Quality Assurance Project Plan

Lacamas Creek Bacteria, Temperature, and Nutrients Source Assessment

By

Molly Gleason and Sheelagh McCarthy

For the

Water Quality Program

Washington State Department of Ecology
Southwest Regional Office
Olympia, Washington

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State of Washington

Publication Information

The final QAPP is available on Ecology's website at https://apps.ecology.wa.gov/publications/summarypages/2110017.html.

Cover photo credit

- Devan Rostorfer, 2020. Lacamas Creek at Goodwin Road.

Each study conducted by the Washington State Department of Ecology must have an approved Quality Assurance Project Plan (QAPP). The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

Related Information

- This QAPP was approved to begin work in June 2021. It was finalized and approved for publication in July 2021.
- Data for this project are available in Ecology's EIM Database,[1] Search Study ID: LacamasSA for 2021 data and TSWA0003 for 2010-11 data.
- Federal Clean Water Act 1996 303(d) Listings Addressed in this Study. See Section 3.3.

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[1] www.ecology.wa.gov/eim
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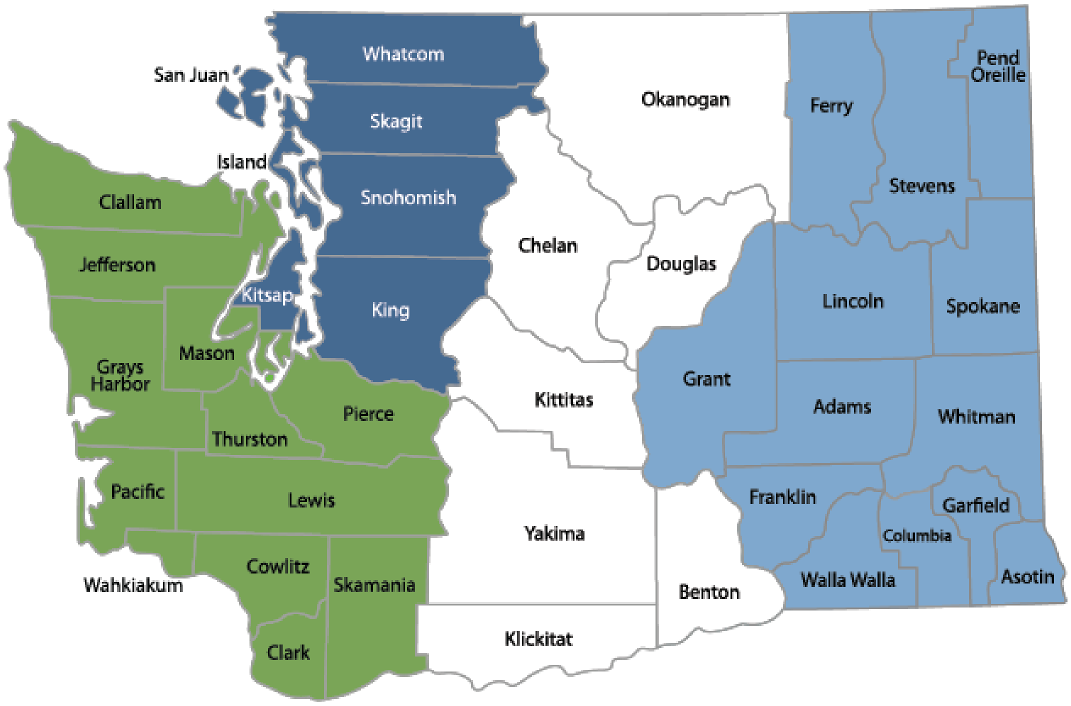

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Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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SWRO: Southwest Regional Office

1.0 Table of Contents

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2.0 Abstract

Lacamas Creek and its major tributaries currently do not meet (exceed) Washington State water quality standards for bacteria, dissolved oxygen, pH and temperature. The Washington State Department of Ecology started a Total Maximum Daily Load (TMDL) study in 2010 to collect and assess water quality data in the Lacamas Creek Watershed. Ecology published a groundwater report from these data in 2013, yet Ecology has not completed an evaluation of the surface water quality.

This study will complete this assessment of the 2010-11 water quality data. The Lacamas Creek Quality Assurance Project Plan (Swanson 2011) includes more details regarding the study design for the 2010–2011 field collection. In addition, bacteria sampling will be conducted in 2021 to find current sources of pollution and evaluate changes since the original 2010-11 FC data collection. Ultimately, this source assessment will serve as the technical foundation for the Lacamas Creek Water Quality Alternative Restoration Plan, which will be developed in 2023 and 2024.

3.0 Background

3.1 Introduction and problem statement

The Washington State Department of Ecology's (Ecology's) goals are to prevent and reduce water pollution and clean up polluted waters. Lacamas Creek and its surrounding tributaries currently are listed on the state's 303(d) polluted list, since the waterbodies do not meet Washington State's water quality standards for bacteria, dissolved oxygen, pH and temperature. Meeting water quality standards is important to protect the beneficial uses provided by Lacamas Creek and the surrounding tributaries. Lacamas Creek provides habitat for fish and supports wildlife. The creek is a potential source of water supply for agriculture, livestock and domestic use. Lacamas Creek is also a major input to the downstream Lacamas Lake, which is a popular area for recreation and public enjoyment. Considering the beneficial uses and the impairments of multiple parameters, Lacamas Creek Watershed was determined to be a high priority for water quality improvement (Giglio and Erickson 1996).

Ecology started a Total Maximum Daily Load (TMDL) study in 2010 to assess water quality across the Lacamas Creek Watershed (Swanson 2011). From September 2010 to October 2011, Ecology collected fecal coliform (FC) bacteria and nutrient samples and measurements for temperature, dissolved oxygen, pH, streamflow, and stream channel morphology. The Lacamas Creek Quality Assurance Project Plan includes more details regarding the study design for the 2010–2011 field collection efforts (Swanson 2011).

Ecology also completed a groundwater assessment to determine how groundwater influences stream flows and surface water quality in Lacamas Creek and surrounding tributaries, and a *Groundwater Interactions and Near Stream Groundwater Quality* report was published in 2013 summarizing those findings (Sinclair and Swanson 2013). Yet, Ecology did not complete the assessment of surface water quality due to staffing limitations.

Ecology will complete the study as a source assessment, which will be the foundation for a TMDL Alternative Restoration Plan. Source assessments and TMDL Alternative Restoration Plans are increasingly important tools for water quality improvement in addition to TMDLs, which have proven to be complex and resource intensive. An Alternative Restoration Plan provides a near-term plan that is more immediately beneficial or practicable for water quality improvement. By adopting this design, this study can work towards improving water quality in an efficient and timely manner.

Source assessments are used to identify and prioritize sources of pollutants, particularly from nonpoint sources. The water quality challenges in the watershed are likely associated with nonpoint source pollution to Lacamas Creek and its tributaries (Giglio and Erickson 1996). Lacamas Creek water quality issues caused by nonpoint pollution likely influence the water quality of Lacamas and Round Lakes, since the creek is a major input of surface water to those lakes.

Lacamas Lake and the 312-acre Lacamas Regional Park are popular areas for recreational use. Recently, the County has issued public health and swimming advisories due to harmful algal blooms likely generated from pollution. Past studies determined that the primary phosphorus loading to Lacamas Lake originates from nonpoint sources of pollution originating from Lacamas Creek (Beak Consultants and Scientific Resources Incorporated 1985). These conclusions support the importance of identifying nutrient pollution sources from Lacamas Creek, which may influence nutrient loading to the Lake and dissolved oxygen impairments in the watershed and Lacamas Lake.

In response to this issue, Ecology will focus on targeting watershed sources of pollution from Lacamas Creek, while local stakeholders will focus efforts in the Lacamas Lake area. Recently, concerned local citizens formed the Lacamas Watershed Council to develop a strategy to address pollution sources that are directly discharging to the Lake. The City of Camas and supporting agencies are developing a lake management plan to outline actions to improve water quality in Lacamas, Fallen Leaf, and Round lakes. This combined effort to cover most of the Lacamas Creek Watershed and address pollution issues from multiple sources is an effective strategy to improve water quality in the watershed and lakes.

3.2 Study area and surroundings

The Lacamas Creek Watershed is located within Watershed Resource Inventory Area (WRIA) 28 in Southwest Washington in Clark County. The watershed makes up an area of 67 square miles of forest, agricultural, residential, commercial, and industrial land. The watershed extends from Hockinson in the north, to the City of Camas in the south, with Vancouver bordering the western edge of the watershed. Lacamas Creek flows 18 miles from relatively undisturbed, forested headwaters through rural, agricultural, and residential areas before entering Lacamas and Round Lakes.

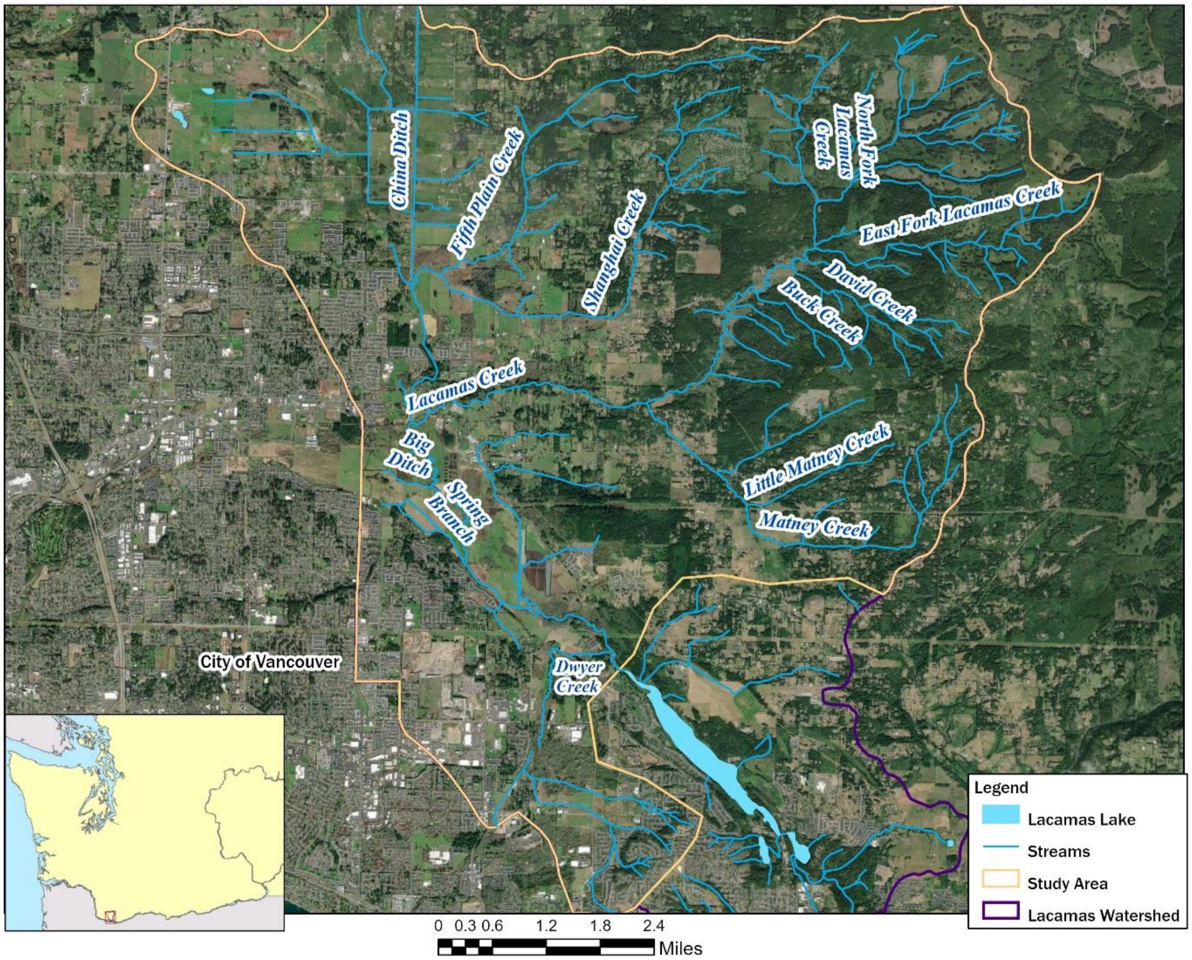

Figure 1. Map of study area.

Below the lakes, Lacamas Creek enters the lower Washougal River, which flows to the Columbia River. The watershed has a complete fish passage barrier located at a dam below Lacamas Lake. This dam is owned and operated by the City of Camas. Restoration practitioners have prioritized the removal of the fish passage barriers to support salmon recovery.

Lacamas Creek above Lacamas Lake has five major tributaries: Matney Creek, Shanghai Creek, Fifth Plain Creek, China Ditch, and Dwyer Creek. There are also many smaller creeks and channelized streams such as Spring Branch and Big Ditch that flow into Lacamas Creek. Upper Lacamas Creek, China Ditch, Fifth Plain Creek, and Shanghai Creek are located in the northwest portion of the watershed, and Spring Branch Creek, Matney Creek and other small ditches are located in the lower watershed.

The study area for this monitoring project lies within the Lacamas Creek Watershed above Lacamas Lake, which includes Lacamas Creek and its five major tributaries and ends at the confluence of Lacamas Creek and Lacamas Lake. Since Lacamas Creek is the major input to the Lake, focusing on the watershed upstream of Lacamas Lake will provide insight into the main sources of pollution flowing into the lakes.

3.2.1 History of study area

Historically, forests and natural wetlands covered much of the northwestern area of the Lacamas Creek Watershed. This landscape has dramatically changed over the past century with development and deforestation of the lowlands to prepare the land for farming.

Beginning in the 1890s, several channels were built to drain the wetlands for farmland and to increase the volume of water delivered to Camas paper mills (Clark County 2004). The largest of these constructed drainage channels include China Ditch, Spring Branch, and Big Ditch, which all drain to Lacamas Creek. Although considered an improvement when developed, these channels have unintended consequences. With fewer wetlands to store runoff from rainstorms, higher volumes of stormwater funnel to streams, eroding stream banks and causing increased flooding in low-lying lands. Currently, wetlands make up only 4% of the Lacamas Creek Watershed.

3.2.2 Land use

Currently, the watershed's dominant land cover is 35% forestlands, followed by 25% hay or pasturelands associated with agriculture, and 16% development. Wetlands make up only 4% of the Lacamas Creek Watershed. Land use in the northern and eastern watershed mainly consist of forests, farmland and rural residential development. Higher-density residential and commercial development are concentrated in the southern and western watershed near the Cities of Camas and Vancouver. Figure 2 shows the land use cover for the Lacamas Creek Watershed.

