DEPARTMENT OF ECOLOGY
State of Washington

Quality Assurance Project Plan

Soos Creek Watershed Temperature, Dissolved Oxygen, and Bacteria TMDL Study

August 2023

Publication 23-03-105

Publication Information

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

This QAPP was approved to begin work in April 2023. It was finalized and approved for publication in August 2023.

The final QAPP is available on Ecology's website at https://apps.ecology.wa.gov/publications/SummaryPages/2303105.html.

Suggested Citation
Mathieu, N., Gleason, M., and C. Neculae. 2023. Quality Assurance Project Plan: Soos Creek Watershed Temperature, Dissolved Oxygen, and Bacteria TMDL Study. Publication 23-03-105. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2303105.html.

Data for this project are available in Ecology's EIM Database. Search Study ID: NMat0009.

The Activity Tracker Code for this study is 16-068.

Federal Clean Water Act 1996 303(d) Listings Addressed in this Study. See Section 3.3.

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COVER PHOTO: Big Soos Creek at Kent-Black Diamond Road in the summer.
PHOTO BY NURI MATHIEU.

Quality Assurance Project Plan

Soos Creek Watershed Temperature, Dissolved Oxygen, and Bacteria TMDL Study

by Nuri Mathieu, Molly Gleason, and Cleo Neculae

August 2023

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2.0 Abstract

Data collected throughout the Soos Creek watershed show that multiple waterbodies do not meet Washington State water quality standards for temperature, dissolved oxygen, and bacteria. This Quality Assurance Project Plan (QAPP) describes data collection, analysis, and computer modeling to confirm and address these water quality issues and characterize the sources of the main water quality problems.

The Soos watershed and its ecological processes are complex and varied. These processes are influenced by human actions (such as development, flow and stream channel alterations, loss of forest cover, and septic systems) and natural processes (such as wetlands, flat terrain, groundwater inflows, and seasonally warm lake water). A key focus of this study will be isolating and characterizing human versus natural impacts.

This work aims to restore and protect beneficial uses in the Soos watershed, particularly to improve conditions for aquatic life (salmonids and other species) and for people to recreate (e.g., swim, fish) in these streams. This study will develop nutrient, heat, and bacteria load limits for creeks in the watershed, as necessary, to protect these uses.

The study will collect information on the amount of flow, quality of the water, and biological growth in the water, stream bottom, and underlying sediments, as well as other attributes of the land, vegetation, and groundwater interaction. Ecology will collect information from April 2023 to April 2024, with more detailed information collected in the summer of 2023, when these water quality problems are more severe. Ecology will use the information to create a linked network of computer models that simulate water movement and quality through the land and in the streams. Management scenarios will be tested in the model to develop pollution limits.

3.0 Background

3.1 Introduction and problem statement

Data collected throughout the Soos Creek watershed demonstrate that multiple stream segments are impaired (do not meet Washington State water quality standards) for temperature, dissolved oxygen (DO), and bacteria (Table 3). Based on those data, the Washington State Department of Ecology (Ecology) included these segments in the 2018 303(d) list of impaired waters[1] (Figure 2), as well as in previous 303(d) lists.

The Soos watershed and its ecological processes are complex and varied. These processes are influenced by both human-caused drivers (such as urbanization, hydrologic alteration, deforestation, and septic waste) and natural drivers (such as wetlands, low gradients, groundwater discharge, and seasonally warm lake water inputs). A key focus of this study will be isolating and characterizing the effects of these drivers.

This Quality Assurance Project Plan (QAPP) details data collection, analysis, and modeling to confirm and address these impairments and characterize drivers. The goal of this work is to restore and protect beneficial uses in the Soos watershed, particularly for aquatic life (salmonids and other species) and recreation (e.g., swimming and fishing).

This QAPP also briefly addresses additional data collection to support the Soos Creek Bioassessment/Fine Sediment TMDL effort to establish a baseline for future effectiveness monitoring for fine sediment changes related to bioassessment-based impairments. This baseline monitoring effort is called Watershed Health baseline monitoring throughout this QAPP.

Previous data collection, modeling, and analysis by King County, the U.S. Environmental Protection Agency (EPA), Tetra Tech, and Ecology characterized the temperature, DO, and bacteria impairments to a large extent. King County conducted a more detailed field study in 2007; however, additional monitoring and modeling are necessary to address these impairments for several reasons related to changes to the Washington Administration Code (WAC) 173-201A (water quality standards):

- Ecology amendments that added supplemental spawning criteria to the Washington State water quality standards for temperature. The supplemental criteria apply to many areas throughout the state, including the lower reaches of the Soos watershed. The 2007 field study only collected temperature data from July to September. It did not include critical times (particularly the month of June) of the supplemental spawning period (September 15 to July 1) that apply to lower Big Soos Creek and the lower portions of Jenkins and Covington creeks.
- Ecology amendments that provide additional water quality and habitat protection for the early life stages of salmonids — including salmon, steelhead, and trout — and their spawning gravel. Specifically, changes to aquatic life DO criteria for fresh water to protect early life stages. These new criteria, which include concentration (in mg/L) and percent saturation criteria, must be evaluated during spawning life stages outside of the 2007 data collection (one week in July) and analysis period, including spring and fall months.

[1] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d

- Ecology amendments to Primary Contact Recreation Bacteria Criteria in Fresh Water in 2020 that changed the appropriate indicator to *Escherichia coli* (*E. coli;* previously fecal coliform).

3.2 Study area and surroundings

The Soos Creek watershed (Figure 1) is inside Water Resource Inventory Area (WRIA) 9 in the Puget Sound lowlands in western Washington State. To summarize, the Soos Creek watershed:

- Drains about 66 square miles and includes four main tributaries: Little Soos, Soosette, Jenkins, and Covington Creeks. All four tributaries drain into the mainstem Big Soos Creek, which then drains into the Middle Green River near Auburn at River Mile (RM) 33.7.
- Includes a network of smaller tributaries with intermittent flow (often dry in summer months), most notably Cranmar Creek, a tributary to Jenkins Creek, and Meridian Valley Creek, which discharges to upper Big Soos Creek.
- Includes the City of Covington and parts of the cities of Auburn, Black Diamond, Kent, Maple Valley, and Renton, as well as unincorporated King County (Figure 2).
- Contains flat topography on the upstream plateau areas (upper portions of the watershed) that cuts down at a moderate gradient to the Green River valley near the lower 5 miles of Big Soos Creek. It likely intersects groundwater aquifers and gains cooling baseflow in the transition between the plateau and the valley.
- Exhibits low summer baseflows in all the creeks, typically ~35 cubic feet per second (cfs) in lower Big Soos Creek and as low as 1 cfs and below at other locations on the impaired creeks in the watershed.
- Contains over 1,300 acres of lakes and over 2,000 acres of wetlands.
- Was comprised of historically forested lowlands surrounding a dense network of interconnected streams, lakes, and wetlands. After extensive logging in the 19th century, the watershed transitioned to rural/agricultural land use. The late 20th century marked a transition to residential land use, with very little forestry or commercial agricultural practices in the present day.
- Is primarily residential (47%), with an estimated population of 117,819[2] in 2010. There are about 10,000 on-site septic systems.
- Has supported historically all five species of North American Pacific salmon (Chinook, coho, chum, pink, and sockeye) as well as steelhead and cutthroat trout (King County 2009). Chinook salmon and steelhead are listed as threatened on the Endangered Species List (NOAA 2016).

[2] https://enviroatlas.epa.gov/enviroatlas/interactivemap/

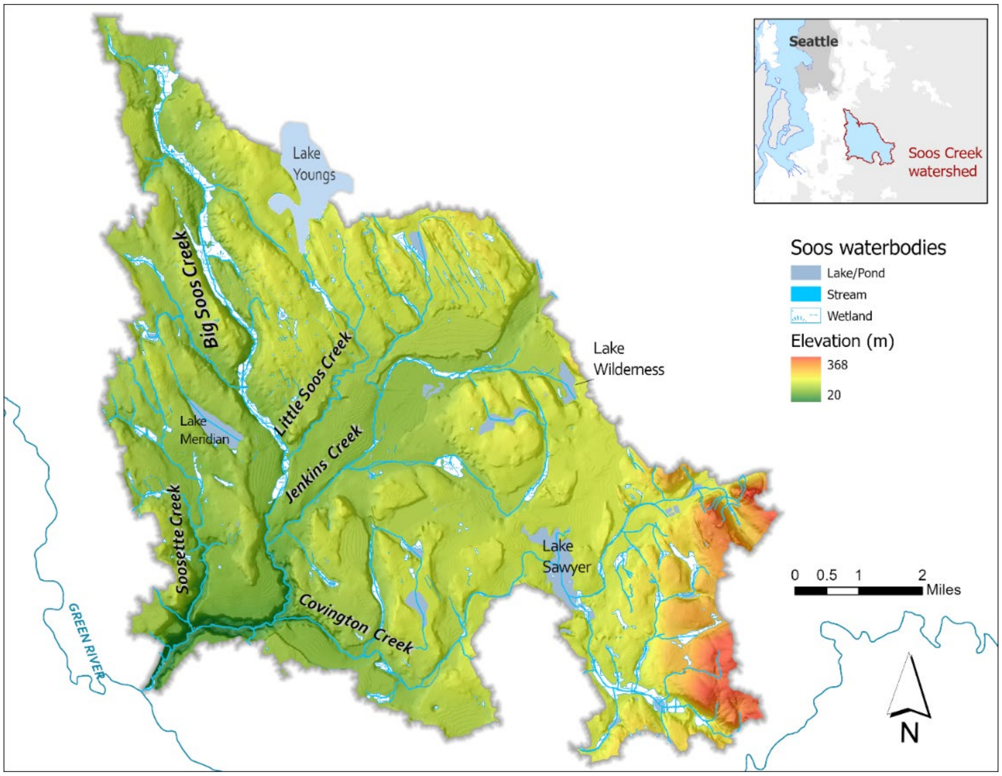

Figure 1. Map of Soos Creek watershed study area.

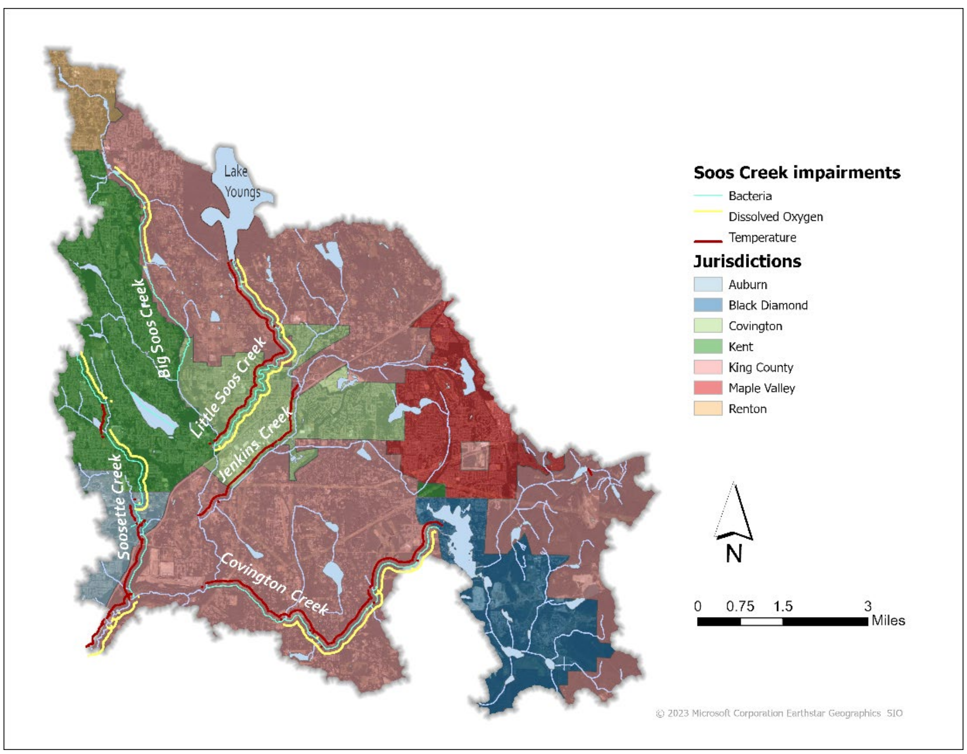

Figure 2. Municipalities and impairments in the Soos Creek watershed.

3.2.1 Climate/Hydrology

The relatively moderate climate of the study area is typical of other Puget Sound lowland watersheds and is characterized by warm, dry summers and cool, wet winters. The hydrograph is also typical of rain-dominated western Washington streams, which reflect high precipitation in the form of rain during the winter and relatively low precipitation during the summer. The 30-year normal annual precipitation for 1981 – 2010 is ~45 to 50 inches per year within the study area based on PRISM Climate Group[3] model outputs.

The watershed exhibits low summer baseflows in all the creeks (Figure 3):

- Lower Big Soos Creek typically ~30 – 40 cfs
- Jenkins Creek ~10 – 20 cfs
- Big Soos Creek above Jenkins Creek ~5 cfs
- Covington Creek ~2 – 5 cfs
- Little Soos Creek ~2 cfs
- Soosette Creek <1 cfs

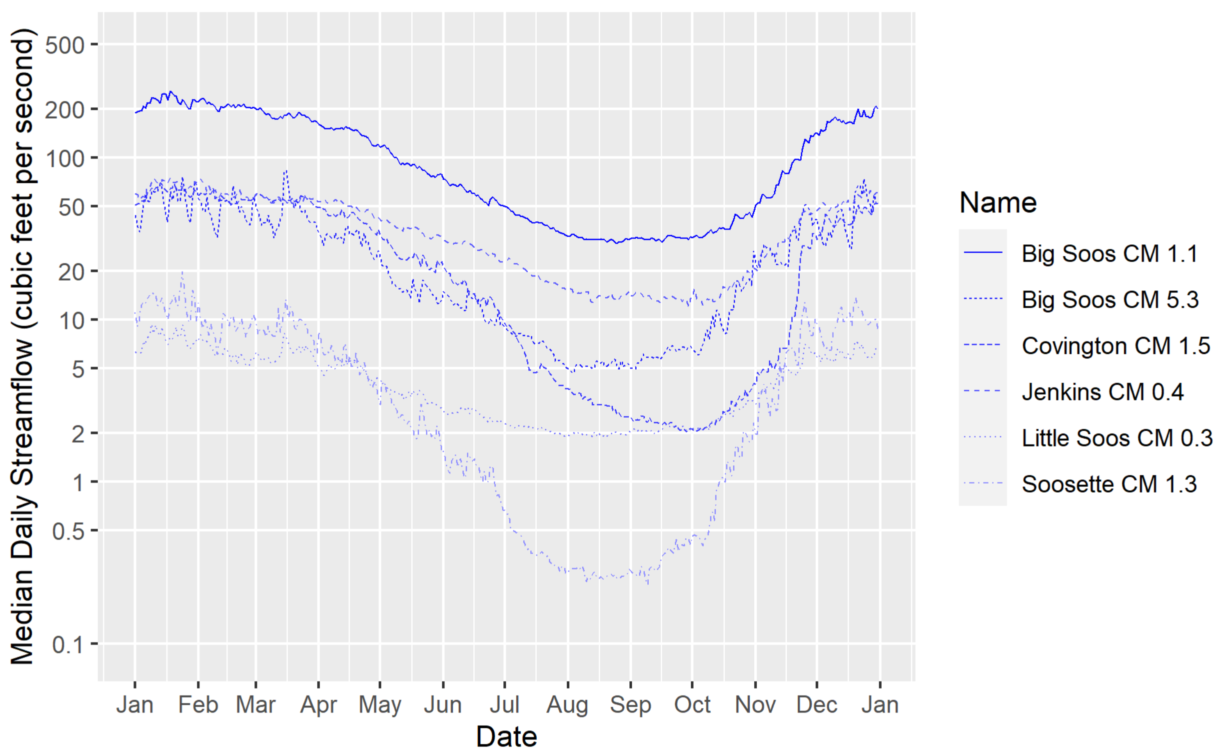

Figure 3. Median streamflow at continuously gaged creek sites in the watershed.
All gages are operated by King County, except for the US Geological Survey (USGS) gage at Big Soos CM 1.1.

[3] PRISM Climate Group at Oregon State University

3.2.2 Topography/Channel Morphology

The topography of much of the watershed, including the upper headwaters of all the creeks, consists of a large rolling glacial till/outwash plain known as the Covington Plain (Woodard et al. 1995), which sits on a plateau about 200 – 300 feet above the Green River floodplain. The watershed is not connected to the Cascade Mountains or any other high-elevation land features, which results in very little recharge from snowmelt.

Upstream of creek mile (CM) 5, on top of the plain, Big Soos Creek is classified as a palustrine channel type (King County 2000) characterized by an unconfined channel with a very low gradient (less than 0.1 percent) and low velocity, that typically flows through wetlands and beaver complexes. Soosette (above CM 2.5), Covington (above CM 1.5), Little Soos, and Jenkins Creeks are all low-gradient streams with some of these features. However, hydromodification and development have likely affected channel confinement, stream meander, and wetland abundance to some degree.

Three of the creeks have significant elevation drops in a concentrated area where watershed drainage cuts channels down through the plateau:

- Big Soos Creek from CM 5 to 2 drops from ~300 ft to ~110 ft elevation (1.2% gradient).
- Covington Creek from CM 1.5 to 0 drops from ~350 ft to ~180 ft elevation (2.2% gradient).
- Soosette Creek from CM 2.5 to 0 drops from ~325 ft to ~95 ft elevation (1.7% gradient).

King County (2000) classifies this portion of Big Soos Creek as a "Moderate Gradient Mixed Control" channel type and describes this stretch of the creek as "a narrow, steep-sided ravine containing long riffles with pools." Based on previous data collection (see section 3.2.2), this is an important stretch of the creek where flow increases dramatically and water quality greatly improves. These moderate gradient sections of all three creeks are areas where the stream is likely to intersect with a hydrogeologic aquifer unit and gain flow from groundwater discharge.

Finally, downstream of CM 2.0, Big Soos Creek represents a floodplain channel type that meanders through a steep-sided valley, which is essentially an arm of the Green River floodplain. The channel gradient is again low (~0.5 percent), and the natural substrate is gravel and cobble, which is conducive to salmonid spawning.

3.2.3 Wetlands and Lakes

Wetlands are present throughout the study area and play an important role in the ecological function of the watershed by reducing peak flows, infiltrating runoff to groundwater, trapping nutrients and sediment, and providing critical habitat.

Based on the National Land Cover Dataset (NLCD) 2016 wetland spatial data, there are currently ~2,100 acres of wetlands in the Soos watershed, consisting primarily of Palustrine Forested and Scrub/Shrub classification (Table 1).

Table 1. Wetland classifications and acreage in the Soos Creek watershed based on NLCD 2016.

Wetland Classification	Area in Acres	% of Total Wetlands
Palustrine Aquatic Bed	13	0.6%
Palustrine Emergent Wetland	208	9.8%
Palustrine Forested Wetland	1,245	58.9%
Palustrine Scrub/Shrub Wetland	600	28.4%
Potentially Disturbed Wetlands	49	2.3%
Total	2,115	100.0%

In addition to large wetland complexes, the plateau features over 1,300 acres of lakes, including (acreage and depth gathered from Lakes of King County — King County[4]; see Figure 1 for location):

- **Lake Youngs** — A 700-acre water storage reservoir (maximum depth 72 feet) near the northern boundary of the study area that supplies drinking water to the City of Seattle.
  - The lake receives inflow from the Cedar River via the Landsburg diversion dam. It also serves as the headwaters to Little Soos Creek, and lake levels control streamflow in the creek.
  - Woodard et al. (1995) suggest that significant groundwater mounding occurs near the lake, with lateral groundwater flow in all directions. It is likely that some of this groundwater discharges to watershed creeks in the middle portion of the study area.
- **Lake Wilderness** — A 67-acre shallow lake (mean depth 21 feet) in the eastern study area that serves as the headwaters to Jenkins Creek.
  - While water levels drive upstream flow in Jenkins for much of the year, the connection to the lake can dry up during summer, when baseflow in lower Jenkins appears primarily driven by groundwater discharge.
- **Lake Sawyer —** A 286-acre relatively shallow lake (mean depth 26 feet) in the southeastern study area that serves as the headwaters to Covington Creek.
  - Similar to Lake Wilderness and Jenkins Creek, Lake Sawyer water levels drive upstream flow in Covington for much of the year. However, the connection to the lake can dry up during summer, when baseflow in Covington appears primarily driven by groundwater discharge.
  - The lake also has a large up-gradient drainage area with two creeks, Rock and Ravensdale, providing inflow. This contributing drainage area is outside the TMDL study area, given that there are no listed impairments; however, the water quality of the lake and its inflows have been extensively studied, which includes a TMDL developed by Ecology for phosphorus (Carroll and Pelletier 1991; Butkus 1993).
- **Lake Meridian** — A 150-acre moderate-depth lake (mean depth 41 feet) in the northwestern study area.
  - The outflow discharges to upper Big Soos Creek during periods of higher flow but dries up during the summer months (Verhey and Mueller 2001)**.**

[4] https://kingcounty.gov/services/environment/water-and-land/lakes/lakes-of-king-county.aspx Accessed. 1-25-2023.

- **Lake Morton** (66 acres; mean depth 15 feet) and **Grass Lake** (15 acres). The outflows from these lakes connect to a tributary that drains to Covington Creek at ~CM 1.9. This tributary goes dry in the summer months.
- **Pipe Lake** (52 acres; mean depth 27 ft) and **Lake Lucerne** (16 acres; mean depth 18ft). These two lakes are hydraulically connected and outflow to upper Cranmar Creek.
- **Shadow Lake** (50 acres; mean depth 22 ft). The outflow forms a tributary that discharges to Jenkins Creek at ~CM3.3 but goes dry in the summer months.
- **Nielson (Holm) Lake** (19 acres) and **Moneysmith Lake** (22 acres). The outflow tributary of these lakes drains to lower Big Soos Creek at ~CM 2.7.

Natural warming of the surface area of lakes in the watershed during summer months can result in the upstream end of tributaries starting well above numeric criteria, particularly for Little Soos Creek and for Covington and Jenkins when Sawyer and Wilderness lakes are discharging to the creek channels.

3.2.4 Hydrogeology, soils, and groundwater movement

The storage and discharge of shallow and deeper groundwater in the Soos watershed provide a key source of flow to the creeks, which can entirely sustain baseflow in many areas during the drier months. Surficial geology, hydrogeologic units, conceptual groundwater movement, and water balance were characterized and estimated in a detailed manner by Woodard et al. (1995). The four hydrogeologic units most relevant to this study are:

- **Qvr (Historical) or A1 (more recent USGS studies): Vashon recessional outwash**. A shallow aquifer unit, which is the surficial unit in the southeast half of the Covington Plain, for most of Covington, Jenkins, and Lower Big Soos Creek subbasins.
    - Many sources have described the water table as seasonally being very close to the surface in areas where this layer is present (King Co. 1990; King Co. 2009; King Co. 2013a).
    - Outwash captures and stores precipitation well, which tends to produce muted hydrographs with lower peak flows in response to runoff events (Dinicola. 1990).
- **Qvt or A2: Vashon till**. A confining unit, which is the surficial unit in the northwest half of the Covington Plain for most of Soosette, Little Soos, and upper Big Soos Creek subbasins.
    - It is the lower confining unit for Qvr (where present) and the upper confining unit for Qva.
    - Till has poor infiltration rates and tends to produce spiked hydrographs with higher peak flows in response to runoff events (Dinicola 1990).
- **Qva or A3**: **Vashon advance outwash**. A productive aquifer unit, which is typically not a surficial unit in the study area, except in areas along steeper bluffs with seepage faces, most notably in Lower Big Soos Creek and the mouths of Soosette and Covington creeks.
    - This unit is assumed to generally be saturated throughout the study area based on water levels in wells.
    - A vertical profile from Woodward et al. (1995) (Plate 1; Transect D) suggests Lake Youngs may interact with this aquifer layer.

- **Q(A)f or B**: **Upper fine-grained unit**. A confining unit that is not surficial throughout the study area and is the lower confining unit below Qva.

A water balance analysis of unpublished July 2007 flow data from the Ecology and King County study (King County 2009; see section 3.2.6) suggests potential large groundwater gains in Big Soos, Jenkins, and Covington creeks (Table 2). Note that uncertainty was not quantified for this flow data, and limited data was available to assess its quality; however, it is useful for guiding the investigation of groundwater-surface water interactions during this study.

Table 2. Estimated groundwater discharge in July 2007 based on flow balance residual.

Creek Name	Upper Creek Mile	Lower Creek Mile	Length (miles)	Flow residual -assumed GW (cfs)	Estimated Seepage Rate (cfs/mile)
Big Soos Creek	11.5	8.6	2.9	0.70	0.24
Big Soos Creek	8.6	6.4	2.2	0.78	0.35
Big Soos Creek	6.4	5.2	1.2	5.27	4.39
Big Soos Creek	4.6	1.1	3.5	7.50	2.14
Covington Creek	6.5	2.2	4.3	1.20	0.28
Covington Creek	2.2	1.5	0.7	2.70	3.86
Jenkins Creek	6.7	3.4	3.3	1.36	0.41
Jenkins Creek	3.4	2.2	1.2	5.99	4.99
Jenkins Creek	2.2	0.4	1.8	7.20	4.00

3.2.4 Fish and wildlife

The varied features of the hydrologic system in Soos Creek support the needs that different types of salmonids have during different life stages. Chinook spawn in areas of the creeks that are wider and can support more redds, such as Big Soos Creek below RM 6, close to the mouth of Little Soos Creek, and the lower portions of Jenkins and Covington creeks. Chum are limited to spawning in Big Soos Creek below RM 6, while coho, steelhead, and cutthroat trout spawn in the smaller waters of Soosette, Covington, and Jenkins Creeks. Rearing occurs throughout the watershed, wherever juveniles can access pools. Chum are an exception because they exit the system soon after emergence from eggs. Juveniles use the deep pools they find in wetlands but also use shallower pools when necessary. Figure 4 shows the timing of salmon life phases in the Green-Duwamish, indicating the times of the year when salmon are expected to be present in the streams of Soos Creek (King County 1990).

