# Lacamas, Round, and Fallen Leaf Lakes Cyanobacterial Lake Management Plan

## Quality Assurance Project Plan

## FINAL

Prepared by Geosyntec Consultants
on behalf of the City of Camas

# Quality Assurance Project Plan

## Lacamas, Round, and Fallen Leaf Lakes Cyanobacterial Lake Management Plan

March 2022

**Approved by:** **Date:**

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## 2 ABSTRACT

The Lacamas, Round and Fallen Leaf Lakes Cyanobacteria Management Plan (LCMP) is designed to characterize the major drivers of cyanobacteria blooms within Lacamas, Round, and Fallen Leaf Lakes. The blooms are becoming increasingly common and longer in duration, which is thought to be a result of excess nutrient loading. These cyanobacteria blooms can result in harmful toxins in the lake waters which result in health issues for the recreating community.

Additional understanding of the causes behind the increase in blooms is needed. While there is a large historical data set pertaining to nutrients in Lacamas Lake, a full nutrient budget has not been completed for this lake in over three decades. Round and Fallen Leaf Lakes have even more limited data sets. As such, before mitigation and prevention measures to curtail blooms can be developed and enacted, a full understanding of current nutrient cycling within the lake must be developed, and the influence of external loading sources must be determined.

Data in the three lakes will be collected over the course of a year, to include water quality sampling of lake water, influent and effluent creek water, and storm water, as well as sediment chemistry. The goal of this data collection is to develop hydrologic and nutrient budgets for Lacamas and Round Lakes, and to obtain a better understanding of the rarely studied Fallen Leaf Lake. The hydrologic and nutrient budgets for Fallen Leaf Lake may have large errors as the lake is small and both its inlets and outlets are ephemeral and storm dependent.

After field data is collected and processed, the LCMP will be developed. The intent of the LCMP is to use science-based information to achieve a more complete understanding of lake nutrient dynamics and to guide management decisions for the lakes. Continued data collection as well as use of the hydrologic and nutrient budgets will inform future management decisions while meeting the requirements and quality controls laid out in this Quality Assurance Project Plan (QAPP) approved by the State of Washington Department of Ecology (Ecology).

# 3 BACKGROUND

## 3.1 Introduction and Problem Statement

Lacamas, Round, and Fallen Leaf Lakes are located in Clark County in southwest Washington State. These lakes are classified as eutrophic based on the most recent available data measurements. Clark County found eutrophic conditions in Lacamas Lake based on chlorophyll a, phosphorus, and Secchi depth measurements during monitoring in 2005, 2006, and 2007. Less data exists for Round Lake, but it was assessed to be eutrophic to hypereutrophic by Beak and SRI (Beak and SRI, 1985). Fallen Leaf Lake was assessed in 2020 by Clark County and was also found to be eutrophic based on chlorophyll-a-based trophic state index (TSI; Carlson, 1977) in 5 out of 6 measurements (with one sample consistent with oligotrophic conditions), near the border between eutrophic and mesotrophic based on Secchi disk TSI, and between eutrophic and hypereutrophic based on phosphorus TSI (Carlson, 1977).

Each lake has experienced algae blooms in recent years, with the blooms of most concern being Harmful Algal Blooms (HABs), which result in the presence of cyanotoxins. Following several years of sporadic HABs (two noted in 2018, and 3-4 in 2019), Lacamas Lake experienced near-continuous HABs from April-October 2020. Round Lake has also seen increases in HABs in recent years; one sample tested above toxicity levels for Microcystin in April 2019, compared to six such samples in 2020. A HAB was reported on July 28, 2021, for both Lacamas and Round Lakes, with the advisory level reduced to a warning on September 30, 2021, despite the blooms remaining present, and warnings lifted in November 2021. Fallen Leaf Lake had its first recorded bloom in 2020.

This QAPP document outlines the process that will lead to the development of an Ecology-approved Lake Cyanobacteria Management Plan (LCMP), which will include management strategies for reducing HABs.

## 3.2 Study Area and Surroundings

The Lacamas, Round, and Fallen Leaf Lake watershed, as delineated by USGS StreamStats, is shown in Figure 1. The watershed is 59.7 square miles (38,184 acres) and includes agricultural, residential, commercial, and industrial land uses. The watershed extends from Hockinson, WA in the northern part of the watershed to the City of Camas in the southern part of the Watershed. Lacamas Creek flows 18 miles from forested areas through both agricultural and residential areas prior to discharging into Lacamas Lake. There are five major tributaries to Lacamas Creek: Matney Creek, Shanghai Creek, Fifth Plain Creek, China Ditch, and Dwyer Creek (Figure 1).

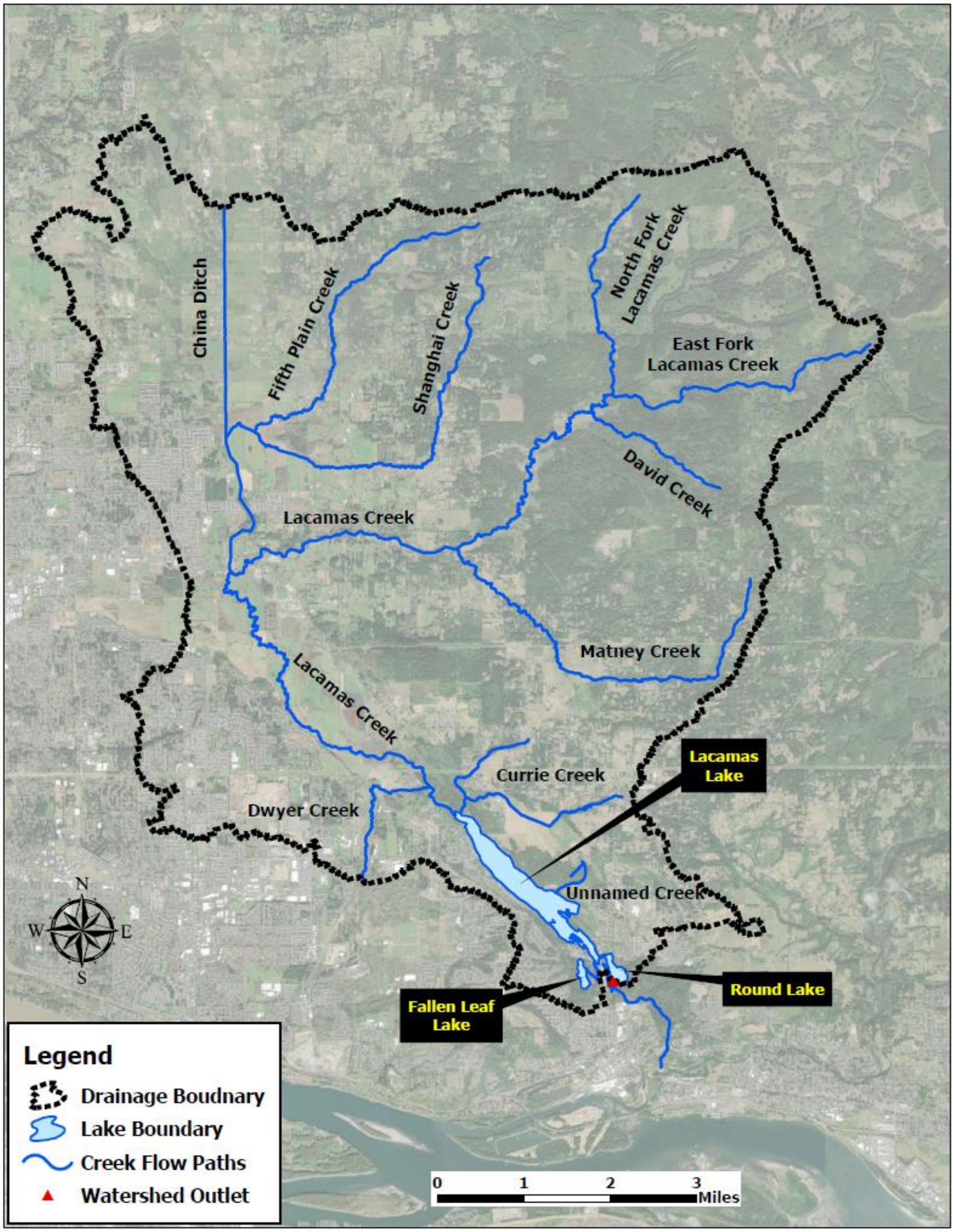

Figure 1. Lacamas/Round Lake watershed as delineated by USGS StreamStats

The largest of the three lakes, Lacamas Lake, is approximately 330 acres in size with a maximum depth of approximately 60 feet. Lacamas Lake is long and narrow in shape, with a length of approximately 2.5 miles, and a maximum width of approximately 0.3 miles. The vast majority of inflow to Lacamas Lake is from Lacamas Creek—the historically gauged flow measured at Lacamas Creek at Goodwin Road accounted for approximately 95% of the flow to the lake as estimated by Beak and SRI (Beak and SRI, 1985). Dwyer Creek enters Lacamas Creek below this gauge location, and there is additional limited inflow from Currie Creek, a small tributary to Lacamas Lake at its northeast end, and an unnamed creek at its southeast end (Figure 1). There are also some direct inflows from stormwater, and likely from groundwater. However, groundwater is not believed to be a major source of nutrients to the lakes (Beak and SRI, 1985).

Round Lake is the most downstream lake in the chain examined for this study. The channel connecting Lacamas and Round Lakes is the dominant inflow to Round Lake. Round Lake is much smaller in size, approximately 26 acres, and is also relatively deep, with a maximum depth of 55 feet. Water exits Round Lake either through the upper dam, where it discharges into lower Lacamas Creek, or through Mill Pond and the lower dam, where it discharges to a short, approximately 100 ft side stream that then discharges into lower Lacamas Creek.

Both Lacamas and Round Lakes are natural but were enlarged after the construction of two dams on Lacamas Creek downstream of Round Lake during the 1880s (Beak and SRI, 1985). Historically, the dams were used to control discharge to the Mill Ditch, which provided flow to a paper mill now operated by Georgia Pacific, and to Lacamas Creek downstream of the Lakes, which flows into the Washougal River. The dams were gifted to the City of Camas by Georgia Pacific in 2018 (Green, 2018). The Mill Ditch is no longer used, and flow below the dams is now directed only into Lacamas Creek (personnel communication, Steve Wall, city of Camas).

Fallen Leaf Lake is located just west of the downstream end of Lacamas Lake. Fallen Leaf Lake is a natural lake, approximately 21 acres in size, and has a maximum depth of approximately 28 feet. Fallen Leaf Lake is higher in elevation and its outlet flows into Lacamas Lake near Lacamas Lake Lodge during periods of high water. During periods of low water, the flows from Fallen Leaf to Lacamas Lake are negligible (Clark County, 2021). Fallen Leaf Lake has three small tributary streams, with a direct drainage area of approximately 0.55 square miles in size (350 acres), which is largely residential (Figure 2).

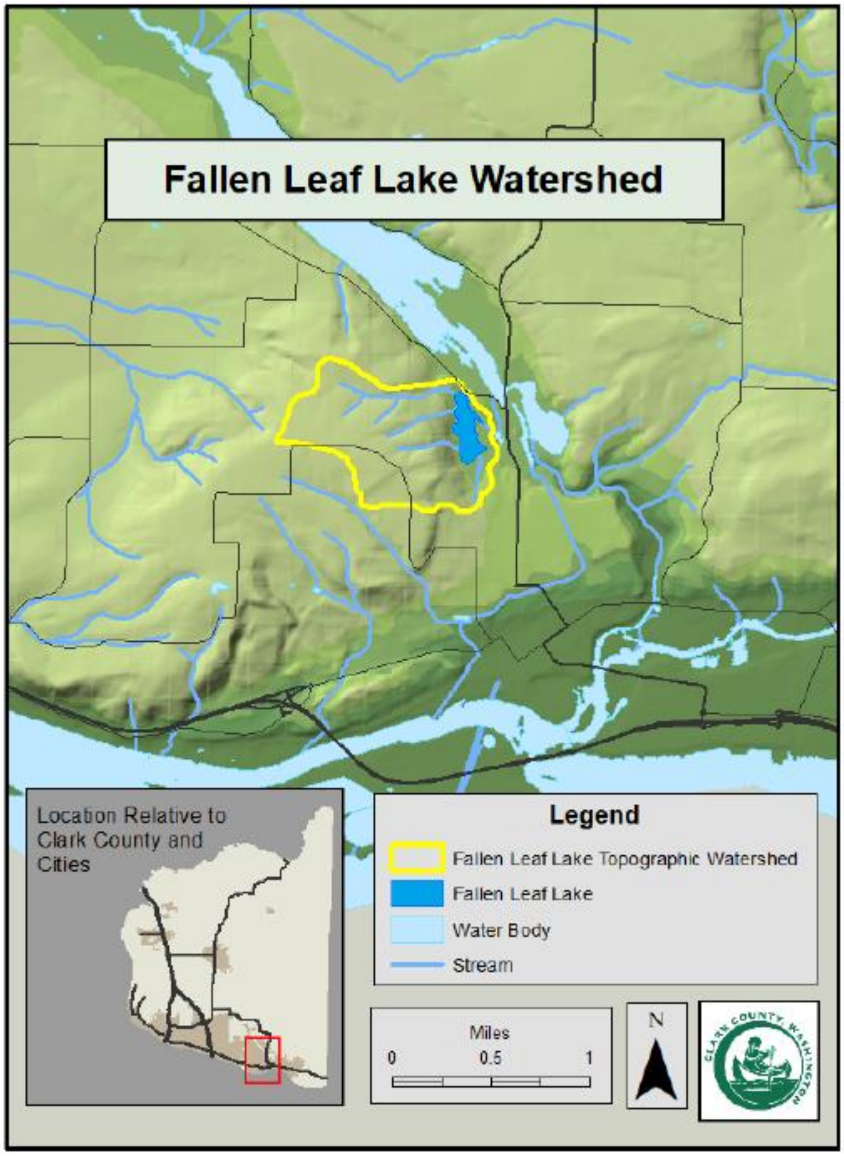

Figure 2. Fallen Leaf Lake watershed (Clark County, 2021)

### 3.2.1 History of study area

Development within the Lacamas/Round Lake watershed largely began in the 1880s. In 1883 La Camas Colony Company was created and the town of La Camas, later changed to Camas, was formed (Beak and SRI, 1985). Also in 1883, work began on the dams used to provide water for the newly constructed paper mill. During this time significant population growth in the area occurred and farms were formed. Beginning in the 1890s, drainage channels were built to drain the wetlands for farmland and to increase the flow of water delivered to the Camas paper mill; These channels led to altered watershed hydrology, which caused erosion of stream banks and increased flooding (Gleason and McCarthy, 2021). The current concrete buttress dams were constructed in 1936 to replace the log dams constructed in the 1880s. The mill discontinued use of lake water for paper manufacturing in 2015 (Georgia-Pacific, 2018).

From 1900 to 1960, dairy cattle operations increased in the pasture areas of the watershed, in part due to improved roadways allowing for easier transportation of milk products to Vancouver, Washington and Portland, Oregon (Beak and SRI, 1985). Subsequently, the land was divided into smaller plots as the size of farms decreased and some became no longer feasible economically. As a result, the watershed includes both large farms and small 5-acre parcels of residential land (Beak and SRI, 1985).