About 22% of the watershed is public property. Federal or local governments in the watershed (i.e. City of Camas and Vancouver) own approximately 1% of the land. Clark County and the State of Washington own 13% and 8%, respectively, of the public lands in this watershed. A portion of this land is associated with the Camp Bonneville Cleanup, which is occurring on a historic military property. US. Army and Department of Ecology are currently cleaning this area to remove munitions and explosives associated with past military training. This property presents riparian restoration opportunities in the future, but the timeline for cleanup and restoration is currently unknown.

3.2.2.1 Point Sources

Point sources refer to sources of pollution discharged from a specific location such as pipes, outfalls and conveyance channels to surface water. The types of point source permits in the watershed include approximately 71 construction stormwater general permits, five industrial stormwater general permits, and 9 sand and gravel general permits. Figure 3 shows the location of properties covered under the specific permit types.

Additionally, there are currently two documented dairies in the watershed. The Washington Department of Agriculture's (WSDA) Dairy Nutrient Management Act regulates and performs routine inspection of these dairies. Since WSDA currently has permit authority to regulate these dairies, Ecology does not administer Concentrated Animal Feeding Operation (CAFO) permits to these dairies.

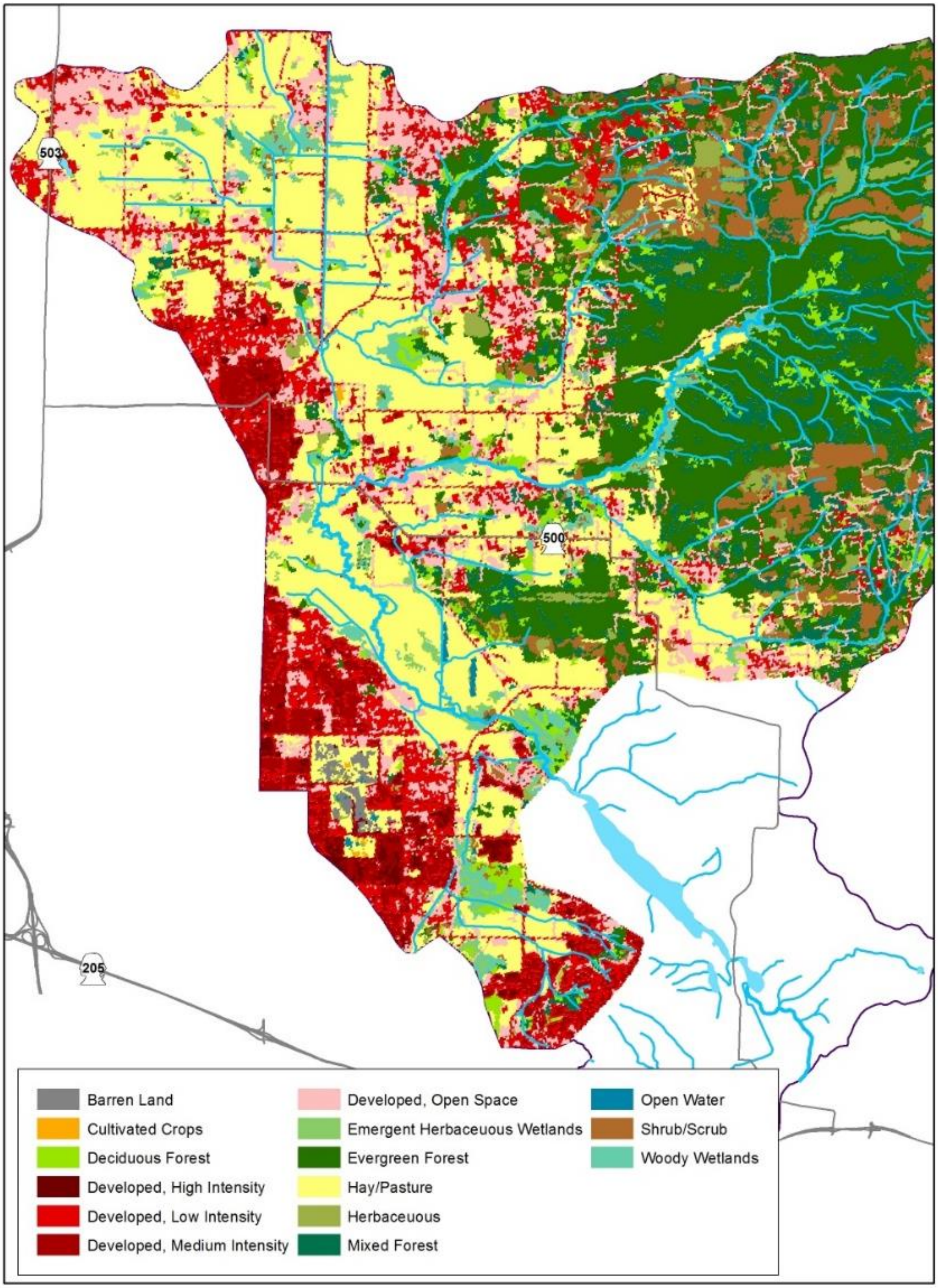

Figure 2. Map of land use in Lacamas Creek Watershed.

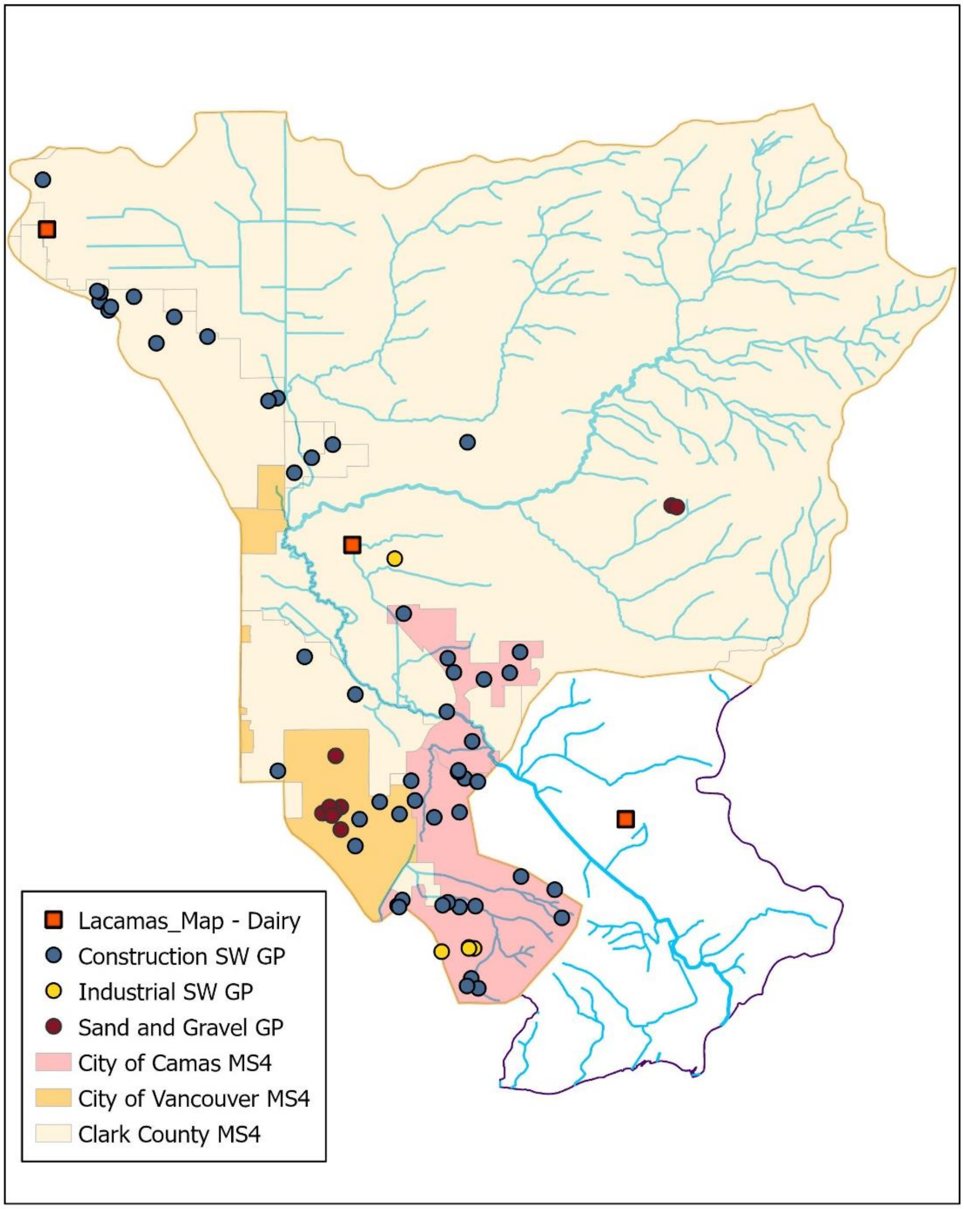

Figure 3. Map of National Pollutant Discharge Elimination Systems (NPDES) Permits and Stormwater Jurisdictions in the Lacamas Creek Watershed.

3.2.2.2 Stormwater

During significant rain events, stormwater runoff can accumulate and transport pollutants to receiving waters and can degrade water quality. Ecology regulates stormwater discharge under the National Pollutant Discharge Elimination Systems (NPDES) Municipal Stormwater Permit program. More information on NPDES permits can be found at [Ecology's Stormwater Permittee and Guidance webpage][3].

[3]https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources

Phase I Municipal Stormwater Permit

The Phase I Municipal Stormwater Permit regulates discharges from municipal separate storm sewer systems (MS4s) owned or operated by the state's largest cities and counties. Ecology issued an NPDES Phase I Municipal Stormwater Permit to Clark County and six other western Washington jurisdictions in July 2019. The permit covers a five-year period from August 1, 2019 to July 31, 2024. Around 88% of the watershed is covered under Clark County's Phase I Stormwater Permit. Clark County has a new Stormwater Management Plan (2020) that outlines the county's responsibilities to protect water through stormwater management. The Plan is located at the Clark County Stormwater webpage[4].

Phase II Municipal Stormwater Permit

The Phase II Municipal Stormwater Permits regulate discharges from relatively smaller MS4s in Washington to manage stormwater before it discharges to surface water. Ecology issued Western Washington Phase II Municipal Stormwater Permits to the Cities of Vancouver and Camas, which respectively cover 7% and 4% of the watershed.

The City of Vancouver issued a 2020 Stormwater Management Plan, which includes information about changes to the City's Municipal Codes, relating to stormwater management as required by the Phase II Municipal Stormwater permit. The Plan is located at the City of Vancouver's Public Works Stormwater Management Plan webpage[5].

Ecology reissued a Phase II permit to the City of Camas on July 1, 2019. The new Permit cycle is from August 1, 2019 to July 1, 2024. The Plan is located at the City of Camas' Public Works Stormwater Management Program webpage[6].

WSDOT Municipal Stormwater Permit

Ecology issues a WSDOT specific Municipal Stormwater Permit that covers stormwater discharge from state highways, which covers roughly 1% of the Lacamas Creek Watershed. State highways in the Lacamas Creek Watershed include SR 500 and SR 503. The current permit went into effect April 5, 2019 and expires April 5, 2024. More details about this permit are at Ecology's WSDOT Municipal Stormwater Permit webpage[7].

3.2.2.3 Nonpoint sources

Nonpoint pollution originates from diffuse sources that are not regulated by point source regulatory tools such as discharge permits. Potential nonpoint sources within the Lacamas Creek Watershed include:

- Natural wildlife including mammals and waterfowl.
- Livestock with direct access to stream.
- Livestock manure applied to fields or leached from storage areas.

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[4] https://clark.wa.gov/public-works/stormwater

[5] https://www.cityofvancouver.us/publicworks/page/stormwater-management-plan

[6] https://www.cityofcamas.us/publicworks/page/stormwater-management-program-swmp

[7] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Stormwater-general-permits/Municipal-stormwater-general-permits/WSDOT-Municipal-Stormwater-Permit

- Pet manure from parks and residential areas.
- Municipal and industrial wastewater and stormwater.
- Failing on-site septic systems.
- Runoff from residential properties adjacent to the creek.

3.2.3 Hydrology

During the wet season (i.e. November to May), the Lacamas Creek Watershed experiences peak flows and flooding in the low-lying lands. Natural groundwater discharge influences Lacamas Creek during the dry season periods with low flow (i.e. typically June to October). Ecology's groundwater assessment in 2013 revealed considerable local variation in the pattern and volume of groundwater discharge to Lacamas Creek (Sinclair and Swanson 2013). Reaches of the creek experienced alternating gains and losses in streamflow caused by groundwater throughout the summer. For example, reaches of Lacamas Creek showed a net streamflow gain from groundwater of +1.34 ft^3/s in July and then a loss of -2.73 ft^3/s in August.

3.2.4 Geology

The bedrock exposed in the Lacamas Creek Watershed consists mostly of basalt (Evarts 2006). In the western part of the watershed, the landscape consists of intermittent bedrock buried beneath sediments originating from the ancestral Columbia River. In middle Pleistocene time, basalt and basaltic andesite erupted from three small volcanoes in the southern half of the watershed (Trimble 1963). In late Pleistocene time, the Missoula floods deposited poorly sorted gravels in the southwestern part of the Lacamas Creek Watershed that grade northward into finer grained sediments.

The Lacamas Creek Surface Water/Groundwater Interactions report (Sinclair and Swanson 2013) provides further descriptions of the hydrogeological setting of the Lacamas Creek Watershed.

3.2.5 Climate

Lacamas Creek Watershed is located in an area that experiences mild, cool and wet winters and relatively dry and warm summers. Temperatures are moderated by the Columbia River and Pacific Ocean. The climate is also influenced by the coastal Willapa Range to the west and the Cascade Range to the east. In Vancouver, the average maximum monthly air temperatures range from 44°F in January to near 80°F in August. Severe temperature extremes are infrequent.

Average annual rainfall for Vancouver is just over 40 inches. Approximately 75% of the annual rainfall falls from October to March, while July and August are typically the driest months. The foothills in the upper Lacamas Creek Watershed receive slightly more rainfall than the lowlands in Camas and Vancouver.

Southwest Washington is experiencing long-term changes that are consistent with those observed globally as a result of human-caused climate change (Snover et al. 2013).

These include increasing temperatures, a longer frost-free season, and earlier peak streamflows in many creeks and rivers.

3.2.6 Summary of previous studies and existing data

3.2.6.1 Ecology TMDL

Ecology originally selected Lacamas Creek for a TMDL in 2010 and published the original Quality Assurance Project Plan in 2011 (QAPP; Swanson 2011). Data collection was completed in 2011 which involved the following monitoring efforts:

- FC sampling at 30 sites and periodically at 9 sites for pollution investigation from October 2010 to September 2011.
- Continuous temperature monitoring.
- Two surface and groundwater synoptic surveys that involved dissolved oxygen, pH, and nutrient sampling twice during summer 2011.
- Riparian habitat and channel surveys.
- Continuous diel monitoring for pH, dissolved oxygen.
- Storm sampling during the dry and wet seasons.

