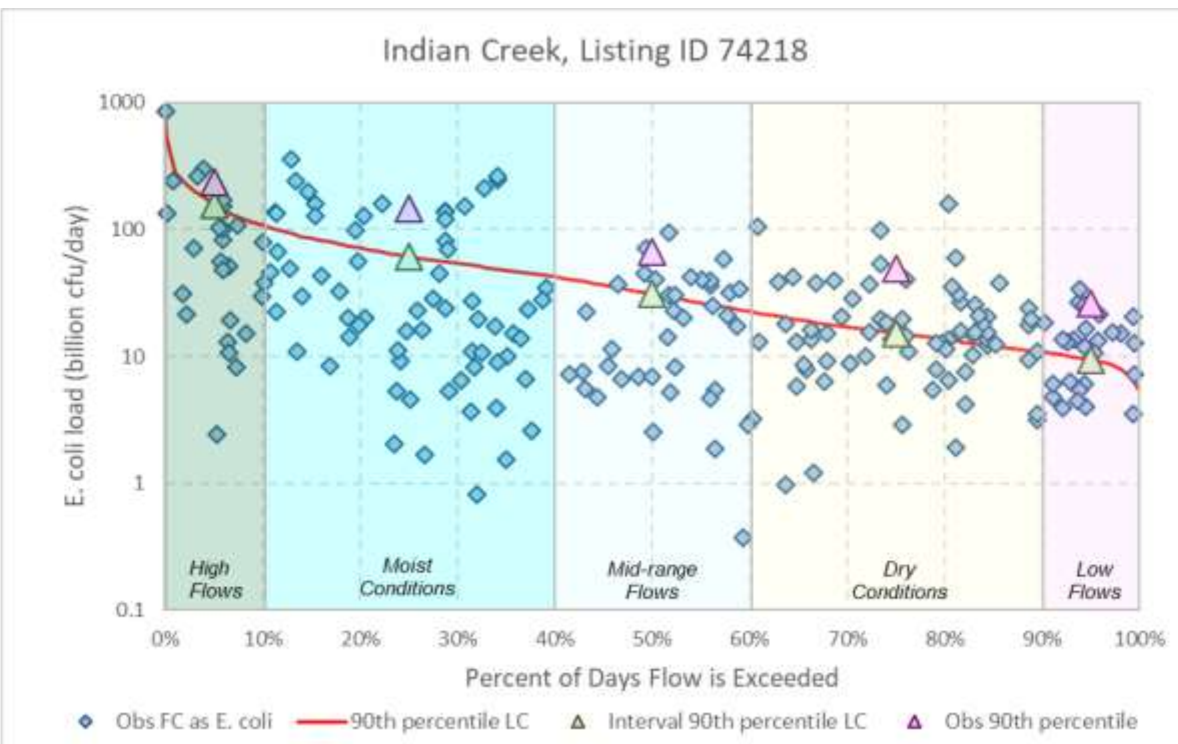


Figure 15. *E. coli* Load Duration Curve for Indian Creek, Listing ID 74218

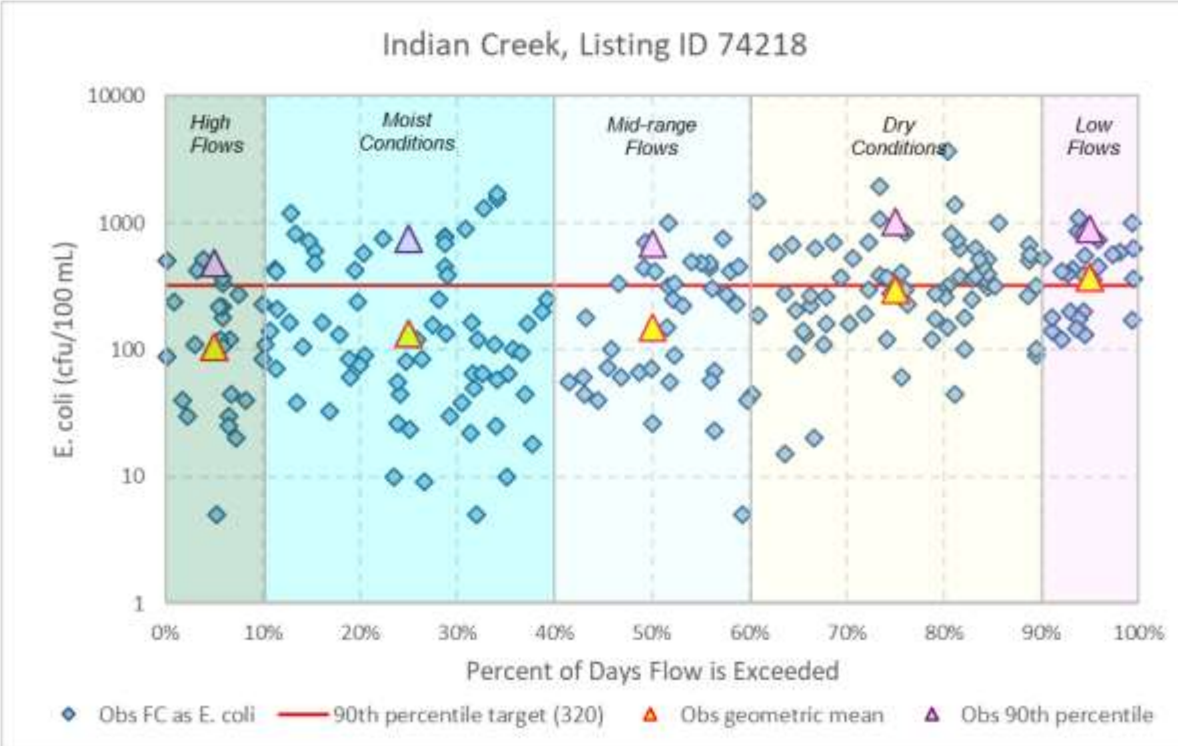


Figure 16. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Indian Creek, Listing ID 74218

Table 13. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 74218

Source	Current Condition 90th Percentile *E. coli* Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Olympia Service Center[1]	1.4	1.4	1.4	0	0
Tumwater	0	0	0	0	0
Thurston County	81	49	22	0	0
Olympia	149	91	41	0	0
WSDOT	5	3	1	0	0
Non-MS4	0	0	0	49	26

[1]The calculation of loads for industrial stormwater permittees are discussed in Section 4.2.1.

5.5 UPPER MOXLIE CREEK, LISTING ID 3761

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for upper Moxlie Creek, which drains to Lower Moxlie Creek (listing ID 3759). The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

