DEPARTMENT OF ECOLOGY
State of Washington

# Programmatic Quality Assurance Project Plan

## Water Quality Impairment Studies

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## Publication Information

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan. This Programmatic plan describes common objectives of water quality impairment studies and the procedures to be followed to achieve those objectives.

This Quality Assurance Project Plan is available on Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1703107.html

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# Programmatic
# Quality Assurance Project Plan

## Water Quality Impairment Studies

March 2017

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EAP: Environmental Assessment Program
MTMU: Modeling and TMDL Unit
NEP: National Estuary Program
SCS: Statewide Coordination Section

# 1.0 Table of Contents

# List of Figures and Tables

Page

## Figures



## Tables

# 2.0 Abstract

The Washington State Department of Ecology conducts water quality impairment studies, ranging in size and complexity, for aquatic areas including marine waters, lakes, rivers, and streams statewide. These studies help us better understand water quality issues, identify sources of pollution, and create implementation strategies such as a Total Maximum Daily Load (TMDL).

This Programmatic Quality Assurance Project Plan (QAPP) describes elements that are regularly used in the water quality impairment study process. It addresses typical conventional parameters causing impairment in water bodies, such as temperature, pH, dissolved oxygen, and turbidity. This QAPP outlines common objectives of water quality impairment studies and the necessary procedures to achieve those objectives. General descriptions for study design, quality objectives and quality control, field and laboratory, and data management procedures are included in this QAPP.

This Programmatic QAPP serves as the main reference for small, simple water quality impairment studies. For large, complex projects, a project-specific QAPP will be used in addition to the Programmatic QAPP. The project-specific QAPP will include details for the individual project.

The purpose of this Programmatic QAPP is to allow for project efficiency and to ensure that all water quality impairment studies use consistent methods and meet all quality objectives.

# 3.0 Background

The surface water bodies of Washington State are part of the identity of the State. The heightened demands on water resources from growing populations and development often lead to increased pollution problems.

Washington State's Department of Ecology (Ecology) strives to make measurable improvements in water quality by:

- Addressing point-source pollution with pollutant limits and other conditions in discharge permits.
- Preventing nonpoint-source pollution through implementation of best management practices (BMPs) that protect water quality.
- Educating the public.
- Partnering with local governments and businesses to keep Washington's waters clean for everyone to enjoy.

## 3.1 Introduction

Ecology's Water Quality Program (WQP) and Environmental Assessment Program (EAP) play integral roles in the state's implementation of the federal Clean Water Act. Ecology is delegated by the United States Environmental Protection Agency (EPA) as the state's water pollution control agency.

WQP is the lead program in implementing all federal and state water pollution control laws and regulations. Three of WQP's major roles are to:

- Maintain, interpret, and update the state's Water Quality Standards.
- Compile and assess water quality data to determine a list of the state's impaired waters.
- Prepare cleanup/implementation plans to address water quality impairment.

EAP provides support to WQP's Clean Water Act work through data collection, technical analysis, and water quality modeling. Together WQP and EAP develop joint water quality improvement and implementation plans to address impaired waters of the state.

This Programmatic Quality Assurance Project Plan (QAPP) describes EAP's data collection and analysis activities that support the following Clean Water Act water quality impairment studies:

- Total Maximum Daily Load (TMDL) or water quality improvement plans.
- Source assessments.
- Straight-to-implementation studies.
- Field sampling and data verification studies, including:
    - Pre-project/reconnaissance field work.
    - Follow-up sampling.
    - Exploratory analysis and modeling.
- Investigative sampling.

## 3.2 Study Area and Surroundings

The study area for EAP's water quality impairment work includes all of the marine and fresh surface waters within Washington's territorial boundaries. Examples of major water systems and features in the state include:

- Columbia River system including:
  - Upper Columbia including Pend Oreille, Kettle, Spokane, and Sanpoil Rivers.
  - Mid-Columbia including Okanogan, Methow, Entiat, Wenatchee, Yakima, and Walla Walla Rivers.
  - Columbia Gorge including Klickitat, White Salmon, Little White Salmon, and Wind Rivers.
  - Lower Columbia including Washougal, Lake, Lewis, Kalama, Cowlitz, and Grays Rivers.
- Puget Sound (part of the Salish Sea) and the rivers that feed into it, including Nooksack, Skagit, Stillaguamish, Snohomish, Green/Duwamish, Puyallup, Nisqually, Deschutes, Skokomish, Hamma Hamma, Duckabush, and Dosewallips Rivers.
- Coastal rivers/embayments including Quillayute, Hoh, Queets, Raft, Quinault, Moclips, Copalis, Chehalis, and Willapa Rivers, as well as Grays Harbor and Willapa Bay.
- Strait of Juan de Fuca including Sekiu, Hoko, Clallam, Pysht, East and West Twin, Lyre, Elwha, and Dungeness Rivers.
- Lower Snake River including Palouse, Tucannon, and Grande Ronde Rivers.
- Beaches on Puget Sound and also estuaries and embayments, including Padilla Bay, Dungeness Bay, Grays Harbor, North Beach, and Sinclair-Dyes Inlets.
- Lakes and reservoirs including Lake Chelan, Moses Lake, Lake Whatcom, Newman Lake, Capitol Lake, Lake Washington, and Ozette Lake.

The geographic scale of individual water quality impairment projects ranges from small (for example, investigative sampling of a stretch of a stream or the impacts of a single point-source discharge) to large (for example, a complex TMDL study modeling an entire large river watershed and its associated estuary).

For major work projects, details for the study area will be provided in the project-specific QAPP.

Tribal sovereignty allows Tribes to administer their own Water Quality Standards (WQS) program in Washington State on trust lands within their reservations if the Tribe qualifies under Section 518(e) of the Clean Water Act (list of current EPA approvals of Tribe WQS: https://www.epa.gov/wqs-tech/epa-approvals-tribal-water-quality-standards). Ecology does not have jurisdiction on reservation land. Surface waters that flow into tribal boundaries are considered waters of the state upstream of the boundary and tribal waters downstream of the boundary, and conversely for waters flowing out of tribal lands. Washington must respect treaty obligations and collaborate with the governments of tribal nations. Many watersheds in Washington have established tribal treaty rights or pending tribal claims to water that relate directly to ensuring sufficient streamflows for fish.

The Washington State Forest Practices Rules (Title 222 WAC) establish standards for forest practices that are designed to protect public resources, including water quality and fish habitat on state forest lands. The Forest Practices Rules address various forestry practices and are set by the Forest Practices Board, an independent state agency. Rules involving water quality protection must be approved by Ecology before they can be adopted by the Forest Practices Board. (http://www.dnr.wa.gov/about/boards-and-councils/forest-practices-board/rules-and-guidelines/forest-practices-rules)

Ecology and the United States Forest Service (USFS) formed a *Memorandum of Agreement* that recognizes the USFS as the Designated Management Agency for meeting Clean Water Act requirements on national forest lands within Washington (USDA and WDOE, 2000). This agreement establishes that the USFS agrees to meet or exceed the water quality requirements in state and federal law on its lands. Ecology works with USFS to determine compliance with the *Memorandum of Agreement* and to ensure the agreement provides reasonable assurance for TMDL implementation and restoration of water quality for federal lands.

### 3.2.1 History of Study Area

For major work projects, the history of the study area will be determined by the project-specific QAPP.

For minor work projects, the history of the study area will be described in the scope-of-work memo.

### 3.2.2 Summary of Previous Studies and Existing Data

Current and historic water quality improvement projects in Washington listed by county can be found on Ecology's website at: WQ Improvement Projects by County.

Ecology's Environment Information Management (EIM) database contains data collected by Ecology and affiliates, such as local governments. EIM allows for the accessibility of discrete and time-series environmental data for air, water, soil, sediment, aquatic animals, and plants from water quality impairment studies and other studies. (EIM Database)

For major work projects, previous studies and existing data specific to the study area will be summarized in the project-specific QAPP.

### 3.2.3 Parameters of Interest and Potential Sources

Parameters of interest for water quality impairment studies addressed in this Programmatic QAPP include temperature, pH, dissolved oxygen (DO), bacteria, and turbidity.

Water quality impairment studies may also address toxics. These studies are not currently described in this Programmatic QAPP but may be addressed in a future version of this document or in a separate toxics Programmatic QAPP. More information on toxic studies within EAP can be found at: https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Toxics-studies.

### 3.2.3.1 Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature also affects the physical and biological properties of the water body which can increase the harmful effects of other pollutants and stream characteristics. For example, the warmer a stream is, the less oxygen it can hold for the organisms the stream supports. Therefore, temperature is an influential factor which can limit the distribution and health of aquatic life.

Temperatures in streams fluctuate over the day and year in response to changes in solar energy inputs, meteorological conditions, river flows, groundwater input, and other factors. Human activities can influence many of these factors that impair the health of the water by either increasing the temperature or by improving these conditions to promote cooler temperatures.

Potential sources of heat load that can increase water temperature are:

- Loss of riparian shade.
- Point-source discharges from wastewater or stormwater outfalls.
- Loss of baseflow/groundwater from water withdrawals.
- Loss of channel complexity/hyporheic exchange.

A more detailed discussion of stream heating processes is included in Appendix B.

### 3.2.3.2 pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. pH is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species. Changes in pH affect the degree of dissociation of weak acids or bases and influence the toxicity of many compounds. While some compounds (e.g., cyanide) increase in toxicity at lower pH, others (e.g., ammonia) increase in toxicity at higher pH.

Human activity and development can raise or lower instream pH through many mechanisms and activities and include:

- Mining activities.
- Industrial or other point-source discharges of acidic or basic substances to surface waters.
- Atmospheric deposition of sulfuric compounds emitted by industry.
- Reduced soil buffering capacity with export of base cations (from the watershed) through forest harvest.
- Increased algal and plant photosynthesis due to cultural eutrophication. Increased photosynthesis is typically driven by increased point-source and nonpoint-source loading of nitrogen and phosphorus. When excess phosphorus or nitrogen is available, algae use it to build additional cell mass, obtaining carbon for new growth from carbon dioxide that is naturally present in river water. Because carbon dioxide affects the pH of the water, carbon uptake by algae causes the river to become less acidic and more basic. As a result, the pH of the river increases during daylight hours when photosynthesis occurs.

#### 3.2.3.3 Dissolved Oxygen

Aquatic organisms are very sensitive to reductions in the level of dissolved oxygen (DO) in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. DO levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants.

DO levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. The diurnal cycle of algal growth adds DO during the daylight hours as the plants perform photosynthesis, but reduces DO levels at night, reaching a minimum around daybreak, as respiration is predominant.

Changes in DO levels can be influenced by:

- High water temperatures that lower the ability of water to hold oxygen, causing warm water to hold less oxygen than cold water.
- Groundwater discharges affect DO levels and nutrient concentrations in streams. DO is often lower in groundwater. Existing groundwater data will be researched to assess the potential influence of groundwater discharges on the impaired water bodies.
- The combination of biological, biochemical, and chemical processes at the sediment-water interface, called sediment oxygen demand, consuming DO in the overlying water.
- Discharges from wastewater or stormwater (point sources) or diffuse sources (nonpoint sources) influencing biochemical oxygen demand (BOD).
- Increased algal and plant photosynthesis due to cultural eutrophication. Increased photosynthesis is typically driven by increased point- and nonpoint-source loading of nitrogen and phosphorus, which increases the severity of the diurnal DO fluctuation. This can result in lower levels of DO than under natural conditions.

#### 3.2.3.4 Bacteria

Fecal coliform bacteria (FC) are used as indicators of fecal contamination and the presence of other disease-causing (pathogenic) organisms from humans and other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. High FC numbers in waterways may indicate an increased risk of infection from pathogens associated with fecal waste.

Other bacteria indicators, such as Escherichia (E.) coli and enterococci, are evaluated as alternative or additional surrogates for pathogens under the triennial review of Washington State Water Quality Standards. However, at the time of this publication, FC remain the designated indicator.

During sufficient precipitation events, rainwater washes the surface of the landscape and impervious surfaces, saturates soils, and raises water tables. Runoff from stormwater can accumulate and transport fecal matter. Stormwater loaded with fecal matter may drain to receiving water bodies and potentially degrade water quality.

Potential sources of bacteria include:

- Waterfowl, rodents, and other warm-blooded wildlife.
- Range and pastured livestock with direct access to the river or stream.
- Livestock manure applied to fields or leached from storage areas.
- Pet manure from residential areas.
- Poorly constructed or maintained on-site septic systems (OSS).
- Pulp and wood waste.
- Municipal and industrial wastewater and stormwater.
- Swales, sub-surface drains, drainage ditches, and flooding through pastures and nearby homes.
- Animal waste tracked by vehicle tires.

#### 3.2.3.5 Turbidity

Turbidity is a measure of light refraction in the water that indicates water quality based on the amount of sediment and suspended solids within the water column. The higher the intensity of scattered light, the higher the turbidity. It is an indicator of suspended particles such as clay, silt, organic matter, and small organisms. Suspended solids in the water column and settled bottom sediments affect fish and other aquatic life.

Potential sources of increased turbidity include:

- Forest or agricultural activities and other practices that cause issues of denuded soil or dirt road drainage.
- Range and pastured livestock with direct access to the river or stream.
- Soil erosion and eroding stream banks.
- Lack of riparian vegetation.
- Stormwater conveyance and runoff.
- Swales, sub-surface drains, and flooding through pastures and nearby homes.

### 3.2.4 Regulatory Criteria or Standards

The Water Quality Standards (WQS) are the basis for protecting and regulating the quality of surface waters in Washington State. The standards implement portions of the federal Clean Water Act by specifying the designated and potential uses of water bodies in the state. They set water quality criteria to protect those uses and acknowledge limitations. The standards also contain policies to protect high quality waters (antidegradation) and, in many cases, specify how criteria will be implemented, such as through permits.

The WQS are established to sustain public health and public enjoyment of the waters, and the propagation and protection of fish, shellfish, and wildlife. A three-part approach was designed to set limits on pollution in water systems in order to protect beneficial uses such as aquatic life, swimming, and fishing.

The *aquatic life* uses contain six categories of aquatic communities and are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) (WAC 173-201A-200; 2003 edition) and are found in Table 1 (see Table 2 for marine standards).

Categories for recreational uses are found in these tables as well. These criteria are used to support TMDLs and other water quality impairment projects.

**Table 1.** Regulatory freshwater designated uses and criteria for parameters of interest in Washington State (WAC 173-201A- 200).

| **Criteria** (Category) | **Temperature** (Highest 7-DADMax) | **Dissolved Oxygen** (mg/L) | **pH** (standard units) | **Turbidity** (NTU) |
|---|---|---|---|---|
| Char Spawning and Rearing | 12.0$^{0}$C | 9.5 | pH shall be within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units. | Turbidity shall not exceed: 5 NTU over background when the background is 50 NTU or less; or a 10% increase in turbidity when the background turbidity is more than 50 NTU |
| Core Summer Salmonid Habitat | 16.0$^{0}$C | 9.5 | | |
| Salmonid Spawning, Rearing, and Migration | 17.5$^{0}$C | 8.0 | pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.5 units. | |
| Salmonid Rearing and Migration *Only* | 17.5$^{0}$C | 6.5 | | Turbidity shall not exceed: 10 NTU over background when the background is 50 NTU or less; or a 20% increase in turbidity when the background turbidity is more than 50 NTU |
| Non-Anadromous Interior Redband Trout | 18.0$^{0}$C | 8.0 | | Turbidity shall not exceed: 5 NTU over background when the background is 50 NTU or less; or a 10% increase in turbidity when the background turbidity is more than 50 NTU |
| Indigenous Warm Water Species | 20.0$^{0}$C | 6.5 | | Turbidity shall not exceed: 10 NTU over background when the background is 50 NTU or less; or a 20% increase in turbidity when the background turbidity is more than 50 NTU |
| **Criteria** | **Bacteria** | | | |
| **Beneficial Use** | **Bacteria Indicator** | | | |
| Extraordinary Primary Contact Recreation | 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. | | | |
| Primary Contact Recreation | Fecal coliform organism levels must not exceed a geometric mean value of 100 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 200 colonies/100 mL. | | | |
| Secondary Contact Recreation | Fecal coliform organism levels must not exceed a geometric mean value of 200 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 400 colonies/100 mL. | | | |

**Table 2.** Regulatory marine water designated uses and criteria for parameters of interest in Washington State (WAC 173-201A-210).

| **Criteria** (Category or Beneficial Use) | **Temperature** (Highest 7-DADMax) | **Dissolved Oxygen** (mg/L) | **pH** (standard units) | **Turbidity** (NTU) |
|---|---|---|---|---|
| Extraordinary Quality | 13.0$^0$C | 7.0 | pH must be within the range of 7.0 to 8.5 with a human-caused variation within the above range of less than 0.2 units. | Turbidity must not exceed: 5 NTU over background when the background is 50 NTU or less; or a 10% increase in turbidity when the background turbidity is more than 50 NTU |
| Excellent Quality | 16.0$^0$C | 6.0 | pH must be within the range of 7.0 to 8.5 with a human-caused variation within the above range of less than 0.2 units. | |
| Good Quality | 19.0$^0$C | 5.0 | | Turbidity must not exceed: 10 NTU over background when the background is 50 NTU or less; or a 20% increase in turbidity when the background turbidity is more than 50 NTU |
| Fair Quality | 22.0$^0$C | 4.0 | pH must be within the range of 6.5 to 9.0 with a human-caused variation within the above range of less than 0.5 units. | |

| **Criteria** | **Bacteria** |
|---|---|
| **Beneficial Use** | **Bacteria Indicator** |
| Primary Contact Recreation | 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. |
| Secondary Contact Recreation | Enterococci organism levels must not exceed a geometric mean value of 70 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 208 colonies/100 mL. |

In addition to the use designations and criteria in Tables 1 and 2:

WAC 173-201A-602 (Table 602) details use designations and criteria for specific freshwaters in Washington: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602

WAC 173-201A-612 (Table 612) cites the designations and criteria for specific marine waters in Washington: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-612

### 3.2.4.1 Temperature

Washington's numeric water quality criteria are based on the temperature needs of the most sensitive species supported by the water body. Washington State uses the temperature criteria described in Tables 1 and 2 to ensure a water body's natural capability for providing full support for its designated aquatic life uses will be maintained.

These cool temperature requirements are expressed as the highest allowable 7-day average of the daily maximum temperatures (7-DADMax) in a water body – or in some specified water bodies, the allowable daily maximum temperature. The change from a daily maximum to a 7-DADMax metric for the majority of the state's streams was determined by scientists involved in the development of EPA's Region 10 *Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003) to include an adequate magnitude and duration (averaging period) to protect salmonids.

The 7-DADMax temperatures represent conditions in the thalweg or main stream channel; therefore it is assumed that aquatic species have access to cold water refugia where they can reside in water that is cooler than the 7-DADMax temperatures. The 7-DADMax temperature criterion also assumes that colder temperatures are available to protect fish at night.

In the State Water Quality Standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2003 edition].

- To protect the designated aquatic life uses of "Char Spawning and Rearing," the highest 7-DADMax temperature must not exceed 12°C (53.6°F) more than once every ten years on average.
- To protect the designated aquatic life uses of "Core Summer Salmonid Habitat," the highest 7-DADMax temperature must not exceed 16°C (60.8°F) more than once every ten years on average.
- To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only," the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.
- To protect the designated aquatic life uses of "Non-anadromous Interior Redband Trout," the highest 7-DADMax temperature must not exceed 18°C (64.4°F) more than once every ten years on average.
- To protect the designated aquatic life uses of "Indigenous Warm Water Species," the highest 7-DADMax temperature must not exceed 20°C (68°F) more than once every ten years on average.

Special consideration is also required to protect the spawning and incubation season of salmonid species. Where lower temperatures are necessary to protect spawning and incubation, the following criteria apply:

- Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and
- Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Washington State uses the criteria described above to ensure full protection for its designated aquatic life uses. The standards recognize, however, that waters display thermal heterogeneity – some are naturally cooler, and some are naturally warmer. When a water body is naturally warmer than the above-described numeric criteria, the state limits the allowance for additional warming due to human activities. The combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally warmer temperature condition.

While the criteria apply throughout a water body, there may be site-specific features, including shallow, stagnant, eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that measurements are taken from well-mixed portions of rivers and streams. For similar reasons, samples are not to be taken from anomalously cold areas such as at discrete points where cold groundwater flow into the water body.

#### 3.2.4.2 pH

Washington State established pH criteria in the Water Quality Standards primarily to protect aquatic life. The standards also serve to protect waters as a source for domestic water supply. Water supplies with either extreme pH or that experience significant changes of pH even within otherwise acceptable ranges are more difficult and costly to treat for domestic water purposes. pH also directly affects the longevity of water collection and treatment systems, and low pH waters may cause compounds of human health concern to be released from the metal pipes of the distribution system.

While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, at the extremes of pH lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient CO2 from bicarbonate in the water to be directly lethal to fish.

In the State's Water Quality Standards, two different pH criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

- To protect the designated aquatic life uses of "Char Spawning/Rearing" and "Core Summer Salmonid Habitat" pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.
- To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration," "Salmon and Trout Rearing and Migration Only," "Non-anadromous Interior Redband Trout," and "Indigenous Warm Water Species," pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

#### 3.2.4.3 Dissolved Oxygen

For dissolved oxygen (DO) Water Quality Standards, minimum concentrations of DO are used as criteria to protect different categories of aquatic communities, some of which are specified for individual rivers, lakes, and streams. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criterion is based on the lowest 1-day minimum oxygen concentrations that occur in a water body.

In the State Water Quality Standards, freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. The following designated aquatic life use(s) and criteria are to be protected:

- To protect the designated aquatic life use of "Char Spawning and Rearing," the lowest 1-day minimum oxygen level must not fall below 9.5 mg/l more than once every ten years on average.
- To protect the designated aquatic life use of "Core Summer Salmonid Habitat," the lowest 1-day minimum oxygen level must not fall below 9.5 mg/l more than once every ten years on average.
- To protect the designated aquatic life use of "Salmonid Spawning, Rearing, and Migration," the lowest 1-day minimum oxygen level must not fall below 8.0 mg/l more than once every ten years on average.
- To protect the designated aquatic life use of "Non-anadromous Interior Redband Trout," the lowest 1-day minimum oxygen level must not fall below 8.0 mg/l more than once every ten years on average.
- To protect the designated aquatic life use of "Salmonid Rearing and Migration Only," the lowest 1-day minimum oxygen level must not fall below 6.5 mg/l more than once every ten years on average.
- To protect the designated aquatic life use of "Indigenous Warm Water Species," the lowest 1-day minimum oxygen level must not fall below 6.5 mg/l more than once every ten years on average.

The DO criteria are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a water body is naturally lower in oxygen than the criteria, the state provides an additional allowance for further depression of oxygen conditions due to human activities.

While the numeric criteria generally apply throughout a water body, the criteria are not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that one take measurements from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously oxygen-rich areas. For example, in a slow-moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that are erroneous for comparing to the criteria.

#### 3.2.4.4 Bacteria

Bacteria criteria are set to protect people who work and play in and on the water from waterborne illnesses. In Washington State, Ecology's Water Quality Standards use fecal coliform (FC) as an indicator bacteria for the state's water bodies (e.g., lakes and streams). Fecal coliform in water indicates the presence of waste from humans and other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The FC criteria are set at levels that are shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

The definitions for the FC criteria are:

- ***Extraordinary Primary Contact*** use 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 mL" [WAC 173-201A-200(2)(b), 2003 edition].
- ***Primary Contact*** use is intended for waters "where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and waterskiing." More to the point, however, the use is designated to any waters where human exposure is likely to include exposure of the eyes, ears, nose, throat, and urogenital system. Since children are also the most sensitive group for many of the waterborne pathogens of concern, even shallow waters may warrant primary contact protection. To protect this use category: "Fecal coliform organism levels must not exceed a geometric mean value of 100 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 200/colonies mL" [WAC 173-201A-200(2)(b), 2003 edition].
- ***Secondary Contact*** use is intended for waters "where a person's water contact would be limited (e.g., wading or fishing) to the extent that bacterial infections of the eyes, ears, respiratory or digestive systems, or urogenital areas would be normally avoided." To protect this use category: "Fecal coliform organism levels must not exceed a geometric mean value of 200 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 400/colonies mL" [WAC 173-201A-200(2)(b), 2003 edition].

Compliance is based on meeting both the geometric mean criterion and the 10% of samples (or single sample if less than ten total samples) limit. These two measures used in combination ensure that bacterial pollution in a water body will be maintained at levels that will not cause a greater risk to human health than intended. While some discretion exists for selecting sample averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal (dry season versus wet season) data sets.

The criteria for FC outlined in Tables 1 and 2 are based on allowing no more than the pre-determined risk of illness to humans that work or recreate in a water body. The criteria used in the state standards are designed to allow seven or fewer illnesses out of every 1,000 people engaged in primary contact activities. Once the FC concentrations in the water reaches the numeric criterion, human activities that would increase the concentration above the criteria are not allowed. If the criterion is exceeded, the state will require that all known and reasonable technologies and targeted BMPs be implemented to reduce human impacts and bring FC concentrations into compliance with the standard.

If natural levels of FC (from wildlife) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution. While the specific level of illness rates caused by animal-versus-human sources are not quantitatively known, warm-blooded animals (particularly those that are managed by humans and thus exposed to human-derived pathogens as well as those of animal origin) are a common source of serious waterborne illness for humans.

#### 3.2.4.5 Turbidity

The state established turbidity criteria in the State Water Quality Standards primarily to protect aquatic life. Two different turbidity criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

- To protect the designated aquatic life uses of "Char Spawning/Rearing," "Core Summer Salmonid Habitat," "Salmonid Rearing and Migration" and "Non-anadromous Interior Redband Trout," turbidity must not exceed: (A) 5 NTU over background when the background is 50 NTU or less; or (B) a 10% increase in turbidity when the background turbidity is more than 50 NTU.
- To protect the designated aquatic life uses of "Salmonid Rearing and Migration Only" and "Indigenous Warm Water Species" turbidity must not exceed: (A) 10 NTU over background when the background is 50 NTU or less; or (B) a 20% increase in turbidity when the background turbidity is more than 50 NTU.

The effects of suspended solids on fish and other aquatic life can be divided into four categories:

- Acting directly on the fish swimming in the water and either killing them or reducing their growth rate, resistance to disease, or other normal functions.
- Preventing the successful development of fish eggs and larvae.
- Modifying natural movements and migrations.
- Reducing available food.

Suspended solids may also serve to transmit attached chemical and biological contaminants to water bodies where they can be taken up in the tissue of fish. This can affect the health of humans or wildlife that eat the fish.

Turbid waters also interfere with the treatment and use of water as potable water supplies and can interfere with the recreational use and aesthetic enjoyment of the water.

### 3.2.5 Global Climate Change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Snover et al., 2013; Mote et al., 2014). Factors affecting these changes include natural climate variability, which influences regional climate on annual and decadal scales, and long-term increases in air temperature due to rising greenhouse gas emissions. Chapter 21 of the U.S. National Climate Assessment report *Climate Change Impacts in the United States* (Mote et al., 2014) described observed and projected changes in air temperatures across the region:

- "Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F."
- "An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099 (compared to the period 1970 to 1999), depending largely on total global emissions of heat-trapping gases. The increases are projected to be largest in summer."

A warming climate affects snowpack and hydrology in important ways. Spring snowpack in Washington is projected to decline -38% to -46% by the 2040s and -56% to -70% by the 2080s under low and moderate warming scenarios (Snover et al., 2013). The impact of this snow loss on hydrology will vary by basin (Mote et al., 2014):

> "Hydrologic response to climate change will depend upon the dominant form of precipitation in a particular watershed, as well as other local characteristics including elevation, aspect, geology, vegetation, and changing land use. The largest responses are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt. By 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower, even for an emissions scenario that assumes substantial emissions reductions (B1)."

By the 2040s, summer flows are projected to decrease by 30% to over 50% in the rivers draining the Cascade Mountains, Olympic Mountains, and western front of the Rocky Mountains in Washington State. These lower flows, combined with rising air temperatures, are expected to cause increased summer stream temperatures. Climate-change modeling scenarios projected annual-maximum, weekly average water temperatures that by the 2080s are from 1 to 6 $^{o}$C higher than 1980s conditions (Mantua et al., 2010). Higher stream temperatures degrade or eliminate habitat for salmonids and can increase disease and predation. Increased water temperatures can also decrease DO levels and increase the impacts of pollutants on receiving waters.

Water quality can also be affected by an expected increase in extreme precipitation events. According to Mote et al., 2014:

> "Averaged over the region, the number of days with more than one inch of precipitation is projected to increase 13% in 2041 to 2070 compared with 1971 to 2000 under a scenario that assumes a continuation of current rising emissions trends (A2), though these projections are not consistent across models."

More extreme precipitation events, combined with warming winter temperatures, increase the risk of winter flooding in mixed rain-snow and rain-dominant watersheds. This will likely increase stormwater management challenges in urban areas. Increased erosion and pollutant runoff is also an expected consequence of more intense storms.

Other climate-change impacts that may result in degraded water quality in rivers and streams include (Mote et al., 2014):

- Increasing wildfires, resulting in increased post-fire erosion and pollutant loading.
- Changes to watershed vegetation from changes to temperature, moisture, and fire regimes.
- Increased agricultural pesticide use to control increased disease, pests, and weeds.

In 2015, the University of Washington Climate Impacts Group published *State of Knowledge: Climate Change in Puget Sound* (Mauger et al., 2015). This report summarized current research on the impacts of climate change in the Puget Sound region for issues ranging from snowpack to human health. The report identified numerous likely changes in freshwater and marine water quality. These changes include:

- Decreased summer freshwater flows.
- Increased sediment loads in winter and spring.
- Warmer freshwater and marine water temperatures.
- Decreased DO levels.
- Changes in estuarine circulation.
- Increased harmful algal blooms.
- Increased acidification (lower marine pH levels).
- Rising sea levels and increased coastal erosion.

The expected changes to Washington's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool and provide thermal refugia for fish. Growing mature riparian-vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may help offset the changes expected from global climate change by increasing stream temperature resiliency. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on freshwater and estuarine resources.

In summary, increased rainfall intensity, and changes to watershed vegetation and land uses, may increase storm-event pollutants. The cumulative impact of climate change is likely to increase the vulnerability of receiving waters to pollutant runoff. This emphasizes the importance of increasing receiving-water resiliency and reducing pollutant sources.

The water quality improvement report serves to meet Washington State's Water Quality Standards based on current and historic patterns of climate. Changes in stream temperature and other receiving water conditions associated with global climate change may require further modifications to the human-source allocations at some time in the future. However, the best way to preserve aquatic resources and to minimize future disturbance to human industry would be to begin now to protect as much of the health of streams, rivers, and estuaries as possible.

Information on climate change in Washington is available from the University of Washington Climate Impacts Group website: https://cig.uw.edu/, and also from Ecology's Climate Change website: https://ecology.wa.gov/Air-Climate/Climate-change.

## 3.3 Water Quality Impairment Studies

This Programmatic QAPP addresses elements that apply to all water quality impairment projects, both *major work projects* and *minor work projects*.