In recent years, the population of Clark County has increased substantially, from approximately 425,400 people in 2010 to 503,300 in 2021, the second highest population growth rate in Washington (Macuk, 2021). The increased population growth has led to both increased development in the watershed and increased use of the lakes for recreation.

### 3.2.2 Summary of previous studies and existing data

Table 1 provides a summary of previous studies regarding water quality in Lacamas, Round, and Fallen Leaf Lakes. Table 2 provides a summary of the relevant available data from those studies.

Table 1. Previous studies pertaining to water quality at Lacamas, Round, and Fallen Leaf Lakes

| Year | Author(s) | Title |
|---|---|---|
| 1985 | Beak Consultants, Inc. and Scientific Resources, Inc. | Lacamas - Round Lake Diagnostic and Restoration Analysis |
| 1989-1999 | Washington State Department of Ecology | Summer Water Quality Monitoring |
| 1990 | Washington State Department of Ecology | Lake Water Quality Assessment Project |
| 1991 | Connin, S. for EPA Region 10 | Characteristics of Successful Riparian Restoration Projects in the Pacific Northwest |
| 1996 | Eilers, J. M., Raymond, R. B., Vache, K. B., Sweet, J. W., Gubala, C. P., Sweets, P. R. | Lacamas Lake Watershed 1995 Water Quality Monitoring Program |
| 1997 | Raymond, R.B., Eilers, J. M., Vache, K. B., Sweet, J. W.,Sweets, P. R., Gubula, C.P. | Lacamas Lake Watershed 1996 Water Quality Monitoring Program |
| 1998 | Raymond, R. | Dye Tracer Mixing Study at Lacamas Lake, 1996 and 1997 |
| 1998 | Raymond, R.B., Eilers, J.M., Bernert, J.A., Vache, K.B. | Lacamas Lake Watershed Restoration Project Program Review |
| 1999 | Mueller, K.W., Downen, M.R. | 1997 Lacamas Lake Survey: The Warmwater Fish Community of a Highly Eutrophic Lowland Lake |
| 1999 | Parsons, J. | Lacamas Lake aquatic plant summary |
| 2002 | Schnabel, J.D. | Lacamas Lake Restoration Program: WY2000 and WY2001 Water Quality Monitoring. |
| 2004 | Schnabel, J.D. | Lacamas Lake Nutrient Loading and In-Lake Conditions |
| 2006 | Schnabel, J.D. | Monitoring Report - Lacamas Lake Annual Data Summary for 2006 |

| Year | Author(s) | Title |
|---|---|---|
| 2007 | Schnabel, J.D. | Monitoring Report - Lacamas Lake Annual Data Summary for 2007 |
| 2011 | Deemer, B,R., Harrison, J.A, Whitling, E.W. | Microbial dinitrogen and nitrous oxide production in a small eutrophic reservoir: An in,situ approach to quantifying hypolimnetic process rates |
| 2012 | Henderson, S. M., Deemer, B. R. | Vertical propagation of lake wide internal waves |
| 2015 | Deemer, B. R., Henderson, S. M., Harrison, J. A. | Chemical mixing in the bottom boundary layer of a eutrophic reservoir: The effects of internal seiching on nitrogen dynamics. |
| 2017 | Perkins, K..R. | Influence of environmental factors on the vertical distribution of phytoplankton in Lacamas Lake, WA |
| 2017 | Harrison, J. A., Deemer, B. R., Birchfield, M. K., O'Malley, M. T. | Reservoir water-level drawdowns accelerate and amplify methane emission |
| 2019 | Nolan, S., Bollens, S. M., & Rollwagen-Bollens, G. | Diverse taxa of zooplankton inhabit hypoxic waters during both day and night in a temperate eutrophic lake. |
| 2019 | Perkins, K. R., Rollwagen-Bollens, G., Bollens, S. M., Harrison, J. A | Variability in the vertical distribution of chlorophyll in a spill-managed temperate reservoir |
| 2021 | Rose, V., Rollwagen-Bollens, G., Bollens, S. M., Zimmerman, J. | Effects of Grazing and Nutrients on Phytoplankton Blooms and Microplankton Assemblage Structure in Four Temperate Lakes Spanning a Eutrophication Gradient |
| 2021 | Clark County Public Works, Clean Water Division | Fallen Leaf Lake Baseline Monitoring Report |

Table 2. Summary of existing water and sediment quality data for Lacamas, Round, and Fallen Leaf Lakes

| **Sample Type** | **Years Sampled** | **Locations** | **Measured Parameters** |
|---|---|---|---|
| *Lacamas Lake* | | | |
| Water Quality | Various, 1984 - 2017 | Deepest location; SR500 bridge; field profiles throughout lake | Temperature, DO, conductivity, pH, turbidity, Secchi, alkalinity, total P, ortho-P, TSS, TKN, nitrate, nitrite, ammonia, chlorophyll a, phytoplankton |
| Sediment | 1984, 1995, 1996 | Deepest location; 3 other locations | Total P, available P, total iron, total aluminum, TKN, ammonia, Paleolimnological parameters (1995) |
| Sediment Flux[1] | 1984, 1996 | Deepest location, 3 other locations | Temperature, DO, conductivity, pH, total P, soluble reactive P, dissolved P, TKN, ammonia, dissolved iron, metals, DDT, DDE |
| Stormwater | 1985 | Lacamas Creek at Goodwin Road, during storm | Temperature, DO, conductivity, pH, turbidity, total P, TSS, TKN, nitrate, nitrite, ammonia, fecal coliform |
| Inflow (Lacamas Creek at Goodwin Road) | 1995, 1996, 2003 | Goodwin Road | Temperature, DO, conductivity, pH, turbidity, total P, TSS, TKN, nitrate, nitrite, ammonia, fecal coliform |
| *Round Lake* | | | |
| Water Quality | 1984-1985 | Deepest location | Temperature, DO, conductivity, pH, turbidity, Secchi, alkalinity, total P, soluble reactive P, TSS, TKN, nitrate, nitrite, ammonia, chlorophyll a, phytoplankton |
| Water Quality | 1990 | Deepest Location | Secchi, Temperature, DO, total P, total N |
| Sediment | 1984 | Deepest location; near inlet | Total P, available P, total iron, total aluminum, TKN, ammonia |
| Sediment Flux | 1984 | Deepest location; near inlet | Temperature, DO, conductivity, pH, total P, soluble reactive P, dissolved P, TKN, ammonia, dissolved iron, metals, DDT, DDE |

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[1] Beak and SRI (1985) conducted elutriate testing to understand potential impacts of dredging and/or wind disturbance. Beak and SRI (1985) also used Dissolved Oxygen data and literature to estimate Phosphorus release under anoxic conditions. Raymond et. al (1998) discussed an evaluation of a 1996 sediment core and found that Phosphorus release was small relative to watershed loading.

| **Sample Type** | **Years Sampled** | **Locations** | **Measured Parameters** |
|---|---|---|---|
| Stormwater | *None* | *none* | *none* |
| Outflow (Lacamas Creek downstream of dams) | *none* | *none* | *none* |
| *Fallen Leaf Lake* | | | |
| Water Quality | 2020 | Deepest location | Temperature, DO, conductivity, pH, Secchi, total P, TKN, nitrate, chlorophyll a, E. coli |
| Sediment | *none* | *none* | *none* |
| Sediment Flux | *none* | *none* | *none* |
| Stormwater | 2020 | Tributaries (storm-dominated) | Temperature, DO, conductivity, pH, turbidity, total P, TSS, E. coli |

### 3.2.3 Water quality parameters of interest and potential sources

This QAPP describes the data collection necessary for the creation of hydrologic and nutrient (phosphorus and nitrogen) budgets for Lacamas and Round Lakes. These budgets will be a powerful tool in identifying the key sources of nutrients that lead to cyanobacterial blooms. In addition, data will be collected at Fallen Leaf Lake to gain a better understanding of hydrologic and nutrient inputs, though budgets for Fallen Leaf Lake may have a large error between inputs and outputs due to its small size and ephemeral nature. The field and laboratory activities to accomplish this are described in Section 7.

The sampling plan described in this QAPP is not intended to measure iron, sulfur, or other micronutrients that are important for cyanobacterial and algal growth. Based on extensive algal blooms that have occurred in the lakes, this document assumes that macronutrients (i.e., phosphorus and nitrogen) limit cyanobacteria and algae growth, not micronutrients.

Nutrients are suspected to enter Lacamas Lake primarily via four sources (Beak and SRI, 1985):

1. External loading via Lacamas Creek. Lacamas Creek has 5 primary tributaries, which contribute nutrients to this primary pathway to Lacamas Lake:
    - *i.* Fifth Plain Creek
    - *ii.* China Ditch
    - *iii.* Shanghai Creek
    - *iv.* Matney Creek
    - v. Dwyer Creek
2. Direct stormwater runoff
3. Direct agricultural runoff
4. Internal loading

Nutrients and water enter Round Lake primarily through its connection with Lacamas Lake, but also through runoff and internal loading. Nutrients and water enter Fallen Leaf Lake through the same processes; however, the primary sources consist of three unnamed tributaries, of which the northwestern most tributary is estimated to be highest in discharge volume (Clark County, 2021).

Direct runoff is a combination of point sources (i.e., municipal stormwater outfalls) and direct discharge to the lake. Agricultural runoff may occur as direct discharge from fields near the lake or through drainage ditches that act as point sources. Groundwater discharge and internal loading vary spatially. Groundwater is not believed to be a major source of nutrients to the lakes (Beak and SRI, 1985).

### 3.2.4 Regulatory criteria or standards

Lacamas and Round Lake’s designated uses include core summer salmonid habitat; primary contact recreation; domestic, industrial, agricultural, stock and wildlife habitat water supply; harvesting; commerce and navigation; boating; and aesthetics. Fallen Leaf Lake is separately designated and has the same designated uses. Algal blooms impair each of these uses. Regulatory criteria (Table 3) apply for conventional pollutants as defined in WAC 173-201A-600 (1)(a)(ii).

Table 3. Lacamas, Round, and Fallen Leaf Lakes regulatory criteria

| **Criterion** | **Value** | **Units** |
|---|---|---|
| Temperature | 16[1] | °C |
| Dissolved Oxygen (DO) | 9.5[2] | mg/L |
| Total Dissolved Gas | ≤ 110 | % |
| pH | 6.5 – 8.5[3] | - |
| Turbidity | 5 over background when background < 50<br>10% increase when background > 50 | NTU |
| E. coli | 100[4]<br>No more than 10% < 320 | CFU or MPN per 100 mL |

[1] Applies as 7-day average of the daily maximum temperature (7DADMax)

[2] Applies as daily minimum

[3] Human-caused variation must be less than 0.2 units

[4] Applies to geometric mean of at least 3 samples

### 3.3 Water Quality Impairment Studies

In accordance with the Clean Water Act, Ecology conducts a water quality assessment of Washington state waters every two years. The result of these assessments is a database of categorical rankings for each applicable standard in each assessment unit. Those assessment units classified as Category 5 make up the 303(d) list of impaired water bodies of the state. Lacamas Lake is currently listed as impaired for phosphorus in the water column, while Round Lake is impaired for pH and DO in the water column. Fallen Leaf Lake has not been assessed by the state for water quality impairment. Lacamas Creek, which feeds Lacamas Lake, is impaired for DO, bacteria, and temperature in the water within the assessment unit just upstream of Lacamas Lake.

Table 4. Impaired water quality parameters in Lacamas, Round, and Fallen Leaf Lake, as well as nearby tributaries

| **Waterbody** | **Parameter** | **Listing ID[1]** |
|---|---|---|
| Lacamas Lake | Total Phosphorus | 6346 |
| Round Lake | DO | 7936 |
| | pH | **7935** |
| Fallen Leaf Lake | *not assessed* | |
| Lacamas Creek | Bacteria - Fecal coliform | 7913 |
| | DO | 7912, 7915 |
| | pH | 7916 |
| | Temperature | 7914, 7917 |
| Dwyer Creek | DO | 7894 |
| Currie Creek | *not assessed* | |

[1] Bolded Listing IDs are listings that appear in the 2014 WQA (approved by EPA on July 22, 2016) but are not brought forth in the draft 2018 WQA (submitted to EPA, but not yet approved).

## 3.4 Effectiveness Monitoring Studies

Not applicable – this is not an effectiveness monitoring study.

# 4 PROJECT DESCRIPTION

## 4.1 Project Goals

The goal of this sampling project is to collect data of sufficient quality and quantity to support development of a LCMP for Lacamas, Round, and Fallen Leaf Lakes by following Ecology's Lake Cyanobacteria Management Plan template and guidance. Specifically, the data will be used to:

- Track changes in the water quality characteristics of Lacamas, Round, and Fallen Leaf Lakes throughout a year
- Quantify the nutrient loading of different sources and inputs of nutrients to Lacamas, Round, and Fallen Leaf Lakes
- Develop hydrologic and nutrient budgets for Lacamas and Round Lakes

## 4.2 Project Objectives

The objectives of this project are to:

- Collect 8 sets of monthly surface water quality data from Lacamas and Round Lakes
- Collect 3 sets of monthly surface water quality data from Fallen Leaf Lake
- Collect 12 sets of monthly water quality data from the major contributing creeks
- Collect continuous temperature data of the water column in Lacamas and Round Lakes
- Collect continuous flow data from Lacamas Creek at Goodwin Road
- Characterize the labile phosphorus in sediment in the three lakes
- Determine the contribution of nutrients in stormwater to Round and Fallen Leaf Lakes
- Obtain a rough picture of lake macroecology through collection of data related to aquatic vegetation and human use

## 4.3 Information Needed and Sources

Information and data available from previous studies is summarized in Section 3.2.2 and Table 1. Additional information, such as GIS layers, will be obtained from the City of Camas or Clark County.

## 4.4 Tasks Required

To complete this project the following tasks will be required:

- Conduct field work
    - Create a health and safety plan
    - Create a sampling schedule
    - Gather water quality sampling and monitoring equipment
    - Re-establish flow monitoring gauge at Lacamas Creek at Goodwin Road
    - Verify surface water sampling locations
    - Calibrate instruments (Section 7.2.3)
    - Install thermistor chains (Section 7.2.3)
    - Collect monthly surface water samples at multiple depths (Section 7.2.3)
    - Track storms (Section 7.2.9)
    - Collect stormwater samples, spread throughout the rainy season (Section 7.2.9)

    - Collect sediment samples (Section 7.2.7)
    - Conduct aquatic vegetation surveys (Section 7.2.5)
    - Conduct lake use surveys (Section 7.2.6)
- Analyze results of field work by measuring completed work against Quality Objectives (Section 6)
- Develop and perform QA/QC on hydrologic and nutrient budgets
- Identify management methods for cyanobacteria control and lake restoration planning
- Determine funding strategy and implementation
- Complete LCMP

### 4.5 Systematic Planning Process

The preparation of this QAPP is sufficient systematic planning for this project.

# 5 ORGANIZATION AND SCHEDULE

## 5.1 Key Individuals and Their Responsibilities

Table 5 shows the responsibilities of those who will be involved in this project.