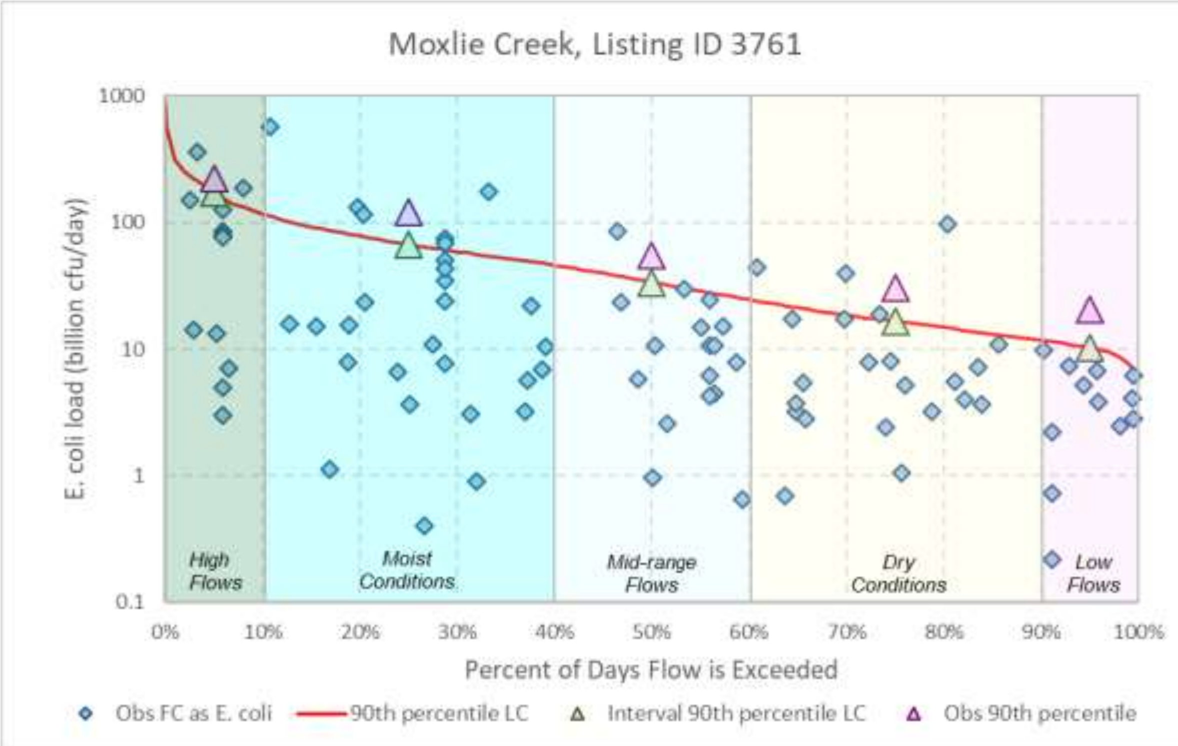


Figure 17. *E. coli* Load Duration Curve for Moxlie Creek, Listing ID 3761

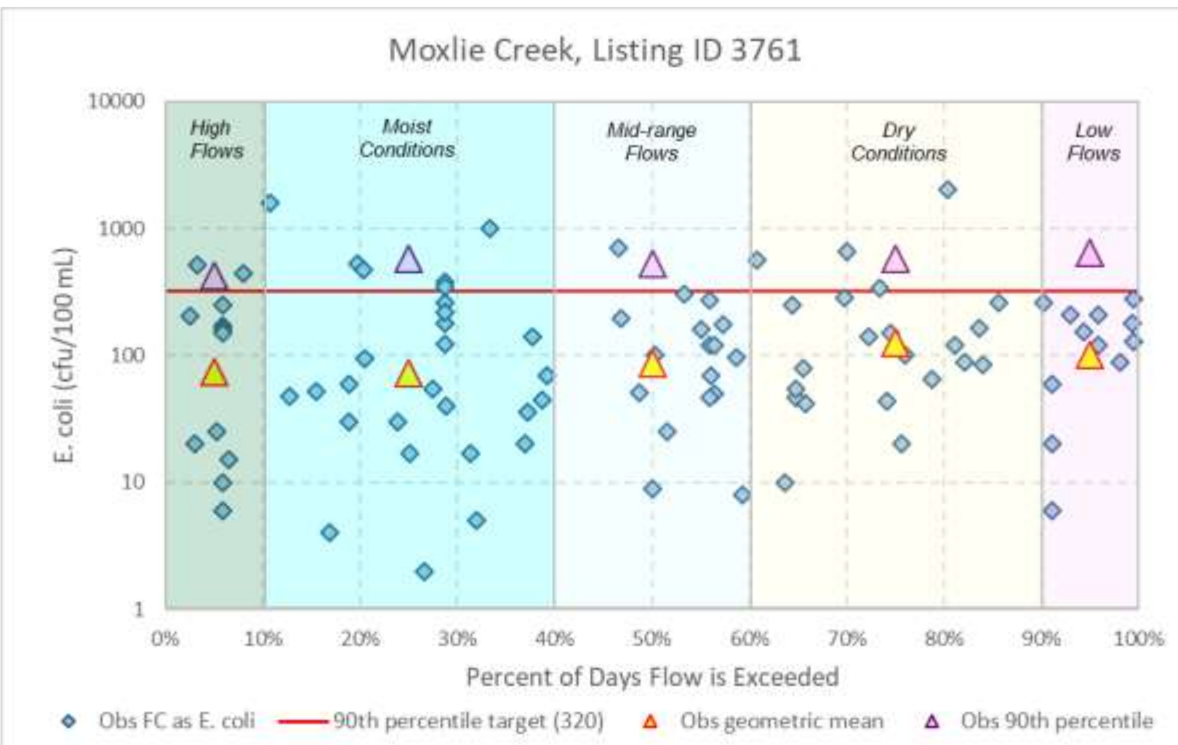


Figure 18. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Moxlie Creek, Listing ID 3761

Table 14. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 3761

Source	Current Condition 90th Percentile E. coli Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	10	5	2	0	0
Thurston County	24	13	6	0	0
Olympia	187	102	46	0	0
WSDOT	4	2	1	0	0
Non-MS4	0	0	0	30	21

5.6 LOWER MOXLIE CREEK, LISTING ID 3759

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for lower Moxlie Creek. The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

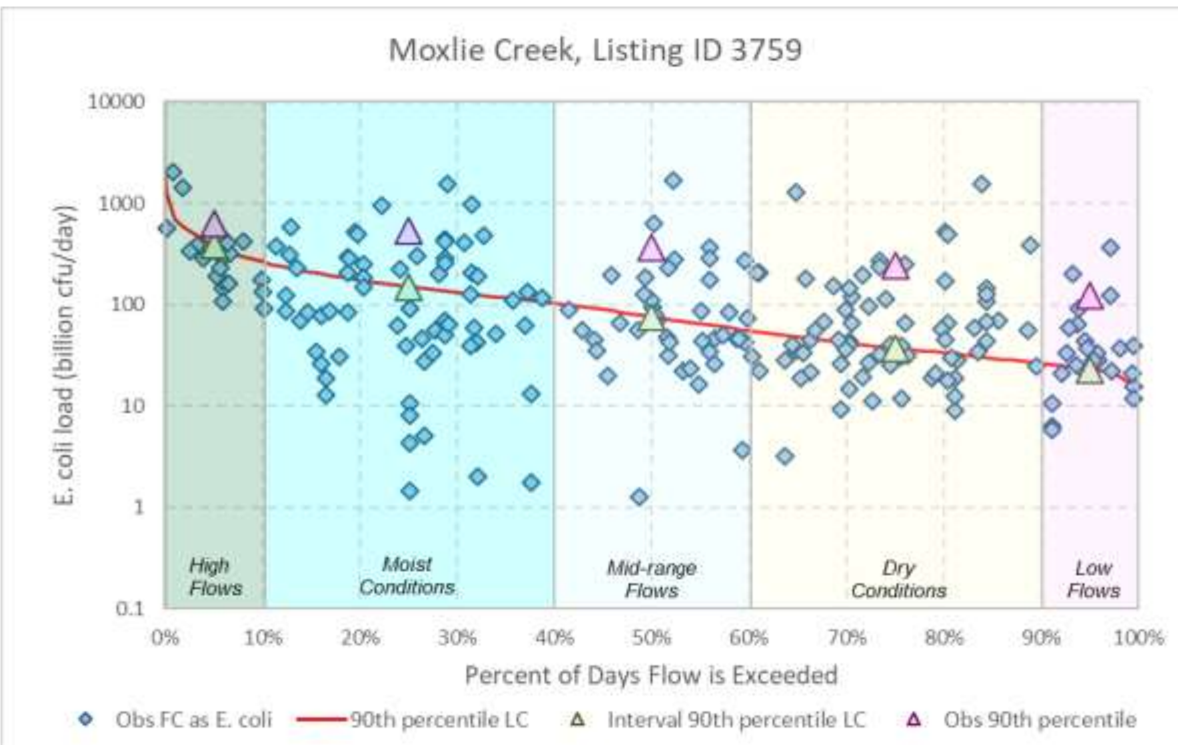


Figure 19. *E. coli* Load Duration Curve for Moxlie Creek, Listing ID 3759

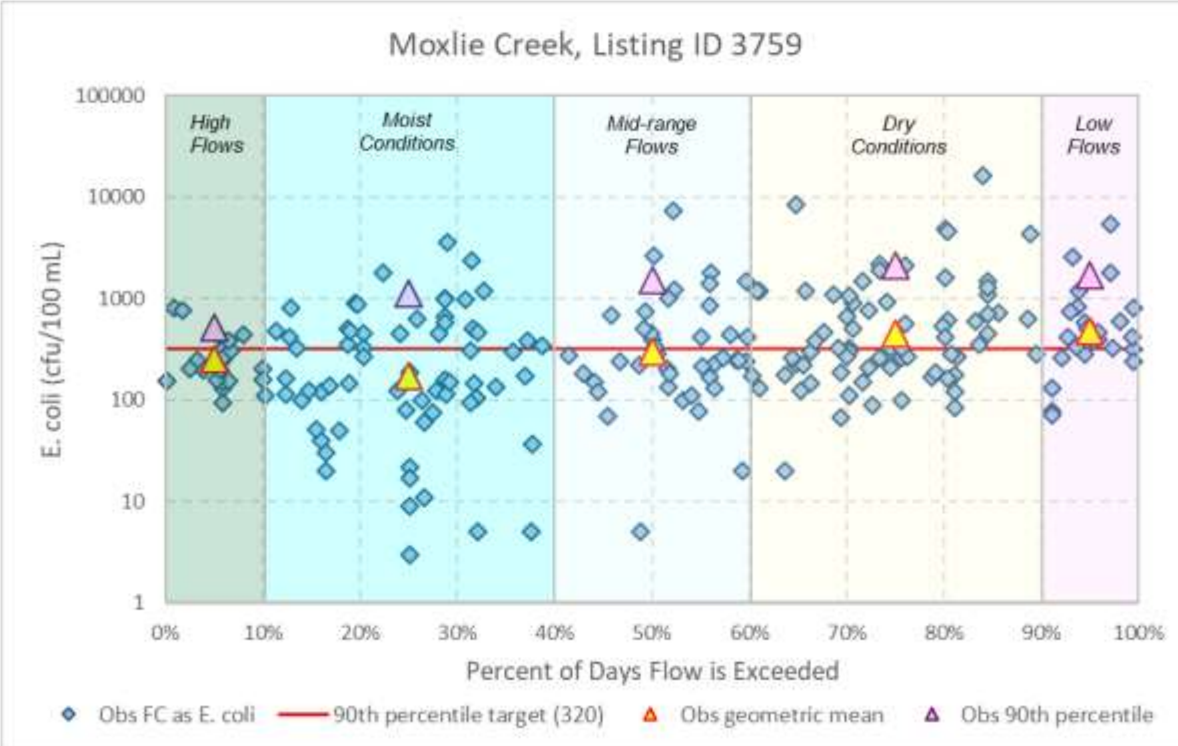


Figure 20. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Moxlie Creek, Listing ID 3759

Table 15. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 3759

Source	Current Condition 90th Percentile E. coli Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Olympia Service Center[1]	1.4	1.4	1.4	0	0
Tumwater	12	10	7	0	0
Thurston County	118	101	68	0	0
Olympia	486	414	279	0	0
WSDOT	10	8	6	0	0
Non-MS4	0.4	0.3	0.2	246	124

[1]The calculation of loads for industrial stormwater permittees are discussed in Section 4.2.1.

5.7 SCHNEIDER CREEK, LISTING ID 45559

The *E. coli* load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for Schneider Creek. The TMDL for this segment is expressed in terms of *E. coli*, reflecting the objective to protect the water body for freshwater primary contact recreation.