A preliminary analysis of the 2010-2011 FC data is presented in Table 1. This analysis was completed using the 2010–2011 data available in Ecology's Environmental Information Management (EIM) database under Study ID TSWA0003. These data were uploaded into EIM, although the measurement and sample results were not fully reviewed. Therefore, these 2010-2011 data will be reviewed in EIM and assessed for quality before being used in the technical analysis of the study report. The results presented in Table 1 therefore may change when presented in the final Source Assessment report. Section 13.1 provides more details on this quality assurance assessment. This preliminary analysis was completed before the update in water quality criteria for bacteria on December 2020 (see Section 3.2.8 for more details), therefore FC results were compared to the FC water quality criteria for geometric mean (not to exceed 100cfu/100mL) and 10% exceedance criteria (no more than 10% of samples are to exceed 200 cfu/ 100 mL).

The preliminary seasonal results show greater exceedances during the dry season (i.e. June to October) at most of the sites across the watershed (see Table 1). Higher FC levels were detected at tributaries in the upper watershed including China Ditch, Shanghai Creek, and Fifth Plain Creek. Big Ditch, which is a constructed drainage channel that feeds to Lacamas Creek, was also found to have high FC levels. Sites that met criteria during the dry season include sites at Dwyer Creek, Spring Branch Creek, upper Fifth Plain Creek, and Lacamas Creek below Lacamas Lake.

Table 1. Preliminary analysis of 2010-11 fecal coliform data presented as results during the entire study period (annual), wet season (November – May), and dry season (June – October). Results are compared to the FC water quality criteria for geometric mean (not to exceed 100 cfu/ 100 mL) and 10% exceedance criteria (no more than 10 % exceed 200 cfu/ 100 mL). Bolded values indicate the site exceeded the FC water quality criteria, which expired December 31, 2020.

Site	Waterbody	Samples (n)	Wet Season Geometric Mean (cfu/100 mL)	Wet Season % Exceed	Dry Season Geometric Mean (cfu/100 mL)	Dry Season % Exceed
LAC00.2	Lacamas Creek	21	18	8%	19	0%
LAC05.6	Lacamas Creek	25	50	**14%**	**123**	**18%**
LAC07.5	Lacamas Creek	25	53	**14%**	**221**	**45%**
LAC09.1	Lacamas Creek	25	37	**14%**	**227**	**55%**
LAC11.1	Lacamas Creek	25	32	**14%**	**108**	**18%**
LAC13.3	Lacamas Creek	25	11	0%	**104**	**18%**
LAC14.8	Lacamas Creek	24	6	0%	74	**18%**
BIG02.0	Ditch	25	47	**14%**	**315**	**73%**
DWY00.1	Dwyer Creek	21	27	0%	**126**	**29%**
GOL00.0	Unnamed Tributary	16	3	0%	68	0%
MAT00.1	Matney Creek	28	28	0%	**150**	**18%**
MAT01.4	Matney Creek	25	22	0%	**162**	**45%**
MAT02.8	Matney Creek	25	9	0%	96	**18%**
MAT04.9	Matney Creek	25	12	0%	87	**18%**
SPR00.3	Spring Branch Creek	25	44	7%	97	9%
CHB00.0	China Ditch Tributary	25	19	0%	**379**	**45%**
CHB00.8	China Ditch Tributary	25	9	0%	**124**	**27%**
CHI00.0	China Ditch	25	30	7%	**120**	**27%**
CHI01.2	China Ditch	25	41	0%	**229**	**64%**
CHI01.9	China Ditch	25	18	0%	86	**27%**
FIF00.2	Fifth Plain Creek	45	33	4%	**115**	**26%**
FIF01.4	Fifth Plain Creek	25	36	7%	**238**	**45%**
FIF01.9	Fifth Plain Creek	28	39	0%	**186**	**45%**
FIF03.4	Fifth Plain Creek	25	21	0%	97	**18%**
FIF04.3	Fifth Plain Creek	25	15	0%	**153**	**45%**
FIF05.5	Fifth Plain Creek	25	5	0%	58	9%
SHA01.3	Shanghai Creek	25	74	**21%**	**402**	**73%**
SHA02.7	Shanghai Creek	25	69	**14%**	**453**	**82%**
SHA03.4	Shanghai Creek	25	23	7%	**151**	**45%**
SHA05.0	Shanghai Creek	21	10	0%	39	**14%**

3.2.6.2. Ecology Groundwater Assessment

As part of this study's initial assessment in 2010, Ecology conducted a groundwater assessment to evaluate how groundwater influences temperature and water quality. The objectives of this study were to assess and quantify groundwater discharge volumes to Lacamas Creek and selected tributaries during critical summer conditions and characterize the quality of groundwater prior to discharge into the creeks. This effort involved stream seepage evaluations, installations and monitoring of instream piezometers, collection and evaluation of groundwater quality samples and monitoring of streambed thermal profiles.

Ecology's assessment determined that Lacamas Creek experiences alternating gains and losses in streamflow caused by groundwater throughout the summer. Net gains of groundwater were found at specific transects of the creek in July, yet a net loss was found at the same reaches in August. Additionally, during the July and August 2011 synoptic surveys, measurable concentrations of dissolved orthophosphate and dissolved total phosphorus were found in all sampled piezometers, ranging from non-detections below 0.003 mg/L to detections of 0.276 mg/L and 0.0221 to 0.602 mg/L respectively. Concentrations of dissolved nitrate and nitrite-N ranged from non-detections below 0.01 mg/L to detections of 0.025 mg/L and ammonia ranged from 0.023 to 2.83 mg/L. A 2013 *Groundwater Interactions and Near Stream Groundwater Quality* report summarizes the results of this assessment (Sinclair and Swanson 2013).

3.2.6.3 Ecology ambient water quality monitoring

Ecology established an ambient monitoring station (28I120) on Lacamas Creek at Goodwin Road for a one-year sampling effort in water year (WY) 2007 (October 2006 through September 2007). This site is located at the most downstream location on Lacamas Creek before the confluence with Lacamas Lake. Monitoring involved the collection of samples (i.e. FC, nutrients, suspended solids, turbidity) and discrete measurements for conventional water quality parameters (i.e. conductivity, dissolved oxygen, pH, and temperature). Table 1 displays the results, which are also available on the Freshwater Information Network webpage[8].

For data collected in WY 2007, Ecology calculated a Water Quality Index (WQI) for each parameter to evaluate water quality conditions using a metric scale of good, moderate concern and poor as shown in Table 2. FC concentrations were elevated throughout the year and were determined to be of moderate concern. Ecology determined total persulfate nitrogen to be poor and total phosphorus to be of moderate concern.

Lacamas Creek at Goodwin Road was selected as an ambient station for continued monitoring for WY 2021 from October 2020 to September 2021. Ecology is monitoring the same parameters as the previous ambient monitoring in WY 2007 with the addition of *E. coli* and metals samples. The data collected at this site will complement this source assessment by providing current water quality data at a downstream location on Lacamas Creek. This site will

[8]https://apps.ecology.wa.gov/eim/search/SMP/RiverStreamSingleStationOverview.aspx?LocationUserIds=28I120&ResultType=RiverStreamOverviewList

be revisited for effectiveness monitoring based on the timeline set by the Lacamas Creek Water Clean Up Plan.

Table 2. Ecology ambient monitoring data for Lacamas Creek at Goodwin Road from WY 2007. Asterisks (*) note that no data were collected.

Date	Time	Fecal coliform (#/100mL)	Dissolved Oxygen (mg/L)	pH (pH)	TSS[1] (mg/L)	Temp[2] (degrees C)	Total Persulfate Nitrogen (mg/L)	Phosphorus (mg/L)	Turbidity (NTU)
10/16/06	15:30	480	9.9	7.24	5	12	1.92	0.0325	5
11/13/06	14:25	*	8.1	6.56	2	9.6	1.55	0.0954	7.9
12/18/06	14:00	3	12.3	*	3	3.7	1.35	0.0315	5.7
1/22/07	14:20	23	11.8	7.20	2	5.8	1.26	0.0262	6.5
2/12/07	14:20	160 (J[3])	11	7.04	6	8	1.47	0.0686	12
3/19/07	12:35	74	10.22	7.18	6	10.6	1.26	0.0310	6.1
4/23/07	12:40	47	10.82	7.05	2	11.2	1.12	0.0375	6.2
5/21/07	12:40	510	10.00	7.34	4	11.9	1.34	0.0333	5
6/11/07	13:00	77	10.95	7.56	3	14.7	1.6	0.0349	5.5
7/16/07	15:10	110	10.39	7.78	5	19.2	3.06	0.0364	6
8/20/07	14:03	430	9.4	7.42	5	16.2	3.51	0.0373	7.5
9/24/07	13:50	180	10.3	7.60	3	13.4	2.36	0.0358	4.1

[1]Total Suspended Solids: TSS; [2]Temperature: Temp; [3] J: Estimate

Table 3. Water Quality Index score calculated for parameters from 2007-2008 data on a scale of 1 (poor) to 100 (good). Blue represents good, yellow represents moderate and pink represents poor. Asterisks (*) note that WQI was not evaluated.

Water Year	Fecal Coliform Bacteria	Dissolved Oxygen	pH	Suspended Solids	Temperature	Total Persulfate Nitrogen	Total Phosphorus	Turbidity
2008	*	82	89	*	96	*	*	*
2007	48	87	95	90	90	1	66	83

3.2.6.4 Clark County Watershed Monitoring

Since 2001, Clark County Public Works, Clean Water Division has collected water quality, habitat, biological and flow data across 10 watersheds in Clark County as part of a long-term stream monitoring program. The purpose of this program is to understand stream conditions, determine long-term water quality trends, and locate problem areas.

As summarized in the 2010 *Stream Health Report*, Clark County collected monthly water quality and annual benthic macroinvertebrate data and determined scores using an Oregon Water Quality Index and a Benthic Index of Biotic Integrity (Clark County 2010). Clark County used these scores to judge conditions on a scale of poor, fair and good status for each watershed and subwatershed. For the Lacamas Creek Watershed, biological health ratings ranged from fair in

Upper Lacamas, Shanghai and Matney Creek to poor for Lower Lacamas and Upper Fifth Plain Creek. The long-term water quality site at Matney Creek was determined to have fair water quality conditions.

More recently, Clark County collected FC data in WY 2017 at sites on Lacamas Creek and selected tributaries (i.e. China Ditch, Fifth Plain Creek, Shanghai Creek and Matney Creek). The results show dry season exceedances at sites in the lower watershed (unpublished data, Clark County Clean Water Division). Similar to Ecology's 2010-11 data, the highest FC levels were found at China Ditch and Fifth Plain Creek. Additionally, preliminary analysis of recent Clark County FC data at the long-term Matney Creek site has shown annual geometric mean exceedances from WY 2017 to WY 2019. A future Stream Health Report by Clark County will summarize these data including new *E. coli* data. Clark County's recent data provides a useful guide for this source assessment by showing continued bacteria problems and identifying specific areas with high *E. coli* results.

3.2.6.5 Streamflow monitoring

Ecology established three short-term continuous stream gages from October 2010 to February 2012 at Fifth Plain Creek, Matney Creek, and China Ditch. Stage, flow, and temperature data were collected at each of the sites and are available as historic monitoring data on the Flow Monitoring Network webpage[9].

Clark County Public Works has historically maintained two streamflow gages at Lacamas Creek at Goodwin Road and Lacamas Creek at NE 217th Ave. Older data is available by request to cleanwater@clark.wa.gov.

3.2.6.6 Lacamas Lake eutrophication studies

In 1983, the Clark County Intergovernmental Resource Center (IRC) received a grant from Ecology to fund a Phase I Diagnostic and Restoration Analysis. The 1983-1984 Lacamas Lake Diagnostic and Restoration Analysis (Beak Consultants and Scientific Resources Incorporated 1985) measured phosphorous loading to the lake and estimated target loading levels. In WY 1984, the lake received 15,046 kg of total phosphorous: 95.6% from Lacamas Creek, 4.0% from Dwyer Creek, and 0.4% from precipitation. The study recommended reducing the lake's phosphorous external loading by 84% to reduce its eutrophic status.

As a response to this study, the County established a Lacamas Lake Restoration Program (LLRP) to promote agricultural best management practices (BMPs), provide public outreach and continue water quality monitoring in the lake and watershed. Ambient water quality monitoring was conducted throughout the 1990s and in WYs 2000-2001. Clark County Public Works, Water Resources Section published a report summarizing results from nutrient monitoring from a site on Lacamas Creek (i.e. Lacamas Creek on Goodwin Road) and in-lake monitoring during WYs 2000 and 2001 (Schnabel and Hutton 2004).

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[9] https://fortress.wa.gov/ecy/eap/flows/regions/state.asp

Clark County also discussed current lake conditions, assessed trends in nutrient loading from 1983 to 2001, and compared current conditions to original program goals.

The study found that phosphorus loading from Lacamas Creek and in-lake phosphorus concentrations decreased by approximately 50% between 1983 and 2001, yet this did not reach the program goal of an 84% reduction. The study also detected high phosphorus concentrations during summer baseflow, which suggests summer is a critical period for phosphorus loading regardless of the winter nutrient retention in the lake. Despite the decrease in phosphorus, nitrate levels may actually be increasing. As a potential side effect of eutrophication, the study also determined that there has been no measureable improvement in summertime hypolimnetic dissolved oxygen concentrations in Lacamas Lake since 1983. Overall, results suggest in-lake conditions have not improved and the lake remains eutrophic.

3.2.7 Parameters of interest and potential sources

3.2.7.1 Bacteria

Escherichia coli (*E. coli*) and FC are both forms of coliform bacteria that indicate the presence of fecal contamination from a warm-blooded animal. These types of bacteria have the potential to cause sickness and disease. A variety of bacteria sources exist in the Lacamas Creek Watershed, which include:

- Wildlife including mammals and waterfowl.
- Livestock with direct access to stream.
- Livestock manure applied to fields or leached from storage areas.
- Pet manure from parks and residential areas.
- Municipal and industrial wastewater and stormwater.
- Failing on-site septic systems.

3.2.7.2 Temperature

Temperature is a critical parameter that influences the physiology and behavior of fish and other aquatic life. Elevated temperatures indirectly affect aquatic life by reducing the solubility of dissolved oxygen in water and increasing the toxicity of pollutants (i.e. cyanides, phenols).

Stream temperatures experience seasonal and daily variations caused by natural factors including changes in flows, solar energy, and air temperature conditions. Human activities influence these natural changes, which include:

- Loss of riparian shade.
- Diminished groundwater inputs from water withdrawal.
- Point-source discharge from stormwater outfalls.
- Changes in channel morphology that either widens or narrows a stream channel and alters exposure of surface water to air temperature changes.