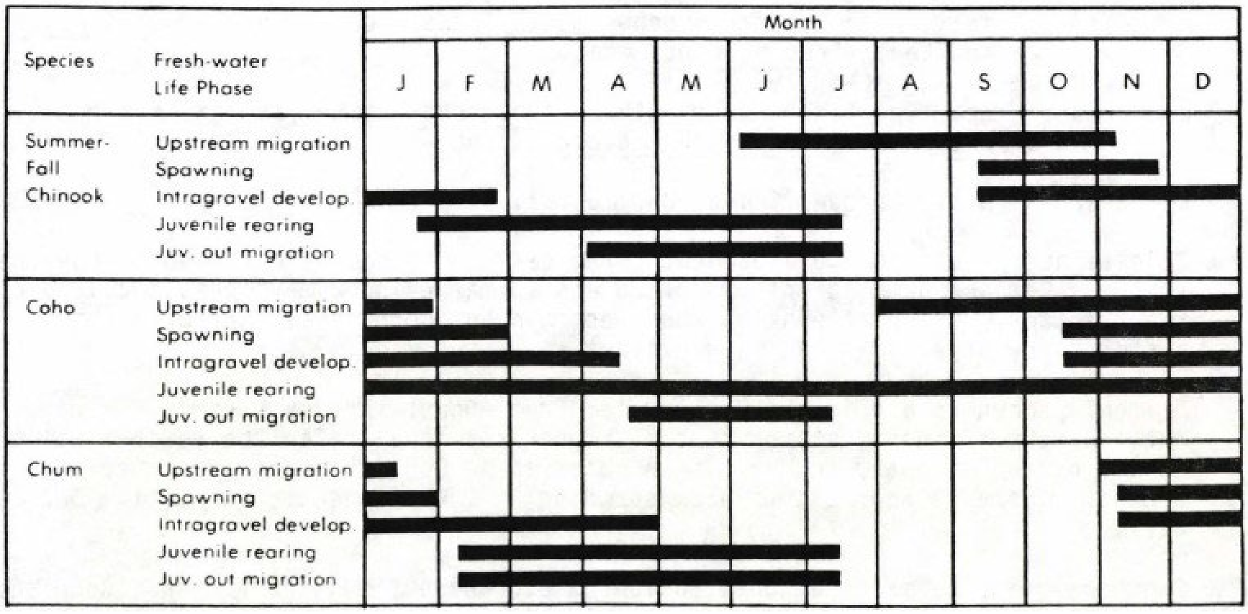

Figure 4. Timing of salmon life phases in the Green-Duwamish watershed.
(From King County 1990)

Numerous wildlife species exist within the watershed, particularly within riparian corridors and wetlands. King County (2013a) provides a detailed inventory of species observed in the Upper Big Soos Creek area. Over 120 bird species and 37 mammal species have been documented in Soos Creek Park. Beavers are active in the watershed, particularly in the Upper Big Soos Creek.

3.2.5 History of study area

The communities in the Soos Creek watershed are within commuting distance to Seattle and other large employment hubs in the metropolitan area, so it is subject to the same high urbanization pressures found in other parts of the region. This rapid urbanization is a recent occurrence in the watershed, however. Before (sub)urban development started taking off in Soos Creek, the land cover was changed first by logging and mining and then agriculture.

The watershed is part of the ancestral lands of the Muckleshoot Tribes. Before Euroamerican settlers started to change the face of the landscape, forests were dominated by species specific to the Puget Lowlands, including Western hemlock, Western red cedar, and Douglas fir. Following logging, the remaining habitat types include second-growth Douglas fir forests; mixed lowland forests comprised of alder, big-leaf maple, cedar, and hemlock; riparian forests dominated by alder, big-leaf maple, cottonwood, salmonberry, osoberry, and elderberry; and pasture lands dominated by nonnative grasses (King County 1990).

Wetlands, marshes, bogs, and fens represent important hydrologic features for the watershed and support rich habitats. The dominant vegetation in these types of wetland environments include trees, such as red alder, Oregon ash, black cottonwood, Western red cedar, Western hemlock, and willows; and shrubs, such as wild crabapple, cranberry, red huckleberry, hardhack, and mountain ash (King County 1991).

The vegetation composition of these ecosystems changed substantially when settlers who colonized the Soos Creek Plateau logged the existing forests and built an infrastructure to process and transport the timber to lumber mills and then to locations outside of the watershed. The infrastructure took advantage of the complex network of interconnected lakes, wetlands, and streams to transport timber from forests to mills, with consequences for stream health.

Another industry that played an important role in the watershed's economy and changed the landscape of Soos Creek is coal mining. Coal was discovered near Black Diamond in the late 1800s and was extracted consistently until the 1940s when oil became a more popular heat source. To transport logging and mining outputs, communities in the watershed were connected to the main railroad between Seattle and Walla Walla.

Both logging and mining industries no longer have a presence in the watershed. However, BNSF still runs a railroad that transects the Soos Creek watershed through the middle of its eastern half and then follows Highway 18 south, exiting the watershed close to where Big Soos Creek drains into the Green River.

Deforested land on the plateau was subsequently settled by "Soos Creek stump ranchers," who removed the tree stumps and brush left from the clear-cuts and converted the land to dairy pastures. Agriculture remained the dominant land use until the 1980s.

Figure 5 shows the current major land uses in the Soos Creek watershed. Soos land use characteristics include:

- The dominant land use is residential (47% of the watershed), characterized by a wide range of development ages and housing density.
- Forest and open space are also common (23% and 13%, respectively); however, much of this land use occurs upstream of Lake Sawyer (to the east and south), outside the area of impairments addressed by the TMDL. Other large forests or open spaces include:
    - Golf courses: Druid's Glen Golf Club (Covington Creek), Meridian Valley Country Club (Upper Big Soos Creek), Lake Wilderness Golf Course (Jenkins Creek), and Washington National Golf Club (Lower Big Soos Creek).
    - Protected forested area surrounding Lake Youngs, a drinking water storage reservoir.
    - Wetlands, surrounding floodplain, and King County parks land in upper Big Soos Creek.
    - Riparian area on lower Big Soos Creek below Jenkins Creek confluence.
- Transportation (9%) is relatively high due to the presence of SR18 in the middle of the watershed and a dense residential road network.
- Commercial and services are concentrated in the central watershed at the core of the City of Covington and, to a lesser extent, the northeast watershed, which encompasses a portion of the City of Maple Valley commercial area.
- Commercial agriculture is virtually non-existent in the watershed, while mining has a minor presence in the form of several sand and gravel operations. Industrial land use is also minimal.

A spatial analysis of land uses within 100 feet of the stream channel shows that residential areas make up 36% of the land near streams, while forests and open spaces represent 29% and 22%, respectively.

The dramatic transformation of the Soos watershed, from forested to agricultural and finally to residential, has resulted in a shift in potential sources of nutrient and bacteria pollution over time.

Recent analysis of parcel records conducted for a separate Puget Sound SPARROW project (Figueroa-Kaminsky et al. 2022) estimates that there are currently about 10,000 on-site septic systems in the Soos watershed.

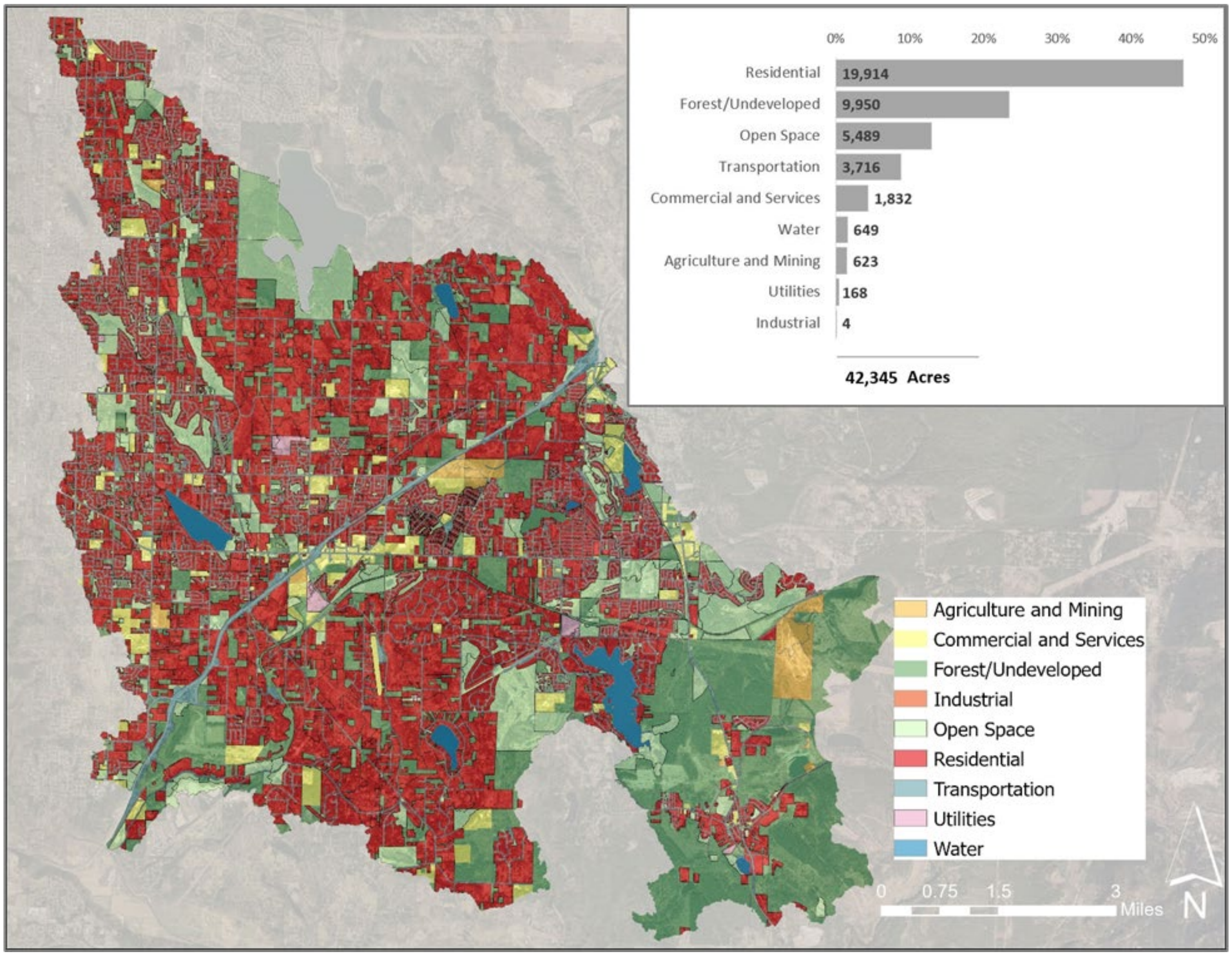

Figure 5. Soos Creek land use characteristics.

Changes to land uses have degraded instream habitat in a watershed that used to support "some of the most diverse and abundant salmonid habitat in the southern Puget Sound region." (King County 1990, p. 3) The multitude of lakes, wetlands, and interactions with groundwater give the watershed a complexity that historically was suitable for supporting a strong salmon population. Anadromous fish that use Soos Creek for spawning and rearing include fall Chinook, coho, chum, cutthroat, and pink salmon. Steelhead are raised at the Soos Creek hatchery, but no redds have been found or smolts trapped in the watershed in the last few years. Other species of salmonids, such as spring and summer Chinook and Dolly Varden char, can no longer be found in the watershed.

Habitat degradation, loss of connectivity due to impassable fish barriers, and management practices at the Soos Creek hatchery, located close to the mouth of the Green River, have limited the spatial distribution of the Chinook redds. A 2014 spawning survey done by the Muckleshoot Indian Tribe found that Chinook redds extended up to RM4 on Big Soos, though most of the redds were concentrated below RM2. Only one redd was found in Covington Creek and none in Jenkins (Nelson 2014).

The study's author hypothesized that the lack of extensive use of the streams for spawning was partly due to the management practices at the hatchery on Lower Big Soos near creek mile 1, where all Chinook are held until the egg quota is met. When the remaining Chinook are released above the hatchery, they are ready to spawn and cannot travel too far upstream to build their redds and spawn. Other factors, such as low flows and warm water temperatures, may hinder Chinook from swimming upstream to spawn.

Water quality for spawning and rearing remains a concern and influences the management of the Soos Creek hatchery. Warm water, low flows (particularly during low precipitation years), and the presence of parasites, like Ichthyophthirius multifiliis or ich, that are deadly to fish, pose a threat to the juveniles being reared at the hatchery in the summer. To avoid the loss of fish, WDFW transports the juveniles to other hatcheries in the Green River during the summer months.

Land cover/land use changes in the watershed have affected water quality in Soos Creek for salmonids and humans. The Soos Creek Basin Plan documents basin-wide findings of elevated fecal coliform levels in surface water (King County 1990). In the 1980s, which corresponds to the period that the basin plan covers, livestock was a significant source of bacterial pollution. Forty years later, few livestock can be found in the watershed, but bacterial pollution levels are still elevated. Sources associated with urbanization, such as leaky sewer pipes, malfunctioning onsite septic systems, and pet waste management, can contribute to bacteria concentrations in surface waters above water quality standards.

3.2.6 Summary of previous studies and existing data

Several historic projects and long-term monitoring programs have generated data and valuable information about the Soos Creek watershed. More detail is provided in subsequent sections on specific parameters. The data sources and studies most relevant to this TMDL include the following:

- The King County Water and Land Resource Division (WLRD) Hydrologic Monitoring Program[5] collects continuous data, including streamflow, water temperature, and air temperature at 6 sites in the Soos watershed, as well as some conductivity (2 sites), turbidity (5 sites), and precipitation (5 sites). Water level is also collected at 4 lakes (Sawyer, Wilderness, Morton, and Lucerne). A portion of this data is presented in this section; additional data plots are in Appendix A.
- King County WLRD Streams Monitoring Program[6] collects monthly water quality monitoring data at 4 sites in the Soos watershed. Data has been collected at some of these stations since the 1960s. A portion of this data is presented in this section; additional data plots are in Appendix A.
- Ecology conducted a temperature, dissolved oxygen, and nutrients (including nitrogen, phosphorus, and organic carbon) survey of the Soos Creek hatchery in 2020 (Neculae and

5 https://kingcounty.gov/services/environment/watersheds/hic/About.aspx
6 https://green2.kingcounty.gov/streamsdata/Default.aspx

Mathieu 2020). Preliminary observations from this work include (Mathieu and Neculae 2023):

- Big Soos Creek stream temperatures were typically slightly cooler downstream of the Soos Creek hatchery than upstream.
- Big Soos Creek dissolved oxygen (DO) levels were typically slightly lower downstream of the Soos Creek hatchery compared to results upstream; however, the decrease was smaller than the instrument accuracy, and DO levels were greater in hatchery process water compared to Soos Creek downstream.
- Nutrient concentrations within the hatchery were:
  - Somewhat elevated for phosphorus, ammonia, and particulate organic carbon in the effluent discharge from May to early July.
  - Very elevated for nitrate-nitrite from late July to mid-Sept due to high background levels in Wilson's spring water.
  - Somewhat elevated for phosphorus, ammonia, and particulate organic carbon in the adult fishpond ladder from late September to October.

- King County and Ecology 2007 water quality study to support TMDL development. This dataset includes continuous temperature monitoring from mid-July through September 2007 and water quality samples, short-term water quality sonde deployment data, periphyton samples, streamflow measurements, and time of travel collected during a synoptic survey in late July 2007. Steady-state QUAL2Kw models (Version 5) were built for Big Soos, Little Soos, Covington, and Jenkins Creek. Some data results are plotted and discussed in this section. Modeling results/observations included:
  - Simulated temperatures were very sensitive to channel geometry in areas with the lowest flow.
  - Big Soos Creek met the 16°C criterion with cooler tributary temperatures and site potential shade. However, shade assumptions in upper wetland areas may not have been valid, and the supplemental spawning criteria were not evaluated because only July critical conditions were simulated.
  - Macrophyte biomass was presumed to be the primary source of algal productivity.
  - Model calibration of macrophyte productivity resulted in very little response to instream nutrient concentrations.
  - Macrophytes were the only bottom algae group simulated, so periphyton biomass and productivity were not estimated, although observed periphyton biomass was collected in some areas.
  - Concluded that observed low DO is primarily caused by high dissolved organic matter (CBOD) and/or sediment oxygen demand in the low gradient headwaters. Sensitivity tests indicated that tributary CBOD was the primary factor in the calibrated model driving low DO in upper Big Soos Creek.
  - Concluded that site potential shade was a significant limiting factor in algae growth.

Temperature

The richest dataset for characterizing temperature impairments in the Soos watershed is the long-term continuous temperature monitoring conducted by the King County WLRD Hydrologic Monitoring Program. This data indicates multiple years of temperature exceedances for both the core summer salmonid habit (16°C 7-DADMax) and, in areas where they apply, supplemental spawning criteria (13°C 7-DADMax for September 15 to July 1). Figures 6-11 display the continuous temperature data for the years 1996 to 2021 and show the exceedances at all King County sites at Big Soos Creek and major tributaries in the watershed.

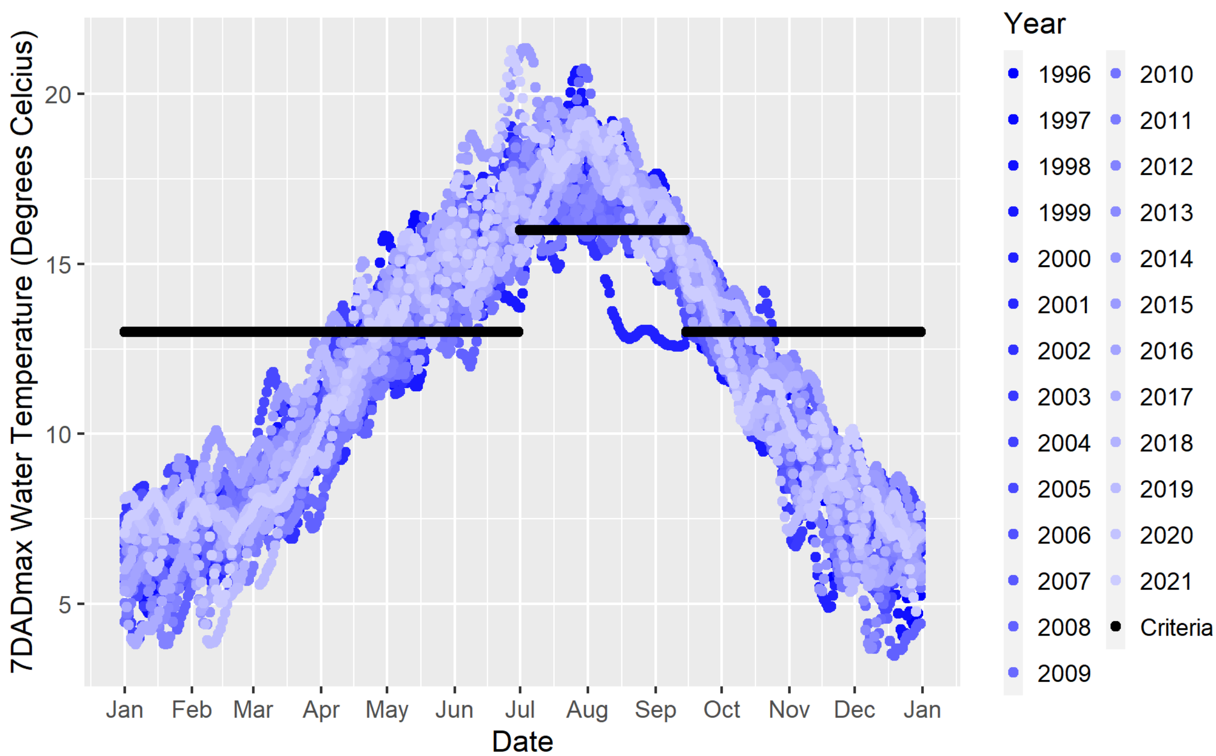

Figure 6. Big Soos Creek at mouth (54a) 7-DADMax water temperatures for 1996 – 2021.

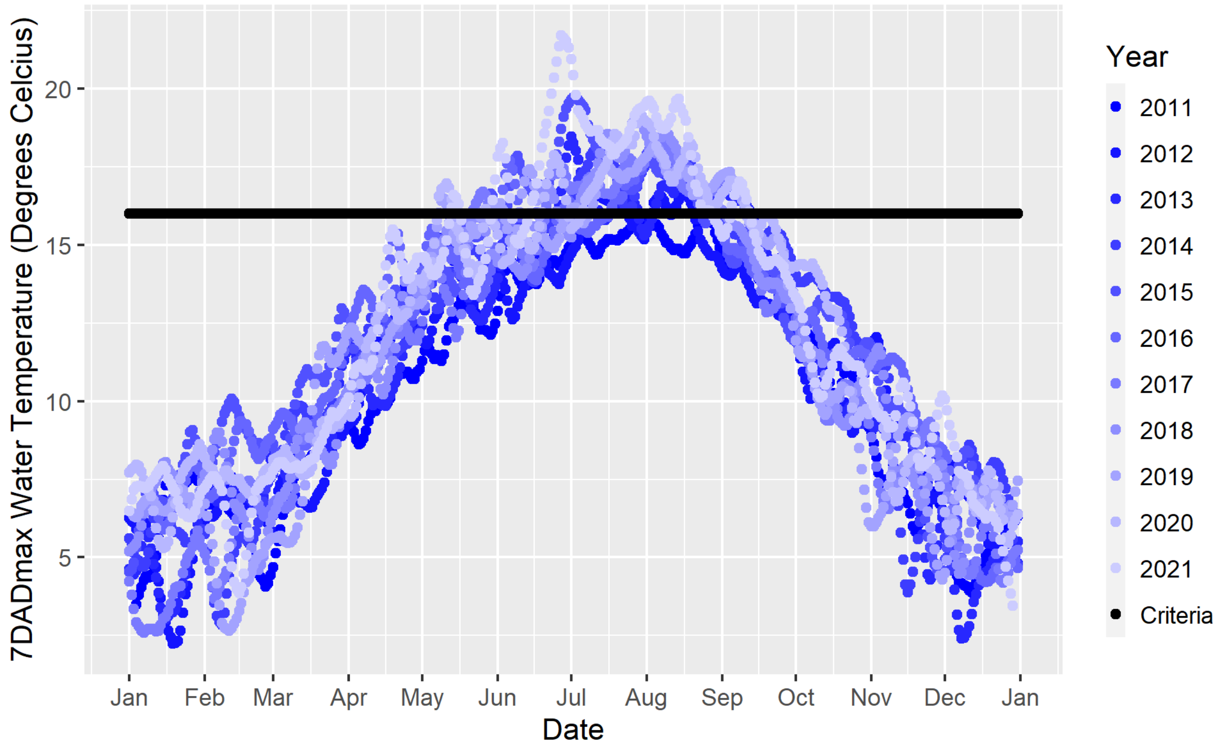

Figure 7. Big Soos Creek at Kent-Black Diamond Rd (54j) 7-DADMax water temperatures for 2011 – 2021.

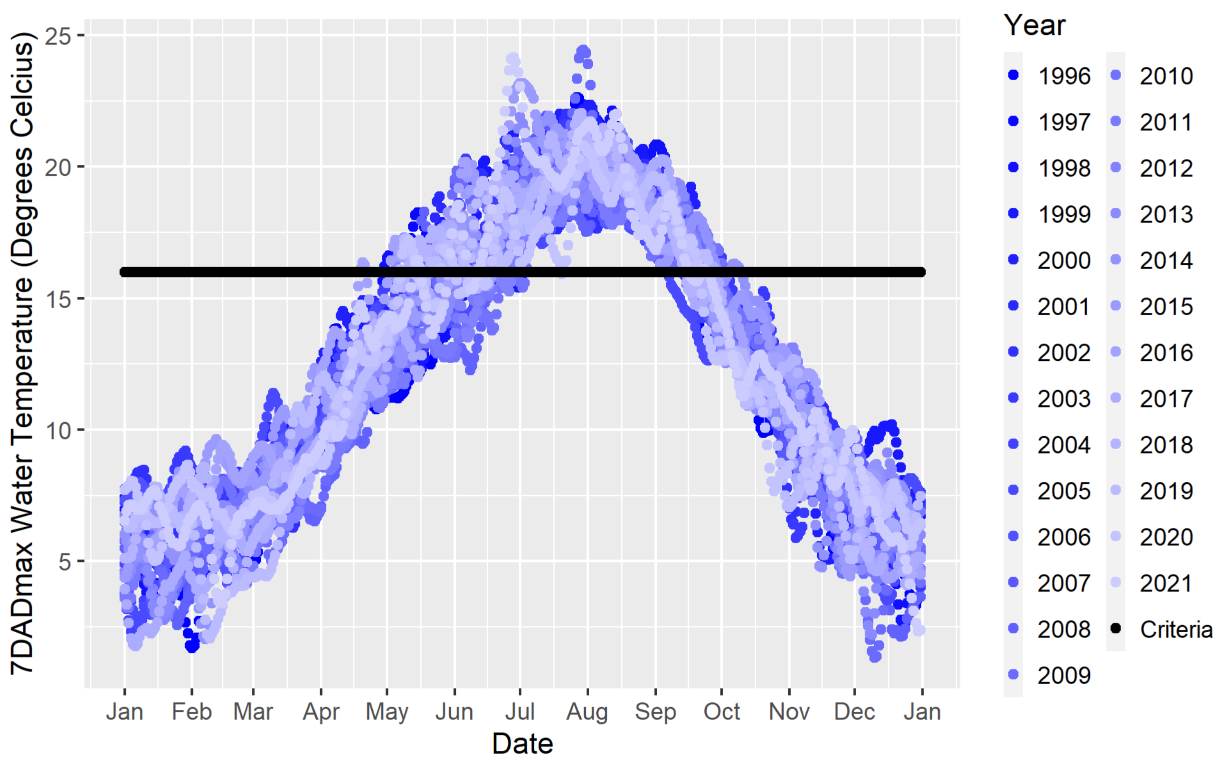

Figure 8. Little Soos Creek at SE 272nd (54i) 7-DADMax water temperatures for 1995 – 2021.

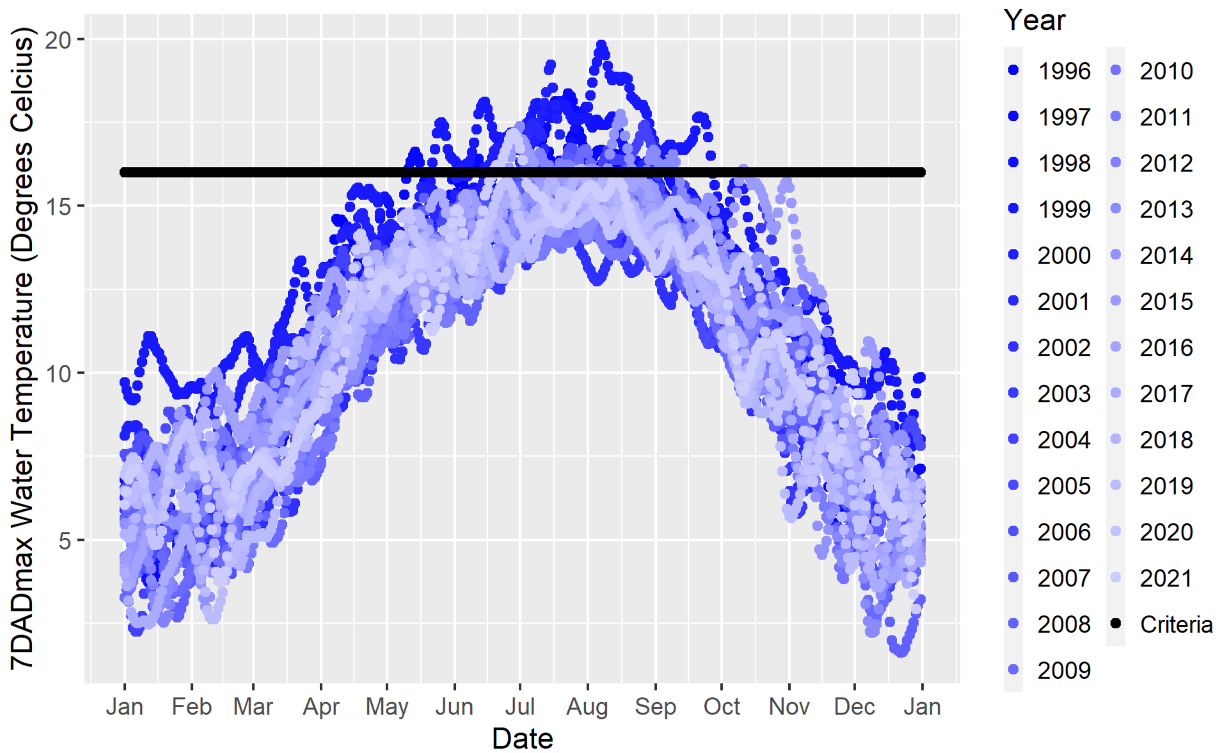

Figure 9. Soosette Creek above SR18 (54h) 7-DADMax water temperatures for 1995 – 2021.