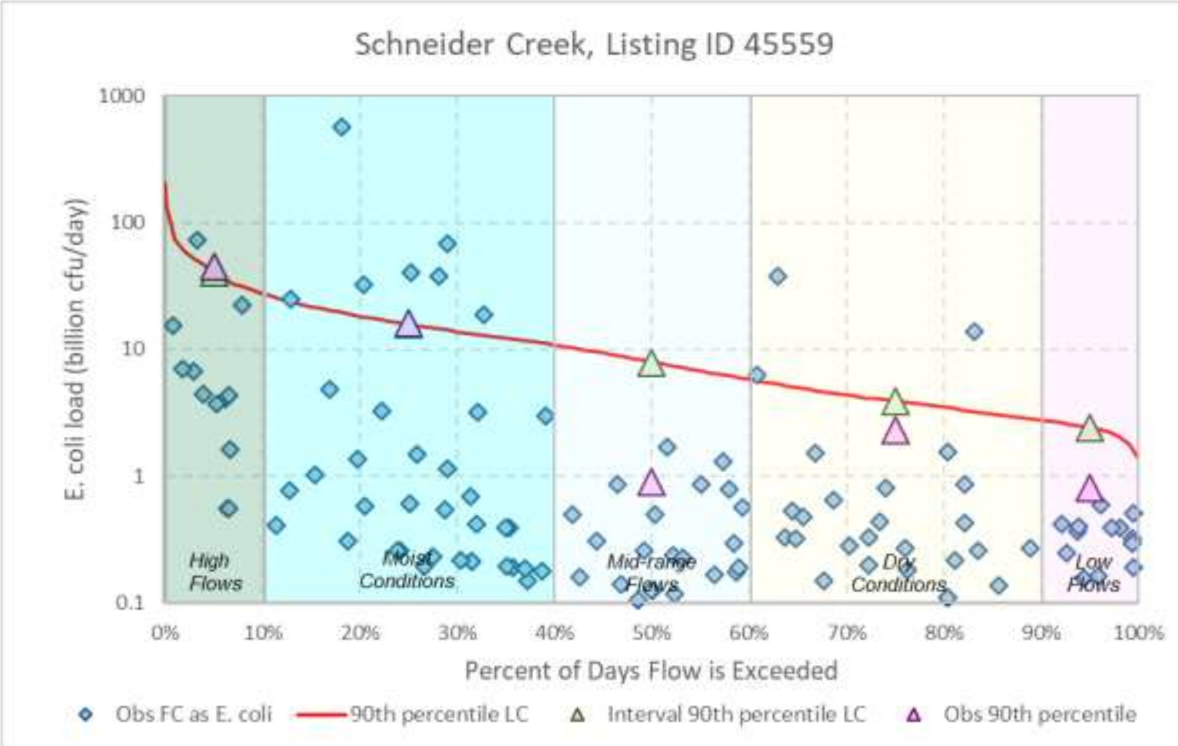


Figure 21. *E. coli* Load Duration Curve for Schneider Creek, Listing ID 45559

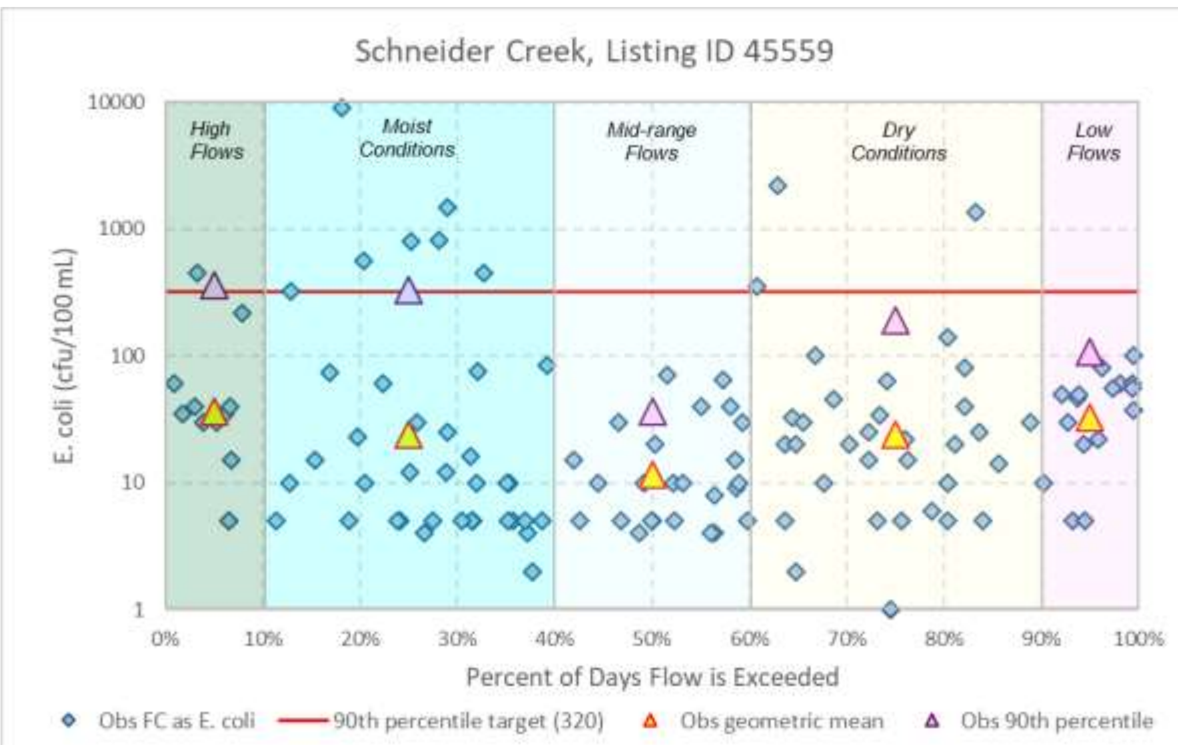


Figure 22. Flow Ranked Fecal Coliform Concentrations as *E. coli* for Schneider Creek, Listing ID 45559

Table 16. Current Condition 90th Percentile *E. coli* Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 45559

Source	Current Condition 90th Percentile E. coli Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Pacific NW Bulkhead Yard (Industrial Stormwater)[1]	0.10	0.10	0.10	0	0
Tumwater	0	0	0	0	0
Thurston County	0.55	0.20	0.01	0	0
Olympia	44.5	15.9	0.80	0	0
WSDOT	0	0	0	0	0
Non-MS4	0.02	0.01	<0.001	2.32	0.81

[1]The calculation of loads for industrial stormwater permittees are discussed in Section 4.2.1.

5.8 MISSION CREEK, LISTING ID 45212

The fecal coliform load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for Mission Creek. The TMDL for this segment is expressed in terms of fecal coliform, reflecting the objective to protect downstream marine water for shellfish harvesting.

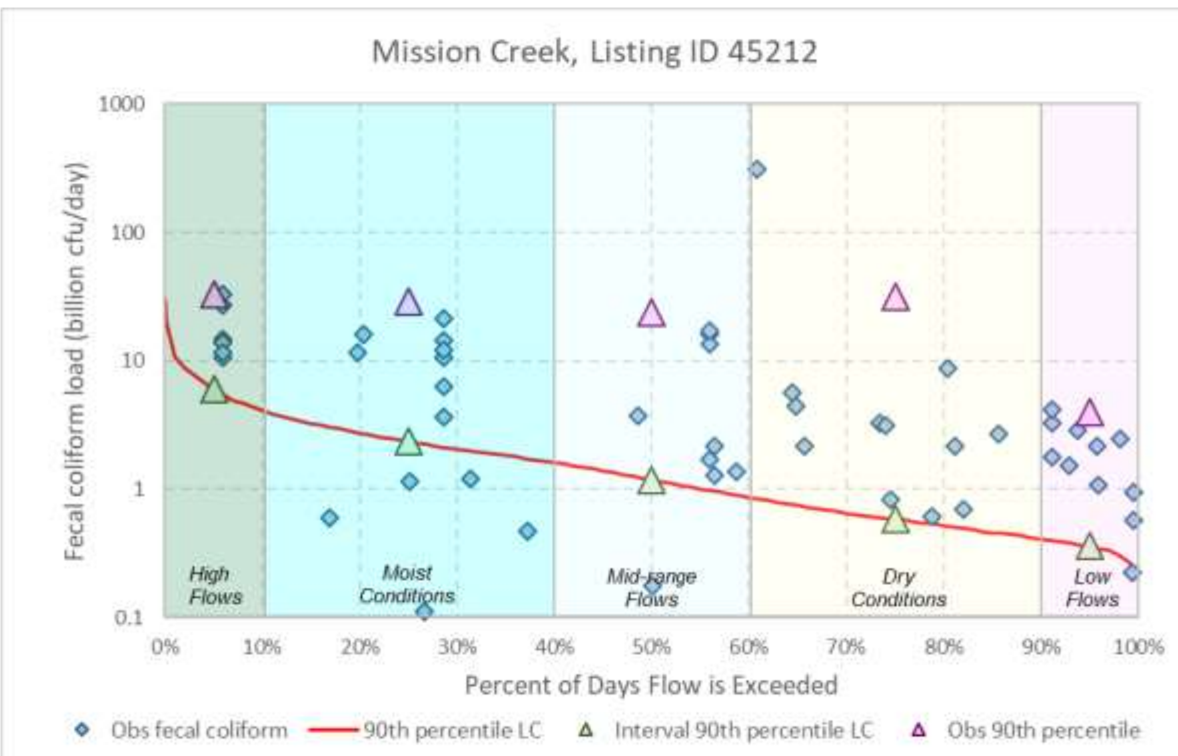


Figure 23. Fecal Coliform Load Duration Curve for Mission Creek, Listing ID 45212

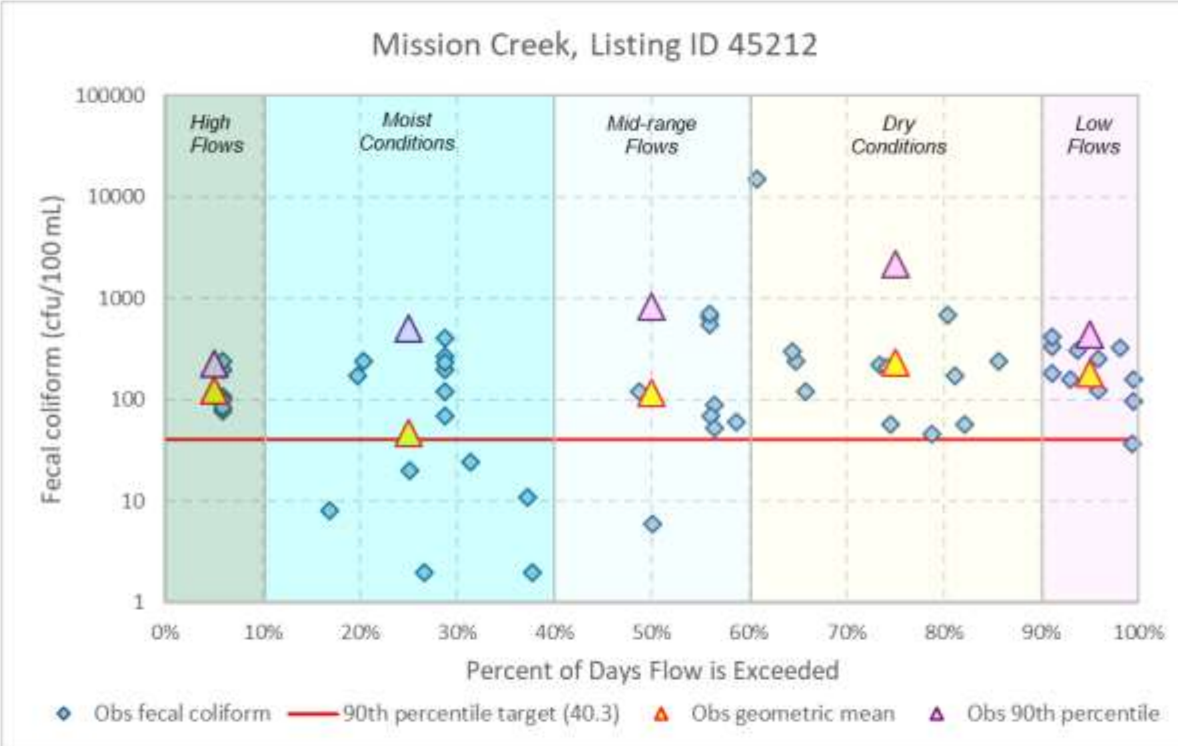


Figure 24. Flow Ranked Fecal Coliform Concentrations for Mission Creek, Listing ID 45212

Table 17. Current Condition 90th Percentile Fecal Coliform Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 45212

Source	Current Condition 90th Percentile Fecal coliform Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0.0	0.0	0.0	0.0	0.0
Thurston County	1.8	1.6	1.3	0.0	0.0
Olympia	31.5	27.5	22.7	0.0	0.0
WSDOT	0.0	0.0	0.0	0.0	0.0
Non-MS4	0.0	0.0	0.0	31.9	4.0

5.9 ELLIS CREEK, LISTING ID 45480

The fecal coliform load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for Ellis Creek. The TMDL for this segment is expressed in terms of fecal coliform, reflecting the objective to protect downstream marine water for shellfish harvesting.