3.2.7.3 Dissolved Oxygen

Dissolved oxygen in water supports all forms of aquatic life and therefore is used as a measure to determine the health of freshwater systems. Dissolved oxygen influences growth rates, susceptibility to diseases, swimming ability, and ability to tolerate other environmental stressors.

Dissolved oxygen in surface water has both a seasonal and a daily cycle, which is influenced by aeration, photosynthesis, respiration and decomposition. Dissolved oxygen will also fluctuate with temperature and pressure changes. There are multiple factors that can reduce the amount of dissolved oxygen in water, which include:

- Decreased or stagnant flow.
- Increasing temperature, which decreases oxygen solubility in water and increases metabolic rates for process such as decay and respiration.
- Algal growth caused by excess nutrients and the resultant consumption of oxygen from respiration during the night and decay of the organic matter.
- Bacteria in water consuming oxygen as organic matter decays.
- Groundwater discharge, which often deliver lower dissolved oxygen inputs.

3.2.7.4 pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. pH affects the ability of fish and other aquatic organisms to regulate basic processes such as respiration and exchange of ions and salts. Failure to regulate these processes can result in sub-lethal effects (e.g. diminished growth rates) and even mortality. pH can also indirectly affect aquatic life by influencing the solubility and toxicity of chemicals and heavy metals in water.

Aquatic life may experience gradual deterioration as the pH values are further removed from the normal range defined by Washington State standards. The range of pH may be influenced by the following factors:

- Mining activities that can produce acidic runoff or acidic groundwater seepage.
- Point source discharges of acidic or basic substances to surface waters.
- Acid rain produced from the reaction of water with nitrogen oxides, sulfur oxides and other acidic compounds emitted from fossil fuel combustion.
- Changes in soil buffer characteristics from forest harvest.
- Algal and plant growth caused by excess nutrients which alters rates in photosynthesis, respiration and decomposition. These processes influence carbon dioxide concentrations and consequently affect pH conditions and range.

3.2.8 Regulatory criteria or standards

Washington State water quality standards listed under the Washington Administration Code (WAC) Chapter 173-201A are the basis for protecting and assessing the health of waterbodies. The purpose of these standards are to protect public health and recreation in state waters as well as protect fish, shellfish, and wildlife. Based on guidance of the Clean Water Act, the standards specify the designated beneficial uses for different waterbodies and assign numeric and narrative criteria based on those uses. The anti-degradation policy provides additional protections for waters that meet a higher quality than the limits set in the standards and are considered an outstanding resource.

The main beneficial uses protected under the water quality standards include:

- Aquatic Life Use for salmonid spawning, rearing, and migration.
- Primary Contact Recreation.
- Water Supply uses for domestic consumption, industrial production, and agriculture or hobby farm livestock.
- Miscellaneous Uses for wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics (WAC 173-201A-600).

Washington Administrative Code (WAC) 173-201A-600 also states that lakes and feeder streams to lakes that do not have individual use designations are protected for the designated uses of Core Summer Salmonid Habitat and Primary Contact Recreation. Since Lacamas Creek and the major tributaries are a major source of surface water to Lacamas and Round Lakes, this beneficial use protection extends across all areas the watershed above the Round Lake outlet. Table 4 includes the designated use classifications and water quality criteria for the different water quality parameters in Lacamas Creek.

As of December 2020, Chapter 173-201A WAC designates *E. coli* as the primary indicator to protect water contact recreation due to the strong correlation with illness from waterborne diseases. The state's new guidelines also require *E. coli* data to be evaluated within a consecutive 90-day period. Table 4 lists the updated contact recreation criteria for *E. coli.*

Table 4. Washington State freshwater use designations (WAC 173-201A-600) and criteria for specific parameters (WAC 173-201A-200).

Water Quality Parameter	Designated Use Classification	Criteria
Temperature	Core summer salmonid habitat, spawning, rearing, and migration	16°C 7-day average of the daily (DAD) maximum temperature[1]
Dissolved Oxygen	Core summer salmonid habitat, spawning, rearing, and migration	9.5 mg/L 1-Daily-Min[2]
pH	Core summer salmonid habitat, spawning, rearing, and migration	6.5-8.5 units[3]
Bacteria (*E.coli*)	Primary contact recreation	Geometric Mean should be less than 100 cfu/100 mL No more than 10% of samples, or any single sample when less than ten, should exceed 320 cfu/100 mL

[1]7-DAD Max represents the highest annual running 7-day average of daily maximum temperatures.
[2]1-Daily Min represents the lowest annual daily minimum oxygen concentration in the water body.
[3]For pH, a human-caused variation within the above range of less than 0.2 units is acceptable.

Table 5 shows the historical and current 2016 303(d) listings for impaired bodies per parameter. These listings do not include the data from the 2010-11 data collection. Updated 303(d) listings from the 2018 water quality assessment (WQA) are currently undergoing a public review, and finalization of the listings are anticipated for late 2021. Updates to water quality criteria may require potential changes to this assessment.

Table 5. Current 2016 303(d) listings in Lacamas Creek Watershed. These listings do not include the data from the 2010-11 data collection.

Waterbody	Parameter	Listing ID	Years Listed
Lacamas Creek	Fecal Coliform	7913	1998, 2004, 2008, 2012, 2014, 2016
Lacamas Creek	Dissolved Oxygen	7912, 7921, 7924	1998, 2004, 2008, 2012, 2014, 2016
Lacamas Creek	Temperature	7917, 7920, 7923	1998, 2004, 2008, 2012, 2014, 2016
Matney Creek	Fecal coliform	22016	1996, 2004, 2008, 2012, 2014, 2016
Matney Creek	Dissolved Oxygen	7929	1998, 2004, 2008, 2012, 2014, 2016
Matney Creek	pH	7928	1998, 2014
Matney Creek	Temperature	7930	1996, 1998, 2004, 2008, 2012, 2014, 2016
Fifth Plain Creek	Bacteria	7905	1996, 1998, 2014, 2016
Fifth Plain Creek	Dissolved Oxygen	7897, 7901, 7908	1998, 2004, 2008, 2012, 2014, 2016
Fifth Plain Creek	Temperate	7900, 7907	1996, 1998, 2004, 2008, 2012, 2014, 2016
Shanghai Creek	Dissolved Oxygen	7944	1996, 1998, 2014, 2016
Shanghai Creek	pH	7943	1996, 1998, 2014, 2016
Shanghai Creek	Temperature	7945	1996, 1998, 2004, 2008, 2012, 2014, 2016
China Ditch	Dissolved Oxygen	7862	1998, 2004, 2008, 2012, 2014, 2016
China Ditch	Temperature	7865	1996, 1998, 2004, 2008, 2012, 2014, 2016
China Ditch Lateral	Dissolved Oxygen	7868	1998, 2004, 2008, 2012, 2014, 2016
China Ditch Lateral	Temperature	7869	1998, 2004, 2008, 2012, 2014, 2016

Waterbody	Parameter	Listing ID	Years Listed
Dwyer Creek	Dissolved Oxygen	7894	1998, 2004, 2008, 2012, 2014, 2016

3.3 Water quality impairment studies

The Lacamas Creek Watershed study will be completed as a source assessment and Alternative Restoration Plan. Alternative Restoration Plans are increasingly important tools for water quality improvement. While TMDLs have proven to be complex and resource intensive, an alternative restoration design provides a near-term plan that is more immediately beneficial or practicable to water quality improvement. Alternative restoration studies are usually narrower in scope, and may not fully quantify the influence of point sources. This Alternative Restoration Plan will be implemented in advance of a TMDL, which may be necessary if water quality standards are still not met.

Additionally, a source assessment is used to identify and prioritize sources of pollutants, mainly from nonpoint sources. Source assessments are an appropriate option under circumstances which are listed below. The Lacamas Creek Watershed meets each of these criteria:

- The watershed is dominated by nonpoint sources.
- The watershed is primarily rural (less than 50% of the watershed area is developed).
- The point sources are dominated by municipal stormwater permittees.
- There is local community and governmental support for water cleanup efforts.
- There are local resources available to support implementation efforts from volunteer groups, organized local government programs and conservation districts.

The Environmental Protection Agency's (EPA) sets recommendations for the watershed planning process of an Alternative Restoration Plan. The EPA evaluates Ecology's Source Assessments and Alternative Restoration Plan and determines approval based on the completion of the following:

- Identification of specific water segments or waters bodies that do not meet water quality standards and identification of pollution sources.
- Analysis to support the use of the alternative restoration approach to meet water quality standards.
- An Implementation Plan to document the actions to address sources of pollution and a projected timeline for milestones and deliverables.
- Identification of available funding opportunities to implement the Alternative Restoration Plan.
- Identification of all entities involved in the implementation and additional parties needed.
- An estimated timeline for when water quality standards will be met.
- Plans for effectiveness monitoring to evaluate progress toward meeting water quality standards, including an adaptive management and evaluation process.

- Commitment to periodically evaluate whether the alternative restoration approach is immediately beneficial or practicable in achieving water quality standards compared to the TMDL approach.

Each of these components will be addressed for the Lacamas Creek Source Assessment and TMDL Alternative Restoration Plan.

4.0 Project Description

4.1 Project goals

The goals for this source assessment are as follows:

- Determine the areas in the Lacamas Creek Watershed (above Lake Lacamas) that do not meet water quality criteria for bacteria, dissolved oxygen, pH and temperature.
- Infer how bacteria levels have changed over time by comparing 2010-11 and 2021 FC results.
- Summarize 2010-2011 nutrient, DO, and pH data.
- Identify priority areas to enhance riparian shade to lower stream temperatures.
- Characterize potential sources of pollution based on a subbasin land use summary.

4.2 Project objectives

The goals for this source assessment are to complete the following objectives.

For bacteria:

- Collect *E. coli* and FC samples from June to October, 2021 at a network of sites (see Figure 4 and Table 13) to understand current bacteria conditions.
- Collect investigative bacteria samples to identify potential sources of pollution (see Section 7.2.1 for more details).
- Compare 2021 *E. coli* results to water quality criteria to determine compliance with water quality standards.
- Compare 2010-11 FC data to 2021 data to infer changes in FC levels and differences in sampling years.
- Complete a seasonality analysis for the 2010-11 data to determine differences in dry and wet season FC levels.

For dissolved oxygen, pH, temperature and nutrients:

- Identify stream segments that do not meet water quality criteria based on 2010-2011 dissolved oxygen, pH, and temperature data.
- Summarize 2010-2011 nutrient results (see Table 16 for list of nutrient parameters) and assess land cover patterns in GIS to connect site-specific nutrient levels with land use activities on a tributary and subwatershed level.
- Summarize more current data from Ecology's ambient monitoring station at Lacamas Creek at Goodwin Road (28I120) and compare with 2010-2011 data.
- Develop shade analysis to determine effective shade and system potential shade for Lacamas Creek using Shade model and determine areas with shade deficits.
- Collect photos at a network of sites (see Figure 4 and Table 13) in 2021 to provide existing riparian vegetation coverage information for the Shade model.

- Characterize stream temperatures through spatial analysis using GIS to show areas out of compliance with temperature standards and priority areas for restoration based on shade analysis.

A subbasin summary will be completed to compare bacteria, nutrients, temperature, and shade results with land use patterns and activities. Potential sources of pollution will be identified using geospatial data and GIS and synthesized on a subbasin scale for major tributaries and sections of Lacamas Creek.

4.3 Information needed and sources

The source assessment will rely on data collected by Ecology and local entities, particularly the original data collected in 2010-2011 for the Lacamas Creek TMDL. These data are available in Ecology's EIM database under Study ID TSWA0003. These data will be reviewed for quality and then used to complete the technical analysis of water quality conditions on a subwatershed and tributary level and determine how water quality has changed since the initial collection.

A data quality assessment will be completed for the 2010-11 water quality measurements and sample results based on available information before use in the study report. This involves reviewing electronic data files downloaded from instruments and documented pre- and post-QC instrument checks. These data will be compared to the acceptable ranges specified for each sensor by the manufacturer and to the acceptance criteria outlined in Table 12 in Section 6.3. The assessment will also involve a review of laboratory case narrative reports and QC results delivered by MEL (MEL 2016). Where available, field notes and other resources will be referenced to check for quality of field measurements and samples. Section 13.1 provides more details on the data quality assessment.

New water quality information will be collected from Ecology's 2021 sampling effort for FC and *E. coli* and from monthly ambient monitoring at Lacamas Creek at Goodwin Road (28I120) by Ecology's Freshwater Monitoring Unit (FMU). Updated information related to existing coverage and type of riparian vegetation will be collected by taking site photos during the 2021 fieldwork.

Frequent discussions with local jurisdictions and partners will continue throughout the fieldwork, source assessment and future development of the TMDL Alternative Restoration Plan. This will be essential for gathering more information about areas of concern (i.e. septic system status, stormwater maps) and sharing updates of ongoing monitoring efforts by Ecology, Clark County and other entities in the watershed.

Geospatial data will be obtained from sources such as Ecology, Clark County, City of Camas, USGS, and other entities for the land use analysis.

4.4 Tasks required

The tasks required to complete this study are outlined in Table 6 below.

Table 6. Outline of the tasks and the programs involved.

Category	Task	Lead
2021 QAPP	Write and publish QAPP	WQP/EAP
Bacteria (2021)	Field work	WQP
Bacteria (2021)	EIM	WQP
Bacteria (2021)	Data analysis	WQP
Data Quality Review	EIM QA	EAP
Data Quality Review	2010-2011 data quality assessment	EAP
Data Quality Review	2021 data quality assessment	WQP
Bacteria (2010-2011)	Data analysis	EAP
Dissolved Oxygen	Data summary and comparison with WQ criteria	EAP
Flow	Data summary	EAP
Nutrients	Data and land use summary	EAP
pH	Data summary and comparison with WQ criteria	EAP
Shade	Shade analysis	EAP
Temperature	Data summary and analysis	EAP
Land Use Summary	Assess land cover patterns in GIS to connect site-specific water quality results with land use activities on a tributary and subwatershed level.	EAP/WQP
Report	Source assessment report	EAP/WQP

4.5 Systematic planning process

This QAPP for the Lacamas Creek source assessment and the original Lacamas Creek TMDL QAPP serve as the basis for the planning process for this project (Swanson 2011).

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

The responsibilities of those who will be involved in this project are outlined in Table 7.

Table 7. Organization of project staff and responsibilities.