Ecology's Environmental Assessment Program (EAP) conducts the following types of well-defined water quality impairment studies that are referred to as *major work projects* and include:

- TMDL studies or water quality improvement plans.
- Source assessments.
- Straight-to-Implementation studies.

These major work projects require moderate to extensive resources and planning, thus a project-specific QAPP is required. The project-specific QAPP will provide information for the background, defined goals and objectives, and a study design specific to the project. Project-specific QAPPs will reference this Programmatic QAPP for many uniform and consistent elements, such as quality objectives and field/lab procedures, and will typically be shorter than this Programmatic QAPP.

EAP also conducts smaller projects, which may be standalone or related to a larger project. These projects are limited in scope, budget, and schedule. These types of projects are categorized as *minor work projects* and include:

- Pre-project/reconnaissance field work.
- Follow-up sampling.
- Exploratory data analysis or modeling.
- Investigative sampling.

Minor work projects are described in detail in this Programmatic QAPP in Section 4. These minor work projects do not require a project-specific QAPP, provided they are standalone, limited in scope, and follow all elements outlined in this Programmatic QAPP. These work plans will require a scope-of-work memo (described in Section 4). Minor work projects that will be part of a larger project, such as an exploratory modeling analysis before a TMDL study, will use this Programmatic QAPP within its scope-of-work memo and may also use it as a reference for the project-specific QAPP for the individual project. Figure 1 demonstrates the process for using the Programmatic QAPP and the need for either a scope-of-work memo or project-specific QAPP.

For modeling work, this Programmatic QAPP describes models commonly used by EAP in water quality impairment studies and the related analytical framework and data needs of the model. Modeling information that is not covered in this Programmatic QAPP and is specific to the water quality impairment study will be described in detail in the project-specific QAPP. New model development will also require a project-specific QAPP. Exploratory modeling will reference this Programmatic QAPP in either a scope-of-work memo or project-specific QAPP for a larger study (Section 4).

A QAPP addendum is required for small projects that (1) represent a *significant* change in goals, objectives, or procedures or (2) use a different technique than what is outlined in this Programmatic QAPP or project-specific QAPP.

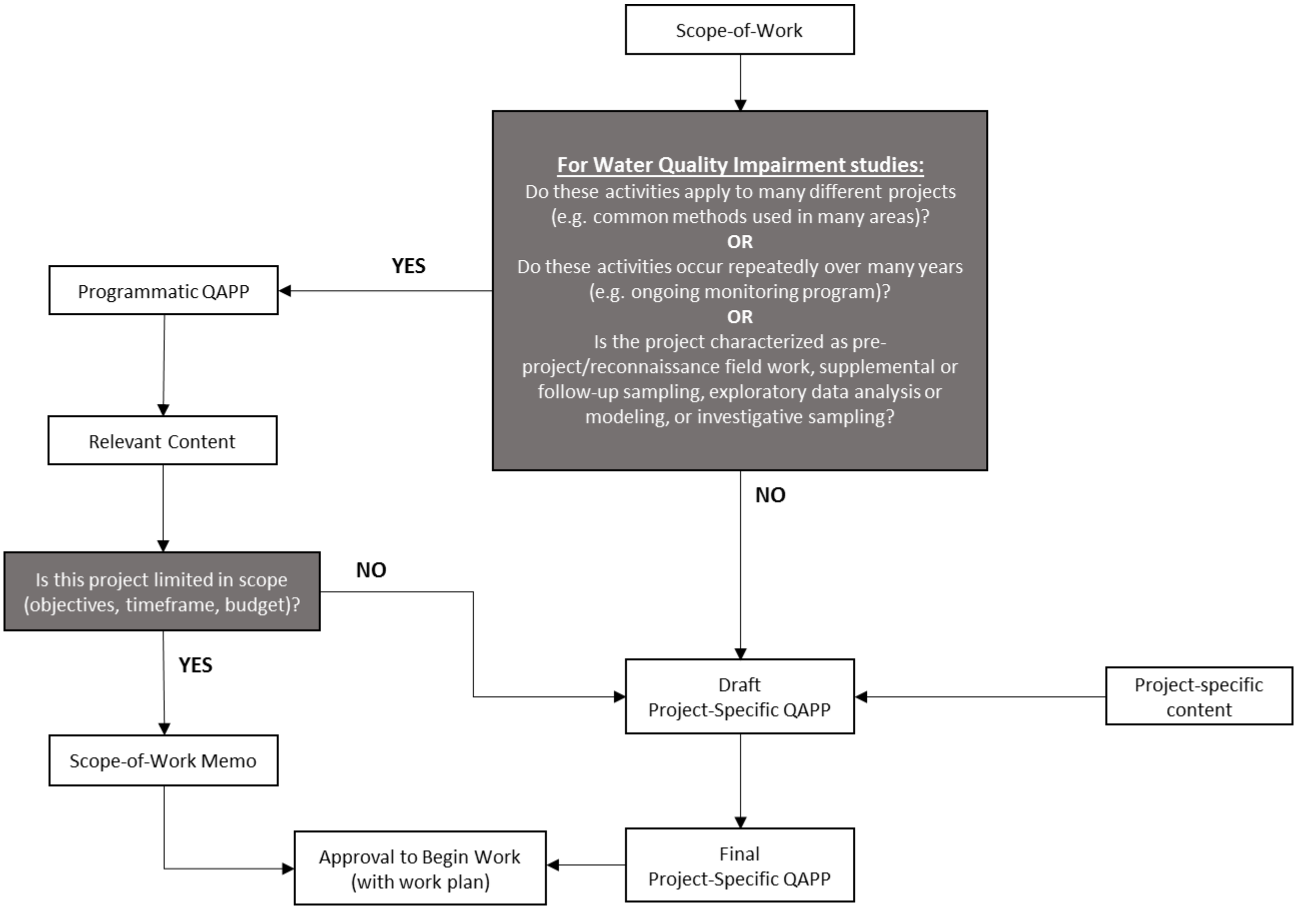


**Figure 1.** Process for using the Programmatic QAPP and determining if a project-specific QAPP is required.

### 3.3.1 TMDL Studies

**What is a Total Maximum Daily Load (TMDL)?**
A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet Water Quality Standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

**Federal Clean Water Act requirements**
The Clean Water Act established a process to identify and clean up polluted waters. The Clean Water Act requires each state to have its own Water Quality Standards designed to protect, restore, and preserve water quality. Water Quality Standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

**The Water Quality Assessment (WQA) and the 303(d) List**
Every two years, states are required to prepare a list of water bodies that do not meet Water Quality Standards. This list is called the Clean Water Act Section 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process.

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data, along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The list of waters that do not meet standards [the 303(d) list] is the Category 5 part of the larger assessment.

The WQA divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list.

- Category 1 – Waters that meet standards for parameter(s) for which they have been tested.
- Category 2 – Waters of concern.
- Category 3 – Waters with no data or insufficient data available.
- Category 4 – Polluted waters that do not require a TMDL because they:
    - 4a – Have an approved TMDL being implemented.
    - 4b – Have a pollution-control program in place that should solve the problem.
    - 4c – Are impaired by a non-pollutant such as low water flow, dams, culverts.
- Category 5 – Polluted waters that require a TMDL – the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website: wq303d-index.

The Clean Water Act requires that a TMDL be developed for each of the water bodies on Category 5 of the 303(d) list.

**TMDL process overview**
Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed, and it specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community, then develops a strategy to control and reduce pollution sources and a monitoring plan to assess effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *Water Quality Improvement Report* (WQIR).

Ecology submits the WQIR to EPA for approval. Once EPA approves the WQIR, Ecology develops a *Water Quality Implementation Plan* (WQIP) within one year. The WQIP identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

**Who participates in a TMDL?**
Stakeholders typically involved in a TMDL include those affected within the watershed, including local communities and municipalities that would be affiliated with potential point and nonpoint sources.

During the study phase of the TMDL, Ecology contacts major stakeholders in the affected cities and counties. Ecology invites stakeholder participation in TMDL studies and in implementing actions to improve water quality in the watershed.

**Elements the Clean Water Act requires in a TMDL**

*Loading Capacity, Allocations, Seasonal Variation, Margin of Safety, and Reserve Capacity*

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet Water Quality Standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load allocation*. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider *seasonal variations* and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well. Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

The EPA requires a TMDL Review Checklist with the minimum recommended elements that should be present in a TMDL document and more information can be found at: https://www.epa.gov/tmdl/program-overview-total-maximum-daily-loads-tmdl.

**Examples**

Examples of TMDL studies include:

- Snoqualmie (Temperature) TMDL Study
  https://fortress.wa.gov/ecy/publications/documents/1110041.pdf
- North Fork Palouse River (DO, pH) TMDL Study
  https://fortress.wa.gov/ecy/publications/SummaryPages/1510029.html
- Puyallup River Watershed (Fecal Coliform) TMDL Study
  https://fortress.wa.gov/ecy/publications/SummaryPages/1110040.html

### 3.3.2 Source Assessments

EAP conducts source assessment studies when more information is needed about the extent of the impairment and the contributing sources, but resources or other obstacles prevent the development of a full TMDL. A source assessment is used to identify and prioritize sources of pollutants. A source assessment study can serve as a standalone report or lay the foundation for a future TMDL, Straight-to-Implementation study, or other water quality cleanup plan.

**Examples**

Recent examples of source assessment studies include:

- Clover Creek Source Assessment (DO, FC, temperature)
  https://fortress.wa.gov/ecy/publications/SummaryPages/1603039.html
- Wenatchee River PCB and DDT Source Assessment (Toxics)
  https://fortress.wa.gov/ecy/publications/documents/1603029.pdf

### 3.3.3 Straight-to-Implementation Studies

Ecology addresses some water quality impairments on the 303(d) list through a Straight-to-Implementation study (STI) in lieu of a TMDL. The STI approach minimizes the need for an extensive technical study where the causes of water quality problems are well-documented and the solutions are already known. STI is typically used in watersheds where either the vast majority or all of the pollution is nonpoint, with few or no point-source contributions. The STI report uses the gathered data to guide future action for implementation and restoration strategies. The STI report can be used to help inform the implementation strategy. The report also may be combined with other data, studies, and analyses, including source assessment reports, within the watershed to determine restoration projects and actions.

**Example**

Example of a STI study:

- Asotin Creek Temperature Straight-to-Implementation Vegetation Study
  https://fortress.wa.gov/ecy/publications/SummaryPages/1203014.html

### 3.3.4 Minor Work Projects

#### 3.3.4.1 Pre-Project/Reconnaissance Field Work

Pre-project and reconnaissance field work are considered minor work projects. This work may initially begin as a standalone effort, or it may evolve into a major work project, such as a TMDL or source assessment. For certain large projects, it is beneficial to initially collect a limited amount of preliminary data within the location of interest in a limited timeframe. This pre-project/reconnaissance field works helps refine the study design and objectives and also focus sampling locations for the larger study. The pre-project/reconnaissance field work may be completed following this Programmatic QAPP, if the sampling efforts evolve into a larger study, the larger study would then require a project-specific QAPP.

#### 3.3.4.2 Follow-Up Sampling

Follow-up sampling typically occurs post-main phase of the original project and is considered a minor work project. This type of work occurs when the original sampling or preliminary analysis outlined in a project-specific QAPP identifies unanticipated information that would support the study goals and objectives. These situations require limited supplemental or follow-up sampling in the same study area. This type of work may be completed following this Programmatic QAPP.

#### 3.3.4.3 Exploratory Data Analysis or Modeling

Most large, comprehensive projects require some level of preliminary data analysis to help understand the environmental context of the water body and its impairments. Preliminary data analysis and modeling is used to help select a modeling framework and refine the data collection and study design for the project-specific QAPP. This work may require a preliminary analysis of existing data that involves more than a simple summary statistics analysis and parameter sensitivity for modeling results. This exploratory work may be conducted based on this Programmatic QAPP.

#### 3.3.4.4 Investigative Sampling

Investigative sampling occurs when either

- New information is found, and additional sampling is necessary, during the original field collection of a study with a project-specific QAPP, or
- A concern is raised by Washington State citizens that requires further investigation on short notice to identify the sources of a pollutant of an impaired water body.

EAP conducts two types of investigative sampling that can be conducted based on this Programmatic QAPP:

- Within-project investigative sampling.
- New project investigative sampling.

Within-project investigative sampling occurs when a project-specific QAPP is already in place. These investigative samples may be collected at sites not included in the associated project-specific QAPP for source identification purposes. If necessary, a site or further sampling at other locations, may be added to further characterize obvious problems in an area. For example, a bacteria sample at the mouth a tributary during a TMDL reveals very high contamination. For the remainder of the bacteria sampling, three upstream locations are added to bracket the source of contamination. These samples, although at new locations, support the goals and objectives of the original TMDL. Within-project sampling does not require a scope-of-work memo, as long as the sampling can be added to the original lab budget. Instead, the sampling should be discussed within the final report of the project.

New project investigative sampling occurs when there is no project-specific QAPP. For example, concerned citizens suspect a water quality impairment on a local water body. A request for more information (a small number of samples) occurs on short notice. New project investigative sampling requires a scope-of-work memo.

# 4.0 Project Description

The overarching goal of Ecology's water quality impairment studies is to meet Washington State's responsibilities under the federal Clean Water Act by identifying and quantifying sources of water quality impairments and developing a plan to address the impairment.

For major work projects, the goals and objectives are defined in their respective project-specific QAPP. The basic project goals and objectives for minor work projects are defined in this document to allow for relevant additional sampling either during the pre-project reconnaissance or post-main phase of data collection and to allow for exploratory data analysis or modeling and investigative sampling.

## 4.1 Goals for Minor Work Projects

### 4.1.1 Pre-Project/Reconnaissance Field Work

The goals for pre-project/reconnaissance field work are to collect samples, measurements, and observations that initially identify potential pollution sources, identify appropriate sampling locations, and obtain other useful information to improve the design and objectives for a larger study. The preliminary data collection is used to investigate the spatial and temporal variability for parameters of interest, particularly where limited or no previous information is available.

### 4.1.2 Follow-Up Sampling

The goal for follow-up sampling is to supplement a previous sampling effort from a study outlined in a project-specific QAPP. This supplemental data collection involves sampling the same parameters of interest that continue to support the initial study goals and objectives from the original project-specific QAPP that may extend outside of the original study timeframe.

This follow-up sampling should be approved by the agency QA Officer before the project begins in order to determine if a scope-of-work memo, QAPP addendum, or neither, is required for additional sampling work.

### 4.1.3 Exploratory Data Analysis or Modeling

The goal of this work is to begin preliminary data analysis or modeling to help determine patterns in available information, evaluate potential modeling frameworks, or identify areas of missing data that will refine the data collection plan and study design of a project-specific QAPP. It is understood that the exploratory data and modeling analysis is limited and will not result in a final modeling tool used to support regulatory actions.

### 4.1.4 Investigative Sampling

If the need for investigative sampling presents itself, the goal will be to collect additional, relevant water quality data either as part of an original study or as a new study where the citizens of Washington have a significant water quality concern. This investigative sampling provides an opportunity for collecting additional water quality data on a short notice.

## 4.2 Objectives for Minor Work Projects

### 4.2.1 Pre-Project and Reconnaissance Field Work

Objectives for pre-project/reconnaissance field work are to improve understanding of the data collection location of interest for a larger study based on an initial assessment. This includes activities such as:

- Float surveys to fully inform the study design by (1) collecting data to better understand the channel geometry and (2) spot sampling and measurements to better identify important surface water and groundwater inputs.
- Limited sonde deployments to measure temperature, DO, and pH, when available data are insufficient or lacking, to help understand timing and range of the parameters and to determine where to deploy sondes throughout the watershed. This helps define the study design and can be refined to help target synoptic sampling events to better aid data analysis and model calibration.
- Initial grab sample collections and in-situ measurements to provide data for defining the study design, such as concentration ranges for water quality parameters of interest, when available data are insufficient or lacking.
- Bacteria/nutrient screening measurements taken at a coarse resolution of the river and at mouths of major tributaries to identify potential large sources that need greater emphasis in the study design.
- Shade estimation of the extent of vegetation cover near the study area.

### 4.2.2 Follow-Up Sampling

Objectives for follow-up sampling are to expand the data collection from a previously defined study. This includes activities such as:

- Dye studies for projects that require developing the channel geometry for modeling work. These dye studies are useful if the initial study design did not require one or enough time-of-travel studies to satisfy model development.
- Float surveys for discovering the depth data from the project if initial sampling was insufficient or requires more information about groundwater inputs.
- Additional measurements or samples after the initial study year, pertaining to the same parameters, locations, and study objectives and goals, with a different year.
- Extended routine measurements and additional data collection that (1) may need to be collected due to scenarios that develop while the study is in progress and (2) represent minimal changes to the budget.

### 4.2.3 Exploratory Data Analysis or Modeling

Objectives for exploratory data analysis or modeling include the initial refining of data collection and study design by activities such as:

- Preliminary exploratory data analysis to explore the patterns in available information.
- Preliminary tests using standard models to inform model selection, scope, and types of measurements needed for the study.
- Modeling that supports future modeling or helps toward the design of an effective sampling plan, but does not result in a final modeling tool used to support regulatory actions.
  - This may include preliminary assessment of parameter sensitivity, preliminary evaluation of theoretical frameworks or software, applications to simplified conditions to explore model capabilities and limitations, and preliminary model grid development to inform data collection.
- Identifying any causes of concern or missing data necessary to meet the project goals and objectives.

### 4.2.4 Investigative Sampling

Within-project investigative sampling to meet the goals and objectives of an ongoing study may include:

- Investigating areas of concern based on preliminary results from the data collection efforts of the original study.
- Additional sampling or monitoring in or around the original study boundaries to better characterize problem areas or sources.
- Bracket sampling to pinpoint source of contamination.
- Additional sample collection or monitoring, not originally anticipated, that is necessary to accurately characterize a water body or represents a target population during the period of interest.

Objectives for new project investigative sampling may include:

- Initial sample collection or monitoring at location of concern.
- Data collection at location of concern with limited notice.
- Analysis and accurate presentation of collected data to interested parties.

## 4.3 Information Needed and Sources

Current and relevant external data sets that are useful and applicable for water quality impairment studies are presented in Appendix A (Table A-1), with a description of the organization and availability and usability of appropriate data. The table indicates established quality assurance (QA) or quality control (QC) programs to ensure credible data sources.

## 4.4 Tasks Required

The tasks required to meet project goals for minor work projects are discussed in detail within Section 4.2. More details about field and lab tasks, and the technical approach, are described in Section 7.

For major work projects, the tasks required are further defined within the project-specific QAPP.

For minor work projects, the tasks required are described in a 1-2 page scope-of-work memo. This memo will contain details for the specific tasks required for the study including parameters, location, time, reason, and budget. This memo will be sent to the supervisor/client and QA Officer.

The approval to begin work (ABW) needs to be approved by the supervisor and QA Officer for the project to begin (Figure 1).

### 4.4.1 Pre-Project/Reconnaissance Field Work

The tasks required for pre-project/reconnaissance field work are described within this Programmatic QAPP and will be documented in the scope-of-work memo.

### 4.4.2 Follow-Up Sampling

The tasks required for follow-up sampling are described within this Programmatic QAPP and will be documented in the scope-of-work memo.

### 4.4.3 Exploratory Data Analysis or Modeling

The tasks required for exploratory data analysis or modeling are described within this Programmatic QAPP. The scope-of-work memo will document the exploratory data analysis parameters and modeling framework.

### 4.4.4 Investigative Sampling

The tasks required for investigative sampling are described within this Programmatic QAPP and will be documented in the scope-of-work memo.

## 4.5 Systematic Planning Process

This Programmatic QAPP and the project-specific QAPP for major work projects represent the systematic planning process and include the key elements:

- Description of the project, goals, and objectives (Section 4).
- Project organization, responsible personnel, and schedule (Sections 5 and 12).
- Study design to support the project goals/objectives and procurement of data (Sections 7, 8, and 9).
- Specification of QA and QC activities to assess the quality performance criteria (Sections 6, 10, and 11).
- Analysis of acquired data (Sections 13 and 14).

# 5.0 Organization and Schedule

## 5.1 Key Individuals and Their Responsibilities

See Table 3 for an organization chart template indicating individuals and designated responsibilities. For major work projects, a completed version of this table is provided in the project-specific QAPP.

For minor work projects, the projects conducted under the Programmatic QAPP are expected to have Ecology's Environmental Assessment Program (EAP) staff filling most of the roles in this table. The scope-of-work memo will summarize key staff and their roles.

## 5.2 Special Training and Certifications

All field staff involved in water quality impairment studies must have either the relevant experience in the required SOPs or be trained by more senior field staff or the project manager who have the required experience. Any staff helping in the field who lack sufficient experience will always be paired with someone who has the necessary training and experience. The experienced staff will then lead the field data collection and oversee/mentor less experienced staff.

The EPA requires documentation of competency from organizations that generate environmental data under Agency funding (EPA, 2011). This may entail participation in certification and accreditation programs.

## 5.3 Organization Chart

**Table 3.** Template for an organization chart.

| **Staff**<br>(All EAP except client) | **Title** | **Responsibilities** |
|---|---|---|
| Name:<br>Program:<br>xx Regional Office<br>Phone: xxx-xxx-xxxx | EAP Client | Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP. |
| Name:<br>xx Unit<br>xx Section<br>Phone: xxx-xxx-xxxx | Project Manager | Communicates/coordinates with client, EAP project staff, managers, and external entities. Keeps project on schedule. Manages budget, staff, and other project resources. |
| Name:<br>xx Unit<br>xx Section<br>Phone: xxx-xxx-xxxx | Principal Investigator | Writes the QAPP. Conducts QA review of data, analyzes and interprets data, and enters data into EIM. Writes the draft report and final report. *Project Manager may assume Principal Investigator role.* |
| Name:<br>xx Unit<br>xx Section<br>Phone: xxx-xxx-xxxx | Field Lead | Oversees field sampling and transportation of samples to the laboratory. Plans/schedules field dates/logistics. Procures sampling equipment. Communicates with lab sample coordinators. Ensures site access is safe and permission has been granted. *Project Manager or Principal Investigator may assume Field Lead role.* |
| Name:<br>xx Unit<br>xx Section<br>Phone: xxx-xxx-xxxx | Field Assistant | Helps collect samples and records field information and has proper training. |
| Name:<br>xx Unit<br>xx Section<br>Phone: xxx-xxx-xxxx | Unit Supervisor for the Project Manager | Provides internal review of the QAPP, approves the budget, and approves the final QAPP. |
| Name:<br>xx Section<br>Phone: xxx-xxx-xxxx | Section Manager for the Project Manager | Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP. |
| Joel Bird<br>Manchester Environmental Laboratory (MEL)<br>Phone: 360-871-8801 | Director | Reviews and approves the final QAPP. |
| xx<br>Contract Laboratory | Project Manager | Reviews draft QAPP, coordinates with MEL QA Coordinator. |
| William R. Kammin<br>Phone: 360-407-6964 | Ecology Quality Assurance Officer | Reviews the draft QAPP and approves the final QAPP. |

EAP: Environmental Assessment Program
EIM: Environmental Information Management database
QAPP: Quality Assurance Project Plan

## 5.4 Proposed Project Schedule

A proposed project schedule contains the estimated or target times for when the field and lab work, data analysis, modeling work, and the draft and final report will be completed. Table 4 provides an example of a project schedule outline.

For major work projects, the project schedule will be outlined within the project-specific QAPP. For minor work projects, the proposed project schedule will be summarized in the scope-of-work memo. In general, timelines should be 13 months or less.

**Table 4.** Template for a proposed project schedule.

| **Field and laboratory work** | **Due date** | **Lead staff** |
|---|---|---|
| Field work completed | month year | name |
| Laboratory analyses completed | month year | |
| **Environmental Information System (EIM) database** | | |
| EIM Study ID | ID number | |
| Product | **Due date** | **Lead staff** |
| EIM data loaded[1] | month year | name |
| EIM data entry review[2] | month year | name |
| EIM complete[3] | month year | name |
| **Final report** | | |
| Author lead / Support staff | lead name / support staff name(s) | |
| Schedule | | |
| Draft due to supervisor | month year | |
| Draft due to client/peer reviewer | month year | |
| Draft due to external reviewer(s) | month year | |
| Final (all reviews done) due to publications coordinator | month year | |
| Final report due on web | month year | |

[1] All data entered into EIM by the lead person for this task.
[2] Data verified to be entered correctly by a different person; any data entry issues identified. Allow one month.
[3] All data entry issues identified in the previous step are fixed (usually by the original entry person); EIM Data Entry.

The field work timeframe is dependent on the goals and objectives of the project. For minor work projects, the sampling phase should be less than 6 months with laboratory analyses completed 1 month post-sampling.

For modeling work, targets and timelines for modeling milestones should be reflected in the schedule.

The schedule should reflect a period of 3-6 months for uploading data into EIM and for EIM data entry review.

The schedules for the review, draft report, and final report are dependent on the type of final report and the amount of technical analyses needed, including the extent of statistical tests and modeling work.

The schedule should allow enough time for review of comments from internal and external reviews, including stakeholders, which may require further work or analysis.

## 5.5 Budget and Funding

EAP manages a biennial budget that includes specific pools for laboratory work, supplies, and sampling equipment. During an annual planning process, new projects are scoped for estimated laboratory and equipment costs, which are approved or declined based on available staff and monetary resources.

The greatest uncertainty in the laboratory workload and cost estimate is whether any sites will be added for investigation purposes (e.g., to further pinpoint pollution sources or bracketing stream reaches). However, efforts will be made to keep the submitted number of samples within the estimate provided.

For investigative, pre-project, or follow-up work that requires laboratory work or field equipment, a request is made to the immediate supervisor for the needed funds. The supervisor works with EAP's management team, including the budget manager, to determine whether the work will be funded.

Estimated staff time and a proposed lab budget will be provided in the project-specific QAPP for major work projects or in the scope-of-work memo for minor work projects.

# 6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness, completeness, and comparability.

## 6.1 Data Quality Objectives

Data quality objectives[1] (DQOs) establish acceptable quantitative criteria on the quality and quantity of the data to be collected, relative to the ultimate use of the data. These criteria are known as performance or acceptance criteria, or DQOs. DQOs represent the overarching quality objectives of the study, including that collected data meet measurement quality objectives (MQOs).

For major work projects, the DQOs will be specified within the project-specific QAPP (e.g., stating the minimum quantity of samples collected during the project that will meet MQO standards and will be comparable to previous study results).

For minor work projects, data are expected to meet all MQOs outlined in this Programmatic QAPP.

## 6.2 Measurement Quality Objectives

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

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

Table 5 presents MQOs for precision and bias, as well as the manufacturer's stated accuracy, resolution, and range for field equipment that will be used in water quality impairment studies. These MQOs are intended for use in both major and minor work projects; however, a project-specific QAPP may set different MQOs, provided a justification for the deviation is given.

[1] DQO can also refer to ***Decision*** Quality Objectives. The need to identify Decision Quality Objectives during the planning phase of a project is less common. For projects that lead to important decisions, DQOs are often expressed as tolerable limits on the probability or chance (risk) of the collected data leading to an erroneous decision. And for projects that intend to estimate present or future conditions, DQOs are often expressed in terms of acceptable uncertainty (e.g., width of an uncertainty band or interval) associated with a point estimate at a desired level of statistical confidence.

### 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. Precision is usually assessed by analyzing duplicate field measurements or lab samples. 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). Field sampling precision will be addressed by submitting replicate samples or collecting replicate measurements.

Precision is also influenced by random error. Potential sources of random error include:

- Field sampling procedures.
- Handling, transporting, and preparing samples for shipment to the laboratory.
- Obtaining a subsample from the field sample for analysis.
- Preparing the sample for analysis at the laboratory.
- Analysis of the sample (including data handling errors).

Precision for replicates will be expressed as percent relative standard deviation (% RSD) or absolute error and assessed following the MQOs outlined in Tables 5, 6, and 7. The targets for precision of field duplicates are based on historical performance by MEL for environmental samples taken around the state by EAP (Mathieu, 2006).

#### 6.2.1.2 Bias

Bias is the difference between the population mean and the true value of the parameter being measured. Bias is usually addressed by calibrating field and laboratory instruments and also by analyzing lab control samples, matrix spikes, and standard reference materials. MQOs for laboratory QC samples (e.g., blanks, check standards, and spiked samples) presented in Tables 6 and 7 will provide a measure of any bias affecting sampling and analytical procedures. Bias affecting measurement procedures can be inferred from the results of QC procedures. MEL will assess bias in the laboratory through the use of blanks (further explained in Section 8.3). Field staff will minimize bias in field measurements and samples by strictly following equipment calibration, measurement, sampling, and handling protocols (explained in detail in Section 10.0).

Potential sources of field and laboratory bias in samples include:

- Sampling procedures.
- Instability of samples during transportation, storage, or processing.
- Interference and matrix effects.
- Inability to measure all forms of the parameter of interest.
- Calibration problems with the measurement system or instruments.
- Contamination of equipment, reagents, or containers.

Table 8 presents the bias data quality objectives for multi-parameter sonde data for instrument QC checks.  First the sonde measurement data are reviewed, adjusted (if applicable), and finalized (see Data Verification section).  The median residual of the finalized data and QC checks is then calculated and compared to the MQOs listed in Table 8.

#### 6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a lab or field method used to detect a substance.  It is commonly described as detection limit.

For field data, the sensitivity of the instrument is described by its range, accuracy, and resolution. This is usually reported for each instrument by the manufacturer.  Examples of this information are provided in Table 5.

For laboratory data in a regulatory context, the method detection limit (MDL) is usually used to describe sensitivity.  The method reporting limit (MRL) is usually a little higher than the MDL and can also be used.  The MRL for each laboratory method is reported in Tables 6 and 7, and MDLs are presented in Section 9.1 (Table 11).  The reporting limits of the methods listed in Tables 6 and 7 are appropriate for the expected range of results and the required level of sensitivity to meet the objectives outlined in this Programmatic QAPP.