Table 5. Organization of project staff and responsibilities

| Staff | Title | Responsibilities |
|---|---|---|
| Steve Wall<br>City of Camas<br>Public Works Director<br>Phone: 360-834-6864 | Client | Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP. City of Camas may also provide staff to support field work. |
| Ariel Mosbrucker<br>Professional<br>Geosyntec Consultants<br>Phone: 971.271.5902 | QAPP and Field Work Project Manager | Reviews the project scope and budget, tracks progress. Oversees development of the QAPP. Oversees field sampling and transportation of samples to the laboratory. Ensures QA review of data is performed appropriately. Ensures data is input into Ecology's Environmental Information Management System (EIM). |
| Dr. Jacob Krall<br>Project Professional<br>Geosyntec Consultants<br>Phone: 971.271.5902 | Modeling and Lake Management Plan Project Manager | Reviews the project scope and budget, tracks progress. Oversees analysis and interpretation of data. Develops nutrient budgets and leads development of the subsequent LCMP. Ensures QA review of data, analysis and interpretation of data are performed appropriately. |
| Dr. Rob Annear<br>Senior Principal<br>Geosyntec Consultants<br>Phone: 971.271.5906 | Principal Investigator | Provides internal review of the QAPP, approves the budget, and approves the final QAPP. Ensures QA review of data, analysis and interpretation of data are performed appropriately. |
| Ryon Foster-Edwards<br>Stormwater Analyst<br>MacKay Sposito<br>Phone: 541-401-9626 | Field Assistant | Helps collect samples and records field information. |
| Dr. Toni Pennington<br>Senior Aquatic Biologist<br>Environmental Science Associates<br>Phone: 971-295-5016 | Aquatic Plants Lead | Plans and leads aquatic plants surveys. |
| Analytical Laboratory (TBD) | N/A | Reviews draft QAPP, coordinates with Geosyntec's QA team. |
| Department of Ecology | Environmental Assessment Program | Reviews and approves the draft QAPP and the final QAPP. |

## 5.2 Special Training and Certifications

At least one member of the field team for each data collection event will have previous experience with the equipment being used. Field staff must read the QAPP prior to conducting data collection activities, and all staff must be familiar with the project's health and safety plan. As water quality and sediment sampling will be conducted by boat, at least one member of each sampling team must have experience operating a boat. If a motorboat of greater than 15 horsepower is used for sampling the operator must complete a boating safety course and carry a Washington State Boater Education Card. All persons on a watercraft must wear an approved personal flotation device in the state of Washington.

## 5.3 Organization Chart

Figure 3 shows the relationship between organizations responsible for reviewing, approving, or executing this QAPP document and the work it outlines.

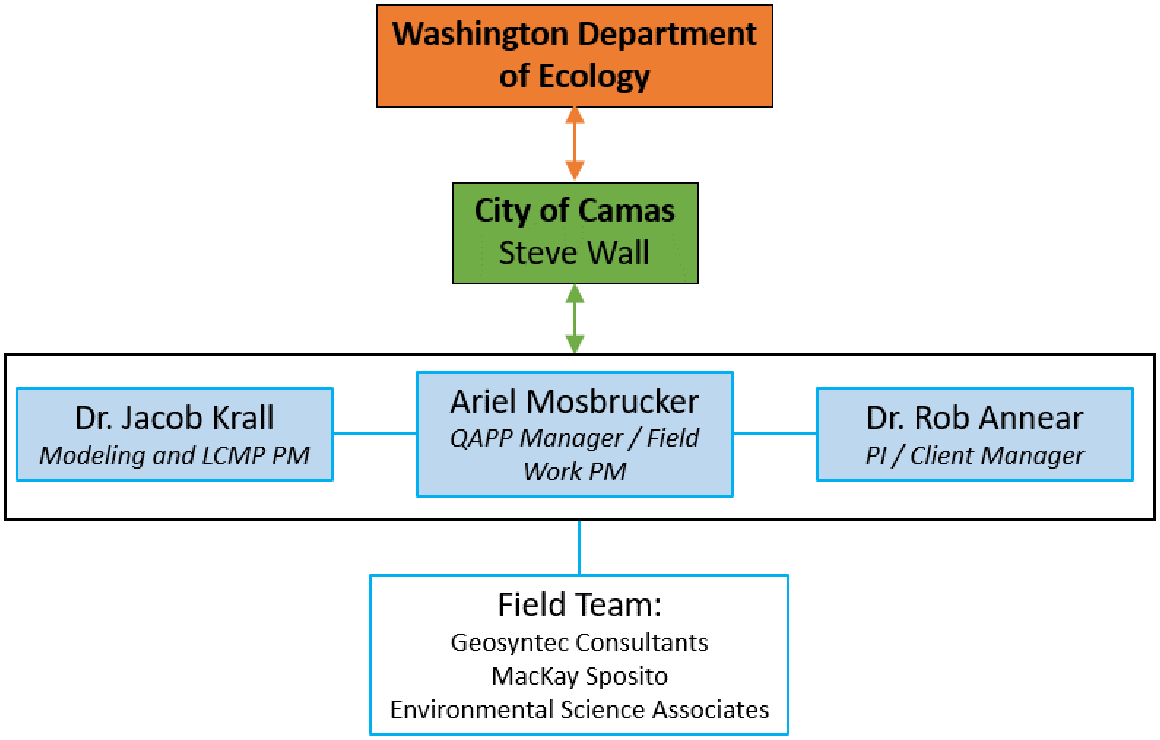

Figure 3. Organizational chart

## 5.4 Proposed Project Schedule

Table 6 through Table 8 list key activities, anticipated completion dates, and lead staff for this project. It should be noted that dates are subject to change based on Ecology approval, contract approval, weather conditions, and other field conditions that might impact the accessibility of the lakes.

Table 6. Schedule for completing field and laboratory work

| **Task** | **Due date** | **Lead staff** |
|---|---|---|
| Field work | May 31, 2023 | Ariel Mosbrucker |
| Laboratory analyses | July 31, 2023 | Analytical Lab |

Table 7. Schedule for data entry

| **Task** | **Due date** | **Lead staff** |
|---|---|---|
| EIM data loaded | December 31, 2023 | Ariel Mosbrucker |

EIM: Environmental Information Management database

Table 8. Schedule for final lake cyanobacteria management plan report

| **Task** | **Due date** | **Lead staff** |
|---|---|---|
| Draft to Ecology | December 31, 2023 | Jacob Krall |

### 5.5 Budget and Funding

This work will be funded through a combination of City of Camas stormwater funds, Washington state capital budget allocations, and Ecology’s Freshwater Algae Control Program Grant. Available funding to date is provided in Table 9.

Table 9. Project budget and funding

| **Funding Source** | **Amount** |
|---|---|
| City of Camas Stormwater Funds | $ 300,000 |
| State Capital Budget Allocation | $ 155,000 |
| Freshwater Algae Control Program Grant | $ 66,666 |
| | ***Total: $ 521,666*** |

Table 10. Laboratory budget details for water quality samples

| Parameter | Method | Approx. Number of Samples | Number of QA Samples | Total Number of Samples | Cost Per Sample ($) | Lab Subtotal ($) |
|---|---|---|---|---|---|---|
| TSS | SM 2540 D-97 | 141 | 23 | 164 | 18 | 3,240 |
| Ammonia | SM 4500-$NH_3$ G | 141 | 23 | 164 | 25 | 4,500 |
| TKN | ASTM D1426-08B | 141 | 23 | 164 | 45 | 8,100 |
| Nitrate + Nitrite | EPA 353.2 | 141 | 23 | 164 | 25 | 4,500 |
| Total P | EPA 365.3 | 141 | 23 | 164 | 30 | 5,550 |
| Soluble Reactive P | EPA 365.3 | 141 | 23 | 164 | 23 | 4,140 |
| Hardness | SM 2340C | 141 | 23 | 164 | 18 | 3,240 |
| Chlorophyll-*a* | SM 10200 H | 57 | 6 | 63 | 45 | 3,600 |
| Phytoplankton Species | N/A | 3 | 0 | 3 | 1200 | 3,600 |

Table 11. Laboratory budget details for sediment samples

| Parameter | Method | Approx. Number of Samples | Number of QA Samples | Total Number of Samples | Cost Per Sample ($) | Lab Subtotal ($) |
|---|---|---|---|---|---|---|
| Total P | EPA 365.3M | 4 | 1 | 5 | 35 | 175 |
| Organic Content | ASTM D2974 – 07a | 4 | 1 | 5 | 35 | 175 |
| Moisture Content | ASTM D2216 | 4 | 1 | 5 | 20 | 100 |
| P-fractionation extraction | Chang and Jackson, 1956, | 4 | 0 | 4 | 1,500 | 6,000 |
| Saloid-bound P | Chang and Jackson, 1956, and EPA 365.3M | 4 | 0 | 4 | 35 | 140 |
| Iron-bound P | Chang and Jackson, 1956, and EPA 365.3M | 4 | 0 | 4 | 35 | 140 |

# 6 QUALITY OBJECTIVES

## 6.1 Data Quality Objectives (DQOs)

The main data quality objective (DQO) for this project is to collect water quality and sediment samples outlined in Section 7 which are representative of the Lacamas, Round, and Fallen Leaf Lakes, and to have them analyzed to support development of hydrologic and nutrient budgets. The analysis will use standard methods to obtain concentration data that meet the measurement quality objectives (MQOs) described below and that are comparable to previous and future study results.

## 6.2 Measurement Quality Objectives (MQOs)

Measurement quality objectives (MQOs) are to obtain data of sufficient quality to meet the study objectives. MQOs include targets for precision, bias, sensitivity, representativeness, comparability, and completeness.

### 6.2.1 Targets for Precision, Bias, and Sensitivity

The MQOs for project results, expressed in terms of acceptable precision, bias, and sensitivity, are described in this section and summarized in Table 12 through

Table 14. MQOs will be verified based on the specific brand and model of field instruments, and analytical laboratory selected for this work. Minor adjustment to these MQOs may be made prior to the start of data collection if necessary.

Table 12. Measurement quality objectives for field measurement equipment

| Parameter | Accuracy | Sensitivity |
|---|---|---|
| Temperature | ± 0.4 degrees C | ± 0.2 degrees C |
| Conductivity | ± 2% | ± 1 µohm/cm |
| ORP | ± 20 mV | ± 0.1 mV |
| DO | ± 10% | ± 0.1 mg/L |
| pH | ± 0.2 S.U. | ± 0.1 S.U. |

Table 13. Measurement quality objectives for laboratory analyses of water samples

| Parameter | Method | Lab Duplicate (RPD) | Field Duplicate (RPD) | Matrix Spike Duplicate (RPD) | Matrix Spike (% Recovery) | Control standard/ surrogate (% Recovery) | Method Reporting Limit Target |
|---|---|---|---|---|---|---|---|
| | | **Bias and Precision** | **Precision** | **Bias and Precision** | **Bias and Accuracy** | **Bias and Accuracy** | **Sensitivity** |
| TSS | SM 2540 D-97 | ≤5% | ≤30% | N/A | N/A | 85 - 115 | 5 mg/L |
| Ammonia | SM 4500-NH$_3$ G | ≤20% | ≤30% | ≤20% | 90 - 110 | 90 - 110 | 0.02 mg/L |
| TKN | ASTM D1426-15B | ≤20% | ≤30% | ≤20% | 72 - 129 | 72 - 129 | 0.04 mg-N/L |
| Nitrate + Nitrite | EPA 353.2 | ≤20% | ≤30% | ≤20% | 90 - 110 | 90 - 110 | 0.02 mg-N/L |
| Total P | EPA 365.3 | ≤20% | ≤30% | ≤20% | 85 - 115 | 85 - 115 | 0.005 mg-P/L |
| Ortho-P | EPA 365.3 | ≤20% | ≤30% | ≤20% | 85 - 115 | 85 - 115 | 0.009 mg-P/L |
| Hardness | SM 2340C | ≤20% | ≤30% | ≤20% | 90 - 116 | 90 - 116 | 0.8 mg-CaCO$_3$/L |
| Chlorophyll-*a* | SM 10200 H | ≤20% | ≤30% | ≤20% | 70 - 130 | 88 - 113 | 0.3 mg/m$^3$ |
| Phytoplankton Species | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

Table 14. Measurement quality objectives for laboratory analyses of sediment samples

| Parameter | Method | Laboratory Duplicate (RPD) | Field Duplicate (RPD) | Matrix Spike Duplicate (RPD) | Matrix Spike (% Recovery) | Control standard/ surrogate (% Recovery) | Method Reporting Limit Target |
|---|---|---|---|---|---|---|---|
| | | Bias and Precision | Precision | Bias and Precision | Bias and Accuracy | Bias and Accuracy | Sensitivity |
| Total P | EPA 365.3M | ≤20% | ≤30% | ≤20% | 75 - 135 | 75 - 135 | 1 mg-P/kg |
| Organic Content | ASTM D2974-07a | N/A | N/A | N/A | N/A | N/A | N/A |
| Moisture Content | ASTM D2216 | N/A | N/A | N/A | N/A | N/A | N/A |
| Saloid-bound P | Modified Chang-Jackson method (Chang and Jackson 1956), followed by EPA 365.3 (water) | Same as Total P in water, above | | | | | |
| Iron-bound P | Modified Chang-Jackson method (Chang and Jackson 1956), followed by EPA 365.3 (eater) | Same as Total P in water, above | | | | | |

#### 6.2.1.1 Precision

Precision is a measure of variability between results of replicate measurements due to random error. It will be assessed using duplicate field measurements and laboratory analysis of duplicate samples. For water samples and surface sediment samples, if the sample container is of sufficient size, two sets of bottles will be filled from the same grab sample. If the sample does not contain sufficient volume for two sets of sample bottles to be filled, a second grab sample will be obtained from the same location within 15 minutes of the first sample for use as a field duplicate. Sediment core duplicates will be obtained by collecting multiple sediment cores within 25 ft of each other.

#### 6.2.1.2 Bias

Bias is the difference between the sample mean and the true value. Bias will be addressed by calibrating field and laboratory instruments, and by analyzing lab control samples, matrix spikes, and/or standard reference materials.

#### 6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. For the purposes of this QAPP it is described as the Method Reporting Limit (MRL; Table 13 and

Table 14).

### 6.2.2 Targets for comparability, representativeness, and completeness

#### 6.2.2.1 Comparability

Comparability will be ensured by following the Standard Operating Procedures (SOPs) specified in Section 8.2. Field staff will be required to review SOPs prior to conducting field sampling to ensure their familiarity with required procedures. Copies of the SOPs will be carried into the field during sampling execution.

#### 6.2.2.2 Representativeness

Representativeness will be ensured by following consistent, documented procedures, including this QAPP. Measurements will be taken as close as practical to the same locations throughout the project, with sample locations recorded via GPS coordinates. Sample coordinates may be adjusted during the first sampling event due to field conditions, but any deviation from the specified sampling location will be documented in the field forms. Following the first sampling event, if sample locations deviate from the target sample location by more than 50 feet, the associated data will be flagged, and the actual sample location will be documented in the field forms. Monthly samples will be taken at least 2 weeks apart to ensure samples are not biased towards a certain set of environmental conditions, with a preference for 3 or more weeks apart. Samples are intended to represent variable flow, seasonality, and weather conditions.