Staff[1]	Title	Responsibilities
Molly Gleason Water Quality Program SWRO Phone: 360-407-6296	Project Manager Field Lead	Clarifies scope of the project. Co-author of the QAPP. Oversees field sampling and transportation of samples to the laboratory. Assists with QA review of data, analysis and interpretation of data, and enters data in to EIM. Writes the draft report and final report.
Sheelagh McCarthy Modeling & TMDL Unit EAP Phone: 360-407-7395	Project Manager EAP Technical Lead	Co-author of the QAPP. Conducts QA review of data, analyzes and interprets data, and enters data into EIM. Writes the draft report and final report.
Lawrence Sullivan Water Quality Program SWRO Phone: 360-407-6389	Unit Supervisor for the WQP Project Manager	Provides internal review of the QAPP, approves the final QAPP, approves the budget, and tracks progress.
Andrew Kolosseus Water Quality Program SWRO Phone: 360-407-6271	Section Manager for the Project Manager	Reviews the project scope and budget, reviews the draft QAPP, approves the final QAPP, and tracks progress..
Cristiana Figueroa-Kaminsky Modeling & TMDL Unit EAP Phone: (360) 407-7392	Unit Supervisor for the EAP Project Manager	Reviews the project scope, tracks progress, reviews the draft QAPP, and approves the final QAPP. Reviews the draft and final reports. Provides technical guidance.
Daniel Dugger Eastern Operations Section EAP Phone: (509) 961-0539	EAP Reviewer	Reviews and approves the draft and final QAPP.
Jim Carroll Eastern Operations Section EAP Phone: 509-406-2459	EAP Reviewer	Reviews and approves the draft and final QAPP.
Alan Rue Manchester Environmental Laboratory Phone: 360-871-8801	Manchester Lab Director	Reviews and approves the final QAPP.
Arati Kaza EAP Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.

[1]EAP: Environmental Assessment Program;
WQP: Water Quality Program;
SWRO: Southwest Regional Office;
QAPP: Quality Assurance Project Plan; EIM: Environmental Information Management database

5.2 Special training and certifications

Field staff will be trained in sampling methods by becoming familiar with procedures and quality control practices outlined in the relevant Ecology standard operating procedures (SOPs), which are listed in Section 8.2.

Staff with experience in evaluating environmental data from past Ecology projects similar to this source assessment will lead the technical assessment of the results.

5.3 Organization chart

Table 7 in Section 5.1 outlines the individuals and organizations involved in this study.

5.4 Proposed project schedule

Tables 8 list key activities, due dates, and lead staff for this project.

Table 8. Project schedule for fieldwork, data management and report.

Task	Due date	Lead staff
Field work completed	October 2021	Molly Gleason
Laboratory analyses	November 2021	MEL Staff
EIM data loaded*	November 2021	Molly Gleason
EIM QA (2010-2011 and 2021 data)	November 2021	Molly Gleason and Sheelagh McCarthy
EIM complete	December 2021	Molly Gleason and Sheelagh McCarthy
Data Quality Assessment	October 2022	Molly Gleason and Sheelagh McCarthy
Technical Analysis (2010-2011 data)	October 2022	Sheelagh McCarthy
Technical Analysis (2021 data)	October 2022	Molly Gleason
Draft to supervisor	December 2022	Molly Gleason and Sheelagh McCarthy
Draft to client/ peer reviewer	December 2022	Molly Gleason and Sheelagh McCarthy
Draft to external reviewers	February 2023	Molly Gleason and Sheelagh McCarthy
Final draft to publications team	April 2023	Sheelagh McCarthy
Final report due on web	June 2023	Molly Gleason and Sheelagh McCarthy

*EIM Project ID: LacamasSA

EIM: Environmental Information Management database

5.5 Budget and funding

Ecology's Water Quality Program will provide the funds for the 2021 data collection. The main budget is for the analysis of *E. coli* and fecal samples by Manchester Environmental Lab (MEL). Table 9 shows the breakdown of the study budget and number of samples. Table 9 includes the number of samples routinely collected twice a month at sites listed in Table 13 and the estimated number of samples periodically collected at sites to investigate sources of pollution (see Section 7.2). These sites will be added throughout the sampling period on a need-to basis based on investigative results or observations where high levels of bacteria are found.

Table 9. Estimated laboratory budget details.

Parameter	Number of Samples	Number of QC Replicate Samples	Total Number of Samples	Cost Per Sample ($)	Lab Subtotal ($)
E. coli (MF[1]) + Fecal coliform (MF[1])	200	20	220	$42	$9240

[1]Membrane filter

6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness, completeness, and comparability. The definitions in this section and information in Tables 10-11 are from the Programmatic QAPP for Water Quality Impairment Studies (McCarthy and Mathieu 2017).

6.1 Data quality objectives

Data quality objectives (DQOs) establish acceptable quantitative criteria on the quality and quantity of the data to be collected, relative to the ultimate use of the data. These criteria are known as performance or acceptance criteria, or DQOs. DQOs represent the overarching quality objectives of the study, including that collected data meet measurement quality objectives (MQOs).

The main DQO for the 2021 data collection is to collect a minimum of 10 water samples for each routine site using established SOPs to meet the measurement quality objectives (MQOs) outlined in the following sections. The quality of the 2010-11 data will be assessed by comparing results to the MQOs listed below.

6.2 Measurement quality objectives

Measurement quality objectives (MQOs) are performance or acceptance criteria for individual data quality indicators, including precision, bias, sensitivity, completeness, comparability, and representativeness.

Field sampling procedures and laboratory analyses inherently have associated uncertainty, which results in data variability. Together precision and bias express data accuracy. MQOs apply equally to laboratory and field data collected by Ecology, to data collected by entities external to Ecology, and to other analysis methods used in water quality impairment studies (Lombard and Kirchmer 2004).

The MQOs for field procedures and laboratory analyses are shown in Tables 10-11 and described in the following sections. Data collected from 2010-2011 and the new bacteria data collected in 2021 will be assessed based on the MQOs in Tables 10-11.

Table 10. MQOs for lab procedures.

Parameter	Method Detection Limit (MDL)[a]	Method Blank Limit	Calibration Standards/ Blanks	Lab Control Samples (% Recovery Limits)	Matrix Spikes or SRMs (% Recovery Limits)	Precision-Field Duplicate (RSD)[b]	Precision-Laboratory Duplicate (RPD)	Estimated Range
Fecal coliform (MF)	1 cfu/100 mL	<MDL	NA	NA	NA	50% of replicate pairs < 20% RSD 90% of replicate pairs <50% RSD	40%	1 – 5000 cfu/100 mL
E. coil (MF)	1 cfu/100 mL	<MDL	NA	NA	NA	50% of replicate pairs < 20% RSD 90% of replicate pairs <50% RSD	40%	1 – 5000 cfu/100 mL
Dissolved Oxygen- Winkler	0.1 mg/L	NA	NA	NA	NA	+/- 0.2 mg/L	± 0.2 mg/L	0 – 15 mg/L
Alkalinity	5.0 mg/L	<MDL[c]	ICV/CCV: 90-110% ICB/CCB: <MDL	80 – 120%	NA	10%	20%	5.0 – > 100 mg/L
Chloride	0.1 mg/L	<MDL[c]	See above	90 - 110%	75 – 125%	5%	20%	0.1 – 250 mg/L
Ammonia	0.01 mg/L	<MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	0.01 – 20 mg/L
Dissolved Organic Carbon	1.0 mg/L	<MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	1.0 – 20 mg/L
Nitrate/Nitrite	0.01 mg/L	<1/2 RL[c]	See above	80 – 120%	75 – 125%	10%	20%	0.01 – 10 mg/L
Total Persulfate Nitrogen	0.025 mg/L	<MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	0.025 – 20 mg/L
Orthophosphate	0.003 mg/L	<MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	0.003 – 1 mg/L
Total Phosphorous	0.005 mg/L	<2.2x MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	0.005 – 10 mg/L
Total Organic Carbon	1.0 mg/L	<MDL[c]	See above	80 – 120%	75 – 125%	10%	20%	1.0 – 20 mg/L
Chlorophyll-*a*	0.05 ug/L	<1/2 RL[c]	NA	NA	NA	20%	20%	1.0 – 100 ug/L
Total Suspended Solids	1.0 mg/L	±0.3 mg/L[d]	NA	80 – 120%	NA	15%	5%	1.0 – 5000 mg/L

Parameter	Method Detection Limit (MDL)[a]	Method Blank Limit	Calibration Standards/ Blanks	Lab Control Samples (% Recovery Limits)	Matrix Spikes or SRMs (% Recovery Limits)	Precision-Field Duplicate (RSD)[b]	Precision-Laboratory Duplicate (RPD)	Estimated Range
Total Non-Volatile Suspended Solids	1.0 mg/L	±0.3 mg/L[d]	NA	80 – 120%	NA	15%	5%	1.0 – 5000 mg/L
Turbidity	1.0 NTU	<MDL	ICV/CCV: 90-110% ICB/CCB: <MDL	90 – 105%	NA	15%	20%	1.0 -100 NTU

MDL = method detection limit; NA = Not any; RL = Reporting Limit; CCB = Continuing Calibration Verification; CCB = Continuing Calibration Blank; ICV = Initial Calibration Verification; ICB = Initial Calibration Blank

[a] Reporting limit may vary depending on dilutions. MDL listed in the table represents lowest possible RL

[b] Field duplicate results with a mean of less than or equal to 5x the reporting limit will be evaluated separately.

[c] Or less than 10% of the lowest sample concentration for all samples in the batch (i.e. 20 samples or fewer)

[d] Filter blank

Table 11. MQOs for field measurements and equipment information.

Parameter	Equipment Type and Method	Precision-Field Duplicates	Bias	Equipment Accuracy	Equipment Resolution	Equipment Range	Estimated Range
Stream Velocity	Marsh McBirney Flo-Mate Model 2000	10%	±0.05 ft/s	0.01 ft/s	0.01 ft/s	-0.5 to +20 ft/s	0.01 – 10 ft/s
Water Temperature	Hydrolab MiniSonde®	+/- 0.2° C	See Table 12	0.01° C	0.01° C	-5 - 50°C	0 – 30° C
Specific Conductivity	Hydrolab MiniSonde®	5% RSD	See Table 12	± 0.5% + 1 uS/cm	1 uS/cm	0 - 100,000 uS/cm	20 – 1000 umhos/cm
pH	Hydrolab MiniSonde®	+/- 0.2 s.u.	See Table 12	+/- 0.2 s.u.	0.01 s.u.	0 - 14 s.u.	6 - 10 s.u.
Dissolved Oxygen	Hydrolab MiniSonde®	5% RSD	See Table 12	± 0.1 mg/L; at <8 mg/L; ± 0.2 mg/L; at 8 to <20 mg/L[a]	0.01 mg/L	0 - 60 mg/L	0.1 – 15 mg/L
Continuous Water Temperature	Hobo Water Temp Pro v2	NA	NA	±0.21°C at 0° to 50°C	NA	0 - 50°C	0 - 30°C

s.u. = standard units

a accuracy is diminished outside of listed range

6.2.1 Targets for precision, bias, and sensitivity

6.2.1.1 Precision

Precision is a measure of variability among replicate measurements due to random error. Potential sources of random error include natural temporal and spatial variability of stream conditions during sampling or variability introduced by field or lab procedures. Precision will be assessed by collecting replicate field samples and analyzing replicate lab samples (Table 10). The number of replicates for the corresponding parameter is listed in Table 16.

6.2.1.2 Bias

Bias is the difference between a sample mean and the true value. Bias in field sampling procedures will be reduced by following the relevant Ecology SOPs as described in Section 8.2. Bias in laboratory procedures will be addressed by analyzing blanks, matrix spikes and standard reference materials. MQOs for laboratory QC samples are in Table 10.

For the 2011 field collection, bias for field measurements was addressed by performing pre-check measurements, pre-calibrations, and post-check measurements to a known standard or NIST certified instrument (i.e. NIST certified thermistor). Table 12 presents the data quality objectives for multi-parameter sonde data for instrument QC checks. First, the sonde measurement data are reviewed, adjusted (if applicable), and finalized. The median residual of the finalized data and QC checks is then calculated and compared to the MQOs listed in Table 12.

Table 12. Acceptance criteria for instrument calibrations and post-checks.

Parameter	Unit	Accept	Qualify	Reject
Dissolved Oxygen	% saturation	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%
Dissolved Oxygen	mg/L	≤ ± 0.5	> ± 0.5 and ≤ ± 1.0	> ± 1.0
pH	standard unit	≤ ± 0.2	> ± 0.2 and ≤ ± 0.8	> ± 0.8
Specific Conductivity	uS/cm	≤ ± 10%	> ± 10% and ≤ ± 20%	> ± 20%
Water Temperature	°C	≤ ± 0.2	> ± 0.2 and ≤ ± 0.8	> ± 0.8
Turbidity	NTU	≤ ± 10%	> ± 10% and ≤ ± 20%	> ± 20%

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. Method detection limit (MDL)[10] is often used to describe sensitivity. Table 10 lists targets for acceptable sensitivity of all lab measurements.

For field measurements, the sensitivity of the instrument is described by its range, accuracy, and resolution. This is usually reported for each instrument by the manufacturer. Examples of this information are provided in Table 11.

For laboratory data in a regulatory context, the method detection limit (MDL) is usually used to describe sensitivity. The method reporting limit (MRL) is usually a little higher than the MDL and can also be used. The MRL for each laboratory method is reported in Table 10, and MDLs are presented in Section 9.1 (Table 15).

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

Ecology's SOPs will be strictly followed to ensure consistency in methods throughout the study and comparability of results between the initial and 2021 data collection efforts. FC samples will be analyzed by MEL using the same laboratory method, Membrane Filtration (MF), to compare 2021 FC data to past FC data.

Factors that influence comparability between studies can include the availability and extent of previous data, training of field staff, field data-collection similarities including site locations, duration, time of year and weather conditions, lab methods, SOPs, and sensitivity.

6.2.2.2 Representativeness

Representativeness is mainly a function of individual study design. Each study is designed to collect sufficient data, meet study-specific objectives, and assess spatial and temporal variability of the measured parameters throughout the study area. Sampling locations and frequency are distributed throughout the watershed or water body in a manner designed to meet study objectives. Typically, a combination of continuous measurements, grab samples, spot measurements, and historic data will be needed to represent the expected variability of spatial and temporal conditions. These elements that influence data quality are addressed in greater detail in Study Design (Section 7.0).

This study's site locations, sampling frequency, and number of samples were designed to ensure the collection of data that will meet the study objectives by being representative of the entirety of Lacamas Creek and its major tributaries. This bacteria sampling plan will be representative of the 2010-2011 field collection by sampling the same sites.

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[10] The lowest quantity of a physical or chemical parameter that is detectable (above background noise) by each field instrument or laboratory method.

Bacteria samples will be collected June to October 2021 to capture dry season conditions. A routine sampling schedule with an outlined site visit route will be followed. This ensures that sites will be visited typically at the same time of day. Based on the SOPs used for this study, samples will only be collected at well-mixed locations with sufficient flow (i.e. more than 0.1 ft/s) in order to collect the most representative sample.