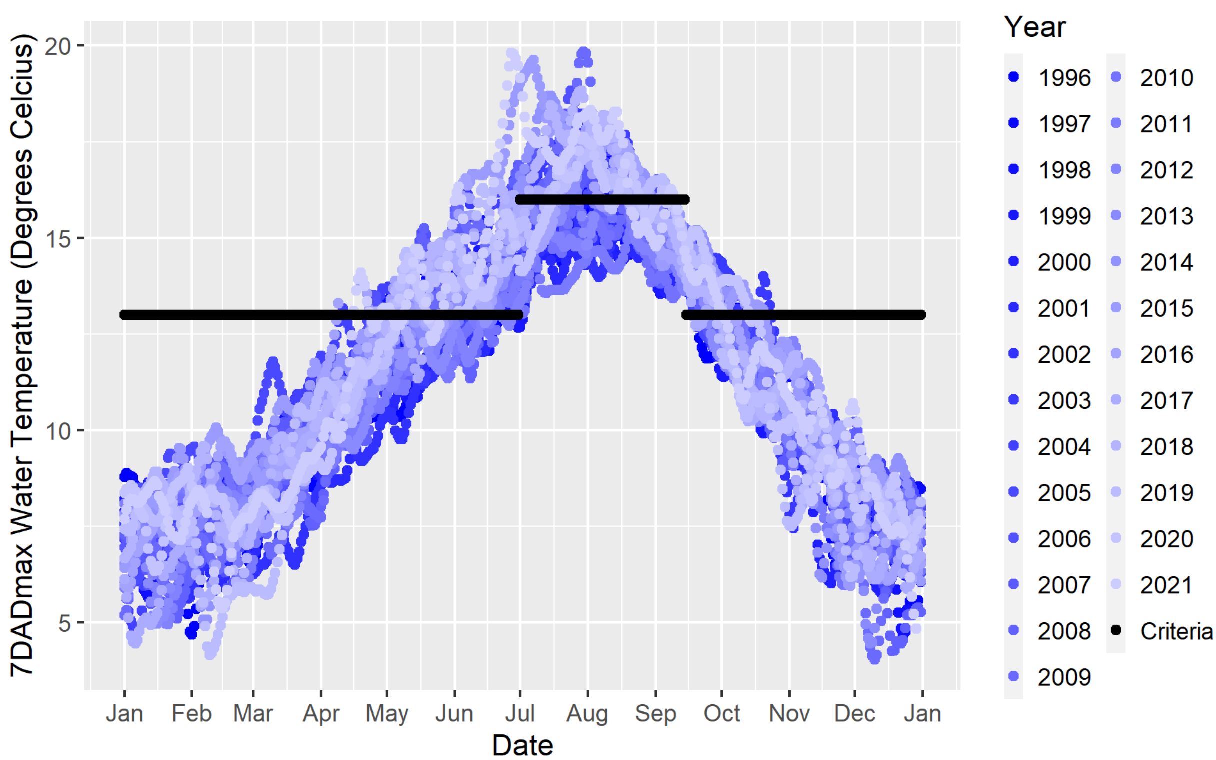

Figure 10. Jenkins Creek near mouth (26a) 7-DADMax water temperatures for 1996 – 2021.

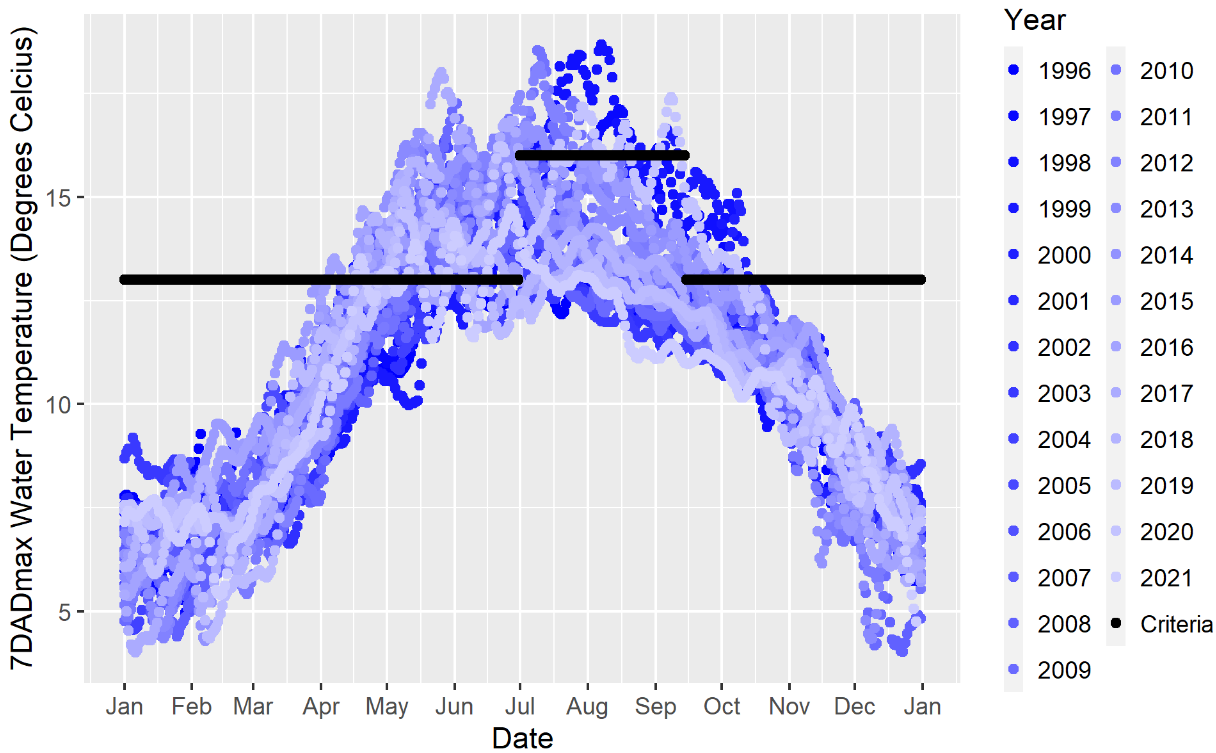

Figure 11. Covington Creek (09a) 7-DADMax water temperatures for 1996 – 2021.

Dissolved Oxygen

Several studies have identified low DO levels that fail to meet Washington State water quality criteria based on Ecology's Water Quality Assessment[7] process. See Figure 2 for segment locations. To summarize:

- **Lower Big Soos Creek (mouth to confluence with Soosette Creek)** — Daily minimum DO concentrations below 9.5 mg/L on 32 days in 2015; the lowest value was 8.18 mg/L.
- **Middle Big Soos Creek (between SE 256th St and SR516)** — Daily minimum DO concentrations below 9.5 mg/L on 2 days in 2015; the lowest value was 2.25 mg/L.
- **Upper Big Soos Creek (upstream of Lake Youngs Way to SE 224th St)** — Very old 303(d) listing based on unpublished data from the early to mid-1990s.
- **Little Soos Creek (entire stream)** — Daily minimum DO concentrations below 9.5 mg/L on 12 days in 2015 and 2 days in 2017; the lowest value was 7.28 mg/L. Additional excursions in earlier years.
- **Jenkins Creek (lower)** — Daily minimum DO concentrations below 9.5 mg/L on 37 days in 2015; the lowest value was 7.78 mg/L.
- **Covington Creek (lower)** — Daily minimum DO concentrations below 9.5 mg/L on 6 of 12 days in 2014 and 3 of 12 days in 2008; the lowest value was 8.3 mg/L. Additional excursions in earlier years.

[7] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d

- **Upper Soosette Creek watershed (labeled as Little Soosette Creek in listings)** — Very old 303(d) listing based on unpublished data from the early to mid-1990s.

King County's long-term monitoring program has also identified seasonally low DO levels during other years in the watershed (Figures 12 – 15), which have not all been included in the water quality assessment. These data show DO frequently below the new 10 mg/L criterion for all the creeks. It should be noted that discrete DO measurements typically do not represent the lowest values as they are dependent on the time of day due to photosynthetic activity and temperature changes.

Limited diel monitoring at an expanded network of sites in 2007 shows that summer daily minimum DO can be even lower than discrete data, and some sites experience moderate daily swings in DO concentration (Figure 16). However, calculated DO saturation values (using temperature and elevation) for this same data suggest that at several locations, including lower Big Soos, Little Soos, and Jenkins, low DO values may be driven primarily by high temperatures, as saturation levels were near or above 95% (Figure 17).

Figure 12. Discrete DO concentrations at King County site A320, Big Soos above hatchery.

Figure 13. Discrete DO concentrations at King County site C320, Covington Creek.

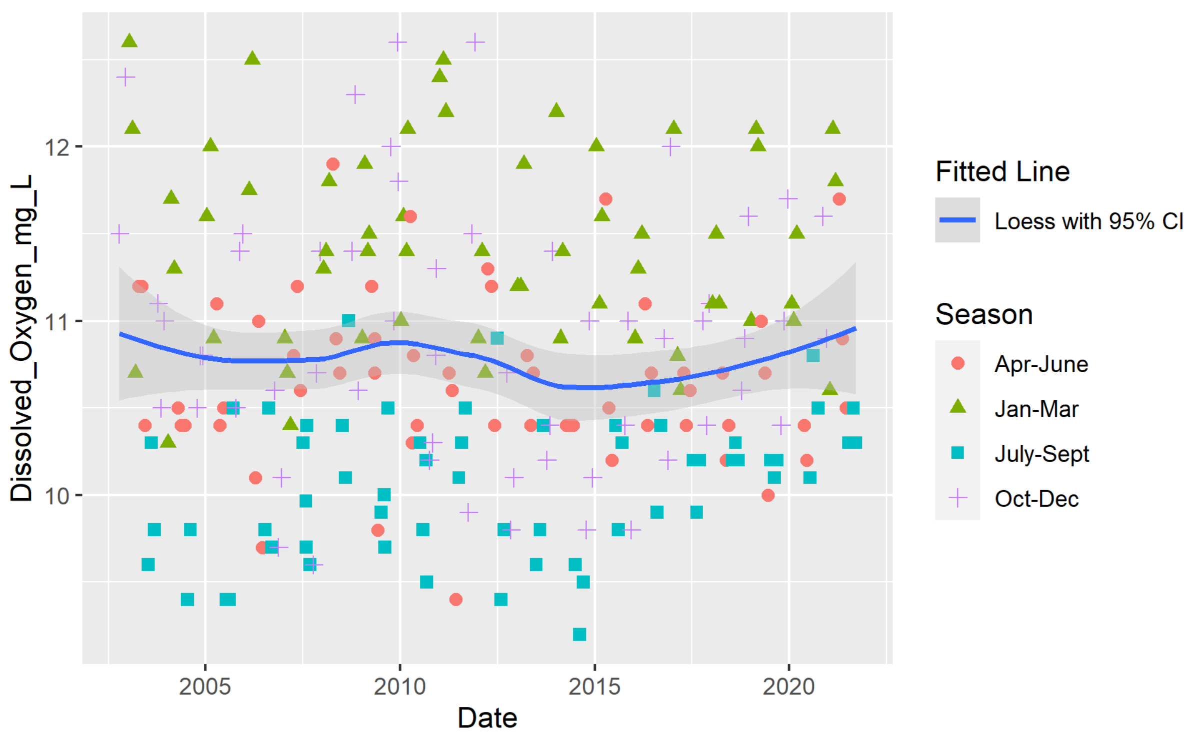

Figure 14. Discrete DO concentrations at King County site D320, Jenkins Creek.

Figure 15. Discrete DO concentrations at King County site G320, Little Soos Creek.

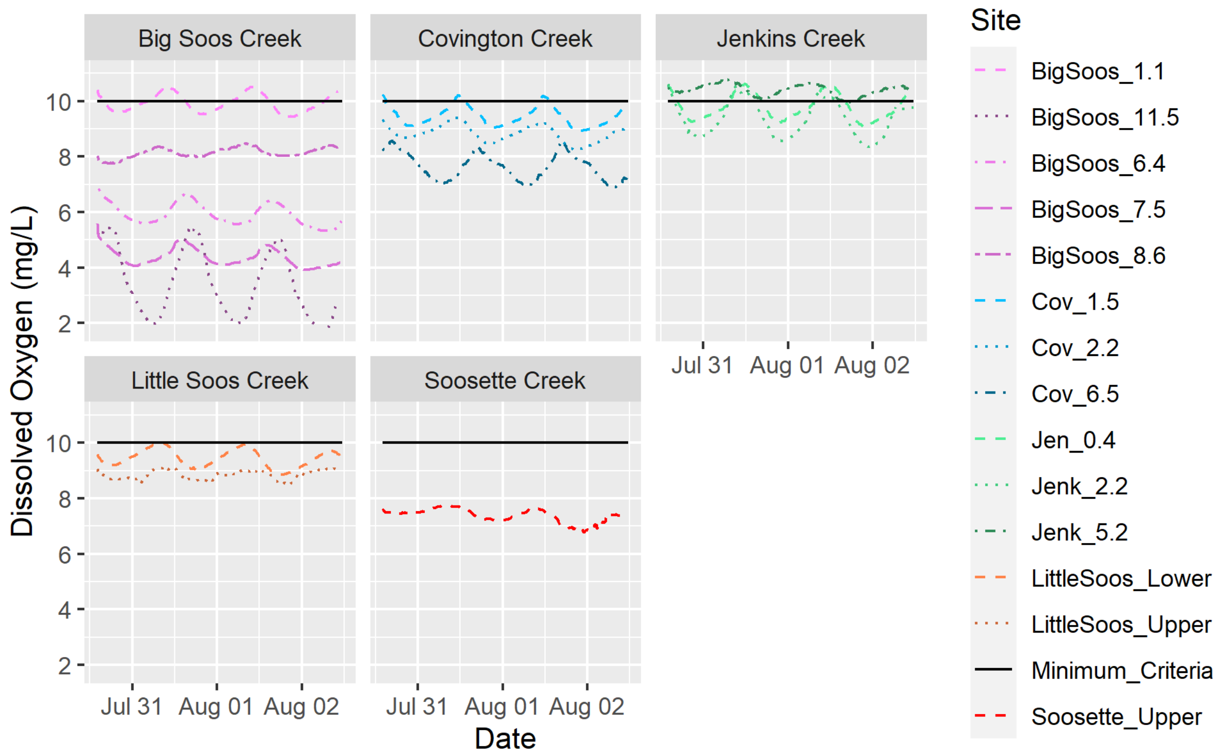

Figure 16. Daily fluctuations in Soos Creek watershed DO during 2007 sonde deployments.

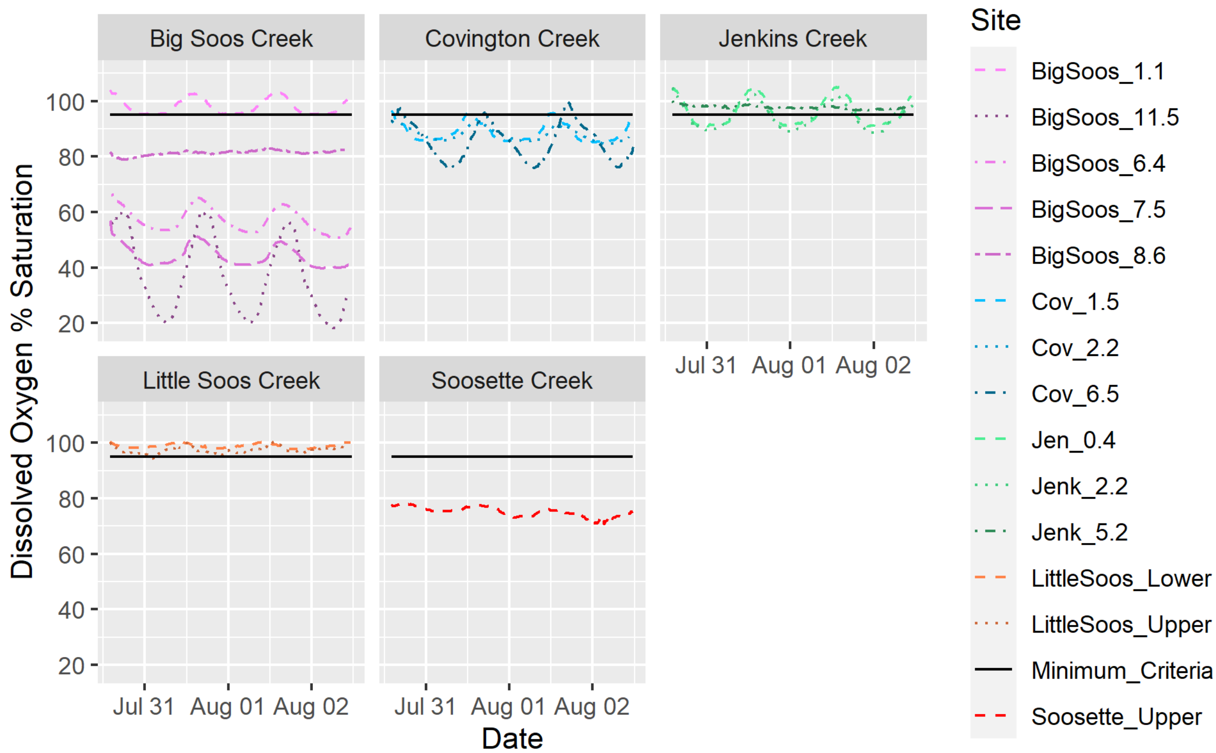

Figure 17. Daily fluctuations in Soos Creek watershed DO percent saturation during 2007 sonde deployments.

Nutrients

Figures 17 – 19 plot the King County WLRD Streams Program historical nutrient data for lower Big Soos Creek. Instream dissolved nutrient concentrations are important to floating algae, floating macrophytes, and bottom algae growth. The growth of these plants may be limited by the concentration of one or more nutrients if the nutrient levels are low enough (below saturation level).

Historical nutrient data suggests potential nutrient limitation or saturation varies throughout the watershed:

- Lower Big Soos Creek - Figure 19 suggests that phosphorus would be the most likely nutrient to limit algal growth with dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (SRP) mass ratios typically above 10:1 in the range of 30:1 – 80:1 in the summer.
  - Figure 17 shows that orthophosphate (equivalent to SRP) is typically in the range of 10 – 20 ug/L in lower Big Soos Creek, which suggests that reductions in instream phosphorus could exhibit some mild control on algal growth, given they are within the general range of saturation levels from the literature (Bothwell 1985; Rier and Stevenson 2006), although Bothwell found diatom saturation levels can be very low.
  - Nitrate-nitrite concentrations suggest that algae growth is likely saturated at these levels, and even significant reductions in DIN would most likely exhibit little control on algal growth. Rier and Stevenson (2006) found 90% saturated growth at 86 ug/L DIN,

approximately an order of magnitude less than typical DIN concentrations in the Soos system.

- Jenkins Creek nutrient levels and potential limitations are similar to Big Soos Creek (Appendix A).
- Covington Creek shows very high DIN:SRP ratios, often above 100:1, and very low SRP concentrations, typically around 4 – 5 ug/L, and high DIN concentrations, which suggest likely phosphorus limitation.
- Little Soos Creek has lower DIN:SRP ratios of 10 – 20:1 and relatively low concentrations of both DIN and SRP. There is a possibility of either nutrient or both (co-limitation) occurring in this system. However, as noted above, low DO levels may be primarily driven by elevated temperatures at this site.

Figure 18. Orthophosphate concentrations at Big Soos Creek at creek mile 1.1 collected by King County, 2003 – 2022.

Figure 19. Nitrate-nitrite concentrations at Big Soos Creek at creek mile 1.1 collected by King County 2003 – 2022.

Figure 20. Ratio of dissolved inorganic nitrogen to soluble reactive phosphorus at Big Soos Creek at creek mile 1.1 based on samples collected by King County 2003 – 2022.

Bacteria

Bacteria impairments identified in the watershed are currently based on historical fecal coliform (FC) data, the previous recreation freshwater indicator for bacteria in the Washington State Water Quality Standards. *Escherichia coli* (*E. coli)* is the new indicator used for primary contact recreation. King County has collected limited *E. coli* data since 2019 (Table 3) in the watershed, which can be used to help estimate the current level of impairment. In addition, King County collected both parameters at the four long-term monitoring sites from Feb 2019 to Jan 2021.

A more formal statistical analysis of trends and relationships is outside the scope of this QAPP; however, the data included in this analysis suggests:

- There is a moderately strong relationship between FC and *E. coli* in the watershed, but that relationship can be variable depending on the location (Figures 21 and 22).
- Recent *E. coli* data for all four monitored creeks demonstrated that primary contact recreation criteria are not being met.
- *E. coli* concentrations are highest in summer months, with concentrations above 100 cfu/100 mL observed between May and October, but most typically in July through September. Estimated exceedances of standards occur in the dry season only.
- FC concentrations in lower Big Soos Creek remain elevated in summer based on long-term data, but the highest concentrations appear to have decreased in recent years (Figure 22).

Table 3. Summary of *E. coli* data collected for King County WRLD 2019 – 2021.

Site	Location	Maximum 90-day Geomean* (cfu/100 mL)	Maximum concentration (cfu/100 mL)	Months with samples above 100 cfu/100 mL
A320	Big Soos CM1.1	209	310	May, June, July, Aug, Sept
C320	Covington	175	210	July, Aug
D320	Jenkins	495	790	Aug, Sept
G320	Little Soos	433	720	July, Aug, Sept, Oct

*replicates averaged

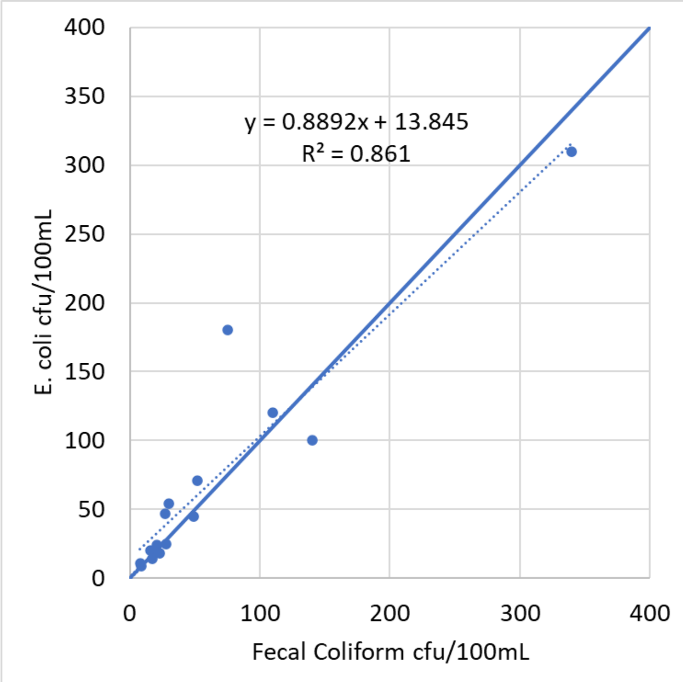

Figure 21. Big Soos Creek at creek mile 1.1 (n=15).

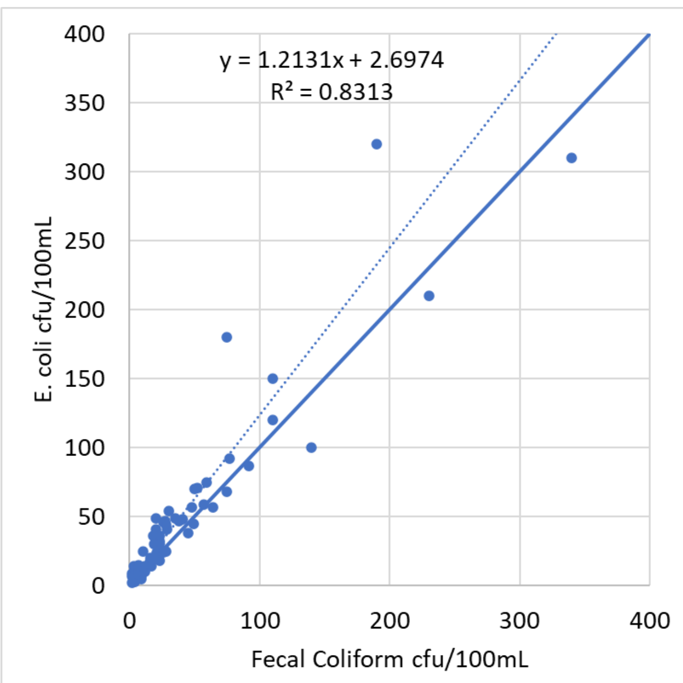

Figure 22. Big Soos, Little Soos, Covington, Jenkins (n=63).

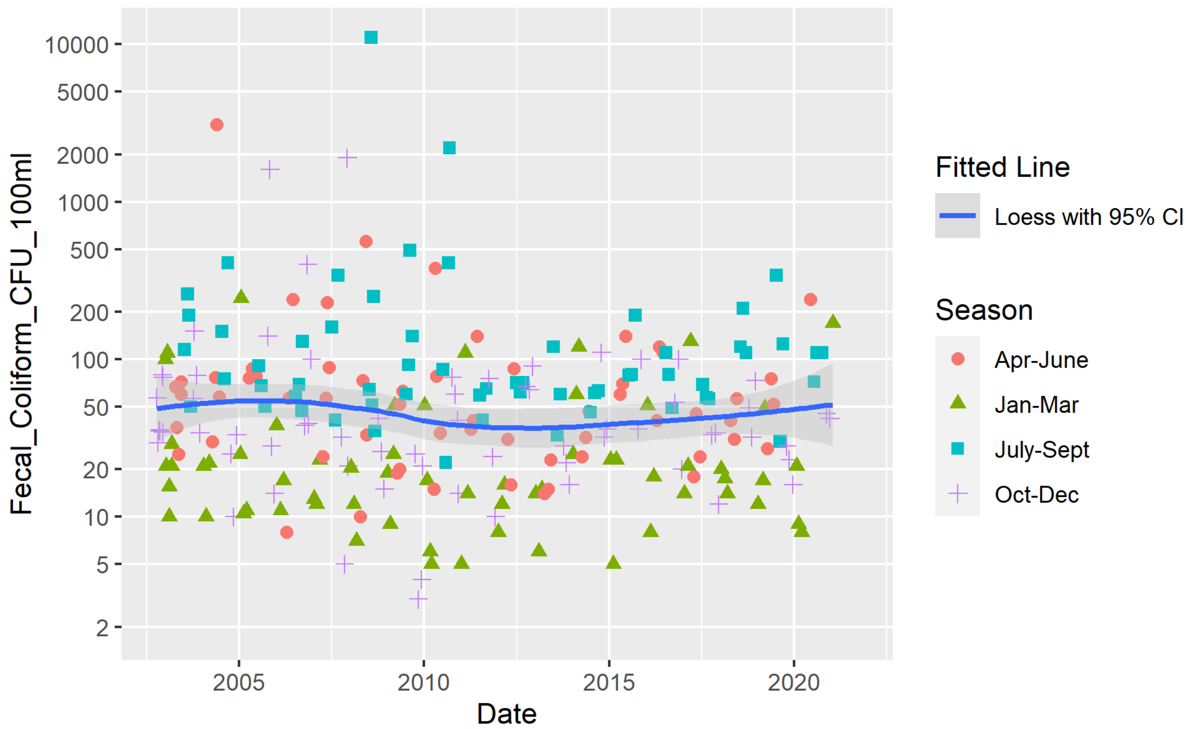

Figure 23. FC concentrations at Big Soos Creek creek mile 1.1 2003 – 2022.
Data collected by King County.

pH

A few pH Category 2 (waters of concern) listings exist in the watershed, although the data was generally collected during low flows or in wetland dominated areas. Further work is needed to characterize pH in the watershed. Long-term monitoring based on discrete pH measurements suggests pH is meeting criteria on Big Soos Creek (Figure 23), as well as Covington, Jenkins, and Little Soos Creeks (Appendix A). Continuous diel pH data collected in July 2007 (Figure 24) shows pH between the two criteria but also shows that pH is below 7 in upper Big Soos Creek wetland areas and is nearing exceedance of the minimum 6.5 pH criteria.

