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State of Washington

Quality Assurance Project Plan

Henderson Inlet Fecal Coliform Total Maximum Daily Load Effectiveness Monitoring Study (Water Quality Study Design)

July 2014

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This Quality Assurance Project Plan is available on Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1403113.html

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Federal Clean Water Act 1996 303(d) Listings Addressed in this Study

See 3.1.3 *Parameters of concern* section.

Quality Assurance Project Plan

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2.0 Abstract

Henderson Inlet and several streams in the Henderson Basin were placed on the 1996 and 1998 303(d) list of impaired water bodies, due to violations of one or more Washington State water quality criteria. The basin has tributaries that do not meet water quality standards for pH, dissolved oxygen, and temperature. To address the listings, the Washington State Department of Ecology (Ecology), with assistance from Thurston County Environmental Health and the Thurston County Conservation District, conducted a study in the basin from 2002 to 2005. The evaluation characterized pH and dissolved oxygen and established Total Maximum Daily Loads (TMDLs) for fecal coliform bacteria (FC).

In 2008 Ecology published the *Henderson Inlet Watershed Fecal Coliform Total Maximum Daily Load: Water Quality Implementation Plan* (Ecology, 2008) which outlined recommendations for reducing FC in the watershed. The plan also set target reductions for FC and recommended additional monitoring to measure progress toward improving water quality.

Since the development of the implementation plan, the Henderson Inlet Watershed Technical Advisory Group determined that most action items identified in the implementation plan have been completed. Subsequently, the group recommended a study to monitor the effectiveness of cleanup action.

This effectiveness monitoring Quality Assurance Project Plan describes a technical study in which Ecology will monitor and compare FC with target reductions outlined in the TMDL. In addition, Ecology will conduct bioassessment monitoring at several locations within the watershed to determine the effectiveness of pollution control measures implemented to mitigate impacts from stormwater discharges into surface waters of the basin. Results of this study will be used to evaluate the effectiveness of implementation actions in the basin.

3.0 Background

Henderson Inlet and several streams in the Henderson Basin were placed on the 1996 and 1998 303(d) list of impaired water bodies, due to violations of one or more Washington State water quality criteria. To address the listings, the Washington State Department of Ecology (Ecology), with assistance from the Thurston County Environmental Health and Thurston County Conservation District, conducted a TMDL study in the basin from 2002 to 2005. Henderson Basin has tributaries that do not meet water quality standards for pH, dissolved oxygen, and temperature. The goal of this study was to monitor concentrations of these four water quality parameters and allocate pollution load estimates for the basin. The allocations were intended to be applied to suspected pollution sources to bring parameters into compliance with water quality standards.

In 2006, Ecology published the *Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study* (Sargeant et al., 2006). The study concluded that low dissolved oxygen levels observed in the Henderson Inlet tributaries and Woodard Creek are likely due to natural causes. Low dissolved oxygen levels in Woodland Creek were also believed to be natural; however, elevated nutrients levels were observed in the upper watershed. The suspected sources of elevated nutrients were identified as inputs from stormwater outfalls. The study also concluded excursions of pH in several of the creeks are considered natural because of proximity to wetlands and soils in the basin (Sargeant et al., 2006).

The 2006 TMDL study found high fecal coliform bacteria (FC) concentrations throughout the watershed (Sargeant al., 2006). Estimates from the TMDL wet season load suggest that 80% of the FC load to Henderson Inlet was from Dobbs and Woodland Creek while 77 % of the dry season load was from Woodland Creek (Figure 1).

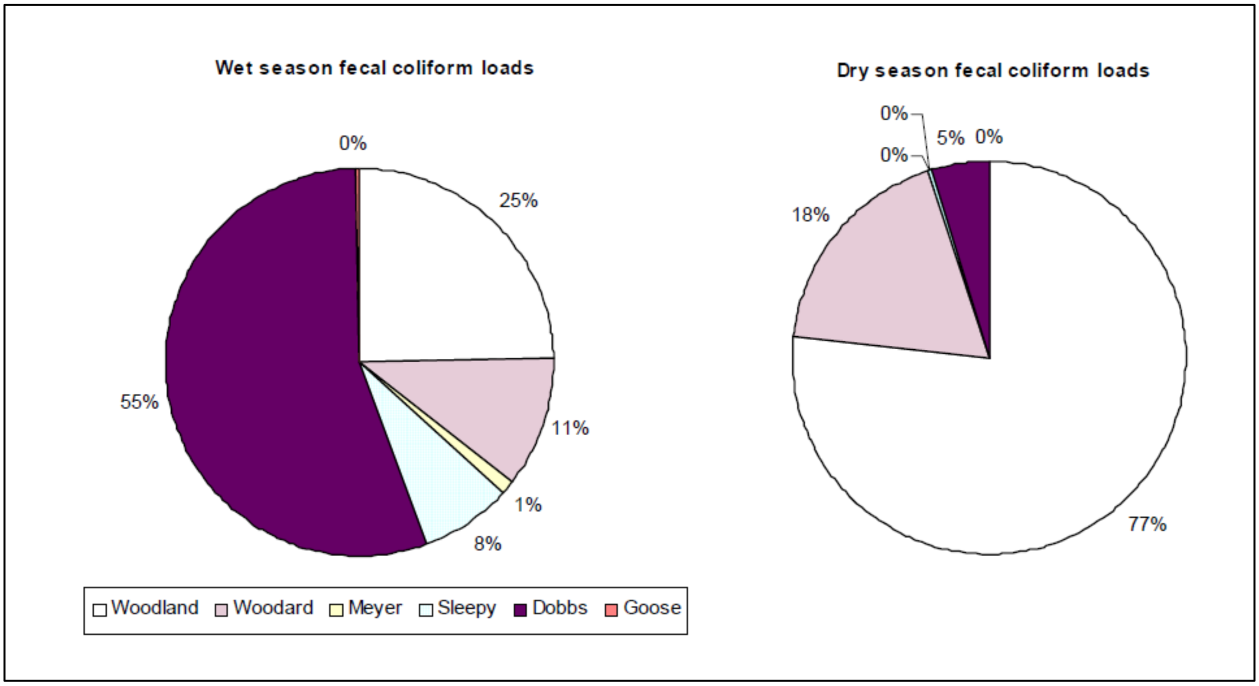

Figure 1. Tributary fecal coliform load contributions to Henderson Inlet (Sargeant et al., 2006).

In 2008, Ecology published the *Henderson Inlet Watershed Fecal Coliform Bacteria Total Maximum Daily Load: Water Quality Implementation Plan* (Ecology, 2008). The Henderson Inlet TMDL implementation strategy, set load allocations for reducing bacteria at several locations and made recommendations for pollution control measures. Many of the control methods included in the recommendations for bacteria were also suggested to help reduce nutrient inputs into the watershed.

The Henderson Inlet watershed falls primarily under the jurisdiction of Thurston County and the city of Lacey. Since the original TMDL study, both local governments, together with local citizen groups, have been actively involved in water quality protection and cleanup actions. Cleanup actions have included a combination of:

- Improved management of stormwater discharges.
- Construction of new stormwater treatment facilities and rehabilitation of existing facilities.
- Implementation of an on-site septic system operations and maintenance program.
- Conversion from septic to sewer systems in residential areas adjacent to Woodland Creek.
- Source investigation including septic surveys, water quality monitoring, and visual surveys of land use and management practices.
- Technical assistance to landowners to develop conservation plans and implement best management practices.
- Informational workshops and other outreach aimed at encouraging landowners to improve land use practices.
- Conduct an extensive pet waste education and outreach campaign.
- Oversight of sources with discharge permits.
- Enforcement.

This Quality Assurance (QA) Project Plan describes a technical study that will be used to monitor and compare FC with target reductions outlined in the TMDL. In addition, bioassessment monitoring will be conducted at several locations within the watershed. This is to assess the effectiveness of pollution control measures implemented to mitigate impacts from stormwater discharges to surface waters of the basin. Results of this study will be compared with implementation actions in the basin to evaluate the effectiveness of the plan. Results of this study are meant to be used to adapt current implementation strategies if needed.

3.1 Study area and surroundings

Henderson Inlet (Figure 2), located in Thurston County, is one of five inlets that form the southern terminus of Puget Sound. It is located between Budd Inlet on the west and Nisqually Reach on the east. The five-mile-long inlet ranges from one-fourth to three-fourths miles wide, averaging about 25 feet deep. Henderson Inlet is a productive shellfish area. Since the 1980s, shellfish harvesting in the lower third of Henderson Inlet has been prohibited or restricted, due to high FC levels in the water.

The 30,000-acre Henderson Basin is the second largest basin in Water Resource Inventory Area (WRIA) 13-Deschutes (Figure 2). Woodland and Woodard Creeks are the largest of the main tributaries to Henderson Inlet, draining 80% of the basin. The other major streams in the watershed −Dobbs Creek, Myer Creek, and Sleepy Creek−drain small areas of the Dickerson Point and Johnson Point peninsulas.

Woodland Creek is the largest creek in the Henderson basin with ninety percent of the watershed contained within an Urban Growth Area (UGA), which includes primarily the City of Lacey but also Olympia (Figure 2). The basin drains an area of approximately 29.7 square miles, and the mainstem of the creek is approximately 11 miles long. The stream channel above Martin Way is intermittent and often dries during the summer. Downstream of Martin Way, several springs provide perennial flow to lower Woodland Creek. Although the Woodland Creek watershed contains substantial areas of undeveloped forests, the primary land use is residential development.

Woodard Creek, the second largest creek in the Henderson Basin, is 7.5 miles long and drains a basin of 8 square miles. The headwaters of Woodard Creek are fed by a large wetland south of Interstate 5 at the Pacific Avenue interchange. Industrial and commercial development on Fones Road surrounds the wetland. The mouth of Woodard Creek is an estuarine wetland that is currently protected as a natural area by the Washington State Department of Natural Resources.

A description of Woodland and Woodard Creeks' basin geology, soils, hydrology, vegetation, fish habitat, and critical areas can be found in the Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1995).