Observations related to environmental conditions, weather and other conditions that may affect the quality of the data will be documented to evaluate the representativeness of the sample.

6.2.2.3 Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system to meet project objectives (Lombard and Kirchmer 2004). The goal for the study is to collect and analyze 100% of the samples for each project. However, problems occasionally arise during sample collection, such as site access problems, equipment malfunction, or sample container shortages, that cannot be controlled; thus, a completeness of 95% is acceptable for sampling and discrete measurements. If equipment fails or samples are damaged, Ecology will attempt to recollect the data under similar conditions, such as the following day, if possible. In general, each project should be designed to accommodate some data loss and still meet project goals and objectives. Challenges that might limit the completeness of this work are described in Section 7.5.

If completeness targets are not achieved, then a determination will be made as to whether the data that were successfully collected are sufficient to meet project needs. This will depend on a number of factors, such as the needs of the modeling/analysis framework, and the times and locations where data were lost. If successfully collected data are not sufficient, then one or a combination of the following approaches will be used:

- Estimate missing data values from existing data, if this can be done with reasonable confidence.
- Conduct targeted additional sampling to fill data gaps.
- Re-collect all or a portion of the data.

If completeness targets are not met, the study report will analyze the effect of the incomplete data on meeting the study objectives, account for data completeness (or incompleteness) in any data analyses, and document data completeness and its consequences in any study reports.

Investigative samples may not meet the minimum requirements for statistical or other data analysis, but will still be useful for source location identification, recommendations, or other analyses.

6.3 Acceptance criteria for quality of existing data

This study involves the technical analysis of existing data collected by Ecology in 2010–2011. An original QAPP was written for the initial data collection which outlined the MQOs and quality control procedures necessary to meet the original TMDL study objectives (Swanson 2011).

A data quality assessment will be completed for 2010-11 water quality measurements and sample results based on available information before use in the technical analysis for this study. These data will be assessed following procedures outlined in this QAPP, the original 2011 QAPP (Swanson), and EIM data quality review procedures. This involves comparing pre- and post-QC instrument checks to the acceptable ranges specified for each sensor by the manufacturer and to the acceptance criteria outlined in Table 11 in Section 6.2. The assessment will also involve a review of laboratory case narrative reports and QC results delivered by MEL (MEL 2016). Where available, field notes and other resources will be referenced to check for quality of field measurements and samples. Section 13.1 provides more details on the data quality assessment.

The quality of ambient monitoring data will be assessed by the FMU group based on criteria outlined in the River and Stream Ambient Water Quality Monitoring QAPP (Von Prause 2021).

Data that are not able to be reviewed for quality due to missing information will not be used in the technical analysis but may be summarized in a qualitative sense. The data quality review will be included in the source assessment report.

7.0 Study Design

The study design for the Lacamas Creek Source Assessment involves a quality assurance and technical analysis of data previously collected in 2010-11, which includes FC and nutrient results and temperature, dissolved oxygen, and pH measurements. These data will be used to complete the technical analysis of water quality conditions on a subwatershed and tributary level.

During the summer of 2021, Ecology will conduct bacteria sampling at a network of locations across the watershed to provide current FC and *E. coli* data. The FC data will be used to compare to past data to infer how levels have changed over time, and the *E. coli* data will be used to identify stream segments that are currently out of compliance with updated water quality criteria. The data collected from both fixed sites (see Figure 4 and Table 13) and investigative sites will be used to identify potential sources of pollution and identify areas to prioritize future implementation efforts.

In addition to bacteria sampling, information related to the riparian vegetation type and coverage will be collected during the 2021 fieldwork. Photos will be taken at the fixed sites (see Figure 4 and Table 13) and at a few reference reaches to collect updated information for the Shade model.

7.1 Study boundaries

The Lacamas Creek Watershed is located within Watershed Resource Inventory Area (WRIA) 28 in Southwest Washington in Clark County. The study boundary encompasses the Lacamas Creek Watershed, which includes Lacamas Creek and five major tributaries (i.e. Matney Creek, Shanghai Creek, Fifth Plain Creek, China Ditch, and Dwyer Creek). The study area ends at the confluence of Lacamas Creek and Lacamas Lake.

Section 3.1 provides more details about the watershed and map of the study area and watershed boundary (see Figure 1).

7.2 Field data collection

Ecology will collect *E. coli* and FC samples at a network of sites. These new data will be used to confirm problem areas identified in the 2010-11 field study and potentially investigate new sources. The new FC data will also be used to determine how FC levels have changed since the initial monitoring effort. Other water quality parameters and flow will not be collected for the 2021 monitoring due to resource and time limitations.

More details on the study design for the original 2010-11 field data collection are detailed in the original QAPP (Swanson 2011).

7.2.1 Sampling locations and frequency

Ecology will conduct routine sampling for *E. coli* and FC twice a month at 19 sites (see Figure 4 and Table 13). These sites are locations previously monitored by Ecology in 2010-11. Most of the sites are located in the public right away. Staff have acquired permissions to access sites that are on private property (e.g. Dwyer Creek at Camas Meadows Golf Course) and natural reserve areas (e.g. Spring Ditch on Lacamas Prairie Natural Reserve owned by Department of Natural Resources).

Sampling at investigative sites may periodically occur to investigate potential areas of concern and sources of pollution. These sites will be added temporarily throughout the sampling period based on results (i.e. bacteria concentrations exceeding water quality criteria) or observations of noticeable potential sources of pollutions (e.g. livestock in waterways, outfalls, etc.). Investigative sites will be used to bracket and identify potential sources of bacteria pollution (e.g., malfunctioning on-site systems, livestock, wildlife, manure spreading, etc.). Investigative samples may be collected at sites not previously included in the this QAPP in order to explore an area of concern.

Sampling will occur twice a month to capture dry season conditions from June to October. This time period was selected, since the preliminary analysis showed greater FC exceedances during the summer and early fall months. The tentative sampling days are as follows:

- June 16, 28.
- July 12, 26.
- August 9, 23.
- September 8, 20.
- October 11, 25.

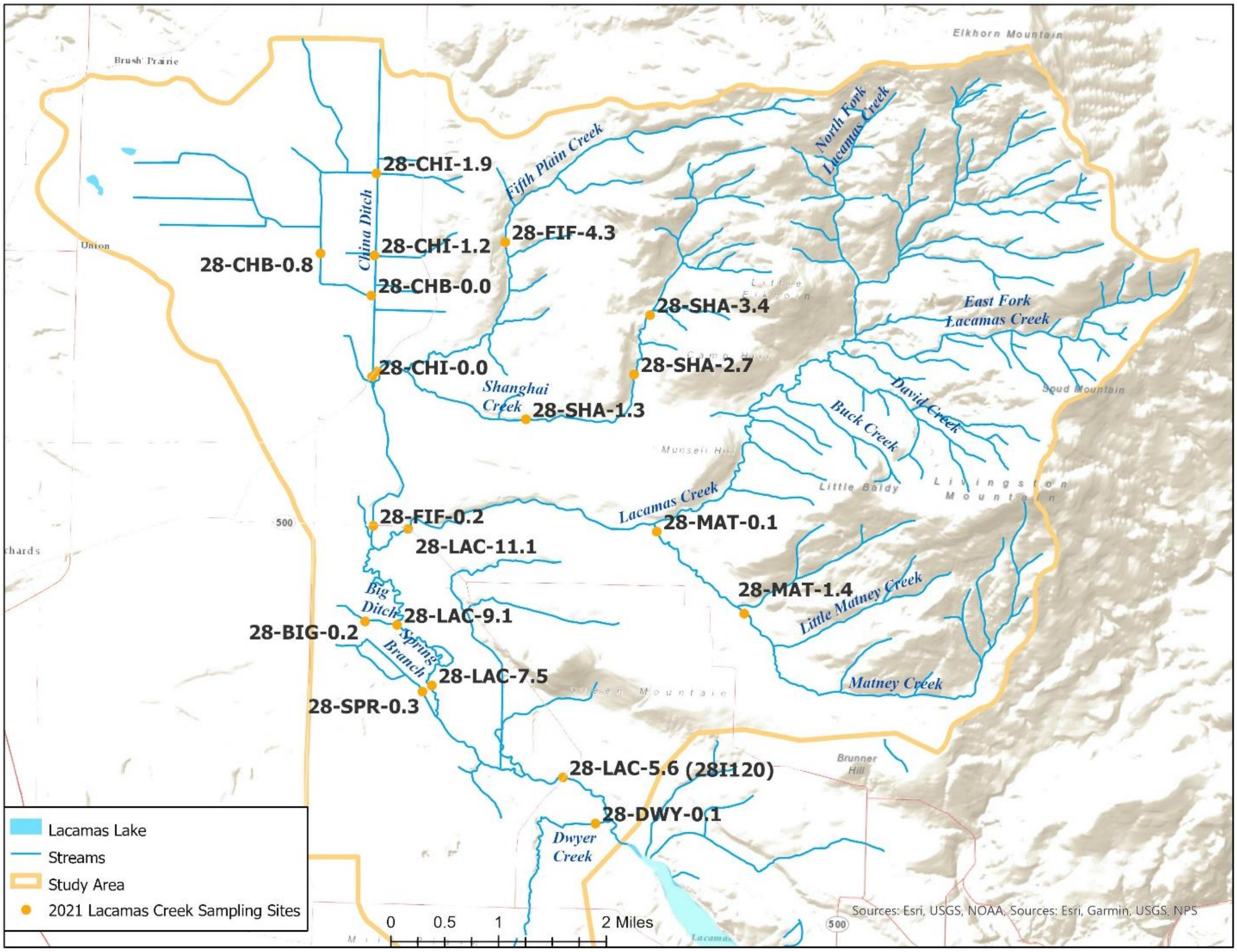

Figure 4. 2021 sampling sites.

Table 13. Sampling sites for 2021 bacteria monitoring.

Site	Waterbody	Latitude	Longitude	Description
28-FIF-0.2	Fifth Plain Creek	45.67198	-122.49457	5th Plain Creek at 4th Plain Rd NE (SR 500). Most downstream Fifth Creek location.
28-CHI-0.0	China Ditch	45.69203	-122.49551	China Ditch at NE Ward Rd and 172nd Ave intersection.
28-FIF-1.9	Fifth Plain Creek	45.6928	-122.49449	5th Plain Creek at NE Ward Rd and 172nd Ave intersection.
28-CHB-0.0	China Ditch	45.70299	-122.49603	China Ditch tributary at Hokinson Meadows Park.
28-CHI-1.2	China Ditch	45.70839	-122.4956	China Ditch at intersection of NE 172nd Ave and NE 119th St.
28-CHB-0.8	China Ditch	45.70848	-122.50595	China Ditch tributary at NE corner of Hokinson Meadows Park.
28-CHI-1.9	China Ditch	45.71945	-122.49564	China Ditch north of 131st St on NE 172nd Ave.
28-FIF-4.3	Fifth Plain Creek	45.71064	-122.47061	5th Plain Creek at Sliderberg Rd and 122nd Circle.
28-SHA-1.3	Shanghai Creek	45.68683	-122.46579	Shanghai Creek at NE 202nd Ave.
28-SHA-2.7	Shanghai Creek	45.69327	-122.4452	Shanghai Creek at NE 222nd Ave.
28-DWY-0.1	Dwyer Creek	45.63267	-122.45051	Dwyer Creek at golf course maintenance shop.
28-LAC-5.6 (28I120)	Lacamas Creek	45.63878	-122.45697	Lacamas Creek at Goodwin Rd. Ambient Monitoring Station 28B120
28-LAC-7.5	Lacamas Creek	45.65071	-122.4825	Lacamas Creek upstream of Spring Branch off 182nd and 38th.
28-SPR-0.3	Spring Ditch	45.64985	-122.48429	Spring Branch Creek near 182nd Ave and 38th Way.
28-BIG-0.2	Big Ditch	45.65913	-122.49566	Big Ditch near Lacamas Ck.
28-LAC-9.1	Lacamas Creek	45.65872	-122.4895	Lacamas Creek near Big Ditch.
28-LAC-11.1	Lacamas Creek	45.6717	-122.48783	Lacamas Creek at 4th Plain Rd NE (SR 500).
28-MAT-0.1	Matney Creek	45.67218	-122.4401	Matney Creek at NE 68th St.
28-MAT-1.4	Matney Creek	45.66142	-122.42297	Matney Creek at NE 53rd St.

7.2.2 Field parameters and laboratory analytes to be measured

E. coli and FC samples will be collected in the field and analyzed at MEL.

7.3 Modeling and analysis design

A basic summary of results will be presented for the 2010-11 and 2021 bacteria, dissolved oxygen, pH, temperature, and nutrient data. For sites with data from both sampling periods, a comparison of 2010-11 to 2020-21 data will be completed to infer changes over time. The evaluation of bacteria and nutrient data will also involve a land use summary to connect the data to land use and land cover patterns on a tributary and subwatershed level.

The analysis of the bacteria, dissolved oxygen, temperature and pH data will involve a comparison to water quality standards for all sites in Lacamas Creek and its tributaries. These regulatory standards are listed in Section 3.2.4. For parameters that do not have a set standard such as nutrients, the data analysis will involve a basic summary of results.

Stream temperatures will be characterized through spatial analysis using GIS to show areas that are out of compliance with temperature standards. Additionally, a shade analysis will be developed to determine effective shade and system potential shade for Lacamas Creek using Shade model and to determine areas with shade deficits.

The assessment of bacteria data requires additional analysis methods. A basic summary of bacteria levels will be done for both 2010-11 and 2021 datasets including an assessment of how FC levels have changed over time. The 2021 *E. coli* data will be used to calculate summary statistics to compare to current bacteria standards. A seasonality analysis and simple loading analysis will be completed for the 2010-11 FC data. The analysis methods are described in the following sections.

This study includes a shade analysis to determine effective shade, potential shade, and shade deficits (the difference between effective and potential shade) along the mainstem of Lacamas Creek, based on the data collection from 2010-11 and site photos from 2021. The models used for the shade analysis include Ecology's TTools and Shade model.

7.3.1.1 Compliance to bacteria standards

Compliance with bacteria standards will be determined using *E. coli* as the primary indicator and the updated recreational use criteria detailed in Table 4 in Section 3.2.8. The updated criteria no longer use FC as the main indicator for freshwater bodies that do not impact shellfish growing areas. Thus, only the recently collected 2021 *E. coli* data will be used to identify areas out of compliance with current bacteria standards.

Compliance to bacteria standards is evaluated based on meeting two numeric criteria, a geometric mean and an upper limit value that 10% of the samples cannot exceed. The upper limit statistic (i.e., not more than 10% of the samples shall exceed) has been interpreted to be comparable to the 90th percentile value of the log-normalized values (Cusimano and Giglio 1995; Fields 2016; Lee 2008; McCarthy 2018; Mathieu 2011). The geometric mean and 10% exceedance criteria will be calculated for the 2021 *E. coli* data and compared to the recreational use criteria outlined in Table 4. These statistics will be calculated for each site for every three-consecutive-month period (i.e. June-August, July-September, and August-October).