Figure 24. Big Soos Creek pH at CM 1.1.

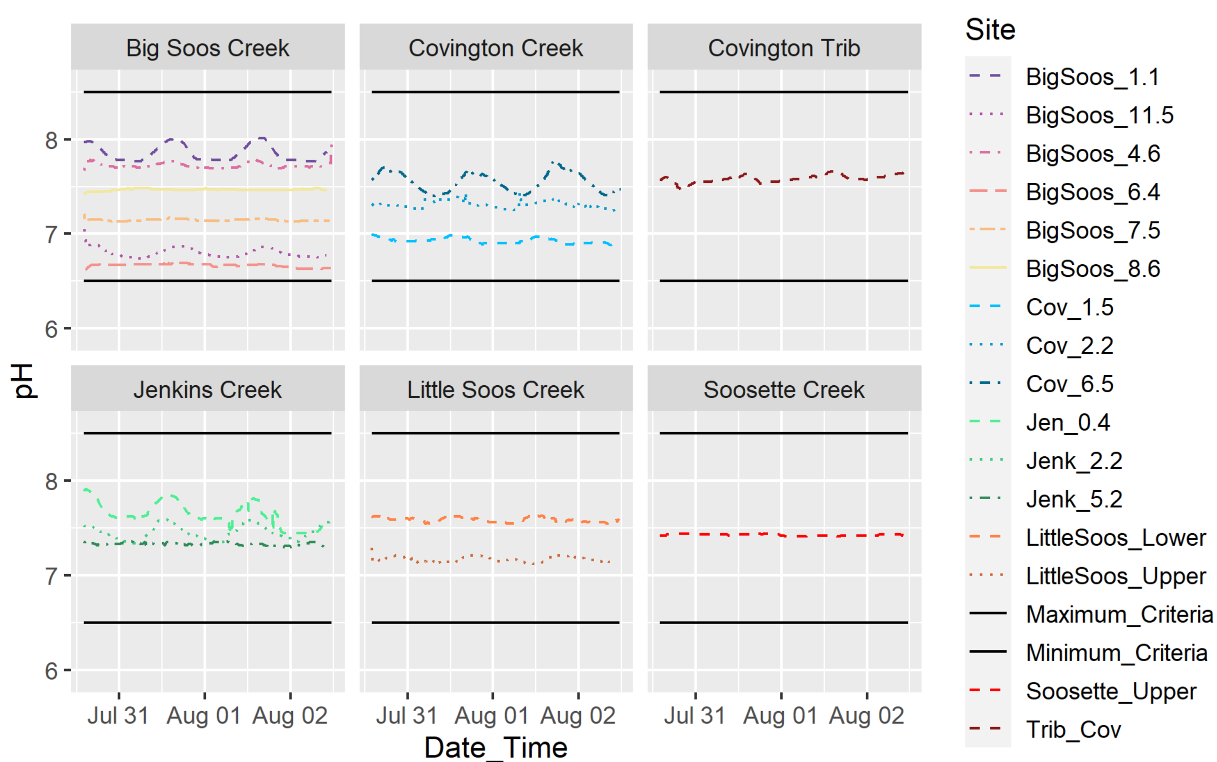

Figure 25. Soos watershed diel pH fluctuations summer 2007.

3.2.7 Parameters of interest and potential sources

The general parameters of greatest interest in this study include temperature, DO, *E. coli*, nitrogen, phosphorus, and carbon. The Programmatic QAPP for Water Quality Impairment Studies (McCarthy and Mathieu 2017) includes additional discussion of potential sources for these parameters.

Water temperature increases and potential sources

Elevated temperatures can harm aquatic life, particularly salmonids and aquatic insects. Potential sources of water temperature increases include:

- Loss of riparian shade resulting in more direct solar radiation reaching the stream surface. This loss can be due to land use changes in the riparian zone immediately adjacent to the stream channel, affecting vegetation species, height, abundance, and quality.
- Loss of baseflow due to water withdrawals and urbanization, which can reduce the amount of cool groundwater or upstream surface water, increasing the stream's bulk mixed temperature and making the stream shallower and more susceptible to warming from solar radiation.
- Widening of channel due to development within the riparian zone, particularly tree removal, can lead to a loss of bank stability and bank erosion. When combined with increased sediment deposition, these practices can lead to a wider, shallower channel that warms more easily in direct sun.
- Loss of floodplain/hyporheic connectivity and channel complexity due to the development and modification of stream channels, including straightening, dredging, and bank armoring.
- Increased air temperatures due to climate changes or loss of riparian buffer microclimate effects.

Dissolved oxygen decreases and potential sources

Depressed stream oxygen levels can harm aquatic life, particularly salmonids and aquatic insects. Potential mechanisms and sources of decreased DO include:

- Increases to stream temperature due to sources described above.
- Increases in dissolved instream nutrient concentrations (inorganic phosphorus, nitrate-nitrite, ammonia, and dissolved organic carbon), which fuels short-term, often direct, increases in algae growth, resulting in increased oxygen consumption from biological respiration.
- Increases in particulate organic matter loading (which includes particulate organic carbon, nitrogen, and phosphorus) to the sediment bed, which is broken down by organisms in the sediment layer or hyporheic zone over a longer period, resulting in increased oxygen consumption from biological respiration (sediment oxygen demand).
- Increase in carbonaceous biochemical oxygen demand (CBOD) due to readily degradable organic carbon loading to the water column.
- Discharge of water with depressed oxygen levels (for example, groundwater or flushing of stagnant water).
- The sources and pathways of these nutrients and low DO water are complex and numerous but can include:
    - Application of chemical or organic fertilizers above plant requirements.

- Pet, livestock, or other domestic animal waste.
- Wildlife waste.
- Decomposing organic matter on surfaces, in soils, or in stagnant water.
- Stormwater infrastructure is a pathway that can potentially short-circuit normal transport and biochemical cycles and result in the discharge of any of the above sources.
- Atmospheric deposition is another pathway that can result in the import of nutrients through either wet or dry deposition.
- Wastewater discharge from sanitary sewer overflows or on-site septic systems. There is no authorized wastewater discharge of treated municipal wastewater effluent in the study area. As summarized in previous sections, there are an estimated 10,000 on-site septic systems in the watershed of varying ages and conditions. These can contribute nutrients to nearby streams even when functioning as intended but contribute more when malfunctioning.
- Industrial process water discharges. There is one sand and gravel facility and one fish hatchery that discharges process water to the impaired waters in this study. Soos Creek hatchery nutrient levels are derived from a combination of background (influent) concentrations, waste from holding adult salmonids (no feeding), and rearing of juvenile salmonids (managed feeding).

Bacteria

Escherichia coli (*E. coli)* and fecal coliform (FC) are both forms of coliform bacteria that indicate the presence of fecal contamination from a warm-blooded animal. These types of bacteria have the potential to cause sickness and disease in humans and pets. As of December 2020, Chapter 173-201A WAC designates *E. coli* as the primary indicator to protect water contact recreation due to the strong correlation with illness from waterborne diseases. The sources of bacteria include:

- Pet waste from parks and residential areas.
- Wildlife waste, including mammals and waterfowl.
- Range and pastured livestock with access to stream or livestock manure applied to fields.
- Municipal and industrial wastewater and stormwater discharges.
- Failing on-site septic systems.

Permitted point sources

The following provides an inventory of current NPDES permits in the study area:

- General Construction Stormwater Permit
  - ~150 permits active as of February 2023
- Municipal Stormwater, Phase II
  - Maple Valley, City of; Permit # WAR045525
  - Covington, City of; Permit # WAR045510
  - Black Diamond, City of; Permit # WAR045505
  - Kent, City of; Permit # WAR045713
  - Auburn, City of; Permit # WAR045502

  - Renton, City of; Permit # WAR045539
  - Kent School District; Permit # WAR045520
- Municipal Stormwater, Phase I
  - King County; Permit # WAR044501
- WSDOT Municipal Stormwater; Permit # WAR043000A
- Sand and Gravel General Permit
  - King County DOT Covington Pit; Permit # WAG503110
  - Iddings Sand & Gravel; Permit # WAG507220
  - Lakeside Industries Kent Site 120; Permit # WAG503267
- Upland Fish Hatchery General Permit
  - WA DFW Soos Creek Hatchery; Permit # WAG133014

3.2.8 Regulatory criteria or standards

Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A-200) establish beneficial uses of waters and incorporate specific numeric and narrative criteria. The criteria are intended to define the level of protection necessary to support the beneficial uses. WAC 173-201A-600 and WAC 173-201A-602 list the use designations for specific areas, while WAC 173-201A-200 lists the criteria for specific parameters.

The designated uses of the waters in the study area in the Soos Creek watershed include:

- **Aquatic Life Use:** *Core summer salmonid habitat.* The key identifying characteristics of this use are summer (June 15 – September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and subadult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.
- **Recreation Use:** *Primary contact recreation.*
- **Water Supply Uses:** *Domestic, Industrial, Agricultural, Stock.*
- **Miscellaneous Uses:** *Wildlife Habitat, Harvesting, Commerce and Navigation, Boating, Aesthetics.*

Table 4 outlines the criteria for protecting the aquatic life and primary contact uses.

Table 4. Designated beneficial use and associated criteria.

Parameter	Beneficial Use	Applicable Period	Criteria
Temp	Aquatic Life- Core summer salmonid habitat	July 2 to Sept 14 (where supple-mental apply); Year-round in areas without	7-day average of the daily maximum temperatures (7-DADMax) less than or equal to 16°C (60.8°F)
Temp	Aquatic Life- Supple-mental Spawning and Incubation for Salmon and Trout [a]	Sept 15 to July 1	7-day average of the daily maximum temperatures (7-DADMax) less than or equal to 13°C (55.4°F)
Dissolved Oxygen	Aquatic Life- Core summer salmonid habitat	Year-round	Water column 1-Day minimum greater than or equal to 10 mg/L or 95% saturation [b]
pH	Aquatic Life- Core summer salmonid habitat	Year-round	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.
E. coli	Primary Contact Recreation	Year-round	*E. coli* organism levels within a 3-month averaging period [c] must not exceed a geometric mean value of 100 CFU or MPN per 100 mL, with not more than 10% of all samples (or any single sample when less than 10 samples exist) obtained within the averaging period exceeding 320 CFU or MPN per 100 mL.

[a] Supplemental criteria only apply to Big Soos Creek below the confluence with Jenkins Creek (47.33674°N, 122.13536°W), Jenkins Creek below Covington Way SE (47.34986°N, 122.11564°W), and Covington Creek downstream of 47.31223°N and 122.07390°W.

[b] Intragravel DO criteria for these aquatic life use categories may be used for compliance purposes. When intragravel DO is used for compliance, the intragravel DO (1-day minimum) concentration must be 8.0 mg/L or greater, and the DO water column (1-day minimum) concentration must be 9.0 mg/L or greater. Intragravel DO must be measured as a spatial median within the same habitat area.

[c] A minimum of three samples collected at well-distributed times within the averaging period is needed to calculate a geometric mean to compare to criteria. Averages should be calculated within the same season.

3.3 Water quality impairment studies

This study will be completed as a TMDL to address temperature, DO, and bacteria impairments. A small component of the monitoring effort is dedicated to baseline monitoring to help evaluate the future effectiveness of actions to address bioassessment impairments and fine sediment listings, which are part of a separate TMDL study (Mohamedali 2018).

The following section generally describes the elements of a TMDL.

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) a set of designated uses for all water bodies, such as salmon spawning, swimming, and fish and shellfish harvesting; (2)

numeric and narrative criteria to achieve those uses; and (3) an antidegradation policy to protect high-quality waters that surpass these conditions.

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. This list is part of the Water Quality Assessment (WQA) process in Washington State. To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data and 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 Category 5 designation, which collectively becomes the 303(d) list.

- **Category 1** — Waters that meet standards for the 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, and culverts.
- **Category 5** — Polluted waters that require a TMDL — the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website[8]. The Clean Water Act requires that a TMDL be developed for each water body on Category 5 of the 303(d) list.

[8] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d

4.0 Project Description

Historical data collection has identified temperature, DO, and bacteria impairments in the Soos Creek watershed, and therefore, these waterbodies are not meeting Washington State water quality standards. The pollutant sources and processes contributing to these impairments are numerous and complex; they can result from many different human causes and natural drivers, as discussed in Section 3.2.7. This project is designed to address these impairments.

This plan outlines extensive data collection, modeling, and analysis that will be used for the following outcomes:

- Set pollutant loading limits for sources related to human activity.
- Estimate land cover, water quality, and associated processes before settlement and development changes began in the 1800s.
- Explore future potential impacts on water quality from population growth, potential changes to infrastructure, and climate change.

4.1 Project goals

The major goals of this project are to:

- Confirm, identify, characterize, and address temperature, DO, and bacteria impairments in the Soos Creek watershed to improve water quality and restore impaired beneficial uses.
- Use a modeling framework and field data to predict the magnitude of pollution sources and the effects of source reduction and other management actions.
- Investigate, characterize, and estimate the historical, current, and potential future conditions of the watershed as they relate to instream temperature, DO, and bacteria.
- Delineate human-caused versus natural influences on temperature and DO in the Soos watershed.

4.2 Project objectives

Data collection objectives

- Routinely collect discrete water samples and water quality measurements at a fixed network of sites throughout the study area between May 2023 and April 2024.
- Characterize diurnal temperature, DO, pH, specific conductivity, and turbidity by collecting continuous data at key locations on Big Soos and major tributaries throughout the study.
- Understand bacteria, DO, and nutrient levels and loads from major tributaries, nonpoint and point sources, and stormwater drainages into Big Soos Creek under various seasonal and hydrological conditions.
- Conduct detailed synoptic surveys with sample and measurement collection at an expanded network of sites to characterize a heat balance and mass balance for flow, bacteria, and nutrients.
- Characterize instream biological productivity by sampling for periphyton and surveying for macrophytes.

- Qualitatively characterize sediment oxygen demand.
- Characterize riparian and channel characteristics by collecting channel geometry measurements and substrate measurements, near-stream vegetation measurements and characteristics, and shade data related to riparian vegetation and channel characteristics.
- Identify areas in Big Soos and major tributaries with gaining reaches where groundwater enters surface water and characterize groundwater influence on water quality.
- Identify areas of potential cold-water refuge and measure temperature differential between refuge (side channel, tributary, etc.) and mainstem.

Modeling and TMDL analysis objectives

- Expand an existing predictive hydrologic watershed model (see sections 4.3 and 7.3) of the entire Soos watershed to estimate nutrients, DO, temperature, and bacteria over a 10-year period from 2014 through 2024.
  - Use watershed loads as a basis for input to wetland and instream models.
  - Use watershed loads as the basis for dividing loads between point and non-point source categories and to guide TMDL implementation.
  - Estimate how land use or hydrologic changes throughout the watershed influence the magnitude and timing of these loads.
- Develop a predictive instream water quality model framework for Big Soos, Jenkins, Covington, Little Soos, and Soosette Creeks for all impaired segments (Figure 2) from May 2023 to April 2024 (see section 7.3 and 7.5 for exceptions and contingencies).
  - Simulate physical processes and heat balance and associated influences on temperature.
  - Develop shade models and effective shade curves.
  - Simulate instream biochemical processes and productivity and associated influences on DO.
  - Simulate *E. coli* bacteria settling and die-off.
  - Evaluate system potential temperature and DO conditions with the model by removing human pollutant sources, hydromodifications, and other potential sources of influence to the extent feasible based on available data.
  - Using critical conditions in the model, determine the loading capacity of pollutants needed to meet temperature, DO, and bacteria water quality criteria and protect beneficial uses.
- Estimate range of potential baseflow loss in the watershed using a combination of previous withdrawal estimates, calculated consumptive use for additional categories, and watershed model unimpacted hydrology scenario.
- Develop pollutant allocation scenarios for point and nonpoint sources to meet the loading capacity of each impaired waterbody.
- Use the calibrated models to evaluate scenarios for future water quality management of the Soos watershed.
- Estimate watershed nutrient, bacteria, and heat loading from different land uses under varying hydrologic conditions.

- Characterize how wetland processes influence these watershed loads before discharging to the impaired streams.
- Characterize driving physical, chemical, and biological instream processes contributing to temperature, DO, and bacteria impairments.

4.3 Information needed and sources

This section provides a brief overview of the information needed for this project. Section 7.3 provides more detailed information on the data needs for the modeling framework.

Information from existing sources (Ecology or otherwise), outside of Ecology's planned new work for this project, that will likely be utilized in this project:

- An existing Hydrologic Simulation Program Fortran (HSPF) watershed hydrology and sediment model calibrated for 2009-2015 by Ecology for the Soos fine sediment TMDL (QAPP: Mohamedali et al. 2018). Ecology has completed the calibration of this model, but the model results have not yet been published.
- Streamflow and other continuous stream data — USGS gage 12112600 on Big Soos Creek[9] and the King County WLRD Hydrologic Monitoring Program[10] network of sites in Soos.
- Meteorological data — National Weather Service (NWS), AgWeatherNet, and other approved data sources.
- LIDAR digital elevation model (DEM) data — King County West 2021 dataset:
  - Washington Geological Survey (WGS), King County, and local partners collaborated with the USGS to develop a county-wide lidar acquisition.
  - Bare Earth DEM and Top Surface DEM; Pixel resolution = 1.5 feet
- Groundwater data — USGS study described in this QAPP.
- River nutrient data — King County WLRD Streams Monitoring Program[11]
- Historic forest, wetlands, and riparian information — Bureau of Land Management (BLM) General Land Office (GLO) Cadastral Survey notes and plat maps[12] from the late 19th century.
- Point source discharge data — Facility reported / Discharge monitoring reports (DMRs)
  - WDFW currently collects routine nutrient and temperature data at the Soos Creek hatchery. Data will be obtained from WDFW contact.
- Extensive spatial nutrient source and land use data compiled for a regional Puget Sound SPARROW model currently under development (Figueroa-Kaminsky et al. 2022). Examples of data categories that will be used are on-site septic system and municipal stormwater infrastructure/outfall locations.
- Stormwater monitoring data — Hobbs et al. (2015) compiled a regional dataset of municipal stormwater contaminant concentrations associated with various land use types. This data consists of 3 years of flow-weighted composite storm event samples, which provides high-

[9] https://waterdata.usgs.gov/monitoring-location/12112600/
[10] https://kingcounty.gov/services/environment/watersheds/hic/About.aspx
[11] https://green2.kingcounty.gov/streamsdata/Default.aspx
[12] https://www.blm.gov/or/landrecords/survey/ySrvy1.php

quality data representative of large portions of the storm hydrographs (in contrast with grab samples).

The information we will collect as part of this study is described in Sections 4.4 and 7.

4.4 Tasks required

This section provides a brief overview of the tasks required to complete this water quality monitoring study. Section 7 provides the details of the study design. The tasks required include the following:

Ecology Modeling and TMDL Unit Tasks

- Routinely collect water quality samples and field measurements throughout the watershed at fixed locations.
- Deploy and maintain instruments to continuously monitor temperature and DO at key locations for at least a year during the project.
- Deploy and maintain instruments to continuously monitor temperature, DO, specific conductivity, and pH at additional locations for a short term (2 days) during water quality synoptic surveys.
- Collect periphyton (mixed organisms typically dominated by diatoms) and macrophytes.
- Measure oxygen demand from streambed sediment (sediment oxygen demand; SOD) to qualitatively account for the rate of oxygen removed from the water column by the decomposition of organic matter by microbial activity.
- Collect flow measurements across the watershed to infer gaining and losing stream reaches and provide quantitative groundwater discharge or baseflow loss estimates.
- Compile data from this study and available other sources.
- Conduct thorough quality assurance/quality control (QA/QC) review of data.
- Conduct exploratory data analysis and evaluate the potential need for additional modeling framework in wetland reaches and small streams or low flow conditions.
- Based on the results of exploratory data analysis, develop an additional modeling framework for the wetland reaches and small streams/low flow conditions if the chosen framework appears to be inadequately representing the wetlands.
- Review existing 2009 – 2015 HSPF watershed hydrology model land uses compared to more recent land uses. Expand model simulation period through 2024 and evaluate model performance for the expanded period.
- Add *E. coli* bacteria and water quality parameter submodules and calibrate the HSPF model for water quality if model performance for the extended hydrology period is adequate.
- Develop and calibrate QUAL2Kw instream models for each creek, as mentioned in section 4.2.
- Develop model framework linkages, where necessary.
- Perform sensitivity and uncertainty analysis on all elements of the modeling framework.
- Develop model scenarios to estimate pollutant loading capacity and explore pre-human development, climate change, and future growth.

- Write, obtain reviews, finalize, and publish at least one report detailing the findings of this study.
- Draft load and wasteload allocations and appendices D and E for the water quality improvement report developed for TMDL submittal.

USGS Tasks

- Identify areas in Big Soos and major tributaries with gaining reaches where groundwater enters surface water and collect nutrient and water quality measurements in these gaining reaches.

Ecology Watershed Health and Effectiveness Monitoring Unit Tasks:

- Conduct instream habitat monitoring protocols for Watershed Health baseline monitoring.

4.5 Systematic planning process

This project was designed with input from Ecology's Water Quality and Environmental Assessment Programs during an extended scoping process in the fall of 2021 (Neculae and Mathieu 2022).

This QAPP, in combination with the *Programmatic QAPP for Water Quality Impairment Studies* (McCarthy and Mathieu 2017) and the extended scoping process, represents the systematic planning process for this study.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

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

Table 5. Organization of project staff and responsibilities.

Staff[1]	Title	Responsibilities
Cleo Neculae Water Quality Program Northwest Regional Office Phone: (206) 594-0138	TMDL Lead and EAP Client	Clarifies scope of the project and co-authors the QAPP. Coordinates with external stakeholders. Provides field support. Provides internal review of the QAPP and approves the final QAPP. Reviews the draft technical report/memos. Co-develops draft allocations; reviews and approves allocation appendices. **Lead author for the water quality improvement report.**
Nuri Mathieu Model & TMDL Unit, WOS Phone: (360) 522-0159	Modeling Principal Investigator	Co-authors the QAPP. Designs the modeling and analysis portions of the study. Conducts QA review of, analyzes, and interprets data. Lead for model development and calibration. **Lead author for the wetland, QUAL2Kw, and scenario modeling technical reports/memos**. Supporting author for other reports/memos. Develops draft allocations for appendices of the water quality improvement report.
Molly Gleason Model & TMDL Unit, WOS Phone: (360) 485-2649	Field Principal Investigator	Co-authors the QAPP. Designs the data collection portions of the study. Oversees field sampling and transportation of samples to the laboratory. Lead for data collection, management, and quality review. Conducts QA review of data, analyzes and interprets data, and enters data into EIM**. Lead author for the study results and data quality report**. Supporting author for other reports/memos.
John Gala Model & TMDL Unit, WOS Phone: (360) 407-7108	Field support and Project Modeler	Provides field support. Helps develop model inputs, assists/reviews with model parameter selection, calibration, and evaluation. Helps develop model scenarios. Leads HSPF and shade modeling tasks. **Lead author for the HSPF modeling technical report**. Supporting author for other reports.
Rich Sheibley USGS Phone: (253) 552-1611	Groundwater Monitoring and Analysis	Leads groundwater monitoring effort and stage monitoring at tributary sites. Lead for data collection, management, and quality review of data for those monitoring elements. **Writes groundwater technical report.**
Jamie Wasielewski Model & TMDL Unit, WOS Phone: (360) 280-0494	Data review and management support	Assists with preparation, data management, data quality review, and EIM data entry and review.
Andy Bookter Freshwater Monitoring Unit, WOS Phone: (360) 485-2649	Gage Monitoring	Leads installation and management of continuous flow and water quality gages. Lead for data collection, management, and quality review of data from gages.
Teizeen Mohamedali Model & TMDL Unit, WOS	Technical support and training	Provides training and support on HSPF model.
Jennifer Wolfe Watershed Health & Effectiveness Monitoring SCS Phone: (360) 764-0645	Watershed health baseline monitoring	Leads field efforts related to watershed health baseline monitoring, including benthic invertebrate and other instream habitat field sampling.

Staff[1]	Title	Responsibilities
Niamh O'Rourke Watershed Health & Effectiveness Monitoring SCS Phone: (360) 791-0220	Watershed health baseline monitoring	Assists with watershed health baseline monitoring, including benthic invertebrate and other instream habitat field sampling.
Molly Ware Model & TMDL Unit, WOS Phone: (360)-280-7712	Field Support	Supports field data collection, and independently collects measurements and samples under direction of Field Principal Investigator.
Cristiana Figueroa-Kaminsky Model & TMDL Unit, WOS Phone: (360) 764-9936	Unit Supervisor for Project Manager	Provides internal review of the QAPP, approves the budget, and approves the final QAPP. Provides technical support and guidance throughout the project. Reviews the draft and final reports.
Stacy Polkowske WOS Phone: (360) 464-0674	Section Manager for Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Dean Momohara MEL Phone: (360) 871-8801	Acting Director	Reviews and approves the final QAPP.
Arati Kaza Phone: (360) 407-6964	Ecology QA Officer	Reviews and approves the draft QAPP and the final QAPP.

[1]All staff except the client are from EAP.
EAP: Environmental Assessment Program
EIM: Environmental Information Management database
MEL: Manchester Environmental Laboratory
QAPP: Quality Assurance Project Plan
WOS: Western Operations Section
SCS: Statewide Coordination Section
BOS: Business Operations Section

5.2 Special training and certifications

All field staff involved in this project either already have the relevant experience in the Standard Operating Procedures (SOPs) listed in Section 8.2 or will be trained by more senior field staff. Any field staff with limited experience will be paired with trained and experienced staff who will lead the field data collection and oversee/mentor less experienced staff.

5.3 Organization chart

See Table 5 for a list of individuals involved in this project.

5.4 Proposed project schedule

Tables 6, 7, and 8 list key activities, due dates, and lead staff for this project.

Table 6. Schedule for completing field, laboratory work, EIM data entry and review.

Task	Start Date	Due date	Lead Staff
Install temperature/DO loggers	April 2023	April 2023	Molly Gleason
Install piezometers & water level loggers	April 2023	May 2023	Rich Sheibley (USGS)
Install flow/water quality gages	May 2023	May 2023	Andy Bookter
Routine surface water (SW) and groundwater (GW) sampling	May 2023	April 2024	Molly Gleason (SW) Rich Sheibley (GW)
Other field studies	May 2023	April 2024	Molly Gleason
Laboratory analyses	May 2023	May 2024	Manchester Environmental Lab
EIM data loaded*	November 2023	November 2024	Molly Gleason
EIM QA	December 2024	December 2024	Jamie Wasielewski
EIM complete	January 2025	January 2025	Molly Gleason

Table 7. Schedule for analysis, modeling, and writing.