#### 6.2.2.3 Completeness

This study has a goal of 95% completeness as related to collection of specified samples. If safety concerns, access, weather, or other factors prevent the collection of a full suite of data during a given month, a second attempt will be made to collect the data within the same month. If the second attempt is unsuccessful, the project team will assess the criticality of the missing data and whether it can be estimated based on other available information. The reason for any missed sampling events will be recorded in the LCMP, which will contain a data summary for the collected data.

If data is deemed incomplete due to laboratory error, a request will be made to for the lab to re-analyze samples, if holding times allow.

## 6.3 Acceptance Criteria for Quality of Existing Data

Available data will be assessed based on its data quality level as listed in Ecology’s EIM database (Ecology, 2021). Only data with a Level 3 or higher QA Assessment Level designation will be used in the LCMP. Additional data not included in EIM may be used if an associated QAPP is available.

## 6.4 Model Quality Objectives

The models created for this project will be simple spreadsheet-based mass balance models. These nutrient and hydrologic budgets will be considered acceptable if calculated inflows and the sum of outflows plus change in storage is within ±20% of each other.

# 7 STUDY DESIGN

This section describes the collection of samples for field or laboratory analysis to support the LCMP for Lacamas, Round, and Fallen Leaf Lakes.

## 7.1 Study Boundaries

The study boundaries for this project consist of the watersheds for Lacamas, Round, and Fallen Leaf Lakes. This consists of the lakes themselves as well as surrounding streams and stormwater conveyance systems in the vicinity of the lakes where they discharge to, or originate from, one of the three lakes. Selected sample points, by sample type, are shown in Figure 4 and described in their respective subsections of Section 7.2. Selected sample points are approximate and include lake sampling points, which were selected based on lake bathymetry and historical sampling locations; creek sampling points, which were selected based on historical sampling locations and locations where bridges or walkways enable easy access for sampling; and stormwater sampling locations, which were selected based on accessibility as determined during a field visit.

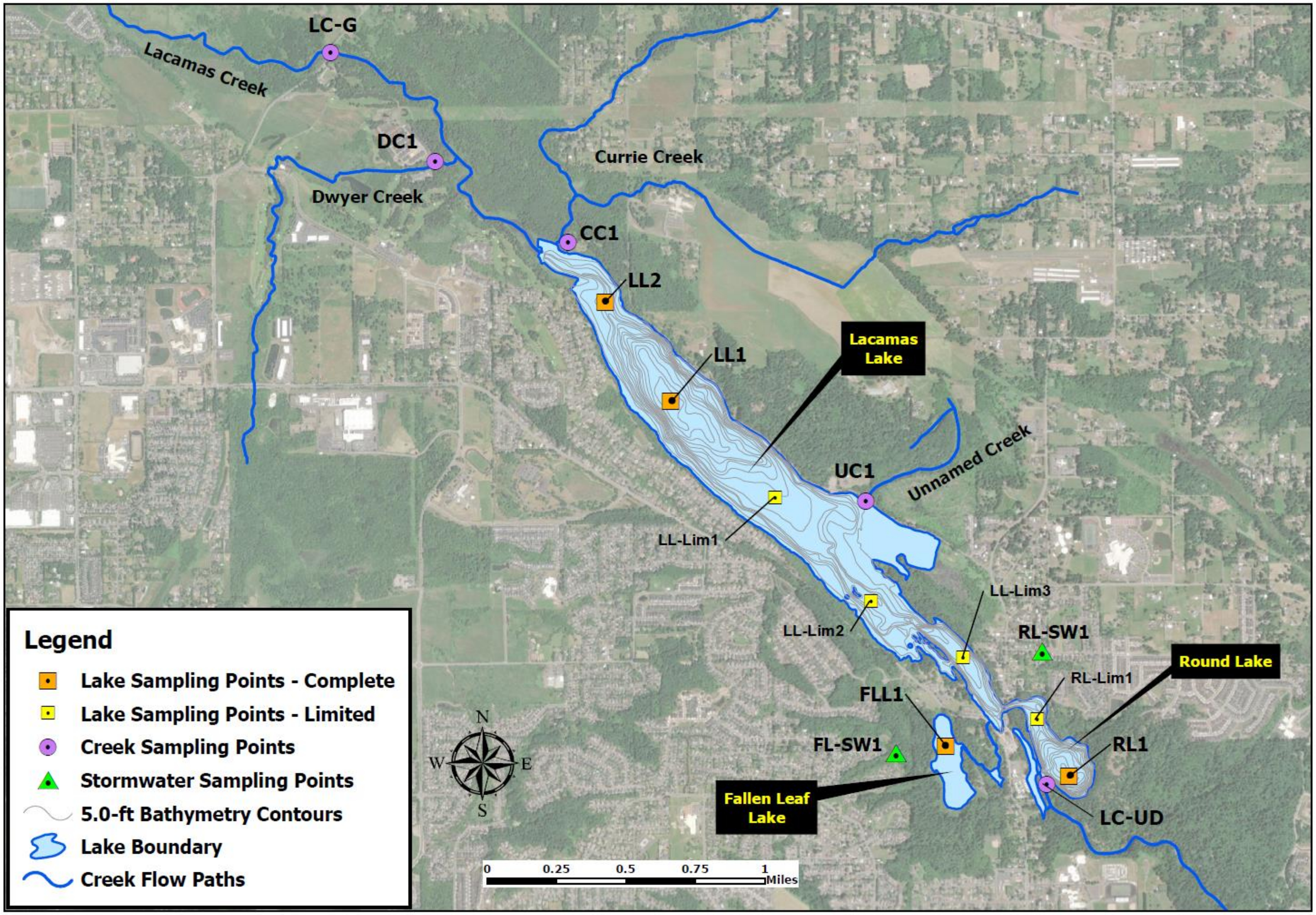

Figure 4. Proposed sampling locations for Lacamas, Round, and Fallen Leaf Lakes

## 7.2 Field Data Collection

### 7.2.1 Hydrology

#### *7.2.1.1 Flow Monitoring*

Flow monitoring will occur for Lacamas Creek at Goodwin Road (LC-G, Figure 4). A gauge has existed here in the past but was decommissioned some time ago. The gauge will be re-established as part of this work.

Outflow from the three lakes will be calculated based on changes in lake storage, calculated via depth measurements, and dimensions of hydraulic structures passing water through each of the upper and lower dams.

#### *7.2.1.2 Meteorological information.*

Multiple sources of data will be used for any meteorological analysis. The sources include Washington State Department of Transportation (WSDOT), Clark County, National Centers for Environmental Information (NCEI), and Automated Surface Observing Systems (ASOS). The open web source Weather Underground will be used for tracking storm forecasts for sampling purposes but will preferentially not be used for data analysis due to a lack of data review protocols with this source (Table 15).

Table 15. Summary of Nearby Meteorological Stations

| Source | Station ID | Latitude | Longitude | Approx. Elevation (ft) | Frequency |
|---|---|---|---|---|---|
| WSDOT | DW4130 | 45.62 | -122.44 | 250 | 15-min |
| WSDOT | DW0646 | 45.61 | -122.43 | 400 | 15-min |
| Clark County | Lacamas | 45.634 | -122.460 | 215 | 15-min |
| NCEI | Portland-Troutdale Airport (72698524242) | 45.551 | -122.410 | 20 | hourly |
| ASOS | Portland-Troutdale (TTD) | 45.551 | -122.410 | 20 | 5-min |
| Weather Underground | KWACAMAS12 | 45.619 | -122.436 | 250 | 5-min |
| Weather Underground | KWACAMAS161 | 45.606 | -122.419 | 282 | 5-min |

#### *7.2.1.3 Other Monitoring*

An observational assessment of whether there is an active surface flow connection between Fallen Leaf Lake and Lacamas Lake will be made during each surface water sampling visit and documented on the field form (Section 7.2.3).

### 7.2.2 Evaporation

#### *7.2.2.1 Locations*

Lake evaporation will be calculated using local meteorological data, and thus there are no evaporation field measurements proposed.

#### *7.2.2.2 Monitoring Methods*

Lake evaporation will be calculated using the U.S. Weather Bureau method presented by Harwell (2012). This requires dewpoint temperature, daily average air temperature, daily average wind speed, and cloud cover from the meteorological data archives.

### 7.2.3 Surface Water

Creek sampling will occur once per month for 12 months from the outset of the project in early 2022. Lake water quality sampling for Lacamas and Round Lakes will occur once per month during the months of April through October, and once in either December or January. Sampling for Fallen Leaf Lake will be limited due to its recent characterization (Clark County Public Works, 2021). However, three sampling events will occur in this lake between the months of May and October to provide a concurrent reference with data from the other two lakes. Sampling events at each location will be at least 2 weeks apart, and preferentially at least 3 weeks apart.

Surface water sampling locations have been identified to characterize water quality in each of Lacamas, Round, and Fallen Leaf Lakes as well as their tributaries (Figure 4). Two types of lake sample locations are identified – complete and limited. All specified field and laboratory data will be collected during all sampling events at complete sampling locations, while only field parameters will be collected at limited sampling locations when certain conditions are present (Table 16).

Table 16. Complete versus Limited Lake Sample Locations

| Complete Lake Sample Locations | Limited Lake Sample Locations |
|---|---|
| • Field parameters collected during every lake sampling event<br>• Samples for laboratory analysis collected during every lake sampling event | • Field parameters collected when an oxycline is present at at least one of the complete lake sampling locations in the same lake<br>• No samples for laboratory analysis will be collected |

Surface water sampling locations are described in Table 17 and Table 18. Locations are intentionally approximate to allow for minor adjustments based on field conditions when initial sampling occurs. In addition, a sampling point may be moved to better align with sample points historically used by Clark County. During initial sampling, geographical coordinates will be recorded, and future sampling will occur as close as reasonably possible to the established coordinates. If a sampling location must be moved, this will be recorded in field logs and the project team will decide whether the moved location will be maintained into the future or whether future sampling will occur at the original location.

Table 17. Lake Sampling Locations

| Site ID | Type | Description | Approx. Location[1] | Estimated max lake depth (m) | Max # depths sampled[2] | Thermistor chain? |
|---|---|---|---|---|---|---|
| LL1 | Lake, Complete | Deepest point in Lacamas Lake | 45.6205, -122.4318 | 20 | 2-3 | Y |
| LL2 | Lake, Complete | Inlet to Lacamas Lake | 45.6257, -122.4366 | 4.6 | 2 | N |
| LL-Lim1 | Lake, Limited | Center of lake SE of LL1 | 45.6037, -122.4047 | 8.5 | - | N |
| LL-Lim2 | Lake, Limited | Center of lake SE of LL-Lim1 | 45.6100, -122.4170 | 6.7 | - | N |
| LL-Lim3 | Lake, Limited | Center of Lake near Heritage Park | 45.6070, -122.4102 | 4.6 | - | N |
| RL1 | Lake, Complete | Deepest point in Round Lake | 45.6008, -122.4024 | 18 | 2-3 | Y |
| RL-Lim1 | Lake, Limited | Round Lake near inlet | 45.6141, -122.423 | 4.6 | - | N |
| FLL1 | Lake, Complete | Deepest point in Fallen Leaf Lake | 45.6024, -122.4115 | 8.8 | 2-3 | N |

[1] Official sampling location coordinates will be established during the first round of sampling based on field conditions. Estimated coordinates are provided to guide field crew members to the approximate desired sampling location during the first sampling event.

[2] This column refers to sample collection for laboratory analysis. Field parameters will be measured every 1.0 m.

Table 18. Creek Sampling Locations

| Site ID | Type | Description | Approx. Location[1] | Estimated max lake depth (m) | Max # depths sampled | Thermistor chain? |
|---|---|---|---|---|---|---|
| LC-G | Creek | Lacamas Creek at Goodwin Road | 45.638786, -122.456912 | N/A | N/A | N/A |
| LC-UD | Creek | Lacamas Creek at outlet from Round Lake Upper Dam | 45.600331, -122.404017 | N/A | N/A | N/A |
| DC1 | Creek | Dwyer Creek at Lacamas Heritage Trail crossing | 45.633073, -122.449174 | N/A | N/A | N/A |
| CC1 | Creek | Currie Creek near outlet across from Camp Currie | 45.628801, -122.439341 | N/A | N/A | N/A |
| UC1 | Creek | Unnamed Creek at SE Leadbetter Road | 45.615173, -122.417336 | N/A | N/A | N/A |

[1] Official sampling location coordinates will be established during the first round of sampling based on field conditions. Estimated coordinates are provided to guide field crew members to the approximate desired sampling location during the first sampling event.

#### *7.2.3.1 Sampling methods: lake samples*

Field parameters (Table 19) will be collected continuously by lowering a water quality sonde from the surface to the bottom of the water column while the sonde records measurements continuously. The sonde’s descent will be paused every 1.0 m until readings stabilize. Temperature (T), specific conductance (SC), pH, DO, oxidation-reduction potential (ORP), and turbidity will be measured.

In addition, thermistor chains will be installed at the deepest location in each of the three lakes (LL1, RL1, and FLL1). These will measure temperature continuously (e.g., every 15 minutes) at a depth interval of approximately 0.75 m, starting 0.5 m from the bottom of the water column and extending through the entire water column of each lake. Data will be downloaded concurrent with lake sampling events.

For collection of samples for laboratory analysis, sampling depths will be selected to produce the best possible estimates of internal loading at the time of sampling. Internal loading of phosphorus into the water column of each lake is likely dependent on vertical mixing. When wind is calm, biological activity reduces DO concentrations in the bottom of the water column. This can lead to bottom-water anoxia, which allows iron-bound phosphorus to move from the sediment bed to the water column. Then, when wind increases, this released phosphorus is mixed through the water column.

The depths at which water samples for laboratory analysis will be collected will vary between locations (Table 17) to A) minimize analytical costs and sampling effort and B) characterize the nutrient chemistry of the water column below the oxycline (i.e., the portion of the water column where DO concentrations change from oxic to anoxic), should it exist. The following steps will be used to determine the depths of samples collected during each sampling excursion:

1. Every collection of water samples should be preceded by measurement of the water column with a multiparameter sonde (field measurements). If the lake water column shows a decrease in DO concentration over depth, often in combination with thermal stratification, a clear change in DO concentration will be important. The depth at which this change occurs represents the oxycline.
2. Two samples should be collected at shallower lake sampling locations, and during times when an oxycline is not present at deeper lake sampling locations (Table 17). In these circumstances, the two samples should be collected 0.5 m below the surface and 0.5 m from the apparent bottom. If bottom sediment is unconsolidated and the depth that is 0.5 m from the bottom is ambiguous, the sample should be collected as deep as possible without collecting unconsolidated fluffy sediment. The turbidity of the sample should be representative of the water column, not the loose floc layer overlying the sediment.
3. Three samples should be collected at deeper lake sampling locations when an oxycline is present (Table 17). When 3 samples are collected, they should be collected at the depths described above for the collection of 2 samples plus also a third depth located 0.5-1.0 m below the oxycline.

To collect samples, a 4- to 6-L vertical Kemmerer bottle or similarly sized Van Dorn sampler will be used at depths greater than 0.5 m. Sampling will occur from the front half of the field vessel to minimize potential for contamination related to the boat engine. Gradations of 0.5 m will be marked on the rope used to suspend the sample collection vessel, and this will determine the precision of the depth at which samples are collected. The sampling vessel will be anchored prior to deployment. When the sampling vessel has been retrieved, it will be used to fill individual sample bottles.