7.3.1.2 Bacteria seasonality analysis

A seasonality analysis will be completed for the 2010-11 FC data. Since the 2010-11 dataset covers a full year, a basic summary and comparison of the dry and wet season results will be completed to determine seasonal differences in FC levels. We will define the dry and wet seasons based on historical precipitation data and compare it with monthly precipitation during sampling in 2010-11. Additionally, we will summarize daily rainfall accumulation for each sampling event and throughout the study period.

Since the 2021 dataset only covers typical dry season conditions (i.e. June to October), only the dry season will be evaluated for the 2021 *E. coli* and FC data. We will compare monthly precipitation totals in 2021 with rainfall patterns in 2010-11 as part of the FC seasonality analysis.

7.3.1.3 Simple bacteria loading analysis

A simple loading analysis will be completed to compare the relative contribution of stream sources and locations of FC loads for the 2010-2011 data. The loading analysis provides a perspective of loading patterns across a watershed and identifies critical areas with bacteria pollution issues. A loading analysis will be performed for both wet and dry seasons to illustrate seasonal loading differences. A separate loading analysis will be done for storm events.

The definition of a load is the amount or concentration of a substance that passes a particular point of a stream in a specified amount of time (Meals et al. 2013). A FC load is calculated by multiplying FC concentrations by streamflow and a conversion factor to estimate the number of colony forming units per day. FC loads will be estimated using the 2010-11 FC concentration and streamflow data. A loading analysis will not be done for the 2021 bacteria data, since streamflow was not included in the monitoring design due to resource and time limitations.

7.3.1 Analytical framework

The following sections describe the analytical framework for developing a shade model for Lacamas Creek based on the descriptions from the Programmatic QAPP for Water Quality Impairment Studies (McCarthy and Mathieu 2017).

7.3.1.1 TTools for ArcGIS

TTools will be used to estimate effective shade inputs for use in shade modeling. TTools is an ArcView extension developed by the Oregon Department of Environmental Quality (ODEQ) and adapted by Ecology (Ecology 2015). Ecology currently maintains an updated, python-scripted ArcGIS version of the tool.

TTools is used to develop GIS-based data from acquired polygon and grids coverages. It specifically uses these coverages to develop vegetation and topography data perpendicular to the stream channel and longitudinal stream-channel characteristics, such as the near-stream disturbance zone and elevation. Typical inputs into TTools are LiDAR data, digital elevation models (DEMs), and aerial imagery (digital orthophoto quadrangles and rectified aerial photos). Stream width, aspect, topographic shade angles, elevation, and riparian vegetation are sampled with TTools for incorporation into the Shade model. The riparian vegetation coverage will contain four specific attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density of the riparian vegetation.

More details about TTools and other computer models used by Ecology are located on the Ecology's Models and Tools for TMDLs webpage[11].

7.3.1.2 Shade Model

Ecology's Shade model is a tool for estimating shade from riparian vegetation (Ecology 2003). Shade was adapted from a program that ODEQ developed as part of Version 6 of its HeatSource model. The model will be used to evaluate solar radiation and effective shade along Lacamas Creek.

Shade calculates effective shade using either the (1) Chen method (Chen 1996; Chen et al. 1998) or (2) the original method by ODEQ from the HeatSource model version 6 (Boyd 1996; Boyd and Kasper 2003).

The Shade model quantifies the potential daily solar load and generates the percent effective shade. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because vegetative cover and topography intercept it. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics, such as height, width, overhang, and density.

The Shade model requires physical and vegetation parameters such as stream width, aspect, topographic shade angles, elevation, and riparian vegetation that will be determined using the TTools GIS extension. Most data inputs for the Shade model are easily available through aerial imagery and digital elevation models. Additional field data are collected to characterize riparian shade (to compare observed shade to model-predicted shade) and vegetation. The TTools output is used as input for the Shade model to generate longitudinal effective shade profiles. Riparian vegetation, stream aspect, topographic shade angles, and latitude/longitude will be used to estimate effective shade. Reach-averaged, integrated, hourly effective shade (i.e., the fraction of potential solar radiation blocked by topography and vegetation) is used as input into the QUAL2Kw model.

More details of the ODEQ HeatSource model are documented on the ODEQ's TMDL Tools webpage[12].

[11] https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs

[12] https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Tools.aspx#:~:text=Heat%20Source%20is%20a%20computer,Source%20methodology%20and%20computer%20programming.

7.3.2 Model setup and data needs

Ttools requires the following data to run to sample vegetation along the stream:

- Single-part or single segment polyline representing a stream centerline.
- Digitized stream bank layers, either bank polyline layers representing the right and left bank delineation or stream bank polygons representing both left and right banks of the stream using aerial imagery.
- 10-meter digital elevation model file to obtain elevation values.
- Vegetation layers used for sampling vegetation.

The Lacamas Creek stream centerline will be created using the National Hydrography Dataset (NHD) flowlines and compared with aerial imagery of the creek. The digitized stream bank layers will be created in GIS using aerial imagery and information from site-visits and channel surveys. The 10-meter digital elevation model file for elevation will be obtained from Ecology's GIS database. The riparian vegetation coverage layer will contain four specific attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density of the riparian vegetation. Riparian vegetation polygons will be created in GIS along the riparian buffer for the distinct groups of vegetation. Riparian vegetation attributes will be determined using a combination of aerial imagery in GIS, bare earth data file (no tree height or structures), and information including field photographs of vegetation collected during site visits in 2010-11 and 2021.

The shade model requires physical and vegetation parameters to estimate effective and potential shade. Ttools output will be used as input for the Shade model to generate longitudinal effective shade profiles. Riparian vegetation, stream aspect, topographic shade angles, and latitude/longitude will be used to estimate effective shade. The shade model uses the following parameters as model inputs based on various data collection methods:

- Stream bankfull and wetted widths determined from a combination of channel survey measurements from GIS digitization from aerial imagery and site visits.
- Riparian information including vegetation type, height, and aerial density based on GIS digitization from aerial imagery and information from site visits.
- Topographic shade, stream elevation, and stream aspect calculated using GIS with Ttools and a 10-meter digital elevation model file.

Field data including hemispherical photographs were collected to characterize riparian shade (to compare observed shade to model-predicted shade) and vegetation.

System potential shade also be estimated using the shade model. System-potential effective shade is the natural maximum level of shade that a given stream is capable of attaining with the growth of system-potential mature riparian vegetation. System-potential mature riparian vegetation refers to the vegetation that can grow and reach a climax succession (in 100 years) at a site without human disturbance, based on climate, elevation, soil properties, plant biology, and hydrologic processes.

7.4 Assumptions underlying design

The study design assumes the following:

- Collected samples will be representative of site conditions at that time and will be sufficient to meet the study objectives.
- Collection of samples and replicates will characterize the variability in parameter concentrations and will meet the study's measurement quality objectives.
- Bacteria concentrations will be consistent enough to trace and identify sources.
- 2010-11 water quality data will be sufficient for the technical analysis. This data will be verified by completing a quality assurance check and comparison to MQOs listed in Section 6.2 (see Section 13.1 for data verification details).
- Ecology's 2010-11 water quality data are relevant to the current status of the subwatersheds.
- Changes in FC level changes from 2010-11 to 2021 can be inferred while considering potential differences in sampling year conditions (i.e. drought conditions) and land use changes.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Logistical issues may interfere with fieldwork and sample collection. These issues include:

- Limited access to sites located on private property. For sites that require permissions for access, permissions will be acquired before the planned sampling.
- Limited time to complete sampling at the fixed and investigative sites. As a contingency plan, the site visit schedule was arranged to ensure the shortest driving route for multiple site visits during the sampling day.
- Low-flow, stagnant or dry conditions prevent sampling during the dry season. Based on the SOPs used for this study, samples will only be collected at well-mixed locations with sufficient flow to collect the most representative sample. A majority of sites previously monitored by Ecology in 2010-11 were flowing year round.
- Sample delivery to MEL may be delayed due to unplanned circumstances (i.e. lab shutdown, transport delays, etc.), and samples may not be processed within the appropriate holding time.

Logistical issues that affect data collection or data quality during this study will be documented and discussed in the final report.

7.5.2 Practical constraints

Practical constraints may arise during this study, which includes availability of adequate resources, both human and budgetary, from EAP and WQP. Practical constraints that affect this study will be discussed with the appropriate supervisor and discussed in the final report.

7.5.3 Schedule limitations

Schedule limitations may affect the timely completion of this study. These limitations include:

- Delayed review and approval for this QAPP.
- Need for additional data collection or more time for technical analysis work.
- Changes in schedule due to limited resources, both human and budgetary, from EAP and WQP.
- Changes in schedule in response to external circumstances (i.e. inclement weather, pandemic).

8.0 Field Procedures

8.1 Invasive species evaluation

Field staff will follow EAP's SOP EAP070 (Parsons et al. 2021) to minimize the spread of invasive species. At the end of each field visit, field staff will clean field gear in accordance with the SOP. Areas of extreme concern have established aquatic invasive species, such as New Zealand mud snails, that are difficult to remove from equipment and are considered an environmental or economic threat. Information on the areas of extreme concern are available on the Ecology's GIS website[13].

8.2 Measurement and sampling procedures

Field staff will follow field sampling protocols to ensure the quality of samples. Protocols are outlined in SOP EAP034 (Ward 2019) and EAP030 (Ward 2018). Field staff will collect grab samples directly into pre-cleaned/sterilized containers supplied by MEL. Relevant technical notes related to sampling conditions will be documented and maintained in a field notebook. Field staff will store samples for laboratory analysis on ice and deliver to MEL within the associated holding time via an Ecology courier. MEL will process all samples for this study and will follow standard analytical methods outlined in the lab user manual (MEL 2016).

8.3 Containers, preservation methods, holding times

Table 14 describes the appropriate containers, preservation techniques, and holding times as outlined in the Manchester Lab User Manual (MEL 2016).

Table 14. Sample containers, preservation, and holding times.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
Fecal coliform (MF) + *E. coli* (MF)	Water	250 mL	250 mL clear w/m poly autoclaved bottle	Fill the bottle to the shoulder; Cool to ≤4°C	24 hours

8.4 Equipment decontamination

Staff will follow all recommended protocols for cleaning and decontaminating sampling equipment. Established Ecology procedures will be followed if an unexpected contamination incident occurs.

[13] https://ecology.wa.gov/Research-Data/Data-resources/Geographic-Information-Systems-GIS/Data#e

8.5 Sample ID

MEL will provide the field lead with work order numbers for each scheduled sampling event. The work order number will be combined with a field ID number assigned by the field lead. This combination of work order number and field ID number represents the sample ID. Sample ID numbers will follow the standard convention established by MEL: YYMMWWW-SS, where YY is the two digit year, MM is the two digit month, WWW is the three digit work order identifier assigned by MEL, and SS is the sample ID number within the work order. All sample IDs will be recorded in field logs, chain of custody forms and in an electronic spreadsheet for tracking purposes.

8.6 Chain of custody

Maintaining a chain of custody procedure and form throughout the collection and delivery of samples will be done for this study. This will ensure samples are accounted for throughout the sampling process.

Samples will be stored in coolers on ice in the field vehicle, which will be locked when field staff are not present. Field staff will deliver the samples to a secure walk-in cooler located at Ecology's headquarters or field operation center. The field lead will fill out a chain of custody form at the time of delivery to the walk-in cooler. This form will detail the number of samples, sample ID, work order number, name of sampler, date and time of sampling, and time of sample delivery to the walk-in cooler.

An MEL courier will pick up the samples and the chain of custody form the following morning. Once at MEL, samples will be inspected, verified and recorded in the lab's electronic tracking system.

8.7 Field log requirements

Field staff will document the progress of sampling events in a field log. The field log will contain information such as:

- Name and location of project.
- Field staff involved in sampling.
- Sequence of events.
- Any changes or deviations from the QAPP.
- Date, time, location, ID, and description of each sample.
- Identity of QC samples collected.
- Environmental conditions.
- Unusual circumstances that might affect interpretation of results.

8.8 Other activities

Additional field activities may include:

- Briefings and trainings for field staff assisting the field lead with sampling.
- Potential field collaboration with external partners who may be included in site visits or side-by-side sampling.

- Continued communication with the MEL to notify of schedule changes and sampling logistics.

9.0 Laboratory Procedures

9.1 Lab procedures table

Table 15 presents the lab procedures and methods for each parameter that will be analyzed for the 2021 sampling.

Table 15. Measurement methods (laboratory).

Analyte	Sample Matrix	Expected # of Samples	Expected Range of Results	Detection or Reporting Limit	Analytical (Instrumental) Method
Fecal coliform (MF)	Water	220	1-30,000 cfu/100mL	1 cfu/100mL	SM9222 D
E. coli (MF)	Water	220	1-30,000 cfu/100mL	1 cfu/100mL	SM9222 G

9.2 Sample preparation method(s)

E. coli and FC samples will be preserved on ice and held in a cooler until delivery to MEL for analysis.

9.3 Special method requirements

There are no special method requirements necessary for the analytes outlined in Table 15.

9.4 Laboratories accredited for methods

MEL will be responsible for the analysis of the samples for this study. MEL is accredited for the specific methods outlined in Table 15.

10.0 Quality Control Procedures

Quality control procedures will be implemented for each step of this study including data collection, data analysis and modeling. The purpose is to assess the quality of the data that are collected and identify potential issues throughout the study implementation.

Precision for field procedures will be assessed by collecting replicate samples. Additionally, all staff involved with sampling will be trained in procedures outlined in the relevant Ecology SOPs as described in Section 5.2.

Laboratory procedures will be evaluated for accuracy using a variety of quality control samples including check standards, duplicates, spikes, and blanks (MEL 2016). Check standards serve as an independent check on the calibration of the analytical system and can be used to evaluate bias. Laboratory duplicates are used to determine laboratory precision. Matrix spikes are used to check for matrix interference with detection of the analyte and can be used to evaluate bias related to matrix effects. Blanks are used to check for sample contamination in the laboratory process.

10.1 Table of field and laboratory quality control

Table 16 presents the quality control requirements for both field and laboratory procedures.

Table 16. Quality control samples, types, and frequency.