**Table 5.** Field procedure MQOs and field equipment information.

| Parameter | Equipment/ Method | Bias (median) | Precision– Field Duplicates (median) | Equipment Information | | | Expected Range |
|---|---|---|---|---|---|---|---|
| | | | | Equipment Accuracy | Equipment Resolution | Equipment Range | |
| **Water Quality Measurements** | | | | | | | |
| Water Temperature | Hydrolab® | See Table 8 | ± 0.2°C | ± 0.1°C | 0.01°C | -5 - 50°C | 0 - 30°C |
| | YSI EXO | | | ±0.01°C[2] | 0.001°C | | |
| | YSI Pro30 | | | ±0.2°C[k] | 0.1°C | -5 - 70°C | |
| | YSI ProODO | | | ± 0.2°C | | | |
| | YSI ProPlus | | | ± 0.2°C | | | |
| | YSI 556 MPS | | | ± 0.15°C | | -5 - 45°C | |
| Conductivity/ Specific Conductance | Hydrolab® | See Table 8 | 5% RSD | ± 0.5% + 1 uS/cm | 1 uS/cm | 0 - 100,000 uS/cm | 20 – 1,000 uS/cm |
| | YSI EXO | | | ±0.5% of reading or .001 mS/cm, w.i.g | 0.0001 to 0.1 mS/cm (range dependent) | 0 - 200 mS/cm | |
| | YSI 556 MPS | | | ± 0.5% of reading or ± 0.001 mS/cm w.i.g [i] | 0.01 mS/cm to 0.1 mS/cm (range dependent) | | |
| | YSI ProPlus | | | ±0.5% of reading or 0.001 mS/cm, w.i.g.[g] | 0.001 mS/cm[h] (range dependent) | | |
| | YSI Pro30 | | | ±1.0% of the reading or 1.0 uS/cm, w.i.g[f] | 0.0001 to 0.1 mS/cm (range dependent) | | |
| Dissolved Oxygen | Hydrolab® LDO | See Table 8 | 5% RSD | ± 0.1 mg/L; at <8 mg/L; ± 0.2 mg/L; at 8 to <20 mg/L[a] | 0.01 mg/L | 0 - 60[c] mg/L | 0.1 - 15 mg/L |
| | Hydrolab® - Clark Cell | | | ± 0.2 mg/L at <20mg/L[a] | 0.01 mg/L | 0 - 50[b] mg/L | |
| | YSI EXO | | | 0 to 20 mg/L: ±0.1 mg/L or 1% of reading, w.i.g.; | 0.01 mg/L | 0 - 50 mg/L | |
| | YSI 556 MPS | | | ± 0.2 mg/L[a] | 0.01 mg/L | 0 - 50 mg/L | |
| | YSI ProODO | | | ± 0.1 mg/L or ± 1% of reading, w.i.g | 0.01 or 0.1 mg/L (auto-scaling) | 0 - 50 mg/L | |
| pH | Hydrolab® | See Table 8 | ± 0.2 s.u. | ± 0.2 s.u. | 0.01 s.u. | 0 - 14 s.u. | 6 - 10 s.u. |
| | YSI EXO | | | | | | |
| | YSI ProPlus | | | | | | |
| | YSI 556 MPS | | | | | | |
| Chlorophyll *a* - *in vivo* | Hydrolab® | n/a | 10% RSD | ± 3% | 0.01 ug/L | 0.03 - 50 ug/L[c] | 0.1 - 50 ug/L |

| Parameter | Equipment/ Method | Bias (median) | Precision–Field Duplicates (median) | Equipment Information | | | Expected Range |
|---|---|---|---|---|---|---|---|
| | | | | Equipment Accuracy | Equipment Resolution | Equipment Range | |
| Oxidation-Reduction Potential | Hydrolab® | n/a | 10% RSD | ± 20 mV | 1 mV | -999 -999 mV | -999 - 999 mV |
| Optical Brighteners | Turner Designs Cyclops 7 | n/a | 10% RSD | n/a | 0.1 ppb | 0.6 –2,500 ppb | 0-500 ppb |
| Secchi depth | manual | n/a | 10% RSD | n/a | 0.1 m | 0 – 30 m | 1-20 m |
| Turbidity | FTS DTS-12 | n/a | 15% RSD | 0 – 399.99 NTU: ± 2% of reading 400 – 1600 NTU: ±4% of reading | 0.01 NTU | 0 – 1,600 NTU | 0 - 500 NTU |
| | Hydrolab® | | | ± 5% of reading; ± 1 NTU | 0.1 NTU | 0 – 3,000 NTU | |
| **Flow Measurements** | | | | | | | |
| Streamflow | SOP EAP024 | n/a | 10% RSD | n/a | n/a | n/a | 0.01 - 2,000 cfs |
| Velocity | Marsh McBirney | ±0.05 ft/s[e] | 5% RSD | ±2% + zero stability[d] | 0.01 ft/s | -0.5 to +20 ft/s | 0.01 - 10 ft/s |
| | OTT MF Pro | n/a | | ±2.0% or ±0.05 ft/s[ac] | 0.003 ft/s | 0 to +10 ft/s | |
| | SonTek® FlowTracker® Handheld ADV® | <0.03 ft/s | | ±1% | 0.01 ft/s | 0.0003 - 13 ft/s | |
| | StreamPro ADCP | n/a | | ±1.0% or ±0.007 ft/s[c] | 0.003 ft/s | -16 to +16 ft/s | |
| Depth | OTT MF Pro | n/a | | ±2.0% or ±0.05 ft | 0.003 ft | 0 to +10 ft | 0.01 - 10 ft |
| | StreamPro ADCP | n/a | | 1% | 1 mm | 0.1 – 7.0m | 0.1 – 3.0 m |
| Water level | Hobo barometric pressure transducer | n/a | n/a | ±1.5 mbar at 25°C | 0.1 mbar | 660 – 1,070 mbar | 660 – 1,070 mbar |
| **Continuous Temperature/ Weather Monitoring** | | | | | | | |
| Continuous Air Temperature | Hobo Water Temp Pro v2 | n/a | n/a | ±0.21°C at 0° to 50°C[ae] | 0.02°C at 25°C | -40° - 70°C | -5 - 40°C |
| | Hobo Tidbit V2 | n/a | n/a | | | -20° - 70°C | |
| Continuous Water Temperature | Hobo Water Temp Pro v2 | n/a | n/a | ±0.21°C at 0° to 50°C[ae] | 0.02°C at 25°C | 0 - 50°C | 0 - 30°C |
| | Hobo Tidbit V2 | n/a | n/a | | | -20° - 30°C | |
| Relative Humidity | Hobo Pro v2 U23 – RH | n/a | n/a | ±2.5% from 10% to 90% RH | 0.03% | 0-100% RH | 30% - 100% RH |

| Parameter | Equipment/ Method | Bias (median) | Precision–Field Duplicates (median) | Equipment Information | | | Expected Range |
|---|---|---|---|---|---|---|---|
| | | | | Equipment Accuracy | Equipment Resolution | Equipment Range | |
| Solar Radiation | Hobo silicon pyranometer smart sensor | n/a | n/a | ±10 $W/m^2$ or ±5%, w.i.g. [j] | 1.25 $W/m^2$ | 0 – 1,280 $W/m^2$ | 0 – 1,280 $W/m^2$ |
| Rain gauge | Rain Gauge smart sensor | n/a | n/a | ±1.0% at up to 20 mm or 1 in. per hour | 0.01 inch | 0–10 cm or 0–5 in. per hour | 0–10 cm or 0-5 in. per hour |

w.i.g., whichever is greater
a accuracy is diminished outside of listed range
b greater than natural range
c equipment range is dynamic; listed range is for medium sensitivity setting
d zero stability check criteria; not a measurement of bias
e also the MQO for accuracy assessed by pre- and post-deployment water bath checks
f for 1,4 m cables; for 10 m, 20 m, 30 m cables: ±2.0% of the reading or 1.0 uS/cm, whichever is greater
g for 1,4 m cables; for 20 m cable: ±1% of reading or 0.001 mS/cm, whichever is greater
h range dependent, for 0.501 to 50.00 mS/cm: 0.01; for 50.01 to 200 mS/cm: 0.1
i for 4 meter cable; for 20 meter cable ± 1.0% of reading or ± 0.001 mS/cm, w.i.g.
j additional temperature induced error ±0.38 W/m /°C from 25°C
k ±0.3°C for cables over 45-meters

**Table 6.** MQOs for inorganic/general chemistry lab procedures.

<table>
<tr><th>Analysis</th><th>Method Lower Reporting and (Detection) Limit[a]</th><th>Method Blank Limit</th><th>Calibration Standards/ Blanks</th><th>Lab Control Samples (% recovery limits)</th><th>Matrix Spikes or SRMs (% recovery limits)</th><th>Precision – Lab Duplicates (RPD)</th><th>Precision – Field Duplicates (median)[b]</th></tr>
<tr><td>Dissolved Oxygen - Winkler</td><td>0.1 mg/L</td><td>n/a</td><td rowspan="3">n/a</td><td>n/a</td><td>n/a</td><td>± 0.2 mg/L</td><td>± 0.2 mg/L</td></tr>
<tr><td>Biochemical Oxygen Demand - 5 day/Ultimate</td><td>2.0 mg/L</td><td><0.2 mg/L</td><td>70-125%</td><td>n/a</td><td>20%</td><td>25% RSD</td></tr>
<tr><td>Chlorophyll a - water</td><td>0.05 ug/L</td><td><½ RL[c]</td><td>n/a</td><td>n/a</td><td rowspan="10">20%</td><td>20% RSD</td></tr>
<tr><td>Chloride</td><td>0.1 (0.03) mg/L</td><td><MDL[c]</td><td rowspan="9">ICV/CCV: 90-110%<br>ICB/CCB: <MDL[c]</td><td>90-110%</td><td>75-125%</td><td>5% RSD</td></tr>
<tr><td>Alkalinity</td><td>5.0 mg/L</td><td><MDL[c]</td><td rowspan="8">80-120%</td><td>n/a</td><td rowspan="9">10% RSD</td></tr>
<tr><td>Nitrate/Nitrite</td><td>0.01 (0.005) mg/L</td><td><½ RL[c]</td><td rowspan="7">75-125%</td></tr>
<tr><td>Ammonia</td><td>0.01 (0.002) mg/L</td><td rowspan="3"><MDL[c]</td></tr>
<tr><td>Total Persulfate Nitrogen</td><td>0.025 (0.013) mg/L</td></tr>
<tr><td>Orthophosphate</td><td>0.003 (0.0013) mg/L</td></tr>
<tr><td>Total Phosphorus - water</td><td>0.005 (0.0024) mg/L</td><td><2.2x MDL[c]</td></tr>
<tr><td>Dissolved Organic Carbon</td><td>1.0 (0.05) mg/L</td><td rowspan="3"><MDL[c]</td></tr>
<tr><td>Total Organic Carbon</td><td>1.0 (0.11) mg/L</td></tr>
<tr><td>Salinity</td><td>0.1 ppt</td><td>CCB <MDL[c]</td><td>95-105%</td><td rowspan="7">n/a</td><td>10%</td></tr>
<tr><td>Total Suspended Solids</td><td rowspan="5">1 mg/L</td><td rowspan="2">±0.3 mg/L[d]</td><td rowspan="5">n/a</td><td rowspan="3">80-120%</td><td rowspan="4">5% [b]</td><td rowspan="6">15% RSD</td></tr>
<tr><td>TNVSS</td></tr>
<tr><td>Total Solids</td><td rowspan="2"><½ RL[c]</td></tr>
<tr><td>Total Volatile Solids</td><td>n/a</td></tr>
<tr><td>Suspended Solids Concentration</td><td>±0.3 mg/L[d]</td><td>90-110%</td><td>n/a</td></tr>
<tr><td>Turbidity</td><td>0.5 (0.01) NTU</td><td><MDL</td><td rowspan="3">ICV/CCV: 90-110%<br>ICB/CCB: <MDL[c]</td><td>90-105%</td><td rowspan="5">20%</td></tr>
<tr><td>Total Nitrogen, Total Carbon - tissue</td><td>10 mg/kg DW</td><td rowspan="2"><2.2x MDL[c]</td><td>90-110%</td><td>70-130%[f]</td><td rowspan="4">50% RSD</td></tr>
<tr><td>Total Phosphorus - tissue</td><td>10 (1.71) mg/kg DW</td><td>85-115%</td><td>75-125%</td></tr>
<tr><td>AFDW - tissue</td><td>10 mg/kg DW</td><td>±0.6 mg/L[d]<br><MDL[ce]</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td></tr>
<tr><td>Chl a - tissue</td><td>0.05 mg/L</td><td><½ RL[c]</td></tr>
</table>

RL: reporting limit; MDL: method detection limit; CCV: Continuing Calibration Verification
CCB: Continuing Calibration Blank; ICV: Initial Calibration Verification; ICB: Initial Calibration Blank
[a] reporting limit may vary depending on dilutions; detection limit in parentheses, no parentheses means MDL = lowest possible RL
[b] field duplicate results with a mean of less than or equal to 5x the reporting limit will be evaluated separately
[c] or less than 10% of the lowest sample concentration for all samples in the batch
[d] filter blank
[e] reinstate blank
[f] standard reference material (SRM) recovery, no matrix spikes preformed on this analyte

**Table 7.** MQOs for microbiology lab procedures.

| Analysis | Method | Method Lower Reporting Limit [a] | Lab Blank Limit | Precision – Lab Duplicates (RPD) | Precision – Field Duplicates (median)[b] |
|---|---|---|---|---|---|
| Fecal Coliform - MF | SM9222D | 1 cfu/100 mL | <MDL | 40% | 50% of replicate pairs < 20% RSD<br>90% of replicate pairs <50% RSD[b] |
| E. Coli - MF | EPA1103.1 (mTEC2);<br>EPA1603;<br>SM9222G | | | | |
| Enterococci - MF | EPA1600 | | | | |
| Fecal Coliform - MPN | SM9221E | 1.8 MPN/ 100 mL | | | 50% of replicate pairs < 50% RSD<br>90% of replicate pairs <100% RSD[b] |
| E. Coli - MPN | SM9221F | | | | |
| Enterococci - MPN | SM9230B | | | | |
| Klebsiella (%KES) | MEL SOP | 0% | | | |

MF: Membrane filtration
MPN: Most probable number
[a] reporting limit may vary depending on dilutions; detection limit in parentheses, no parentheses means MDL = lowest possible RL
[b] field duplicate results with a mean of less than or equal to 5x the reporting limit will be evaluated separately

**Table 8.** Multi-parameter sonde MQOs.

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

Criteria expressed as a percentage of readings; for example, buffer = 100.2 uS/cm and Hydrolab = 98.7 uS/cm; (100.2-98.7)/100.2 = 1.49% variation, which would fall into the acceptable data criteria of less than 5%.

* Turbidity uses stand-alone probe (i.e., FTS DTS-12).

## 6.2.2 Targets for Comparability, Representativeness, and Completeness

### 6.2.2.1 Comparability

To improve comparability to previously collected Ecology data, field staff will strictly follow EAP protocols and adhere to data quality criteria. In addition, all field measurements will follow approved EAP SOPs (see Table 9, Section 8.2).

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

Ecology may compare data collected from the study to data collected by other entities or for other projects, if:

- Data were collected with approved QAPP(s) and functionally equivalent SOP(s), and also accredited laboratories analyzed the data. The entity that collected the data is an organization whose data are regularly used and is known to produce known and usable data (see Section 4.3),
- Documentation such as QAPPs, SOPs, and data QC assessments are available to demonstrate that the data are of known and usable quality, *or*
- The minimum analytical sensitivity for the methods used is comparable to the detection and reporting limits in this QAPP and is lower than applicable regulatory criteria.

### 6.2.2.2 Representativeness

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

The ability for continuous monitoring equipment (such as temperature loggers or multi-parameter sondes) to capture the representativeness of the river or stream's characteristics at the deployment location is assessed through recommended spot and check measurements.

- For shallow or well-mixed rivers and streams:
  - A transect of spot measurements may be taken across the width of the channel that includes, at a minimum, a measurement at the desired deployment location, within several feet of both banks, and in the thalweg (if different from the deployment location).
  - Good reconnaissance of the deployment location (both in the field and with GIS/aerial photography) to ensure there are no tributaries, outfalls, or groundwater seepage immediately upstream. As a general rule, equipment should be deployed upstream of bridge crossings to avoid influence from roadside drainage ditches and also upstream of recreational wading/swimming.

- For deeper or vertically-stratified rivers and streams:
  - In addition to the above, vertical profiles of spot measurements should be made at the deployment location and in the thalweg or deepest location nearby. At a minimum, profile measurements should be taken just below the water surface, at the deployment depth, and near the streambed, with measurements at other levels to provide a representative profile.

#### 6.2.2.3 Completeness

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

For continuous deployed measurements, additional variables can negatively impact completeness including vandalism/theft/tampering, equipment failure, unacceptable fouling or drift, and unpredictable hydrologic events (large storms or steep drops in water level between visits). For these reasons, a completeness of 80% is acceptable for continuous measurements. Given these difficulties, redundancy is an important component when designing studies with continuous data collection, particularly at important boundary conditions and within the most critical areas.

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

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

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

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

## 6.3 Model Quality Objectives

To meet project goals and objectives, model quality results should be comparable to models used in similar TMDL or other water quality impairment modeling studies. A summary of results for comparison purposes is available in *A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies* (Sanderson and Pickett, 2014). Sensitivity and uncertainty analyses should also be conducted to assess the variability of the model results to specific parameters and level confidence in key output values.

Model quality includes the following considerations (discussed in detail in Section 13.4), all of which are important and must be balanced with one another:

- **Goodness-of-fit:** The accuracy with which the model is able to predict observed data. This can be described by (1) precision, using statistics such as Root Mean Squared Error (RMSE), (2) bias, using statistics such as the relative error and (3) accuracy, visually using plots of modeled and observed values.
- **Accurate representation of processes**: Mechanistic models should achieve accurate predictions by invoking correct explanations of observed data and reasonably simulating real-world processes. For example, a model might accurately predict low stream temperatures by incorrectly invoking groundwater instead of shade. Such a model might have good goodness-of-fit, but for the wrong reasons, which is termed "curve-fitting". Selection of model parameters based on physical principles and careful multi-dimensional analysis of model results should help to ensure that curve-fitting is not occurring.
- **Sensitivity to key inputs**: Models should accurately predict the sensitivity of water body response to key inputs, such as the sensitivity of temperature to shade or of dissolved oxygen (DO) to nutrients.

More specific qualitative quality objectives for water quality impairment models include:

- For channel geometry, as applicable, accurately represent depth, width, and velocity, across a range of flows that correspond to the critical period for the parameters of interest.
- For instream flow, capture the patterns and key statistics of flow regimes relevant to the project goals, such as minimum summer low flows, hydrograph response to precipitation or snowmelt events, timing of peak flow, or accurate representation of total volumes.
- For watershed hydrology, accurate representation of flow regimes, along with representation of the flow "compartments" of the watershed, such as surface runoff, percolation, evaporation, shallow interflow, and surface-groundwater exchange.
- For temperature, simulate observed temperatures and accurately represent spatial and temporal patterns. These temperature simulations require substantially correct explanations for observed patterns, such as the correct combinations of channel geometry, shade, groundwater, and hyporheic flow characteristics.
- For DO and pH, simulate observed trends and accurately represent spatial and temporal patterns. These simulations should represent the overall balance of processes, such as algal productivity, respiration, and reaeration. These simulations should also represent the sensitivity of algal growth to nutrient concentrations.

- For nutrients, accurately simulate nutrient concentrations by correctly accounting for (1) nutrient sources, such as groundwater, tributaries, runoff, agricultural return flows, direct releases, and point sources, and (2) nutrient sinks, such as groundwater recharge, sediment adsorption and settling, and algal or plant uptake.

For modeling work conducted during water quality impairment studies, the primary quality objective is that the assumptions, limitations, goodness-of-fit, and uncertainty are characterized. This allows natural resource managers, stakeholders, and policy makers to evaluate the level of quality and uncertainty of model results against the magnitude of the decision or regulatory action to determine which decisions the model results can support. Therefore, it is critical that modeling staff do as clear, accurate, and thorough of a job as possible while communicating each of these aspects of the model.

# 7.0 Study Design

The study design for individual projects varies widely, based on the size and complexity of the water body and the project goals and objectives.

This Programmatic QAPP covers general study design elements that apply to minor work projects. The duration of the study design, including field work and technical analysis that may involve modeling, for minor work projects should be short (less than 13 months) and limited in total number of locations and frequency and also budget (less than $10,000 laboratory costs).

For major work projects, the detailed study design is provided in each project-specific QAPP.

For minor work projects, the scope-of-work memo will describe the study design based on the reference material within this Programmatic QAPP.

## 7.1 Study Boundaries

For major work projects, the study boundaries will be determined in the project-specific QAPP.

For minor work projects, the study boundaries will be described in the scope-of-work memo.

## 7.2 Field Data Collection

### 7.2.1 Sampling Location and Frequency

For major work projects, the sampling locations and frequency will be determined in the project-specific QAPP.

For minor work projects, the sample location and frequency will be described in the scope-of-work memo. For minor work projects, too few samples are typically collected to be able to characterize the sample population. However, it is recommended that at least 2 samples are collected at each sampling location on 2 separate days with the same conditions. This allows for the initial sample concentration range to be generally confirmed.

### 7.2.2 Field Parameters and Laboratory Analytes to be Measured

For major work projects, parameters will be determined in the project-specific QAPP.

For minor work projects, any of the field or lab parameters described in Sections 8 and 9 of this Programmatic QAPP may be collected or measured.

### 7.2.3 Synoptic Surveys

For DO, pH, and nutrient studies, Ecology usually collects the primary data for model calibration during synoptic surveys. Synoptic surveys are conducted, when possible, during periods of relatively steady-state conditions in the river or stream and during clear, stable weather conditions. Surveys should be designed to collect measurements and samples chronologically from upstream to downstream stations, replicating time-of-travel if possible. Surveys typically involve multiple teams of samplers, in order to collect a large amount of data over the sampling duration.

### 7.2.4 Source Identification Sampling

If regular sampling confirms high levels of fecal coliform bacteria (FC), nutrients, or other parameters at a particular site, staff may further investigate the area using source identification sampling to find the pollution sources. Source identification sampling typically involves bracketed sampling, where sampling occurs upstream and downstream of an area thought to have high concentrations in ever-decreasing distance, within the constraints of time and money. This continues until the source of the high levels is found and further bracketing is deemed unnecessary.

### 7.2.5 Stormwater Monitoring

Previous Ecology studies (Swanson, 2006; Collyard and Anderson, 2014) have defined a "storm event" as a minimum 0.3 inches of rainfall in a 24-hour period, preferably preceded by no more than trace rainfall in the previous 24 hours. Statistical analysis of storm data may show that this threshold is higher or lower for individual drainages. Site-specific conditions such as percent impervious surfaces, stormwater conveyance infrastructure, soil types, and depth to the water table can influence the level of runoff to a water body.

If the location of stormwater outfalls and discharges can be identified and are accessible, thermistors are typically installed to monitor for temperature at these locations throughout the study. During synoptic surveys, grab samples should be taken from any known stormwater outfalls/infrastructure that have measurable flow.

Storm sampling typically consists of multiple teams sampling sites multiple times throughout the course of one day or deployment of flow-triggered, unattended samplers. Minor work projects may occasionally require limited storm sampling for reconnaissance, investigative, or follow-up sampling.

## 7.3 Modeling and Analysis Design

### 7.3.1 Model Selection

EAP uses a variety of modeling tools for water quality impairment studies based on the water body, study parameters, and goals and objectives. Model selection requires choosing a particular model framework to represent the site-specific representation of the study water body and parameters of interest.

Model selection can include:

- Using an existing model,
- Modifying an existing model to fit the project goals and objectives, or
- Developing a new model.

This Programmatic QAPP is intended for using an existing model as part of an exploratory analysis for a minor study. For water quality impairment studies that require either modifying an existing model or developing a new model, a project-specific QAPP will be needed for full model development.

Model selection is influenced by:

- Ability and efficiency of a model to address project goals and objectives.
- Project schedule and timeline.
- Extent of available data.
- Knowledge and familiarity with the model and available information.

The current version of each of Ecology's models is made available through EAP at: Models and Tools.

#### 7.3.1.1 QUAL2Kw Model

Ecology's QUAL2Kw modeling framework (Pelletier et al., 2006; Pelletier and Chapra, 2008) is used for detailed evaluation of water quality parameters, such as temperature, pH, DO, and nutrients, under critical flow and weather conditions.

The original version of Ecology's QUAL2Kw model was a steady-flow model used to simulate water temperature and water quality parameters with diurnal variations.

A new version is now available, which can simulate non-steady, non-uniform flow using kinematic wave (KW) flow routing. This version has the option to use repeating diel conditions with either steady or non-steady flows. It also includes optional transient storage zones for surface and hyporheic transient storage zones. The KW approach allows for a continuous simulation of the river with continuously changing channel velocity and depth in response to changing flows and time-varying boundary conditions (e.g., tributary loading and meteorology) for periods of up to one year. Incorporation of KW transport and continuous boundary forcing allows QUAL2Kw to be used in projects that need to simulate continuous changes in water quality, such as the summer low-flow period, rather than for a single day at a time.

Meteorological conditions have strong influences on water temperature. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, and headwater temperature. Some of these parameters, such as effective shade from the Shade model, are calculated, and others are obtained from weather station information. Stream temperature is also affected by point-source effluent temperatures. Temperature data will be obtained from discharge monitoring report (DMR) data, where available.

Additional water quality parameters, including nutrients, will also be obtained for simulation of pH and DO. These parameters will be specified or simulated as time-varying functions. Point-sources will be incorporated into the model based on available data. These point-sources will also be evaluated separately using a mass balance equation to calculate effluent discharge to ensure the point source meets temperature Water Quality Standards at the edge of the mixing zone (Ecology, 2007).

The QUAL2Kw model can simulate continuous changes in temperature, nutrients, algal/macrophyte biomass, and DO over the entire growing season, including representation of diel variations. Other features of this modeling framework include the following elements:

- One dimensional. The channel is well-mixed vertically and laterally. Also includes up to two optional transient storage zones connected to each main channel reach (surface and hyporheic transient storage zones).
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying time scale. Parameters included that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, headwater and tributary temperature, and hyporheic flow temperature.
- Dynamic water-quality kinetics. All water quality state variables are simulated on a continuously varying time scale for biogeochemical processes.
- Heat and mass inputs. Point and nonpoint loads and abstractions are simulated.
- Two algal species in the water column: phytoplankton and bottom algae (periphyton).
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of nitrogen and phosphorus.
- Sediment diagenesis and heterotrophic metabolism in the hyporheic zone are simulated.
- Automatic calibration. Includes a genetic algorithm to automatically calibrate the kinetic rate parameters.
- Monte Carlo simulation.

Tributary inflows, groundwater inflows/outflows, and point-source inflows will be handled as boundary inputs to the mainstem model. Nutrient loads from diffuse inputs such as groundwater, and direct inputs such as tributaries, will be measured directly in the field during synoptic surveys and estimated between surveys. Some loads may be estimated based on interpolation, where appropriate.

Once calibrated, the QUAL2Kw models are typically used for evaluating TMDL loading capacity and developing allocations under critical conditions.

#### 7.3.1.2 TTools

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

TTools is used to develop GIS-based data from acquired polygon and grids coverages. It specifically uses these coverages to develop vegetation and topography data perpendicular to the stream channel and longitudinal stream-channel characteristics, such as the near-stream disturbance zone and elevation. Typical inputs into TTools are LiDAR data, digital elevation models (DEMs), and aerial imagery (digital orthophoto quadrangles and rectified aerial photos).

Stream width, aspect, topographic shade angles, elevation, and riparian vegetation are sampled with TTools for incorporation into the Shade model. The riparian vegetation coverage will contain 4 specific attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density of the riparian vegetation.

#### 7.3.1.3 Shade Model

Ecology's Shade model is a tool for estimating shade from riparian vegetation. Shade was developed as a Microsoft Excel sheet and was adapted from a program that ODEQ developed as part of Version 6 of its HeatSource model.

Shade.xls calculates effective shade using one of two methods:

- Chen's method, based on the Fortran program, HSPF SHADE that Y.D. Chen developed for his 1996 Ph.D. dissertation at the University of Georgia (Chen, 1996), and it is further documented in the Journal of Environmental Engineering (Chen 1998a, 1998b).
- The original method by ODEQ from the HeatSource model version 6.

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

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

Documentation of ODEQ HeatSource model: [www.deq.state.or.us/wq/TMDLs/TMDLs.htm](www.deq.state.or.us/wq/TMDLs/TMDLs.htm)

#### 7.3.1.4 HSPF Model

HSPF is a comprehensive, basin-scale watershed and stream-reach model that is capable of simulating hydrology, pollutant-load generation, and fate and transport of pollutants in instream channels. It allows the integrated simulation of runoff processes and instream interactions and is capable of simulating sub-daily dynamic time series of runoff and also pollutant loads and concentrations. HSPF represents subsurface interactions, vegetation, topography, and natural storage in hydrology simulations.

The required data for HSPF modeling include:

- Input/execution data, including precipitation and meteorology data (potential evapotranspiration, air temperature, dew point, solar radiation, wind speed, and cloud cover), diversions and point sources, and atmosphere deposition.
- Watershed characteristic data, including land use/cover, soils, DEM, and channel information (i.e., hydraulics and geometry).
- Calibration/validation data, including observed flow and water quality measurements such as temperature, pH, DO, nutrients, and biochemical oxygen demand.

After hydrology simulations are complete, water quality simulations will be completed to support predictions of temperature, DO, and pH in the watershed, using the RQUAL functions in HSPF. The DO simulation could also require simulation of nutrients and algal growth, if the monitoring data of the segments simulated in HSPF show significant diurnal DO swing, which indicates that low DO is caused by eutrophication. The pH simulation requires simulation of carbon dioxide, total inorganic carbon, and alkalinity. The HSPF water quality model will be calibrated using observed instream data (nutrients, DO, carbon dioxide, total inorganic carbon, alkalinity, pH, temperature). Output from the HSPF model will be used to provide boundary conditions (i.e., model inputs, such as altered hydrology and pollutant runoff data) to the QUAL2Kw water quality model.

The HSPF model will also be used to evaluate different BMP implementation scenarios. Specifically, most of the structural BMPs (e.g., infiltration BMPs, detention/retention) can be represented in the model directly to simulate the potential impact on instream water quality. Representation of existing and potential BMPs is dependent on available data and information; therefore, the specific simulations will be determined once data are obtained and reviewed for TMDL analyses. For some of the non-structural BMPs, such as nutrient management and pasture management, an efficiency-based approach will be used to estimate impacts and land simulation parameters such as reduced nutrient inputs from specific land uses. Estimates will be adjusted to reflect the assumed efficiencies.

Parameter values obtained by calibrating and validating the QUAL2Kw model to short-term monitoring events will be used to refine the temperature, pH, and DO representation in HSPF. The updated HSPF model will be used to further refine the inputs for QUAL2Kw to achieve the best fit to support TMDL calculations.

HSPF is available through EPA at: https://www.epa.gov/tmdl/tmdl-modeling. It has also been packaged into a variety of software packages, such as TetraTech's LSPC model and the Western Washington Hydrologic Model (WWHM).

#### 7.3.1.5 RMA Model

The River Metabolism Analyzer (RMA) is a simplified modeling tool developed by Ecology (Pelletier, 2013) that can be used to solve for gross primary production, ecosystem respiration, reaeration, and limitation due to light, temperature, and nutrients. It examines continuous monitoring data from a stream to analyze stream metabolism and reaeration.

The data required to run RMA include:

- Diel DO, pH, and temperature.
- Alkalinity.
- Concentration of the limiting nutrient.
- Depth of water where data were collected.

RMA is used to predict responses to parameter changes with the following methods:

- Delta method to solve for reaeration, gross primary production, and respiration.
- Night-time regression to solve for reaeration and respiration.
- Inverse modeling to solve for gross primary production, respiration, reaeration, light limitation, and temperature limitation.
- Predictive modeling to evaluate model response to changes in any model parameters, including nutrient limitation.

Continuous data will be used in RMA to analyze reach-scale productivity and respiration. RMA is used to determine reach-scale water quality dynamics and estimate the sediment oxygen demand (SOD). Hobson et al. (2014) suggests that the SOD can be estimated by subtracting the gross primary productivity from ecosystem respiration, both of which are outputs of the RMA tool. This SOD can then be used directly in the QUAL2Kw model.