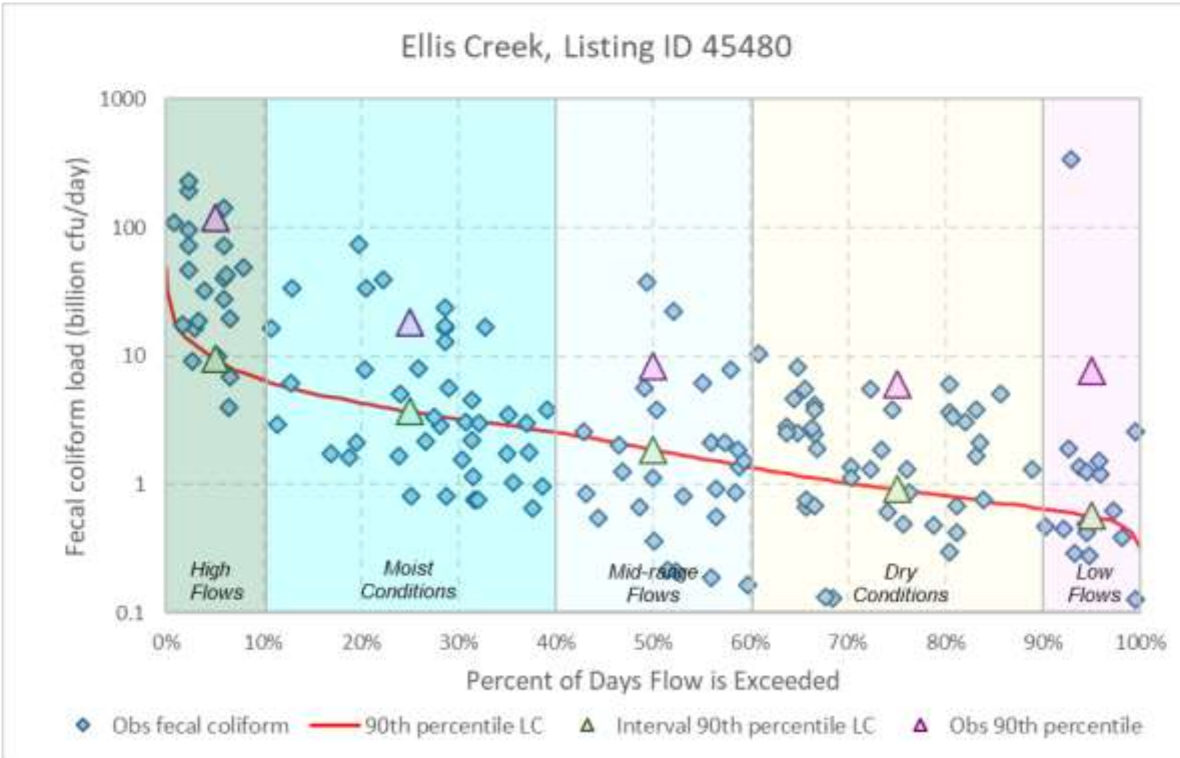


Figure 25. Fecal Coliform Load Duration Curve for Ellis Creek, Listing ID 45480

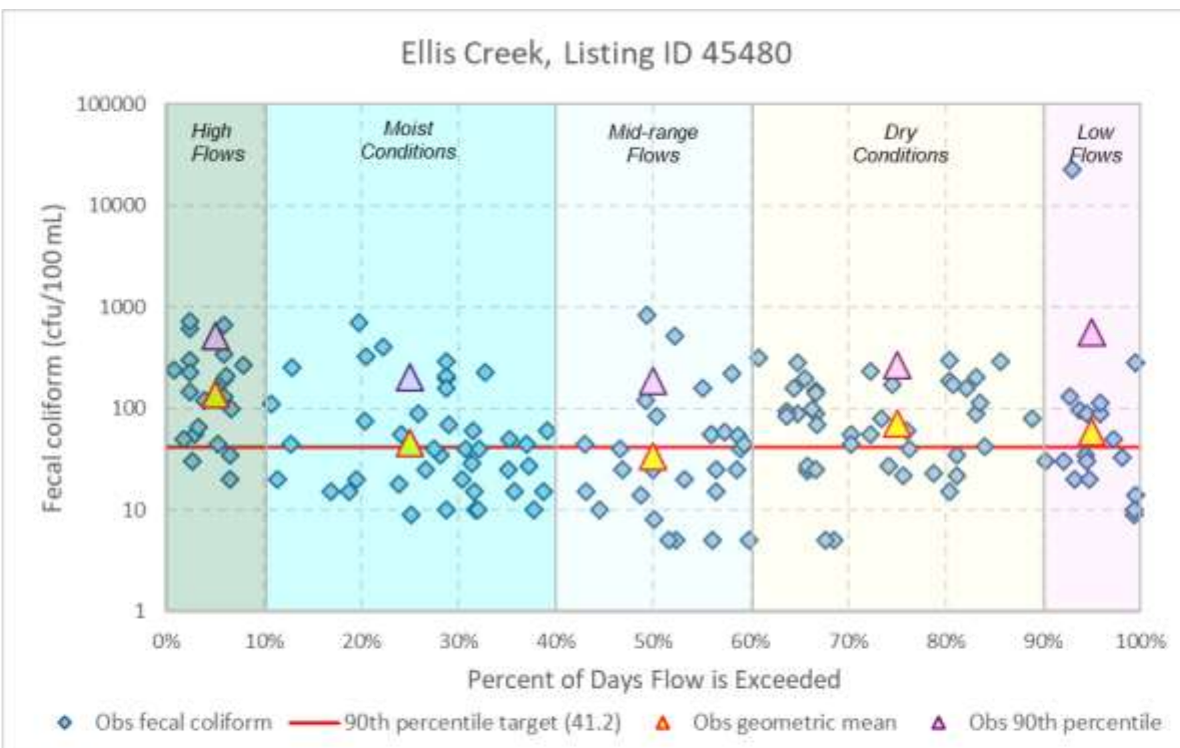


Figure 26. Flow Ranked Fecal Coliform Concentrations for Ellis Creek, Listing ID 45480

Table 18. Current Condition 90th Percentile Fecal Coliform Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 45480

Source	Current Condition 90th Percentile Fecal coliform Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0.0	0.0	0.0	0.0	0.0
Thurston County	92.6	14.3	6.5	0.0	0.0
Olympia	18.3	2.8	1.3	0.0	0.0
WSDOT	0.0	0.0	0.0	0.0	0.0
Non-MS4	9.2	1.4	0.6	6.0	7.7

5.10 EAST ADAMS CREEK, LISTING ID 45462

The fecal coliform load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for the eastern branch of Adams Creek. The TMDL for this segment is expressed in terms of fecal coliform, reflecting the objective to protect downstream marine water for shellfish harvesting. This branch of Adams Creek drains to Budd Inlet/South Puget Sound separately from the western branch of Adams Creek, which is also impaired for bacteria.

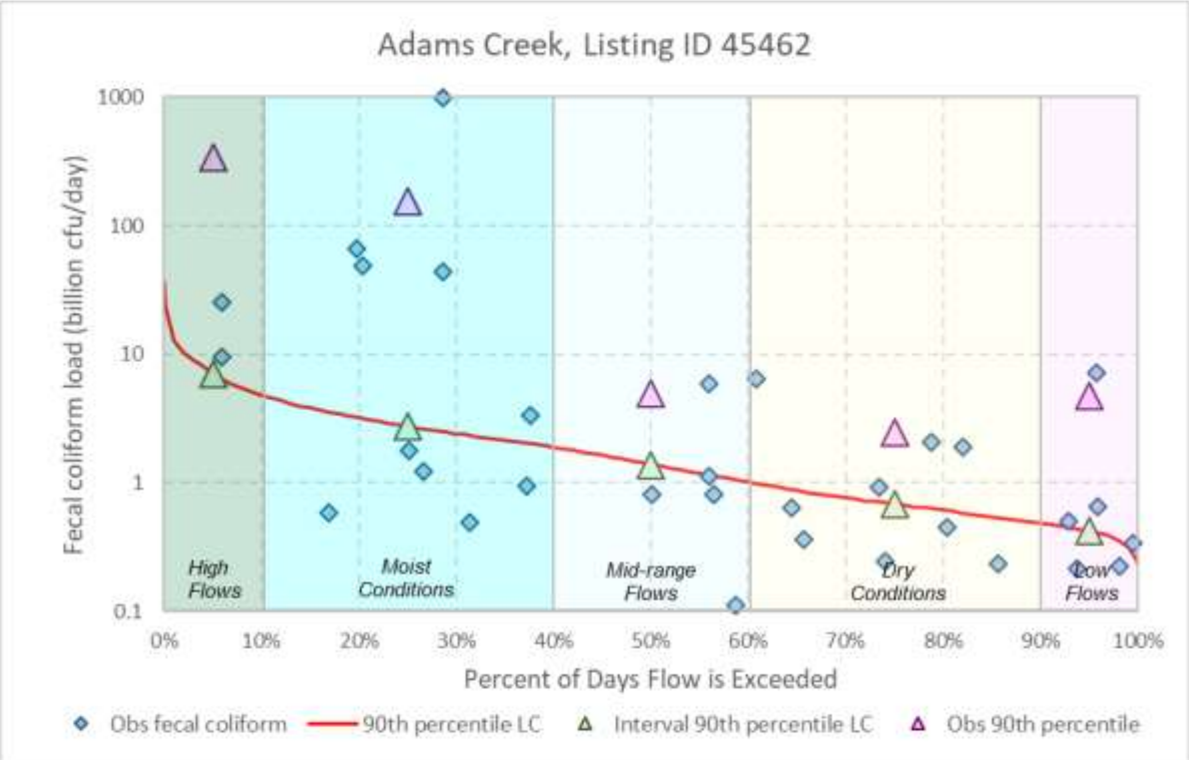


Figure 27. Fecal Coliform Load Duration Curve for Adams Creek (East), Listing ID 45462