Parameter	Field Blanks	Field Replicates	Laboratory Calibration Verification/Blanks	Analytical Duplicates	Matrix Spikes	Lab Control Samples
Fecal coliform (MF)	NA	10%	1/batch	1/batch	NA	NA
E. coli (MF)	NA	10%	1/batch	1/batch	NA	NA
Dissolved Oxygen- Winkler	NA	1/20 samples	1/50 samples	NA	NA	NA
Alkalinity	1/synoptic survey	1/10 samples	ICV/CCV: Beginning of sequence ICB/CCB: 1/10 samples and end of sequence	1/batch	NA	1/batch
Chloride	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Ammonia	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Dissolved Organic Carbon	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Nitrate/Nitrite	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Total Persulfate Nitrogen	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Orthophosphate	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch

Parameter	Field Blanks	Field Replicates	Laboratory Calibration Verification/Blanks	Analytical Duplicates	Matrix Spikes	Lab Control Samples
Total Phosphorous	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Total Organic Carbon	1/synoptic survey	1/10 samples	See above	1/batch	1/batch	1/batch
Chlorophyll-*a*	1/synoptic survey	1/5 samples	NA	1/batch	NA	NA
Total Suspended Solids	1/synoptic survey	1/10 samples	NA	1/batch	NA	1/batch
Total Non-Volatile Suspended Solids	1/synoptic survey	1/10 samples	NA	1/batch	NA	1/batch
Turbidity	1/synoptic survey	1/10 samples	NA	1/batch	NA	1/batch

CCV = Continuing Calibration Verification; CCB = Continuing Calibration Blank; ICV = Initial Calibration Verification; ICB = Initial Calibration Blank; NA = Not any.
Batch is represented by 20 samples or fewer.

10.2 Corrective action processes

Staff will follow corrective actions if any procedures are found to be inconsistent with this QAPP and the original 2011 Lacamas Creek TMDL QAPP (Swanson 2011). These actions will also be necessary if analysis or modeling results do not meet MQOs or performance expectations, or if some other unforeseen problem arises. For the data analysis and modeling part, this may involve activity from project personnel and technical leads to decide on the next steps that are necessary to improve model performance.

Corrective actions related to lab procedures include:

- Requesting or retrieving missing information.
- Qualifying results if QC criteria are not met.
- Requesting collection of additional samples.

Corrective actions related to field procedures include:

- Collecting new samples to provide data that meet this study's QC criteria.
- Increased staff training.
- Modification or correction of field procedures.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

Relevant technical notes related to 2021 sampling will be documented in a field notebook. Field notebooks will be reviewed for missing information before leaving each site. Staff will enter data into a Microsoft (MS) Excel spreadsheet specifically for the project after returning from the field. Field notebooks and spreadsheet files will be maintained and kept with the project data files. The field lead will review and check field technical notes and electronic spreadsheets for missing or erroneous information.

Lab results will be received via an internal data transfer from MEL's Laboratory Information Management system (LIMS). The project manager/field lead will be responsible for reviewing the data, lab QC results and relevant qualifiers before uploading to EIM. If necessary, the project manager/field lead will determine if additional qualifiers or comments are necessary. The project manager/field lead will upload the data to the EIM database under the EIM Study ID LacamasSA.

11.2 Laboratory data package requirements

MEL data review and reporting will follow the procedures outlined in the MEL *Lab User's Manual* (MEL, 2016). MEL will provide a case narrative, which includes results of analysis and QC evaluation. In addition to the case narrative, lab results will be received via an internal data transfer from LIMS. The field lead will check for omissions.

11.3 Electronic transfer requirements

MEL provides a system to transfer data electronically in a readily usable format to minimize data entry problems and facilitate data analysis. This system involves transferring data from LIMS in a downloadable spreadsheet format.

11.4 EIM/STORET data upload procedures

The project manager/field lead will upload data to EIM after reviewing lab QC results. The project manager/field lead will follow existing Ecology business rules and procedures outlined on the EIM Help Center webpage[14] for entering, loading, editing and data quality checks. The technical lead will review entries in EIM to detect and correct potential data entry errors.

11.5 Model information management

Data management for modeling work for this study will mainly include Excel spreadsheets.

Modeling information, including inputs, outputs, GIS files, will be archived. Modeling results will be included within the final report.

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[14] https://apps.ecology.wa.gov/eim/help/HelpDocuments

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

Typically, Ecology field staff certify and review field procedure performance by conducting side-by-side sampling and split samples. These reviews are not true audits but instead serve to improve fieldwork consistency, reinforce understanding of Ecology SOPs, and strengthen Ecology's QA program. This review will be scheduled once during this study to quality check the performance of the main field lead with a staff from the Environmental Assessment Program.

MEL undergoes routine on-site audits in accordance with WAC-173-50-080. MEL's Laboratory Accreditation Unit (LAU) conduct these audits.

12.2 Responsible personnel

This study's field lead, Molly Gleason, will guide sampling that involves more than one staff. Typically, Ecology field staff certify and review field procedure performance by conducting side-by-side sampling and split samples. This study's field lead and a staff from EAP's FMU responsible for collecting samples at the Lacamas Creek ambient station will conduct side-by-side sampling to quality check (QC) sampling performance.

12.3 Frequency and distribution of reports

Results of the 2021 data collection will continue to be shared with the public throughout the June-October sampling period. Data will be updated monthly in Ecology's EIM database as well as on an Ecology approved virtual data visualization platform (i.e. Tableau page). This Tableau page created specifically for this project provides an interactive display of maps and charts contained in a workbook to enhance data interpretation and communicate the data to partners.

A final report summarizing the technical analysis of the 2010-11 and 2021 data is planned to be published by 2023. The outline for the progress of the report development is provided in Section 5.4.

12.4 Responsibility for reports

Sheelagh McCarthy (lead author) and Molly Gleason will be responsible for the final report.

13.0 Data Verification

Data verification is the process of evaluating the completeness, correctness, and compliance of a specific data set against the method or procedural requirements (EPA, QA/G-8 2002).

13.1 Field data verification, requirements, and responsibilities

Data verification will involve both in-field and post-field procedures. In the field, technical notes related to sampling will be documented in a field notebook, and notes will be verified for completion before leaving each site. Post-fieldwork, field notes will be manually entered into an electronic spreadsheet. Both field notebooks and spreadsheets will be reviewed for missing or erroneous information by the project manager/field lead before data is entered into EIM. After the data is reviewed and entered in EIM, entered data will be verified and compared to the field notebook by the technical lead or WQP staff who did not enter the data.

A quality assurance assessment will be completed for DO and pH water quality measurements collected in 2010-11 based on available information. This involves an assessment of sensor performance based on assessment criteria outlined in Table 12 in Section 6.3. Electronic data files downloaded from instruments will be reviewed, and pre- and post-QC instrument checks will be compared to the acceptable ranges specified for each sensor by the manufacturer. Results will be qualified if results do not meet these criteria. Any documented comments or notes associated with the data will also be accounted for in the evaluation.

Data verification will also be completed for continuous temperature data from 2010-11. This will involve reviewing plots of water and air temperature data with QC checks from a certified reference thermometer or thermistor. Data will be rejected based on deployment/retrieval times, disruption from exposure to air, fouling and equipment failure. Instrument drift or bias will be evaluated by reviewing measurement offset from pre-and post- QC checks. The project manager will use best professional judgement to determine if drift adjustments are necessary based on these results. SOP EAP130 will serve as a guide for continuous data processing and decisions on drift adjustment (Mathieu 2019).

Data verification will be completed for 2010-11 and 2021 samples. This will involve a review of the accuracy and completeness of EIM data entries and a review of laboratory case narrative reports and QC results delivered by MEL (MEL 2016).

13.2 Laboratory data verification

MEL staff will perform laboratory verification following standard laboratory practices (MEL 2016). Once the data package is delivered, the project manager/field lead will review the data package for completeness and check the laboratory QC results. If any issues are discovered, the project manager/field lead will communicate with the appropriate MEL staff to resolve the issues.

13.3 Validation requirements, if necessary

Not applicable.

13.4 Model quality assessment

Shade model results will be compared graphically with effective shade estimated from hemispherical photographs. Similar to previous Ecology reports (McCarthy 2020; Newell 2018; Snouwaert and Stuart 2013) the quality assessment will be qualitatively based on agreement between modeled effective shade and estimated shade from hemispherical photographs taken at similar locations along the creek.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

The project manager will use the results of the verification process, compliance with defined MQOs, and evaluation of quality of the data to ultimately determine the usability of the data in the technical analysis and incorporation in the final report. The results of this quality assessment will be documented in the final report including an evaluation of whether the project-specific goals and objectives were met.

14.2 Treatment of non-detects

Non-detects will be included in the technical analysis. The non-detect will be reported at the reporting limit and qualified as "U" in EIM.

For a more general discussion of treatment of non-detects, see SOP EAP093 (Gries 2017).

14.3 Data analysis and presentation methods

A data quality assessment will be completed for both the 2010–2011 data and the 2021 data and will be included in the final report. Data found to be of acceptable quality for project objectives will be analyzed before being summarized. Any relevant and interesting data analysis will be presented in the final report using a combination of tables and plots of various kinds. Maps created in GIS will also be used to display results spatially. The data analysis methods used in this study are outlined in Section 7.2.

14.4 Sampling design evaluation

The sampling design will be determined as effective if the collected and existing data meet the MQOs, meet the criteria for completeness, representativeness and comparability and provide enough statistical power to make conclusions. The project manager will document the data quality evaluation and whether the project-specific goals and objectives were met in the final source assessment report.

14.5 Documentation of assessment

The data quality assessment will be documented in the final source assessment report.

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16.0 Appendices

Appendix A. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Anthropogenic: Human-caused.

Bankfull stage: Formally defined as the stream level that "corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold, 1978).

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Char: Fish of genus *Salvelinus* distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light-colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Chronic critical effluent concentration: The maximum concentration of effluent during critical conditions at the boundary of the mixing zone assigned in accordance with WAC 173-201A-100. The boundary may be based on distance or a percentage of flow. Where no mixing zone is allowed, the chronic critical effluent concentration shall be 100% effluent.

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: 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 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.

Diel: Of, or pertaining to, a 24-hour period.

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

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100. http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

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

Enterococci: A subgroup of the fecal streptococci that includes *S. faecalis*, *S. faecium*, *S. gallinarum,* and *S. avium*. The enterococci are differentiated from other streptococci by their ability to grow in 6.5% sodium chloride, at pH 9.6, and at 10 degrees C and 45 degrees C.

Eutrophic: Nutrient rich and high in productivity resulting from human activities such as fertilizer runoff and leaky septic systems.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

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 nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

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.

Near-stream disturbance zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars.

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.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

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 to be 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.

Phase I stormwater permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

Phase II stormwater permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

Point source: Source of pollution that discharges 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, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

Reach: A specific portion or segment of a stream.

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

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

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.

Streamflow: Discharge of water in a surface stream (river or creek).

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.

Synoptic survey: Data collected simultaneously or over a short period of time.

System potential: The design condition used for TMDL analysis.

System-potential channel morphology: The more stable configuration that would occur with less human disturbance.

S**ystem-potential mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System-potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System-potential riparian microclimate can also include expected changes to wind speed and relative humidity.

System-potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system-potential condition uses best estimates of *mature riparian vegetation, system-potential channel morphology, and system-potential riparian microclimate* that would occur absent any human alteration.

Thalweg: The deepest and fastest moving portion of a stream.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) 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.

Total suspended solids (TSS): Portion of solids retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

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.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less.

303(d) list: Section 303(d) of the federal Clean Water Act, requiring 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.

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days before and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

90^{th} percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90^{th} percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

Acronyms and Abbreviations

BMP	Best management practice
DO	(see Glossary above)
DOC	Dissolved organic carbon
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
FC	(see Glossary above)
GIS	Geographic Information System software
GPS	Global Positioning System
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NAF	New Approximation Flow
NPDES	(See Glossary above)
NSDZ	Near-stream disturbance zones
QA	Quality assurance
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures

SRM	Standard reference materials
TIR	Thermal infrared radiation
TMDL	(see Glossary above)
TOC	Total organic carbon
TSS	(see Glossary above)
USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area
WSTMP	Washington State Toxics Monitoring Program
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
Cfs	cubic feet per second
Cfu	colony forming units
Cms	cubic meters per second, a unit of flow
Ft	feet
G	gram, a unit of mass
Kcfs	1000 cubic feet per second
Kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mm	millimeter
mg	milligram
mgd	million gallons per day
mg/d	milligrams per day
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mg/L/hr	milligrams per liter per hour
mL	milliliter
mmol	millimole or one-thousandth of a mole
mole	an International System of Units (IS) unit of matter
ng/g	nanograms per gram (parts per billion)
ng/kg	nanograms per kilogram (parts per trillion)
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity units
pg/g	picograms per gram (parts per trillion)
pg/L	picograms per liter (parts per quadrillion)
psu	practical salinity units
s.u.	standard units

µg/g	micrograms per gram (parts per million)
µg/kg	micrograms per kilogram (parts per billion)
µg/L	micrograms per liter (parts per billion)
µm	micrometer
µM	micromolar (a chemistry unit)
µmhos/cm	micromhos per centimeter
µS/cm	microsiemens per centimeter, a unit of conductivity

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy* (USGS, 1998).

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella (Kammin 2010).

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time and is characteristic of both the measurement system and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI) (Kammin 2010; Ecology 2004).

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process (USGS 1998).

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured (Ecology 2004).

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS (Kammin 2010; Ecology 2004).

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator (USEPA 1997).

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator (USEPA 1997).

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system (Kammin 2010; Ecology 2004).

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean (Kammin 2010).

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading (Kammin 2010).

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity (USEPA 2006).

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA 2006).

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin 2010).

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability, and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier – data are usable for intended purposes.
- J (or a J variant) – data are estimated, may be usable, may be biased high or low.
- REJ – data are rejected, cannot be used for intended purposes.
  (Kammin 2010; Ecology 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set (Ecology 2004).

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero (Ecology 2004).

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis (USEPA 1997).

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport (Ecology 2004).

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples (Kammin 2010).

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples (USEPA 1997).

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects (Ecology 2004).

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness (USEPA 2006).

Measurement result: A value obtained by performing the procedure described in a method (Ecology 2004).

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed (EPA 1997).

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples (Ecology 2004; Kammin 2010).

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero (Federal Register, October 26, 1984).

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin 2010).

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all parameters (Kammin 2010; Ecology 2004).

Population: The hypothetical set of all possible observations of the type being investigated (Ecology 2004).

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator (USGS, 1998).

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data (Kammin 2010).

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives (Kammin 2010; Ecology 2004).

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data (Ecology 2004).

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where “Abs()” is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled (USGS, 1998).

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator (USGS, 1998).

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population (USGS, 1998).

Sample (statistical): A finite part or subset of a statistical population (USEPA 1997).

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit (Ecology 2004).

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method (USEPA 1997).

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency (USEPA 1997).

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin 2010).

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin 2010).

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis (Kammin 2010).

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning (USEPA, 2006).

References for QA Glossary

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