Task	Start Date	Due Date	Lead Staff
Write first draft of observational results and quality report	Jan 2025	June 2025	Molly Gleason
USGS analysis and draft groundwater report	Jan 2025	June 2025	Rich Sheibley
HSPF Extended Hydrology Evaluation	Nov 2023	Feb 2024	John Gala
HSPF Model Setup and Calibration	March 2024	Jan 2025	John Gala
Write first draft of HSPF report	Jan 2025	June 2025	John Gala
Develop/calibrate wetland models	July 2024	Jan 2025	Nuri Mathieu
Write wetlands analysis documentation	Jan 2025	June 2025	Nuri Mathieu
QUAL2Kw Model develop/calibrate	July 2024	June 2025	Nuri Mathieu
Sensitivity and uncertainty analysis	July 2025	July 2025	Nuri Mathieu
Scenario modeling	August 2025	December 2025	Nuri Mathieu
Write QUAL2Kw and Scenarios Technical Report	Jan 2026	June 2026	Nuri Mathieu

Table 8. Schedule for final reports.

Report	Task	Due Date	Lead Author
Observational Data	Draft to supervisor	July 2025	Molly Gleason
Observational Data	Final report due on web	Dec 2025	Molly Gleason
HSPF*	Draft to supervisor	Jan 2026	John Gala
HSPF*	Final report due on web	June 2026	John Gala
Wetlands, QUAL2Kw, & Scenarios	Draft to supervisor	July 2026	Nuri Mathieu
Wetlands, QUAL2Kw, & Scenarios	Final report due on web	Dec 2026	Nuri Mathieu

*Contingent on extended period hydrology evaluation (see section 6.4)

5.5 Budget and funding

Tables 9 and 10 outline the cost for samples for different monitoring elements of the project. Table 11 outlines the budget for USGS activities (see Section 4.4 and 7.2) over the federal fiscal year schedule. Table 12 lists the total budget for the project.

Table 9. Laboratory budget details for surface water and biological samples.

Parameter	Number of Samples	Number of Duplicate Samples	Number of Blank Samples	Total Number of Samples	Cost Per Sample	Lab Subtotal
E. coli + Fecal coliform	571	114	NA	685	$50.00	$34,250.00
Alkalinity	201	24	4	228	$20.00	$4,580.00
Dissolved Organic Carbon (DOC)	201	24	4	228	$45.00	$10,305.00
Total Organic Carbon (TOC)	201	24	4	228	$35.00	$8,015.00
Total Non-volatile Suspended Solids (TNVSS)	181	20	4	205	$30.00	$6,150.00
Total Suspended (TSS)	181	20	4	205	$15.00	$3,075.00
Total Phosphorus	201	24	4	228	$20.00	$4,560.00
Ammonia	201	24	4	228	$15.00	$3,435.00
Nitrate + Nitrite as N	201	24	4	228	$15.00	$3,435.00
Total Persulfate Nitrogen	201	24	4	228	$20.00	$4,580.00
Orthophosphate	201	24	4	228	$20.00	$4,580.00
Chlorophyll	120	24	4	148	$60.00	$8,880.00
Chloride	200	24	4	228	$15.00	$3,420.00
5-Day Biochemical Oxygen Demand	107	15	4	126	$60.00	$7,560.00
Periphyton - Areal Biomass as Ash Free Dry Weight (AFDW)	30	3	NA	33	$24.93	$822.69
Periphyton - Chlorophyll	30	3	NA	33	$46.60	$1,537.80
Periphyton - Percent Total Solids	30	3	NA	33	$11.92	$393.36
Periphyton Identification	30	3	NA	33	$300	$9,900.00

Table 10. Laboratory budget details for groundwater samples.

Parameter	Number of Samples	Number of Duplicate Samples	Number of Blank Samples	Total Number of Samples	Cost Per Sample	Lab Subtotal
Alkalinity	120	12	4	136	$20.00	$2,720.00
Dissolved Organic Carbon (DOC)	120	12	4	136	$45.00	$6,120.00
Total Organic Carbon (TOC)	120	12	4	136	$35.00	$4,760.00
Total Phosphorus	120	12	4	136	$20.00	$2,720.00
Ammonia	120	12	4	136	$15.00	$2,040.00
Nitrate + Nitrite as N	120	12	4	136	$15.00	$2,040.00
Total Persulfate Nitrogen	120	12	4	136	$20.00	$2,720.00
Orthophosphate	120	12	4	136	$20.00	$2,720.00
Chloride	120	12	4	136	$15.00	$2,040.00
Iron	120	12	4	136	$40.00	$5,440.00

Table 11. Estimated budget for contract with the USGS by Fiscal Year[a].

Project Type	FY 2023	FY 2024	FY 2025	Total for Project Type
Salaries	$67,800	$104,300	$24,800	$196,900
Equipment and Supplies	$7,800	$2,100	-	$9,900
Publishing and Data Release	-	-	$7,700	$7,700
Indirect and Facilities Costs	$65,800	$92,600	$22,500	$180,900

[a]The Federal Fiscal Year (FY) begins in October and ends in September.

Table 12. Project budget.

Monitoring Type	Cost
Fixed Network Monitoring; Water Quality Synoptic Survey — Sample Costs	$119,478.85
Groundwater Monitoring — Sample Costs	$33,320.00
USGS Joint Funding Agreement — Ecology funding	$295,400
USGS Joint Funding Agreement — Cooperative matching funds	$100,000

6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. The standard and approved requirements for project quality objectives listed in the QAPP are referenced from *Programmatic QAPP for Water Quality Impairment Studies* (McCarthy and Mathieu 2017).

6.1 Data quality objectives

Data collected for this project should meet the measurement quality objectives (MQO) to be used for the project goals. Decisions can be made on a case-by-case basis for data that do not meet the MQO as to whether the data can be used for project purposes (e.g., informational, estimated values). The final report will document how any data that did not meet MQOs were used and the rationale for including them.

6.2 Measurement quality objectives

Field sampling procedures and laboratory analysis inherently have associated error. MQOs state the allowable error for a project. Precision and bias provide measures of data quality and are used to assess agreement with MQOs.

6.2.1 Targets for precision, bias, and sensitivity

6.2.1.1 Precision

Precision is a measure of variability in replicate measurements due to random error. Precision is usually assessed using duplicate field measurements or duplicate samples for lab samples.

Tables 5 and 8 of the *Programmatic QAPP for Water Quality Impairment Studies* (McCarthy and Mathieu 2017) present measurement MQOs for precision for field equipment used in this study. These include YSI EXOs, Hydrolab, and HOBO Tidbit V2 instruments for water quality measurements and StreamPro and OTT MF Pro instruments for streamflow measurements. Table 13 presents the MQOs for equipment used in this project that are not included in the Programmatic QAPP.

Table 13. Manufacturer specifications for field equipment used in this project.

Parameter	Equipment	Precision–Field Duplicates (median)	Equipment Accuracy	Equipment Resolution	Equipment Range	Expected Range
Dissolved Oxygen	Onset HOBO DO Data Logger	5% RSD	± 0.2 mg/L from 0–8 mg/L; ± 0.5 mg/L from 8 to 20 mg/L	0.02 mg/L	0–20 mg/L	0.1–15 mg/L
Turbidity	YSI EXO	15% RSD	0 to 999 FNU: 0.3 FNU or ±2% of reading, whichever is greater; 1000–4000 FNU: ±5% of reading	0.1 FNU, NTU	0–4000 FNU, NTU	0–1000 FNU, NTU

6.2.1.2 Bias

Bias is the difference between the sample population mean and the true value. Bias is usually addressed by calibrating field and laboratory instruments and analyzing lab control samples, matrix spikes, and standard reference materials. Table 6 and 7 of the Programmatic QAPP (McCarthy and Mathieu 2017) presents the MQOs for surface water and groundwater field samples and associated lab analyses for this study. Section 7.2.2 of this QAPP provides a list of parameters that will be monitored for this study (see Table 14).

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance and is commonly described as the detection limit. Table 6 of the Programmatic QAPP (McCarthy and Mathieu 2017) presents the MQOs for the method reporting limits for the parameters of interest for this project.

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 adhere to data quality criteria and follow EAP protocols outlined in the Standard Operating Procedures (SOPs) outlined in Section 8.2.

6.2.2.2 Representativeness

See Section 6.2.2.2 of the Programmatic QAPP (McCarthy and Mathieu 2017).

To ensure representativeness in wetland and ponded areas, we will avoid collecting samples and measurements where the channel is less defined, behind beaver dams, near aquatic vegetation, or in areas with very low velocity (0.2 ft/s). We will instead look for a more channelized location with increased velocity downstream of the impacted reach.

6.2.2.3 Completeness

See Section 6.2.2.2 of the Programmatic QAPP (McCarthy and Mathieu 2017).

The completeness goal will be reduced from 80% to 50% for continuous time series data collected from more challenging site conditions, including low flows (<2 cfs), low velocities (<0.2 ft/s), and wetland reaches or other areas with excessive aquatic plant growth, such as macrophyte beds.

6.3 Acceptance criteria for quality of existing data

Any water quality data from outside this study used in the TMDL analysis must meet the agency's credible data policy requirements: Water Quality Policy 1-11 Chapter 2 — Ensuring Credible Data for Water Quality Management[13]. The final report will include an assessment of data quality for any outside data used for TMDL analysis and certification that the data meets a

[13] https://apps.ecology.wa.gov/publications/SummaryPages/2110032.html

level of quality acceptable for use in TMDL development. The data quality assessment would include one or all the following elements:

- Reference to a peer-reviewed and published Quality Assurance (QA) Project Plan or equivalent plan.
- Demonstration that the data collected yielded results of comparable quality to the study (based on data quality objectives and requirements in this QA Project Plan).
- Documentation that the objectives of the QA Project Plan or equivalent quality assurance procedures were met and that the data are suitable for water quality-based actions. The assessment of the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at the 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 gathered (e.g., chemical/physical data for TMDL analyses).
  - Description of the limitations on use of the data (e.g., these measurements only represent storm-event conditions).
  - Datasets must be complete, that is, not censored to include only part of the data results from the project.

6.4 Model quality objectives

Universally applied quantitative criteria for model performance do not exist. Quantitative criteria can be appropriate if thoughtfully set for individual projects. This project uses quantitative and qualitative model quality objectives to assess model performance.

See Section 6.3 of the Programmatic QAPP (McCarthy and Mathieu 2017) for a discussion of the broader model quality objectives for water quality impairment studies and a list of specific qualitative model quality objectives related to the key driving processes. All these objectives apply to this project. They outline what constitutes a good representation of channel geometry, instream flow, watershed hydrology, temperature, DO, pH, and nutrients.

The primary quality objective for the QUAL2Kw models for temperature and DO is to visually demonstrate a good match to spatial, daily, and seasonal patterns by using mechanisms and parameter values that are well supported by the study data and by scientific literature and theory.

Table 14 presents numerical targets that will be used to help evaluate the QUAL2Kw model's water quality calibration. These targets will guide a thoughtful, comprehensive evaluation of model quality within a larger domain. As such, poor calibration in parts of the model outputs (in either space or time) compared to any of these targets does not necessarily indicate that the model's calibration is unacceptable. Conversely, a good or fair rating does not necessarily mean the model will be deemed acceptable for all study objectives.

Ecology will not determine the overall quality of the model predictions based on a single statistic alone or comparison to a single established criterion. Instead, Ecology will assess overall quality based on:

- The model's ability to simulate key drivers and processes evident in observed data.

- Multiple statistical metrics that evaluate model bias, accuracy, and correlation.

Table 14 targets will be applied to the entire spatial domain of each creek, and not individual sites, except that upper and lower Big Soos Creek may be divided based on wetland influence before target comparison. Targets will be applied seasonally (wet and dry season) depending on hydrologic conditions in the study year. Any changes to what domain the targets are applied to will be well documented, with an appropriate justification, in the final report. Quality objectives for PointWQ, if utilized, will be the same as for QUAL2Kw, as described in Table 14.

Table 14. QUAL2Kw and PointWQ model calibration targets.

Parameter (unit)	Metric	Measure	Good	Fair	Poor
Temperature (°C)	Daily Max	RMSE	<0.8	0.8–1.6	>1.6
Temperature (°C)	Daily Max	Bias	<0.4	0.4–0.8	>0.8
DO (mg/L)	Daily Min	RMSE	<1.0	1.0–2.0	>2.0
DO (mg/L)	Daily Min	Bias	<0.5	0.5–1.0	>1.0
pH (standard units)	Daily Min/Max	RMSE	<0.3	0.3–0.6	>0.6
pH (standard units)	Daily Min/Max	Bias	<0.15	0.15–0.3	>0.3

Bias = Mean error; RMSE = Root Mean Square Error (see QA glossary in Appendix C).

Within the HSPF modeling community, thresholds for specific model metrics are sometimes used to communicate the general quality of model calibration. Table 15 provides thresholds that will be used to gauge the level of accuracy (e.g., from poor to good) expected from the HSPF model application.

Time constraints for this project dictate that if the existing calibrated HSPF model does not meet good/fair performance for flow (Table 15) after being extended to 2024, we will not use HSPF for this project. However, the domain for performance evaluation will be separated by the subbasin draining to each gage location. Therefore, we will continue developing and calibrating the HSPF model for nutrients for parts of the watershed with acceptable performance if most of the gage locations indicate acceptable model performance. Similarly, if months or seasons of the HSPF model have poor performance, we will supplement with other data sources (from this study and others referenced in section 4.3).

Table 15. General range of percent difference between simulated and observed values that can be used to evaluate HPSF model performance.[a]

Parameter	Metric	Measure	Good	Fair	Poor
Hydrology/Flow	Monthly Mean	RPD	<15%	15–25%	> 25%
Hydrology/Flow	Monthly Mean	R	>0.9	0.8–0.9	<0.8
Water temperature	Daily Mean	RPD	<13%	13–18%	> 18%
Water Quality/ Nutrients	Seasonal Mean[b]	RPD	<25%	25–35%	> 35%

[a]Adapted from Duda et al. 2012

[b]Discrete prediction (nearest matching based on temporal output resolution) and observation value pairs averaged by 6-month seasons (wet and dry).

RPD = Relative Percent Difference; R = Pearson's correlation coefficient (see QA glossary in Appendix C).

The HSPF quality objectives for nutrients in Table 15 will also be applied to outputs for the wetland modeling framework. Data collection within the wetlands will be limited, and obtaining representative data in certain areas will be challenging. We will rely more heavily on data collected at the downstream location (SOOS-7.5; see section 7.2) for wetland model calibration and evaluation.

Exploratory modeling of DO downstream effects at the confluence of the Green/Duwamish will be conducted in parallel to this study. Quality objectives for that work will be developed in a technical memorandum.

The Modeling Principal Investigator will consult with the project team, consider the breadth of information regarding calibration, and document a determination in the final model report that outlines the acceptable uses and overall acceptability of the model. See section 13.4 for more detailed information on the model quality assessment process.

7.0 Study Design

The study design focuses on collecting field data to develop a water quality modeling framework that meets the project goals and objectives (see Section 4).

7.1 Study boundaries

The Soos Creek watershed is in the Puget Sound lowlands in western Washington State, inside WRIA 9. The study boundary encompasses the Soos Creek watershed, which includes Big Soos Creek, Little Soos Creek, Jenkins Creek, Covington Creek, and Soosette Creek, as shown in Figure 1. Study sites within the study area are shown in Figure 26.

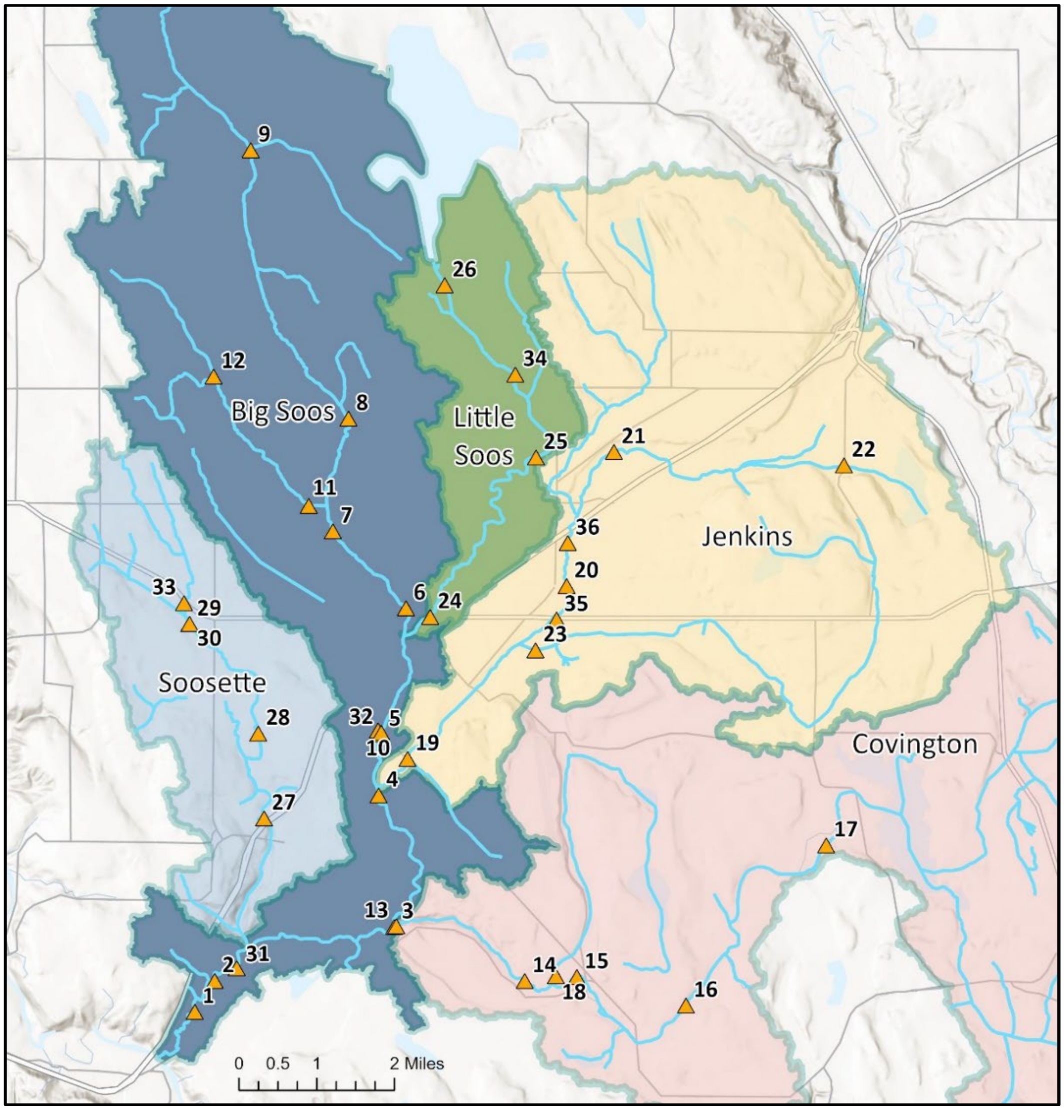

Figure 26. Map of proposed monitoring sites (see Table 16).

7.2 Field data collection

Ecology will collect field data for at least one year, from May 2023 to April 2024. Ecology may extend the data collection if flow, air temperature, or weather conditions during this period do not include a period that represents typical conditions where high water temperatures or low DO occur (for example, a very cool, rainy summer with abnormally high flows). Data collection will involve the following elements:

- **Fixed network monitoring:** Ecology will collect bacteria samples (*E. coli* and fecal coliform), discrete water quality measurements (DO, temperature, pH, specific conductivity, and turbidity), and flow measurements twice monthly at a fixed network of sites. Nutrient samples will also be collected at select sites once a month.

- **Continuous water quality monitoring:**
  - Ecology will collect continuous DO and temperature data using Onset HOBO DO Data Loggers at 10 sites at the major tributaries: 5 of the sites are King County gages, and 5 will be at locations upstream of the King County gages where there is year-round flow. Temporary DO monitoring locations may be established close to the transition of the stream to a wetland or lake, flow permitting.
  - Ecology will deploy continuous temperature dataloggers (HOBO tidbits) from May to October 2023 at about 2/3 of the fixed network sites to collect surface water and air temperature. Several sites will also have a datalogger measuring air relative humidity. The timing of deployments is intended to encompass critical summer low flow conditions and the transition period from supplemental to summer numeric water quality criteria. Temperature loggers may be deployed at additional sites at small tributaries, seeps, or stormwater discharge locations not listed in Table 16, depending on equipment availability and flow conditions during spring reconnaissance.
  - Ecology will deploy YSI EXO Multiparameter water quality sondes at two sites, one on Big Soos Creek and one on Jenkins Creek, to collect continuous pH, DO, specific conductivity, and temperature for one year (May 2023 – April 2024). Ecology's Freshwater Monitoring Unit (FMU) will maintain the deployed sondes, perform QC procedures, and manage the data collection at these two sites. The principal investigator and project manager will serve as backup for water quality sonde maintenance as needed based on FMU staff availability.
- **Synoptic water quality surveys:** Ecology will conduct at least five and up to eight intensive sampling events from May 2023 to March 2024 to characterize *E. coli*, fecal coliform bacteria, nutrients, and diurnal water quality (see Table 20). The survey involves sample collection and short-term (2 – 4 days) deployment of YSI EXO and Hydrolab water quality sondes to measure pH, DO, specific conductivity, temperature, and turbidity at select sites across the watershed.
- **Synoptic biological monitoring survey:** The survey assesses biological productivity by collecting periphyton (mixed organisms typically dominated by diatoms) and macrophytes. Sediment oxygen demand measurements for at least 48 hours will be attempted in a qualitative mode.
- **Streamflow gages:** Ecology will install and maintain two continuous flow gages at a site on Big Soos Creek and Jenkins Creek (same sites with continuous multiparameter water quality monitoring). Ecology's FMU will manage the flow gage until the foreseeable future to continue gathering baseline streamflow information for the Soos Creek Bioassessment TMDL. Table 17 lists the Soos Creek watershed gages and agencies responsible for maintaining the gage.
- **Synoptic flow monitoring survey:** The survey's primary purpose is to collect flow measurements across the watershed to infer gaining and losing stream reaches and provide quantitative groundwater discharge or baseflow loss estimates. That data also provides a more detailed understanding of the overall water balance during different flow conditions. Ecology will collect flow measurements at key locations along all five creeks and all known

and accessible flow inputs. During these surveys, we measure channel geometry across the width of the channel and will also investigate potential groundwater influence.

- **Stage monitoring at tributaries:** Ecology is collaborating with USGS to collect water level (stage) at the upper reaches of the remaining tributaries to Big Soos Creek (Little Soos, Covington, and Soosette Creeks). USGS will install HOBO water level loggers (i.e., pressure transducers) at sites near the transition of the creeks to upstream lakes and collect continuous data for one year, flow permitting. Ecology will use this data in combination with discrete flow measurements collected twice a month by Ecology and continuous data from downstream streamflow gages to estimate the flow at these locations and provide information on channel geometry (see Section 7.3.2).
- **Time-of-travel surveys:** Ecology will perform time-of-travel surveys at several reaches of Soos Creek to understand how water and pollutants move through the system and to characterize average stream velocities for different reaches. The surveys will occur at different streamflow regimes during summer and fall and coincide with the synoptic flow monitoring surveys.
- **Riparian vegetation and stream channel surveys:** Ecology will conduct one to three surveys during the summer of 2023 to measure channel geometry, characterize near-stream vegetation, and collect shade data on all five modeled creeks. Riparian vegetation surveys consist of channel geometry measurements and substrate measurements, near-stream vegetation measurements and characteristics, and shade data from transects along the five tributaries. One full survey will be conducted in July, and additional surveys for just channel geometry may be conducted in September and November, depending on the quality of July survey data and available time.
    - For locations in Table 19, channel surveys will generally follow standard procedures (EAP084; Urmos-Berry 2019) with 10 transects surveyed, spaced 100 feet apart. At some locations, we may be unable to complete 10 transects due to private access.
    - For Big Soos Creek, additional transects may be established between creek mile 1.1 and 7.5 with a goal of a transect at least every 500 meters. Some areas of this reach may not be accessible for surveys.
    - For all other creeks, additional channel geometry transects may be completed in several locations with public or private access agreements.
    - We may also collect longitudinal depth profiles during the channel surveys.
    - During channel surveys, we will investigate potential cold-water refuge and take discrete temperature measurements within the refuge and main channel.
    - Additional channel surveys in September and November may be conducted within the wetted portion of the channel only at select representative transects to develop channel geometry rating curves from varying flow conditions.
    - The vegetation aspect of the survey involves evaluating vegetation height, overhang, and density to estimate effective shade inputs. This will be conducted once during the July survey. At each fixed network site, a minimum of three hemispherical photographs will be taken within the wetted channel. One photo will be taken at the transect nearest to the deployed temperature logger and two additional photos at the transects immediately upstream and downstream. Ideally, a photo will be taken at each of the 10 transects,

depending on available time. Additional hemispherical photos will be taken on land (one on the right bank and one on the left bank) within 100 feet of the wetted channel to characterize riparian canopy density.

- **Stormwater infrastructure baseflow monitoring:** Ecology will monitor documented stormwater infrastructure discharge locations near the point of discharge, which include open conveyances, ditches, pipes, and storm drains within the study area that have substantial baseflow (i.e., enough flow to collect samples and measurements) to the creeks, particularly during the transition period from supplemental to summer numeric water quality criteria. By monitoring during this period and throughout the wet season, Ecology will monitor stormwater infrastructure baseflow during critical periods of expected DO, temperature, and bacteria impairments. Ecology will collect nutrient and bacteria samples (see Table 20) and discrete water quality measurements (DO, temperature, pH, specific conductivity) at this subset of stormwater discharge locations. Sampling will occur during the routine fixed monitoring schedule from October 2023 to March 2024, flow permitting. Loggers may be installed at the stormwater locations to collect continuous temperature data from May to October 2023.
- **Groundwater monitoring:** USGS will install piezometers, collect continuous temperature data, collect nutrient samples, and discrete water quality measurements from the hyporheic zone of gaining reaches. Piezometer installations will consist of two phases:
  - Phase 1 involves temporary installation at approximately 15 sites in April 2023 (see Table 19).
  - Phase 2 involves the final installation of piezometers at any sites with signs of surface and groundwater interaction based on the results from the first phase of installations.
  - USGS will also install vertical profile temperature rods in the stream bed during Phase 2 to measure temperature gradients and estimate flux direction and rate.
  - The minimum target is at least one Phase 2 piezometer installed in each of the five potential major gaining reaches (Jenkins CM 3.4-2.2 & 2.2-0.4; Big Soos CM 6.4-5.2 & 4.6-1.1; CM Covington 2.2-1.5).
  - USGS will also identify at least 5 off-stream groundwater sampling locations that represent regional groundwater quality in aquifers that are likely connected with the creeks in the Soos watershed. Potential locations could include public water supply wells, springs, monitoring wells, and private domestic wells.
  - For the full term of the data collection until May 2024, USGS will collect continuous temperature measurements from the rods, as well as monthly nutrient groundwater samples, water levels, and water quality measurements from the piezometers and off-stream locations.
- **Aerial drone surveys:** Ecology may conduct some aerial drone surveys in the summer of 2023. All drone work will follow Ecology's policy for using unmanned aerial systems (UAS). A project checklist will be completed, reviewed, and approved by Ecology management and drone coordinator and then posted on Ecology's website for UAS projects[14]. These surveys will serve two potential purposes:

[14] https://ecology.wa.gov/About-us/Accountability-transparency/Drones#applications

    - High-resolution imagery/mapping of Upper Soos Creek wetlands to map inundation extent/surface area, vegetation, and macrophyte/duckweed growth/coverage in the upper reaches.
    - Thermal imaging of limited stretches of Big Soos, and maybe Jenkins and/or Covington, to help identify the location of groundwater discharges and potential cold-water refuge.
- **Green River Downstream Impacts:** Ecology will collect limited data from the Green River, downstream of the confluence of Big Soos Creek, in the summer of 2023 to help evaluate potential downstream impacts. Data collection will include:
    - Short-term (2 – 14 days) deployment of YSI EXO and Hydrolab water quality sondes to measure pH, DO, specific conductivity, and temperature at 3 locations downstream of the confluence during July.
    - Ecology will collect continuous DO and temperature data using an Onset HOBO DO Data Logger upstream of the confluence from mid-June through September.
    - Ecology may also collect hemispherical riparian canopy photos, channel geometry measurements, and time of travel data, depending on staff and equipment availability.
- **Watershed health baseline monitoring**: Ecology will collect benthic macroinvertebrate samples to characterize the Benthic Index of Biotic Integrity (B-IBI) paired with a suite of watershed health monitoring metrics to characterize physical instream habitat at 150 – 200 m long reach transects. These watershed health metrics will include the following: bank quality, bank stability, channel dimensions, fish cover, habitat dimensions, habitat extent, large woody debris, riparian cover, riparian disturbance, riparian vegetation structure, side channel quantity, sinuosity, and substrate characteristics. Each location will only be visited once between July and mid-October 2023.