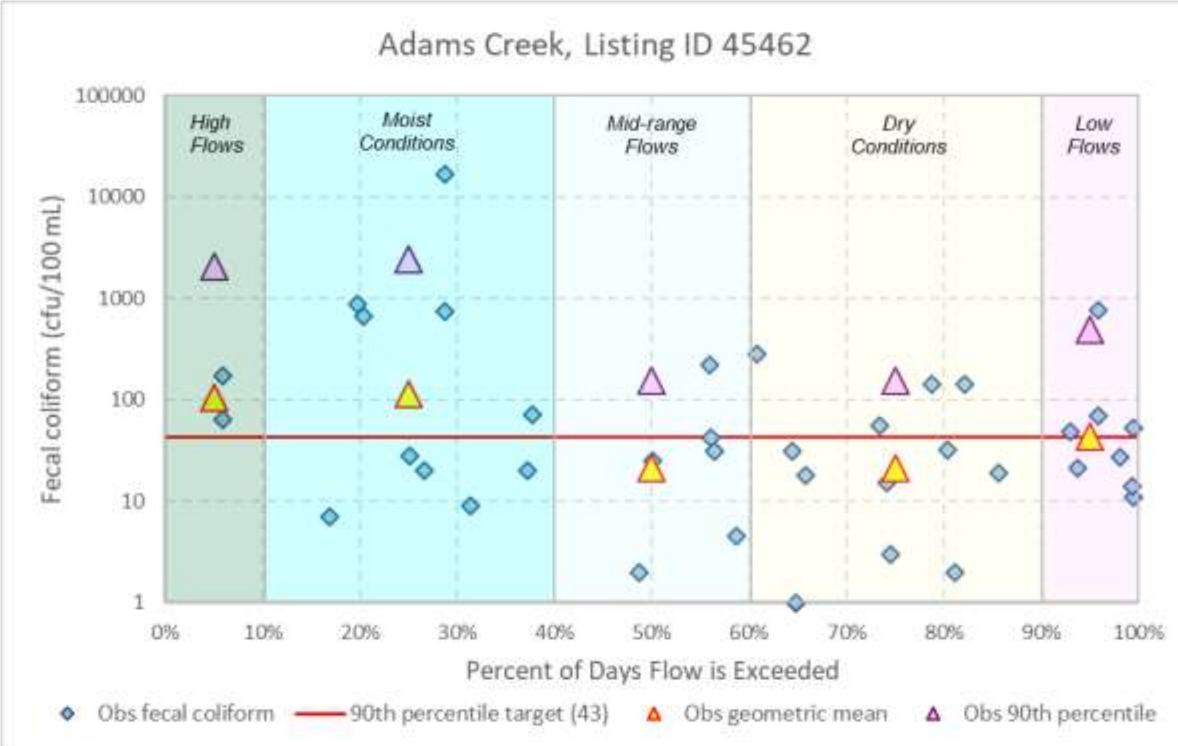


Figure 28. Flow Ranked Fecal Coliform Concentrations for Adams Creek (East), Listing ID 45462

Table 19. Current Condition 90th Percentile Fecal Coliform Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 45462

Source	Current Condition 90th Percentile Fecal Coliform Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0.0	0.0	0.0	0.0	0.0
Thurston County	28.9	13.3	0.4	0.0	0.0
Olympia	0.0	0.0	0.0	0.0	0.0
WSDOT	0.0	0.0	0.0	0.0	0.0
Non-MS4	310.6	142.4	4.5	2.5	4.8

5.11 WEST ADAMS CREEK, LISTING ID 45695

The fecal coliform load duration curve, flow ranked concentrations, and a summary table of the current condition 90th percentile loads are presented below for the western branch of Adams Creek. The TMDL for this segment is expressed in terms of fecal coliform, reflecting the objective to protect downstream marine water for shellfish harvesting. This branch of Adams Creek is separate from the eastern branch, but also discharges to Budd Inlet/South Puget Sound.

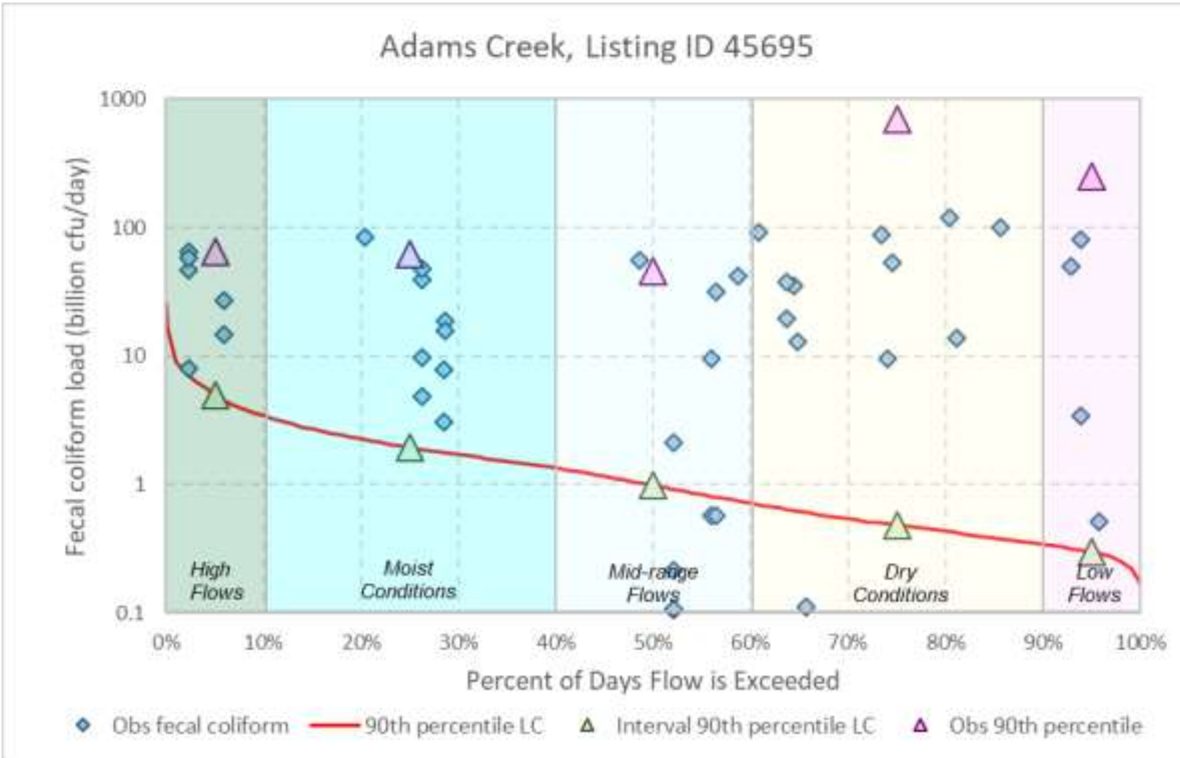


Figure 29. Fecal Coliform Load Duration Curve for Adams Creek (West), Listing ID 45695

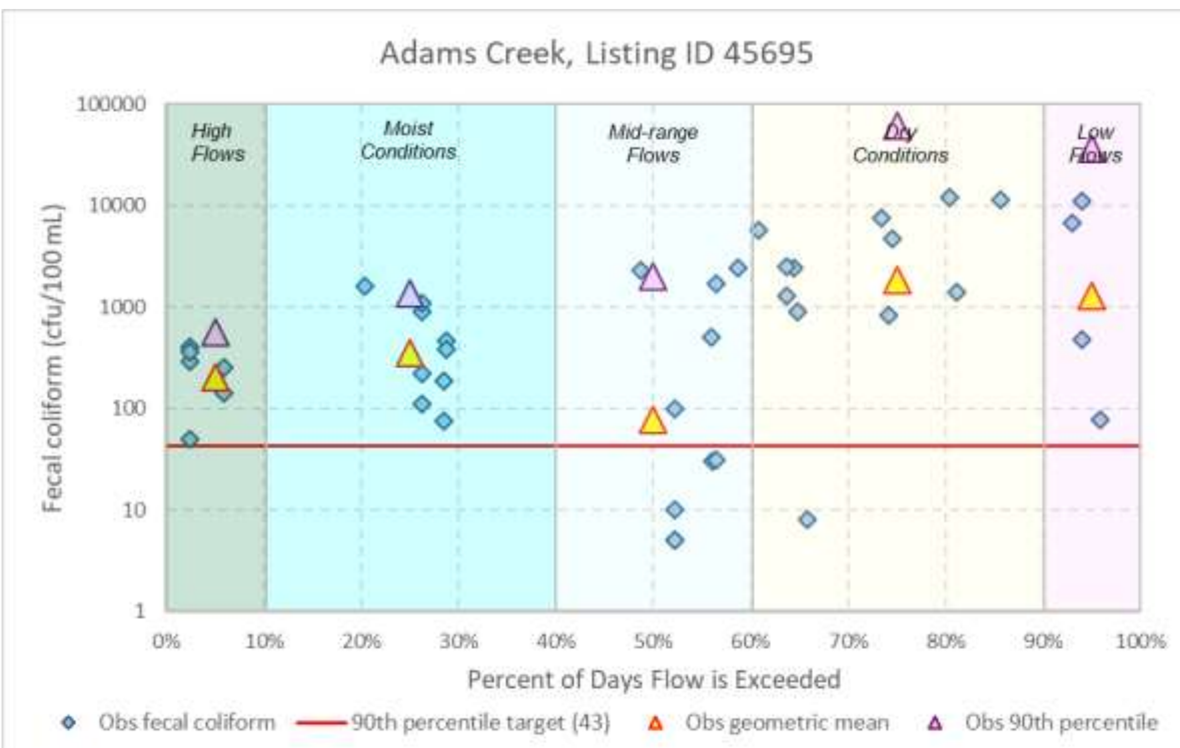


Figure 30. Flow Ranked Fecal Coliform Concentrations for Adams Creek (West), Listing ID 45695

Table 20. Current Condition 90th Percentile Fecal Coliform Load (billion cfu/day) Attributed to Sources Based on Area, Listing ID 45695

Source	Current Condition 90th Percentile Fecal coliform Load (billion cfu/day) by Flow Condition				
	High	Moist	Mid-range	Dry	Low
Tumwater	0.0	0.0	0.0	0.0	0.0
Thurston County	32.3	31.0	22.6	0.0	0.0
Olympia	0.0	0.0	0.0	0.0	0.0
WSDOT	0.0	0.0	0.0	0.0	0.0
Non-MS4	32.9	31.6	23.1	697	250

6.0 REQUIRED REDUCTIONS

Figure 31 through Figure 35 show the percent reductions grouped into categories for each bacteria-impaired segment based on the percent reduction required by flow interval. The categories help inform which waterbodies have the highest percent reductions needed for a particular flow interval. The percent reductions were determined by calculating the reduction needed from the observed 90th percentile value to meet the 90th percentile TMDL in the tables in Section 5.0. The percent reduction levels are defined as follows:

- Low (percent reduction range < 30%)
- Moderate (percent reduction range 30 – 60%)
- High (percent reduction range 60 – 90%)
- Very high (percent reduction range >90%)

In addition to displaying the average percent reductions needed for each bacteria-impaired segment, the average percent reduction by monitoring site is in Figure 36 through Figure 38.