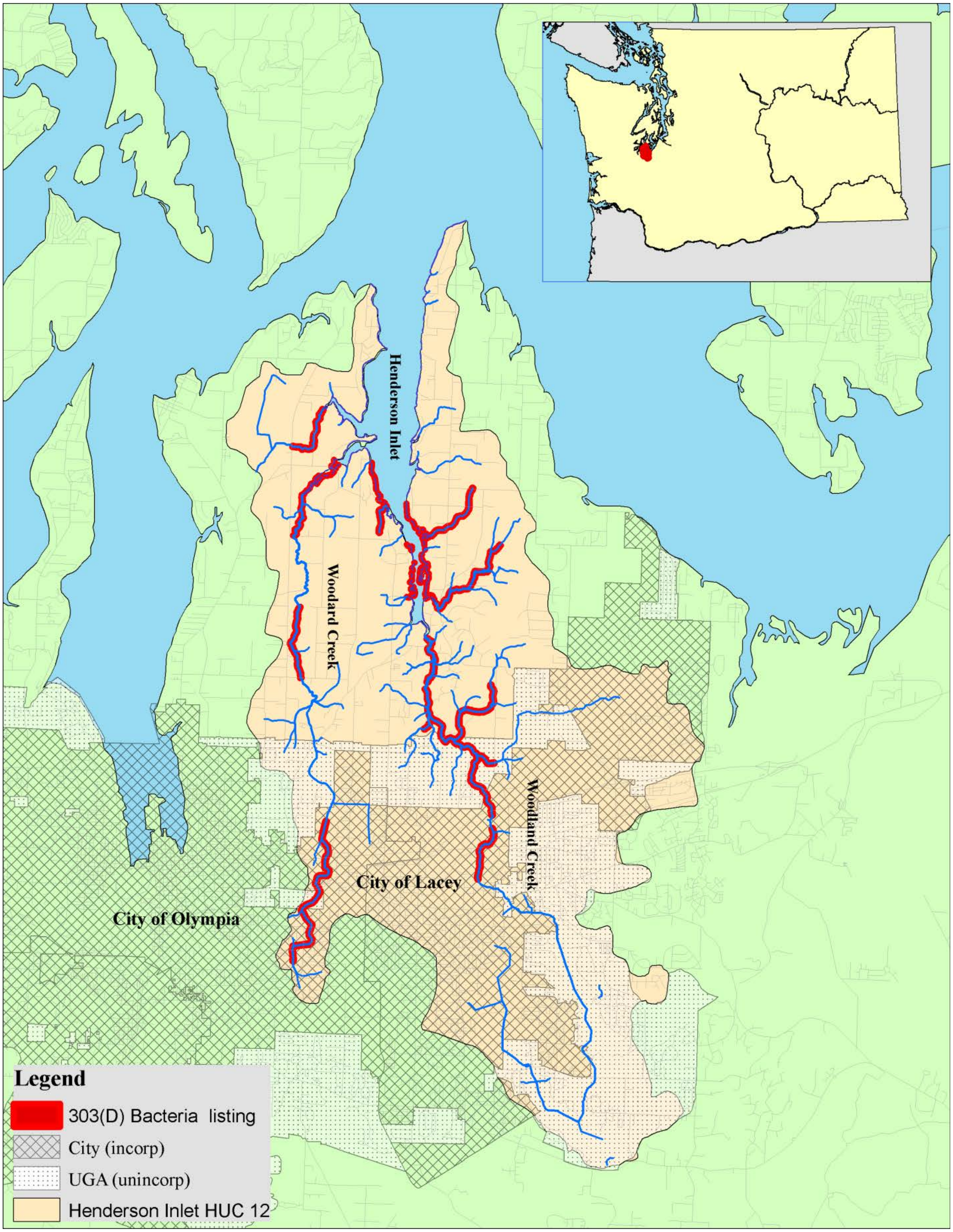

Figure 2. Study area for the Henderson Inlet Fecal Coliform Total Maximum Daily Load Effectiveness Monitoring study.

3.1.1 Logistical problems

Logistical problems are rare but could interfere with sampling. These problems could include: excessive precipitation during typically dry periods, scheduling conflicts, sample bottle delivery errors, vehicle or equipment problems, site access issues, or limited availability of personnel or equipment. Any circumstance that interferes with data collection and quality will be noted and discussed in the final report.

3.1.2 History of study area

Henderson Inlet is a productive shellfish harvesting area. However, declining water quality in Henderson Inlet led to several downgrades in shellfish classification between 1984 and 2005. In response, Thurston County created a Shellfish Protection District and appointed a stakeholder group of eleven citizens living or working in the area to develop a strategy to restore water quality in the inlet.

In 2003, the advisory group recommended long-term strategies necessary to protect and restore shellfish harvest in Henderson Inlet (Thurston County, 2003). They based recommendations on the conclusion that the bacteria problems are primarily nonpoint source pollution. Sources were identified as a combination of failing onsite sewage systems, poor agricultural practices, and stormwater runoff in the basin (Thurston County, 2003).

In 2005, the Henderson Inlet and Nisqually Reach Shellfish Protection Districts merged and partnered with Thurston County to develop an implementation work plan for both basins (Thurston County, 2005). Since that time, a total of 240 acres of shellfish harvesting area in Henderson Inlet have been upgraded from 2005 to 2012 as either Approved or Conditionally Approved.

3.1.3 Parameters of concern

Henderson Inlet is designated *Extraordinary* quality marine water. Beneficial uses include *Extraordinary* aquatic life use and primary contact recreation, including shellfish harvest. The designation of *Extraordinary Primary Contact* in both fresh and marine waters means that waters provide extraordinary protection against waterborne disease or serve as tributaries to extraordinary quality shellfish harvesting.

Tributaries to Henderson Inlet are considered *Extraordinary* quality water and are protected for the designated uses of salmon and trout spawning, core rearing, and migration, and also *Extraordinary* primary contact recreation.

Table 1 shows the Category 5, 4A, and 2 bacteria listings on the state Water Quality Assessment for FC in the Henderson Inlet Watershed, approved by EPA in 2012 (Ecology, 2014). A full list of water quality impairments is available in Washington's Water Quality Assessment 303(d)/305(b) Integrated Report Viewer (http://apps.ecy.wa.gov/wats/Default.aspx).

Table 1. Henderson Inlet and tributaries on the 2012 303(d) list and impaired water bodies that do not meet water quality standards for fecal coliform bacteria.

Water body Name	Category	WBID Code	NHD Reach Code	Assessment Listing ID	Township/ Range/Section
College Creek	4A	17110019007929	1228108470708	45290	18N-1W-15
College Creek	4A	17110019013153	1228214470935	45297	18N-1W-42
Eagle Creek	4A	17110019013550	1228512471268	45287	18N-1W-4
Fleming Creek	5	17110019013161	1228214470935	45124	19N-1W-21
Fox Creek	4A	17110019007227	1228551471388	45286	18N-1W-4
Jorgenson Creek	4A	17110019013148	1228214470935	45288	18N-1W-4
Myer Creek	4A	17110019015362	1228512471268	45546	19N-1W-20
Palm Creek	2	17110019000236	1228512471268	45295	18N-1W-4
Quail Creek	4A	17110019007897	1228132470720	46176	18N-1W-4
Sleepy Creek	4A	17110019007953	1228059470689	40614	19N-2W-18
Woodard Creek	4A	17110019007870	1228205470752	3772	19N-1W-19
Woodard Creek	4A	17110019008037	*	6657	18N-1W-16
Woodard Creek	4A	17110019013141	1228214470935	45027	18N-1W-9
Woodard Creek	4A	17110019007448	1228351471193	45082	18N-1W-4
Woodard Creek	4A	17110019013145	*	45123	18N-1W-15
Woodard Creek	4A	17110019008024	1228512471268	45125	18N-1W-18
Woodard Creek	4A	17110019007538	1228215471135	45127	19N-1W-31
Woodard Creek	4A	17110019007929	1228108470708	45226	18N-1W-42
Woodard Creek	4A	17110019013153	1228214470935	45292	18N-1W-4
Woodard Creek	4A	17110019013550	1228512471268	46188	18N-1W-19

WBID: Water-body Identification
NHD: National Hydrography Dataset
*Reach code not assigned

3.1.4 Results of previous studies

Washington State Department of Health (DOH)

The DOH Shellfish Area Program is responsible for monitoring water quality in shellfish growing areas in Washington. Growing area classifications are assigned based on the results of the monitoring. The classification determines whether shellfish in the area can be harvested for human consumption. Each year DOH develops annual growing area reports using water quality data collected in the previous year. This is to determine whether growing areas still meet their classification status and to assess potential sources of pollution.

Additional information on classification, monitoring, and reports is available at DOH's website: (http://www.doh.wa.gov/CommunityandEnvironment/Shellfish/GrowingAreas/AnnualReports.aspx)

Based on DOH's most recent 2013 annual growing report for Henderson Inlet, most of the Henderson Inlet growing area is classified as *Approved* for commercial shellfish harvest (Figure 2). However, FC contamination still occurs in *Conditionally Approved* areas during rainfall events. The report indicates that in 2013 the *Conditionally Approved* portion of the growing area was closed 12 times for a total of 68 days, while the entire growing area was closed once for 5 days. The designated area is closed to shellfish harvest for 5 days following rainfall of greater than 0.75" in a 24-hour period. In response to this data assessment, the report recommends adjusting the current criterion for the *Conditionally Approved* classification to the more restrictive 0.5" of rain in a 24-hour period.

Figure 3. DOH shellfish growing area classification and sampling sites for Henderson Inlet (DOH, 2013).

2011 Henderson Inlet Remediation Assessment

In 2011 DOH evaluated Henderson Inlet FC monitoring data collected by the Shellfish Area Program from 2001 through 2009 (Determan, 2011). The purpose of the evaluation was to see if FC concentrations were declining (Figure 4) over time and if the decline was related to decreases in rainfall. Using three analytical approaches, the evaluation confirmed that fecal pollution significantly declined over time and was weakly correlated with decreasing rainfall. Based on this information, the final report suggests that reduced precipitation only accounts for a small proportion of the overall declining trends in FC. Thus, remedial actions implemented to improve water quality in the basin were likely responsible for at least some of the reduction.