7.2.1 Sampling locations and frequency

All monitoring sites and location information are listed in Tables 16, 17, and 18 and displayed in Figure 26. Table 19 outlines the monitoring elements and frequency of monitoring at each site. Sampling locations may be moved, for example, to obtain data more representative of the waterbody or inflow to an alternate nearby location with sufficient flow to collect grab samples and water quality measurements. Additional locations may be added during the study based on site conditions and resource availability. For watershed health monitoring locations (Table 18), locations are assigned one of three priority groupings (high, medium, and low) since the Watershed Health Monitoring Unit will not know what capacity and resources they will have for monitoring until later in the summer. The high-priority sites will be monitored, and medium and low-priority sites will only be monitored if resources allow.

Table 16. Proposed monitoring site ID and location information.

Map #	Site ID	Location Description	Lat	Long
1	SOOS-0.5	Big Soos Creek at Hatchery Footbridge	47.30848	-122.16909
2	SOOS-1.1	Big Soos Creek at USGS Station	47.31241	-122.16542
3	SOOS-2.7	Big Soos near Black Diamond Road and 165th Ave SE	47.31924	-122.13195
4	SOOS-4.6	Big Soos East of 154th Ave at SE 296th SE	47.33582	-122.13491
5	SOOS-5.2	Soos Creek at Kent-Black Diamond Rd	47.34353	-122.13443
6	SOOS-6.4	Soos Creek at Hwy 516th	47.3594	-122.1298
7	SOOS-7.5	Big Soos South of 256th Ave	47.36911	-122.14338
8	SOOS-8.6	Big Soos at SE 240th St	47.3833	-122.1405
9	SOOS-10.75	Big Soos at Gary Grant Park on 208th	47.41705	-122.15866
10	SOOS TRIB 1-0.1	Big Soos Tributary at Creek Mile 5.3	47.3440	-122.13502
11	SOOS TRIB 2-0.2	Big Soos Tributary on 256th	47.37225	-122.14792
12	SOOS TRIB 2-1.75	Big Soos Tributary on 132nd SE	47.38862	-122.16558
13	COV-0.1	Big Soos downstream of 168th Way bridge	47.31934	-122.13157
14	COV-1.5	Covington Creek at SE 323nd St	47.31239	-122.10773
15	COV-2.0	Covington at Covington Nursery	47.3129	-122.0980
16	COV-3.5	Covington Creek at SE 328th Pl	47.30933	-122.07769
17	COV-5.7	Covington Creek near SE 304th AND 220th	47.32947	-122.051647
18	COV TRIB-0.1	Covington Tributary on 180th Ave SE	47.31297	-122.10194
19	JEN-0.3	Jenkins Creek near mouth	47.34036	-122.12946
20	JEN-2.5	Jenkins Creek at Jenkins Creek Park Trail	47.36222	-122.09990
21	JEN-4.0	Jenkins Creek on 188th Ave SE	47.37905	-122.09107
22	JEN-6.0	Jenkins Creek at 224th Ave	47.37744	-122.048305
23	CRAN-0.15	Cranmar Creek at mouth	47.35410	-122.10568
24	LITTLE SOOS-0.4	Little Soos Creek at SE 272nd	47.35825	-122.12530
25	LITTLE SOOS-2.7	Little Soos at 177TH AVE SE	47.37842	-122.10564
26	LITTLE SOOS-4.8	Little Soos Creek	47.40010	-122.12260
27	SOOSETTE-1.3	Soosette Creek above SR 18	47.33290	-122.15620
28	SOOSETTE-2.6	Soosette Creek at 288th St	47.34358	-122.15727

Map #	Site ID	Location Description	Lat	Long
29	SOOSETTE-3.5	Soosette Creek near Springwood Park	47.35744	-122.17008
30	Big Soos-SW-1.4	Stormwater infrastructure discharge to Big Soos Creek near USGS Station	47.314005	-122.161295
31	Big Soos-SW-5.3	Stormwater infrastructure discharge to Big Soos Creek near USGS Station	47.343711	-122.134412
32	Soosette-SW-2.5	Stormwater infrastructure discharge to Soosette south of SE Kent-Kangely Road	47.360047	-122.171098
33	Little Soos-SW-3.9	Stormwater infrastructure discharge to Little Soos on 238th Street	47.388840	-122.109454
34	Jenkins-SW-2.3	Stormwater infrastructure discharge to Jenkins Creek south of SE 272nd Street	47.357981	-122.101775
35	Jenkins- SW-3.0	Stormwater infrastructure discharge to Jenkins Creek at Jenkins Creek Park	47.367624	-122.099689
n/a	GRE-33.8	Green River upstream of Big Soos Creek (BSC)	47.302232	-122.175430
n/a	GRE-32.2	Green River in Auburn Narrows Park ~1 to 2 mi downstream of BSC	47.304583	-122.199215
n/a	GRE-29.5	Green River at Isaac Evans Park ~4 miles downstream of BSC	47.332271	-122.212293
n/a	GRE-23.8	Green River at Riverview Park upstream of Mill Creek; ~10 miles downstream of BSC	47.370135	-122.244861

Table 17. Continuous streamflow gages.

Agency	Agency Site ID	Study Specific Site ID	Location Description
USGS	12112600	SOOS-0.5	Big Soos Creek at USGS Station
King County	54J	SOOS-5.2	Soos Creek at Kent-Black Diamond Rd
Ecology	TBD	SOOS-7.5	Big Soos South of 256th Ave
King County	09A	COV-1.5	Covington Creek at SE 323nd St
King County	26a	JEN-0.3	Jenkins Creek near mouth
Ecology	TBD	JEN-2.5	Jenkins Creek at Jenkins Creek Park Trial
King County	54i	LITTLE SOOS-0.4	Little Soos Creek at SE 272nd
King County	54h	SOOSETTE-1.3	Soosette Creek above SR 18

Table 18. Proposed watershed health baseline monitoring stations.

WHM* Site ID	Priority	Rank	Location Description	Latitude	Longitude	King County Site Code
EFF755XX-BS00.7	HIGH	1	Big Soos Creek near hatchery	47.30855	-122.16904	09SOO0943
EFF755XX-SO01.3	HIGH	1	Soosette Creek near SR 18	47.33173	-122.15528	09SOO1022
EFF755XX-LS00.3	HIGH	1	Little Soos Creek near SE 27nd St	47.35860	-122.12512	09SOO1209
EFF755XX-CO01.5	HIGH	1	Covington Creek at SE 323nd St	47.31240	-122.10778	E3516
EFF755XX-MV00.2	HIGH	1	Meridian Valley Creek close to confluence with Big Soos	47.37249	-122.14803	09SOO1106
EFF755XX-JE02.6	HIGH	1	Jenkins Creek at Jenkins Creek Park Trial	47.36222	-122.09990	09JEN1318
EFF755XX-BS06.5	MED	2	Big Soos Creek near SE 272nd, upstream of Little Soos	47.35882	-122.12924	S320_MK
EFF755XX-JE00.4	MED	3	Jenkins Creek below Covington Way SE	47.34641	-122.12076	soos05
EFF755XX-CO03.6	MED	4	Covington Creek at SE 328th Pl	47.30933	-122.07769	09COV1418
EFF755XX-LS01.7	MED	5	Little Soos at SE 256th St	47.37283	-122.11390	09SOO1283
EFF755XX-RA00.4	MED	6	Ravensdale Creek upstream of Lake Sawyer	47.32877	-122.02207	09COV1756
EFF755XX-BS04.7	MED	7	Big Soos downstream of Jenkins	47.33641	-122.13510	09SOO1134
EFF755XX-CO00.7	MED	8	Covington Creek at 168th Way SE	47.31919	-122.11905	09COV1165
EFF755XX-BS02.8	LOW	9	Big Soos downstream of Covington	47.31817	-122.13596	09SOO1130
EFF755XX-GI01.0	LOW	10	Covington tributary near 3rd Ave	47.31721	-122.00522	09COV1862
EFF755XX-CO02.2	LOW	11	Covington Creek at SE Auburn Black Diamond Rd	47.31235	-122.09658	E349
EFF755XX-BS11.5	LOW	12	Big Soos Creek at Gary Grant Park	47.41720	-122.15879	09SOO1040
EFF755XX-JE01.0	LOW	13	Jenkins Creek near mouth	47.34047	-122.12953	E216

Table 19. Monitoring locations, monitoring element, and frequency.

Map #	Site ID	Location	WQ Measurements[a]	Bacteria Sampling	Nutrient Sampling	BOD Sampling	Synoptic Bio Monitoring	Riparian & Channel Survey	Continuous water & air temperature	Continuous DO/Temperature	Continuous WQ[c]	Streamflow/Stage Monitoring	Discrete Flow Measurements	Time of Travel	Stormwater Infrastructure Baseflow Monitoring	Groundwater Monitoring[e]
1	SOOS-0.5	Big Soos Creek at Hatchery Footbridge	2x/mo	2x/mo	4x	1x/ mo		3x	6mo		4x[b]		2x/mo			
2	SOOS-1.1	Big Soos Creek at USGS Station	2x/mo	2x/mo	1x/mo	1x/ mo	3x	3x	6mo	1 yr	4x[b]	1yr[d]	5-8x	3x		1x
3	SOOS-2.7	Big Soos near Black Diamond Road and 165th Ave SE	2x/mo	2x/mo	5-8x	1x/ mo		3x	6mo		4x[b]		5-8x	3x		1x
4	SOOS-4.6	Big Soos East of 154th Ave at SE 296th SE	5-8x					3x					5-8x			
5	SOOS-5.2	Soos Creek at Kent-Black Diamond Rd	2x/mo	2x/mo	5-8x	1x/ mo	3x	3x	6mo		4x[b]	1 yr[d]	5-8x	3x		1x
6	SOOS-6.4	Soos Creek at Hwy 516th						3x								1x
7	SOOS-7.5	Big Soos South of 256th Ave	2x/mo	2x/mo	1x/mo	1x/ mo	3x	3x	6mo	1 yr	1y	1yr	5-8x	3x		1x
8	SOOS-8.6	Big Soos at SE 240th St														1x
9	SOOS-10.75	Big Soos at Gary Grant Park on 208th	4x	4x	4x			3x	6mo		4x[b]		4x			
10	SOOS TRIB 1-0.1	Big Soos Tributary at Creek Mile 5.3	5-8x										5-8x			
11	SOOS TRIB 2-0.2	Big Soos Tributary 256th	2x/mo	2x/mo	1x/mo	3x			6mo		4x[b]					
12	SOOS TRIB 2-1.75	Big Soos Tributary on 132nd SE	4x		4x				6mo							
13	COV-0.1	Big Soos downstream of 168th Way bridge	2x/mo	2x/mo	1x/mo	3x		3x	6mo		4x[b]		5-8x			
14	COV-1.5	Covington Creek at SE 323nd St	2x/mo	2x/mo	5-8x		3x	3x	6mo	1 yr	4x[b]	1 yr[d]	5-8x	3x		1x
15	COV-2.0	Covington at Covington Nursery						3x								1x
16	COV-3.5	Covington Creek at SE 328th Pl	2x/mo	2x/mo	1x/mo			3x	6mo	1 yr	4x[b]	1yr	5-8x	1x		

Map #	Site ID	Location	WQ Measurements[a]	Bacteria Sampling	Nutrient Sampling	BOD Sampling	Synoptic Bio Monitoring	Riparian & Channel Survey	Continuous water & air temperature	Continuous DO/Temperature	Continuous WQ[c]	Streamflow/Stage Monitoring	Discrete Flow Measurements	Time of Travel	Stormwater Infrastructure Baseflow Monitoring	Groundwater Monitoring[e]
17	COV-5.7	Covington Creek near SE 304th and 220th	2x/mo	2x/mo				3x		1 yr	4x[b]		2x/mo			1x
18	COV TRIB-0.1	Covington Tributary on 180th Ave SE	2x/mo		4x								4x			
19	JEN-0.3	Jenkins Creek near mouth	2x/mo	2x/mo	1x/mo	3x	3x	3x	6mo	1 yr	4x[b]	1 yr[d]	5-8x	3x		1x
20	JEN-2.5	Jenkins Creek at Jenkins Creek Park Trail	2x/mo	2x/mo	5-8x			3x		1 yr	1 y	1yr	5-8x	3x		1x
21	JEN-4.0	Jenkins Creek on 188th Ave SE	2x/mo	2x/mo				3x	6mo		4x[b]					1x
22	JEN-6.0	Jenkins Creek at 224th Ave	2x/mo	2x/mo	1x/mo			3x	6mo	1 yr			5-8x			
23	CRAN-0.15	Cranmar Creek at mouth	2x/mo	2x/mo	5-8x	3x	3x	3x	6mo				5-8x			
24	LITTLE SOOS-0.4	Little Soos Creek at SE 272nd	2x/mo	2x/mo	1x/mo	3x	3x	3x		1 yr	4x[b]	1 yr[d]	5-8x			1x
25	LITTLE SOOS-2.7	Little Soos at 177TH AVE SE	2x/mo	2x/mo				3x	6mo		4x[b]			3x		
26	LITTLE SOOS-4.8	Little Soos Creek	2x/mo	2x/mo	5-8x			3x	6mo	1 yr	4x[b]	1yr	5-8x			
27	SOOSETTE-1.3	Soosette Creek above SR 18	2x/mo	2x/mo	1x/mo	3x	3x	3x	6mo	1 yr	4x[b]	1 yr[d]	5-8x	3x		1x
28	SOOSETTE-2.6	Soosette Creek at 288th St	2x/mo	2x/mo	5-8x			3x		1 yr	4x[b]	1 yr[d]	5-8x			
29	SOOSETTE-3.5	Soosette Creek near Springwood Park	2x/mo	2x/mo					6mo							
30	Big Soos-SW-1.4	Stormwater infrastructure discharge to Big Soos Creek near USGS Station							6mo						x/mo[g]	
31	Big Soos- SW-5.3	Stormwater infrastructure discharge to Big Soos Creek near USGS Station							6mo						X[g]	
32	Soosette- SW-2.5	Stormwater infrastructure discharge to Soosette south of SE Kent-Kangely Road													X[g]	

Map #	Site ID	Location	WQ Measurements[a]	Bacteria Sampling	Nutrient Sampling	BOD Sampling	Synoptic Bio Monitoring	Riparian & Channel Survey	Continuous water & air temperature	Continuous DO/Temperature	Continuous WQ[c]	Streamflow/Stage Monitoring	Discrete Flow Measurements	Time of Travel	Stormwater Infrastructure Baseflow Monitoring	Groundwater Monitoring[e]
33	Little Soos- SW-3.9	Stormwater infrastructure discharge to Little Soos on 238th Street							6mo						X[g]	
34	Jenkins- SW-2.3	Stormwater infrastructure discharge to Jenkins Creek south of SE 272nd Street							6mo						X[g]	
35	Jenkins- SW-3.0	Stormwater infrastructure discharge to Jenkins Creek at Jenkins Creek Park							6mo						X[g]	
n/a	GRE-33.8	Green River upstream of Big Soos Creek (BSC)	6x					1x~		4 mo	1x[b]			1x~		
n/a	GRE-32.2	Green River in Auburn Narrows Park ~1 to 2 mi downstream of BSC	3x					1x~			1x[b]			1x~		
n/a	GRE-29.5	Green River at Isaac Evans Park ~4 miles downstream of BSC	3x					1x~			1x[b]			1x~		
n/a	GRE-23.8	Green River at Riverview Park upstream of Mill Creek; ~10 miles downstream of BSC	3x					1x~			1x[b]			1x~		

#x: number of monitoring events
d: days of monitoring
mo: month
yr: year
BOD: Biochemical Oxygen Demand
~: optional; dependent on available staff time and resources.
[a] Water quality (WQ) measurements include DO, specific conductivity, temperature, and pH.
[b] Monitoring involves 3 sequential days of continuous sonde deployment.
[c] Continuous water quality parameters include DO, specific conductivity, temperature, pH, and turbidity.
[d] Continuous streamflow gage established before the start of this TMDL monitoring effort and managed by a separate agency (see Table 17).
[e] Stormwater infrastructure baseflow monitoring includes a collection of bacteria and nutrient samples and water quality measurements (DO, specific conductivity, temperature pH, and turbidity).
[f] This frequency represents the first phase of monitoring. For the second phase, piezometers will be re-installed at sites that show signs of surface and groundwater interaction based on the results from the first phase. These sites will be selected from this list and monitored for the full year of the project (1 yr).
[g] Frequency of sampling at the stormwater infrastructure drainages will depend on whether there is sufficient flow to allow for collection of samples and measurements.

7.2.2 Field parameters and laboratory analytes to be measured

Table 20 lists the parameters that will be collected in this study.

Table 20. Laboratory and field parameters with monitoring type.

Parameter	Data Type	Fixed Network Monitoring	Continuous Water Quality Monitoring	Synoptic Water Quality Survey	Synoptic Biological Survey	Stream Flow/Stage Monitoring	Time of Travel	Riparian Habitat Survey	Stormwater Monitoring	Groundwater Monitoring
E. coli/fecal coliform	S	X		X					X	
Total Suspended Solids (TSS)	S	X		X					X	
Total Non-volatile Suspended Solids (TNVSS)	S			X						
5-day Biochemical Oxygen Demand (BOD)	S	X		X						
Alkalinity, Total as CaCO3	S			X						X
Chloride	S			X						X
Dissolved Organic Carbon (DOC)	S	X		X						X
Total Organic Carbon (TOC)	S	X		X					X	X
Total Phosphorus	S	X		X					X	X
Ammonia (NH_3)	S	X		X					X*	X
Nitrate + Nitrite as N (NO_2/NO_3)	S	X		X					X	X
Total Persulfate Nitrogen (TPN)	S	X		X					X	X
Orthophosphate (OP)	S	X		X					X	X
Chlorophyll (Field filtered)	S			X						
Periphyton — Areal Biomass as Ash Free Dry Weight (AFDW)	S				X					
Periphyton — Percent Total Solids	S				X					
Periphyton — ID	S				X					
Periphyton — Total Nitrogen, tissue	S				X					
Periphyton — Total Phosphorus, tissue	S				X					
Iron (Fe)	S									X
Water Temperature	DM	X		X			X			X

Parameter	Data Type	Fixed Network Monitoring	Continuous Water Quality Monitoring	Synoptic Water Quality Survey	Synoptic Biological Survey	Stream Flow/Stage Monitoring	Time of Travel	Riparian Habitat Survey	Stormwater Monitoring	Groundwater Monitoring
Specific Conductivity	DM	X		X			X			X
pH/ORP	DM	X		X			X			X
Dissolved Oxygen	DM	X		X			X			X
Dissolved Oxygen — Winkler (as QC)	DM	X		X			X			X
Turbidity	DM	X		X			X			X
Stream velocity	DM	X				X	X	X		
Stream Depth	DM	X					X	X		
Vertical Hydraulic Gradient	DM									X
Water Temperature	CM		X	X	X		X			X
Solar Radiation	CM							X		
Specific Conductivity	CM		X	X			X			
pH/ORP	CM		X	X			X			
Dissolved Oxygen	CM		X	X	X		X			
Turbidity	CM			X			X			
Air Temperature	CM		X	X			X			
Rhodamine	CM						X			
Stream velocity	CM					X	X			
Water Level/ Stage	CM					X				

S= sample analyzed in the laboratory
DM= discrete measurement parameters
CM= continuous measurement parameters

7.3 Modeling and analysis design

The modeling framework for this study will require multiple modeling and analysis tools, as well as some flexibility and contingency in how, where, and when they are applied. The following sections describe the framework, data requirements, assumptions, potential challenges, and contingencies.

7.3.1 Analytical framework

The project goals and objectives necessitate a framework that can provide a reasonable estimate of numerous constituents and processes, most importantly:

1. How land use contributes to low DO levels, high temperature, and *E. coli* bacteria loads in the watershed.
2. How wetlands affect nutrients, water quality, and hydrology in impaired downstream waterbodies.
3. How instream physical and biogeochemical processes affect temperature, DO, and bacteria levels in the creeks that are impaired for these parameters.

Ecology plans to use two primary tools (described in greater detail in a subsequent section) to accomplish these tasks:

- QUAL2KwV6.1 — A one-dimensional instream model for water quality.
- Hydrological Simulation Program Fortran (HSPF) — A watershed model that simulates nonpoint source runoff and pollutant loadings for a watershed, combines these with point source contributions, and performs flow and water quality routing in reaches.
    - The scope for this project will not allow for re-calibration of HSPF. For this project, we will extend an existing HSPF model in time through 2024 with minimal fractional-based corrections for land use changes. If the extension in time does not demonstrate skill with the current calibration (as shown in section 6. 4), we will not use all or portions of the extended HSPF model for this project.
    - However, even if the extended HSPF model is not utilized, we will likely still use the existing HSPF model (see Section 4.3; Mohamedali et al. 2018) for other purposes, such as to assist in estimates of pre-industrial and future hydrology, as well as baseflow loss.

We will also explore the use of other models as follows:

- **Wetland modeling**
    - WetQual — WetQual is a process-based model which simulates hydrologic processes as well as N, P, total suspended sediment (TSS), and C cycles and their dynamics in natural and constructed wetlands (Hantush et al. 2013; Kalin et al. 2013 and 2020; Sharifi et al. 2013 and 2017).
- **Instream modeling tools**
    - PointWQ — an Excel workbook tool that combines two historical spreadsheet modeling tools: rTemp and River Metabolism Analyzer (RMA). The Programmatic QAPP and

Models & Tools for TMDLs - Washington State Department of Ecology[15] provide more detail on these tools.

- **Model pre and post-processing tools**
  - Gap Light Analyzer (GLA) — Imaging software to extract forest canopy structure and gap light transmission indices from true-color hemispherical (fisheye) photographs.
  - Ttools — An Arc-GIS add-in used to process stream channel and riparian corridor spatial information for input into the shade model.
  - Shade.xlsm model — An Excel spreadsheet interface model written in VBA for calculating effective riparian shade.
  - rQUAL2Kw — An R package developed by Ecology used to interface with Fortran executable for QUAL2Kw and pre and post-process model input and output files.

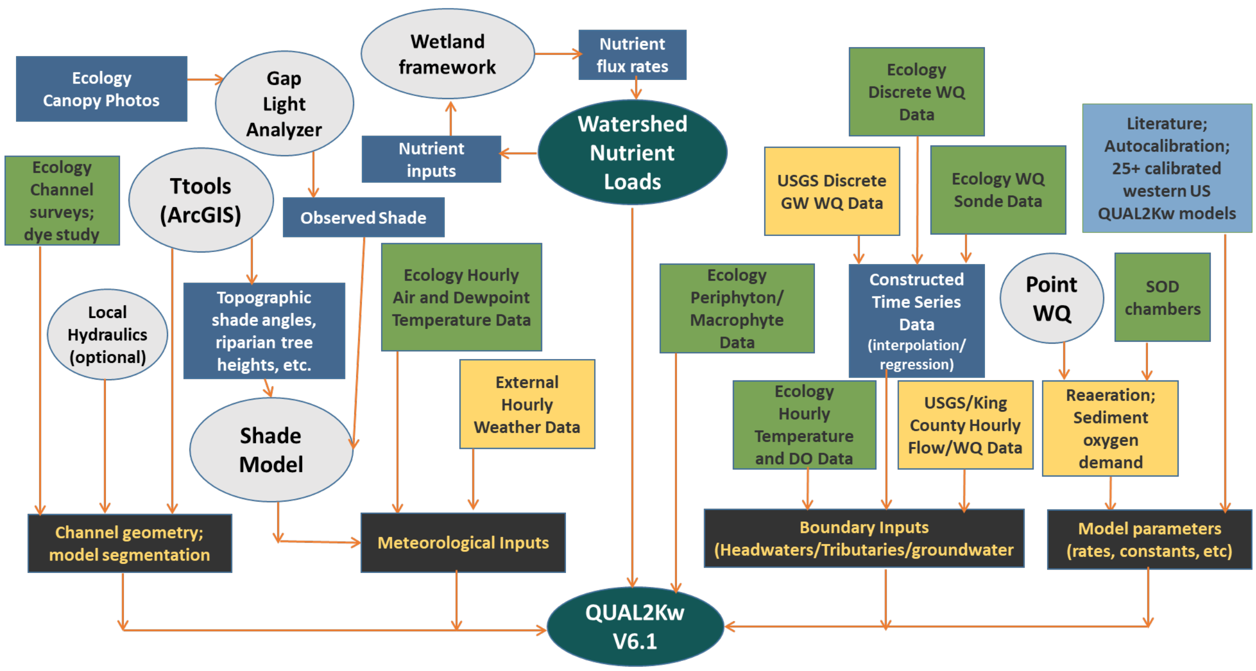

Figure 27. Conceptual diagram of model framework, including inputs and tools.

QUAL2Kw framework

The QUAL2Kw v6.0 model framework and complete documentation are available at Models & Tools for TMDLs — Washington State Department of Ecology. Version 6.1 and documentation will be added to the website soon. The programmatic QAPP describes the features of this framework in greater detail.

Unlike previous versions of QUAL2Kw, versions 6.0 and 6.1 can simulate a river continuously throughout a season or year. This is useful because it allows one model scenario to simulate

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

conditions during different parts of the critical season and to be calibrated to multiple datasets collected at different times.

QUAL2Kw V6.1 is an appropriate choice for determining the nutrient and heat loading capacity for the TMDL for multiple reasons, including that the model is:

- Capable of simulating advanced bottom algae growth dynamics, including growth, respiration, scouring, nutrient/light/temperature limitation, and (importantly) internal cell nutrient concentrations and quotas.
- Capable of simulating dynamic conditions for a full periphyton and macrophyte growth season, including flow, temperature, and (importantly) solar radiation/shade. An hourly time series input may be used for each reach of the model.
- Capable of simulating three separate algal groups within a model reach.
- Well-documented and routinely used for nutrient-related DO and temperature TMDL development in EPA Region 10.
- Actively enhanced and maintained by Ecology.