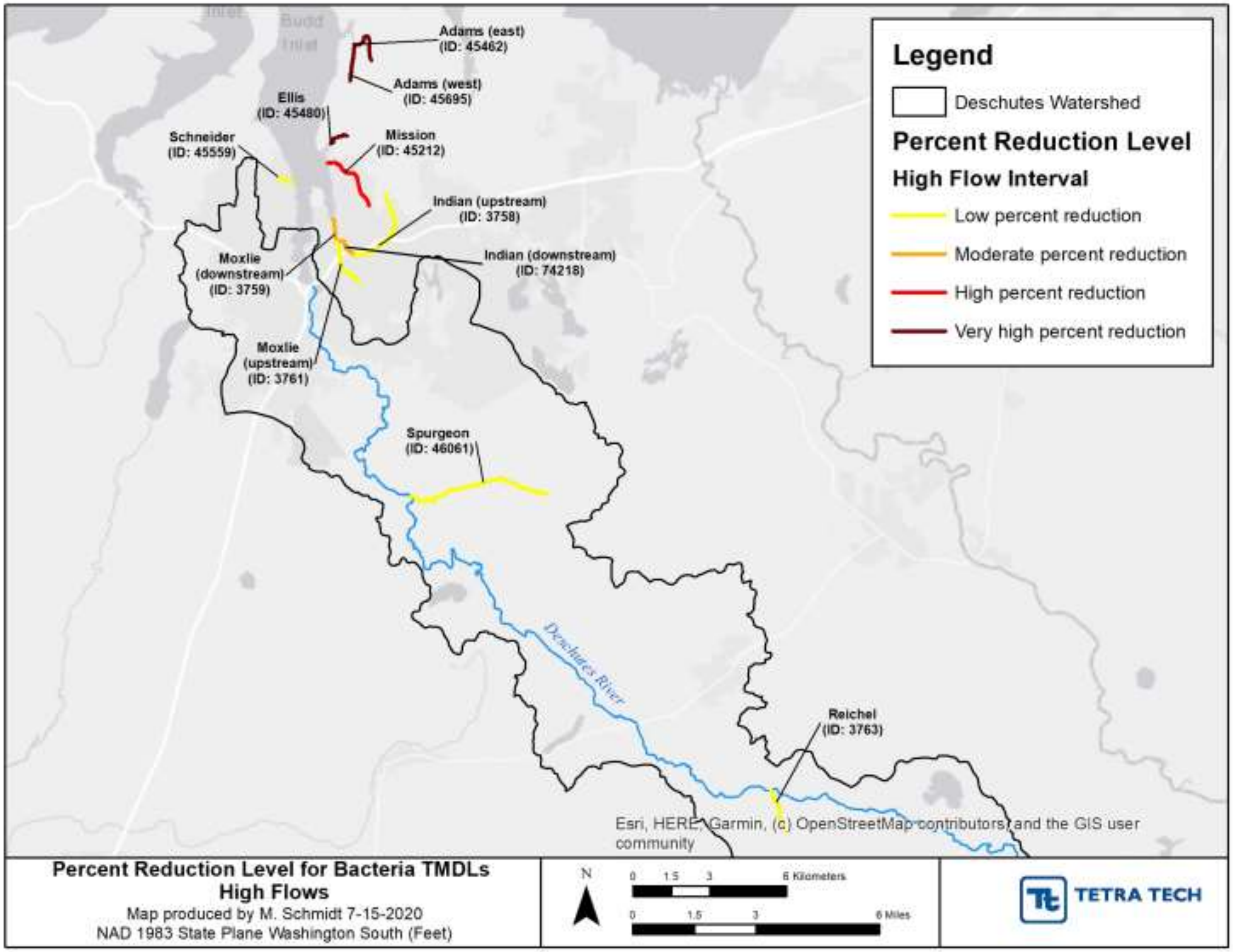


Figure 31. Relative Percent Reduction Level for Bacteria TMDLs – High Flow Interval

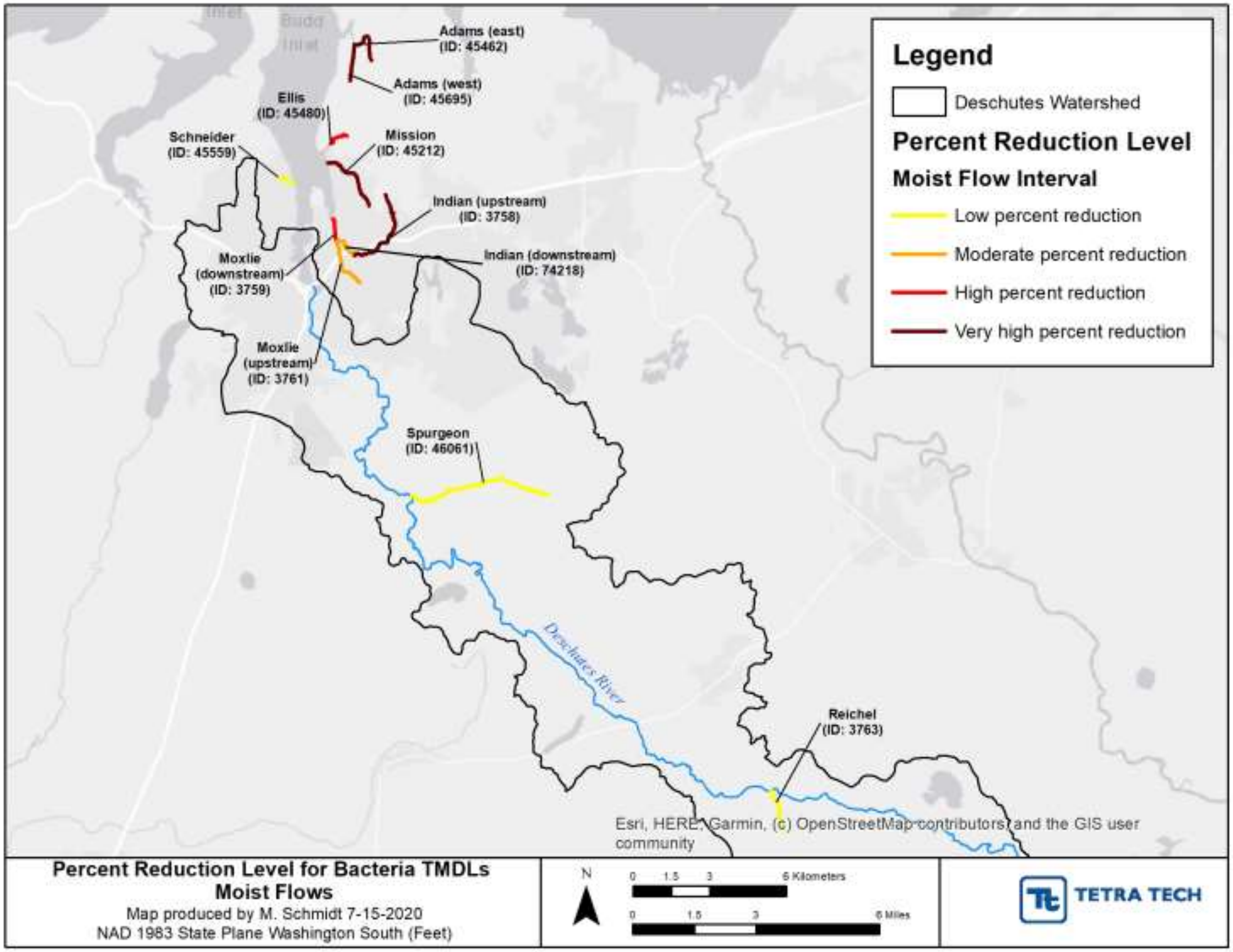


Figure 32. Relative Percent Reduction Level for Bacteria TMDLs – Moist Flow Interval