Sample bottles will be handled only with gloved hands, and they will be stored in resealable plastic bags in coolers on ice before and after sampling. Sample bottles will be supplied by the analytical laboratory and thus will not need cleaning; the sampling vessel will be rinsed 3-5 times with distilled water prior to each sampling day and will be flushed with surface water from each location prior to sampling from that location.

### *7.2.3.2 Sampling methods: creek samples*

Creek samples should be collected on a dry day. Specifically, an antecedent dry period of > 6 h with < 0.04 in of rain is required, with an antecedent dry period of > 24 h with < 0.10 in of rain preferred when possible.

Samples should be collected from within the flowing portion of the stream, as close to the thalweg as possible. Samples will be collected as grab samples using a sampling pole or bucket on a string. Sampling vessels will be decontaminated prior to each sampling event using a phosphate-free lab-grade detergent, such as Citranox® or Liquinox®, and will be rinsed with distilled water before sampling at each location.

### *7.2.3.3 Laboratory analytes and field parameters*

Laboratory analytes and field parameters planned for this sampling regime are shown in Table 19. For field measurements at creek sampling locations, a handheld water quality meter or a water quality sonde should be used to measure T, SC, pH, turbidity, ORP, and DO. At lake sampling locations, a water quality sonde should be used to measure these field parameters, and Secchi disk depths should also be recorded. With respect to water quality sonde measurements, a DO optode will be the preferred type of DO sensor due to its speed and ease of use. All sensors will be calibrated according to equipment manufacturer recommendations. For laboratory analytes, laboratory-provided bottles will be obtained and filled with sample, and samples will be stored on ice in a cooler until delivery to the lab.

Table 19. Field and lab measurement parameters for surface water samples

| Parameter | Sample Type | Field Filtered? | Lab or Field Measurement? | Analytical Method |
|---|---|---|---|---|
| Temperature | Lake, Creek | N | Field | Multi-parameter sonde |
| Specific Conductance | Lake, Creek | N | Field | Multi-parameter sonde |
| Dissolved Oxygen | Lake, Creek | N | Field | Multi-parameter sonde |
| Oxidation-Reduction Potential | Lake | N | Field | Multi-parameter sonde |
| pH | Lake, Creek | N | Field | Multi-parameter sonde |
| Secchi depth | Lake | N | Field | Secchi disk |
| Suspended Solids | Complete Lake, Creek | N | Lab | SM 2540 D-97 |

| **Parameter** | **Sample Type** | **Field Filtered?** | **Lab or Field Measurement?** | **Analytical Method** |
|---|---|---|---|---|
| Ammonia | Complete Lake, Creek | N | Lab | SM 4500-$NH_3$ G |
| TKN | Complete Lake, Creek | N | Lab | ASTM D1426-15B |
| Nitrate + Nitrite | Complete Lake, Creek | N | Lab | EPA 353.2 |
| Total P | Complete Lake, Creek | N | Lab | EPA 365.3 |
| Ortho-P | Complete Lake, Creek | Y | Lab | EPA 365.3 |
| Hardness | Complete Lake, Creek | N | Lab | SM 2340C |
| Chlorophyll-*a*[1] | Complete Lake | N | Lab | SM 10200 H |
| Phytoplankton Species[2] | Complete Lake | N | Lab | N/A |

[1] Chlorophyll-a samples will only be taken at depths less than approximately 10 meters, as previous research has shown little to no chlorophyll at deeper depths (Perkins et al., 2019).

[2] Only one phytoplankton species sample from each lake is planned for analysis. This sample will be obtained in late summer or early fall.

### 7.2.4 Waterfowl

Waterfowl are not believed to be a major contributor to nutrients in Lacamas, Round, or Fallen Leaf Lakes. As such, waterfowl surveys will not be conducted.

### 7.2.5 Aquatic Vegetation Survey

The objective of aquatic vegetation surveys are to quantify the plant populations in each lake and better understand the pervasiveness of native and invasive plant species at a high level. These aquatic vegetation surveys are not meant to be an exhaustive study but rather focused on gaining a baseline understanding of the current populations. If this initial survey indicates that additional data are needed, a more detailed survey may be undertaken as part of future studies.

Watercraft-based aquatic vegetation surveys will be conducted for each of Lacamas and Round Lakes. Fallen Leaf Lake will not be surveyed as it was surveyed recently by Clark County (Clark County, 2021). Protocols will follow the point-intercept method specified in Ecology's Aquatic Plant Sampling Protocols guidance document (Parsons, 2001) and detailed in Madsen, 1999. Briefly, the littoral zone of each lake will be divided into 50 x 50 m grids, approximately 30 to 50 of the grid points will be selected as sample points, and presence/absence data for vegetation species will be recorded at each sample point. The littoral zone will be defined by a qualified individual and surveys will not surpass areas with an overlying water depth of greater than 35 ft (10.5 m). Plant species will be identified to species by a qualified aquatic plant botanist.

### 7.2.6 Lake Use Survey

Lake use surveys will be conducted four times: one for each of a weekday and weekend day in each of spring and summer. Surveys will be conducted for up to two hours at each of Heritage Park, Lacamas Park, Fallen Leaf Lake Park, the Leadbetter Road boat launch, and the Lacamas Shores boat launch, between 8 am and 4 pm. Observers will use clicker counters or alternative devices, and will record the following information:

- Site name
- Date, start and end time
- Weather, including temperature, visibility, approximate cloud cover, approximate wind speed
- Observer name
- Number of vehicles with and without boat trailers
- Number and type of watercraft entering the water (motorized, non-motorized)
- Number of swimmers and fishermen not associated with boats
- Number of hikers/walkers/picnic goers
- Number of dogs or other pets

### 7.2.7 Sediment Sampling

Sediment samples will be collected at each of the four complete lake sampling locations (LL1, LL2, RL1, and FLL; Figure 4) once during the sampling year, in spring. Sediment sampling will occur prior to seasonal lake stratification if possible.

#### *7.2.7.1 Sampling methods*

Where possible, samples will be collected as 1-m cores in 3- or 4-inch diameter core liners. Samples will be capped, taped, and stored vertically on ice in the field at or below *in situ* temperature until processing or analysis.

Sediment cores will be collected in the following manner:

- Samples will be obtained by vibracoring where practicable, and by power grab when vibracoring is not practicable.
- A position check will be conducted either pre- or post-sampling to confirm DGPS accuracy and recorded in the field logbook.
- The vessel will maneuver to the proposed sample location and the water depth will be measured and recorded.
- The coring apparatus will be suspended from the vessel to the vertical position and then lowered until the core cutter meets the sediment.
- A core catcher cap will be placed on the bottom of the core tube as soon as the core tube breaks the water surface.
- Core penetration and recovery depth will be recorded, and the core will be inspected for acceptability using the following criteria:
    - Core tube is not overfilled.
    - Overlying water is present (indicates minimal leakage).

  - Estimated recovery is greater than 75%.
  - Core tube appears intact without obstructions or blocking.
  - The desired penetration depth of about 1 m is achieved.
- While the core tube is on deck, the overlying water will be siphoned off, if necessary, using plastic tubing or similar siphoning device. The core tube will be capped, and the exterior of the core tube will be scribed with the sample ID and recovery information.
- The core tube may be temporarily stored on the vessel and then transported to shore for processing, or may be processed on the vessel

The percent recovery will be estimated by measuring the total core length minus the void space within the core; the percent recovery is the sample length divided by the penetration depth. Percent recovery and total drive depth are used to determine the *in-situ* depth of subsamples. The core catcher will be inspected for signs of sediment loss during retrieval. The following data will be recorded on the sediment core log:

- Sampling location, time, and water depth
- Mudline elevation
- Core tube penetration depth and sample recovery
- Physical description of core tube (e.g., intact, bent, full core catcher)

If sample acceptance criteria are not achieved, the core may be set aside, and additional core drives will be advanced. If necessary, the best of three core drives will be accepted (deepest drive depth, highest % recovery), even if core recoveries are less than 75%. Sampling crews may increase the sampling area to a radius of 50 ft or more from the proposed location to try and improve sample recovery.

For processing, core tubes will be split open longitudinally (with or without a liner) and sediment will be visually logged using ASTM International Visual-Soil Classification Methods (D-2488). The core processing logs will include:

- Sediment type, density/consistency, including sediment particle size estimates
- Debris (wood, large rocks etc.) or vegetation
- Actual sample length and “representative” length before compaction during core collection
- Visual stratification and lenses
- Biological activity (e.g., shells, tubes, presence of organisms)
- Other distinguishing characteristics or features

After logging, samples will be photographed prior to sectioning the top 5 cm of each core. Sediment will be scooped out of the core tube using stainless-steel spoons; sediment in direct contact with the sidewalls of the tube will be avoided. Stainless-steel spoons, small spatulas, photographs, and a tape measure will be used in the logging process. Samples will be stored in laboratory provided containers and placed in a cooler with ice. The 0-5 cm section, representing the readily available in-lake nutrient load, will be submitted for analysis.

If coring is not possible due to logistical constraints (see Section 7.5.1) sediment grab samples may be collected in lieu of cores.

#### *7.2.7.2 Analysis of Sediment Samples*

Sediment samples will be analyzed for the parameters specified in Table 20. Saloid-bound P and iron-bound P will be determined by extracting the iron-bound P fraction using the modified Chang-Jackson method (Chang and Jackson, 1956). Saloid-bound P is representative of the stored P that is releasable under aerobic conditions, and iron-bound P is representative of the stored P that is releasable under anaerobic conditions. The remaining sediment P is considered stable. The fractionations and extraction will be performed by SiREM lab in Knoxville, TN, and the P fractions will be subsequently determined by the selected Ecology-certified laboratory by analyzing the appropriate extracts for total P content using the method listed in Table 20.

Measurement of nitrogen species in sediment is excluded for several reasons. Foremost, algal blooms in all three lakes have historically occurred when the lake is stratified and the bottom water is anoxic. Under these conditions, the potential for release of phosphorus from lake sediments is at its greatest, and the nitrogen to phosphorus ratio in Lacamas Lake has tended to decrease over the summer (e.g., Schnabel, 2007), indicating the potential for release of phosphorus from lake sediments is of greater significance than release of nitrogen from lake sediments. Furthermore, nitrogen concentrations are difficult to manage and control, as some algal species can fix nitrogen from the atmosphere when nitrogen is limited. For these reasons, analysis of sediment in the lake will focus on phosphorus species.

Table 20. Analytical measurement parameters for sediment samples

| **Parameter** | **Method** |
|---|---|
| Total P | EPA 365.3 M |
| Organic content | ASTM D2974 – 07a |
| Moisture content | ASTM D2216 |
| Saloid-bound P | Modified Chang-Jackson method (Chang and Jackson, 1956), followed by EPA 365.3 |
| Iron-bound P | Modified Chang-Jackson method (Chang and Jackson, 1956), followed by EPA 365.3 |

### 7.2.8 Groundwater

Previous investigations have determined that most groundwater contributions likely enter the lakes along their southwestern edge (E&S Environmental Chemistry, Inc. 1997). However, it is unlikely that the groundwater in this area carries high nutrient loads, as the overlying area is a residential development which is connected to the sanitary system and contains little agriculture. As such groundwater is not likely to be a significant source of nutrients to any of the three lakes and will therefore not be monitored as part of this effort.

As part of the LCMP, research will be performed to determine if any additional information on groundwater movement in the area has been published since the 1997 study. If any new and relevant information is found it will be referenced in the LCMP and estimates of groundwater inflow to the lakes will be updated as necessary.

### 7.2.9 Overland \ Stormwater Flow

#### *7.2.9.1 Sampling Locations*

Stormwater sampling sites were selected using the following general guidance (USGS, 2009; Center for Watershed Protection, 2008):

- Sites should be readily accessible for field crews, preferentially at public locations or in public right of way.
- Sites should be safe locations to conduct sampling activities.
- Site proximity should be considered to ensure efficient sampling of multiple sites during storm events.
- Site locations should avoid stagnant or tailwater conditions and those with steep slopes.

Fifteen locations were identified from GIS desktop analysis and were visited in person to determine viability for sampling based on the general guidance above. Two sites were selected for stormwater sampling: one which discharges to Round Lake and one which discharges to Fallen Leaf Lake (Table 21). Sites discharging to Lacamas Lake were not included due to the inclusion of sampling for small creeks tributary to Lacamas Lake (Section 7.2.3.2), which will capture some stormwater, and due to the size of Lacamas Lake, which is less likely to be affected by inputs from direct stormwater inflows.

Table 21. Stormwater Sampling Locations

| Site | Lake Drainage | Approx. Location |
|---|---|---|
| RL-SW1 | Round Lake | 45.607249, -122.404298 |
| FL-SW1 | Fallen Leaf Lake | 45.602022, -122.415203 |

#### *7.2.9.2 Sample Collection Methods*

Stormwater sampling will occur during the spring and fall seasons. These are time periods during which direct stormwater contribution from the surrounding areas to the three lakes is highest in proportion to inflow from other sources. Two samples are targeted for each season from each location.

To the maximal extent possible, the storms sampled will adhere to the following criteria:

- Antecedent dry period: > 6 h with < 0.04 in of rain (USGS, 2014)
- Predicted storm duration: > 6 h (USGS, 2014 )
- Predicted storm depth: > 0.15 in (City of Portland BES, 2015)

All samples will be grab samples collected in accordance with Ecology stormwater sampling manuals (Ecology, 2015). Sampling vessels will be decontaminated prior to each sampling event using a phosphate-free lab-grade detergent, such as Citranox® or Liquinox®, and will be rinsed at least three times with native water before sampling at each location. Two types of measurements will be collected from each site: field and analytical laboratory (Table 22).

Table 22. Field and lab measurement parameters for stormwater samples

| Parameter | Field Filtered? | Lab or Field Measurement? | Analytical Method |
|---|---|---|---|
| Temperature | N | Field | Multi-parameter sonde |
| Specific Conductance | N | Field | Multi-parameter sonde |
| Dissolved Oxygen | N | Field | Multi-parameter sonde |
| pH | N | Field | Multi-parameter sonde |
| Suspended Solids | N | Lab | SM 2540 D-97 |
| Ammonia | N | Lab | SM 4500-NH$_3$ G |
| TKN | N | Lab | ASTM D1426-15B |
| Nitrate + Nitrite | N | Lab | EPA 353.2 |
| Total P | N | Lab | EPA 365.3 |
| Ortho-P | Y | Lab | EPA 365.3 |
| Hardness | N | Lab | SM 2340C |

## 7.3 Modeling and Analysis Design

A full numerical model is not planned for this project. An analytical phosphorus model, such as the Vollenweider mass-balance model, will be developed. This model predicts the lake phosphorus concentration based on the phosphorus loading, mean hydraulic residence time, and a first-order loss coefficient (which represents processes such as sedimentation), which will be a calibration parameter. This will be performed as a simple spreadsheet model.

The data collected as part of this study is expected to be sufficient to complete the hydrologic and nutrient budgets for Lacamas and Round Lakes. Due to its size and lack of continuous direct connection with the other two lakes, budgets for Fallen Leaf Lake may have a large error.