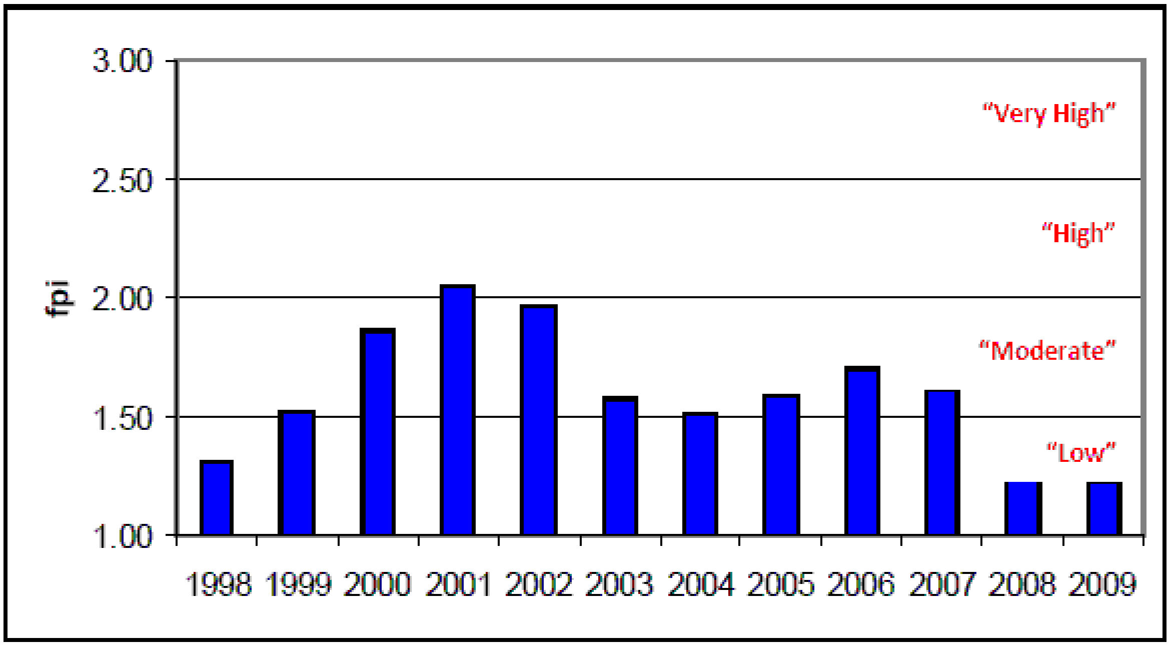

Figure 4. Trend in fecal pollution in Henderson Inlet (Determan, 2010).

The fecal pollution indices (FPIs) were calculated from results obtained from 24 continuously monitored sites throughout Henderson Inlet (FPI=1.0: "Negligible" impact).

Washington Department of Ecology Studies

Dobbs Creek

From November 2007 through April 2008, Ecology conducted FC monitoring on Dobbs Creek to assess compliance with water quality criteria and identify potential new sources (Dickes, 2009). Results indicate bacteria concentrations at four of the five sampled mainstem stations did not meet water quality standards. FC concentrations and loading were found to be elevated in response to rainfall events. Although no sources of FC were directly identified, the report indicated much of the loading was occurring in the upper watershed, above River Mile (RM) 1.23.

Thurston County Studies

Water Resources Monitoring Report

Thurston County, with support of the City of Lacey, conducts monthly FC monitoring at Tanglewilde stormwater outfall, Woodard Creek at RM 2.9, Woodland Creek at Draham Road and Woodland Creek at Pleasant Glade Road. Results from this monitoring are synthesized in annual reports published by Thurston County (Thurston County, 2012).

Water quality sampling at the Tanglewilde stormwater outfall began in 2005. The stormwater outfall collects runoff from the Tanglewilde neighborhood and portions of Martin Way and Carpenter Road and discharges into Woodland Creek. FC results from water year 2010/2011 indicate that although the geometric mean is meeting water quality criteria, the 90th percentile is consistently exceeding water quality standards (see Section 3.1.5). High FC levels typically occur during the wet season when outfall base flows are dominated by stormwater (Thurston County, 2011). Dry season base flows are generally dominated by groundwater. The outfall has been identified as a major contributor to bacteria and nutrient pollution to Woodland Creek. Thurston County has implemented major pollution control activities to reduce stormwater volume and improve water quality in the Tanglewilde neighborhood (Thurston County, 2011).

Woodland Creek at Draham Road has met both parts of the FC criteria in water years 2009/2010 and 2010/2011. Woodland Creek at Pleasant Glade (the mouth station) has been monitored by Thurston County since 1983. This site has consistently exceeded both parts of the FC standard with the exception of water year 2010/2011 when both parts of the standard were met. In addition, high nutrient concentrations have also been identified at both locations. Suspected sources of FC pollution include contaminants in stormwater runoff, impacts from agricultural practices, and failing septic systems upstream of this site.

Thurston County has sampled FC on Woodard Creek at RM 2.9 since 1993. FC results from water year 2010/2011 indicate both parts of the water quality standards were violated. FC concentrations at this site have consistently failed the geometric mean and 90th percentile water quality criteria since 1993. Suspected sources of FC pollution include contaminants in stormwater runoff, impacts from agricultural practices, and failing septic systems upstream of this site.

3.1.5 Regulatory criteria or standards

The FC criteria have two statistical components: a geometric mean and an upper limit value that 10% of the samples cannot exceed. In Washington, the upper limit statistic (i.e., not more than 10% of the samples shall exceed) has been interpreted as a 90th percentile value of the log-normalized values.

Henderson Inlet and its tributaries are available to the public for *Primary* (e.g., swimming) and *Secondary* (e.g., wading) *Contact Recreations*. Recreational and tribal/commercial shellfish are harvested in the approved sections of Washington beaches.

Freshwater Criteria

Bacteria targets in the water quality standards are set to protect people working and playing in the water from contracting waterborne illnesses. They are also set to protect tributaries flowing to shellfish harvesting areas. In Washington, surface water quality standards use FC as an "indicator bacteria" for the state's freshwaters (e.g., lakes and streams). FC in water indicate the presence of waste from humans and other warm-blooded animals, which is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. Ecology's selection of FC as the indicator for pathogens in surface waters is explained in *Setting Standards for the Bacteriological Quality of Washington's Surface Water Draft Discussion Paper and Literature Summary* (Hicks, 2002). The paper reviews the use of FC as an indicator bacteria and epidemiological studies of indicator bacteria in both fresh and marine waters.

The designated use of *Extraordinary Primary Contact* is intended for waters capable of "providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas." To protect this use category, "Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL." [WAC 173-201A-200] (Table 2). The upper limit criterion (i.e., the level that not more than 10 percent of the samples shall exceed) has been interpreted in this study as the 90th percentile of sample values.

Table 2. Freshwater and Marine fecal coliform criteria for Henderson Inlet watershed

Criteria	Geometric Mean	Not more than 10% (90th Percentile)
Extraordinary Primary Contact Recreation	50 cfu/100 mL	100 cfu/100 mL
Primary Contact Recreation	14 cfu/100 mL	43 cfu/100 mL

cfu: colony-forming units

Marine water criteria

In marine waters, water quality standards for bacteria are set to protect shellfish consumption and people who work and play in and on the water. Marine water criteria apply when the salinity is ten parts per thousand (17,700 umhos) or greater. Ecology uses the following bacterial indicators in the Henderson Inlet marine waters:

- In waters protected for both *Primary Contact Recreation* and *Shellfish Harvesting*, the state uses FC as indicator bacteria to gauge the risk of waterborne diseases.

The presence of these bacteria in the water indicates the presence of waste from humans and other warm-blooded animals.

To protect either *Shellfish Harvesting* or *Primary Contact Recreation* in the study area: "Fecal coliform organism levels must not exceed a geometric mean value of 14 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 43 colonies/100 mL." [WAC 173-201A-210] (Table 2). The upper limit criterion (i.e., the level that not more than 10% of the samples shall exceed) has been interpreted in this study as the 90th percentile of sample values.

Results of water samples collected randomly from one site and analyzed for bacteria typically follow a lognormal distribution; this is why the geometric mean is used for central tendency of the data set. The geometric mean is a mathematical expression of central tendency (average) of multiple sample values in a group of lognormal sample values. This average dampens the effect of extreme values that could bias an arithmetic average.

Compliance with bacteria water quality standards is based on meeting both the geometric mean criterion and the "10 percent of samples" criterion. If ten or fewer total samples exist, then no single sample may exceed the 90th percentile. These two measures used in combination ensure that bacterial pollution in a water body will be maintained at a set level of risk to human health. While some discretion exists for selecting sample averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal data sets.

If FC concentrations in the water exceed the numeric criteria, human activities that would increase concentrations above the criteria need to be managed in order to allow waters to meet standards. The state, in collaboration with local governments, tribes, and watershed stakeholders, will work to ensure that human activities are conducted in a manner that will bring FC concentrations back into compliance with water quality standards.

If natural levels of FC (from wildlife, for example) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution beyond natural levels. Though the presence of bacterial contamination from wildlife is typical in most environments, there still may be a risk of human illness.

TMDL Targets

Although compliance is measured as meeting water quality standards, FC targets are routinely established to assist water quality managers in assessing the progress toward compliance with established criteria. Table 3 lists the TMDL target stations and corresponding critical season, limiting water quality criteria, and target percent reductions needed to bring the limiting criterion into compliance with water quality standards (Ecology, 2008). This information will be the basis of the sampling design for this study and will be used to measure progress in meeting goals outlined in the TMDL.

Table 3. TMDL study target stations and criteria used for assessing fecal coliform targets and reductions needed to meet state water quality standards.