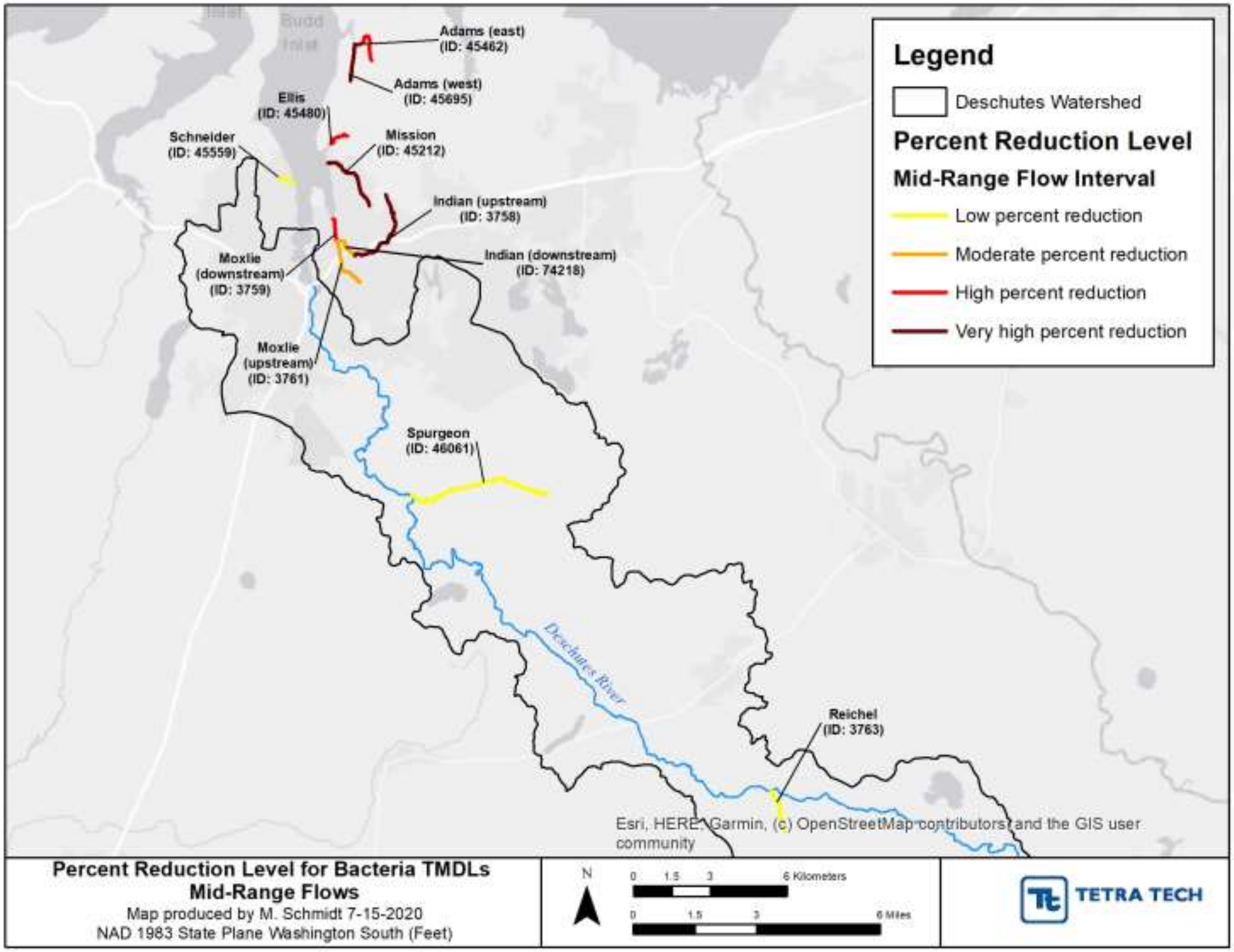


Figure 33. Relative Percent Reduction Level for Bacteria TMDLs – Mid-Range Flow Interval

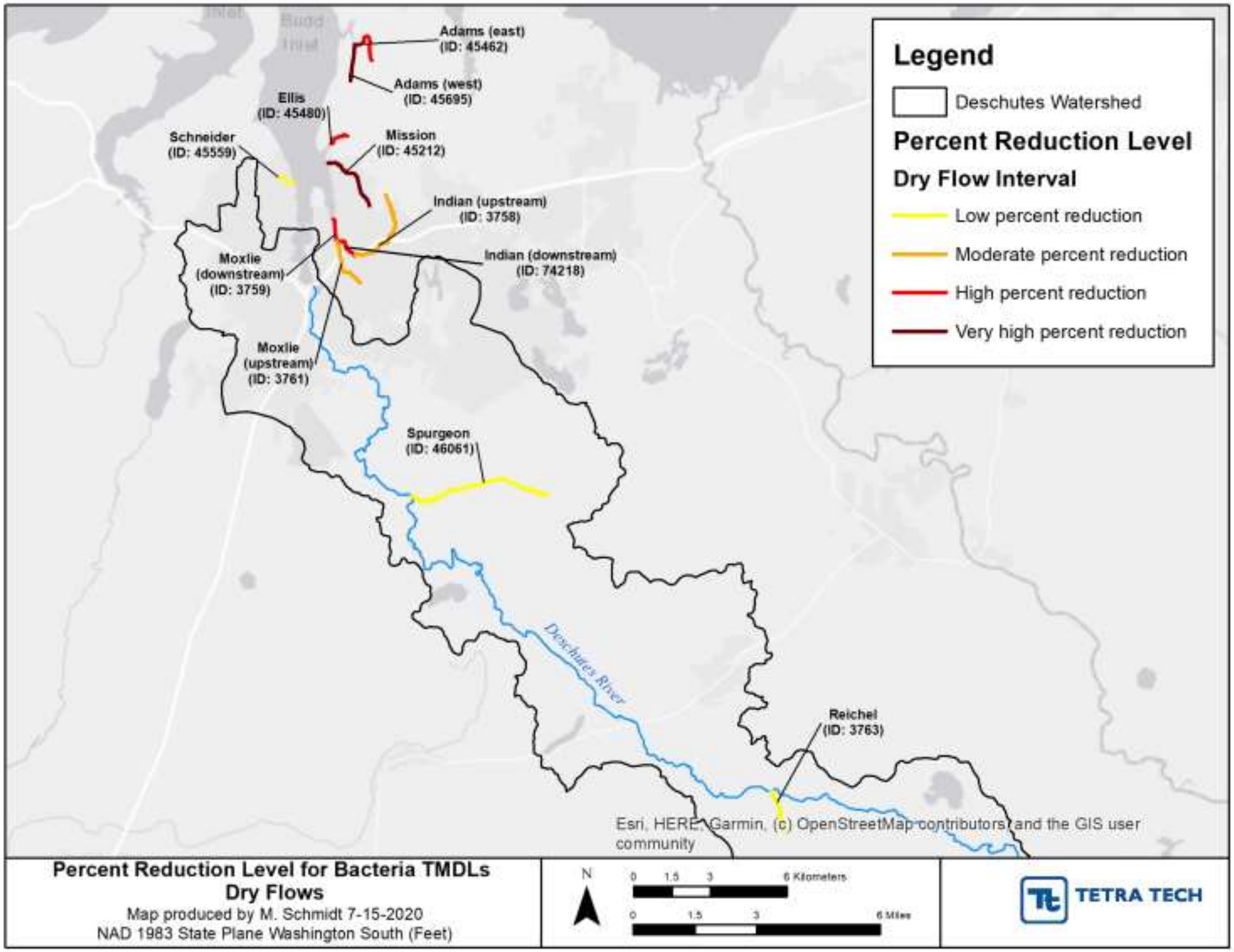


Figure 34. Relative Percent Reduction Level for Bacteria TMDLs – Dry Flow Interval

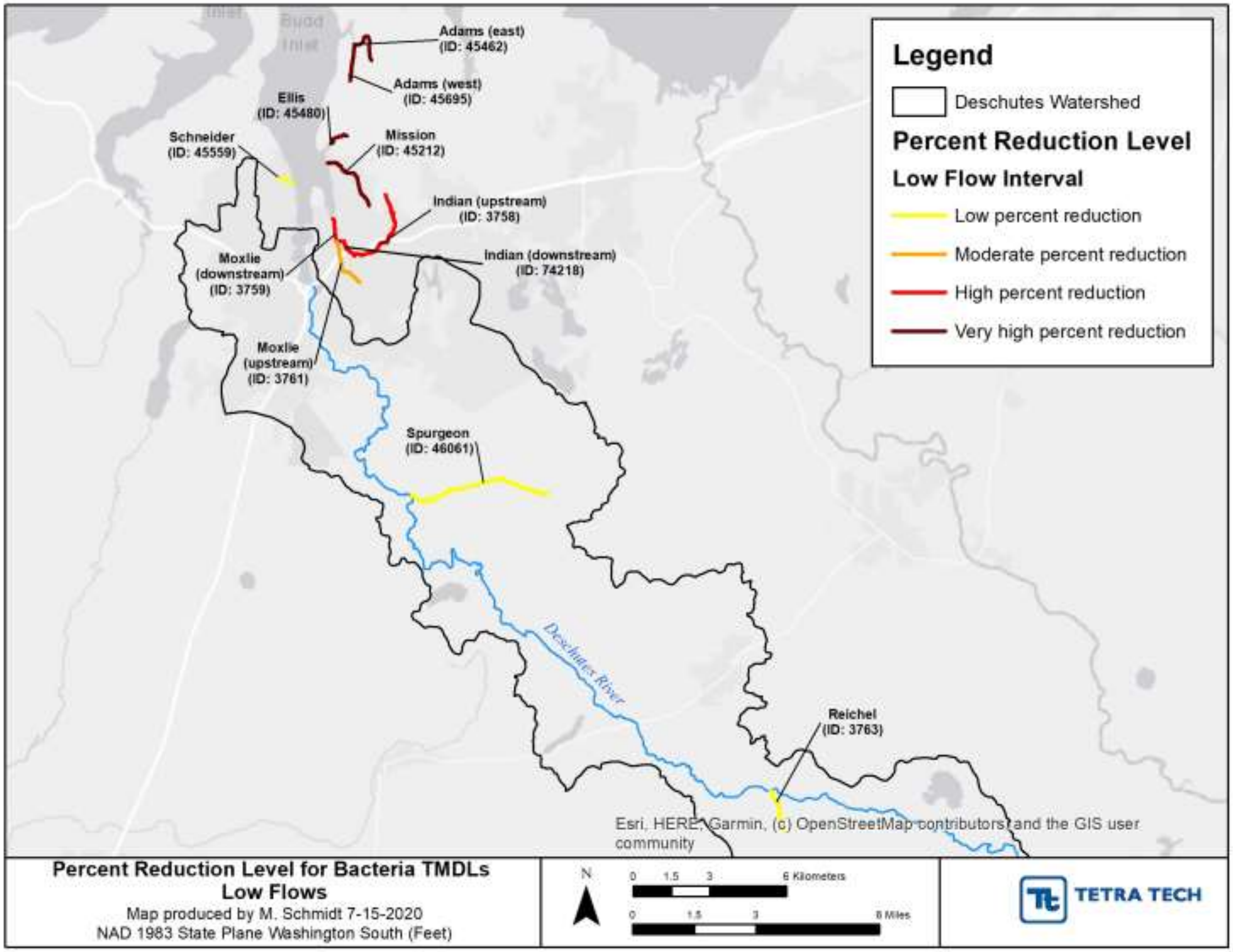


Figure 35. Relative Percent Reduction Level for Bacteria TMDLs – Low Flow Interval