### 7.3.1 Hydrologic Budget

The hydrologic budget of the connected Lacamas and Round Lakes will be defined as described in Equation 1:

$$P + Q_{LC\text{-}G} + Q_{DC} + Q_{CC} + Q_{DC} + Q_{SR} + GW = Q_{LC\text{-}UD} + Q_{LC\text{-}LD} + EVAP + \Delta S \qquad (1)$$

where

$P$ is the volume of precipitation falling directly on the lake

| | |
|---|---|
| $Q_{LC-G}$ | is inflow via Lacamas Creek at Goodwin Road |
| $Q_{CC}$ | is inflow via Currie Creek |
| $Q_{DC}$ | is inflow via Dwyer Creek |
| $Q_{SR}$ | is inflow via surface runoff |
| $GW$ | is groundwater inflow volume |
| $Q_{LC-UD}$ | is flow at Lacamas Creek originating from the Upper Dam |
| $Q_{LC-LD}$ | is flow at Lacamas Creek originating from the Lower Dam |
| $EVAP$ | is evaporation from the lake surface |
| $\Delta S$ | is the change in lake storage |

Of these variables only $Q_{LC-G}$ will be directly measured. $Q_{CC}$, $Q_{DC}$, and $Q_{SR}$ will be estimated from drainage area characteristics. $Q_{LC-UD}$ and $Q_{LC-LD}$ will be estimated based on lake level and dam operations, and P and EVAP will be calculated from meteorological data. GW and S will be unknowns whose values will be checked against estimates from previous studies, and lake level changes, respectively.

### 7.3.2 Nitrogen Budget

The budgets for total nitrogen in the water column of the connected Lacamas and Round Lakes will be defined as described in Equation 2:

$$L_{LC-G-N} + L_{DC-N} + L_{CC-N} + L_{SR-N} + GW_N + L_{INT-L-N} + L_{INT-R-N} + L_{ATM-N} = E_{UD-N} + E_{LD-N} + \Delta S_N + D \tag{2}$$

where

| | |
|---|---|
| $L_{LC-G-N}$ | is the load of nitrogen entering via Lacamas Creek at Goodwin Road |
| $L_{CC-N}$ | is the load of nitrogen entering via Currie Creek |
| $L_{DC-N}$ | is the load of nitrogen entering via Dwyer Creek |
| $L_{SR-N}$ | is the load of nitrogen entering via surface runoff |
| $GW_N$ | is the load of nitrogen entering via groundwater |
| $L_{INT-L-N}$ | is the internal load of nitrogen entering the water column from the sediment bed in Lacamas Lake |
| $L_{INT-R-N}$ | is the internal load of nitrogen entering the water column from the sediment bed in Round Lake |
| $L_{ATM-N}$ | is loading via atmospheric deposition |
| $E_{UD-N}$ | is the export of nitrogen via flow out of the lake from the upper dam |
| $E_{LD-N}$ | is the export of nitrogen via flow out of the lake from the lower dam |
| $S_N$ | is the change in nitrogen stored in the lake |
| $D$ | is the loss of nitrogen to the atmosphere via denitrification. |

Of these variables, $L_{LC-G-N}$ will be calculated from measured flow and measured nitrogen concentrations. $L_{CC-N}$, $L_{DC-N}$, $L_{SR-N}$, and $E_{UD-N}$ will be calculated from estimated flow and measured nitrogen concentrations. $E_{LD-N}$ will be calculated from estimated flows and the nitrogen concentration exiting the upper dam. $L_{INT-N}$ will be calculated from measured sediment and sediment flux concentrations. $GW_N$, $L_{ATM-N}$, D, and $S_N$ will be unknowns that may be estimated via literature values.

### 7.3.3 Phosphorus Budget

The budgets for total phosphorus in the water column of the connected Lacamas and Round Lakes will be defined as described in Equation 3:

$$L_{LC\text{-}G\text{-}P} + L_{DC\text{-}P} + L_{CC\text{-}P} + L_{SR\text{-}P} + GW_{P} + L_{INT\text{-}L\text{-}P} + L_{INT\text{-}R\text{-}P} + L_{ATM\text{-}P} = E_{LD\text{-}P} + E_{UD\text{-}P} + \Delta S_{P} \qquad (3)$$

where

| | |
|---|---|
| $L_{LC\text{-}G\text{-}P}$ | is the load of phosphorus entering via Lacamas Creek at Goodwin Road |
| $L_{DC\text{-}P}$ | is the load of phosphorus entering via Dwyer Creek |
| $L_{CC\text{-}P}$ | is the load of phosphorus entering via Currie Creek |
| $L_{SR\text{-}P}$ | is the load of phosphorus entering via surface runoff |
| $GW_{P}$ | is the load of phosphorus entering via groundwater |
| $L_{INT\text{-}L\text{-}P}$ | is the internal load of phosphorus entering the water column from the sediment bed in Lacamas Lake |
| $L_{INT\text{-}R\text{-}P}$ | is the internal load of phosphorus entering the water column from the sediment bed in Lacamas Lake |
| $L_{ATM\text{-}P}$ | is loading via atmospheric deposition |
| $E_{UD\text{-}P}$ | is the export of phosphorus via flow out of the lake from the upper dam |
| $E_{LD\text{-}P}$ | is the export of phosphorus via flow out of the lake from the lower dam |
| $\Delta S_{P}$ | is the change in phosphorus stored in the lake. |

Of these variables, $L_{LC\text{-}G\text{-}P}$ will be calculated from measured flow and measured nitrogen concentrations. $L_{CC\text{-}P}$, $L_{DC\text{-}P}$, $L_{SR\text{-}P}$, and $E_{UD\text{-}P}$ will be calculated from estimated flow and measured phosphorus concentrations. $E_{LD\text{-}P}$ will be calculated from estimated flows and the phosphorus concentration exiting the upper dam. $L_{INT\text{-}P}$ will be calculated from measured sediment and sediment flux concentrations. $GW_{P}$, $L_{ATM\text{-}P}$, and $S_{P}$ will be unknowns that may be estimated via literature values.

## 7.4 Assumptions of Study Design

Assumptions underlying this study design appear in Table 23.

Table 23. Assumptions underlying study design

| Task | Assumptions |
|---|---|
| **Hydrology** | • Efforts to reestablish continuous flow gauging on Lacamas Creek at Goodwin Road will be successful.<br>• Equations presented by Harwell (2012) for the U.S. Weather Bureau method of estimating evaporation render pan evaporation measurements unnecessary.<br>• Stormwater drainage areas are sufficiently defined to allow for reasonable estimation of runoff.<br>• Water level data near the Round Lake dams will be available for the duration of the field study. |

| Task | Assumptions |
|---|---|
| **Surface Water Sampling** | • A set of surface water measurements and samples can be accomplished in 1-2 workdays, allowing preparation and follow-up activities to occur within one week.<br>• Stratification will be sufficiently stable when it occurs for field measurements to characterize it and anoxic bottom water to be sampled.<br>• Staff will be available to keep to a consistent field sampling schedule and to process samples and organize data in between sampling trips.<br>• Ecology's EIM database will be sufficient for storage of field analytical results and corresponding metadata. |
| **Stormwater Sampling** | • Stormwater sampling points will have flow during qualifying events when samplers go to the field to obtain samples |
| **Hydrologic Budget** | • Groundwater flows are not significant.<br>• Sufficient data will be available to estimate flows exiting the lakes into lower Lacamas Creek. Hydrologic mass balance will be conducted quarterly to assess sufficiency of data. |
| **Nutrient Budgets** | • Internal loading estimates will be reasonable when based on a limited number of bottom water and sediment samples. |

## 7.5 Possible Challenges and Contingencies

### 7.5.1 Logistical problems

Sampling locations will be visited during trial field sampling runs prior to the collection of data. Logistical and/or health and safety issues encountered during these dry runs will receive careful consideration.

Of the three lakes, only Lacamas Lake contains a true boat launch. Round Lake has a dirt ramp for launching small watercraft while Fallen Leaf Lake does not have any type of ramp. Travel from Lacamas to Round and Fallen Leaf Lakes is not possible for a typical sampling vessel due to clearance between the lake water surface and the SR500 bridge. Furthermore, motorized vessels are not permitted on Round or Fallen Leaf Lakes, though the field staff may request an exemption from the City of Camas, if possible. As such, multiple types of vessels will be needed to conduct sampling, and boats will need to be launched and loaded at each lake.

Sediment sampling may prove difficult if it must occur from a small, non-motorized watercraft. In this case, the team will need to explore the possibility of alternate options, such as installation of a temporary floating dock above the sample points in Round and Fallen Leaf Lakes, or the use of small pontoon boats or rowboats. If necessary, sediment samples in Round and Fallen Leaf Lakes may need to be surface grab samples rather than core samples or may need to be collected by hand using SCUBA gear.

Logistical problems for surface water and sediment sampling may include the ability to sample all locations in close temporal proximity, as watercraft will need to be launched and reloaded at each of the three lakes, safe access to each of the creek sampling locations, and timely availability of rental equipment and contractors. Furthermore, access to Currie Creek is through Camp Currie, whose gate is locked for portions of the year. Samplers will need to work with the City of Camas to obtain access to this location during the off season.

Logistical problems for overland flow sampling could include timing of rain, ability to safely reach sampling points during low-light conditions, and ability to reach and sample all locations during the same storm.

Finally, the lakes experience heavy use during summer months. Issues such as vandalism or theft of thermistors may arise.

### 7.5.2 Practical constraints

Most sampling will need to be done with at least two people present for safety reasons. Sampling will require at least 2 days per month for surface water samples, along with an additional day for each of equipment preparation and post-sampling equipment maintenance. Back-up staff will need to be identified to accommodate work absences (e.g., vacation, sick time) so that these events do not lead to missed sampling excursions.

### 7.5.3 Schedule limitations

Logistical issues may lead to sampling events that are not evenly spaced between months, or even missed sampling events. Sample events are most critical during the likely period of stratification (May through October), so it is essential that the QAPP be reviewed and approved in time for sampling to start, preferably by April 2022, but no later than May 2022, to ensure at least one sampling collection event occurs before the critical time period is reached.

# 8 FIELD PROCEDURES

## 8.1 Invasive Species Evaluation

Environmental ethics and Washington law prohibit the transportation of aquatic plants, animals, and many noxious weeds. The procedures explained in this section describe the field procedures that will be used to prevent the transport of aquatic invasive species (AIS) into Lacamas, Round, and Fallen Leaf Lakes while conducting field work.

In general, equipment used in the field must be easy to inspect and clean. If feasible, each piece of equipment should be used in a singular water body. Non-felt soles and boot-foot waders will be used during fieldwork in sediment or waterways since the spread of New Zealand mud snails and other AIS has been associated with felt-soled wading gear. Since sampling from Lacamas, Round, and Fallen Leaf Lakes will not take place in an area of extreme concern for AIS in Washington, additional decontamination steps for other equipment are not necessary.

Throughout field activities, it is essential to minimize the contact between equipment and potential sources of invasive species. For instance:

i. Sample collection should be prioritized from the least to most impacted areas.
ii. Activities that involve contact with sediment (i.e., wading) or disturbance of sediment (i.e., running boats in very shallow water)should be avoided.
iii. A catch pan will be used underneath the sediment coring apparatus when it is retrieved to avoid getting plants, sediment, fish, or other AIS on the boat deck and bilges.
iv. Driving and walking through muddy areas with high weed growth should be avoided.

Field gear used for sampling will be used only after drying from its previous use. For example, boots and waders should be stored on a drying rack until dry, not left in a gear bag.

After completion of fieldwork, equipment and gear will be inspected and cleaned, preferably before leaving the sampling site. Visible vertebrates, invertebrates, plants, algae, or sediment on equipment will be removed manually or with a scrub brush. Bilges, samplers, or any other equipment will be drained since they could hold water from the site. Areas that are difficult to clean manually will be flushed until the rinse water is clean. More detailed information on how to clean boats and motors can be found in Attachment B of EAP070 (linked in Table 24).

Procedures described in this SOP must be followed except when the fieldwork includes:

i. Moving short distances by foot within the same watershed
ii. Transiting by boat to different sites within a waterbody

If procedures in this SOP are not workable for a particular part of the project, exceptions will be documented prior to commencement of work.

## 8.2 Measurement and Sampling Procedures

Prior to sampling, field staff will review relevant SOPs to ensure samples and field measurements are collected properly (Table 24).

Table 24. Standard operating procedures

| Activity | SOP | Year | Title and Link |
|---|---|---|---|
| All field work | EAP070 | 3/2018 | Minimize the Spread of Invasive Species |
| Measurement of field parameters | EAP011 | 1/2019 | Instantaneous Measurements of Temperature in Water |
| | EAP031 | 1/2018 | Collection and Analysis of pH Samples |
| | EAP032 | 7/2017 | Collection and Analysis of Conductivity Samples |
| | EAP108 | 2/2019 | Collecting In Situ Water Quality Data |
| Continuous T measurements | EAP080 | 4/2018 | Continuous Temperature Monitoring of Freshwater in Rivers and Streams |
| Collection of water quality samples | EAP034 | 7/2017 | Collection, Processing, and Analysis of Stream Samples |
| Collection of sediment samples | EAP110 | 11/2018 | Sampling Sediment for Chemistry |
| Collection of stormwater samples | 18-10-026 | 7/2018 | Calculating Pollutant Loads for Stormwater Discharges |
| | 18-10-023 | 7/2018 | Collecting Grab Samples from Stormwater Discharges |

## 8.3 Containers, Preservation Methods, Holding Times

Hold times, sample size requirements, and containers required for sampling efforts are presented in Table 25 and Table 26.

Table 25. Containers and hold times for water quality parameters

| **Parameter** | **Method** | **Min. Volume (mL)** | **Hold Time (d)** | **Container Type[1]** | **Preservative[2]** |
|---|---|---|---|---|---|
| Suspended Solids | SM 2540 D-97 | 1000 | 7 | HDPE | a |
| Ammonia | SM 4500-$NH_3$ G | 500 | 28 | HDPE | a, b |
| TKN | ASTM D1426-15B | 500 | 28 | HDPE | a, b |
| Nitrate + Nitrite | EPA 353.2 | 500 | 28 | HDPE | a, b |
| Total P | EPA 365.3 | 500 | 28 | HDPE | a, b |

| **Parameter** | **Method** | **Min. Volume (mL)** | **Hold Time (d)** | **Container Type**[1] | **Preservative**[2] |
|---|---|---|---|---|---|
| Ortho- P | EPA 365.3 | 500 | 2 | HDPE | a |
| Hardness | SM 2340C | 500 | 182 | HDPE | c |
| Chlorophyll-*a* | SM 10200 H | 1000 | 2[3] | AG | a |
| Phytoplankton Species | SM 10200 E | 500 | -[4] | HDPE | a, d |

[1] HDPE = high-density polyethylene, AG = amber glass

[2] a = cool 0-6°C, b = pH<2 with $H_2SO_4$, c = pH<2 with $HNO_3$, d = ethanol or isopropyl alcohol (contact lab) or Lugol's solution

[3] Requirement is to filter within 48 hours.