#### 7.3.1.6 rTemp

Ecology's rTemp is a simple response temperature model that is used to predict a time-series of water temperatures in response to heat fluxes determined by meteorological data, groundwater inflow, hyporheic exchange, and conduction between the water and sediment. It is a one-dimensional heat response model that can be used to calculate long-term temperature time series for small streams.

#### 7.3.1.7 Other models

Additional models that can be used in conjunction with the models listed above or separately:

- CE-QUAL-W2 is a water quality and hydrodynamic model in 2D (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs and river basin systems. W2 models basic eutrophication processes such as temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships. http://www.ce.pdx.edu/w2/
- Water Quality Analysis Simulation Program (WASP) is a generalized framework for modeling contaminant fate and transport in surface waters supported by EPA. www.epa.gov/athens/research/wasp.html
- Hydrologic Engineering Center's River Analysis System (HEC-RAS) can be used for one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling. HEC-RAS is frequently used in flood-risk modeling. http://www.hec.usace.army.mil/software/hec-ras/

- Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT is a small watershed to river basin-scale model. It is used to simulate the quality and quantity of surface water and groundwater and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used for assessing soil erosion prevention and control, nonpoint source pollution control, and regional management in watersheds. http://swat.tamu.edu/
- Watershed Analysis Risk Management Framework (WARMF) calculates flows and concentrations for most conventional pollutants (coliform, TSS, BOD, nutrients). It also provides a road map to guide stakeholders to reach consensus on a TMDL implementation plan. WARMF is now compatible with the data extraction and watershed delineation tools of EPA BASINS. WARMF is organized into 5 linked modules under one GIS-based graphical user interface (GUI).

### 7.3.2 Model Setup and Data Needs

Preliminary model setup and data needs will be identified as part of model exploration and selection to meet the project goals and objectives within the scope-of-work memo. Detailed model setup and data needs will be determined within a project-specific QAPP.

If a particular process or limitation in the current model framework needs to be addressed with modifications to the modeling software, the project-specific QAPP should describe anticipated code changes and how the new coding will be quality-tested and documented in the project file.

#### 7.3.2.1 Data Gaps and Uncertainties

During exploratory model set up and development, data gaps may be identified. After the initial data set is used for exploratory model development, the project lead should identify uncertainties in data or gaps. A summary table may be used to describe what is known or not known about the quality of the initial data sets.

For exploratory modeling and data analysis, these data gaps or uncertainties will be identified within the scope-of-work memo to support and refine the study design of the larger project that will require a project-specific QAPP.

## 7.4 Assumptions Underlying Design

Data collection assumptions:

- Collection of samples and replicates will characterize the variability in parameter concentrations.
- Samples will provide sufficient information to be representative of the time and location and allow the attainment of project goals.
- Data collected will be sufficient to develop continuous time-varying boundary conditions for the model.

Modeling work contains inherent assumptions when representing a water body through a simplified mathematical-representation that is not able to account for each variable and element influencing the system. Modeling assumptions may include:

- Data that are used in the model are representative of the spatial and temporal variation within the sampling location.
- Water body hydrodynamics for model simulations, such as river flows or tidal exchange, are representative of the system.
- Algae and bacteria (bottom algae, phytoplankton, and heterotrophic biofilm) and aquatic plants are primarily limited by a single limiting factor at any given time, such as nutrients (e.g., phosphorus, nitrogen, or carbon), light, or scouring, depending on whichever factor predominantly controls the growth and biomass of the organisms.
- Periphyton growth rates, in relation to nutrients, are controlled by intracellular concentrations, not external concentrations in the water column. Internal concentrations can differ from external because periphyton are capable of variable stoichiometry, or storing nutrients in excess of needs during periods of increased supply.
- Process kinetics and rate constants used in the model will be representative of the processes that the model mathematically simulates.
- Water quality constants and kinetics determined within the calibrated model would be similar under critical environmental conditions used for other modeling scenarios.
- One-dimensional models such as QUAL2Kw assume that the modeled sections are vertically and laterally well-mixed. Two-dimensional models assume fully mixed conditions in the third dimension.

Data limitations such as data gaps, limitations in boundary conditions and calibration data, and measurement error may also influence modeling assumptions underlying design.

## 7.5 Possible Challenges and Contingencies

### 7.5.1 Logistical Problems

Logistical problems that interfere with sampling can occur during field work. These problems include:

- Denial of access to private property. At most sampling locations, samples can be collected from a bridge at a public road crossing, but occasionally access to private property is necessary. If permission to access private property is denied, an attempt will be made to find a nearby alternate sampling location.
- Difficulty of timing sampling with adequate storm events. Some projects include storm event/rain-on-snow or other event sampling, and these samplings can be difficult. For example, these events can occur at any time, including weekends or days late in the week when shipping samples to the lab is problematic.
- Inability to measure streamflows due to:
    - Deep water or high velocity, where personnel safety will always be the first consideration. The use of a bridge board, ADCP, or flow gaging station may be necessary.

    - Soft bottom substrates from deep mud or silt at the bottom of stream, ditch, or slough that can pose a significant safety hazard in many locations and will prevent collecting a flow measurement by wading. The stream bottom will be tested using a wading rod prior to stepping in. If the substrate is too soft, the use of a bridge board, ADCP, or flow gaging station may be necessary.
    - Vegetation. Aquatic or streamside vegetation can grow in water bodies during the dry season and impact stage or velocity measurements. Cut vegetation can clog waterways at certain times throughout the year. Where vegetation is significant, an attempt will be made to find an alternate location.
- Excessive precipitation or significant changes in flow during or preceding a synoptic survey, flow/seepage survey, or other sampling event that requires steady-state conditions. The project manager should monitor weather closely leading up to the survey and schedule one or more backup surveys, in the event a survey must be canceled.
- Sustained overcast weather during or preceding synoptic surveys, or other sampling events designed to measure autotrophic biological productivity. The project manager should monitor weather closely leading up to the survey and schedule one or more backup surveys, in the event a survey must be canceled.
- Inability to measure certain inflows (e.g., from culverts that can be seen but cannot be accessed or easily measured). Field staff will attempt to gain access to the inflow at the next logistically feasible access points. Pictures of the inflow will be taken and rough visual estimate of the flow recorded, if access is not possible.
- Sample holding times and transport. Numerous logistical issues can arise when transporting/shipping samples and attempting to meet holding times including:
    - Bacteria samples collected before 10 AM cannot be shipped/courier transported to the MEL overnight and meet the 24-hour holding time. These samples must be delivered directly to the lab by 3 PM on the day of collection.
    - Inclement weather can cancel or delay flights or commercial shipping vehicles. Attempts should be made to reschedule sampling events during inclement weather.
    - Overnight shipping drop-off times for commercial shipping options is usually between 3 and 4:30 PM. Delays in sampling or driving can result in missing the drop-off deadline.
- Seasonal considerations, sampling around low tide schedule, tidegates, irregular operation of pump stations, sample bottle delivery errors, vehicle and equipment problems, site access issues, traffic conditions, road safety, and limited availability of personnel or equipment.

Any circumstance that interferes with data collection and quality will be noted and discussed in the final report.

### 7.5.2 Practical Constraints

Practical constraints that can interfere with a project include:

- Scheduling problems with personnel.
- Availability of adequate resources, both human and budgetary, from EAP and WQP.
- Difficulties obtaining historic data for analyses.
- Access to hardware or software required to run the preferred model.

Any practical constraints that would affect the ability to meet project goals and objectives will be discussed with the appropriate supervisor as needed and discussed in the final report.

### 7.5.3 Schedule Limitations

Changes in project prioritization and workload for both EAP and WQP staff could affect the project schedule. Factors that can cause delays to the proposed project schedule include:

- Time required for QAPP review and approval.
- The need for additional sampling or technical analysis work, or the need for policy decisions.
- Addressing comments from reviewers, both internal and external, that may require additional work.
- Changes to schedule based on current needs and available resources from EAP and WQP.

Any unforeseen limitations that would affect the project schedule will be discussed with the appropriate supervisor as needed and discussed in the final report.

# 8.0 Field Procedures

## 8.1 Invasive Species Evaluation

Field staff will follow EAP's SOP EAP070 on minimizing the spread of invasive species (Parsons et al., 2012). At the end of each field visit, field staff will clean field gear in accordance with the SOP for minimizing the spread of invasive species for areas of both moderate and extreme concern. Areas of extreme concern have or may have invasive species, such as New Zealand mud snails that are very difficult to clean off equipment and are especially disruptive to native ecological communities.

Field staff will minimize the spread of invasive species after conducting field work by:

- Inspecting and cleaning all equipment by removing any visible soil, vegetation, vertebrates, invertebrates, plants, algae, or sediment. If necessary, a scrub brush will be used and then rinsed with clean water either from the site or brought for that purpose. The process will be continued until all equipment is clean.
- Draining all water in samplers or other equipment that may harbor water from the site. This step will take place before leaving the sampling site or at an interim site. If cleaning after leaving the sampling site, field staff will ensure that no debris will leave the equipment and potentially spread invasive species during transit or cleaning.

Established Ecology procedures will be followed if an unexpected contamination incident occurs.

## 8.2 Measurement and Sampling Procedures

Field sampling and measurement protocols will follow standard operating procedures (SOPs) developed by EAP for water quality impairment studies and TMDL development (Table 9).

Field staff will collect grab samples directly into pre-cleaned/sterilized containers supplied by Ecology's Manchester Environmental Laboratory (MEL) and described in the MEL *Lab Users Manual* (MEL, 2016). Field staff will store samples for laboratory analysis on ice and deliver to MEL within the associated holding time via either the Ecology courier or direct drop-off after sampling. MEL follows standard analytical methods outlined in its user manual.

**Table 9.** Field activities, data, and relevant SOPs.

| Field Activity | Typical Use of Data | Relevant SOPs |
|---|---|---|
| Grab samples | Investigative sampling; statistical summary; model calibration | EAP015 (Joy, 2006) |
| Discrete flow measurement | Loading calculations; flow balance/ seepage analysis; developing stage-discharge rating curves for gaging | EAP024 (Mathieu, 2016); EAP055 (Shedd et al., 2013); EAP056 (Shedd, 2014), EAP058 (Burks, 2009), EAP060 (Springer and Shedd, 2010) |
| Time of travel | Model channel geometry confirmation/ calibration data | EAP037 (Carroll, 2015); Kilpatrick and Wilson (1982) |
| Bacteria samples | Rollback analysis; loading analysis | EAP030 (Ward and Mathieu, 2014) |
| Continuous temperature logger deployment | Calculating 7-DADMax; developing and calibrating temperature models | EAP044 (Bilhimer et al., 2013); EAP080 (Ward, 2015) |
| Light extinction/secchi disk | Light extinction rates for model | Berkman and Canova (2007) |
| HemiView canopy photos | Site-specific effective shade for comparison to Shade model output | EAP045 (Stohr and Bilhimer, 2008) EAP046 (Stohr, 2008) |
| Channel surveys | Developing model channel geometry | EAP084 (Swanson, 2013) |
| Periphyton sampling (for areal biomass) | Biomass ranges for model calibration | Barbour and others (1999) EAP085 (Mathieu et al., 2016) |
| Periphyton sampling (for biota) | Biological assessment/integrity; informing model calibration decisions around nutrient sensitivity | Plotnikoff and Wiseman (2001) |
| Piezometers installed | Groundwater/hyporheic exchange | EAP061 (Sinclair and Pitz, 2010) |
| Winkler samples | Dissolved Oxygen; used as QC check for measurements taken with meter | EAP023 (Ward and Mathieu, 2011) |
| DO, pH, specific conductance, chlorophyll a, temperature–discrete and continuous measurements | Characterization of ambient conditions; model calibration data; comparison to criteria | EAP033 (Swanson, 2007); EAP011 (Dugger and Ward, 2015) |
| Turbidity – discrete and continuous measurements | Providing continuous estimates of total suspended solids, suspended sediment concentration, and total phosphorus; providing model inputs for simulating light extinction | n/a |
| Well depth, water level in-situ | Groundwater | EAP052 (Marti, 2009); EAP061 (Sinclair and Pitz, 2010) |
| Macrophyte biomass | Biomass ranges for model calibration | Aquatic Plant Sampling Protocols Publication No. 01-03-017 (Parsons, 2001) |
| Riparian habitat survey | Vegetation characteristics for Ttools and Shade model | EAP084 (Swanson, 2013); EAP045 (Stohr and Bilhimer, 2008) |
| Longitudinal floats | Channel depth for channel geometry; bottom temperature and water quality for groundwater identification | EAP096 (Stuart and Mathieu, 2015) |
| Benthic flux/ sediment oxygen demand (DOD) | Calibration/input data for benthic flux or SOD in model | EAP036 (Roberts, 2007) |
| Optical brightener measurements | Source tracking of wastewater | EAP091 (Anderson and Swanson, 2014) |
| Salinity and vertically-averaged salinity | Determining applicable criteria (marine vs freshwater) | EAP075 (Mathieu, 2016) |

The SOPs listed in Table 9 can be found at this EAP website: Published SOPs

### 8.2.1 Continuous Temperature Monitoring

Continuous temperature data collection includes the deployment of continuous temperature data loggers (thermistors) throughout the project-specific monitoring network of sites (SOPs EAP044 and EAP080). Typically:

- All stations have one thermistor deployed for water temperature, and selected sites will have another thermistor for air temperature. One or more major stations also typically include a sensor to measure for relative humidity.
- Most thermistors are programmed to record temperature at 30-minute intervals.
- Water thermistors are deployed in the thalweg of a stream, suspended off the stream bottom, and in a well-mixed area.
- Data are downloaded monthly.

### 8.2.2 Multi-Parameter Meters

Multi-parameter water quality probes can be used to measure pH, dissolved oxygen (DO), DO percent saturation, conductivity, temperature, depth, rhodamine dye concentration, oxidation-reduction potential (ORP), and total dissolved gas (TDG). These instruments can be used for instantaneous measurements from site-to-site throughout a day, for depth profiling, or for short- and long-term unattended monitoring at specific time intervals. Examples of multi-parameter instruments include Hydrolab®, DataSonde®, MiniSonde®, and HL4 Multiprobes.

### 8.2.3 Travel-Time Dye Study

Travel times are estimated within important river reaches to understand how water and pollutants move through the system and to calibrate the model (SOP EAP037). Time-of-travel studies typically use fluorescent dye (20% Rhodamine Water Tracing Dye, or Rhodamine WT) to trace the movement of a dye cloud from an upstream point to a downstream point, in order to calculate the average velocity of that body of water. Rhodamine WT dye is used by Ecology, USGS, and others to provide safe and effective time-of-travel measurements.

Field measurements of dye concentration in the stream are made using a multi-parameter sonde, such as a Hydrolab®, equipped with a rhodamine fluorometer, recording measurements every 5-10 minutes at key locations downstream from the initial point of dye release. Over a period of time in the stream, the dye will dissipate, becoming visually undetectable.

Ecology notifies the appropriate officials and local emergency contacts before injecting the dye. Announcing the dye studies prevents unnecessary emergency actions in the event a spills complaint is submitted (e.g., someone calls the sheriff or the Ecology Spills hotline because the river just turned red/pink).

### 8.2.4 Longitudinal Profiles

Measurements of specific conductance and temperature can be used as an indication of the locations and magnitude of groundwater and other flow contributions to the river. Ecology field staff walk or float down the stream or river, equipped with monitoring equipment to measure localized water quality changes. A global positioning system (GPS) simultaneously records location coordinates.

### 8.2.5 Biological Monitoring

Benthic macroinvertebrate and periphyton communities are used to assess stream conditions (Plotnikoff and Wiseman, 2001). Macroinvertebrates and periphyton provide information about environmental conditions based on the range of tolerance individual taxa have to environmental conditions. Based on their unique tolerance levels, those taxa – either present or missing – indicate habitat conditions. Fish community evaluations are not used because relatively few taxa in western North America exist, and harvests are restricted for several threatened or endangered species including salmon (Moyle et al., 1986).

Measurements of chemical and physical components alone do not provide enough information to fully address surface water problems. Biological assessments (Adams, 2010) enhance chemical and physical evaluation by:

- Capturing impacts of pollutants for which there are currently no criteria and no regulation by Washington's Water Quality Program.
- Directly measuring the most sensitive resources at risk.
- Measuring stream components that reflect natural variation over time.
- Providing a diagnostic tool that synthesizes chemical, physical, and biological perturbations (Hayslip, 1993).

Biological monitoring includes periphyton and macrophyte surveys. Periphyton surveys involve collecting periphyton samples from rocks along the river or stream. Macrophyte surveys can be completed by (1) using a Lowrance HDS echo sounder to map submerged aquatic vegetation or (2) collecting biomass samples along the river bottom.

### 8.2.6 Riparian Vegetation/Shade Surveys

Riparian vegetation surveys are used to collect field data required for modeling stream temperatures (SOPs EAP084 and EAP045). Survey data consist of channel geometry and substrate measurements, near-stream vegetation measurements and characteristics, and shade data. Vegetation survey data include vegetation heights and overhang, vegetation zone and near-stream disturbance zone (NSDZ) measurements. These vegetation survey data are important for ground-truthing ortho-photographs and vegetation height data used in the models. Hemispherical photography and Solar Pathfinder™ shade measurements are also used for riparian vegetation data collection.

Effective shade estimates of the aerial density of vegetation shading the stream include:

- Hemispherical images of the sky, overhanging vegetation, and topography at stream center. These photographs will be taken at each mainstem network site and at a few reference reaches to verify existing riparian vegetation compared to aerial photos. The digital images will be processed and analyzed using the HemiView© software program.

- Effective shade data using a Solar Pathfinder™ that uses a polished, transparent, convex plastic dome to estimate shade from a given obstacle to the stream at different hours of the day and months of the year.
- Taking spot measurements of riparian vegetation heights within 150 ft of both banks, using a laser range/height finder. Detailed riparian tree height data are not typically needed because of the availability of LiDAR and other spatial GIS data sets. These spot measurements help ground-truth the vegetation heights determined from a LiDAR top-of-surface elevation model or aerial photography.

### 8.2.7 Optical Brightener (OB) Surveys

In conjunction with investigative sampling and where appropriate, Ecology uses fluorometry as an inexpensive and practical source tracking method to identify or confirm human sources of contamination (SOP EAP091). Fluorometry is a chemical method that identifies human fecal contamination or increased nutrient loading by detecting optical brighteners (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).

Ecology deploys two Turner Designs Cyclops 7 OB sensors to test for concentrations of OBs over a predetermined amounts of time, depending on resources and site characteristics. Staff 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, anthropogenic (human-derived) contamination is likely entering the water somewhere between the sensors. This information, along with land use data and field observations, gives staff more certainty about whether contamination sources are from failing or malfunctioning onsite sewage systems or wastewater treatment plants.

For bacteria sampling with OB sensors, staff may find these scenarios:

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

Staff are unlikely to find these scenarios (Ecology only sample OBs when high bacteria/nutrients are found):

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

OBs degrade quickly−within minutes to hours−in UV light (Hartel et al., 2008), 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.

OBs can persist in sediment (Hartel et al., 2008), so OB concentrations may 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 decrease UV degradation. These factors may complicate analyses, but Ecology typically plans multiple sampling events during wet and dry seasons to address these issues.

### 8.2.8 Hydromodification and Channel Morphology Assessment

Hydromodification activities include channelization and channel modification, impoundments, as well as streambank and shoreline erosion. A frequent result of channelization and channel modification activities is a diminished suitability of instream and streamside habitat for fish and wildlife. These activities can also alter instream patterns of water temperature and sediment type, as well as the rates and paths of sediment erosion, transport, and deposition. Hardening of banks along waterways has increased the movement of nonpoint-source pollutants from the upper reaches of watersheds into coastal waters (EPA, 2013b).

Measurements of channel dimensions are typically taken to define the channel morphology within a water quality model or impairment study (SOP EAP084). Metrics can include: wetted channel profile, full bank profile, off-channel features, channel disturbance zone widths, and overbank floodplain widths.

### 8.2.9 Snow Depth and Coverage Measurements

WARMF, HSPF, and SWAT predict snow depth and coverage as state variables in the model simulation in slightly different ways. To provide a comparison point for these model predictions, measurements of snow depth and snow water equivalent (SWE), as well as landscape photographs to provide estimates of snow coverage, will be taken at least twice per month during the winter while snow is on the ground at four locations in the watershed. The sites for these measurements need to meet the following criteria:

- Snow depth measurement locations will be readily accessible throughout the winter, fairly flat (<10% slope), not covered by heavy forest canopy, not covered by heavy grass or weeds, and not disturbed by regular foot or animal traffic.
- Snow coverage photo locations will generally be along public roads, at locations near the top of a hill where a good vista is provided of at least a square mile of landscape, such that it is easy to see from that location how much of the landscape is covered by snow.

Snow depth, SWE, and coverage are secondary parameters in the watershed model, and it is acceptable for data to be approximate or qualitative in nature.

## 8.3 Containers, Preservation Methods, Holding Times

**Table 10.** Sample containers, preservation methods, and holding times based on information provided from MEL (2016).

| Parameter | Matrix | Recommended Quantity | Container | Holding Time | Preservative |
|---|---|---|---|---|---|
| **General Chemistry** | | | | | |
| Alkalinity[1] | Water | 500 mL - NO headspace | 500 mL w/m poly bottle | 14 days | Cool to ≤6°C; Fill bottle completely; DO NOT agitate sample |
| Biochemical Oxygen Demand (BOD) | Water | 2000 ML | 1 gallon cubitainer | 48 hours | Cool to ≤6°C; Keep in the dark |
| Chloride | Water | 100 mL | 500 mL w/m poly bottle[6] | 28 days | Cool to ≤6°C |
| Chlorophyll | Water | 500 – 1,000 mL | 1,000 mL amber poly bottle | 24 hours to filtration, 28 days after filtration | Cool to ≤6°C; If filtered in the field; freeze filters in acetone at ≤-10°C |
| Conductivity | Water | 300 mL | 500 mL w/m poly bottle[6] | 28 days | Cool to ≤6°C |
| Dissolved Organic Carbon (DOC) | Water | 125 mL | 125 mL n/m poly bottle[2] ; 0.45 um pore size filters | 28 days | Filter in field with 0.45um pore size filter; 1:1 HCl to pH <2; Cool to ≤6°C |
| Fluoride | Water | 100 mL | 500 mL w/m poly bottle | 28 days | Cool to ≤6°C |
| Grain Size | Soil/sed | 100 g | 8 oz plastic jar | 6 months | Cool to ≤6°C |
| Nitrogen - Total Kjeldahl (TKN) | Water | 125 mL | 125 mL clear w/m poly bottle (do not combine with other ingredients) | 28 days | H2SO4 to pH <2; Cool to ≤6°C |
| Ammonia | Water | 125 mL[7] | 125 mL clear w/m poly bottle[2] | 28 days | H2SO4 to pH <2; Cool to ≤6°C |
| Nitrate/Nitrite | Water | 125 mL[7] | 125 mL clear w/m poly bottle[2] | 28 days | H2SO4 to pH <2; Cool to ≤6°C |
| Nitrate | Water | (2) 125 mL[7] | (1) 125 mL amber and (1) 125 mL clear w/m poly bottle | 48 hours | Cool to ≤6°C; H2SO4 to pH <2 for clear bottle |
| Nitrite | Water | 125 mL[7] | 125 mL amber w/m poly bottle | 48 hours | Cool to ≤6°C |
| Nitrogen - Total Persulfate (TPN) | Water | 125 mL[7] | 125 mL clear w/m poly bottle[2] 0.45um pore size filters for dissolved TPN | 28 days | H2SO4 to pH <2; Cool to ≤6°C |
| Orthophosphate (OP) | Water | 125 mL[6] | 125 mL amber w/m poly bottle[8] 0.45 um pore size filters for dissolved OP | 48 hours | Filter in field with 0.45um pore size filter; Cool to ≤6°C |

| Parameter | Matrix | Recommended Quantity | Container | Holding Time | Preservative |
|---|---|---|---|---|---|
| pH | Soil/sed | Fill jar completely – NO headspace | 2 oz glass jar | 24 hours | Cool to ≤6°C |
| pH | Water | Fill jar - NO headspace | 500 mL w/m poly bottle | 15 minutes* | Cool to ≤6°C; Fill bottle completely |
| Total Phosphorus (TP) | Water | 60 mL | 125 mL clear n/m poly bottle[2] | 28 days | 1:1 HCl to pH <2; Cool to ≤6°C |
| Suspended Sediment Concentration | Water | 1,000 mL | 1,000 mL w/m poly bottle[6] | 7 days | Cool to ≤6°C |
| Suspended Solids (TSS) | Water | 1,000 mL | 1,000 mL w/m poly bottle[6] | 7 days | Cool to ≤6°C |
| Total Solids (TS) | Water | 250 mL | 500 mL w/m poly bottle[6] | 7 days | Cool to ≤6°C |
| Dissolved Solids (TDS) | Water | 500 mL | 500 mL w/m poly bottle[6] | 7 days | Cool to ≤6°C |
| Nonvolatile Solids (TNVS) | Water | 1,000 mL | 1,000 mL w/m poly bottle[6] | 7 days | Cool to ≤6°C |
| Sulfate | Water | 100 mL | 500 mL w/m poly bottle[6] | 28 days | Cool to ≤6°C |
| Sulfide | Soil/sed | 100 g | 4 oz glass jar | 28 days | Zinc acetate; cool to ≤6°C |
| Sulfide | Water | 100 mL, NO headspace | 500 mL w/m poly bottle[2] | 7 days | Zinc acetate; NaOH to pH >9; cool to ≤6°C; Fill bottle completely |
| Total Organic Carbon | Soil/sed | 25 g | 2 oz glass jar | 14 days[4]; 6 months if frozen | Cool to ≤6°C; PSEP: may freeze at ≤-10°C |
| TOC | Water | 125 mL | 60 mL n/m poly bottle[2] | 28 days | 1:1 HCl to pH <2; Cool to ≤6°C |
| Turbidity | Water | 500 mL | 500 mL w/m poly bottle[1, 6] | 48 hours | Cool to ≤6°C |
| **Microbiology[3]** | | | | | |
| % Klebsiella KES | Water | 250 mL, 500 for QC | 250 mL glass/polypropylene autoclaved bottle[5] | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| Enterocci | Soil/sed /tissue | 250 g | Sterile specimen cup or Whirlpak bag | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| Enterocci | Water | 250 mL, 500 for QC | 250 mL glass/polypropylene autoclaved bottle[5] | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| Fecal Coliform | Soil/Sed /Tissue | 250 g | Sterile specimen cup or Whirlpak bag | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| Fecal Coliform | Water | 250 mL, 500 for QC | 250 mL glass/polypropylene autoclaved bottle[5] | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |

| Parameter | Matrix | Recommended Quantity | Container | Holding Time | Preservative |
|---|---|---|---|---|---|
| Total Coliform (ME) | Soil/sed /tissue | 250 mL | Sterile specimen cup or Whirlpak bag | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| Total Coliform (TC) | Water | 250 mL, 500 for QC | 250 mL glass/polypropylene autoclaved bottle [5] | 24 hours | Fill the bottle to the shoulder; Cool to ≤10°C |
| **Biological Assessment** | | | | | |
| Invertebrates | Water | | Wide mouth polyethylene jar (128 oz or 3.8 L) | Roughly 3 months | 95% Ethanol (add 3 parts by volume for each part sample) |
| Periphyton | Water | <1,000 mL | 1,000 mL amber w/m poly jar (1 L) | 24 hours to filtration; 28 days after filtration (frozen) | Cool to ≤6°C |
| Total Carbon & Nitrogen - plant tissue | Water | | 1,000 mL amber w/m poly bottle | 24 hours pre-filtration; 100 days post-filtration | Cool slurry to ≤4°C; keep in dark; dry filter at 103-105°C & store in desiccator |
| Total Phosphorus - plant tissue | Water | | 1,000 mL amber w/m poly bottle | 14 days pre-acidification; 6 months post | Cool to ≤6°C; keep in dark. |

* pH analysis may not be used for regulatory compliance under the Clean Water Act when the sample cannot be analyzed immediately (within 15 minutes) upon collection.

w/m, wide mouth
[1] Do not combine alkalinity with parameters that must be shaken (e.g., pH, turbidity, TSS, and other solids tests).
[2] Container is sent by lab with preservative in it.
[3] Microbiology: Submit 1 500 mL bottle if 2 tests are requested, and 250 mL for each additional test. Bottles are not guaranteed sterile after 6 months. Return all unused bottles to lab for autoclaving.
[4] Frozen sediments and tissue can be held for up to 6 months before analysis per Puget Sound Estuary Protocol (PSEP) Guidelines.
[5] If chlorine is suspected in sample, then request bottle with thiosulfate preservative in it.
[6] May be able to analyze several general chemistry parameters from the same container. For 500 mL

1. TNVS< TVS, TS
2. pH and Conductivity – NO headspace when sampling for pH; fill jar completely
3. Alkalinity, Chloride, Sulfate – NO headspace when sampling for alkalinity; fill jar completely

DO NOT combine alkalinity with turbidity, solids, or any other test that requires vigorous shaking. For 1 liter

- Turbidity and TDS
- TSS and TNVSS

Add salinity to any *unpreserved* bottle

[7] May be able to analyze several nutrient parameters from the same container.
For 125 mL – unpreserved: Orthophosphate, Nitrite only, Nitrate only.
For 125 mL – preserved: Nitrate/Nitrite, TPN, Ammonia
[8] Filter in field.

Do not combine TKN with any other nutrient, since this analysis is not performed by MEL and will be sub-contracted to an alternate laboratory. Do not combine BOD, TOC, or Chlorophyll with any other parameter. `

## 8.4 Equipment Decontamination

Equipment decontamination may be necessary when sampling substances that contain high levels of contaminants, bacterial contamination, or organic materials that adhere to the sampling devices. Equipment decontamination ensures that reusable field equipment is free from residual contamination, including contaminants from water, sediment, plant, and animal tissues, in order to obtain accurate and representative samples.

Cleaning procedures are dependent on the contaminants that may be encountered while sampling (Friese, 2014). Equipment rinse blanks can be used to assess whether the cleaning procedures are effective.

Established Ecology procedures will be followed if an unexpected contamination incident occurs.

## 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. Sample ID numbers will follow the standard convention established by MEL: YYMMWWW-SS, where YY is the two digit year, MM is the two digit month, WWW is the three digit work order identifier assigned by MEL, and SS is the sample ID number within the work order. All sample IDs will be recorded in field logs and in an electronic spreadsheet for tracking purposes.

## 8.6 Chain-of-Custody, if required

Chain-of-custody is a series of procedures designed to document a sample or set of samples from the moment of collection, through transport, analysis, and reporting. Chain-of-custody requires that each sample be properly identified and that a record be kept of the names of all persons who handle the sample. The person with custody must have full and verifiable control of the samples at all times.

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 arrival at Ecology's Operations Center or shipping location, the chain-of-custody portion of the Laboratory Analysis Required sheet will be filled out. Samples will be placed in the walk-in cooler or will be shipped to MEL to meet holding times. Ecology staff will remain with samples to prevent tampering until security inspections have been completed.