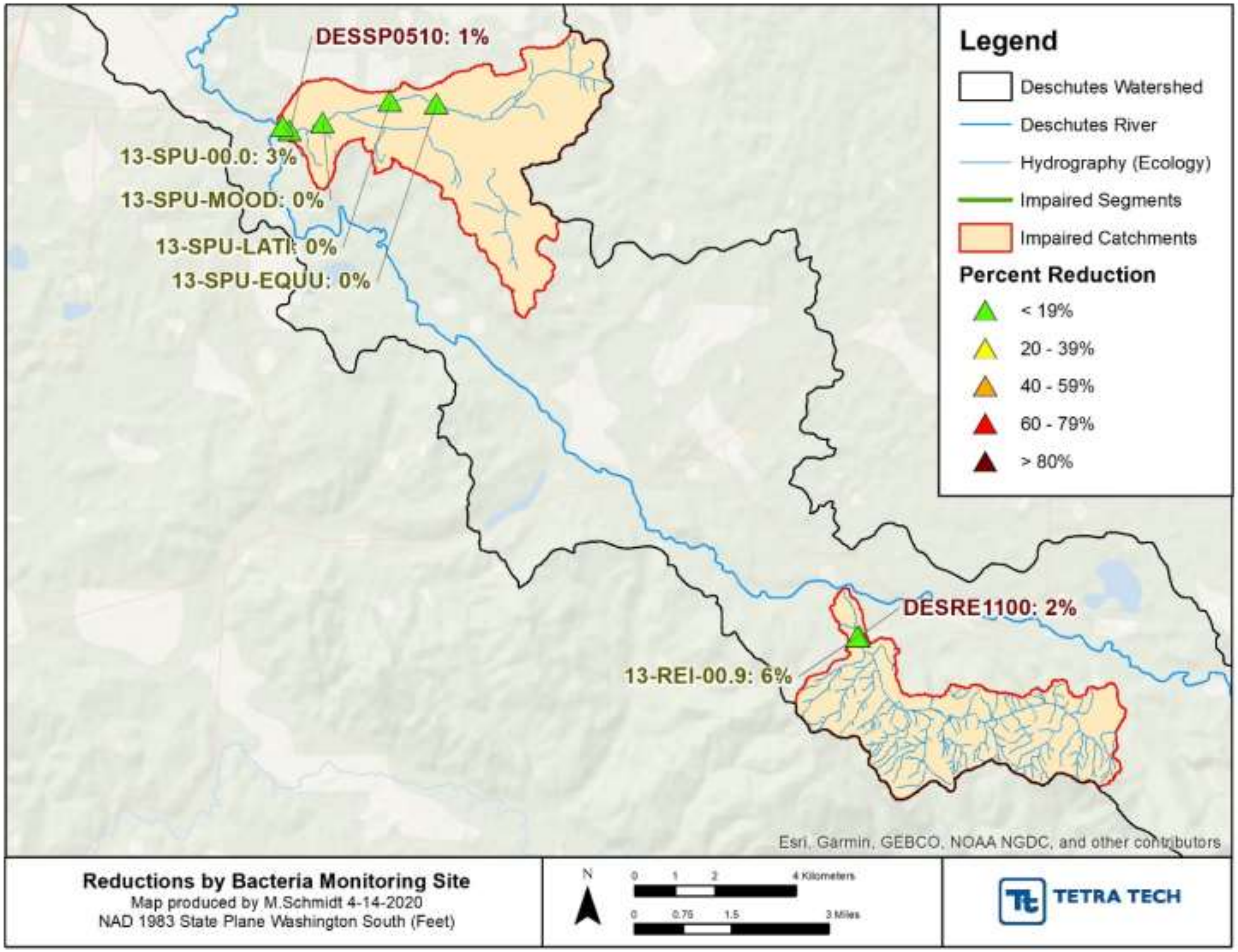


Figure 36. Average reduction required by bacteria monitoring site (Spurgeon and Reichel).

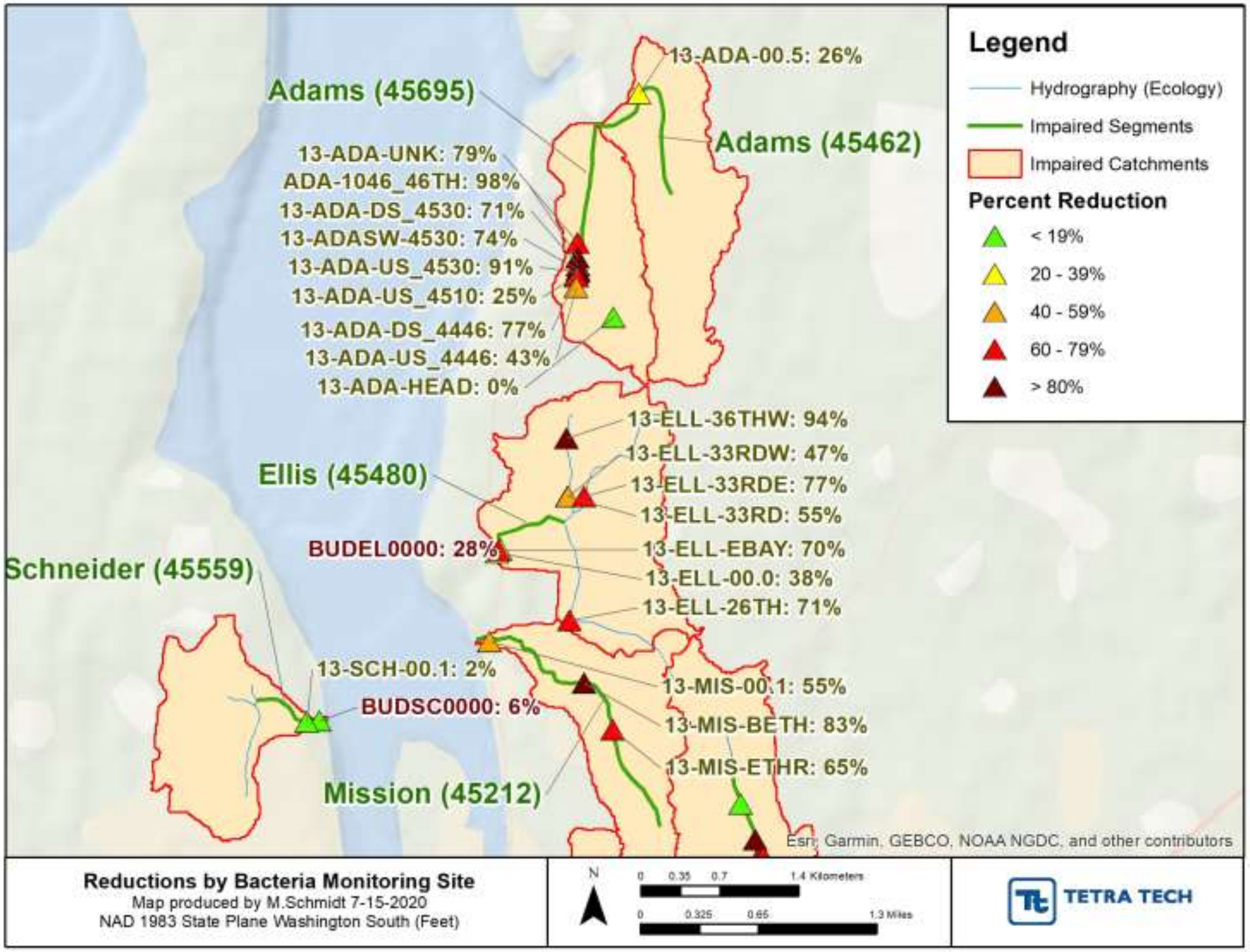


Figure 37. Average reduction required by bacteria monitoring site (Adams, Ellis, Mission, and Schneider).

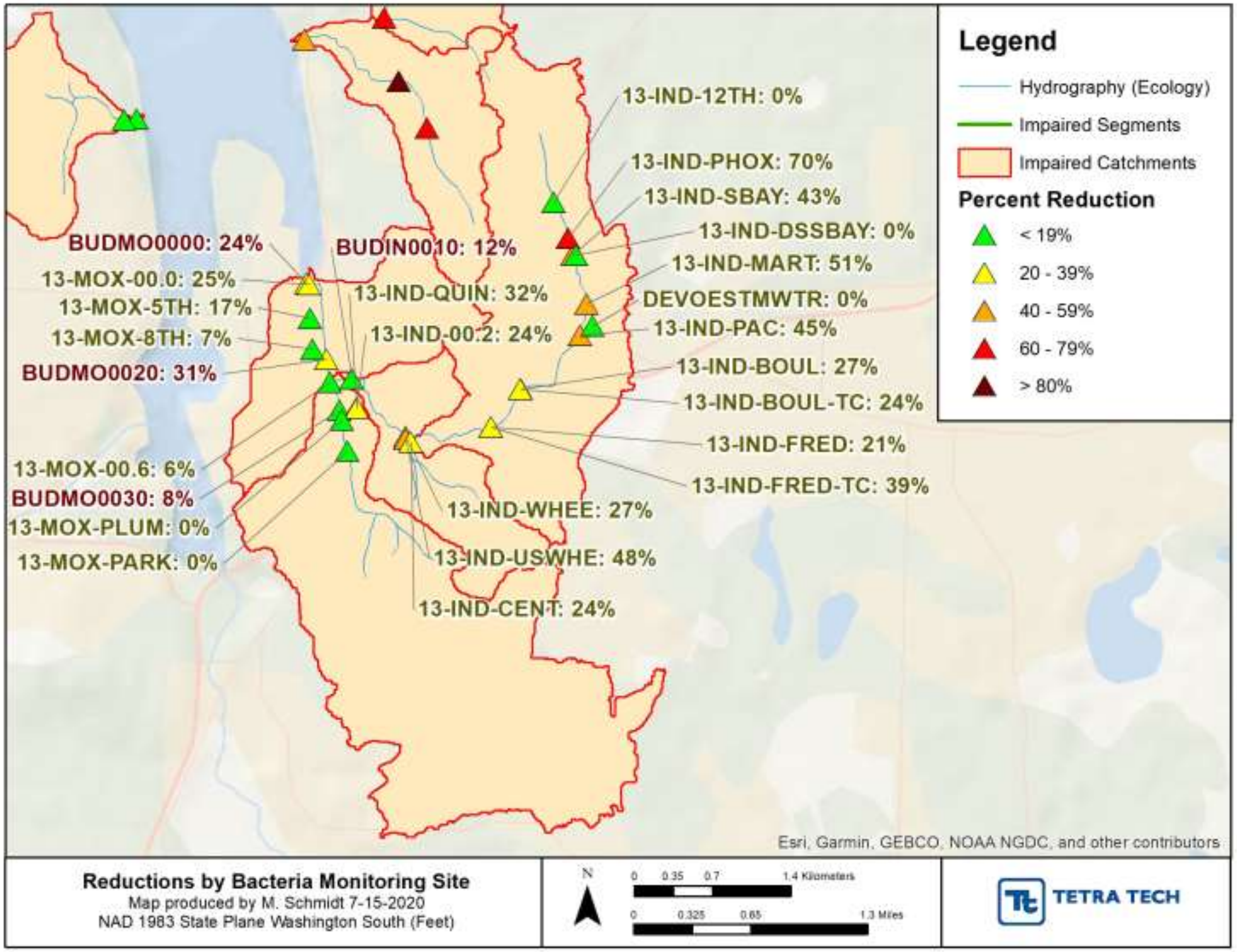


Figure 38. Average reduction required by bacteria monitoring site (Moxlie and Indian).

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