Station Description	Site ID	Critical season	TMDL Geomean	TMDL 90th percentile	% reduction needed	Limiting criterion	Target value (cfu/100 mL)	*N**
Woodland Creek and tributaries								
Woodland Creek at RM 2.6	WL2.6	Dry	87	108	43	geo	50	4
Woodland Creek at RM 0.2	WL0.2	Dry	192	271	93	geo	14	8
Woodland Creek at RM 0.2	WL0.2	Wet	102	552	92	90th	43	8
College Creek	CC0.4	Wet	161	694	86	90th	100	8
Eagle Creek	WL2.25T	Dry	204	2180	95	90th	100	4
Palm Creek	WL1.95T	Wet	54	246	59	90th	100	8
Fox Creek	WL1.9T	Wet	41	451	78	90th	100	8
Jorgensen Creek	WL1.2T	Dry	412	904	89	90th	100	4
Quail Creek	WL1.1T	Wet	212	2510	96	90th	100	8
Henderson Inlet tributaries								
Dobbs Creek	DB0.1	Wet	299	2420	96	90th	100	10
Fleming Creek off Johnson Point Rd	FCRM1.3	new/Dry	na	na	na	na	na	na
Sleepy Creek	SL0.8	Wet	90	835	88	90th	100	8
Myer Creek	MY0.1	Wet	109	741	87	90th	100	6
Goose Creek	GO0.4	Wet	54	773	87	90th	100	7
Woodard Creek at RM 6.9	WD6.9	Wet	na	415	76	90th	100	8
Woodard Creek at RM 3.4	WD3.4	New	na	na	na	na	na	na
Woodard Creek at RM 0.0	WD0.0	Wet	na	450	90	90th	100	8
Stormwater outfall stations (Storm event only)								
Stormwater discharge into Taylor wetland	SWPOND	Wet	na	4590	98	90th	100	4
Stormwater pipe at Woodland RM 2.6	WL2.6SW	Wet	617	1920	95	90th	100	6
WSDOT stormwater discharge at Woodland RM 3.1	WL3.1SW	Wet	31	624	84	90th	100	9
Stormwater pipe from Interstate 5 at Woodland RM 3.1	WLSW2	Wet	539	659	91	geo	50	3
Stormwater Discharge at Woodland RM 3.7	WL3.7SW	Wet	446	8370	99	90th	100	11

**N*: number of samples collected.

3.2 TMDL Effectiveness Monitoring Studies

What is TMDL Effectiveness Monitoring?

TMDL process

The TMDL process typically includes the following steps:

1. Scientific study to (1) characterize the pollution parameters identified in the Section 303(d) list of impaired water bodies, and (2) identify pollutant sources.
2. Modeling pollutant impacts on the environment and quantifying the extent of impairment.
3. Estimating the loading capacity of the receiving water to assimilate pollutants and still meet Washington State water quality standards.
4. Determining the TMDL of pollutants by allocating the loading capacity to wasteload allocations for point sources (discrete sources that receive an NPDES permit) and to load allocations for nonpoint (diffuse) sources.
5. Developing a Water Quality Improvement Report (WQIR) that includes the TMDL study and an implementation strategy.
6. Submitting the WQIR to EPA for approval.

Based on the approved TMDL, an implementation plan is developed to correct pollution problems identified in the TMDL. Community involvement is encouraged during this period, as pollution control strategies are reviewed and converted into feasible solutions and activities that are economically feasible and capable of early implementation. These implementation activities are continued, as necessary, to meet and maintain compliance with state water quality standards. Effectiveness monitoring is used to determine the progress of the TMDL implementation activities and initiate and adaptive management action plan where necessary.

TMDL Effectiveness Monitoring

TMDL effectiveness monitoring is a fundamental component of any TMDL implementation activity. It measures to what extent the water body has improved and whether it has been brought into compliance with the state water quality standards (Collyard and Onwumere, 2012). Effectiveness monitoring takes a holistic look at TMDL implementation, watershed management plan implementation, and other watershed-based cleanup efforts. Success may be measured against TMDL load allocations or targets, correlated with baseline conditions or desired future conditions.

The TMDL effectiveness evaluation benefits by providing:

- Measurement of progress toward implementation of recommendations−how much watershed has been restored and how much more effort is required.
- More efficient allocation of funds and optimized planning and decision-making.

- Identification of restoration activities that worked and those that were most successful for the money spent.
- Technical feedback to refine the initial TMDL model, best management practices, nonpoint source plans, and permits.

Implementation monitoring

Implementation monitoring assesses whether activities were carried out as planned. The most common use of implementation monitoring is to determine whether BMPs were implemented as specified in TMDLs or other pollution control plan. Typically, this is carried out as a review or site inspection and does not involve any water quality measurements.

Implementation monitoring is the most cost-effective means to reduce nonpoint-source pollution because it can provide immediate feedback to managers on whether the BMP process is being carried out as intended. Implementation monitoring itself cannot directly link management activities to water quality changes. It must be supported by adequate water quality monitoring design that is capable of providing reasonable assurances progress is being made towards meeting water quality standards. Both of these monitoring activities are a critical part of an evaluation of and implementation of TMDLs and are necessary to meet many of the objectives outlined in this study.

Implementation of pollution control activities in the Henderson Inlet watershed fall primarily under the jurisdiction of Thurston County and the city of Lacey. Both local governments have been actively involved in water quality protection and cleanup actions. In addition, the Thurston County Conservation District and local citizen groups have also been actively involved in water quality protection and improvement.

There are two primary long-term implementation strategy's develop to guide implementation of pollution control measures in the basin. In 2003 the Shellfish Protection District published recommendations for a long-term strategy necessary to protect shellfish harvest in the basin (Thurston County, 2003). This strategy is specific to reducing bacterial contamination in Henderson Inlet. The second strategy, developed by Ecology in 2008 as a requirement for all TMDLs, is to reduce bacteria throughout the watershed (Ecology, 2008). A list of cleanup actions, priority, and timeline for implementation is outlined in *Henderson Inlet Watershed Fecal Coliform Bacteria Total Maximum Daily Load: Water Quality Implementation Plan* (Ecology, 2008).

As part of this study, Ecology will work with the local groups involved with implementation to develop a comprehensive list of pollution control actions implemented in the watershed. This data will be compared to recommendations outlined in both implementations strategies to assess progress towards meeting water quality cleanup and protection goals. The results of this exercise will be summarized in the final report and applied in adaptive management strategies if applicable.

4.0 Project Description

The effectiveness monitoring study will require both collecting field data and compiling implementation information from regionally active stakeholder groups. Although the original TMDL technical study conducted synoptic field surveys for FC during storm events, this study will conduct instream FC study using a fixed station network. However, because TMDL targets were set based on FC samples collected during storm events (>0.30" of rain), the sampling schedule may be adjusted if too few rain events meeting the criteria fall on proposed sampling dates.

Where appropriate, Ecology will also use optical brightener (OB) sensors to help detect or confirm the presence of human-derived FC pollution. OBs are chemical additives commonly used in laundry detergents, and their presence indicates human wastewater sources of FC.

In addition to water quality data, Ecology will also collect biological and habitat data at several locations to provide an estimate of watershed health. Biological and physical habitat parameters are typically responsive to water quality impairments and can be effective for evaluating water quality improvements. Generally, these parameters integrate the effects of different pollutant stressors and provide an overall measure of the aggregate impact of stressors (Barbour et al., 1999).

FC data from this study will be analyzed and compared to both water quality criteria and targets set at locations identified in the TMDL. To the extent possible, FC data will be combined with data from past studies and current monitoring efforts by DOH and assessed for trends over time. Variables (covariates) that could affect FC concentrations in the watershed will also be assessed in the trend analysis. These may include covariates such as population, precipitation, flow, salinity and time.

The resulting information will be altogether assessed using a weight-of-evidence approach to measure the effectiveness of pollution control activities (Collyard and Onwumere, 2013).

4.1 Project goals

The goal of the proposed study is to measure the effect of pollution control measures implemented in the Henderson Inlet watershed on FC in surface waters. A secondary goal of this project is to collect habitat and bioassessment data in the watershed to evaluate the effectiveness of stormwater systems discharging into surface waters.

4.2 Project objectives

Objectives of the study are to:

- Collect biweekly FC samples at a fixed network of TMDL target locations.
- Collect a minimum of 4 FC samples from 5 stormwater outfalls identified in TMDLs.

- Collect biological and habitat data at 5 locations in Woodland and Woodard Creeks.
- Compare data collected in this study with TMDL targets.
- Use current and historic data to measure trends in fecal coliform in concentrations in fresh and marine waters over time.
- Catalog and map implementation activities in the watershed with available data.
- Evaluate changes in water quality data after best management practices were implemented.
- Recommend future actions.

4.3 Information needed and sources

Meeting these goals requires a comprehensive list of pollution control measures implemented to protect or restore water quality. This information will be needed from Thurston County, Cities of Lacey and Olympia, Thurston County Conservation District, and non-profit organization involved in implementing TMDL and Shellfish Protection District plan recommendations. Also required are historical and current fecal coliform, precipitation, salinity, and other covariate data from regional monitoring programs, to assess trends over time.

4.4 Target population

The target population for this study is surface waters within the Henderson Inlet watershed with 303(d) FC.