Elements of chain-of-custody include:
- Sample identification.
- Security seals and locks.
- Security procedures.
- Chain-of-custody record.
- Field log book.

## 8.7 Field Log Requirements

A field log, typically using a water-resistant field notebook or an equivalent electronic collection platform, will be maintained by the field lead and used during each sampling event. Corrections will be made in the field notebook with single line strikethroughs, with an initial and date of corrections. Before leaving each site, staff will check field notebooks or electronic data forms for missing or improbable measurements. The following information, as applicable, will be recorded during each visit to each site:

- Name and location of project.
- Field staff.
- Sequence of events.
- Environmental conditions.
- Any changes or deviations from the QAPP.
- Date, Time, Location, ID, and description of each sample.
- Identity of QC samples collected.
- Field instrument calibration procedures.
- Field measurement results.
- Instrument ID of any sensors and meters used.
- Pertinent observations.
- Any problems with sampling or unusual circumstance that might affect interpretation of results.
- Datalogger deployment date/time, instrument ID.
- Suspected sample composition and concentrations.
- Transportation of samples.
- Location references, such as maps or photographs, of the sampling site.

## 8.8 Other Activities

For minor work projects, other activities will be discussed in the 1-2 scope-of-work memo. For major work projects, these will be described in further detail in the project-specific QAPP. Other activities may include:

- Briefings and trainings for field staff.
- Periodic maintenance for field instrumentation to be described in the instrument maintenance logbook. Any maintenance needed for field equipment will be performed by trained field staff, following the associated Ecology SOP or the equipment manufacturer’s guidance.
- Procedures and equipment of homogenizing non-aqueous matrices.
- Procedures for lab notification regarding sampling and other topics.

# 9.0 Laboratory Procedures

## 9.1 Lab Procedures Table

**Table 11.** Laboratory measurement methods

| Analyte | Sample Matrix | Expected Range of Results | Method | Method Detection Limit* |
|---|---|---|---|---|
| Alkalinity | Water | 20 – 200 mg/L as $CaCO_3$ | SM 2320B | 5.0 mg/L |
| Ammonia | Water | <0.01 – 30 mg/L | SM 4500 NH3H | 0.002 mg/L |
| Ash-Free Dry Weight- plant tissue | Tissue | 1 – 1,000 mg/L | SM 10300C(6) | 10 mg/kg (RL) |
| Biochemical Oxygen Demand 5-day (BOD5) | Water | 2 – 210 mg/L | SM 5210B | 2.0 mg/L (RL) |
| Chloride | Water | 0.3 – 100 mg/L | EPA 300.0 | 0.03 mg/L |
| Chlorophyll a | Water | 0.5 – 60 ug/L | SM 10200H(3) | .05 mg/L (RL) |
| Chlorophyll a | Tissue | 10 – 10,000 ug/L | SM 10200H(3) | .05 mg/L (RL) |
| Conductivity | Water | 20 – 31,000 uS/cm | SM 2510B | 0.026 umhos/cm |
| Dissolved Organic Carbon | Water | <1 – 20 mg/L | SM 5310B; EPA 415.1 | 0.05 mg/L |
| Dissolved Oxygen (Winkler) | Water | 0.1 – 15 mg/L | SM 4500OC | 0.1 mg/L |
| E. coli | Water | 1 – 10,000 cfu/100 mL | MF – SM 9222G1 MPN – SM 9221F | 1.0 MPN/100 mL (RL) |
| Enterococci | Water | 1 – 1,200 cfu/100 mL | MF – EPA 1600 MPN – ASTM D6503 | 1.0 cfu/100 mL (RL) |
| Fecal Coliform – MF | Water | 1 – 15,000 cfu/100 mL | SM 9222 D | 1.0 cfu/100 mL (RL) |
| Fecal Coliform – MPN | Marine water | 1 – 15,000 MPN/100 mL | SM 9221 E | 1.8 MPN/100 mL (RL) |
| Nitrate/Nitrite | Water | <0.01 – 30 mg/L | SM 4500NO3I | 0.005 mg/L |
| Orthophosphate | Water | 0.01 – 5.0 mg/L | SM 4500PG | 0.0013 mg/L |
| Total Carbon- plant tissue | Tissue | 1 – 20% | EPA 440.0 | 0.1% of DW |
| Total Nitrogen- plant tissue | Tissue | 0.1 – 5% | EPA 440.0 | 0.1% of DW |
| Total Non-Volatile Suspended Solids | Water | <1 – 2,000 mg/L | EPA 160.4 | 1.0 mg/L (RL) |
| Total Organic Carbon | Water | <1 – 20 mg/L | SM 5310B | 0.11 mg/L |
| Total Persulfate Nitrogen | Water | 0.5 – 50 mg/L | SM 4500-NB | 0.013 mg/L |
| Total Phosphorous | Water | 0.01 – 10 mg/L | SM 4500-PH | 0.0024 mg/L |
| Total Phosphorus- plant tissue | Tissue | 500 – 5,000 mg/kg DW | EPA 200.7 | 1.71 mg/kg DW |
| Total Suspended Solids | Water | <1 – 2,000 mg/L | SM 2540D | 1.0 mg/L (RL) |
| Turbidity | Water | 0 – 1,000 NTU | SM 2130 B | 0.01 NTU |

*Method Detection Limit can vary based on sample dilutions.
EPA: Approved U.S. Environmental Protection Agency (EPA) analytical method; SM: Standard Methods (APHA, 2012); ASTM: American Society for Testing and Material; RL: Reporting limit; MPN: Most probable number

## 9.2 Sample Preparation Methods

Winkler samples will be prepared and processed according to SOP EAP023 (Ward and Mathieu, 2013). Collection and preservation of samples analyzed at the laboratory will be prepared according to MEL internal SOPs. Each SOP contains specific safety and Material Safety Data Sheet (MSDS) information.

## 9.3 Special Method Requirements

This Programmatic QAPP contains common lab procedures for minor and major work projects. Any special method requirements should be addressed in the 1-2 page scope-of-work memo or in the project-specific QAPP.

## 9.4 Laboratories Accredited for Methods

Most of the chemical analyses completed for water quality impairment studies are performed at MEL, which is accredited for all the methods listed in Table 11. In rare occasions, an alternative laboratory may be necessary, in which case the laboratory must be accredited by Ecology's Lab Accreditation Unit (LAU) for each method performed. For non-potable waters, LAU accretes methods that are published at 40 CFR 136.3.

# 10.0 Quality Control Procedures

Implementing quality control (QC) procedures provides the information needed to assess the quality of the data that is collected. These procedures also help identify problems or issues associated with data collection, data analysis, or modeling, while the project is underway.

## Field Quality Control Procedures

Field blanks are used to check for sample contamination. Field staff will prepare blanks in the field by:

- Filling the bottles directly with deionized water, for most water quality samples. For filtered parameters, deionized water will be filtered through a new syringe and filtered into the sample bottle.
- For samples where a secondary container other than the sample bottle is used (such as composite), the secondary container will be cleaned and used in the same way to produce blanks as for field samples.
- Handling and transporting the filtering equipment and blank samples to MEL in the same manner that the rest of the samples are processed.

For field instruments, EAP staff will perform the following QC procedures:

- **Pre-calibration:** Minimize bias in the Hydrolab® or other multi-parameter sonde field measurements by pre-calibrating the instrument before each run, using NIST standards when possible.
- **NIST post check:** Assess any potential bias from instrument drift, fouling, or interference in probe measurements by:
    - For pH and conductivity, post-checking the probes against NIST-certified pH and conductivity standards.
    - For DO, post-checking the probe against 100% saturation with an air check or saturated water bath (as recommended by the meter instruction manual).
    - For temperature, checking the probe’s temperature readings before and after each project using an NIST-certified thermometer.
    - For turbidity, post-checking the probes against NIST-certified turbidity standards.
    - For other parameters, post-check with a NIST-certified, if feasible.
    - The results from each field instrument will be assigned an accuracy rating based on the criteria in Table 12.
- **QC meter field checks**
    - Collect a minimum of three field checks using an NIST calibrated field meter listed in Table 5 (MQO) or a meter of comparable accuracy, resolution, and range.
    - One field check will be collected at deployment, one mid-deployment, and one upon retrieval of the deployed instrument.
    - DO meters used for field checks must use an optical DO technology, such as Luminescent Dissolved Oxygen (LDO).

- **Winkler QC field checks**
    - For DO deployments, in addition to field DO meter checks, a minimum of three Winkler samples must be collected.
- **Fouling checks**
    - For deployments of longer than two weeks, or sites with heavy fouling, assess bias from instrument fouling by collecting a final measurement upon retrieval of a deployed sonde, then immediately cleaning the sensors at the site, and finally taking another measurement immediately after cleaning.
- **Field calibration frequency**
    - For discrete/field check instruments, these should be checked weekly, unless otherwise specified in a project-specific QAPP. If the instrument's check results exceed the 'Excellent' criteria in Table 12, then the instrument must be recalibrated. For instruments capable of holding a calibration for an extended period of time, such as optical DO sensors, it is recommended to avoid recalibrating instruments that pass check criteria; this allows for more consistent results throughout the course of the project.
    - For deployed instruments, these are checked during pre-deployment and after retrieval only. Deployed instruments are not buffer checked or recalibrated mid-deployment, unless otherwise specified in a project-specific QAPP.

**Table 12.** Ratings of accuracy for field instruments

| Measured field parameter | Excellent | Good | Fair | Poor |
|---|---|---|---|---|
| Water temperature | ≤ ± 0.2°C | > ± 0.2 – 0.5°C | > ± 0.5 – 0.8°C | > ± 0.8°C |
| Specific conductance | ≤ ± 3% | > ± 3 – 10% | > ± 10 – 15% | > ± 15% |
| Dissolved Oxygen* | ≤ ± 0.3 mg/L or ≤ ± 5%, whichever is greater | > ± 0.3 – 0.5 mg/L or > ± 5 – 10%, whichever is greater | > ± 0.5 – 0.8 mg/L or > ± 10 – 15%, whichever is greater | > ± 0.8 mg/L or > ± 15%, whichever is greater |
| pH | ≤ ± 0.2 units | > ± 0.2 – 0.5 units | > ± 0.5 – 0.8 units | > ± 0.8 units |
| Turbidity | ≤ ± 0.5 units or ≤ ± 5%, whichever is greater | > ± 0.5 – 1.0 units or > ± 5 – 10%, whichever is greater | > ±1.0 – 2.0 units or > ± 10 – 20%, whichever is greater | > ± 2.0 units or > ± 20%, whichever is greater |

*****percent criteria based on saturation check; mg/L criteria based on Winkler field checks

## Laboratory Quality Control Procedures

The primary types of QC samples used to evaluate and control the accuracy of laboratory analyses are check standards, duplicates, spikes, and blanks (MEL, 2016). Check standards serve as an independent check on the calibration of the analytical system and can be used to evaluate bias. MEL routinely duplicates sample analyses in the laboratory to determine laboratory precision. Matrix spikes are used to check for matrix interference with detection of the analyte and can be used to evaluate bias as it relates to matrix effects. Blanks are used to check for sample contamination in the laboratory process.

Total precision for field sampling and laboratory analysis will be assessed by collecting replicate samples. The difference between field variability and laboratory variability is an estimate of the field variability.

Laboratory and field QC procedures are presented in Tables 13 and 14 for field measurements.

## 10.1 Table of Field and Laboratory Quality Control

**Table 13**. Quality control samples, types, and frequency for the laboratory and field.

<table>
<tr><th rowspan="2">Parameter</th><th colspan="5">Laboratory</th><th colspan="2">Field</th></tr>
<tr><th>Calibration Verification/ Blanks</th><th>Method Blanks</th><th>Analytical Duplicates</th><th>Matrix Spikes</th><th>Lab Control Samples (LCS)</th><th>Field Blanks</th><th>Field Replicates</th></tr>
<tr><td>Alkalinity</td><td rowspan="10">ICV/ICB = Beginning of sequence<br><br>CCV/CCB = 1/10 samples & end of sequence</td><td rowspan="16">1/batch</td><td rowspan="16">1/batch</td><td>n/a</td><td rowspan="10">1/batch</td><td rowspan="9">1/synoptic survey OR 1/quarter</td><td rowspan="14">1/10 samples</td></tr>
<tr><td>Chloride</td><td rowspan="9">1/batch</td></tr>
<tr><td>Ammonia</td></tr>
<tr><td>Nitrate/Nitrite</td></tr>
<tr><td>Total Persulfate Nitrogen</td></tr>
<tr><td>Orthophosphate</td></tr>
<tr><td>Total Phosphorus</td></tr>
<tr><td>Dissolved Organic Carbon</td></tr>
<tr><td>Total Organic Carbon</td></tr>
<tr><td>Total Carbon, Nitrogen, and Phosphorus - Tissue</td><td>n/a</td></tr>
<tr><td>Chlorophyll a - tissue</td><td rowspan="6">n/a</td><td rowspan="7">n/a</td><td rowspan="2">n/a</td><td>n/a</td></tr>
<tr><td>Ash-Free Dry Weight - tissue</td><td>n/a</td></tr>
<tr><td>Biochemical Oxygen Demand 5-day (BOD5)</td><td rowspan="2">1/batch</td><td rowspan="3">1/synoptic survey OR 1/ quarter</td></tr>
<tr><td>TSS, TNVSS, TS, SSC, TDS</td></tr>
<tr><td>Chlorophyll a - water</td><td rowspan="3">n/a</td><td rowspan="2">1/5 samples</td></tr>
<tr><td>E. coli, Enterococci, Fecal Coliform, %KES</td><td>n/a</td></tr>
<tr><td>Dissolved Oxygen (Winkler)</td><td>1/50 samples or 1/month*</td><td>n/a</td><td>n/a</td><td>n/a</td><td>1/20 samples</td></tr>
</table>

CCV = Continuing Calibration Verification; CCB = Continuing Calibration Blank;
ICV = Initial Calibration Verification; ICB = Initial Calibration Blank; SSC: Suspended Solids Concentration.
Batch is represented by 20 samples or fewer.
*bi-iodate normality check

**Table 14.** Quality control for field measurements

| Measurement Parameter | Field Measurements | |
|---|---|---|
| | Replicates | Field Check |
| Dissolved Oxygen | 1/20 measurements | 3/deployment |
| pH | 1/20 measurements | 3/deployment |
| Specific Conductivity | 1/20 measurements | 3/deployment |
| Temperature | 1/20 measurements | 3/deployment |
| Turbidity | 1/20 measurements | 3/deployment |
| Flow | 1/10 measurements | n/a |

For field blanks, one field blank per synoptic survey should be collected and one field blank should be sampled quarterly during routine monitoring projects. These field blanks and replicates may vary depending on site-specific criteria, as determined by the project manager. Variations will be documented in the project-specific QAPP. Considerations for collecting field blanks include the number of sampling events and sample number, likelihood of contamination, and parameter being sampled.

Laboratory check standards, method blanks, and analytical duplicates are reported as a minimum amount per batch of 20 samples or fewer. For laboratory procedures, the project manager may specify which samples will be analyzed in duplicate and may instruct the lab to spike certain samples for matrix spikes.

For certain projects, the project manager may choose to have MEL analyze SRMs for total phosphorus in periphyton tissue.

## 10.2 Corrective Action Processes

QC results may indicate problems with data during the course of the project. Corrective action processes will be used if activities are found to be inconsistent with the QAPP, if field instruments yield unusual results, if results do not meet MQOs or performance expectations, or if some other unforeseen problem arises. There may be cause for field instruments to be recalibrated, following SOPs, while still on site. For data analysis and modeling work, this may involve activity from project personnel and technical experts to decide on the next steps that need to be taken to improve model performance.

The lab will follow prescribed procedures to resolve the problems, such as:

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

# 11.0 Data Management Procedures

All major and minor work projects will follow the data management procedures outlined in this Programmatic QAPP.

## 11.1 Data Recording and Reporting Requirements

Staff will record all field data in a water-resistant 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 or a project database as soon as practical after they return from the field. For data 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.

All final spreadsheet files, paper field notes, and final products created as part of the data collection and data QA process will be kept with the project data files.

All continuous data will be stored in a project database that includes station location information and data QA information. This database will facilitate summarization and graphical analysis of the data for uploading to the EIM geospatial database.

## 11.2 Laboratory Data Package Requirements

Lab results will be checked for missing and 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.

Laboratory-generated data reduction, review, and reporting will follow the procedures outlined in the MEL *Lab Users Manual* (MEL, 2016). The final data report is sent to the Ecology project manager. The data report will show the laboratory sample number, the name of the analysis, and the level(s) of the target analyte(s), unless special requirements were arranged. Variability in lab duplicates will also be quantified, using the procedures outlined in the 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. Protocol is already in place for how and what MEL transfers to EIM through LIMS.

## 11.4 EIM/STORET Data Upload Procedures

All applicable field measurement and sample data will be available in EIM, the geospatial database, once the project data have been verified (EIM Database). All data will be uploaded to EIM by the EIM data engineer after the data have been reviewed for QA and finalized. EIM data will be independently reviewed by another EAP staff member for data entry errors at an initial 10% frequency. If significant entry errors are discovered, a more intensive review will be undertaken. Some parameters are currently not accommodated by the EIM database, including longitudinal survey data, Echo sounder data, and time of travel data, as they represent information with a complex spatial component that is not well-suited to a location-based database.

## 11.5 Model Information Management

Data management for modeling work ranges from basic spreadsheets to the development of large relational databases. Modeling data can include input data, version management, output files, and post-processing of results.

Ecology will maintain and provide the final version of the model, including input, output, executables, electronic copies of the data, GIS, and other supporting documentation (including records documenting model development). Intermediate versions will be saved during model development; some data from intermediate versions may be archived to document the development process or preserve critical earlier versions. Ecology will maintain copies of these in a task subdirectory, subject to regular system backups, for a maximum period of 3 years after task termination, unless otherwise directed by agency management. The underlying data sets, having been determined to be of acceptable quality and used for the model, will be organized prior to the public comment phase of the project, so that they can be easily shared upon request.

Modeling staff will be instructed about the importance of routinely archiving work assignment data files from hard drive to compact disc or server storage. Information will be stored on Ecology servers that are routinely backed up. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software is performed to keep up with evolutionary changes in computer storage, media, and programs.

# 12.0 Audits and Reports

All major and minor work projects will follow the audit and report procedures outlined in this Programmatic QAPP. Any other planned audits for major work projects will be documented within the project-specific QAPP.

## 12.1 Field, Laboratory, and Other Audits

Field staff may be audited at any time by appropriate project manager or supervisor or by QA staff to ensure that field work is being completed according to this Programmatic QAPP, a project-specific QAPP, and published Ecology SOPs. Projects that involve complex data analysis and modeling work may be audited by the appropriate project manager, supervisor, or other personnel familiar with the modeling or analysis procedures.

All accredited laboratories must undergo routine on-site audits in accordance with WAC-173-50-080. On-site audits are conducted by MEL's Laboratory Accreditation Unit (LAU).
Ecology occasionally conducts field consistency reviews, by experienced EAP field staff not assigned to the project. Field consistency reviews are not true audits but instead serve to improve field work consistency, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen Ecology's data QA program.

## 12.2 Responsible Personnel

Personnel responsible for audits are:

- Field audits: project managers or supervisors.
- Lab audits: MEL's LAU.
- Field consistency reviews: experienced (at least 3 years) EAP field staff.
- Data analysis and modeling work: project managers or their supervisors.

## 12.3 Frequency and Distribution of Reports

Results of the field data collection, data quality assessment, and any data analysis or modeling must be documented in either a published report or technical memo.

For major work projects, a peer-reviewed technical report or water quality improvement report will be completed and published to Ecology's website. The final report will also be distributed to all managers, clients, tribes, municipalities, and other stakeholders involved or interested in the study as determined by the EAP publications distribution form. EAP has specific publication guidelines depending on the type of final report, either TMDL or non-TMDL, that describe the exact requirements necessary for publication.

Model documentation may be accomplished in one document at the end of the project or in stages during different phases of the project. For complex projects, the project team may elect to write separate reports on the data collected, hydrodynamic calibration, water quality calibration, and model scenarios.

Model documentation should include the following:

- Model assumptions.
- Data quality assessment results.
- Values, or range of values, used for all channel geometry, boundary conditions, and initial condition inputs, and the basis for these inputs.
- Data sources for climate and shade inputs.
- All rate parameters.
- For calibration and validation exercises, a presentation of model goodness-of-fit, preferably including plots and summary statistics.
- Presentation of sensitivity analyses, as appropriate.
- Detailed description of how model inputs were changed for system potential/natural conditions scenarios, if applicable, and the basis for these inputs.
- Results of model output uncertainty assessment.

The use of models in the regulatory sense requires comprehensively detailed documentation. In addition, a model that underlies a decision (such as a TMDL or NPDES permit) is subjected to the same public comment process as the regulatory action, even in cases when the model was previously peer-reviewed. The expected sequence of the documentation process should be considered in the project scoping and schedule.

For minor work projects, the results must be documented in (1) a technical memo, (2) the final project report (if associated with a major project), or (3) an addendum to that report. The technical memo must be completed within the timeframe specified in the scoping memo or a subsequent scope change memo, and distributed to the appropriate clients and supervisors. The memo may or may not be published.

## 12.4 Responsibility for Reports

The project manager is responsible for verifying data completeness and usability before the data are used in the technical report and entered into EIM. The project manager is also responsible for writing the final technical report or memo, unless an alternate author is agreed upon and documented at the start of the project.

For major work projects, EAP section managers are responsible for assigning a peer reviewer with the appropriate expertise for the technical report. Depending on the type of final report, there may be an internal and external review process. The peer reviewer is responsible for completing EAP's Peer Review Form and working with the report author to resolve or clarify any issues with the report.

For complex or contentious modeling projects, an additional peer review may be needed, particularly for projects that support regulatory decisions. More information can be found about the peer review process in the *Guidance on the Development, Evaluation, and Application of Environmental Models* (CREM, 2009) or in the *Science and Technology Policy Council Peer*

*Review Handbook* (EPA, 2015). For these complex modeling projects, a peer review is recommended to ensure the work used "Best Available Science" including credible data, information, and literature (WAC 365-195-905, RCW 90.48.580). These projects will include information about how "Best Available Science" was established within the project-specific QAPP.

# 13.0 Data Verification

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

## 13.1 Field Data Verification, Requirements, and Responsibilities

The project workbook file containing raw field data will be labeled "Draft" until data verification and validation is complete. Validated data will be moved to a separate file labeled "Final".

### 13.1.1 In-Field Data Verification

Field notebooks and electronic information storage will be checked for missing or improbable measurements, and initial data will be verified before leaving each site. This process involves checking the data sheet (written or electronic) for omissions or outliers. If measurement data are missing or a measurement is determined to be an outlier, the measurement will be flagged in the data sheet and repeated if possible. The field lead is responsible for in-field data verification.

### 13.1.2 Post-Field Work Data Verification

Upon returning from the field, data are either manually entered (data recorded on paper) or downloaded from instruments and then uploaded into the appropriate database or project folder (see Data Management Section). Manually entered data will be verified/checked by a staff member who did not enter the data. Downloaded electronic data files will also be checked for completeness and appropriate metadata (e.g., filename, time code).

### 13.1.3 Raw Sensor Data Verification and Adjustment

Following data entry verification, raw field measurement data will undergo a quality analysis verification process to evaluate the performance of the sensors. Field measurement data may be adjusted for bias or drift (increasing bias over time) based on the results of fouling, field, or standards checks following general USGS guidelines (Wagner, 2007) and this process:

**Review Discrete Field QC Checks**

1. Review post-check data for field QC check instruments, reject data as appropriate.
2. Assign a quality rating to the field check values (excellent, good, fair, poor) based on the post-check criteria in Table 12.

**Review/Adjust Time Series (Continuous) Data**

3. Plot raw time series with field checks.
4. Reject data based on deployment/retrieval times, site visit disruption, blatant fouling events, and sensor/equipment failure.

5. Review sensor offsets for both pre-calibration and post-deployment buffer/standard checks. Flag any potential chronic drift or bias issues specific to the instrument.
6. If applicable (see Section 10), review fouling check and make drift adjustment if necessary. In some situations an event fouling adjustment may be warranted based on abrupt changes in flow, stage, sediment loading, etc.
7. Review residuals from both field checks and post-checks, together referred to as QC checks. Adjust data as appropriate, using a weight-of-evidence approach. Give the most weight to post-checks with NIST standards, then field checks rated excellent, then good, and then fair. Do not use field checks rated poor. Potential data adjustments include:
    a. *Bias* – Data are adjusted by the average difference between the QC checks and deployed sonde. Majority of QC checks must show bias to use this method.
    b. *Regression* – Data adjusted using regression, typically linear, between QC checks and deployed sonde. This accounts for both a slope and bias adjustment. The regression must have at least 5 data points and an $R^2$ value of >0.95 to use for adjustment. Do not extrapolate regressions beyond the range of the QC checks.
    c. *Calibration/Sensor Drift* – Data adjusted using linear regression with time from calibration or deployment to post-check or retrieval. Majority of QC checks, particularly post checks, must confirm pattern of drift.
8. Typically, choose the adjustment that results in the smallest residuals and bias between the adjusted values and QC checks. Best professional judgement and visual review are necessary to confirm adjustment.
9. If the evidence is weak, or inconclusive, do not adjust the data.

If Ecology staff adjust any data, it will be noted in the final report. Data adjustment must be performed or reviewed by a project manager or principal investigator with the appropriate training and experience in processing raw sensor data. Water quality impairment staff are currently drafting an SOP for continuous data collection and adjustment; this SOP will contain more detail and be referenced in a subsequent version of this QAPP.

### 13.1.4 EIM Data Verification

After data have been finalized and entered into the EIM database, a staff member who was not involved in the EIM data entry will review the data in EIM for completeness and potential errors following Ecology's internal EIM review protocols.

## 13.2 Verification of Laboratory Data

MEL staff will perform laboratory verification following standard laboratory practices (MEL, 2016). After the laboratory verification, the field lead, principal investigator, or project manager 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 reviewer will bring any discovered issues to the project manager for resolution. The project manager will review data requiring additional qualifiers.

## 13.3 Validation Requirements, if necessary

Data validation is an analyte- and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set (EPA, QA/G-8, 2002).

The data validation process follows verification and is almost always performed by a qualified chemist who is independent of the data collectors and users. Validation involves a detailed review of laboratory data packages, using professional judgment and objective criteria, to determine if MQOs for precision, bias, and sensitivity specified in an approved QAPP have been met. However, validation also requires the reviewer to assess data quality using instrument calibration records, results for QC samples (e.g., blanks, replicates, spiked recovery samples, standard reference materials), sample-specific instrument records, and other appropriate information.

## 13.4 Model Quality Assessment

Absolute criteria for model acceptance or rejection are usually not appropriate because of uncertainty and lack of available literature on model performance criteria, inherent error in input and observed data, and the approximate nature of model formulations. However, model performance will be evaluated, using quantitative and qualitative criteria, to determine the relative quality of model calibration and model results. As stated previously, the quality objectives listed in Section 6.3 will not be used to pass/fail or accept/reject the model itself, only to help modelers and stakeholders determine if additional model refinements, input parameters, or data are needed.

### 13.4.1 Calibration and Validation

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict the entire multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigating how a system would likely respond to a perturbation from its current state.

To provide a credible basis for predicting and evaluating water quality scenarios and management options, the ability of the model to represent real-world conditions should be optimized and evaluated through a process of model calibration and, if appropriate, through validation (CREM, 2009; EPA, 2002).

Model calibration is necessary because of the inherent uncertainty of water quality models. The water quality models used are mechanistic, based on mass balance processes, but use kinetics to quantify these processes that may be derived empirically, from laboratory studies or from other ecological systems. Model calibration is the method of adjusting model parameters and kinetics to achieve an optimal match between the predicted trends of the model to the observed conditions. Model calibration involves a qualitative graphical comparison and basic statistical methods that are used to compare model predictions and observations.

However, care must be taken to avoid “overfitting of the model”, which is sometimes called “curve-fitting”. Model inputs should be justified based on their applicability to the environmental conditions being modeled, and model internal and secondary results should be carefully examined for spurious results that suggest overfitting of the model. The most appropriate and defensible calibration of the model, based on realistic input values and internally consistent results, may not produce the best statistical fit.

The values of the parameters, kinetics and rates used within the model are typically within the range defined by scientific literature and other water quality impairment studies in similar water bodies. However, in some cases, the need for kinetic values outside the range found in associated literature is necessary to accurately represent the modeled system; these situations must be justified with evidence for their reasonableness and documented within the model report.

Once calibration is completed, model validation may occur, if appropriate data are available. EPA defines model validation as “subsequent testing of a pre-calibrated model to additional field data, usually under different external conditions, to further examine the model’s ability to predict future conditions” (USEPA 1997). This process occurs through using the same model calibration framework for a separate field data set within the same water body, without adjusting any rates or coefficients. The matching of observed versus predicted trends in a second simulation helps validate the accuracy of the model. This type of validation also provides a direct measure of the degree of uncertainty that can be expected when the model is applied to conditions outside the calibration series.

There are two general approaches to calibration and validation:

- Use all available observed data to calibrate and improve the model, termed the “all data” calibration method. Under this scenario, model validation is less formal and involves evaluating model goodness-of-fit and how well the mechanistic processes are captured under varying conditions in the model.
- Use one observed data set to calibrate the model, and reserve a second “blind” observed data set to validate the model.

Within EAP, the “all data” calibration method is typically employed for dynamic models which cover a longer period. Usually, calibration will focus on the most critical time period and areas of the water body. Informal validation then occurs by evaluating model performance in less critical areas and time periods. Historically, EAP performed “blind” validation for steady-state models with one synoptic survey used for calibration and another synoptic survey used for validation. Both methods are acceptable practices and may be used depending on the model selection and project-specific circumstances.

The chosen model calibration and validation approach is influenced by factors including:

- Extent of observed data.
- Objectives of the study.
- Type of model or specific framework.

The quality of model performance will be evaluated using statistical tests. Model performance statistics are used, not as absolute criteria for acceptance of the model, but rather (1) as guidelines to supplement the visual inspection of model-data plots and (2) to determine appropriate endpoints for calibration and validation of the model. This section lists a suite of tests that are used during model quality assessment. The exact statistical tests will be determined during model calibration and may include any of the following. In addition, if determined necessary and appropriate, additional tests of model fit may be applied. Validation should use the same tests as used for calibration.

#### 13.4.1.1 Precision

Precision is a measure of the variability in the model results relative to measured values. Model resolution and performance are measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between observed and simulated values. Other metrics that might be used to assess precision include the Coefficient of Determination, the Nash-Sutcliffe Coefficient of Model Efficiency, absolute mean error, and relative error.

**Root-Mean-Square Error Statistic (RMSE).** The RMSE ($E_{rms}$) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O - P)^2}{n}}$$

where,
$O$ = observation
$P$ = model predication at same location and time as the observation
$n$ = number of observed-predicted pairs
$E$ = mean error

A RMSE of zero is ideal. The RMSE is an indicator of the deviation between model predictions and observations. The $E_{rms}$ statistic is an alternative to (and is usually larger than) the absolute mean error. It tends to emphasize large errors, so that a few large errors can greatly increase the $E_{rms}$ statistic even if most errors are small.