[4] Hold time not specified for preserved samples. If not field-preserved, samples must be shipped to lab overnight on ice.

Table 26. Containers and hold times for sediment parameters

| **Parameter** | **Analytical Method** | **Minimum Mass (g)** | **Hold Time (d)** | **Container** |
|---|---|---|---|---|
| Total P | EPA365.3M | 20 | 28 | glass jar |
| Organic Content | ASTM D2974 - 2031 | 20 | 10 | glass jar |
| Moisture Content | ASTM D2216 | 20 | 10 | glass jar |
| Saloid-bound P | Modified Chang-Jackson method (Chang and Jackson, 1956), followed by EPA 365.3 | 25 | 28 | glass jar |
| Iron-bound P | Modified Chang-Jackson method (Chang and Jackson, 1956), followed by EPA 365.3 | 25 | 28 | glass jar |

### 8.4 Equipment Decontamination

Field staff may encounter cyanotoxins while sampling in support of this project. No other exposure of equipment to toxic chemicals is anticipated as part of the planned sampling described here.

Equipment will be decontaminated between sampling locations to prevent the spread of invasive species, for sample quality assurance/quality control, and to keep the equipment in good working order. Decontamination of equipment will consist of thorough rinsing with native water at sampling locations and with distilled water at the end of each sampling day.

## 8.5 Sample ID

A self-adhesive, non-removable label will be affixed to each sample container and completed with an indelible marker prior to sample collection. Sample labels will contain the following information:

- Site name
- Project number
- A unique sample identification number (see below for correct sample designation nomenclature for quality control samples)
- Initials of sample collector(s)
- Time and date collected
- Analysis required
- Sample preservative (if applicable)

Locations where field quality control (QC) samples are collected will be documented in field records. The following standard abbreviations will be used:

- d.1 – start of the sample depth interval in feet to closest tenth of a foot
- d.2 – end of sample depth interval in feet to closest tenth of a foot
- yymmdd – date of sample collection
- field duplicate samples will use “FD” followed by sequential numbering (i.e., FD1, FD2, etc.) so that the laboratory cannot identify where the sample came from. Field notes will record what sample is represented by each field duplicate.
- Equipment blank sample IDs will use QCEB-#

## 8.6 Chain-of-Custody

Chain-of-custody forms will be used to trace the possession and handling of samples, from the time of their collection, through analysis, until their final disposition. These forms will document the names of the relinquishing and receiving parties and the time and date of the transfer of custody. Field personnel will complete the following information on each chain of custody form:

- Project number
- Client or project name
- Project location
- Sample identification number
- Date and time of sample collection
- Sample matrix

- Sample preservative
- Analyses requested
- Sampler's signature
- Signature of person relinquishing sample custody to the laboratory courier or FedEx
- Date and time relinquished
- Sampler remarks

One chain-of-custody form will accompany each set of coolers sent to the laboratory. The chain of custody form will be placed in a sealed plastic bag inside the cooler. A custody seal will be placed on each cooler after packing and prior to shipment. For multiple cooler shipments, the cooler number designation (e.g., cooler 1 of 2, cooler 2 of 2) will be written on the custody seal. Shipping of samples to the laboratory will be accomplished by FedEx or equivalent overnight service. Samples will remain in the custody of the sampling team until custody is relinquished to FedEx or a laboratory courier. Each sample shipment will be tracked via the FedEx tracking number to ensure that prompt delivery of the shipment to the laboratory has occurred. A copy of the chain-of-custody form will then be transmitted to the project manager and uploaded to the project file folder.

### 8.7 Field Log Requirements

Field activities will be documented meticulously using permanent waterproof ink on field worksheets that are organized in a field sampling log. All entries will be initialed and dated accordingly. When changes are necessary, personnel will draw a single line through the error, write the corrections adjacent to it, and initial it. Documented field procedures should be detailed enough to allow the data user to easily understand the procedures. All field procedures must include a list of the required field log entries such as:

- Project Name
- Project location
- Field personnel information
- Sequence of events
- Any changes or deviations from the QAPP
- Environmental conditions (e.g., air and water temperature, wind, cloud cover, etc.)
- Date, time, location, ID, and description of each sample
- Instrument calibration procedures, if needed.
- Field equipment decontamination procedures
- Field measurement results
- Identity of QC samples collected
- Unusual circumstances that might affect interpretation of results

### 8.8 Other Activities

The laboratory will be alerted at least three business days in advance of anticipated lake, surface water, and sediment sampling, so they are prepared to receive samples. The lab may not be alerted in advance of stormwater sampling due to the uncertain timing inherent to stormwater sampling.

A tailgate safety meeting will occur at the beginning of each field workday. Safety meetings will include a brief review of the health and safety plan, a more detailed discussion of activities being performed for the first time or changes to previously executed activities, and any special considerations, such as expected weather.

# 9 LABORATORY PROCEDURES

## 9.1 Lab Procedures Table

Samples will be sent to an Ecology-accredited analytical laboratory for analyses of water quality parameters (Table 27) and sediment parameters (

Table 28) when practicable. If an Ecology-accredited laboratory that accepts outside samples is not available for a specific parameter, or if Ecology-accredited laboratories have prohibitive turnaround times or costs, laboratories with other certifications will be considered.

Containers will be provided by analytical laboratories with preservative already in them, so field sampling personnel will not be responsible for adding preservative. Phytoplankton concentration will be quantified, and species will be identified according to standard methods.

Filtered samples will be filtered in the field through 0.45 μm polytetrafluoroethylene (PTFE) or polyethersulfone (PES) syringe-tip filters attached to polypropylene (PP) syringes, or through 0.45 μm PES high-capacity cartridge filters.

Table 27. Analytical methods for water quality samples

| Parameter | Matrix | Sample Type[1] | Approx. # Samples | Target MDL | Analytical Method |
|---|---|---|---|---|---|
| Suspended Solids | W | L, C, S | 164 | 5 mg/L | SM 2540 D-97 |
| Ammonia | W | L, C, S | 164 | 0.02 mg/L | SM 4500-$NH_3$ G |
| TKN | W | L, C, S | 164 | 0.04 mg-N/L | ASTM D1426-15B |
| Nitrate + Nitrite | W | L, C, S | 164 | 0.02 mg-N/L | EPA 353.2 |
| Total P | W | L, C, S | 164 | 0.005 mg-P/L | EPA 365.3 |
| Ortho-P | W | L, C, S | 164 | 0.009 mg-P/L | EPA 365.3 |
| Hardness | W | L, C, S | 164 | 0.8 mg-$CaCO_3$/L | SM 2340C |
| Chlorophyll-*a* | W | L | 63 | 0.3 mg/m$^3$ | SM 10200 H |
| Phytoplankton Species | W | L | 3 | N/A | N/A |

[1] L = lake samples, C = creek samples, S = storm samples (Figure 4)

Table 28. Analytical methods for sediment samples

| Parameter | Matrix | # Samples | Target MDL | Analytical Method |
|---|---|---|---|---|
| Total P | S | 5 | 0.2 mg-P/kg | EPA 365.3M |
| Organic Content | S | 5 | - | ASTM D2974 – 07a |
| Moisture Content | S | 5 | - | ASTM D2216 |
| Saloid-bound P | S | 4 | *Same as Total P in water* | Modified Chang-Jackson (Chang and Jackson, 1956), followed by EPA 365.3M |
| Iron-bound P | S | 4 | *Same as Total P in water* | Modified Chang-Jackson (Chang and Jackson, 1956), followed by EPA 365.3M |

### 9.2 Special Method Requirements

For biological analyses (e.g., concentrations and species counts of phytoplankton), a ≥24 h notice is required before sending samples to the analytical laboratory because analyses must begin within 12 h of receiving samples.

### 9.3 Laboratories Accredited for Methods

Samples collected will be analyzed by an Ecology-accredited analytical laboratory where practicable, which will be selected at a later date. If an Ecology-accredited laboratory is not available for a specific parameter due to prohibitive turnaround time or costs, laboratories with other accreditations may be considered.

# 10 QUALITY CONTROL PROCEDURES

Field quality control (QC) will be accomplished through calibration and validation of equipment, as well as the measurement of field duplicates. Laboratory QC will be assessed through the internal laboratory QC performed, including method blanks, laboratory control sample (LCS) recoveries, surrogate recoveries, laboratory duplicates, and matrix spike/matrix spike duplicate recoveries as applicable to the analytical method.

## 10.1 Instrument Calibration

Laboratory instruments will be calibrated according to the specified analytical methodology and manufacturer’s instructions. Calibration of instruments is required to ensure the analytical system is operating correctly and functioning at the proper sensitivity to meet established reporting limits. Each instrument will be calibrated with standard solutions appropriate to the type of instrument and the calibration range established for the given analytical method. The frequency of calibration and calibration verification and the concentration of calibration standards are determined by the manufacturer's guidelines and the analytical method.

## 10.2 Field Quality Control

QC samples will be obtained in the field and analyzed in the lab to allow for assessment of MQOs. The selected analytical laboratory will use its standard, established procedures and the requirements of each method to analyze a sufficient number of blanks, spikes, and surrogates. For field samples, duplicates will be obtained at a minimum rate of 1 in every 10 sample sets for each type of matrix. Here, a sample set is defined as the full suite of analytical parameters intended to be collected at a given location and depth. Specifically:

- 1 duplicate sediment core section from a random location will be obtained and analyzed.
- 1 duplicate set of lake water samples will be obtained from a random depth and location for every 10 sample sets.
- 1 duplicate set of creek water samples will be obtained from a random location for every 10 sample sets.
- 1 duplicate set of stormwater samples will be obtained from a random location.
- Field equipment blanks will be collected at a rate of one sample per every third sampling events for both creek and storm sample locations. This represents a field blank rate of at least 10 percent. Equipment blanks will not be collected for lake samples as Kemmerer or Van Dorn samplers will be cleaned only by rinsing with native water at each location since the sample bottle must pass through the water column to obtain samples anyway.

Trip blanks are not necessary as no volatile parameters are being analyzed as part of this QAPP.

## 10.3 Corrective Action Process

Field activities will be reviewed as soon as practicable following each sampling event, including calibration frequency, decontamination method, and sample collection locations. If activities are found to be inconsistent with this QAPP, field staff will be asked to review relevant SOPs, and additional sampling may be conducted to replace inadequate data if time allows. For laboratory analyses, the lab may be asked to re-analyze samples that do not meet MQOs if holding times allow.

## 11 DATA MANAGEMENT PROCEDURES

### 11.1 Data Recording and Reporting Requirements

Final laboratory data and electronic data deliverables (EDDs) will be stored on Geosyntec's server in the, "Data," folder within the project folder (PNW0463). Field data will be carefully recorded using field template forms or well-kept notes, which will be uploaded to the same folder the first business day after work is completed. For work completed by subcontractors, subcontractors will email the project manager all field data and notes within three business days of returning from the field. The project manager will then save this data to the same folder.

Hand-recorded data will be manually digitized as necessary, with all digitized data undergoing peer review for accuracy.

### 11.2 Laboratory Data Package Requirements

The Ecology-certified analytical laboratory will essentially generate EPA Level II documentation during this investigation. This level of documentation is generally considered legally defensible and consists of the following:

- Holding times
- Laboratory method blank data
- Sample data
- Matrix/surrogate spike data
- Duplicate sample data

Completed, final data reports will be provided in pdf format.

### 11.3 Electronic Transfer Requirements

All laboratory results, including QC sample results, will also be provided as an EDD in excel format.

### 11.4 Data Upload Procedures

Compiled data will be input into Ecology's Environmental Information Management (EIM) data system following completion of the Lake Cyanobacterial Management Plan. A project named, "Lacamas, Round, and Fallen Leaf LCMP 2022," or similar, will be created in EIM to hold the data. Inputs will be peer reviewed and corrected if necessary.

### 11.5 Model Information Management

A full numerical model is not planned for this project. An analytical phosphorus model, such as the Vollenweider mass-balance model, will be developed. This model predicts the lake phosphorus concentration based on the phosphorus loading, mean hydraulic residence time, and a first-order loss coefficient (which represents processes such as sedimentation), which will be a calibration parameter. This will be a simple spreadsheet. The final version of the spreadsheet will be clearly labeled as final with the date of completion. Graphs will be included in the same spreadsheet as the calculations. Because only an analytical mass-balance is proposed, there are no substantial input and output data storage needs.

# 12 AUDITS AND REPORTS

## 12.1 Field, Laboratory, and other Audits

When practicable, this work will use only Ecology-accredited laboratories, which undergo audits from Ecology’s Laboratory Accreditation Unit (LAU) every 3 years. If an Ecology-certified laboratory that accepts outside samples is not available for a specific parameter, or if Ecology-certified laboratories have prohibitive turnaround times or costs, laboratories with other certifications will be considered. In these cases, associated certification information will be documented in the LCMP.

No other audits are planned. Depending on who is conducting the field work Geosyntec may send out field staff to periodically participate in field sampling conducted by subconsultants.

## 12.2 Responsible Personnel

Ecology’s LAU is responsible for auditing analytical laboratories. Laboratory audits include an examination of documents and procedures, examination of equipment, review of quality assurance procedures, and discussion with laboratory staff.

## 12.3 Frequency and Distribution of Reports

The data collected as part of QAPP execution will result in a single report: the LCMP. The final report will be conveyed to Ecology via email, and will follow Ecology’s Freshwater Algae Control Program Lake Cyanobacteria Management Plan template:

https://www.ezview.wa.gov/Portals/_1962/Documents/LacamasCleanWater/Ecology_CyanobacteriaManagementTemplateGuidance.pdf

## 12.4 Responsibility for Reports

The final LCMP will be completed by Geosyntec Consultants and its subcontractors on behalf of the City of Camas.

# 13 DATA VERIFICATION

## 13.1 Field Data Verification, Requirements, and Responsibilities

Field data will be hand-digitized from notes as necessary. Data will then be peer reviewed both for accuracy and reasonableness. Reasonableness will include identifying any data that are noticeably different from nearby samples or previous samples at the same location. Any questionable data points will be relayed to the project manager, who will discuss the questionable data with field staff. A decision will then be made on whether to keep, flag, or discard the data in question. The project manager or a designated staff member will periodically (i.e., at minimum once per quarter) review field data for completeness and legibility.

## 13.2 Lab Data Verification

The Ecology-certified analytical laboratory will perform internal data verification before releasing data to the project manager. The lab will report to the project manager if holding times are exceeded or if preservation temperatures exceed method requirements. In these cases, the project manager will decide whether samples should be analyzed. If the samples are analyzed, a data flag will be applied.

## 13.3 Validation Requirements

Formal data validation is defined as, "an analyte-specific and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set," (EPA, 2002). This requires a qualified, independent individual to review raw field or instrument records and bench sheets. Data validation is not necessary for this project as individual water quality results are not tied to legal water quality limits or requirements. If data obtained during this study suggest that any of the sampling locations have a previously unknown water quality impairment for any of the measured parameters, data validation may become necessary.

## 13.4 Model Quality Assessment

The models created for this project will be simple spreadsheet-based mass balance models. These nutrient and hydrologic budgets will be evaluated by comparing inflows, retained mass and volume, and outflows. If the budget is accounted for within the range specified by the Model Quality Objectives (Section 6.4), the model will be considered of sufficient quality. If the difference does not meet the objectives, data, such as estimated flows, may be reexamined, or additional data may need to be collected.