4.5 Study boundaries

Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIA
- 13-Deschutes River

HUC number
- 17110019

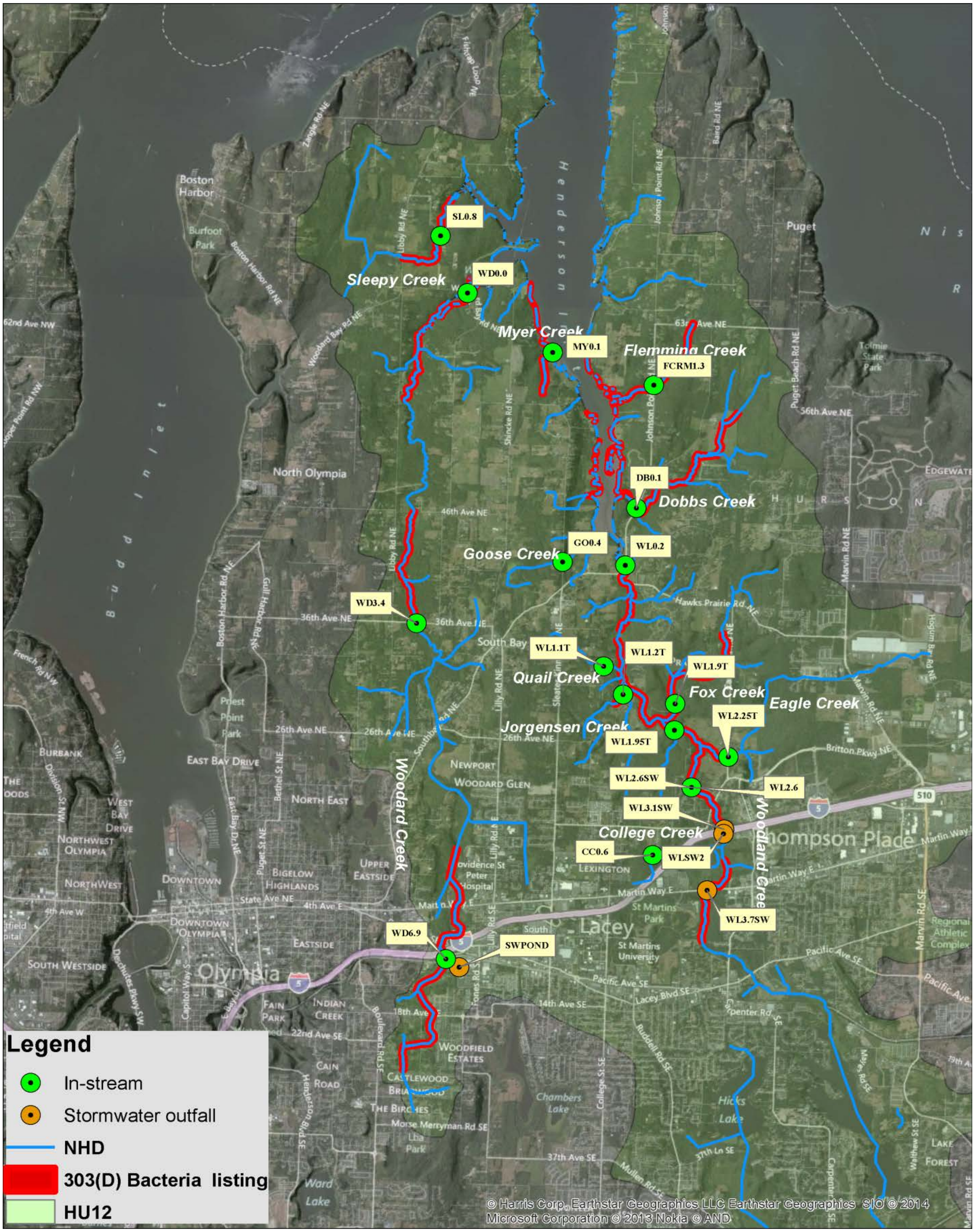

Figure 5. Map showing boundary of project study area.

4.6 Tasks required

Not applicable.

4.7 Practical constraints

See Section 3.11

4.8 Systematic planning process

Not applicable.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 4. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Donovan Gray Water Quality Program Southwest Regional Office Phone: 360-407-6407	EAP Client	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP.
Andrew Kolosseus, Water Quality Program Southwest Regional Office Phone: 360-407-7543	EAP Client Unit Supervisor	Reviews and approves the final QAPP.
Rich Doenges Water Quality Program Southwest Regional Office Phone: 360-407-6271	EAP Client Section Manager	Reviews and approves the final QAPP.
Scott Collyard Directed Studies Unit WOS, EAP Phone: 360-407-6455	Project Manager	Writes the QAPP. Oversees field sampling and transportation of samples to the laboratory. Conducts QA review of data, analyzes and interprets data, and enters data into EIM. Writes the draft report and final report.
Paul D. Anderson Directed Studies Unit WOS, EAP Phone: 360-407-7548	Principal Investigator	Co-authors QAPP and technical sections of the effectiveness monitoring report. Collects field samples and records field information. Assists project manager with project duties as needed.
Meaghan Mounger Directed Studies Unit WOS, EAP Phone: 360-407-6530	Field Assistant	Helps collect samples and records field information.
George Onwumere Directed Studies Unit WOS, EAP Phone: 360-407-6730	Unit Supervisor for the Project Manager	Reviews and approves the project scope and budget, tracks progress, reviews and approves the draft QAPP, final QAPP, draft report, and final report
Robert F. Cusimano WOS, EAP Phone: 360-407-6596	Section Manager for the Project Manager	Provides internal review and approves the final QAPP.
Joel Bird Manchester Environmental Laboratory Phone: 360-871-8801	Director	Reviews and approves the final QAPP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management database
QAPP: Quality Assurance Project Plan
WOS: Western Operations Section

5.2 Special training and certifications

Not applicable.

5.3 Organization chart

See Table 4.

5.4 Project schedule

Table 5 shows the schedule for completing field and laboratory work, data entry into EIM, and reports.

Table 5. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Field and laboratory work	Due date	Lead staff
Field work completed	June 2015	Paul D. Anderson
Laboratory analyses completed	July 2015	
Environmental Information System (EIM) database		
EIM Study ID	PAND0004 as of publication date WHM_EFF2 as of April 2017	
Product	Due date	Lead staff
EIM data loaded	September 2015	Paul D. Anderson
EIM data entry review	October 2015	Scott Collyard
EIM complete	November 2015	Paul D. Anderson
Final report		
Author lead / Support staff	Scott Collyard/ Paul D. Anderson	
Schedule		
Draft due to supervisor	January 2016	
Draft due to client/peer reviewer	February 2016	
Draft due to external reviewer(s)	March 2016	
Final (all reviews done) due to publications coordinator	April 2016	
Final report due on web	May 2016	

5.5 Limitations on schedule

Not applicable.

5.6 Budget and funding

The estimated laboratory budget and number of lab samples shown in Table 6 is based on the proposed schedule in Table 6. The greatest uncertainty in the cost estimate is with the storm event sampling, sites where streams are ephemeral, and source identification sampling. Efforts will be made to keep the submitted number of samples within the estimate; however, because not all storm and investigation sites have been selected yet, this is an estimate only.

Table 6. Number of samples per parameter, estimated analytical cost per parameter, and total cost for the study, 2014-2015.

Parameter	Number of Samples	Number of QA Samples	Total Number of Samples	Cost Per Sample	MEL Subtotal	Contract Fee
Fecal Coliform - MF	476	48	524	$24.93	$13,063	n/a
Total Organic Carbon	20	2	22	$35.77	$786.94	
Macroinvertebrates	5	1	6	$300.00		$1800.00
Periphyton	5	1	6	$305.00		$1830.00
Periphyton % Total Organic Carbon	5	1	6	$45.92	$275.52	
Ash-Free Dry Weight	5	1	6	$24.93	$149.58	
Periphyton Total % Solids	5	1	6	$11.92	$71.52	
Periphyton + Nutrients	5	1	6	$241.95	$1451.7	
Periphyton Chlorophyll *a*	5	1	6	$46.60	$279.60	
Periphyton Metals	5	1	6	$217.00	$1302.00	
				Subtotal:	$17,379.70	
				Contracting Subtotal:		$3630
				Total for study:	$21,009.70	

6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. Quality objectives apply equally to laboratory and field data collected by Ecology, to data used in this study collected by entities external to Ecology, and to other analysis methods used in this study.

6.1 Decision Quality Objectives

Not applicable.

6.2 Measurement Quality Objectives

Field sampling procedures and laboratory analyses inherently have associated uncertainty, which results in data variability. Measurement quality objectives (MQOs) state the acceptable data variability for a project. *Precision* and *bias* are data quality criteria used to indicate conformance with MQOs. The term *accuracy* refers to the combined effects of precision and bias (Lombard and Kirchmer, 2004).

Precision is a measure of the variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for laboratory duplicate samples will be expressed as relative percent difference (RPD). Precision for field replicate samples will be expressed as the relative standard deviation (RSD) for the group of duplicate pairs (Table 7).

Bias is defined as the difference between the sample value and true value of the parameter being measured. Bias affecting measurement procedures can be inferred from the results of quality control (QC) procedures. Bias in field measurements and samples will be minimized by strictly following Ecology's measurement, sampling, and handling protocols.

Field sampling precision and bias will be addressed by submitting replicate samples. Ecology's Manchester Environmental Laboratory (MEL) will assess precision and bias in the laboratory through the use of duplicates and blanks.

Table 7 outlines analytical methods, expected precision of sample duplicates, and method reporting limits. The targets for precision of field replicates are based on historical performance by MEL for environmental samples taken around the state by Ecology's Environmental Assessment Program (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives. The laboratory's MQOs and QC procedures are documented in the MEL *Lab Users Manual* (MEL, 2008).

Table 7. Measurement quality objectives for field and laboratory analyses.

Parameter	Method	Field Replicate/Lab Duplicate	Lowest Concentrations of Interest
Field Measurements			
Discharge Volume	Marsh McBirney Flow-Mate Flowmeter	10% RSD	0.01 ft/s
Conductivity	YSI conductivity meter	10% RSD	10 uS/cm
Optical Brighteners	Turner Designs Cyclops 7	10% RSD	0.1 ppb
Laboratory Analyses			
Fecal Coliform - MF	SM 9222D	40% RSD	1 cfu/100 mL
Water/Periphyton Total Organic Carbon	SM 5310 B	20% RSD	0.1 % carbon
Percent Total Solids	EPA2540		5 %
Periphyton Chlorophyll A	SM10300C(5)	20% RSD	0.1 ug/L
Periphyton Metals[1]	EPA200.2 EPA200.7	20% RSD	0.05 mg/Kg
Periphyton Nutrients[2]	EPA440.0 EPA200.7	50% RSD	0.01%
Periphyton Taxonomy	USGS	20% RSD	NA
Macroinvertebrate Taxonomy	Plotnikoff and Wiseman, 2001	20% RSD	NA

[1]Metals: As, Al, Cd, Cu, Fe, Mn, Ni, Pb, Zn
[2]Nutrients: Total C/N/ P
MF: membrane filter

6.2.1 Targets for Precision, Bias, and Sensitivity

6.2.1.1 Precision

Precision is a measure of the variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for laboratory duplicate samples will be expressed as relative percent difference (RPD). Precision for field replicate samples will be expressed as the relative standard deviation (RSD) for the group of duplicate pairs (Table 7).

6.2.1.2 Bias

Bias is defined as the difference between the sample value and true value of the parameter being measured. Bias affecting measurement procedures can be inferred from the results of QC procedures. Bias in field measurements and samples will be minimized by strictly following Ecology’s measurement, sampling, and handling protocols. Field sampling precision bias will be addressed by submitting replicate samples (Table 12). MEL will assess bias in the laboratory through the use of duplicates and blanks.