However, an important consideration of the RMSE approach is that when it is used to assess time series diel or continuous model outputs, it severely penalizes the model for small phase shifts in timing. One approach that can be used to address this is to establish a time window, calculate the range of model predictions for the time window, then count a deviation from prediction only if the observation falls outside this range within this time window. Another approach is to compare only the daily minimum, maximum, or average.

**Coefficient of Determination.** The coefficient of determination ($R^2$) is defined as

$$R^2 = \frac{\sum_{i=1}^{n}(P_i - \bar{O})^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where,
$P_i$ = $i^{th}$ prediction

$O_i$ = i[th] observation

where the overbar indicates the mean of the *n* observed values. The coefficient of determination varies between 0 and 1 and indicates the proportion of the total variation in observations explained by the model.

**Nash-Sutcliffe Coefficient of Model Fit Efficiency.** The coefficient of model fit efficiency or Nash-Sutcliffe coefficient ($E_{ns}$) is particularly useful for evaluating model fit to continuous data, taking into account both the difference between model and observed values and the variance of the observations. The statistic is defined as

$$E_{NS} = 1.0 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

The resulting coefficient ranges from minus infinity to 1.0, with higher values indicating better agreement. At a value of zero, the test indicates that the model is a good predictor of the observed mean, while negative values indicate that the model is a better predictor of the observed mean.

**Absolute Mean Error.** The absolute mean error ($E_{abs}$) between model predictions and observations is defined as

$$E_{abs} = \frac{\sum |(O - P)|}{n}$$

An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a value less than zero.

#### 13.4.1.2 Bias

Bias is the systematic deviation or difference between the modeled and observed (i.e., measured) values. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration. Mathematically, bias is evaluated through use of standard metrics such as the mean error, relative error, or relative percent difference (% RPD). The % RPD provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

**Relative Percent Difference.** The relative percent difference (%RPD) is defined as

$$RPD = \left[\frac{|P_i - O_i| * 2}{O_i + P_i}\right] * 100$$

**Mean Error Statistic.** The mean error ($E$) or overall bias between model predictions and observations is defined as

$$E = \frac{\sum(O - P)}{n}$$

A mean error of zero is ideal.  A non-zero value is an indication that the model might be biased toward either over- or under-prediction, and typically represented by either a plus or negative sign (e.g., +0.5 or -0.5).  Mean error can also be expressed as a relative statistic by dividing it by the average observed value.

**Relative Error Statistics.** The relative error statistics (*RE*) between model predictions and observations can be calculated by dividing the RMSE ($E_{rms}$) or absolute mean error ($E_{abs}$) statistics by the mean of the observations.  A relative error statistic of zero is ideal.  When it is non-zero, it represents the percentage of deviation between the model prediction and observation.

#### 13.4.1.3 Representativeness

Model results will be assessed to determine how representative they are of the population of interest, the model-specified population boundaries.  Representativeness can be assessed narratively by examining patterns in the range of spatial and temporal conditions from the model results and their similarity with known or likely characteristics of the modeled water body. Individual modeling projects will address representativeness in the project-specific QAPP and will consider factors such as model approach, input and calibration data collection methods, seasonality, time of day, flow conditions, and weather.

#### 13.4.1.4 Qualitative assessment

Graphical assessments and spatial assessments with GIS may be used to provide a qualitative assessment of the goodness-of-fit.

Model results (for hydrology and water quality) will be compared with associated observed measurements using graphical presentations.  Such visual comparisons are extremely useful in evaluating model performance over the appropriate temporal and spatial range.  For example, continuous monitoring data can be compared with continuous modeling results to ensure diurnal variation and minimum/maximum values are well represented.  Model performance is ultimately determined through best professional judgment and experience with previous projects.

### 13.4.2 Analysis of Sensitivity and Uncertainty

This section presents options for evaluating model performance that are used in the water quality impairment analysis.  The methods described below will use appropriate and comparable spatial and temporal pooling of data to help provide a more comprehensive understanding of model uncertainty.

The technical analysis can also include the evaluation of model uncertainty and sensitivity to ensure that the achievement of project goals is appropriately supported by the quality of the model results.  Uncertainty and sensitivity results will be presented in the final report using a combination of tables and plots, such as time series plots, histograms, and box plots.

Modelers qualitatively assess the sensitivity of model parameters through parameter perturbation.  Another sensitivity analysis includes testing the response of key model outputs to changes in key model inputs (e.g., testing the model outputs of DO sensitivity to nutrient inputs or temperature sensitivity to shade).  A summary of any model sensitivity analyses will be included in a technical memo or in a final project-specific report. Details may include the variables modified for model calibration, the percent modification (e.g., ± 10%) or modified value, the change in the modeling or model-fitness results, and the normalized sensitivity coefficient (Brown and Barnwell, 1987).

**Normalized sensitivity coefficient (NSC)** is defined as,

$$NSC = \frac{\Delta Y_O / Y_O}{\Delta X_i \,/\, X_i}$$

where,

$\Delta Y_o$ = Change in the output variable $Y_o$
$\Delta X_i$ = Change in the input variable $X_i$

Algorithmic techniques for sensitivity and uncertainty assessment may also be used and are available through several water quality modeling programs (Monte Carlo Simulation, first-order error analysis, or automated objective function optimization).

For advanced sensitivity and uncertainty analysis, EAP typically uses YASAIw - A Monte Carlo simulation add-in for Microsoft Excel (Pelletier, 2009). This add-in is a free open-source framework for Monte Carlo simulation in Excel. YASAIw is a modification of the original YASAI add-in that was developed by Rutgers University. The modified version (YASAIw) adds several new features including more distributions, correlated random variables, sensitivity analysis, and the ability to run user-defined macros during simulation.

Uncertainty analysis is the terminology associated with the examination of how the lack of knowledge in model parameters, variables, and processes propagates through the model structure as model output or forecast error. Sources of model uncertainty are characterized by EAP staff during the initial stages of planning in order to better understand how the model input data and parameters would potentially influence model output and prediction. Potential sources of model uncertainty include:

- Estimated model parameter values.
- Observed model input data.
- Model structure and forcing functions.
- Numerical solution algorithms.

Uncertainty can be assessed qualitatively or quantitatively. For all modeling work, a qualitative assessment of uncertainty should be made based on the results of calibration, validation, and sensitivity analyses. This analysis can be useful in assessing the Margin of Safety in a TMDL study. A variety of tools are available for a quantitative uncertainty analysis through EPA guidance (e.g., CREM, 2009) or modeling textbooks (e.g., Rekhow and Chapra, 1983).

# 14.0 Data Quality (Usability) Assessment

## 14.1 Process for Determining Project Objectives Were Met

### 14.1.1 Study Data Usability

The project manager will assess all data (qualified and unqualified), results of verification and validation process, compliance with MQOs, and the overall quality of the data set to provide a final determination regarding usability in the context of the project-specific goals and objectives. The final report will document whether the final, acceptable-quality data set meets the needs of the project (i.e., allows desired conclusions/decisions to be made with the desired level of certainty).

### 14.1.2 Assessment of External Data for Usability

Any water quality data generated outside of this Programmatic QAPP or the project-specific QAPP that are used in a water quality impairment study must meet the requirements of the Agency's credible data policy. Note that this requirement does not apply to non-water quality data such as flow or meteorological data.

Some of the data sources have their own data assessment processes in place, and data that do not meet established quality criteria are often flagged with appropriate data qualifiers. Qualified data will be used with caution or discarded based on professional judgment.

The usability of data from external sources that do not have readily available information on whether the data were peer reviewed or followed QA/QC procedures or SOPs will also be assessed. This assessment will include exploratory data analysis, plotting and visually assessing quality, and comparison/correlation to other data sources collected at nearby locations.

If not already detailed in a project-specific QAPP, the final report will include

- An assessment of data quality for external data sources used in the analysis which do not have readily available QA/QC information.
- An assessment that these data meet requirements of Washington State regulation and Ecology policy for use in the project.

The data quality assessment will include one or more of the following elements:

- Reference to a peer-reviewed and published QAPP.
- Demonstration that the collected data yielded results of comparable quality to the study, based on data quality objectives and requirements in this Programmatic QAPP.
- Documentation that the objectives of the QAPP or equivalent QA procedures were met and that the data are suitable for water quality-based actions. Assessment of the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at time of sampling.

- Documentation of the planning, implementation, and assessment strategies used to collect the information, including:
    - Documentation of the original intended use of the information (e.g., chemical/physical data for TMDL analyses).
    - Description of the limitations on use of the data (e.g., these measurements represent only storm-event conditions).

## 14.2 Treatment of Non-Detects

Any non-detects will be included in the study analysis. General considerations for modeling when using non-detects may be treated in several ways:

- Non-detect may be replaced with half the detection limit.
- Non-detect may be replaced with a raw laboratory instrument value.
- Non-detect may be treated as an indeterminate value between zero and the detection limit. For example, when comparing model predictions to observed data where the observed data are a non-detect, any predicted value less than the detection limit would be considered an exact match.

Regression on-order statistics (ROS) or Kaplan-Meier may be more appropriate for summary statistics, distributional analysis, and other analyses.

For bacteria values below the detection limit, a conservative value of the detection limit minus one significant digit will be used (Sargent and Lowe, 2014). For bacteria values above the detection limit, the upper detection limit plus one significant digit will be used. If treated differently, this should be documented within the project-specific QAPP.

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

## 14.3 Data and Analysis Presentation Methods

Data found to be of acceptable quality for project objectives will be analyzed before being summarized or used for modeling. Any relevant and interesting data analysis will be presented in the final report using a combination of tables and plots of various kinds, such as time series plots, histograms, and box plots. In addition to using data for modeling purposes, a variety of statistical analyses can be used. These are discussed in the following sections.

### 14.3.1 Statistical Analyses

The following sections present several statistical methods commonly used in water quality impairment studies.

#### 14.3.1.1 Statistical Rollback Method

The statistical rollback method (Ott, 1995) will be used to establish bacteria reduction targets for stream segments. The rollback method simply compares monitoring data to standards, and the difference is the percentage change needed to meet the standards.
The method is applied by Ecology in other bacteria TMDL and water quality impairment evaluations (Cusimano and Giglio, 1995; Pelletier and Seiders, 2000; Joy, 2000; Coots, 2002; Joy and Swanson, 2005; Swanson, 2009).

Ideally, at least 20 samples taken throughout the year are needed from a broad range of hydrologic conditions to determine an annual bacteria distribution. If bacteria sources vary significantly by season and create distinct critical conditions, seasonal targets may be required. Fewer data provide less confidence in bacteria reduction targets, but the rollback method is robust enough to provide pollutant allocations and targets for planning implementation measures using smaller data sets. Compliance with the most restrictive of the dual bacteria standard criteria determines the bacteria reduction needed at a stream sampling site. The rollback method is applied as follows:

> *The geometric mean (approximate median in a log-normal distribution) and 90$^{th}$ percentile statistics are calculated and compared to the water quality bacteria criteria. If one or both do not meet the criteria, the whole distribution is "rolled-back" to match the more restrictive of the two criteria. The 90$^{th}$ percentile criterion usually is the most restrictive.*

The rolled-back geometric mean or 90$^{th}$ percentile bacteria value then becomes the recommended *target* bacteria value for the site. The term *target* is used to distinguish these estimated numbers from the actual water quality criteria. The degree to which the distribution of bacteria counts is *rolled-back* to the target value represents the estimated percent of bacteria reduction required to meet the bacteria water quality criteria and standards.

The bacteria targets are only in place to assist water quality managers in assessing the progress toward compliance with the bacteria water quality criteria. Compliance is ultimately measured as meeting both parts of the water quality standards criteria. Any water body with bacteria targets is expected to:

- Meet both the applicable geometric mean and "not more than 10% of the samples" criteria.
- Protect designated uses for the category.

#### 14.3.1.2 Analysis of Distribution

The Shapiro-Wilk test will be used to determine whether data are normally distributed. The Shapiro-Wilk test is one of the most powerful tests available for detecting departures from a hypothesized normal distribution for data sets less than or equal to 50. A rejection of the null hypothesis indicates that the distribution of the data is significantly different than that of a normal distribution.

The null-hypothesis of the Shapiro-Wilk Normality Test is that the population is normally distributed. The null hypothesis is rejected if the *p*-value is less than the chosen alpha level (0.05). If the *p*-value is less than the chosen alpha level, the data are not normally distributed. If the *p*-value is greater than 0.05, the null hypothesis that the data came from a normally distributed population cannot be rejected. Because the test is biased by sample size, a Q–Q plot is required for verification, in addition to the test.

All data will be $\log_{10}$ transformed before the test unless otherwise stated.

> $H_0$ = data come from a normal distribution
> $H_a$ = data do not come from a normal distribution

If the p-value is below the significance threshold (typically 0.05), then the null hypothesis is rejected and the alternative hypothesis is accepted.

#### 14.3.1.3 Load Duration Curve

Hydrologists commonly characterize stream values, such as flow and load, using a duration curve, which is the percentage of time during which the value of a given parameter is equaled or exceeded. Discharge rates are typically sorted from the highest value to the lowest. Using this convention, flow duration intervals are defined and expressed as a percentage, with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 corresponding to the lowest (i.e., drought conditions) (Cleland, 2002).

Load duration curves (LDC) will be used to incorporate the assimilative capacity of the watershed as a function of flow and allows for the maximum allowable loading to vary with flow conditions (Cleland, 2002). LDC is a useful tool for characterizing the pollutant problems over the entire flow regime. LDC will assess bacteria, whereas temperature and DO will not be assessed using LDC due to limits in it application. To assess flow conditions when water quality criteria are not met, LDC analysis involves using:

- Measured or estimated/modeled flow data.
- Water quality criteria.
- Concentration/load data.

Bacteria load reductions will be estimated for each monitoring station by calculating the percent reduction and using the difference between the existing loading and the LDC.

The development of LDC requires the development of flow duration curves. Flow duration curves will be developed at each fixed-network monitoring location (Studley, 2001). Regression analysis will be used to assess the relationship between the USGS continuous discharge data and discharge measurements from all other instantaneous sampling locations. Pollutant loads are the product of two constituents: water quality sample concentrations such as bacteria and stream discharge.

LDC will be useful to characterize water quality and provide a visual display to better present the problem and TMDL targets. LDC and instantaneous discharge measurements will be used to estimate total bacteria loads and unit bacteria loads. Total loads will characterize annual and seasonal results. Unit loads will be used to estimate daily and storm results. As a result, the expected duration or percentage of time of load in any given year will be estimated.

#### 14.3.1.4 Beales Loading Estimate

Beales ratio estimator from *Principles of Surface Water Quality Modeling and Control* by Thomann and Mueller (1987) provides a mass loading rate estimate of a pollutant. The formula for the unbiased stratified ratio estimator is used when continuous flow data are available for sites with less frequent pollutant sample data. The average load is then:

$$\bar{W}_p = \bar{Q}_p \cdot \frac{\bar{W}_c}{\bar{Q}_c} \cdot \left[ \frac{1 + \left(\frac{1}{n}\right) \cdot \left( \frac{S_{QW}}{\bar{Q}_c \, \bar{W}_c} \right)}{1 + \left(\frac{1}{n}\right) \cdot \left( \frac{S_Q^2}{\bar{Q}_c^2} \right)} \right]$$

where,

$W_p$ is the estimated average load for the period,
*p* is the period,
$Q_p$ is the mean flow for the period,
$W_c$ is the mean daily loading for the days on which pollutant samples were collected,
$Q_c$ is the mean daily flow for days when samples were collected,
*n* is the number of days when pollutant samples were collected.

Also,

$$S_{QW} = \left[\frac{1}{n-1}\right] * \left[ \left(\sum_{i=1}^{n} Q_{ci} * W_{ci}\right) - n * \overline{W_c Q_c} \right]$$

$$S^2{}_Q = \left[\frac{1}{n-1}\right] * \left[ \left(\sum_{i=1}^{n} Q_{ci}{}^2\right) - n * \bar{Q}_c^2 \right]$$

where,

$Q_{ci}$ are the individually measured flows, and
$W_{ci}$ is the daily loading for the day the pollutant samples were collected.

#### 14.3.1.5 The Simple Method to Calculate Urban Stormwater Bactera Loads

The Simple Method Model (Schueler, 1987) is a land-use-based approach used to estimate the relative contribution of point and nonpoint sources to bacteria loads in stormwater runoff in the study area. The model uses estimates of drainage area, impervious cover, stormwater runoff bacteria concentrations, and annual precipitation. Point-source wasteload allocations are assigned to areas with residential, commercial, industrial, and state-roadway land use. Nonpoint-source load allocations are assigned to areas with forest land use. The agricultural and rural land use will be divided between load allocation and wasteload allocation.

The following process estimates contribution from sources during precipitation-driven conditions:

1. Perform GIS analysis on land-use types above the monitoring sites using satellite imagery.
2. For each land use, calculate relative stormwater bacteria loads from nonpoint and point sources with a 10% margin of safety using the Simple Method Model.

3. Based on the proportional contributions to stormwater bacteria loads, assign load allocations for nonpoint sources and specific wasteload allocations for the point sources.

The Simple Method (CWP 2005) uses available data and assumptions to approximate the seasonal number of bacteria discharged in stormwater from different land use areas within the watershed. Estimated percentage of total bacteria loading ('loading proportion') is then computed for each land use category. This provides a relative contribution of stormwater bacteria loads from point sources based on the land use (type and area) covered under each jurisdiction. The Washington State Department of Transportation (WSDOT) wasteload allocations were based on the respective road areas in each watershed sub area.

#### 14.3.1.6 Statistical tests for significant changes between stations

The Wilcoxon signed rank test is a non-parametric statistical test used to determine whether the median difference between paired observations is equal to zero. The Wilcoxon signed rank test is used to determine if a significant change in streamflow or bacteria concentrations occurred between two stations.

The parametric paired T-test may also be used, provided both data sets fit a normal or log-normal distribution.

## 14.4 Sampling Design Evaluation

The project manager will decide whether (1) the data package meets the MQOs, and criteria for completeness, representativeness, and comparability and (2) meaningful conclusions (with enough statistical power) can be drawn from summary statistics. If so, the sampling design will be considered effective.

### 14.4.1 Modeling and Analysis Design Evaluation

The sampling design is based on the data needs of the modeling and analytical tools that will be used to complete the analysis. The combination of data collected and existing data are expected to be sufficient for the selected modeling tools. The process of using the data to develop and calibrate the model(s) will implicitly involve the evaluation of the sampling design. Compliance with this QAPP helps ensure that these modeling tools, used with data collected during this project and existing data, will be satisfactory to meet project goals and objectives. The success of the data collection design used by modeling will be assessed as part of the quality assessment for the model.

The project team will prepare written documentation addressing the calibrated model's ability to meet the project goals and objectives included in the final report. If a model falls short of fully meeting goals and objectives, the project team will conduct a thorough review of the problem and potential corrective actions (e.g., by collecting additional data or modifying model code, and providing them to the client and appropriate managers). The project team will also provide an analysis of the degree to which any model that does not fully meet acceptance criteria might still be useful for addressing study questions.

The project team will determine appropriate uses of the model on the basis of an assessment of the types of decisions to be made, model performance, and available resources.

If the project team determines that the quality of the model is insufficient to address the project goal and study objectives, the project team will consult with peers, experts, and partners (from Ecology, EPA, and other team members) as appropriate. This will involve the levels of uncertainty present in the models, which user requirements can be met, and any actions needed to address the issue.

A detailed evaluation of the ability of the modeling tools to meet user requirements will be provided in either the final report or the technical memo, which may ultimately be included as an appendix to the final report.

## 14.5 Documentation of Assessment

In the final report or memo, the project manager will include a summary and detailed description of the data quality assessment and model quality evaluation findings. This summary is usually included in the Data Quality section of reports. The final report will also provide results of the data analysis, uncertainty analysis, and margin of safety.

# 15.0 References

Adams, K., 2010. Quality Assurance Monitoring Plan: Ambient Biological Monitoring in Rivers and Streams: Benthic Macroinvertebrates and Periphyton. Washington State Department of Ecology, Olympia, WA. Publication No. 10-03-109. https://fortress.wa.gov/ecy/publications/SummaryPages/1003109.html

Anderson, P. and T. Swanson, 2014. Standard Procedures for Turner Designs Cyclops-7 Submersible Optical Brightener Sensors and Precision Measurement Engineering, Inc. Cyclops-7 Loggers, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP091. Published SOPs

American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), 2012. Standard Methods for the Examination of Water and Wastewater; 22nd Edition; American Public Health Association, Washington, D.C.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling, 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, 33399 Washington, D.C.

Bilhimer. D., A. Stohr, and S. Brock, 2013. Standard Operating Procedure for Continuous Temperature Monitoring of Fresh Water Rivers and Streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature. Version 3.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP044. Published SOPs

Burks, T.W., 2009. Standard Operating Procedure for the Operation of SonTek® FlowTracker® Handheld ADV®. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP058. Published SOPs

Carroll, J., 2012. Standard Operating Procedure for Time-of-Travel Studies in Freshwater Using a Dye Tracer, Version 2.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP037. Published SOPs

Casola, J.H., J.E. Kay, A.K. Snover, R.A. Norheim, L.C. Whitely Binder, and the Climate Impacts Group, 2005. Climate Impacts on Washington's Hydropower, Water Supply, Forests, Fish, and Agriculture. A report prepared for King County (Washington) by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle).

Chapra, S.C., 1997. Surface Water-Quality Modeling. McGraw-Hill, New York, N.Y.

Chapra, S.C. and G.J. Pelletier, 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Department, Tufts University, Medford, MA.

Chapra, S.C., G.J. Pelletier, and H. Tao, 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.,

Chen, Y.D., 1996. Hydrologic and water quality modeling for aquatic ecosystem protection and restoration in forest watersheds: a case study of stream temperature in the Upper Grande Ronde River, Oregon. PhD dissertation. University of Georgia, Athens, GA.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter, 1998a. Stream temperature simulation of forested riparian areas: I. watershed-scale model development. Journal of Environmental Engineering. April 1998. pp. 304-315.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter, 1998b. Stream temperature simulation of forested riparian areas: II. model application. Journal of Environmental Engineering. April 1998. pp. 316-328.

Cleland, B., 2002. TMDL Development from the "Bottom Up" – Part II: Using Duration Curves to Connect the Pieces. America's Clean Water Foundation, Washington, DC 20002. www.tmdls.net/tipstools/docs/BottomUp.pdf

Collyard, S. and P. Anderson, 2014. North Ocean Beaches Fecal Coliform Bacteria Source Investigation Study, Water Quality Study Design. Washington State Department of Ecology, Olympia, WA. Publication No. 14-03-108. https://fortress.wa.gov/ecy/publications/SummaryPages/1403108.html

Coots, R., 2002. Colville River FC Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-036. https://fortress.wa.gov/ecy/publications/SummaryPages/0203036.html

CREM (Council for Regulatory Environmental Modeling), 2009. Guidance on the Development, Evaluation, and Application of Environmental Models. EPA/100/K-09/003. Office of the Science Advisor, Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington, DC.

Cusimano, R. and D. Giglio, 1995. Salmon Creek Nonpoint Source Pollution TMDL. Washington State Department of Ecology, Olympia, WA. Publication No. 95-355. https://fortress.wa.gov/ecy/publications/SummaryPages/95355.html

Dugger, D. and W. Ward, 2015. Standard Operating Procedures for Instantaneous Measurements of Temperature in Water, Version 1.2. Washington State Department of Ecology, Olympia, WA. SOP Number EAP 011. Published SOPs

Ecology, 2003a. Shade.xls - a tool for estimating shade from riparian vegetation. Washington State Department of Ecology, Olympia, WA. Models and Tools.

Ecology, 2003b. QUAL2Kw.xls - A Diurnal Model of Water Quality for Steady Flow Conditions. Washington State Department of Ecology, Olympia, WA. Models and Tools.

Ecology, 2007. Water Quality Program Guidance Manual: Implementing Washington State Temperature Standards through TMDLs and NPDES Permits. Washington State Department of Ecology, Olympia, WA. Updated October 2010. Publication No. 06-10-100. https://fortress.wa.gov/ecy/publications/summarypages/0610100.html

Ecology, 2016a. Permits – Point Source Pollution. Water Quality Program, Washington State Department of Ecology, Olympia, WA. https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-quality-permits

Ecology, 2016b. Standard Operating Procedures. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Published SOPs

EPA, 1997. Compendium of Tools for Watershed Assessment and TMDL Development. U.S. Environmental Protection Agency, Office of Water, Washington D.C. EPA 841-B-97-006.

EPA, 2000. BASINS Technical Note 6. Estimating Hydrology and Hydraulic Parameters for HSPF. U.S. Environmental Protection Agency, Office of Water 4305. Publication No. EPA-823-R00-012. http://water.epa.gov/scitech/datait/models/basins/upload/2000_08_14_BASINS_tecnote6.pdf

EPA, 2002a. Guidance on Environmental Data Verification and Data Validation. EPA QA/G-8. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, D.C. EPA/240/R-02/004.

EPA, 2002b. Guidance for Quality Assurance Project Plans for Modeling. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, D.C. EPA/240/R-02/007.

EPA, 2003. Region 10 Guidance for Pacific Northwest State and Tribal Temperature. http://yosemite.epa.gov/r10/water.nsf/Water+Quality+Standards/WQS+Temperature+Guidance/

EPA, 2009. Water Quality Analysis Simulation Program (WASP). Version 7.4 Release Notes. Watershed and Water Quality Modeling Technical Support Center. U.S. Environmental Protection Agency. Athens, Georgia. www.epa.gov/athens/wwqtsc/html/wasp.html

EPA, 2015. Science and Technology Policy Council Peer Review Handbook, 4th Edition. Washington, D.C. https://www.epa.gov/sites/production/files/2015-10/documents/epa_peer_review_handbook_4th_edition_october_2015.pdf

Gries, T., 2017. Standard Operating Procedures for Use of Non-detect Environmental Data, Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP093. Published SOPs

Hambrook Berkman, J.A. and Canova, M.G., 2007. Algal biomass indicators (ver. 1.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, section 7.4. http://pubs.water.usgs.gov/twri9A/

Hamlet A.F. and D.P. Lettenmaier, 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. Journal of the American Water Resources Association, 35(6):1597-1623.

Hartel, P.G., K. Rodgers, G.L. Moody, S.N.J. Hemmings, J.A. Fisher, and J.L. McDonald, 2008. Combining Targeted Sampling and Fluorometry to Identify Human Fecal Contamination in a Freshwater Creek. Journal of Water and Health 6(1): 105-116. http://www.ncbi.nlm.nih.gov/pubmed/17998611

Hayslip, G.A. (Ed.), 1993. EPA Region 10 In-Stream Biological Monitoring Handbook: for Wadable Streams in the Pacific Northwest. U.S. Environmental Protection Agency, Region 10, Environmental Services Division, Seattle, WA. 75 pp.

Hobbs, W. and M. Friese, 2016. Wenatchee River PCB and DDT Source Assessment. Washington State Department of Ecology, Olympia, WA. Publication No. 16-03-029. https://fortress.wa.gov/ecy/publications/summarypages/1603029.html

Hobson A.J., B.T. Neilson, N. von Stackelberg, M. Shypryt, J, Ostermiller, G. Pelletier and S.C. Chapra, 2014. Development of a Minimalistic Data Collection Strategy for QUAL2Kw. Journal of Water Resources Planning and Management. 04014096(13).

Joy, J., 2000. Lower Nooksack River Basin Bacteria TMDL Evaluation. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-006. https://fortress.wa.gov/ecy/publications/SummaryPages/0003006.html

Joy, J., 2006. Standard Operating Procedure for Grab sampling – Fresh water, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP015. Published SOPs

Joy, J. and T. Swanson, 2005. Walla Walla River Basin Fecal Coliform Bacteria TMDL. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-041. https://fortress.wa.gov/ecy/publications/SummaryPages/0503041.html

Kilpatrick, F.A. and J.F. Wilson Jr., 1982. Measurement of Time-Of-Travel in Streams by Dye Tracing. U.S. Geological Survey. Techniques of Water-Resources Investigations, Book 3, Chapter A9.

Lombard, S. and C. Kirchmer, 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html

Mantua, N.J., I. Tohver, and A.F. Hamlet, 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102(1-2): 187-223.

Marti, P.B., 2009. Standard Operating Procedure for Manual Well-Depth and Depth-to-Water Measurements. Washington State Department of Ecology, Olympia, WA. SOP Number EAP052. Published SOPs

Mathieu, N., 2006. Replicate Precision for Twelve Total Maximum Daily Load (TMDL) Studies and Recommendations for Precision Measurement Quality Objectives for Water Quality Parameters. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-044. https://fortress.wa.gov/ecy/publications/SummaryPages/0603044.html

Mathieu, N., 2013. Standard Operating Procedure for Measuring Vertically Averaged salinity in Brackish Waters, Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP075. Published SOPs

Mathieu, N., 2016a. Standard Operating Procedure for Measuring Streamflow for Water Quality Studies, Version 3.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP024. Published SOPs

Mathieu, N., 2016b. Standard Operating Procedures for the Collection of Periphyton Samples for TMDL Studies, Version 1.1. Washington Department of Ecology, Olympia, WA. SOP Number EAP085. Published SOPs

Mathieu, N. and C. James, 2011. Puyallup River Watershed Fecal Coliform Total Maximum Daily Load. Washington State Department of Ecology, Olympia, WA. Publication No. 11-10-040. https://fortress.wa.gov/ecy/publications/documents/1110040.pdf

Mathieu, N., S. Collyard, and T. Mohamedali, 2011. Standard Operating Procedure for Collection of Periphyton Samples for TMDL studies. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP085. Published SOPs

Mauger, G.S. et al., 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA. 281 pp. https://cig.uw.edu/resources/special-reports/ps-sok/

MEL, 2016. Manchester Environmental Laboratory Lab Users Manual, 2016. http://teams/sites/EAP/manlab/LabUsers/LabUserDocs/Lab%20Manual%202016v10.pdf

Mote, P.W., E. Salathé, and C. Peacock, 2005. Scenarios of future climate for the Pacific Northwest, Climate Impacts Group, University of Washington, Seattle, WA. 13 pp.

Mote, P. et al., 2014. Ch. 21: Northwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, p. 487-513. http://nca2014.globalchange.gov/report/regions/northwest

Moyle, P.B., L.R. Brown, and B. Herbold, 1986. Final report on development and preliminary tests of indices of indices of biotic integrity for California. Final report to the U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

ODEQ, 2003. Heat Source Model Documentation. www.deq.state.or.us/wq/TMDLs/TMDLs.html and www.heatsource.info

Ott, W., 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

Parsons, J., 2001. Aquatic Plan Sampling Protocols. Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-017. https://fortress.wa.gov/ecy/publications/publications/0103017.pdf

Parsons J., D. Hallock, K. Seiders, B. Ward, C. Coffin, E. Newell, C. Deligeannis, and K. Welch, 2012. Standard Operating Procedure to Minimize the Spread of Invasive Species. Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP070. Published SOPs

Pelletier, G. and K. Seiders, 2000. Grays Harbor FC Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-020. https://fortress.wa.gov/ecy/publications/SummaryPages/0003020.html

Pelletier, G., 2009. YASAIw.xla – A modified version of an open source add-in for Excel to provide additional functions for Monte Carlo simulation. Washington State Department of Ecology, Olympia, WA. YASAIw.xla. Models and Tools.