The QUAL2Kw models will be used to predict the effect of bacteria, heat, nutrients, and flows from various sources on instream temperature, DO, bacteria, and pH in the five modeled creeks (Big Soos, Little Soos, Covington, Jenkins, and Soosette). The model will be used to test various management scenarios, which can include point source reductions or nonpoint improvements, such as nutrient reductions from upgrading septic systems or temperature improvements from adding shade.

The temporal domain of the model will be one full year of simulation from May 2023 to April 2024 to fully understand seasonal nutrient dynamics and bacteria loading, as well as temperature influences during the transitional months between core summer and supplemental spawning criteria. The temporal or spatial domain of the final models may be reduced if it's determined they adequately capture conditions that influence impairment or a particular creek drops to very low or zero flow.

The spatial domain of the QUAL2Kw models will start as the length of the creeks that cover water quality impairments (Figure 2); however, some areas of this domain may rely on PointWQ, WetQUAL, other tools when and where QUAL2Kw models cannot be adequately developed. See 'Wetland Modeling Framework' and section 7.5 for additional details on these contingencies.

rQUAL2Kw will link the QUAL2Kw models for the four tributary creeks to the Big Soos Creek model for calibration and scenarios. rQUAL2Kw may also link multiple models for separate sections of the same creek based on flow conditions or configuration needs.

HSPF framework

HSPF is a process-based watershed model. The User's Manual (Bicknell et al. 2005) describes HPSF as "a set of codes that can simulate the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams." The model simulates runoff processes and instream interactions and can simulate sub-daily dynamic time series of runoff and pollutant loads and concentrations. The model has been used extensively by the EPA, USGS, and the academic community and maintains a strong scientific basis.

Locally, it has been used extensively and applied by King County in watersheds within their jurisdiction for stormwater retrofit planning and other studies. The model simulates fundamental hydrologic processes that make up the water budget, including precipitation, evaporation, evapotranspiration, interception, surface runoff, interflow, and infiltration, as well as various components of groundwater flow and storage. Mohamedali (2018) updated and calibrated the model. We plan to extend this calibrated model into 2024 for this project.

The processes and algorithms within the model have been developed from theory, lab experiments, and empirical watersheds (Duda et al. 2012). These processes are controlled by associated rates and parameters that the user specifies for the pervious (PERLNDs) and impervious (IMPLNDs) land areas within the watershed, within the PWATER and IWATER submodules, respectively. The submodule HYDR then simulates instream hydraulic processes, which keep track of the water balance within each reach, including reach-level precipitation, evaporation, and all other inflows and outflows.

The watershed model for this TMDL will start with an existing HSPF model of the Soos Creek watershed (see section 7.3.2). If the extended calibrated HSPF model performs as specified in Section 6.4, then we will explore the addition of the submodules itemized below to the existing HSPF model within the time constraints specified in Section 5.4. Otherwise, we will use other methods of estimating watershed nutrient loads, as specified in Section 7.5.

- PWTGAS — A submodule of the PERLND module that estimates water temperature and concentrations of DO and carbon dioxide in surface, interflow, and groundwater outflows from a land segment.
- IWTGAS — A submodule of the IMPLND module that estimates water temperature and concentrations of DO and carbon dioxide in surface outflows from a land segment.
- PQUAL —A submodule of PERLND module that simulates accumulation, storage, wash-off, and removal of general water quality constituents in overland flow, the soil matrix, interflow, and active groundwater. PQUAL includes atmospheric deposition as an input and removal of a constituent via first-order decay rate while in storage.
- IQUAL — A submodule of IMPLND module that is very similar to PQUAL, except it only provides simulation of constituents and processes in the overland flow compartment related to impervious surfaces and, by nature, does not include simulation in soil, interflow, or groundwater. In place of the soil matrix, IQUAL does simulate separate storage and wash-off (overland flow portion is assumed to be not associated with solids directly) of the constituent that is bound/associated with solids that have accumulated on impervious surfaces (which is simulated in SOLIDS submodule).
- HTRCH — A submodule of the RCHRES module that simulates the processes determining the water temperature in a reach.
- GQUAL — A submodule of the RCHRES module that simulates the behavior of the generalized quality constituent in the stream channel. The primary function of this submodule for the study will be to simulate constituents in the smaller streams not simulated by QUAL2Kw for input to the QUAL2Kw model; however, it will be simulated for the whole Soos stream network and may provide supplemental information to inform QUAL2Kw simulations. GQUAL can consider one or more of the following processes:
    - Advection of dissolved material

- o Decay processes. One or more of the following can be modeled: hydrolysis, oxidation by free radical oxygen, photolysis, volatilization, biodegradation, and generalized first-order decay.
- o Production of one generalized quality constituent because of decay of another generalized quality constituent by any of the listed decay processes except volatilization. This capability is included to allow for situations in which the decay products of a chemical are of primary interest to the user.
- o The following additional processes are considered if the generalized quality constituent being modeled is sediment-associated: Advection of adsorbed suspended material, deposition and scour of adsorbed material with sediment, decay of suspended and bed material, adsorption/desorption between dissolved and sediment-associated phase.

This TMDL study will also consider adding the following optional submodules to the existing HSPF model depending on available time and necessity:

- NITR and PHOS (optional) — These submodules simulate detailed nutrient cycling in soils, primarily agricultural soils used for plant/crop production. The simulation of nitrogen and phosphorus can be simplified using the PQUAL submodule, which does not consider plant uptake and transformations, only transport and decay. Given the relatively small amount of agriculture in the watershed, the project will start using PQUAL for these parameters but may utilize the NITR and/or PHOS submodules if necessary. PHOS may be used to simulate the adsorption/desorption of inorganic phosphorus in soils, particularly given the number of on-site septic systems.
- RQUAL (optional) — This submodule of RCHRES simulates more complex biochemical transformations within the water column, including oxygen demand balances, pH and inorganic carbon species, plankton/benthic algae/zooplankton dynamics, nitrogen/phosphorus specific transformations. Given that QUAL2Kw will be used to simulate these processes in most of the stream network, including all impaired waters, it is not anticipated that this module will be necessary. In addition, most of the smaller waterbodies do not have flow during the summer and early fall months when these processes are most relevant.
- ATEMP (optional) — Used to adjust for air temperature differences between the meteorologic station and site due to elevation differences. It can be bypassed by adjusting the gage temperature directly.
- PSTEMP (optional) — Used to simulate soil temperatures.

Wetland modeling framework

The study will explore using several tools to simulate wetland influences on watershed hydrology and instream hydrodynamics, as well as attenuation of sediment, bacteria, and nutrient loads. The following potential approaches will be explored; however, limited time is available to dedicate to this task, so the wetland analysis may ultimately also rely on previous research and/or investigation of potential local reference sites:

- HSPF — HSPF watershed model may be used to simulate off-stream wetlands with no hydraulic surface water connection. These wetlands will be simulated as a PERLND water type HRU.

- We may also explore using the advanced wetland feature, which routes a defined percentage of flow to a flowing wetland reach (with a separate FTABLE in the RCHRES module) before routing to a stream reach.
- However, one application had difficulty with simulations that included a dry or low flow period (Wu et al. 2017) using this approach for sediment and nutrient assimilation.
- HSPF's RCHRES module does not include all constituents and processes necessary to completely simulate wetland plant-soil-water biogeochemical cycling.

- QUAL2Kw — We will initially attempt to simulate flowing wetland reaches as part of the QUAL2Kw framework.
  - With the sediment diagenesis module enabled, QUAL2Kw can simulate most of the important wetland plant-soil-water biogeochemical cycling processes.
  - It has the additional benefit of being able to simulate surface-transient storage zones, which can be used to estimate biogeochemical transformations in inundated off-channel areas of wetlands with limited interaction with the main channel.
- WETQUAL — This framework provides the most complete simulation of wetland plant-soil-water biogeochemical cycling of nutrients. It does not simulate how this cycling affects DO or inorganic carbon species (pH) nor simulate water temperature/heat balance at all. For these reasons, we will explore its use as a supplemental tool which could be applied either:
  - In tandem with HSPF, where WetQual can be used to prescribe nutrient fluxes in HSPF.
  - Or as a field scale model to evaluate the potential for attenuation of nutrients and biogeochemical processing at representative wetland location/s.

7.3.2 Model setup and data needs

Each tool utilized in the modeling framework has specific data needs and setup procedures. However, many of the datasets collected and compiled for the project will be used to set up or calibrate multiple models/tools.

QUAL2Kw setup and data needs

Figure 27 in section 7.3.1 provides a conceptual map of what data and tools may be used to develop the QUAL2Kw model.

Modeling staff will use outputs from Ttools to help develop initial model segmentation. Ttools will sample geospatial features, including elevation at 50-meter intervals along the NHD-based watercourse lines (adapted to match recent LIDAR and aerial photos). The 50-meter segments will be combined based on the necessary model resolution to provide numerical stability and capture system dynamics appropriately. Segment lengths may be variable to achieve roughly comparable travel times within each segment. Final model segments will be 1 kilometer at maximum.

We will develop channel geometry using the power rating curves option in QUAL2Kw (Chapra 2008) of the form:

$$W = aQ^b \qquad D = cQ^f \qquad V = kQ^m$$

Where:

W = width (m) **a** = width coefficient **b** = width exponent

$\mathbf{D}$ = depth (m)	$\mathbf{c}$ = depth coefficient	$\mathbf{f}$ = depth exponent
$\mathbf{V}$ = velocity (m/s)	$\mathbf{k}$ = velocity coefficient	$\mathbf{m}$ = velocity exponent
$\mathbf{Q}$ = flow (cms)		

These power functions are related by the continuity equation:

$$\mathbf{Q = WDV = (aQ^b)(cQ^f)(kQ^m)}$$

We plan to base the power functions for each model segment upon the following:

- Width:
  - Digitize wetted edges from National Agriculture Imagery Program (NAIP) orthophotos at a 1:2000 scale using ArcGIS. Calculated widths from digitized edges using Ttools (Ecology 2015). These orthophotos are typically taken during the summer months. We will likely digitize widths from multiple years taken during different flows to help develop curves.
  - Use routine flow transect data collected by Ecology and USGS for the study. We plan to measure flow at a set transect location, to the extent possible, and document when a transect moves. We will attempt to locate transects in a location/habitat representative of the surrounding reach.
  - Channel surveys will provide summer wetted widths and channel shape within bankfull width for several locations, although private access and small parcel size limits where these surveys can be conducted.
  - Given that much of the wetted area of the creeks is not visible in aerial photos, we may have to rely on transect data and LiDAR to estimate wetted width in inaccessible areas with overhang.
- Velocity:
  - We will calculate velocities from time-of-travel dye study results. We plan two time-of-travel studies and will use historical data from 2007, where possible.
  - Use routine flow transect data collected as described above.
- Depth:
  - Given width and velocity from the above information, we will likely calculate depths from the continuity equation shown above.
  - However, we may use flow and channel geometry transect data to develop depth curves in some areas if wetted width data proves too limiting.

We will primarily use hourly and discrete data collected by Ecology, USGS, and King County for headwaters and continuous source inputs. Hourly inflow time series must be developed for each model headwaters and all continuous sources to the models, including point sources (such as hatchery or stormwater discharge) and non-point sources (such as small tributaries or diffuse groundwater). The sources of estimating these inflows will vary based on several factors. Sources of QUAL2Kw model inflow data will likely include estimated continuous flow:

- Based on a stage-discharge rating curve developed by Ecology's Stream Hydrology Unit for a flow gaging station. This method's equipment accuracy and QA/QC procedures for continuously measured stage and discrete flow measurements are very high quality. However, it is resource intensive and logistically infeasible to install this type of flow gage at all needed locations. This method cannot be used for diffuse groundwater or very small inflows.

- Based on a stage-discharge relationship developed using continuous stage data from a standalone pressure transducer and discrete flow measurements. For this method, the instruments measuring stage are easy to deploy and relocate in small streams with shallow channels.
- Based on a statistical relationship (often a simple linear regression) between discrete flow measurements and an estimated flow times series from an appropriately selected Ecology SHU unit, USGS, or King County flow gage at another location, as described above.
- Based on flows from an Ecology calibrated HSPF model derived from hydrologic and land use data as described in this section. For other applications outside this study, other hydrologic model flow estimates, such as the WRF-Hydro model, may be utilized.
- For groundwater inflows specifically, based on baseflow water balances during synoptic flow surveys, gaining/losing reaches identified during USGS groundwater study, interflow/groundwater simulation from the HSPF model, baseflow separation techniques, and time series of other flow gage residuals.

Table 21 provides more detail on how measurements are linked to water quality constituents in the model.

Table 21. State variables/constituents in the QUAL2Kw model and methods for measuring or estimating in the study.

Model Variable	Symbol	Units*	Measured/estimated as
Conductivity	s	µmhos	Specific Conductance
Inorganic suspended solids	$m_{i,}$	mgD/L	TNVSS
Dissolved oxygen	o	mgO_2/L	DO
Slow-reacting CBOD	c_s	mg O_2/L	r_{oc} * DOC * SF
Fast-reacting CBOD	c_f	mg O_2/L	r_{oc} * DOC * FF
Organic nitrogen	n_o	µgN/L	TPN - NO_3/NO_2N - NH_4N
Ammonia nitrogen	n_a	µgN/L	NH_4N
Nitrate nitrogen	n_n	µgN/L	NO_3/NO_2N
Organic phosphorus	p_o	µgP/L	TP - Orthophosphate
Inorganic phosphorus	p_i	µgP/L	Orthophosphate
General Algae (as phytoplankton)	$a_{p,1}$	µgA/L	Chlorophyll (CHLA)
General Algae (as macrophytes or epiphytes)	$a_{p,2}$	gD/m^2	Macrophyte/epiphyte tissue ash-free dry weight * LF
Detritus	m_o	mgD/L	r_{dc} * (TOC - DOC) - r_{da} * CHLA or TSS - TNVSS - r_{da} * CHLA
Pathogen	x_1	cfu/100 mL	*E. coli*
Generic constituent	gen_1	user defined	Chloride
Alkalinity	Alk_1	$mgCaCO_3/L$	ALK
Total inorganic carbon	c_T	mole/L	Calculated from pH and alkalinity
Bottom algae biomass	a_b	gD/m^2	periphyton tissue ash-free dry weight * LF
Bottom algae nitrogen	IN_b	mgN/m^2	periphyton tissue N#
Bottom algae phosphorus	IP_b	mgP/m^2	periphyton tissue P#
Hyporheic biofilm biomass (optional)	a_h	gD/m^2	Estimated using RMA, reach sediments, and model

Note: r_{xx} refers to a stoichiometric ratio. The letters used in the subscripts are c = carbon, d = dry weight, and o = dissolved oxygen (DO).
SF = slow-reacting fraction; FF = fast-reacting fraction; LF = live fraction (in many projects assumed to be 1, all volatile organic tissue assumed to come from living organism).
# These simulated parameters are not field measured in many other projects. Some limited analysis may occur, depending on resources.

QUAL2Kw allows for flexible use of three algal groups (Table 22). Each modeled waterbody for the study could have a unique configuration for these groups (Table 23). For example, one waterbody could include a phytoplankton, rooted macrophyte, and periphyton representation.

Table 22. Algal constituent groups and simulation options in QUAL2Kw.

Model Constituent Group	Live Transport?	Water column vs Sediment Nutrient Uptake	Luxury Uptake of Nutrients?
General Algae 1	Yes = phytoplankton No = macrophyte	1 = phytoplankton <1 = macrophyte	No
General Algae 2	Yes = phytoplankton No = macrophyte	1 = phytoplankton <1 = macrophyte	No
Bottom Algae	Not an option for this group	1 = periphyton <1 = macrophyte	Yes

Table 23. Potential algal configurations for simulation in QUAL2Kw.

Algae category	Model Constituent Group	Live transport?	Water column vs. sediment nutrient uptake fraction
Periphyton	Bottom Algae	N/A	1 (water)
Phytoplankton	General Algae 1 or 2	Yes	1 (water)
Floating macrophyte (such as duckweed)	General Algae 1 or 2	No	1 (water)
Rooted macrophyte (such as elodea)	Any*	No	0 (sediment)
Attached epiphytes (diatoms growing on macroinvertebrates)	Any*	No	1 (water)

*Can be simulated as bottom algae to include luxury consumption, but available light is not integrated by depth (assumes macrophytes only receive the amount of light that can reach the bottom of the stream). For light integrated by depth, simulate as General Algae 1 or 2.

Table 24 details necessary meteorological inputs needed and anticipated data sources.

Table 24. Meteorological inputs needed and data sources.

Input (hourly)	Units*	Source
Air temperature	°C	Deployed temperature loggers
Dewpoint temperature	°C	Deployed relative humidity loggers
Cloud cover	Fraction; 1= 100% cloud cover	External Meteorological network
Effective shade	Fraction; 1= 100% shade	Derived using Ttools and Shade model
Solar radiation	$Watts/m^2$	External Meteorological network
Wind speed	m/s	External Meteorological network

Approved external meteorological network data sources are described in the Programmatic QAPP (McCarthy and Mathieu 2017). Sites near but outside the study area will likely be utilized, including:

- National Weather Service (NWS) sites at the nearby airports just west (SEATAC) and north (Renton) of the study area.
- AgWeatherNet locations just south of the study area near the western (WSU Puyallup) and eastern (Enumclaw-King Co Conservation District) study boundaries.

HSPF setup and data needs

The watershed model for this TMDL will start with an existing HSPF model of the Soos Creek watershed. The model has been calibrated for hydrological parameters for Water Years (WYs) 2001 – 2015, using 2007 land-use conditions. This model was developed and refined by several different entities. The development and calibration of the original HSPF model for the Soos Creek watershed is described in detail in Aqua Terra (2003). King County (2013b), the Muckleshoot Indian Tribe (Carlson and Massmann 2015), and Ecology (Mohamedali 2018) have further developed and refined this model. The most recent Ecology effort added sediment simulation to the model and extended the simulation through WYs 2009 – 2015.

This effort will extend the model simulation further through WY 2024. The model simulation may be truncated for computational efficiency but will simulate at least 10 years, not including model spin-up. The model period will initiate not later than WY 2011 to allow time for the model to spin up and stabilize by WY 2014. Model spin-up is a way to ‘warm up’ the model for a certain amount of time until model results are not as sensitive to initial conditions.

We will review major land use changes from Ecology’s fine sediment and flow HSPF model calibration (Mohamedali 2018), originally based on 2007 land use and updated in some localized areas based on 2012 land use. The National Land Cover Database 2019 dataset and most recent local tax parcel assessment data will be used for comparison. If deemed necessary due to significant change, Ecology may make minor adjustments for changes in land use in some areas. We will evaluate model fitness for hydrology, but it is outside the scope of the study to refine the hydrology calibration in the HSPF model. If the hydrological performance does not match the performance reported by Mohamedali (2018), we will not use this model for this project, as specified in section 6.4.

If the hydrological calibration holds, we will update the model to predict temperature and nutrients if this work can be completed within the schedule in Section 5.4. Model input parameters are specified in a User Control Input (UCI) file, which contains most of the information to run the model except time-series data (e.g., precipitation and evaporation). The UCI file is a txt (ASCII) file and is the main one the user interacts with to specify model input parameters. The UCI file is divided into several ‘blocks’, with each containing information related to different parts of the model (e.g., global parameters, linkages to time-series data, specific modules in the model and associated parameters, and linkages/connections between, for example, land segments and reaches). Setting up the model involves setting up the UCI file. This can be done via the HSPF GUI or via a text editor.

RESPEC (2018) provides detailed calibration guidance and parameter ranges for the submodules of interest that will be added to the watershed model for this study. We will also use existing information, including from the HSPFParm database (EPA, 1999), data gathered for the Puget

Sound SPARROW model (Figueroa-Kaminsky et al. 2022), parameters for previous HSPF modeling applications, and values derived from research literature to refine parameter estimates during the calibration process and to ensure that values are within typical/expected ranges.

Several approaches to mechanistic simulation of loading from on-site septic systems will be explored, including traditional approaches using the available submodules or more advanced techniques using additional code developed for HSPF special use block.

In general, we will utilize the same measured data used to derive boundary inputs for the QUAL2Kw model (Section 7.3.2.1 and Table 21) as calibration data for the HSPF model. We will also compare the range of loads and constituent yields (load/area) for different HRUs to comparable outputs in the Puget Sound SPARROW model, where applicable.

7.3.3 Model scenarios

After calibrating the modeling framework, the project team will develop multiple management and future conditions scenarios. Currently planned scenarios include:

- **Existing conditions**: as described in section 7.3.2.
- **Load capacity under critical conditions:** Pollutant load reductions, where necessary, to meet water quality criteria under identified critical conditions (low flow, high air temperatures, etc.). We may utilize the HSPF model framework to implement non-point nutrient and bacteria reductions for the QUAL2Kw models.
- **Load capacity under typical conditions** (optional): Pollutant load reductions, where necessary, to meet water quality criteria under identified typical conditions (median flow, median air temperatures, etc.).
- **Pre-human development under critical and typical conditions**: Given the significant influence of natural factors within the Soos watershed (groundwater, lakes, wetlands, beavers, low gradients), there is a strong possibility that DO levels are naturally below, and temperatures are naturally above, the biologically based numeric criteria in several areas and waterbodies. We will develop this scenario following current Ecology guidance, in consultation with EPA Region 10, following Ecology's modeling natural conditions consideration checklist (see Appendix B for the planned application of each element).
- **Climate change impacts:** We may use dynamically downscaled Weather Research and Forecasting (WRF) model outputs from the UW Climate Impacts Group[16] as meteorological inputs to the HSPF and QUAL2Kw model frameworks.
    - The analysis will focus on projected impacts on precipitation and air temperature, given the lack of snowmelt in the watershed, but will also include humidity, wind, and solar radiation impacts. Predictions are available for a suite of global climate models and emissions scenarios at an hourly temporal and 12 km spatial resolution.
    - The project team will select final models, time periods, and emissions scenarios based on discussions before climate scenario work begins to use the most recent information on climate emissions projections.
    - HSPF would then be used to develop the predicted future hydrology in the Soos watershed.

[16] https://cig.uw.edu/datasets/dynamically-downscaled-hydroclimate-projections-wrf-model/

  - The above approach depends on enough remaining time available for this task and whether the extended HSPF existing hydrology is of acceptable quality. Instead, we may use simpler tools to develop a relative air temperature scenario.
- **Future growth impacts**: To construct these scenarios, the project team will consult with local and regional municipal planners and Ecology Water Quality Program representatives. A hypothetical example could be 25% of OSS converted to sewer and exported from the watershed or 20% of OSS upgraded from gravity to advanced treatment. These scenarios will also have decision points about the impacts of projected population growth on septic wastewater load, impervious surface, and land use changes. Our goal is at least two future growth impact scenarios; however, we may develop additional scenarios depending on if time is available and determined need.

7.3.4 Exploratory modeling of downstream impact to the Green River

The QUAL2Kw V6.1 modeling framework will be used to rebuild a coarse model of the Green River using an existing version 5 model built for earlier temperature TMDL development efforts (Coffin et al. 2011) as a starting point. The model network will also include a branch for the lower mile of Big Soos Creek.

This exploratory framework will not be used to develop load capacity or allocations but rather to determine the relative impact of loading from Big Soos Creek to the Green River under different loading inputs (sensitivity tests).

Sensitivity scenarios will pay particular attention to how certain nutrient-productivity relationships in the Green River might be affected by Big Soos Creek's "background" and hatchery loadings, including:

- Organic carbon/CBOD decay rate in the water column
- Oxidation of nitrogen/NBOD in the water column
- Periphyton growth on coarse substrates
- Microbial growth in the hyporheic zone
- Sediment diagenesis in areas with fine substrates

Given the difference in objective and the limited observed data available for this application, this model will not follow the same calibration procedures or be compared to the same quality objectives. A separate project work plan memo will be developed with more detail on the plan for this supplemental project. The final technical report will include documentation of the exploratory model results, quality, and assumptions.

7.4 Assumptions underlying design

See Section 7.4 in the Programmatic QAPP (McCarthy and Mathieu, 2017) for an expanded list of applicable data collection and modeling assumptions.

Data Collection Assumptions

- Data collected in 2023 – 2024, in combination with other external data sources, will be sufficient to develop continuous time-varying boundary conditions for the QUAL2Kw model and, if the extended HSPF model is adequate for hydrology, calibrate it for water quality parameters.

- Data from the synoptic surveys will capture more detailed system dynamics during critical periods during the data collection.

Modeling Assumptions

- The QUAL2Kw model is one-dimensional, which means it assumes that the modeled sections of the creeks in the Soos watershed are vertically and laterally well-mixed. Channel geometry and other reach scale characteristics are set based on average conditions for the model segment length and are assumed to reasonably represent the variations throughout the reach. For example, the channel for a reach may be modeled in the shape of a run habitat with moderate to shallow depths but contain some length of very shallow riffle and deeper pool habitats within it.
- In a similar manner to QUAL2Kw reach representation, HSPF has a limited spatial definition (lumped parameter approach), which assumes that all the physical characteristics within a hydrologic response unit are homogenous.
- Both QUAL2Kw and HSPF have simplified representations of more complex hydraulics or urban drainage. These frameworks assume that any effect due to more complex infrastructure (for example, backwater due to culverts) is minimal at the scale of model development.
- Assumptions made during model development and calibration will be documented in the final report.

7.5 Possible challenges and contingencies

See Section 7.5 in the Programmatic QAPP (McCarthy and Mathieu, 2017) for an expanded list of potential logistical problems, practical constraints, and schedule limitations.

7.5.1 Logistical problems

In addition to those listed in the Programmatic QAPP, we anticipate logistical issues will be more common, compared to other projects, for the following:

- **Private property access on the tributaries**. Given that these waterbodies are too small to be considered navigable, we cannot survey large reaches of these modeled creeks by floating. We will need to rely on private property permission to survey reach scale dynamics such as channel geometry or periphyton/macrophyte coverage; however, private parcels are generally relatively small in the study area.
    - Starting in the summer of 2022, we are mitigating this issue by working to secure additional property access and scouting access to several larger areas of public land within the study area. Site access has already been secured for locations in Table 16 of section 7.2. Additional access may be expanded before data collection.
- **Inadequate flow and depth**. Several areas of the QUAL2Kw modeling domain can reach very low flows, near stagnant water conditions, and even dry up completely during summer and early low-flow conditions. Low flows, shallow depths, and slow velocities can be extremely difficult to model without significant error.

- We will mitigate this issue by maintaining a flexible approach to equipment deployment and data collection. Deployment equipment will be checked at least bi-weekly in the summer and moved to downstream flowing or more representative locations if necessary.
  - We will not use data from conditions where a clean representative sample/measurement of water that moves downstream cannot be obtained.
  - We will not use model results from extremely low flow conditions either. If necessary, we may use PointWQ and sonde/temperature logger deployment data in place of the QUAL2Kw framework to assess impairments in lower flow conditions.
- **Upper Big Soos wetland access.** The wetland affected reaches of upper Big Soos often have poorly defined channels that are challenging and, in places, unsafe to access. Abundant instream debris and inundated vegetation make it inaccessible by wading or small watercraft. These features also make it difficult to distinguish the inundated channel or characterize vegetation potential from aerial photographs.
  - We will mitigate this issue by using a combination of modeling tools to assess the furthest upstream portions of Soos Creek. For these areas, we'll rely on predicted model hydrology and nutrient fluxes, wetland surface areas and volumes, and downstream water quality observations to develop and calibrate the modeling framework.
  - We plan to monitor depth and wetted extent at several discrete locations during wetland mapping surveys under a range of conditions to improve FTABLEs, rating curves, and other hydraulic relationships in this area.
  - We propose a high-resolution drone aerial image flight over the upper wetlands during the study to map wetted extent and vegetation more clearly.
- **Permit approvals for new gaging stations.** The length of approval time for any local permits or permissions can be variable and take many months. There is some uncertainty as to whether all necessary permits and approvals will be acquired by May 2023.
  - If permits are not secured by the start of the project, we plan to use temporary standalone supplemental sonde and pressure transducer deployments to collect continuous depth and water quality data until the more permanent gages with telemetry can be installed.