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as detection limit. In a regulatory sense, the method detection limit (MDL) is usually used to describe sensitivity. Targets for field and lab measurement sensitivity required for the project are listed in Table 7.

6.2.2 Targets for Comparability, Representativeness, and Completeness

6.2.2.1 Comparability

The 2014-2015 study will follow the same method and SOPs for FC that were followed in the 2003 TMDL QAPP (Sargeant et al., 2003). FC samples will also be collected at the same locations as TMDL target sites as well as additional locations (Table 8, Figure 4).

All data used in statistical comparisons and trend analysis from all agencies will be assessed for precision before analysis. If FC data sets do not meet standards for precision and biases, they will not be used in any analysis.

6.2.2.2 Representativeness

The study is designed to have enough sampling sites at sufficient sampling frequency to meet study objectives. Bacteria values are known to be highly variable over time and space. Sampling variability can be somewhat controlled by strictly following standard procedures and collecting QC samples, but natural spatial and temporal variability can contribute greatly to the overall variability in the bacteria value. Resources limit the number of samples that can be taken at one site spatially or over various intervals of time.

6.2.2.3 Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for the Henderson Inlet study is to correctly collect and analyze 100% of the samples for each of the sites. However, problems occasionally arise during sample collection that cannot be controlled; thus, a completeness of 95% is acceptable. Potential problems are flooding, site access problems, or sample container shortages.

7.0 Sampling Process Design (Experimental Design)

7.1 Study Design

The study objectives will be met through characterizing fresh water annual and seasonal FC concentrations and, where appropriate, loads in surface waters within the study area. FC concentrations will be monitored at TMDL target locations and other key locations within the study area from June 2014 through June 2015. This study will use a fixed network of FC monitoring sites that will be sampled biweekly. Additional monitoring during storm events (>0.3 inch rain) will occur if insufficient events are not captured within the sampling schedule.

FC storm-event and seasonal data from this study will be compared to TMDL storm event targets to determine progress toward goals. If additional FC reductions are still necessary, new targets will be calculated based on 2014-2015 fixed-network FC data.

Bioassessment will be conducted at several locations in the watershed to assess impacts from stormwater outfalls in the watershed. Macroinvertebrate and periphyton data will be collected above and below major stormwater outfalls and areas where land use has changed in Woodard and Woodland Creeks. Influences of outfalls and land use will be assessed by using current Benthic Index of Biotic Integrity models for the Puget Sound Lowlands. Relevant biological metrics, metal and nutrient concentrations in periphyton, and habitat metrics will be used to compare upstream and downstream locations.

Fixed-network

Data from the fixed network will provide an estimate of the annual and seasonal geometric mean 90th percentile statistics. The schedule should provide a minimum of 26 samples per fixed site to develop annual statistics. Streamflow estimates will provide FC load comparisons to help prioritize additional implementation efforts or to correlate load reductions to pollution control activities over time.

The fixed-network sites will be sampled a minimum of twice monthly from June 2014 through May of 2015. The proposed location of the fixed-network sites are listed in Table 8 and shown in Figure 2. Sites were selected based on recommended target stations identified in the TMDL (Category 4A and Category 5) and 2 bacteria listings (Ecology, 2014).

Sites may be added or removed from the sampling plan, depending on access and new information provided during the QAPP review, field observations, and preliminary data analysis.

Source identification and optical brightener (OB) surveys

If regular sampling confirms high FC concentrations at a site, staff may further investigate the area using targeted sampling to find FC pollution sources. Targeted sampling involves multiple samplings over ever-decreasing distances to identify sources of FC pollution.

A similar approach to targeted sampling is bracketed sampling. Bracketed sampling is simply targeting an area thought to have high FC concentrations by sampling upstream and downstream of the area in ever-decreasing distances until the source of the FC is found and further bracketing is deemed unnecessary.

In conjunction with targeted sampling and where appropriate, Ecology plans to use fluorometry as an inexpensive and practical bacterial source tracking (BST) method to identify or confirm *human* sources of fecal contamination. Fluorometry is a chemical BST method that identifies human fecal contamination by detecting OBs, also known as fluorescent whitening agents. OBs are added to most laundry detergents and represent about 0.15% of the total detergent weight (Hartel et al., 2008). Because household plumbing systems mix with effluent from washing machines and toilets together, OBs are associated with human sewage in septic systems and wastewater treatment plants (Hartel et al., 2008).

Storm monitoring

For purposes of comparing FC results with the TMDL targets reductions, Ecology will try to capture a minimum of 5 grab samples from storm events during the wet season (November through April). A storm event is defined as a minimum 0.3 inch of rainfall in a 24-hour period. Storm sampling will likely consist of multiple teams sampling all sites throughout the course of one day.

Bioassessment

Biological communities provide information about environmental conditions based on the range of tolerance that individual taxa have to environmental conditions. An assessment of benthic macroinvertebrate and periphyton communities will be conducted following Ecology's biological monitoring methodology and protocols (Mathieu et al., 2013, Adams, 2010).

Physical habitat measurements and periphyton nutrient and metal samples will be taken where taxonomy samples are collected, to describe the environment at the time of sampling. Biological and habitat assessments will occur during Ecology's biological assessment index period (between July and October 2014). Six sampling locations are currently proposed (Table 8).

7.1.1 Field measurements

Streamflow data

Stream discharge information will be obtained at target sampling locations to provide loading information. There are currently no active flow gauges in the watershed. However, there are staff gages installed at Woodland Creek at 36th Avenue, Woodland Creek at Pleasant Road, and

Dobbs Creek at Johnson Point Road that will be used. Flows will be calculated from stage height records and rating curves that were developed for these sites before and during the project. During the field surveys, staff will measure flow at selected stations and/or record staff gauge reading. Staff will estimate discharge and instantaneous flow measurement, following the Stream Hydrology unit protocols manual (Kardouni, 2013).

Optical brightener sampling

Ecology will deploy two Turner Designs Cyclops 7 OB sensors to test for concentrations of OBs over predetermined amounts of time, depending on resources and site characteristics. Staff will install one sensor upstream of the suspected source and another sensor downstream. If OBs are present and the upstream sensor records significantly lower OB concentrations than the downstream sensor, staff will assume that anthropogenic (human-derived) fecal contamination is entering the water somewhere between the sensors. This information, coupled with land use data and field observations, will give staff more certainty about whether FC sources are from failing or malfunctioning onsite sewage systems or wastewater treatment plants. Staff may find these scenarios:

- High FC and high OBs (suggests malfunctioning onsite sewage systems or wastewater treatment plant or leaky sewer pipe).
- High FC and low OBs (suggests other warm-blooded animals or human sources, such as an outhouse, that do not mix gray water and toilet water).

Staff is unlikely to find these scenarios (Ecology will only sample OBs when high FC is found):

- Low FC and high OBs (suggests gray water in the stormwater system).
- Low FC and low OBs (suggests no source of FC contamination).

OB detection can be less effective in the presence of organic matter. Organic matter can fluoresce and compromise OB detection, especially if the total organic carbon (TOC) concentration is over 40 mg/L (Hartel et al., 2008). Because organic matter has broadband, featureless spectra and the emission spectra of OBs are in the 415 to 445 nm range (Hartel et al., 2008), Turner Designs OB sensors use a narrow emission spectrum of 445 nm. This allows for more confidence that only OBs are detected and not organic matter. Because most streams in western Washington have TOC concentrations well below 40 mg/L and the OB sensor is designed to eliminate most of the organic matter interference, the small amount of interference in some waters with organic matter is acceptable in this study. To ensure that any possible interference is minimal, TOC will be sampled as necessary when OB sensors are deployed.

OBs degrade quickly−within minutes to hours− in UV light (Hartel et al., 2007), although some studies indicate conflict on their photo-decay rates (Tavares et al., 2008). Confirmation of OBs in waters likely means that a source of OBs is nearby.

Optical brighteners can persist in sediment (Hartel et al., 2007), so Ecology may find that OB concentrations increase during storm events from sediment re-suspension. Storms may inundate any onsite sewage systems installed below the high water mark. This could cause OBs to move more quickly from malfunctioning onsite sewage systems to waterways. Also, storms can carry

OBs more quickly downstream without as much time for UV attenuation, and more turbid waters may also decrease UV degradation. These factors may complicate analyses, but Ecology is planning multiple sampling events during wet and dry seasons to allow for a clear and complete analysis of the data.

This is a new BST method for Ecology's Directed Studies Unit that should prove useful, if staff follow appropriate protocols and interpret data correctly. To ensure proper OB sampling techniques are followed, Ecology has recently developed and adopted a standard operating procedure (SOP) for OB sampling (Anderson and Swanson, 2014).

Conductivity

Because FC are sensitive to saltwater, die-off rates change when they enter marine and estuarine waters. Freshwater stations under tidal influence will be monitored during low tide so FC samples reflect the freshwater input. Conductivity will be checked to ensure that fresh water is sampled.

7.1.2 Sampling location and frequency

FC fixed-network sampling locations for this study are outlined in Table 8 and Figure 4. Locations were selected based on stormwater bacterial reductions and target locations identified in the 2006 TMDL report (Sargeant et al., 2006). The fixed-network sites will be sampled a minimum of twice monthly from June 2014 through May 2015. Additional monitoring during storm events (>0.3 inch rain) will occur if insufficient events are not captured in the sampling schedule.

Table 8. Proposed FC sampling locations for 2014-2015 Henderson Inlet Effectiveness Monitoring study.