Pelletier, G., S. Chapra, and H. Tao, 2006. QUAL2Kw – A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environmental Modelling and Software 21 (2006) 419-425.

Pelletier, G. and S. Chapra, 2008. QUAL2Kw theory and documentation (version 5.1) A modeling framework for simulating river and stream water quality. Washington State Department of Ecology, Olympia, WA.

Pelletier, G., 2013. RMA.xls – River metabolism analyzer for continuous monitoring data. Washington State Department of Ecology, Olympia, WA. Models and Tools.

Plotnikoff, R.W. and C. Wiseman, 2001. Benthic Macroinvertebrate Biological Monitoring Protocols for Rivers and Streams. Washington State Department of Ecology, Olympia, WA. https://fortress.wa.gov/ecy/publications/documents/0103028.pdf

RCW 90.48.575 Water quality data – definitions. Washington State Department of Ecology, Olympia, WA. http://apps.leg.wa.gov/rcw/default.aspx?cite=90.48.575

Reckhow, K.H., 1986. Statistical Goodness-of-Fit Measures for Waste Load Allocation Models. Work Assignment No. 33, EPA Contract No. 68-01-6904.

Reckhow, K.H. and S.C. Chapra, 1983. Engineering Approaches for Lake Management, Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers, Woburn, MA.

Roberts, M., 2015. Standard Operating Procedure for Benthic Flux Chambers, Version 1.2. Washington State Department of Ecology, Olympia, WA. SOP Number EAP036. Published SOPs

Sanderson, T. and P. Pickett, 2014. A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies. Washington State Department of Ecology, Olympia, WA. https://fortress.wa.gov/ecy/publications/documents/1403042.pdf

Sargeant, D. and J. Lowe, 2014. Quality Assurance Project Plan: Beach Environmental Assessment, Communication, and Health (BEACH) Program: Monitoring Washington State Marine Beaches. Washington State Department of Ecology, Olympia, WA. https://fortress.wa.gov/ecy/publications/documents/1403128.pdf

Shedd, J.R., C. Springer, and C.J. Clishe, 2013. Standard Operating Procedure of the Teledyne RD Instruments Stream-Pro Acoustic Doppler Current Profiler. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP055. Published SOPs

Shedd, J.R., 2014. Standard Operating Procedure for Measuring and Calculating Stream Discharge. Version 1.2. Washington State Department of Ecology, Olympia, WA. SOP Number EAP056. Published SOPs

Sinclair, K. and C. Pitz, 2010. Standard Operating Procedure for installing, measuring, and decommissioning hand-driven in-water piezometers. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP061. Published SOPs

Snouwaert, E. and T. Stuart, 2015. North Fork Palouse River Dissolved Oxygen and pH Total Maximum Daily Load. Washington State Department of Ecology. Olympia, WA. Publication No. 15-10-029. https://fortress.wa.gov/ecy/publications/documents/1510029.pdf

Snover, A.K. et al., 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle, WA. 128 p. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

Stohr, A., 2008. Standard Operating Procedures for the Computer Analysis of Hemispherical Digital Images Collected as Part of a Temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit Technical Study, Version 2.2. Washington State Department of Ecology, Olympia, WA. SOP Number EAP 046. Published SOPs

Stohr, A. and D. Bilhimer, 2008. Standard Operating Procedures for Hemispherical Digital Photography Field Surveys Conducted as Part of a Temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit Technical Study, Version 2.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP 045. Published SOPs

Stuart, T., 2012. Asotin Creek Straight-to-Implementation Vegetation Study. Washington Department of Ecology, Olympia, WA. Publication No. 12-03-014. https://fortress.wa.gov/ecy/publications/documents/1203014.pdf

Stuart, T. and N. Mathieu, 2015. Standard Operating Procedure for Collection of Longitudinal Stream Depth Profiles. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP096. Published SOPs

Studley, S., 2001. Estimated flow-duration curves for selected ungaged sites in Kansas. USGS Water-Resources Investigations Report: 2001-4142. http://pubs.er.usgs.gov/publication/wri014142

Swanson, T., 2007. Standard Operating Procedure for Hydrolab® DataSonde® and MiniSonde® Multiprobes, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP033. Published SOPs

Swanson, T., 2009. Quality Assurance Project Plan: Liberty Bay Tributaries FC Bacteria TMDL. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-102. https://fortress.wa.gov/ecy/publications/documents/0903102.pdf

Swanson, T., 2013. Standard Operating Procedure for Conducting Riparian Vegetation and Stream Channel Surveys in Wadeable Streams for Temperature TMDL studies. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP084. Published SOPs

Tavares, M.E., M.I.H. Spivey, M.R. McIver, and M.A. Mallin, 2008. Testing for Optical Brighteners and Fecal Bacteria to Detect Sewage Leaks in Tidal Creeks. Journal of the North Carolina Academy of Sciences 124(3): 91-97. http://uncw.edu/cms/aelab/Reports%20and%20Publications/2008/2008,NCAS,%20Optical%20Brighteners.pdf

Thomann, R.V. and J.A. Mueller, 1987. Principles of Surface Water Quality Modeling and Control. Harper and Row, Publishers, Inc., New York, NY.

US Department of Agriculture Forest Service and Washington State Department of Ecology. 2000. Memorandum of Agreement between the USDA Forest Service, Region 6 and the Washington State Department of Ecology for meeting responsibilities under federal and state water quality laws. Portland, Oregon.

WAC 173-201A, 2011. Water Quality Standards for Surface Waters in the State of Washington Washington State Department of Ecology, Olympia, WA. http://app.leg.wa.gov/WAC/default.aspx?cite=173

WAC 365-195-90, 2003. Criteria for including the best available science in developing policies and development regulations. Washington State Department of Ecology, Olympia, WA. http://apps.leg.wa.gov/wac/default.aspx?cite=365-195-915

Ward, W.J., 2011. Standard Operating Procedures for Continuous Temperature Monitoring of Fresh Water Rivers and Streams. Washington State Department of Ecology, Olympia, WA. SOP Number EAP080. Published SOPs

Ward W.J. and N. Mathieu, 2011a. Standard Operating Procedure for the Collection and Analysis of Dissolved Oxygen (Winkler Method). Version 2.3. Washington State Department of Ecology, Olympia, WA. SOP Number EAP023. Published SOPs

Ward, W.J. and N. Mathieu, 2011b. Standard Operating Procedures for the Collection of Fecal Coliform Bacteria Samples in Surface Water. Washington State Department of Ecology, Olympia, WA. SOP Number EAP030. Published SOPs

# 16.0 Appendices

# Appendix A. External QA/QC Information and Data Sources

As noted in Section 4.3, Table A-1 presents relevant external data sets useful and applicable for water quality impairment studies. This table also indicates if there is an established quality assurance (QA) or quality control (QC) program to ensure credible data sources. Website links to either QA/QC information or data sources, as noted, are provided.

**Table A-1.** Relevant external QA/QC information

| Organization | Data | Established QA/QC Program? | Accredited Laboratories, SOPs & Equipment? | QA/QC Documentation or Publications Readily Available? | Link to QA/QC Information (or data sources, as noted) |
|---|---|---|---|---|---|
| EPA: National Aquatic Surveys | water quality & biological | Yes | Yes | Yes | https://www.epa.gov/national-aquatic-resource-surveys/manuals-used-national-aquatic-resource-surveys |
| EPA: STORET Water quality, land use & legacy data | historical & current water quality & microbial database | Yes[1] | Yes | Yes | https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange |
| EPA: Air Quality System | meteorological & air quality data | Yes | Yes | No | Data Source: https://www.epa.gov/aqs/aqs-memos-quality-assurance-audits |
| NOAA | meteorological & bathymetry | Yes | Yes | Yes | http://www.cio.noaa.gov/services_programs/IQ_Guidelines_011812.html |
| AgWeatherNet (WA State Univ.) | meteorological | Yes | Yes | No | Data Source: http://www.weather.wsu.edu/ |
| MesoWest (Univ. of Utah) | meteorological | Yes | Yes | Yes | http://mesowest.utah.edu/html/help/qc.html |
| USGS | national water information system | Yes | Yes | No | Data Source: http://waterdata.usgs.gov/nwis |
| USGS | surface water/ streamflow & biological | Yes | Yes | Yes | https://www2.usgs.gov/datamanagement/qaqc.php<br>https://water.usgs.gov/owq/quality.html<br>http://pubs.usgs.gov/of/2007/1307/ |
| USGS | water resources spatial data | Yes | Yes | No | Data Source: http://water.usgs.gov/maps.html |
| USGS | Washington National Park Service | Yes | Yes | No | Data Sources:<br>https://water.usgs.gov/nps_partnership/noca.php<br>https://water.usgs.gov/nps_partnership/olym.php<br>https://water.usgs.gov/nps_partnership/mora.php |
| USDA | agricultural chemical discharge/ qualitative data | Yes | Unknown | No | Data Source: https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/ |
| USFS | stream temperature | Yes | Yes | Yes | https://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/resources.html |

| Organization | Data | Established QA/QC Program? | Accredited Laboratories, SOPs & Equipment? | QA/QC Documentation or Publications Readily Available? | Link to QA/QC Information (or data sources, as noted) |
|---|---|---|---|---|---|
| National Park Service | water quality & biological | Yes | Yes | Yes | https://www.nature.nps.gov/water/vitalsigns/vitalsignsdocs.cfm |
| Natural Resources Conservation Service Soils | soils | Yes | Yes | Yes | http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=stelprdb1247805 |
| NIST | calibration, standard reference material | Yes | Yes | Yes | https://www.nist.gov/nist-quality-system |
| WDNR | forest practices/land use data | Yes | Unknown | No | Data Source: http://www.dnr.wa.gov/programs-and-services/forest-practices/providing-gis-data-forest-practices-activities-throughout |
| WSDOT | stormwater monitoring | Yes | Yes | Yes | https://www.wsdot.wa.gov/Environment/WaterQuality/StormwaterMonitoring.htm |
| Snohomish County | surface, groundwater quality & flow data | Yes | Yes | Yes | http://snohomishcountywa.gov/Archive.aspx?AMID=73 |
| Spokane County | groundwater monitoring | Yes | Yes | Yes | https://www.spokanecounty.org/1285/Groundwater-Monitoring |
| King County | meteorological buoys | Yes | Yes | Yes | http://green2.kingcounty.gov/lake-buoy/parameters.aspx |
| King County | water quality, sediment, & flow | Yes | Yes | Yes | http://green2.kingcounty.gov/ScienceLibrary/default.aspx? http://www.kingcounty.gov/services/environment/watersheds/hic/About.aspx |
| King County | benthic & biological | Yes | Yes | Yes | http://www.kingcounty.gov/services/environment/data-and-trends/monitoring-data/stream-bugs/puget-sound-monitoring-tools/quality-assurance-project-plan.aspx |
| City of Seattle | stormwater | Yes | Unknown | No | Data Source: http://www.seattle.gov/util/Documents/Plans/StormwaterManagementPlan/index.htm |
| Pierce County | stormwater | Yes | Yes | No | Data Source: http://www.piercecountywa.org/index.aspx?NID=1851 |
| Pierce County | water quality & biological data | Yes | Yes | No | Data Source: http://www.co.pierce.wa.us/index.aspx?nid=1852 |
| Whatcom County | water quality data | Yes | Yes | Yes | http://www.whatcomcounty.us/2172/Resource-Library |

[1] Most of the current data submitters to EPA STORET database have established QA/QC programs, several of which are listed in this table. Some legacy data may not have been collected with a QA/QC program. Results should be evaluated at the study level, and the quality or lack of information should be discussed in the final report.

# Appendix B. Overview of Stream Heating Processes

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature within a particular segment of a stream are induced by the balance of the heat exchange between the water and the surrounding environment during transport through the segment. If there is more heat energy entering the water in a stream segment than there is leaving, the temperature will increase. If there is less heat energy entering the water in a stream segment than there is leaving, then the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer), and stream temperature change is outlined in Figure B-1.

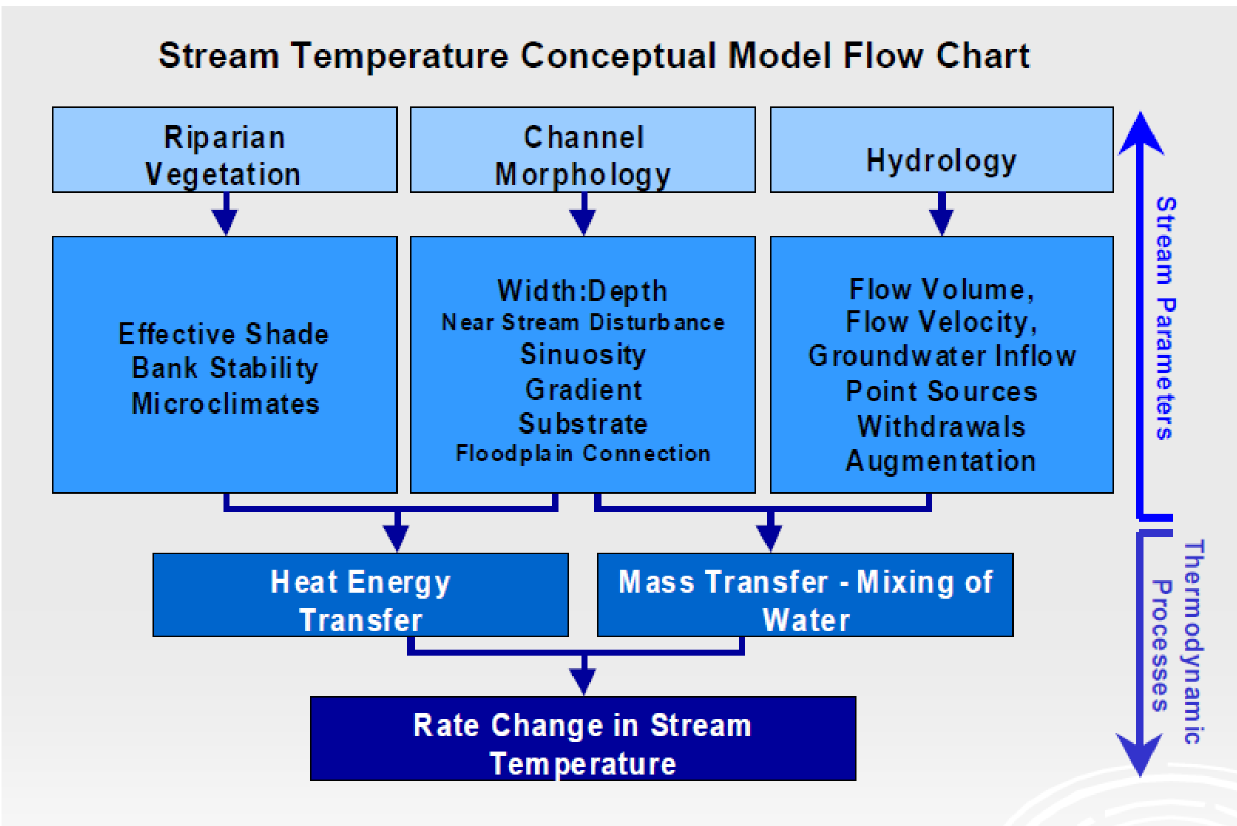


Figure B-1. Conceptual model of factors that affect stream temperature.

Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- **Stream depth.** Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- **Air temperature.** Daily average stream temperatures and daily average air temperatures are both highly influenced by incoming solar radiation (Johnson, 2004). When the sun is not shining, the temperature in a volume of water tends toward the dew-point temperature (Edinger et al., 1974).

- **Solar radiation and riparian vegetation.** The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- **Groundwater.** Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream and the difference in temperatures between the groundwater and the stream.

Water temperature can also be strongly affected by tributaries and human discharges, depending on their temperature. In lakes and reservoirs, water temperatures can be affected by thermal stratification and wind.

## Heat budgets and temperature prediction

Heat exchange processes occur between the water body and the surrounding environment, and these processes control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure B-2 shows the major heat energy processes or fluxes across the water surface or streambed.

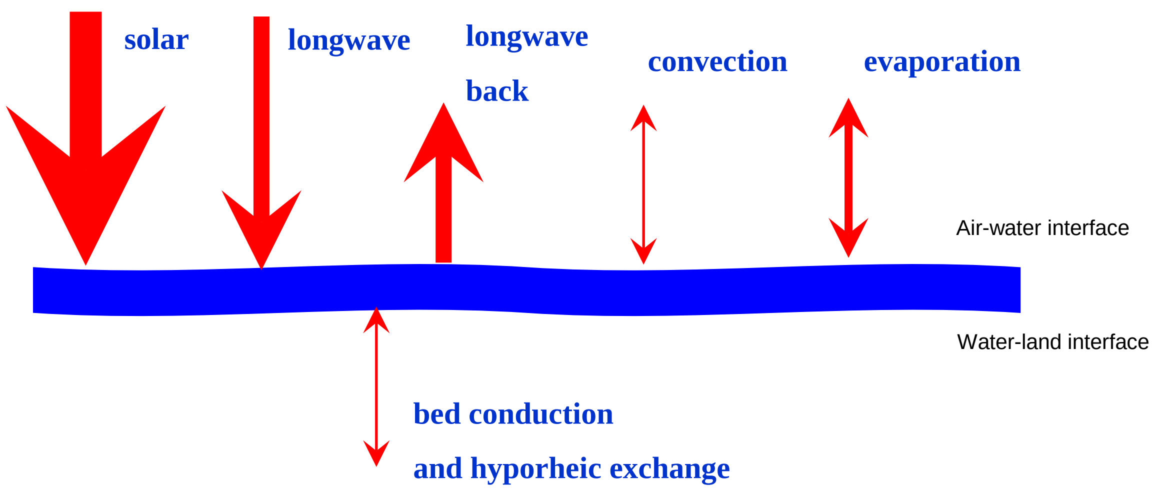


Figure B-2. Surface heat exchange processes that affect water temperature

(net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed). Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- **Shortwave solar radiation**. Shortwave solar radiation is the radiant energy which passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range between 0.14 and 4 um.

  [Example text: At MesoWest's Liberty weather station on Swauk Creek, the daily average global shortwave solar radiation for July-August 2005 was 318 W/m$^2$. ***OR*** At Washington State University's (WSU) TreeForest Research and Extension Center (TFREC) station in Wenatchee, the daily average global shortwave solar radiation for August 2002 was 259 W/m2. At the University of Washington Atmospheric Sciences building roof in Seattle, the daily average global shortwave solar radiation for July-August 2001 was 240 W/m$_2$ (NOAA, 2003).]

  The peak values during daylight hours are typically about 3 times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear. Solar exposure was identified as the most influential factor in stream heating processes (Sinokrot and Stefan, 1993; Johnson and Jones; 2000; Danehy et al., 2005).

- **Longwave atmospheric radiation.** The longwave radiation from the atmosphere ranges in wavelength from about 4 to 120 um. Longwave atmospheric radiation depends primarily on air temperature and humidity, and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m$^2$ at mid latitudes (Edinger et al., 1974).

  [Example text: NOAA's Integrated Surface Irradiance Study (ISIS) station in Seattle measures longwave radiation.]

- **Longwave back radiation from the water to the atmosphere.** Water sends heat energy back to the atmosphere in the form of longwave radiation in the wavelength range from about 4 to 120 um. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m$^2$ (Edinger et al., 1974).

The remaining heat exchange processes generally have less magnitude and are as follows:

- **Evaporation flux at the air-water interface** is influenced mostly by wind speed and the vapor pressure gradient between the water surface and the air. When the air is saturated, the evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation, the reversal of evaporation takes place; this term then becomes a gain component in the heat balance.
- **Convection flux at the air-water interface** is driven by the temperature difference between water and air and by wind speed. Heat is transferred in the direction of decreasing temperature.

- **Streambed conduction flux and hyporheic exchange** component of the heat budget represents the heat exchange through conduction between the bed and the water body and the influence of hyporheic exchange. The magnitude of streambed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher. This heat transfer usually affects the temperature diel profile, rather than the magnitude of the maximum daily water temperature.

  Hyporheic exchange can be an important mechanism for stream cooling in some basins (Johnson and Jones, 2000, Poole and Berman, 2000, Johnson, 2004). The hyporheic zone is defined as the region of saturated substrate located beneath the channel characterized by complex hydrodynamic processes that combine stream water and groundwater. The resulting fluxes can have significant implications for stream temperature at different spatial and temporal scales. For example, studies in the Walla Walla River in Oregon have shown water temperatures declining downstream in section of the river as hyporheic interstitial flow cools in a riffle reach and then remixes into the stream in a pool reach.

*(Replace Figure B-3 and B-4 and corresponding text with graphs and language specific to the study watershed, if that information is available, to show shaded/unshaded reaches and heat budget.)*

Figures B-3 and B-4 show surface heat flux in a relatively unshaded stream reach and in a more heavily shaded stream reach, respectively.

Figure B-3 shows an example of the estimated diurnal pattern of the surface heat fluxes in one of Washington's coastal rivers for the week of August 8-14, 2001. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar shortwave heat flux (Adams and Sullivan, 1989). The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream.

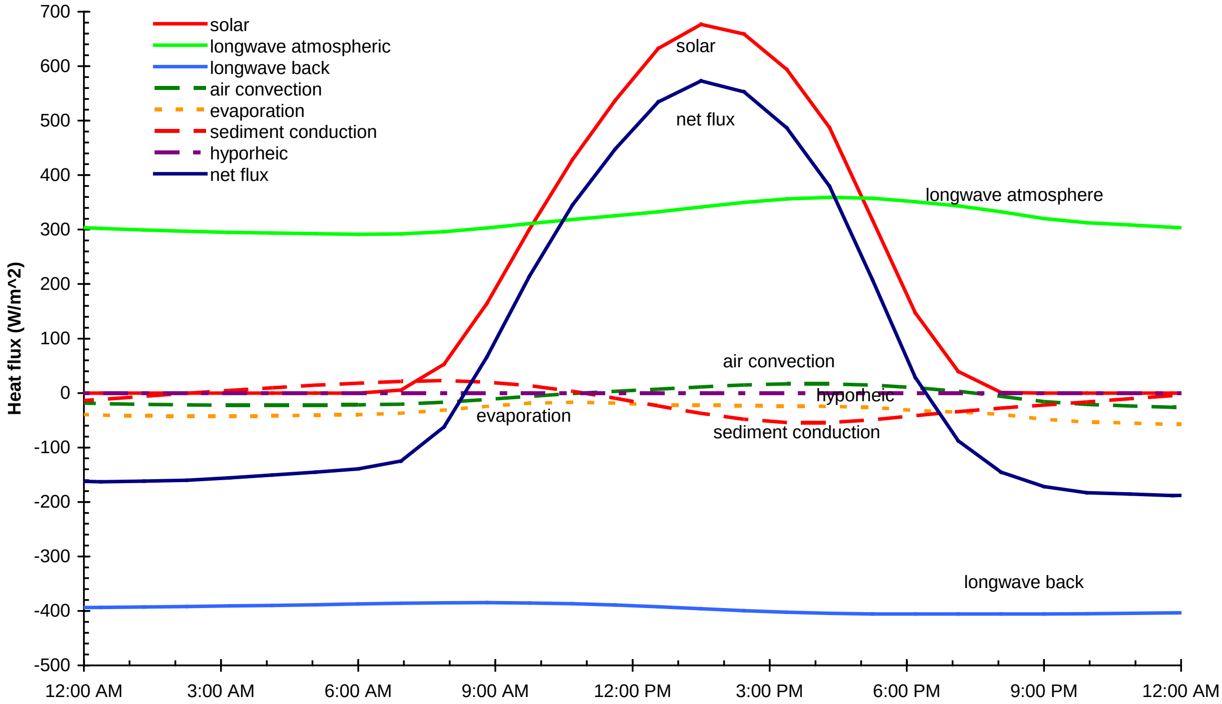


Figure B-3. Estimated heat fluxes in a river during August 8-14, 2001.

(net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Figure B-4 shows an example of the estimated diurnal pattern of the surface heat fluxes in a more heavily shaded location in the same river. Shade that is produced by riparian vegetation or topography can reduce the solar shortwave flux. Other processes – such as longwave radiation, convection, evaporation, bed conduction, or hyporheic exchange – also influence the net heat flux into or out of a stream.

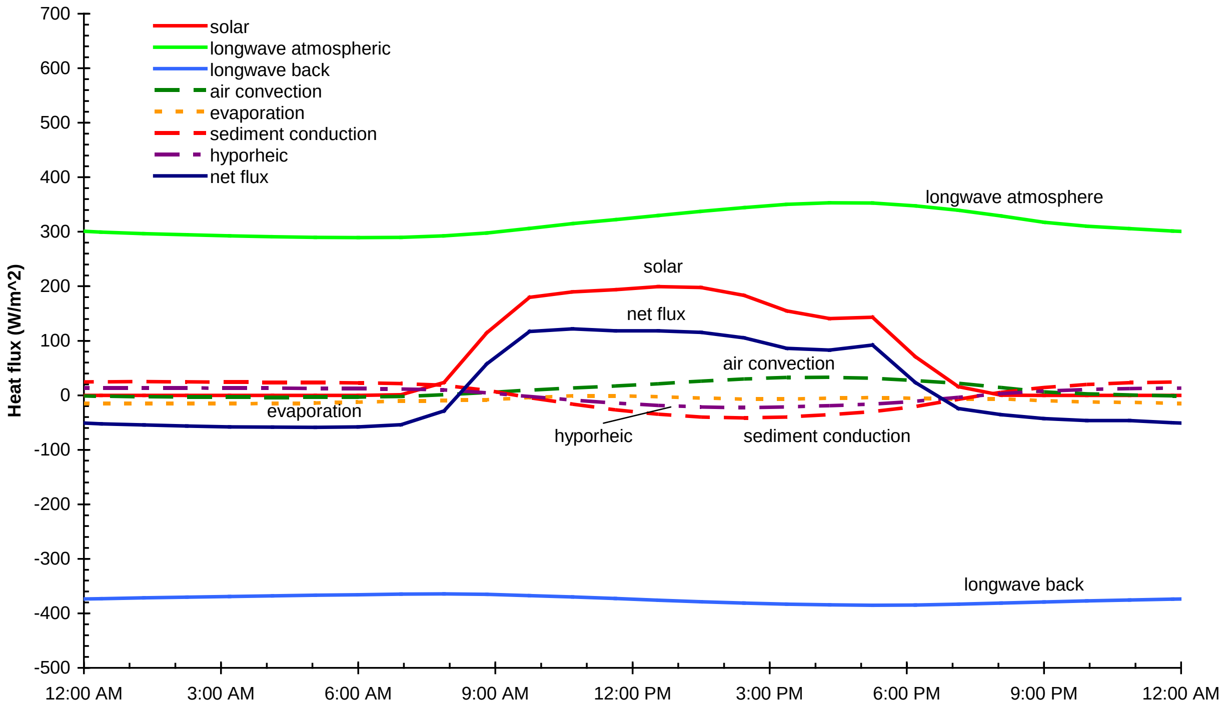


Figure B-4. Estimated heat fluxes in a more shaded section of a river during August 8-14, 2001.

(net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Heat exchange between the stream and the streambed has an important influence on water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the day (Figure B-5). Heat is typically transferred from the water into the streambed during the day, then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

*(Insert graph, if available, of surface and piezometer temperatures for specific study basin)*

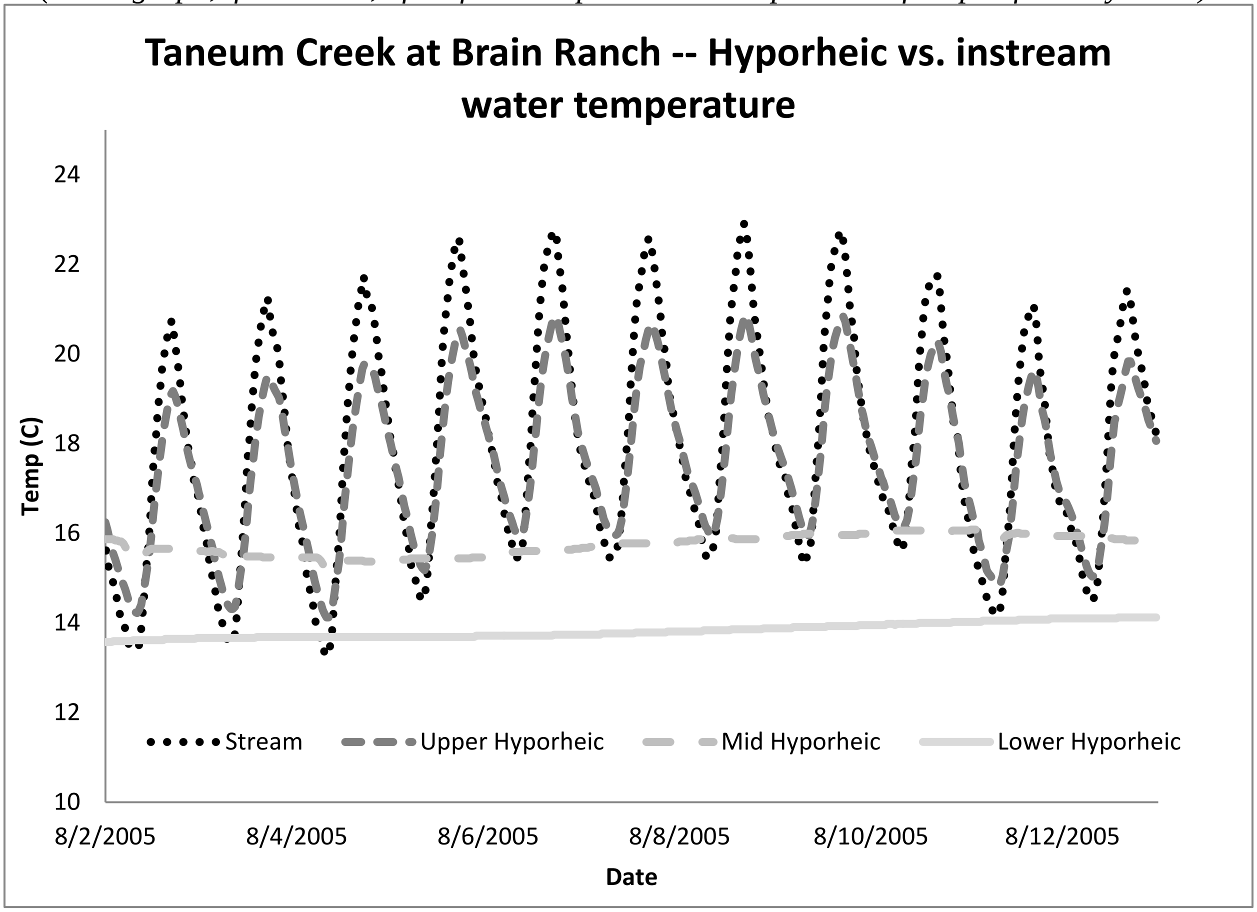


Figure B-5. Water and streambed temperatures in early August 2005 in Taneum Creek at Brain Ranch (station 39TAN-04.0).