# 14 DATA QUALITY (USABILITY) ASSESSMENT

## 14.1 Process for Determining Project Objectives Were Met

After data verification is complete, the project manager or designee will compare the overall data package to MQOs and DQOs as specified in Section 6. Data may be rejected for the following reasons:

- The method used was inappropriate for the analyte, or prevents comparison to other samples collected as part of this project
- It is determined that significant contamination may be present in a sample
- A sample was taken from an incorrect location
- A sample was insufficiently preserved, based on pH or a gross exceedance of temperature
- Incompatible equipment, such as incorrect bottle type, was used
- A sample's hold time was grossly exceeded
- Field duplicate or lab duplicate samples exceed their RPD specified in Table 13 and
- Table 14 by more than a factor of 2

The reason for any rejected data will be documented. After any rejected data is removed from the data set, data completeness and representativeness will be evaluated. If data completeness goals have not been met, additional measurements may be taken, or the lab may be asked to reanalyze samples, as possible and necessary.

## 14.2 Treatment of Non-Detects

The treatment of non-detect data will vary based on frequency of occurrence:

- If all samples for a parameter are non-detect, that parameter will be assumed to be absent at the sample location.
- If less than ten percent of samples for a given parameter at a given location are non-detect, if data is not determined to be critical to understanding lake chemistry, or if the data set is too small to implement regression on order statics (ROS), statistical analyses will use half of the detection limit in place of results.
- If greater than ten percent of samples for a given parameter at a given location are non-detect, or if the parameter in question is of critical importance for lake management, ROS statistics will be used to fill in non-detect values where possible.

## 14.3 Data Analysis and Presentation Methods

Data analysis will seek to use collected data to A) build on the existing conceptual understanding of the limnology of Lacamas, Round, and Fallen Leaf Lakes as it pertains to nutrient dynamics and algae growth and B) constrain water and nutrient fluxes to facilitate the creation of quantitative nutrient budgets. This discussion describes analyses to be completed after data sets for individual variables have been verified and summarized.

"Flow-through" figures will simplify in-lake dynamics and focus only on the inflows into and outflows from the lake. These maps will be created both for data collected during individual sampling excursions and for average fluxes measured over the year. As visual representations of the nutrient budget equations presented in Section 7.3, they will show relative magnitudes of different terms in Equations 1-3.

The understanding gained from this exercise will be summarized in a narrative form, thus enhancing the conceptual understanding of nutrient limnology and algal dynamics in the lake.

### 14.4 Sampling Design Evaluation

This sampling plan is expected to yield enough statistical power to develop a useful spreadsheet-based model of lake nutrients.

### 14.5 Documentation of Assessment

Final lab reports, including data qualifiers, will be provided in an Appendix to the LCMP. A comparison of data completeness to goals will also be provided.

## 15 REFERENCES

Beak Consultants Incorporated (Beak) and Scientific Resources Incorporated (SRI), 1985. Lacamas-Round Lake Diagnostic and Restoration Analysis, Final Report.

Carlson, R.E., 1977. "A trophic state index for lakes," *Limnol. Oceanogr.* 22:361-368.

Center for Watershed Protection, 2008. Monitoring to Demonstrate Environmental Results: Guidance to development local stormwater monitoring studies using six example study designs.

Chang, S. C. and M. L. Jackson, 1956. Fractionation of Soil Phosphorus. Soil Science, 84(2), 133-144. August.

City of Portland BES, 2015. Underground Injection Control Permit. Stormwater Discharge Monitoring Plan.

Clark County Public Works, 2021. Fallen Leaf Lake Baseline Monitoring Report. Clean Water Division, for the City of Camas, WA. March.

Connin, Sean, 1991. Characteristics of successful riparian restoration projects in the Pacific Northwest (No. PB-92-196039/XAB; EPA-910/9-91/033). Environmental Protection Agency, Seattle, WA (United States).

Deemer, B. R., Harrison, J. A., & Whitling, E. W., 2011. Microbial dinitrogen and nitrous oxide production in a small eutrophic reservoir: An in situ approach to quantifying hypolimnetic process rates. Limnology and oceanography, 56(4), 1189-1199.

Deemer, B. R., Henderson, S. M., & Harrison, J. A., 2015. Chemical mixing in the bottom boundary layer of a eutrophic reservoir: The effects of internal seiching on nitrogen dynamics. Limnology and Oceanography, 60(5), 1642-1655.

Ecology, 2021. EIM Help – Study Form. Version 3.10. June. Accessed via: https://apps.ecology.wa.gov/eim/search/Help/HelpDisplay.aspx?helpID=StudyQAPlanningLevelCD

Ecology, 2020. Freshwater Algae Control Program Lake Cyanobacterial Management Plan Template Guidance, Fiscal Year 2020 Guidance. Ecology_CyanobacteriaManagementTemplateGuidance.pdf (wa.gov)

Ecology, 2015. Stormwater sampling manual: A guide for the industrial stormwater general permit. Camas, WA. Manual 107. July.

EPA, 2002. Guidance on Environmental Data Verification and Data Validation. EPA QA/G-8. November. g8-final.pdf (epa.gov)

Georgia-Pacific Consumer Operations LLC, 2018. Operation and Maintenance Plan for the Lacamas Lake Dams.

Gleason, Molly and McCarthy, Sheelagh, Washington State Department of Ecology, 2021. Quality Assurance Project Plan. Lacamas Creek Bacteria, Temperature, and Nutrients Source Assessment. September. Publication 21-10-017.

Green, Cooper, 2018. "G-P gifts 190 acres to Camas." Camas-Washougal Post-Record. https://www.camaspostrecord.com/news/2018/sep/20/g-p-gifts-190-acres-to-camas

Harrison, J. A., Deemer, B. R., Birchfield, M. K., & O'Malley, M. T., 2017. Reservoir water-level drawdowns accelerate and amplify methane emission. Environmental science & technology, 51(3), 1267-1277.

Henderson, S. M., & Deemer, B. R., 2012. Vertical propagation of lakewide internal waves. Geophysical research letters, 39(6).

Howe, R., A. Wolf, E.E. Gnass Giese, and J. Horn, 2018. Lower Green Bay and Fox River Area of Concern Habitat Restoration Plan and Path Toward Delisting Project. Technical report submitted to the Wisconsin Department of Natural Resources. Part 1, Appendix 1.3. https://www.uwgb.edu/UWGBCMS/media/gbaoc/images/AOC-2016-17-Migratory-Waterfowl-Survey-Methodology-Excerpt.pdf

Lee H., Stenstrom M., 2005. Utility of Stormwater Monitoring. Water Environment Research Vol 77 Number 3.

Macuk, Anthony, 2021. "Clark County population tops 500,000." The Columbian. https://www.columbian.com/news/2021/aug/12/clark-county-population-tops-500000/

Madsen, J., 1999. Aquatic Plant Control Technical Note MI-02: Point intercept and line intercept methods for aquatic plant management. Us Army Engineer Waterways Experiment Station.

Moyer, Kelly, 2020. "Georgia-Pacific reinvesting in Camas paper mill." Camas-Washougal Post-Record. https://www.camaspostrecord.com/news/2020/feb/27/georgia-pacific-reinvesting-in-camas-paper-mill/

Mueller, Karl W., and Downen, Mark R., 1997. 1997 Lacamas Lake Survey. The warmwater fish community of a highly eutrophic Lowland Lake. Warmwater Enhancement Program, Washington Department of Fish and Wildlife.

Nolan, S., Bollens, S. M., & Rollwagen-Bollens, G., 2019. Diverse taxa of zooplankton inhabit hypoxic waters during both day and night in a temperate eutrophic lake. Journal of Plankton Research, 41(4), 431-447.

Parsons, J., 1999 Lacamas Lake aquatic plant summary. Washington Department of Ecology

Parsons, J., 2001. Aquatic Plant Sampling Protocols. Washington State Department of Ecology Environmental Assessment Program, Olympia, WA. June. Publication No. 01-03-017. https://apps.ecology.wa.gov/publications/documents/0103017.pdf

Perkins, K.R., 2017. Influence of environmental factors on the vertical distribution of phytoplankton in Lacamas Lake, WA. Washington State University, Vancouver. Spring 2017. Gretchen Rollwagen-Bollens Aquatic Ecology Lab.

Perkins, K. R., Rollwagen-Bollens, G., Bollens, S. M., & Harrison, J. A. 2019. Variability in the vertical distribution of chlorophyll in a spill-managed temperate reservoir. Lake and Reservoir Management, 35(2), 119-126.

Eilers, J.M., R.B. Raymond, K.B. Vache, J.W. Sweet, C.P. Gubala, and P.R. Sweets, 1996. Lacamas Lake Watershed 1995 Water Quality Monitoring Program. A Report to Clark County Department of Community Development, Water Quality Division, Vancouver, WA. E&S Environmental Chemistry, Inc., Corvallis, Oregon

Raymond, R.B., J.M. Eilers, K.B. Vache, J.W. Sweet, P.R. Sweets, C.P. Gubala, 1997. Lacamas Lake Watershed 1996 Water Quality Monitoring Program. A Report to Clark County Department of Community Development, Water Resources and Development Engineering. Vancouver, WA. E&S Environmental Chemistry, Inc., Corvallis, Oregon

Raymond, R.B., 1998. Dye tracer mixing study at Lacamas Lake, 1996 and 1997. Technical Memorandum prepared for Clark County Community Development Department, Vancouver, WA. E&S Environmental Chemistry, Inc., Corvallis, Oregon

Rose, V., Rollwagen-Bollens, G., Bollens, S. M., & Zimmerman, J., 2021. Effects of Grazing and Nutrients on Phytoplankton Blooms and Microplankton Assemblage Structure in Four Temperate Lakes Spanning a Eutrophication Gradient. Water, 13(8), 1085.

Schnabel, J.D., 2002. Lacamas Lake Restoration Program: WY200 and WY2001 Water Quality Monitoring. Clark County Public Works, Vancouver, Washington.

Schnabel, J.D., 2004. Lacamas Lake Nutrient Loading and In-Lake Conditions. Clark County Public Works Water Resources, Vancouver, Washington.

Schnabel, J.D., 2006. Lacamas Lake Annual Data Summary for 2006. Clark County Public Works Water Resources, Vancouver, Washington.

Schnabel, J.D., 2007. Lacamas Lake Annual Data Summary for 2007. Clark County Public Works Water Resources, Vancouver, Washington.

USGS, 2014. Evaluation of the Washington State Department of Transportation Stormwater Monitoring and Effectiveness Program for 2014–19

USGS, 2009. Scientific framework for Stormwater Monitoring by the Washington State Department of Transportation. USGS. File Report 2009-1236

# 16 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.

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

**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.

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

**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.

**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.

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

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

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

**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.

**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.

**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.

**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.

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

**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.

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

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

## Acronyms and Abbreviations

| | |
|---|---|
| AIS | Aquatic invasive species |
| ASOS | Automated Surface Observing Systems |
| DO | Dissolved Oxygen (see Glossary above) |
| DQI | Data quality indicators |
| DQO | Data Quality Objective |
| e.g. | For example |
| Ecology | Washington State Department of Ecology |
| EDD | Electronic Data Deliverable |
| EIM | Environmental Information Management database |
| EPA | U.S. Environmental Protection Agency |
| et al. | And others |
| GPS | Global Positioning System |
| HAB | Harmful algal bloom |
| i.e. | In other words |
| LAU | Ecology's Laboratory Accreditation Unit |
| LCMP | Lake Cyanobacteria Management Plan for Lacamas, Round, and Fallen Leaf Lakes |
| LCS | Laboratory control sample |
| MQO | Measurement quality objective |
| NPDES | National Pollutant Discharge Elimination System (See Glossary above) |
| NCEI | National Centers for Environmental Information |
| ORP | Oxidation-reduction potential |
| QA | Quality assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| SC | Specific conductance |
| SOP | Standard operating procedures |
| T | Temperature |
| TKN | Total Kjeldahl Nitrogen |
| TN | Total nitrogen |
| TP | Total phosphorus |
| TSS | Total Suspended Solids (See Glossary above) |
| USGS | United States Geological Survey |
| WAC | Washington Administrative Code |

## Units of Measure

| | |
|---|---|
| °C | degrees centigrade |
| cfs | cubic feet per second |
| cfu | colony forming units |
| cms | cubic meters per second, a unit of flow |
| dw | dry weight |
| ft | feet |
| g | gram, a unit of mass |
| kg | kilograms, a unit of mass equal to 1,000 grams |
| m | meter |
| mg | milligram |
| mg/Kg | milligrams per kilogram (parts per million) |
| mg/L | milligrams per liter (parts per million) |
| mL | milliliter |
| NTU | nephelometric turbidity 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) |
| µmhos/cm | micromhos per centimeter |
| µS/cm | microsiemens per centimeter, a unit of conductivity |
| ww | wet weight |

## 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:

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

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:

$$[\mathrm{Abs}(a-b)/((a + b)/2)] * 100$$

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

40 CFR 136. Title 40 Code of Federal Regulations, Part 136: Guidelines Establishing Test Procedures for the Analysis of Pollutants. Available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=3cf9acace214b7af340ea8f6919a7c39&mc=true&node=pt40.25.136&rgn=div5 (accessed 26 Feb. 2020).

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Available at: https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html (accessed 6 Mar. 2020).

Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York, NY.

Kammin, W., 2010. Definition developed or extensively edited by William Kammin, 2010. Washington State Department of Ecology, Olympia, WA.

USEPA, 1992. Guidelines for exposure assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C. EPA/600/Z-92/001. Available at: https://www.epa.gov/sites/production/files/2014-11/documents/guidelines_exp_assessment.pdf (accessed 26 Feb. 2020).

USEPA, 2001. EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5. U.S. Environmental Protection Agency, Washington, DC. EPA/240/B-01/003. Available at: https://www.epa.gov/quality/epa-qar-5-epa-requirements-quality-assurance-project-plans (accessed 26 Feb. 2020).

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/sites/production/files/2015-06/documents/g4-final.pdf

USEPA, 2009. Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use, OSWER No. 9200.1-85, EPA 540-R-08-005. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/nscep.

USEPA, 2014. Compendium: Project Quality Assurance and Quality Control: Chapter 1. U.S. Environmental Protection Agency, Washington, DC. SW-846 Update V. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/chap1_1.pdf (accessed 26 Feb. 2020).

USEPA, 2016. Definition and Procedure for the Determination of the Method Detection Limit, Revision 2. EPA 821-R-16-006. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/sites/production/files/2016-12/documents/mdl-procedure_rev2_12-13-2016.pdf (accessed 6 Mar. 2020).

USEPA, 2020. Glossary: Environmental Sampling and Analytical Methods (ESAM) Program. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/esam/glossary (accessed 26 Feb. 2020).

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. U.S. Geological Survey, Reston, VA. Available at: https://pubs.usgs.gov/of/1998/ofr98-636/ (accessed 26 Feb. 2020).

WAC 173-50-040. Title 173 Washington Administrative Code. Accreditation of Environmental Laboratories: Definitions. Available at: https://apps.leg.wa.gov/WAC/default.aspx?cite=173-50-040 (accessed 26 Feb. 2020).