Sample Site	Station Description	Station ID	Latitude	Longitude
Woodland Creek and tributaries				
Woodland Creek at RM 2.6	Woodland Creek at 21 Court	WL2.6	47.0631	-122.809
Woodland Creek at RM 0.2	Woodland Creek at Hawks Prairie Road	WL0.2	47.0917	-122.822
College Creek	College Creek at RM 0.6 at bike path near Lacey City Hall	CC0.6	47.0542	-122.815
Eagle Creek	Eagle Creek (mouth), right bank tributary	WL2.25T	47.0672	-122.802
Palm Creek	Upstream from mouth, left bank tributary	WL1.95T	47.0739	-122.812
Fox Creek	At Pleasant Glade Road, right bank tributary	WL1.9T	47.0749	-122.822
Jorgensen Creek	Jorgenson Creek (mouth), left bank tributary	WL1.2T	47.0705	-122.812
Quail Creek	Quail Creek (just upstream from mouth), left bank tributary	WL1.1T	47.0785	-122.826
Henderson Inlet tributaries				
Dobbs Creek	Dobbs Creek at Johnson Creek Road	DB0.1	47.0992	-122.82
Flemming Creek	Flemming Creek at Johnson Point Road	FC1.3	47.1152	-122.818
Sleepy Creek	Sleep Creek at Libby Road	SL0.8	47.1338	-122.858
Myer Creek	Myer Creek near Snug Harbor Drive	MY0.1	47.1191	-122.837
Goose Creek	Goose Creek at Sleater Kinney Road	GO0.4	47.0919	-122.834
Woodard Creek and tributaries				
Woodard Creek at RM 6.9	Woodard Creek at bike path, Taylor wetland outlet	WD6.9	47.0399	-122.853
Woodard Creek at RM 3.4	Woodard Creek at 36th Avenue	WD3.4	47.0834	-122.861
Woodard Creek at RM 0.0	Woodard Creek at Woodard Bay Road	WD0.0	47.1265	-122.853
Stormwater outfall stations (storm event only)				
Stormwater discharge into Taylor wetland	Discharge from City of Olympia stormwater ponds west of Fones Road	SWPOND	47.0854	-122.854
Stormwater pipe at Woodland RM 2.6	Stormwater pipe entering Woodland Creek just downstream of 21st Court NE bridge, left bank	WL2.6SW	47.0631	-122.809
WSDOT stormwater discharge at Woodland RM 3.1	Tributary from WSDOT vault, north I-5 culvert, right bank	WL3.1SW	47.0578	-122.802
Stormwater pipe from Interstate 5 at Woodland RM 3.1	Small stormwater pipe discharges from above I-5 culvert (north) to Woodland Creek	WLSW2	47.0572	-122.802
Stormwater Discharge at Woodland RM 3.7	Stormwater discharge from pipe south side Martin Way	WL3.7SW	47.0498	-122.805

Proposed biological monitoring locations for Woodland and Woodard Creeks are presented in Table 9. Locations were selected based on the presence of upstream stormwater outfall locations. Bioassessments are scheduled to be conducted one time at each of the purposed sampling stations during July through October (biological index period). An additional sample event may be necessary outside the biological index period during the wet season, if locations are dry during sampling period. Influences from stormwater outfalls will be determined by comparing results between outfall upstream and downstream locations. Overall stream health will be measured by calculating regional Benthic Index of Biotic Integrity for all sampling sites.

Table 9. Proposed biological sampling locations for 2014-2015 Henderson Inlet Effectiveness Monitoring study.

Sample Site	Station Description	Station ID	Latitude	Longitude
Woodland Creek at RM 2.9	Woodland Creek at Durham Road	WL2.9	47.0609	-122.804
Woodland Creek at RM 2.6	Woodland Creek at 21st Court	WL.2.6	47.0609	-122.804
Woodland Creek at RM 1.6	Woodland Creek at Pleasant Glade Road	WL1.6	47.0634	-122.8087
Woodard Creek at RM 4.5	Woodard Creek at 28th Ln NE	WD4.5	47.0833	-122.8604
Woodard Creek at RM 3.4	Woodard Creek at 36th Avenue	WD3.4	47.07180	-122.8560

Sampling Schedule

The tentative field sampling schedule is listed below. Some dates will likely change, due to unanticipated circumstances.

6/30/2014	1/5/2015
7/7/2014	1/20/2015
7/21/2014	2/2/2015
8/4/2014	2/17/2015
8/18/2014	3/2/2015
9/2/2014	3/16/2015
9/15/2014	3/30/2015
9/29/2014	4/13/2015
10/13/2014	4/27/2015
10/27/2014	5/11/2015
11/10/2014	5/26/2015
11/24/2014	
12/8/2014	
12/22/2014	

7.1.3 Parameters to be determined

See Table 10.

7.2 Maps or diagram

See Figure 2.

7.3 Assumptions underlying design

Not applicable.

7.4 Relation to objectives and site characteristics

Not applicable.

7.5 Characteristics of existing data

Not applicable.

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

Freshwater samples will be collected using Ecology's SOPs EAP030 for bacteria (Ward and Mathieu, 2011) and EAP015 grab sampling (Joy, 2013). Ten percent of FC samples will be replicated in the field in a side-by-side manner to assess field and laboratory variability. Samples will be collected in the thalweg and just under the water's surface in freshwater outflows. A sampling pole may be used to ensure no disturbed sediment is collected.

Field measurements will be taken at all sampling sites and recorded in a notebook or equivalent electronic field form. Measurements for pH and dissolved oxygen will be collected using a calibrated YSI Exo or Hydrolab MiniSonde®, following Ecology's SOP EAP033 (Swanson, 2010) and manufacturer's recommendations.

Where fecal contamination is identified, OB sensors may be used to help determine the source of the contamination. OBs will be measured following Ecology SOP EAP091 (Anderson and Swanson, 2014).

Benthic macroinvertebrate samples will be collected at selected locations using Ecology's SOP EAP073 (Adams, 2010). In addition, periphyton samples will be collected using Ecology's SOP EAP085 (Mathieu et al., 2013). Greater than ten percent of the biological samples will be replicated in the field in a-side-by side manner to assess field and laboratory variability. Biological samples will be collected in riffle areas within stream reaches. The stream reach will be defined as 20 times bankfull width.

8.2 Containers, preservation methods, holding times

Table 10 shows the sample containers, preservation, and holding times required to meet the goals and objectives of this project.

Table 10. Sample containers, preservation, and holding times.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
Fecal Coliform - MF	Water	250 mL	250 mL poly autoclaved	Cool to ≤6°C	24 hours
Total Organic Carbon	Water	50 mL	60 mL poly	1:1 HCl to pH<2; Cool to ≤ 6°C	28 days
Total Organic Carbon	Tissue	5 g wt	50 mL poly centrifuge tube	Cool to <6°C	14 days
Percent Total Solids	Tissue	5 g wt	50 mL poly centrifuge tube	Cool to <6°C	7 days
Periphyton Chlorophyll A	Tissue	10 mL	Glass test tube	Acetone, cool to <6°C, keep in dark	28 days post filtration
Periphyton Metals[1]	Tissue	5 g wt	50 mL poly centrifuge tube	Cool to <6°C	6 months
Periphyton Biomass+nutrients[2]	Tissue	1000 mL	Amber poly	Cool to <4°C keep in dark	24 hr
Periphyton Ash-Free Dry Weight	Tissue	10 mL	Glass test tube	Cool to <6°C	28 days post filtration
Periphyton Taxonomy	Stream riffles	8 ft^2	poly	Lugol’s solution	1 year
Macroinvertebrate Taxonomy	Stream riffles	1000 cm^2	poly	Ethanol	1 year

MF: membrane filter
[1] Metals to be analyzed: aluminum, arsenic, cadmium, copper, lead, iron, silver, and zinc.
[2] Nutrients: N/P/C

8.3 Invasive species evaluation

Field staff will follow EAP’s SOP070 on minimizing the spread of invasive species (Parsons et al., 2012). The Henderson Inlet study area is not in an area of extreme concern. Areas of extreme concern have, or may have, invasive species like New Zealand mud snails that are particularly hard to clean off equipment and are especially disruptive to native ecological communities. For more information, please see Ecology’s website on minimizing the spread of invasive species at www.ecy.wa.gov/programs/eap/InvasiveSpecies/AIS-PublicVersion.html.

8.4 Equipment decontamination

Not applicable. There is no expectation that a sampler or sampling equipment will come in contact with high levels of contaminants.

8.5 Sample ID

MEL will provide the field lead with work order numbers for all scheduled sampling dates. The work order number will be combined with a field ID number that is given by the field lead. This combination of work order number and field ID number constitute the sample ID. All sample IDs will be recorded in field logs and in an electronic spreadsheet for tracking purposes.

8.6 Chain-of-custody

Once collected, samples will be stored in coolers in the sampling vehicle. When field staff are not in the sampling vehicle, it will be locked to maintain chain-of-custody. Upon return to the Operations Center, the chain-of-custody portion of the Laboratory Analysis Required sheet will be filled out and the coolers will be placed in the walk-in cooler.

8.7 Field log requirements

A field log will be maintained by the field lead and used during each sampling event. The following information will be recorded during each visit to each site:

- Name of location
- Field staff
- Environmental conditions
- Date, Time, Sample ID, samples collected, identity of QC samples
- Field measurement results
- Pertinent observations
- Any problems with sampling

Data collected using the OB sensor and/or logger will be recorded electronically. However, a separate log sheet will be maintained for each location that the OB sensor is used. If the OB sensor is being used to collect real time data the following information will be recorded:

- Name of location
- Field staff
- Environmental conditions
- Date, start and stop time
- Location of deployment (logger only)
- Description of area covered
- Pertinent observations
- Any problems with the OB sensor

8.8 Other activities

Any field staff new to the type of sampling being conducted for this study will be trained by senior field staff or the project manager, following relevant Ecology SOPs. Any maintenance needed for the YSI Exo, Turner Designs Cyclops 7 or Hydrolab MiniSonde® will be performed by trained field staff, following Ecology's SOP EAP033 and manufacturer instructions and recommendations. Before sampling begins, staff will send MEL a schedule of sampling events. This will allow the lab to plan for the arrival of samples. All samples will be collected between Monday and Wednesday so that holding times will be met for all fecal samples. The lab will be notified immediately if there will be any deviations from the scheduled date of sampling. To ensure that the appropriate number and type of required sample containers are available, the field lead will work with the laboratory courier to develop a schedule for delivery of sampling containers.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

Table 11 shows the field and laboratory measurement methods required to meet the goals and objective of this project.

Table 11. Measurement methods (field and laboratory).