The bulk temperature of a vertically mixed volume of water in a stream segment under natural conditions tends to increase or decrease with time during the day according to whether the net heat flux is either positive or negative. When the sun is not shining, the water temperature tends toward the dew-point temperature (Edinger et al., 1974; Brady et al., 1969). The equilibrium temperature of a natural body of water is defined as the temperature at which the water is in equilibrium with its surrounding environment and the net rate of surface heat exchange would be zero (Edinger et al., 1968; 1974).

The dominant contribution to the seasonal variations in the equilibrium temperature of water is from seasonal variations in the dew-point temperature (Edinger et al., 1974). The main source of hourly fluctuations in water temperature during the day is solar radiation. Solar radiation generally reaches a maximum during the day when the sun is highest in the sky unless cloud cover or shade from vegetation interferes.

The complete heat budget for a stream also accounts for the mass transfer processes which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a segment of a stream. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries, human discharges and withdrawals, and groundwater inflows and outflows. Mass transfer relates to transport of flow volume downstream, instream mixing, and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water.

## Thermal role of riparian vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (e.g., Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patrick, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in direct, unobstructed solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al., 1992; Beschta et al., 1987; Bolton and Monahan, 2001; Castelle and Johnson, 2000; CH2M Hill, 2000; GEI, 2002; Ice, 2001; and Wenger, 1999. All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. Important benefits that riparian vegetation has upon the stream temperature include:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Channel morphology can be strongly affected by near-stream vegetation. Specifically, stream vegetation is often part of human impacts on land-cover type and condition, which can affect flood plain and instream roughness, the contribution of coarse woody debris, sedimentation, stream substrate composition, and stream bank stability.

Although the warming of water temperatures as a streamflows downstream can be a natural process, the rates of heating can be dramatically lower when high levels of shade exist and heat flux from solar radiation is minimized. There is a natural maximum potential level of vegetation and associated shade that a given stream is capable of attaining in an undisturbed situation. In general, the importance of shade decreases as the width of a stream increases.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

## Effective shade

Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al., 1998; Ice, 2001; OWEB, 1999; Teti, 2001; Teti and Pike, 2005). Effective shade is defined as the fraction or percentage of the total possible solar radiation heat energy that is prevented from reaching the surface of the water:

$$\text{effective shade} = (J_1 – J_2)/J_1$$

where $J_1$ is the potential solar heat flux above the influence of riparian vegetation and topography, and $J_2$ is the solar heat flux at the stream surface.

Canopy cover is the percent of sky covered by vegetation and topography at a given point. Shade is influenced by cover but changes throughout each day, as the position of sun changes spatially and temporally with respect to the canopy cover (Kelley and Krueger, 2005).

In the Northern Hemisphere, the earth tilts on its axis toward the sun during the summer, allowing longer day length and higher solar altitude. Both are functions of solar declination, a measure of the earth's tilt toward the sun (Figure B-6). Latitude and longitude positions fix the stream to a position on the globe, while aspect provides the direction of streamflow. Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation, producing shade (Table B-1). The solar position has a vertical component – solar altitude – and a horizontal component – solar azimuth – that are both functions of time, date, and the earth's rotation.

While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, including (Ice, 2001; OWEB, 1999; Boyd, 1996; Teti, 2001; Teti and Pike, 2005):

- Hemispherical photography
- Angular canopy densiometer
- Solar pathfinder

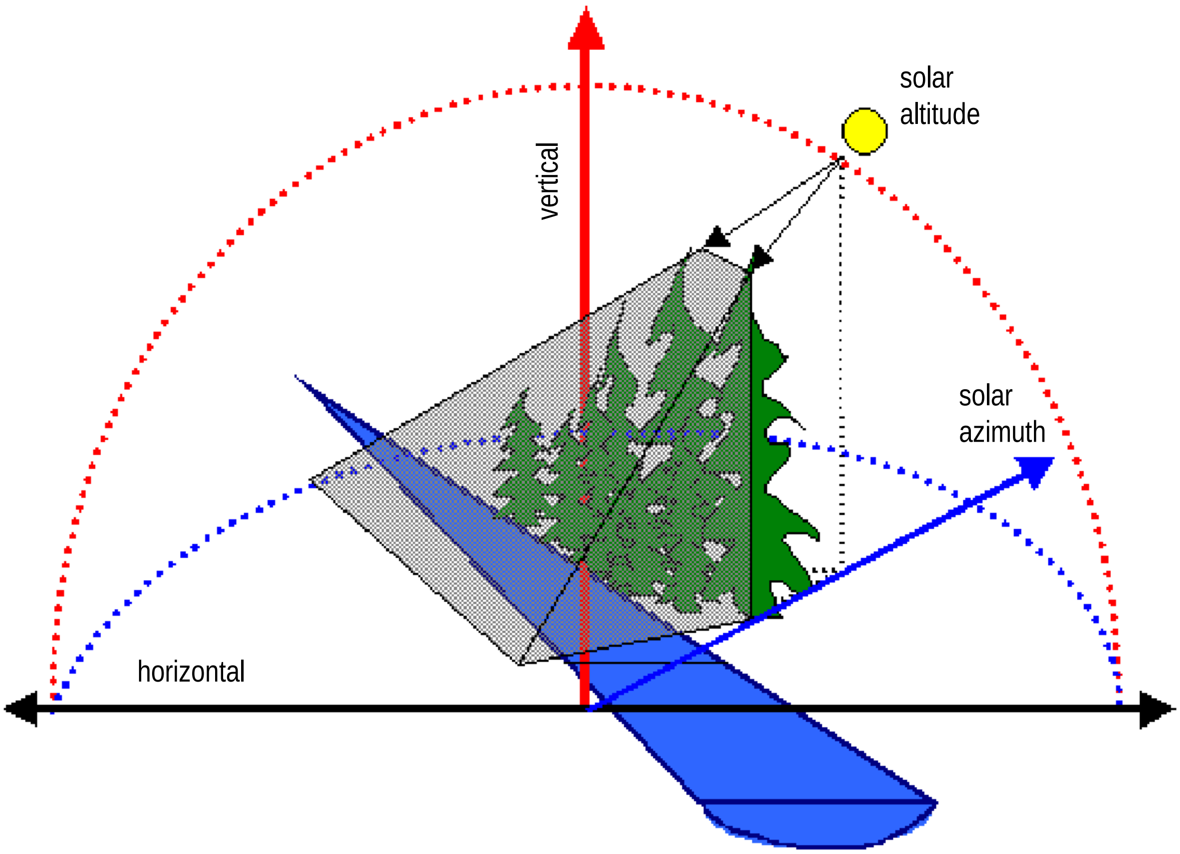


Figure B-6. Parameters that affect shade and geometric relationships. *Solar altitude* is a measure of the vertical angle of the sun's position relative to the horizon. *Solar azimuth* is a measure of the horizontal angle of the sun's position relative to north. (Boyd and Kasper, 2003.)

Hemispherical photography is generally regarded as the most accurate method for measuring shade, although the equipment that is required is significantly more expensive compared with other methods. Angular canopy densiometers (ACD) and solar pathfinders provide a good balance of cost and accuracy for measuring the importance of riparian vegetation for preventing increases in stream temperature (Beschta et al., 1987; Teti, 2001, 2005). Whereas canopy density is usually expressed as a vertical projection of the canopy onto a horizontal surface, the ACD is a projection of the canopy measured at an angle above the horizon at which direct beam solar radiation passes through the canopy. This angle is typically determined by the position of the sun above the horizon during that portion of the day (usually between 10 AM and 2 PM in mid to late summer) when the potential solar heat flux is most significant. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80% to 90%.(Brazier and Brown, 1973; Steinblums et al., 1984).

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table B-1 (Ecology 2003; Chen, 1996; Chen et al., 1998; Boyd, 1996; Boyd and Park, 1998).

Table B-1. Factors that influence stream shade.

| Description | Parameter |
|---|---|
| Season/time | Date/time |
| Stream characteristics | Aspect, **channel width** |
| Geographic position | Latitude, longitude |
| Vegetative characteristics | **Riparian vegetation height, width, and density** |
| Solar position | Solar altitude, solar azimuth |

**Bold** indicates influenced by human activities.

## Riparian buffers and effective shade

Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown 1973; Steinblums et al., 1984). The shading effectiveness of riparian vegetation is correlated to riparian area width (Figure B-7). The shade as represented by angular canopy density (ACD) for a given riparian buffer width varies over space and time because of differences among site potential vegetation, forest development stages (e.g., height and density), and stream width. For example, a 50-foot-wide riparian area with fully developed trees could provide from 45% to 72% of the potential shade in the two studies shown in Figure B-7.

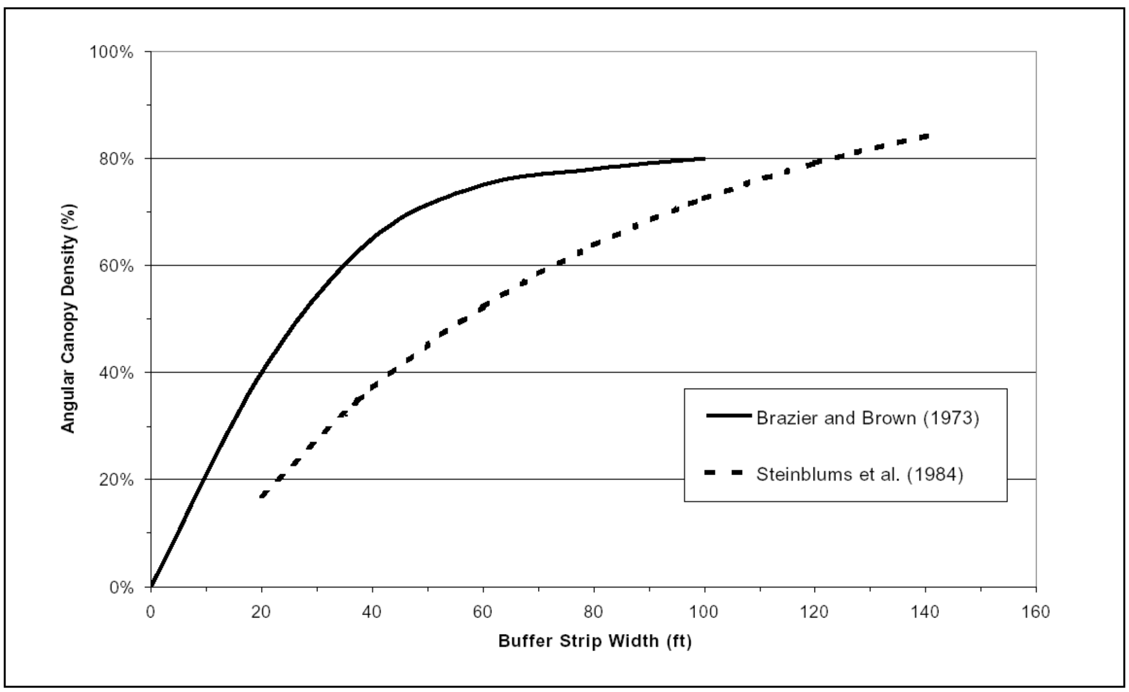


Figure B-7. Relationship between angular canopy density and riparian buffer width for small streams in old-growth riparian stands (after Beschta et al., 1987; and CH2M Hill, 2000).

The Brazier and Brown (1973) shade data show a stronger relationship between ACD and buffer strip width than the Steinblums et al. (1984) data: The $r^2$ correlation for ACD and buffer width was 0.87 and 0.61 in Brazier and Brown (1973) and Steinblums et al. (1984), respectively. This difference supports the use of the Brazier and Brown curve as a base for measuring shade effectiveness under various riparian buffer proposals. These results reflect the natural variation among old-growth sites studied, and show a possible range of potential shade.

Several studies of stream shading report that most of the potential shade comes from the riparian area within about 75 feet (23 m) of the channel (CH2M Hill, 2000; Castelle and Johnson, 2000):

- Beschta et al. (1987) report that a 98-foot-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-foot (24-m) buffer provides maximum shade to streams.
- Steinblums et al. (1984) concluded that a 56-foot (17-m) buffer provides 90% of the maximum ACD.
- Corbett and Lynch (1985) concluded that a 39-foot (12-m) buffer should adequately protect small streams from large temperature changes following logging.
- Broderson (1973) reported that a 49-foot-wide (15-m) buffer provides 85% of the maximum shade for small streams.
- Lynch et al. (1984) found that a 98-foot-wide (30-m) buffer maintains water temperatures within 2°F (1°C) of their former average temperature in small streams (channel width less than 3 m).

GEI (2002) reviewed the scientific literature related to the effectiveness of buffers for shade protection in agricultural areas in Washington and concluded that buffer widths of 10 m (33 feet) provide nearly 80% of the maximum potential shade in agricultural areas. Wenger (1999) concluded that a minimum continuous buffer width of 10-30 m should be preserved or restored along each side of all streams on a municipal or county-wide scale to provide stream temperature control and maintain aquatic habitat. GEI (2002) considered the recommendations of Wenger (1999) to be relevant for agricultural areas in Washington.

Steinblums et al. (1984) concluded that shade could be delivered to forest streams from beyond 75 feet (22 m) and potentially out to 140 feet (43 m). In some site-specific cases, forest practices between 75 and 140 feet from the channel have the potential to reduce shade delivery by up to 25% of maximum. However, any reduction in shade beyond 75 feet would probably be relatively low on the horizon, and the impact on stream heating would be relatively minimal because the potential solar radiation decreases significantly as solar elevation decreases.

## Microclimate - surrounding thermal environment

A secondary consequence of near-stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures. Evapotranspiration by riparian plant communities increases relative humidity. Physical blockage by riparian vegetation reduces wind speed.

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet (45 m) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams (channel width less than 4 m) in the foothills of the western slope of the Cascade Mountains in Western Washington with predominantly Douglas-fir and western hemlock.

Bartholow (2000) provided a thorough summary of literature of documented changes to the environment of streams and watersheds associated with extensive forest clearing. Changes summarized by Bartholow (2000) are representative of hot summer days and indicate the mean daily effect unless otherwise indicated:

- **Air temperature**. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (*Cervus canadensis*) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7°C for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima.

  Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988). In an evaluation of buffer strip width, Brosofske et al. (1997) found that air temperatures immediately adjacent to the ground increased 4.5°C during the day and about 0.5°C at night (estimate). Fowler and Anderson (1987) measured a 0.9°C air temperature increase in clearcut areas, but temperatures were also 3°C higher in the adjacent forest. Chen et al. (1993) found similar (2.1°C) increases. All measurements reported here were made over land instead of water, but in aggregate support about a 2°C increase in ambient mean daily air temperature resulting from extensive clearcutting.

- **Relative humidity**. Brosofske et al. (1997) examined changes in relative humidity within 17 to 72 m buffer strips. The focus of their study was to document changes along the gradient from forested to clearcut areas, so they did not explicitly report pre- to post-harvest changes at the stream. However, there appeared to be a reduction in relative humidity at the stream, estimated at 7% during the day and 6% at night. Relative humidity at stream sites increased exponentially with buffer width. Similarly, a study by Chen et al. (1993) showed a decrease of about 11% in mean daily relative humidity on clear days at the edges of clearcuts.

- **Wind speed**. Brosofske et al. (1997) reported almost no change in wind speed at stream locations within buffer strips adjacent to clearcuts. Speeds quickly approached upland conditions toward the edges of the buffers, with an indication that wind actually increased substantially at distances of about 15 meters from the edge of the strip, and then declined farther upslope to pre-harvest conditions. Chen et al. (1993) documented increases in both peak and steady winds in clearcut areas; increments ranged from an estimated 0.7 to 1.2 meters per second.

## Thermal role of channel morphology

Changes in channel morphology impact stream temperatures. As a stream widens, the surface area exposed to heat flux increases, resulting in increased energy exchange between a stream and its environment (Chapra, 1997). Further, wide channels are likely to have decreased levels of shade due to the increased distance created between vegetation and the wetted channel and the decreased fraction of the stream width that could potentially be covered by shadows from riparian vegetation. Conversely, narrow channels are more likely to experience higher levels of shade.

Channel widening is often related to degraded riparian conditions that allow increased streambank erosion and sedimentation of the streambed, both of which correlate strongly with riparian vegetation type and condition (Rosgen, 1996). Channel morphology is not solely dependent on riparian conditions. Sedimentation can deposit material in the channel, fill pools, and aggrade the streambed, reducing channel depth and increasing channel width.

Channel modification usually occurs during high-flow events. Land uses that affect the magnitude and timing of high-flow events may negatively impact channel width and depth. Channel straightening can increase flow velocities and lead to deeply incised streambanks and washout of gravel and cobble substrate. Riparian vegetation conditions will affect the resilience of the streambanks/flood plain during periods of sediment introduction and high flow. Disturbance processes may have differing results depending on the ability of riparian vegetation to shape and protect channels.

Channel morphology can also be the result of upland land practices or disconnection of the flood plain. Erosion in watershed can result in high bed load and shallower, wider channels downstream. The separation of the flood plain from the main channel of a river can result in sediment being carried in the channel that would otherwise be deposited in the flood plain. It can also increase velocities and bank erosion.

Channel morphology is related to riparian vegetation composition and condition by:

- **Building streambanks**. Traps suspended sediments, encourages deposition of sediment in the flood plain, and reduces incoming sources of sediment.
- **Maintaining stable streambanks**. High rooting strength and high streambank and flood plain roughness prevent streambank erosion.
- **Reducing flow velocity** (erosive kinetic energy). Supplies large woody debris to the active channel, provides a high pool to riffle ratio, and adds channel complexity that reduces shear stress exposure to streambank soil particles.

## References for Appendix B


Adams, T.N. and K. Sullivan, 1989. The physics of forest stream heating: a simple model. Timber, Fish, and Wildlife, Report No. TFW-WQ3-90-007. Washington State Department of Natural Resources, Olympia, WA.

Bartholow, J.M., 2000. Estimating cumulative effects of clearcutting on stream temperatures, Rivers, 7(4), 284-297.

Belt, G.H., J. O'Laughlin, and W.T. Merrill, 1992. Design of Forest Riparian Buffer Strips for the Protection of Water Quality: Analysis of Scientific Literature. Report No. 8. Idaho Forest, Wildlife, and Range Policy Analysis Group, University of Idaho, Moscow, ID.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra, 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. In: Streamside management: forestry and fisher interactions, E.O. Salo and T.W. Cundy, editors, pp 192-232. Proceedings of a conference sponsored by the College of Forest Resources, University of Washington, Seattle, WA. Contribution No. 57 – 1987.

Blann, K., J.F. Nerbonne, and B. Vondracek, 2002. Relationship of riparian buffer type to water temperature in the driftless area ecoregion of Minnesota. North American Journal of Fisheries Management 22:441-451.

Bolton, S. and C. Monohan, 2001. A review of the literature and assessment of research needs in agricultural streams in the Pacific Northwest as it pertains to freshwater habitat for salmonids. Prepared for: Snohomish County, King County, Skagit County, and Whatcom County. Prepared by: Center for Streamside Studies, University of Washington, Seattle, WA.

Boyd, M.S., 1996. Heat source: stream, river, and open channel temperature prediction. Oregon State University. M.S. Thesis. October 1996.

Boyd, M. and C. Park, 1998. Sucker-Grayback Total Daily Maximum Load. Oregon Department of Environmental Quality and U.S. Forest Service.

Boyd, M. and B. Kasper, 2003. Analytical methods for dynamic open channel heat and mass transfer: Methodology for heat source model Version 7.0. www.deq.state.or.us/wq/TMDLs/tools.html

Brady, D.K., W.L. Graves, and J.C. Geyer, 1969. Surface heat exchange at power plant cooling lakes. Cooling water discharge project report No. 5. Edison Electric Institute, New York, NY. Publication No. 69-901.

Brazier, J.R. and G.W. Brown, 1973. Buffer strips for stream temperature control. Res. Pap. 15. Forest Research Laboratory, Oregon State University. 9 p.

Broderson, J.M., 1973. Sizing buffer strips to maintain water quality. M.S. Thesis, University of Washington, Seattle, WA.

Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin, 1997. Harvesting effects on microclimate gradients from small streams to uplands in western Washington. Ecological Applications 7(4): 1188-1200.

Brown, G.W. and J.T. Krygier, 1970. Effects of clear-cutting on stream temperature. Water Resources Research 6(4):1133-1140.

Brown, G.W., G.W. Swank, and J. Rothacher, 1971. Water temperature in the Steamboat drainage. U.S. Department of Agriculture Forest Service, Research Paper PNW-119, Portland, OR. 17 p.

Castelle, A.J. and A.W. Johnson, 2000. Riparian vegetation effectiveness. Technical Bulletin No. 799. National Council for Air and Stream Improvement, Research Triangle Park, NC. February 2000.

CH2M Hill, 2000. Review of the scientific foundations of the forests and fish plan. Prepared for the Washington Forest Protection Association. www.wfpa.org/

Chapra, S.C., 1997. Surface water quality modeling. McGraw-Hill Companies, Inc.

Chen, J., J.F. Franklin, and T.A. Spies, 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. Agricultural and Forest Meteorology 63, 219-237.

Chen, Y.D., 1996. Hydrologic and water quality modeling for aquatic ecosystem protection and restoration in forest watersheds: a case study of stream temperature in the Upper Grande Ronde River, Oregon. PhD dissertation. University of Georgia, Athens, GA.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L Nutter, 1998. Stream temperature simulation of forested riparian areas: I. watershed-scale model development; II. model application. Journal of Environmental Engineering. April 1998. pp 304-328.

Childs, S.W. and L.E. Flint, 1987. Effect of shadecards, shelterwoods, and clearcuts on temperature and moisture environments. Forest Ecology and Management, 18, 205-217.

Corbett, E.S. and J.A. Lynch, 1985. Management of streamside zones on municipal watersheds. P. 187-190. In: R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Folliott, and R.H. Hamre (eds.). Riparian ecosystems and their management: reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985. Tucson, AZ.

Danehy, R.J., C.G. Colson, K.B. Parrett, and S.D. Duke, 2005. Patterns and sources of thermal heterogeneity in small mountain streams within a forested setting. Forest Ecology and Management, 2005. 208(1-3): p. 287-302.

Ecology, 2003. Shade.xls - a tool for estimating shade from riparian vegetation. Washington State Department of Ecology, Olympia, WA. Models and Tools.

Edgerton, P.J. and B.R. McConnell, 1976. Diurnal temperature regimes of logged and unlogged mixed conifer stands on elk summer range. Station Research Note PNW-277. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 pp.

Edinger, J.E., D.W. Duttweiler, and J.C. Geyer, 1968. The response of water temperatures to meteorological conditions. Water Resources Research, Vol. 4, No. 5.

Edinger, J.E., D.K. Brady, and J.C. Geyer, 1974. Heat exchange and transport in the environment. EPRI Publication No. 74-049-00-3, Electric Power Research Institute, Palo Alto, CA.

Fowler, W.B. and T.D. Anderson, 1987. Illustrating harvest effects on site microclimate in a high-elevation forest stand. Research Note PNW-RN-466. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 pp.

Fowler, W.B., J.D. Helvey, and E.N. Felix, 1987. Hydrologic and climatic changes in three small watersheds after timber harvest. Res. Pap. PNW-RP-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 pp.

GEI, 2002. Efficacy and economics of riparian buffers on agricultural lands, State of Washington. Prepared for the Washington Hop Growers Association. Prepared by GEI Consultants, Englewood, CO.

Holtby, L.B., 1988. Effects of logging on stream temperatures in Carnation Creek, B.C., and associated impacts on the coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Ice, G., 2001. How direct solar radiation and shade influences temperatures in forest streams and relaxation of changes in stream temperature. In: Cooperative Monitoring, Evaluation, and Research (CMER) workshop: heat transfer processes in forested watershed and their effects on surface water temperature, Lacey, WA. February 2001.

Johnson, S.L., 2004. Factors influencing stream temperatures in small streams: substrate effects and a shading experiment. Canadian Journal of Fisheries and Aquatic Sciences 61:913-923.

Johnson, S.L. and J.A. Jones, 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 57 (2): 30-39.

Kelley, C.E. and W.C. Krueger, 2005. Canopy Cover and Shade Determinations in Riparian Zones. Journal of the American Water Resources Association, 41 (1): 37-46.

Levno, A. and J. Rothacher, 1967. Increases in maximum stream temperatures after logging in old growth Douglas-fir watersheds. U.S. Department of Agriculture, Forest Service PNW-65, Portland, OR. 12 p.

Lynch, J.A., G.B. Rishel, and E.S. Corbett, 1984. Thermal alterations of streams draining clearcut watersheds: quantification and biological implications. Hydrobiologia 111:161-169.

OWEB, 1999. Water quality monitoring technical guidebook: chapter 14, stream shade and canopy cover monitoring methods. Oregon Watershed Enhancement Board.

Patrick, J.H., 1980. Effects of wood products harvest on forest soil and water relations. Journal of Environmental Quality 9(1):73-79.

Poole, G.C. and C.H. Berman, 2000. Pathways of Human Influence on Water Temperature Dynamics in Stream Channels. U.S. Environmental Protection Agency, Region 10, Seattle, WA. 20 pp. www.krisweb.com/biblio/gen_usepa_pooleetal_2000_pathways.pdf.

Rishel, G.B., J.A. Lynch, and E.S. Corbett, 1982. Seasonal stream temperature changes following forest harvesting. Journal of Environmental Quality 11(1):112-116.

Rosgen, D., 1996. Applied river morphology. Wildland Hydrology publishers. Pagosa Springs, CO.

Schueler, Thomas R., 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Department of Environmental Programs, 225 pp. and appendices.

Sinokrot, B.A. and H.G. Stefan, 1993. Stream temperature dynamics: measurements and modeling. Water Resources Research. Vol. 29, No. 7, pp. 2299-2312.

Steinblums, I., H. Froehlich, and J. Lyons, 1984. Designing stable buffer strips for stream protection. Journal of Forestry 821(1): 49-52.

Swift, L.W. and J.B. Messer, 1971. Forest cuttings raise water temperatures of a small stream in the southern Appalachians. Journal of Soil and Water Conservation 26:11-15.

Teti, P.A., 2001. A new instrument for measuring shade provided by overhead vegetation. Cariboo Forest Region Research Section, British Columbia Ministry of Forests, Extension note No. 34.

Teti, P.A. and R.G. Pike, 2005. Selecting and testing an instrument for surveying stream shade. BC Journal of Ecosystems and Management 6(2):1-16. URL: www.forrex.org/jem/2005/vol6_no2_art1.pdf

Wenger, S., 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens, GA.

# Appendix C. Glossary, Acronyms, and Abbreviations

## General Glossary

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

**Anthropogenic:** Human-caused.

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

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

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

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

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

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

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

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

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

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

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

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

**Eutrophication:** The process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.

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

**Fecal Coliform bacteria (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).

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

**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.

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

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

**Near-Stream Disturbance Zone (NSDZ):** The active channel area without riparian vegetation that includes features such as gravel bars.

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

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

**Parameter:** Water quality constituent being measured (analyte).

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

**Periphyton:** A complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces.

**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:** Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites 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.

**Riffle:** A shallow stream reach, with visible surface turbulence, where water flows swiftly over rough streambed substrates.

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

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

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

**Stormwater:** The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snowmelt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

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

**Surface waters of the state:** Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

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

**System potential:** The design condition used for TMDL analysis.

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

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

**Thalweg:** The path of a stream that follows the deepest part of the channel.

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

**Total Suspended Solids (TSS):** Portion of solids retained by a filter.

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

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

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

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

**303(d) list:** Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface Water Quality Standards and are not expected to improve within the next two years.

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

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

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

## Acronyms and Abbreviations

| | |
|---|---|
| APHA | American Public Health Association |
| ASTM | American Society for Testing Materials |
| BMP | Best management practice |
| BOD | Biochemical Oxygen Demand |
| CREM | Council for Regulatory Environmental Modeling |
| DEM | Digital elevation models |
| DNR | Washington State Department of Natural Resources |
| DO | Dissolved oxygen |
| DOC | Dissolved organic carbon |
| DW | Dry weight |
| EAP | Environmental Assessment Program |
| Ecology | Washington State Department of Ecology |
| ECY | Washington State Department of Ecology |
| e.g., | For example |
| EIM | Environmental Information Management database |

| | |
|---|---|
| EPA | U.S. Environmental Protection Agency |
| et al. | and others |
| FC | Fecal coliform bacteria |
| GIS | Geographic Information System software |
| GPS | Global Positioning System |
| i.e. | in other words |
| LDC | Load duration curve |
| LDO | Luminescent dissolved oxygen |
| LiDAR | Light Detection and Ranging |
| MDL | Method detection limit |
| MEL | Manchester Environmental Laboratory |
| MF | Membrane Filtration |
| MOA | Memorandum of Agreement |
| MPN | Most Probable Number |
| MQO | Measurement quality objective |
| NPDES | National Pollutant Discharge Elimination System |
| QA | Quality assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| RE | Relative error |
| RL | Reporting limit |
| RPD | Relative percent difference |
| RSD | Relative standard deviation |
| SOP | Standard operating procedures |
| SRM | Standard reference materials |
| TMDL | Total maximum daily load |
| TNVSS | Total nonvolatile suspended solids |
| TOC | Total organic carbon |
| Trib | Tributary |
| TSS | Total suspended solids |
| USDA | United States Department of Agriculture |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| WAC | Washington Administrative Code |
| WQA | Water Quality Assessment |
| WQIP | Water Quality Improvement Plan |
| WQIR | Water Quality Improvement Report |
| WQP | Water Quality Program |
| WQS | Water Quality Standards |
| WRIA | Water Resource Inventory Area |

**Units of Measurement**

| | |
|---|---|
| °C | degrees centigrade |
| cfs | cubic feet per second |
| cfu | colony forming units |
| DW | dry weight |

| | |
|---|---|
| ft | feet |
| ft/s | feet/second |
| g | gram, a unit of mass |
| kg | kilograms, a unit of mass equal to 1,000 grams |
| km | kilometer, a unit of length equal to 1,000 meters |
| m | meter |
| mbar | millibar |
| mm | millimeter |
| mg | milligram |
| mg/kg | milligrams per kilogram (parts per million) |
| mg/L | milligrams per liter (parts per million) |
| mL | milliliter |
| mS/cm | millisiemens per centimeter, a unit of conductivity |
| mV | millivolts |
| NTU | nephelometric turbidity units |
| s.u. | standard units |
| ug/L | micrograms per liter (parts per billion) |
| um | micrometer |
| umhos/cm | micromhos per centimeter |
| uS/cm | microsiemens per centimeter, a unit of conductivity |
| $W/m^2$ | watts per square meter |

## Quality Assurance Glossary

Edited by Kammin, 2011 (Ecology)

**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 are usable for intended purposes.
- J (or a J variant), data are estimated, may be usable, may be biased high or low.

- REJ, data are rejected, cannot be used for intended purposes (Kammin, 2010; Ecology, 2004).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

## References for QA Glossary

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html

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

USEPA, 1997. Glossary of Quality Assurance Terms and Related Acronyms. U.S. Environmental Protection Agency.

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. U.S. Environmental Protection Agency. http://www.epa.gov/quality/qs-docs/g4-final.pdf

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. U.S. Geological Survey. http://ma.water.usgs.gov/fhwa/products/ofr98-636.pdf