Analyte	Sample Matrix	# of Samples	Expected Range of Results	Method	Method Detection Limit
Field Procedures					
Optical Brighteners[1]	Water	As needed[1]	0-500 ppb	Turner Designs Cyclops-7	0.1 ppb
Laboratory Procedures					
Fecal Coliform - MF	Water	624	1-10,000 cfu/100 mL	SM 9222 D	1 cfu/100 ml
Total Organic Carbon[2]	Water	As needed[2]	1-10 mg/L	SM 5310 B	0.1 mg/L
Periphyton Total Organic Carbon	Tissue	6	1 – 20 %	SM53	0.1% carbon
Periphyton Percent Total Solids	Tissue	6	1 – 30 %	EPA2540	1 mg/L
Periphyton Chlorophyll a	Tissue	6	.1 – 5 ug/cm^2	SM10300C(5)	0.05 ug/L
Periphyton Metals[3]	Tissue	6	0.05 – 2000 mg/Kg	EPA200.2 EPA200.7	0.05 – 5 mg/Kg
Periphyton Ash-Free Dry Weight	Tissue	6	0.05 – 5 mg	SM10300C	0.05 mg
Periphyton nutrients[4]	Tissue	6	0.01-0.5% of DW	EPA400 EPA200.7	0.01% of DW
Periphyton Taxonomy	Stream riffles	6	Variable	USGS	NA
Macroinvertebrate Taxonomy	Stream riffles	6	Variable	Plotnikoff and Wiseman, 2001	NA

[1]Optical brightener measurements will be taken only in areas where consistently high FC results are found.
[2]Total organic carbon samples will be collected in conjunction with OB measurements only when total organic carbon is suspected to be above high (>20 mg/L).
[3]Metals to be analyzed: aluminum, arsenic, cadmium, copper, lead, iron, silver, and zinc.
[4]Nutrients: C/P/N.

9.2 Lab procedures table

See Table 11 in Section 9.1.

9.3 Sample preparation method(s)

Periphyton will be sampled by removing rocks from sampling point. Before staff process, they will lightly rinse rock surfaces with reverse osmosis/de-ionized (RO/DI) water to remove loosely bound sediment and macroinvertebrates. The surfaces of the rocks will then be scraped with a stiff plastic brush to remove the loosely attached periphyton matrix. This material will be composited in a plastic tray rinsed into a 1-L acid-washed bottle, using RO/DI water, and placed on ice. A minimum of 125 cm^2 will be sampled at each sampling point.

Periphyton samples will then be prepared for chlorophyll-a and ash-free dry weight analysis by filtering 10 mL sub-sample through a 0.45 micron filter. Remaining composite samples will then be split, centrifuged, and analyzed for percent total solids, total metals, and %TOC. See Table 10 in Section 8.2 for appropriate sample containers and holding times.

9.4 Special method requirements

There are no special methods that will be used for this study.

9.5 Lab(s) accredited for method(s)

All chemical analysis will be performed at MEL, which is accredited for all methods (Table 10). Rhithron Associates, Inc. in Missoula, Montana will process and analyze macroinvertebrate and periphyton samples.

10.0 Quality Control (QC) Procedures

10.1 Table of field and lab QC required

Table 12 shows the QC requirements for this project.

Table 12. Quality control samples, types, and frequency.

Parameter	Field		Laboratory			
	Blanks	Replicates	Check Standards	Method Blanks	Analytical Duplicates	Matrix Spikes
Fecal Coliform -MF	n/a	10%	n/a	1/batch	1/20 samples	n/a
Total Organic Carbon water	10%	10%	1/batch	1/batch	1/batch	1/batch
Total Organic Carbon tissue	n/a	10%	1/batch	1/batch	1/batch	1/batch
Percent Total Solids	n/a	10%	1/batch	1/batch	1/batch	1/batch
Periphyton Chlorophyll a	n/a	10%	1/batch	1/batch	1/batch	1/batch
Periphyton Metals		10%	1/batch	1/batch	1/batch	1/batch
Periphyton Ash-Free Dry Weight	n/a	10%	1/batch	1/batch	1/batch	1/batch
Periphyton nutrients	n/a	10%	1/batch	1/batch	1/batch	1/batch
Periphyton Taxonomy	n/a	10%	-	-	-	-
Macroinvertebrate Taxonomy	n/a	10%	-	-	-	-

10.2 Corrective action processes

QC results may indicate problems with data during the course of the project. The lab will follow prescribed procedures to resolve the problems. Options for corrective actions might include:

- Retrieving missing information.
- Re-calibrating the measurement system.
- Re-analyzing samples within holding time requirements.
- Modifying the analytical procedures.
- Requesting additional sample collection or additional field measurements.
- Qualifying results.

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

Staff will record all field data in a field notebook or an equivalent electronic collection platform. Before leaving each site, staff will check field notebooks or electronic data forms for missing or improbable measurements. Staff will enter field-generated data into Microsoft (MS) Excel® spreadsheets as soon as practical after they return from the field. If data were collected electronically, data will be backed up on Ecology servers when staff return from the field. The field assistant will check data entry against the field notebook data for errors and omissions. The field assistant will notify the field lead or project manager of missing or unusual data.

Lab results will be checked for missing and/or improbable data. MEL will send data through Ecology's Laboratory Information Management System (LIMS). The field lead will check MEL's data for omissions against the "Request for Analysis" forms. The project manager will review data requiring additional qualifiers.

Field and laboratory data will be tested for trends, using a Seasonal Kendall trend test in SYSTAT® version 13. Summary statistics for all data will be generated using MS Excel®.

11.2 Laboratory data package requirements

Laboratory-generated data reduction, review, and reporting will follow the procedures outlined in the MEL Users Manual (MEL, 2008). Variability in lab duplicates will be quantified, using the procedures outlined in the MEL Users Manual. Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory QA/QC results will be sent to the project manager for each set of samples.

11.3 Electronic transfer requirements

MEL will provide all data electronically to the project manager through the LIMS to EIM data feed. There is already a protocol in place for how and what MEL transfers to EIM through LIMS.

11.4 Acceptance criteria for existing data

Not applicable. No special criteria are necessary to assess the usability of existing data.

11.5 EIM/STORET data upload procedures

All FC, TOC, dissolved oxygen, and pH data will be entered into EIM, following all existing Ecology business rules and the EIM User's Manual for loading, data quality checks, and editing.

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

Not applicable. There is not a need for audits for this study. However, there could be a field consistency review by another experienced EAP field staff during the period of this project. The aim of this review is to improve field work consistency, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen our data QA program.

12.2 Responsible personnel

See Section 12.1.

12.3 Frequency and distribution of report

Throughout the course of the study, the project manager or principal investigator will electronically send bacteria sample results of over 100 cfu/100 mL for freshwater and 14 cfu/100 mL for marine samples to all interested parties within one week of laboratory analysis. A final report will be published according to the project schedule in Section 5.4.

12.4 Responsibility for reports

Scott Collyard will be the lead on the final report. Paul D. Anderson will provide support.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

The field lead will verify initial field data before leaving each site. This process involves checking the data sheet for omissions or outliers. If measurement data are missing or a measurement is determined to be an outlier, the measurement will be repeated.

After each sampling week, the field assistant will compare all field data to determine compliance with MQOs. The field assistant will note values that are out of compliance with the MQOs and will notify the field lead. At the conclusion of the study, the field lead will compile a summary of all out of compliance values (if any) and provide it to the project manager for a decision on usability.

13.2 Lab data verification

MEL staff will perform the laboratory verification following standard laboratory practices. After the laboratory verification, the field lead will perform a secondary verification of each data package. This secondary verification will entail a detailed review of all parts of the laboratory data package with special attention to laboratory QC results. The field lead will bring any discovered issues to the project manager for resolution.

13.3 Validation requirements, if necessary

All laboratory data that have been verified by MEL staff will be validated by a project staff member. Field measurement data that was verified by a project staff member will be validated by a different staff member.

After data entry and data validation tasks are completed, all field, laboratory, and flow data will be entered into the EIM system. EIM data will be independently reviewed by another field assistant for errors at an initial 10% frequency. If significant entry errors are discovered, a more intensive review will be undertaken.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining whether project objectives have been met

After all laboratory and field data are verified, the field lead or project manager will thoroughly examine the data package, using statistics and professional judgment, to determine if MQOs have been met. The project manager will examine the entire data package to determine if all the criteria for MQOs, completeness, representativeness, and comparability have been met. If the criteria have not been met, the field lead and project manager will decide if affected data should be qualified or rejected based upon the decision criteria from the QAPP. The project manager will decide how any qualified data will be used in the technical analysis.

14.2 Data analysis and presentation methods

FC data will be tested for trends, using a Seasonal Kendall trend test in SYSTAT® version 13. Any significant trends will be presented in a chart showing the direction of the trend and the associated data. A summary will be written, discussing the test statistics, significance, confidence intervals, and any assumptions. Summary statistics for all data will be generated using MS Excel®. These summary statistics will be presented in tables.

14.3 Treatment of non-detects

Any non-detects will be included in the study analysis. To do this, the non-detect will be replaced by half the detection limit.

14.4 Sampling design evaluation

The project manager will decide whether the data package meets the MQOs, criteria for completeness, representativeness, and comparability, and whether meaningful conclusions (with enough statistical power) can be drawn from the Seasonal Kendall and summary statistics. If so, the sampling design will be considered effective.

14.5 Documentation of assessment

In the technical report, the project manager will include a summary of the data quality assessment findings. This summary is usually included in the data quality section of reports.

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18.0 Appendix. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Anthropogenic: Human-caused.

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

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.

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

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

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

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

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.

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

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

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 that clear more than 5 acres of land.

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.

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.

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.

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

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

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

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

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

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.

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

Acronyms and Abbreviations

BMP	Best management practice
BST	Bacterial source tracking
DOH	Washington State Department of Health
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
FC	(See Glossary above)
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NPDES	(See Glossary above)
OB	Optical brightener
QA	Quality assurance
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedure
TMDL	(See Glossary above)
TOC	Total organic carbon

USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

Units of Measurement

°C	degrees centigrade
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
mg/L	milligrams per liter (parts per million)
mL	milliliter
s.u.	standard units
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)
ug/L	micrograms per liter (parts per billion)
uS/cm	microsiemens per centimeter, a unit of conductivity

Quality Assurance Glossary

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

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

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

Bias: The difference between the population 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 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 is usable for intended purposes.
- J (or a J variant), data is estimated, may be usable, may be biased high or low.
- REJ, data is 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 that can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Split Sample: The term split sample denotes when a discrete sample is further subdivided into portions, usually duplicates. (Kammin, 2010)

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

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

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

References for QA Glossary

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