7.5.2 Practical constraints

We do not anticipate additional practical constraints outside those discussed in the Programmatic QAPP.

7.5.3 Schedule limitations

Technical and scientific work, including modeling, often involves unforeseen analysis. There is always the possibility that during the modeling process, additional analysis is warranted to improve the scientific robustness of the study. Any additional analysis will take more time. This includes time spent working through the modeling challenges and contingencies listed below. Any new policy issues that come up may also take extended discussions and time to resolve.

The potential logistical problems or practical constraints related to data collection could result in the need to collect additional data into the summer of 2024. For example, a dye study may need to be repeated for a particular reach if results are inconclusive or a sonde fails. In general, this additional work should be able to be completed within a few months of the scheduled data collection period. It would only result in a minor project delay, as other data quality assessment work and project activities could be completed before the additional data collection.

7.5.4 Modeling challenges and contingencies

Several challenges exist in developing the modeling framework, including:

- Accurate modeling of water quality in the upper Big Soos Creek wetlands. Given the logistical challenges described above, combined with the location-specific variability (heterogeneity) of the creek and channel type.
    - We will mitigate this challenge by maintaining a flexible, increasingly simplified modeling approach that utilizes several potential frameworks, if necessary. The use of WETQUAL will allow for greater statistical uncertainty analysis. If WETQUAL proves overly complex and a good fit is not obtained, we will use QUAL2Kw, and if that is unsuccessful, we will use a bulk upstream productivity approach using sonde and nutrient data and the PointWQ framework.
- Mechanistic watershed modeling can be challenging as it simulates many complexities that are difficult or impossible to measure to generate loading estimates. It is within the realm of possibility that the HSPF flow calibration may not be adequate when the model is extended over time or that the simulated loadings will have a relatively poor fit to observed data.
    - We will mitigate this challenge by using other previously mentioned pollutant load estimates (SPARROW), observed data, and field staff observations. This will provide context from multiple perspectives when developing a scheme for allocating nutrient loading to specific source categories and pathways.
    - Puget Sound SPARROW model — USGS and the Washington State Department of Ecology are collaborating on the development of refined, seasonal load estimates of total nitrogen and total phosphorus within watersheds draining to Washington waters of the Salish Sea for the years 2005 – 2020 (Figueroa-Kaminsky et al. 2022). The modeling approach for this work is based on SPARROW (Spatially Referenced Regression on Watershed Attributes), a watershed modeling technique developed by the USGS. SPARROW is typically used to estimate stream loads throughout a stream network.
- *E. Coli* modeling using HSPF and QUAL2Kw is not a typical practice for TMDL development in Washington State. The models may not accurately simulate bacteria loading, attenuation, and transport.
    - We will mitigate this challenge by using load duration curves for TMDL development if bacteria modeling proves unsuccessful.
- Macrophyte growth, low gradients, and downstream controls on hydraulics may make it difficult to develop hydraulic rating curves in some watershed sections, particularly in upper Big Soos Creek.
    - If congruent with meeting this project's schedule, we may develop localized HEC-RAS unsteady flow hydraulic models for some sections of the watershed to help develop rating curves for the QUAL2Kw model segments affected.
    - HEC-RAS — The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is software that allows one to perform one-dimensional steady flow hydraulics, one and two-dimensional unsteady flow river hydraulics calculations, quasi-unsteady and full

unsteady flow sediment transport-mobile bed modeling, water temperature analysis, and generalized water quality modeling (nutrient fate and transport).
  - Or we would flag any listing for which an allocation cannot be determined due to local hydraulic considerations.

8.0 Field Procedures

8.1 Invasive species evaluation

Field staff will follow SOP EAP070 on minimizing the spread of invasive species (Parsons et al. 2021). At the end of each field visit, field staff will clean field gear following the SOP to minimize the spread of invasive species in areas of both moderate and extreme concern. Areas of extreme concern have or may have invasive species, such as New Zealand mud snails (NZMS), that are very difficult to clean off equipment and are especially disruptive to native ecological communities. Lower Big Soos Creek (downstream of Hatchery and CM 0.5) has been identified as an area of extreme concern based on confirmed NZMS presence at one location in 2016. In addition to following all protocols, we will minimize risk by collecting data in tributaries and Upper Big Soos Creek before moving to downstream locations and Lower Big Soos Creek.

Field staff will minimize the spread of invasive species after conducting fieldwork 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 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

8.2.1 Fixed network monitoring

Ecology will collect bacteria samples (*E. coli* and fecal coliform), nutrient samples, and discrete water quality measurements (DO, temperature, pH, specific conductivity) twice monthly at a fixed network of sites (see Table 19). Flow measurements will be collected at select sites without established flow gages. Ecology staff will follow the following SOPs for fixed network monitoring:

- EAP015 — Manually Obtaining Surface Water Samples (Joy 2019).
- EAP024 — Measuring Streamflow for Water Quality Studies (Mathieu 2019).
- EAP030 — Collection of Fecal Coliform Bacteria Samples in Surface Water (Ward and Mathieu 2020).
- EAP058 — Operation of the SonTek® FlowTracker® Handheld ADV® (Burks 2021).

8.2.2 Continuous water quality monitoring

Ecology will deploy Onset HOBO DO Data Loggers at 10 sites to collect continuous DO and temperature for at least one year from May 2023 to April 2024. DO loggers may also be deployed at temporary monitoring locations near where the stream transitions to a wetland or lake if there is representative flow (May – July 2023; October 2023 – April 2024). Ecology will follow manufacturer guidelines and relevant continuous water quality monitoring SOPs to perform quality assurance, deployment, and data collection procedures (EAP129; Mathieu and Stuart 2019). Ecology will check for functionality and biofouling and collect Winkler samples twice a month to quality-check the continuous DO records (Ward and Mathieu 2017).

Ecology will also deploy continuous temperature dataloggers (HOBO tidbits) at several fixed network sites (see Table 19). Each site will have at least two thermistors: one to measure water temperature and one to measure air temperature. The thermistors will be programmed to measure temperature at 30-minute intervals. Several sites will also have a datalogger measuring air relative humidity. Ecology will collect discrete temperature measurements twice a month during fixed network monitoring to quality-check the water temperature records.

Ecology will follow the following SOPs to collect temperature and DO data:

- EAP011 — Instantaneous Measurements of Temperature in Water (Nipp 2022).
- EAP044 — Collecting Data to Support a Temperature TMDL Study (Bilhimer 2022).
- EAP080 — Continuous Temperature Monitoring of Freshwater Rivers and Streams (Nelson and Dugger 2022).
- EAP023 — Collection and Analysis of Dissolved Oxygen (Winkler Method; Ward and Mathieu 2019).
- EAP129 — Short-term Continuous Data Collection with a Multiparameter Sonde, Part 1: Field Procedures (Mathieu and Stuart 2019).
- EAP130 — Short-term Continuous Data Collection with a Multiparameter Sonde, Part 2: Data Processing (Mathieu 2019).
- EAP033 — Hydrolab® DataSonde®, MiniSonde®, and HL4 Multiprobes (Anderson 2020).

Ecology MTU is currently transitioning to an improved approach for DO sonde calibration. The approach will be documented in a technical memo and/or a new SOP that will replace EAP033. This new SOP will outline best practices for calibration and deployment for all instrument types.

Ecology's FMU will deploy YSI EXO Multiparameter water quality sondes at a site on Big Soos Creek and Jenkins Creek to collect continuous pH, DO, specific conductivity, and temperature for one year. FMU will maintain the deployed sondes, perform QC procedures, and manage the data collection at these two sites following procedures outlined in SOP EAP101 Continuous Water Quality Monitoring Site Visits and Data Processing (Nelson et al. 2023, in publication).

8.2.3 Synoptic water quality survey

Ecology will conduct up to eight synoptic surveys from May 2023 to March 2024. This will involve the collection of nutrient samples, discrete water quality measurements, and short-term (48-hour) deployment of either YSI EXO and/or Hydrolab multiparameter water quality sondes. Ecology will follow the following SOPs to complete these surveys:

- EAP129 — Short-term Continuous Data Collection with a Multiparameter Sonde, Part 1: Field Procedures (Mathieu and Stuart 2019).
- EAP130 — Short-term Continuous Data Collection with a Multiparameter Sonde, Part 2: Data Processing (Mathieu 2019).
- EAP033 — Hydrolab® DataSonde®, MiniSonde®, and HL4 Multiprobes (Anderson 2020).

8.2.4 Synoptic biological monitoring survey

Ecology will conduct at least three biological surveys during summer of 2023 at key locations along Big Soos Creek and at the mouth of major tributaries. Surveys involve collecting periphyton samples from epilithic habitat, or the surfaces of coarse gravel and rocks, and macrophyte biomass samples by following procedures outlined in the following documents:

- EAP111 — Periphyton Sampling, Processing and Identification in Streams and Rivers (Larson and Collyard 2019).
- Aquatic Plant Sampling Protocols (Parsons 2001).
- A Review of Aquatic Plant Monitoring and Assessment Methods (Madsen and Wersal 2017).

Depending on the availability of sediment benthic flux chambers, sediment oxygen demand may be characterized by installing sediment benthic flux chambers in up to 4 representative reaches along the creek or tributaries during the synoptic surveys if resources allow. The benthic chambers will remain in place for 24 to 48 hours. Once deployed, Winkler DO grab samples and DO measurements will be collected at dawn and dusk.

The following SOPs will be followed:

- EAP036 — Benthic Flux Chambers (Roberts 2017).
- EAP033 — Hydrolab® DataSonde®, MiniSonde®, and HL4 Multiprobes (Anderson 2020).
- EAP023 — Collection and Analysis of Dissolved Oxygen (Winkler Method; Ward and Mathieu 2019).

8.2.5 Synoptic flow measurement survey

Ecology will collect flow measurements at key locations along Big Soos Creek and at the confluences with major tributaries. Ecology will follow the following procedures to collect flow measurements:

- EAP024 — Measuring Streamflow for Water Quality Studies (Mathieu 2019).
- EAP056 — Measuring and Calculating Stream Discharge (Shedd 2021).
- EAP058 — Operation of the SonTek® FlowTracker® Handheld ADV® (Burks 2021).

8.2.6 Streamflow gage

FMU will establish gage stations equipped with either a gas-bubbler system or an electronic transducer to calculate the stream stage at two sites on Big Soos and Jenkins Creek. FMU will first visit the sites to evaluate site suitability and representativeness of flow conditions before installing gages. FMU staff will visit streamflow gages approximately once every six weeks to measure flow using Acoustic Doppler Velocimeters (ADVs) and confirm the stage to maintain calibration of the data logger. Staff will also perform necessary equipment maintenance during these site visits. Staff will follow procedures outlined in SOP EAP056: Measuring and Calculating Stream Discharge (Shedd 2021).

The data loggers will record stage measurements every 15 minutes and send the information via a GOES telemetry system. A rating curve will be developed to predict streamflow based on stage height records and velocity measurements at different stages. After the rating curve is applied to the stage record, the stream information will be delivered to FMU's Freshwater DataStream webpage[17].

8.2.7 Stage monitoring at tributaries

USGS will deploy HOBO water level loggers (pressure transducers) at three sites on Little Soos, Covington, and Soosette creeks to measure continuous stream stage. USGS uses this type of logger to collect stage data in small streams in the Puget Lowland region to support Ecology's Stormwater Action Monitoring (SAM) project (Song and Sheibley 2020).

Loggers will be checked under controlled conditions in the lab and cleaned before deployment. Continuous stage will be monitored for one year if there is representative flow. Measurements will be collected at 15-minute intervals. USGS will visit bimonthly to download data and check on the loggers. USGS will review and analyze the continuous stage data before releasing it to the USGS Science Base database. Ecology will collect bimonthly discrete flow measurements at these sites for fixed network monitoring (Section 8.2.1).

Ecology will develop a flow-depth relationship using the continuous depth data and discrete flow measurements following procedures described in SOP EAP024 Measuring Streamflow for Water Quality Studies (Mathieu 2019). See Section 7.3.2 for more details.

8.2.8 Time of travel

Ecology will follow SOP Time-of-Travel Studies in Freshwater Using a Dye Tracer (Carroll 2022) to conduct this survey. The survey involves using a safe fluorescent dye (20% Rhodamine WT) to trace the movement of a dye cloud from upstream to downstream to calculate the average velocity of that body of water (Carroll 2022). Dye concentrations will be detected using YSI EXO multiparameter sondes and Hydrolab DataSondes and Minisondes equipped with a rhodamine fluorometer, recording measurements every 5 – 10 minutes at key locations downstream from the point of dye release. Ecology will notify King County, other appropriate officials, and local emergency contacts before using the dye.

8.2.9 Riparian vegetation and stream channel surveys

Ecology will follow the following procedures to conduct these riparian and channel surveys:

- EAP084 — Conducting Riparian Vegetation and Stream Channel Surveys in Wadeable Streams for Temperature Total Maximum Daily Load Studies (Urmos-Berry 2019).
- EAP045 — Hemispherical Digital Photography Field Surveys Conducted as Part of a Temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit Technical Study (Mathieu 2019).
- EAP046 — Computer Analysis of Hemispherical Digital Images Collected as Part of a TMDL or Forests and Fish Unit Technical Study (Stohr 2019).

[17] https://apps.ecology.wa.gov/continuousflowandwq/

- EAP097 — Collection of Longitudinal Stream Depth Profiles (Stuart and Mathieu 2021).

Field staff will use a hemispherical lens and digital camera to take 360° pictures of the sky to calculate the shade provided by vegetation and topography at the center of the stream. The digital images will be processed and analyzed using the Gap Light Analyzer software program.

Field staff will follow the guidance outlined in Torgersen et al. (2012) for identifying and classifying potential cold-water refugia.

8.2.9 Stormwater infrastructure baseflow monitoring

For the initial screening of stormwater discharge locations in the study area, Ecology may collect initial flow measurements to determine whether the drainage has sufficient flow for collecting samples and measurements. Ecology staff will follow the following SOPs for the initial screening and routine monitoring of stormwater locations:

- EAP015 — Manually Obtaining Surface Water Samples (Joy 2019).
- EAP024 — Measuring Streamflow for Water Quality Studies (Mathieu 2019).
- EAP030 — Collection of Fecal Coliform Bacteria Samples in Surface Water (Ward and Mathieu 2020).
- Collecting Grab Samples from Stormwater Discharges, Version 1.1 (Lowe et al. 2018).

8.2.10 Groundwater monitoring

USGS will follow their guidance documents to assess groundwater and surface-water interactions (Cunningham 2011; Rosenberry and LaBaugh 2008). USGS will utilize temperature profile rod methods (Constantz and Stonestrom 2003; Naranjo and Turcotte 2015; Irvine et al. 2017) and an IDTempPro computer program (Voytek et al. 2014) to evaluate vertical temperature profiles and infer groundwater-surface water exchanges.

Staff will collect groundwater samples with a peristaltic pump using low-flow sampling procedures. A flow-through cell and water quality sonde will measure temperature, pH, conductivity, DO, and ORP. Measurements will be collected at five-minute intervals until the measurements have stabilized.

8.2.11 Watershed health baseline monitoring

Watershed health baseline monitoring will follow the methods and procedures described in Cusimano et al. (2006) and the metric calculations and SOPs described in Janisch (2020), except for the guidance around probabilistic sampling design (since the sites that will be monitored will be specific to the Soos watershed and as identified in Section 7.2.1).

8.3 Containers, preservation methods, holding times

See Section 8.3 in the Programmatic QAPP (McCarthy and Mathieu 2017).

8.4 Equipment decontamination

See Section 8.4 in the Programmatic QAPP (McCarthy and Mathieu 2017).

8.5 Sample ID

See Section 8.5 in the Programmatic QAPP (McCarthy and Mathieu 2017).

8.6 Chain of custody

See Section 8.6 in the Programmatic QAPP (McCarthy and Mathieu 2017).

8.7 Field log requirements

See Section 8.7 in the Programmatic QAPP (McCarthy and Mathieu 2017).

8.8 Other activities

See Section 8.8 in the Programmatic QAPP (McCarthy and Mathieu 2017).

9.0 Laboratory Procedures

9.1 Lab procedures table

MEL will analyze all surface water and groundwater samples by following MEL's internal SOPs. MEL will also analyze periphyton tissue for total carbon, nitrogen, and phosphorus. Periphyton taxonomy will be analyzed by Rhithron Associates, Inc. in Missoula, Montana.

See Table 11 in the Programmatic QAPP (McCarthy and Mathieu 2017) for lab methods for parameters sampled for this study. The table includes sample matrix, expected range of results, and method detection limits.

9.2 Sample preparation methods

Sample collection and preservation of samples analyzed at the laboratory will be prepared according to MEL's internal SOPs or the following SOPs:

- EAP015: Manually Obtaining Surface Water Samples (Joy 2019).
- EAP034: Collection, Processing, and Analysis of Stream Samples (Ward 2019).
- EAP023: Collection and Analysis of Dissolved Oxygen (Ward and Mathieu 2019).
- EAP111: Periphyton Sampling, Processing and Identification in Streams and Rivers (Larson and Collyard 2019).

9.3 Special method requirements

Not applicable.

9.4 Laboratories accredited for methods

MEL is accredited for the methods listed in Section 9 of the Programmatic QAPP (McCarthy and Mathieu 2017). Rhithron Associates, Inc. is accredited for periphyton taxonomy and enumeration.

10.0 Quality Control Procedures

Table 25 shows this study's quality control (QC) procedures. The *Programmatic QAPP for Water Quality Impairment Studies* (McCarthy and Mathieu 2017) explains these procedures in detail.

Table 25. Quality control procedures

QC Type	QC Procedures
Field Measurement QC	• Meter/logger pre-calibration • Meter/logger post-checks • Meter/logger field QC measurements • Fouling checks • Winkler DO samples
Field Sample QC	• Field replicates • Field blanks
Laboratory Sample QC	• Calibration/Verification blanks • Method blanks • Analytical duplicates • Matrix spikes • Lab control samples

10.1 Table of field and laboratory quality control

In Section 10 of the Programmatic QAPP (McCarthy and Mathieu 2017), Table 18 outlines the field and lab QC procedures for samples; Table 14 outlines the QC procedures for field measurements.

Table 26 presents the QC procedures for field samples and lab analyses not defined in the Programmatic QAPP.

Table 26. Quality control lab procedures for field and lab.

Parameter	Lab Blanks	Lab Method Blanks	Lab Duplicates	Lab Matrix Spikes	Field Blanks	Field Duplicates
Periphyton Taxonomy	N/A	N/A	N/A	N/A	N/A	10%

10.2 Corrective action processes

See Section 10 of the Programmatic QAPP (McCarthy and Mathieu 2017).

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

Staff will record all field data in a water-resistant field notebook or field form. Before leaving each site, staff will check field notes 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. Ecology-collected continuous data will be stored in a project database that includes station location information and data QA information and will be uploaded to the EIM database following appropriate data upload procedures. The EIM Study ID for this project is NMAT0009.

Watershed health monitoring data will also be added to the Watershed Health Monitoring Web[18] (WHMWeb). WHMWeb is a tool built by Ecology that translates statistically robust regional assessments of watershed conditions into metrics diagnostic of watershed health.

USGS-collected data will be reviewed and uploaded to the publicly accessible ScienceBase database[19]. Ecology will access the data through ScienceBase and collect hard copies of the field notebooks and forms.

11.2 Laboratory data package requirements

See Section 11 of the Programmatic QAPP (McCarthy and Mathieu 2017). Refer to Sections 9.1 and 14.2 for information about requested reporting of non-detects.

11.3 Electronic transfer requirements

MEL will provide all data electronically to the project manager through the LIMS to EIM data feed. This data includes results for surface water samples collected by Ecology and groundwater samples collected by USGS. The protocol for how and what MEL transfers to EIM through LIMS is already in place. Ecology staff will review and upload all MEL data transferred from LIMs to EIM.

11.4 EIM/STORET data upload procedures

All field measurement data will be entered into EIM, following all existing Ecology business rules and the EIM User's Manual for loading, data quality checks, and editing.

[18] https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Habitat-monitoring/Watershed-health
[19] (https://www.sciencebase.gov/catalog/)

11.5 Model information management

Modeling can be a complex process involving multiple steps and procedures and various iterations. Model information will be managed by meticulous file organization and naming conventions that will identify, track, and date model input/output files associated with each significant model run and each major iteration in model calibration.

This will be done by:

- Creating separate sub-folders to contain the inputs and outputs of each significant model/scenario run with the date of each model run.
- Tracking model runs in an Excel spreadsheet that includes the name for each significant model run/scenario run, the name(s) and location(s) of associated input and output files, and major parameters changed for different model scenarios.
- If the model version is changed during the modeling process, all sub-folders/files associated with each version of the model will be placed within a larger folder that identifies the model version used for those model runs.

The approximate size of HSPF model files for a single combined hydrologic and sediment model run are:

- Input files: 10 MB
- Output files: 300 MB
- Post-processing files: 100 MB

The approximate size of QUAL2Kw model files for a model run with all constituents simulated and full dynamic outputs enabled are:

- Input files: 25 MB
- Output text files: 0.2 to 2 GB
- Excel spreadsheet: 0.1 to 1 GB

We will reduce model storage capacities by using rQUAL2Kw (which does not require an Excel spreadsheet version of the model) to advance the model for most versions/scenarios beyond initial model development. We will only retain output text files for major versions of the model or scenarios and delete interim versions, given that these can be regenerated later. Some interim model outputs may be retained as binary files generated by rQUAL2Kw to reduce storage space.

It is difficult to predict how many total model runs will be needed for model calibration and model scenarios, so the total size of model-related files generated by this study cannot be estimated. However, we do not anticipate that file storage will be a limiting factor based on the available storage on shared network and modeling server drives.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

See Programmatic QAPP (McCarthy and Mathieu 2017). Field audits are not planned for this project; audits may be added if requested by management or field staff.

12.2 Responsible personnel

See Programmatic QAPP (McCarthy and Mathieu 2017).

12.3 Frequency and distribution of reports

The results of the field data collection, data quality assessment, data analysis, and modeling will eventually be presented in several technical reports and memos. The Environmental Assessment Program will publish the final reports according to the project schedule in Section 5.4.

We plan to publish interim pieces of the technical work (for example, a data and quality assessment and an HSPF watershed model documentation) in separate reports or technical memos to limit the size and complexity of the report and provide external information in a shorter timeframe.

The principal investigators will provide an informal and brief (less than one page) summary email with bullet points describing project progress to the client quarterly.

USGS will provide a technical report that summarizes the hydrogeologic setting and the results of data collection outlined in section 7.2 under Groundwater Monitoring.

12.4 Responsibility for reports

- The modeling principal investigator will be the primary author for the final instream modeling and scenarios technical report.
- The field principal investigator will author the report on data collection and data quality analysis.
- USGS will be responsible for the groundwater report.
- The project modeler will help author parts of the final report related to data analysis and modeling and will be the lead author for any HSPF model documentation.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

See Section 13 of the Programmatic QAPP (McCarthy and Mathieu 2017). Throughout field sampling, the field lead and all crew members are responsible for station positioning, sample collection, and sensor deployment procedures as specified. Additionally, technicians systematically review all field documents (such as field logs, chain-of-custody forms, and sample labels) to ensure data entries are consistent, correct, and complete, with no errors or omissions. A second staff person always checks the work of the staff person who primarily collected or generated data results.

13.2 Laboratory data verification

See Section 13 of the Programmatic QAPP (McCarthy and Mathieu 2017).

13.3 Validation requirements, if necessary

See Section 13 of the Programmatic QAPP (McCarthy and Mathieu 2017).

13.4 Model quality assessment

Section 13 of the Programmatic QAPP (McCarthy and Mathieu 2017) provides more detail.

13.4.1 Calibration and evaluation

Temperature and DO calibration will focus on linking key mechanisms and scientific explanations to adjustments to model parameters and inputs. We will evaluate model calibration by assessing the goodness of fit to observed data and the model's ability to capture daily, seasonal, and spatial patterns. Section 6.4 contains specific model quality objectives.

For the QUAL2Kw instream models, we will use rQUAL2kw to calculate model skill statistics for different groups of data to explore the range of spatial and temporal variability in model quality. Model quality objectives will not be applied to all groups, but at a minimum, they will be applied seasonally (wet vs dry season) to the whole model domain. It may be necessary to divide individual waterbodies into spatial groups (for example, upper and lower Big Soos Creek) to evaluate fitness if it is clear the model performs well in one general area (for example, Lower Big Soos Creek) and poorly in another general area (for example wetland impacted upper Big Soos Creek). It is possible that the models could be adequate to meet study objectives in some areas but not in other areas.

The general calibration procedure for the QUAL2Kw models will follow a pre-determined constituent order and process:

- Manual adjustments to ungaged inputs to develop a dynamic water balance.
- Manual adjustments to channel geometry to match time of travel data and other hydraulic observations (widths, velocities, depths).

- Manual adjustments to input data, channel geometry, light and heat parameters/models, and reach specific adjustments to hyporheic flow to match patterns in temperature data. Examples of adjustments include:
  - Localized groundwater temperatures within the range of observations.
  - Increasing channel depths and reducing velocities or adding "pool" model segments.
  - Selecting a different longwave model and adjusting longwave parameters.
- Manual adjustments to suspended solid parameters (settling rates).
- Automatic calibration process for remaining water quality parameters.
- Manual adjustment to water quality parameters, as necessary, within the recommended ranges of the literature and previous QUAL2Kw applications (see Mathieu and Khan 2020; Appendix F; Tables F-10 and F-11).
- Manual adjustments, only if deemed critical, to water quality parameters outside the pre-established ranges. Each adjustment that falls outside these ranges will have thorough documentation of a scientifically defensible explanation in the model report.

We do not plan to reserve a random set of observations or seek out an independent data set to validate/corroborate the QUAL2Kw models. While this type of traditional model validation can be very valuable in evaluating model performance, it comes at the cost of reduced information used to understand the system and calibrate the model. Resource constraints on data collection for this application make it ideal to use all available data to set up and calibrate the model.

The dynamic hourly simulation of all constituents over a wide range of conditions, coupled with model skill evaluation of many different spatial/temporal groups over this wide range (see above), will result in a level of evaluation sufficient for the project goals and objectives.

In general, HPSF calibration and evaluation will follow available guidance (Donigian 2000; Donigian 2002; Donigian et al. 2009; Duda et al. 2012).

If the HSPF model is extended, we will perform an informal validation after model calibration by comparing nutrient load estimates for Soos Creek watershed subbasins from the previously described Puget Sound SPARROW pollutant load model. However, given the large difference in spatial scale and objectives between these studies and the TMDL study, we will not necessarily accept or reject the results of the HSPF model based on this evaluation.

Any PointWQ models will be evaluated in a manner like the QUAL2Kw models. The wetland modeling framework will be evaluated like the HSPF model, focusing on nutrient parameters.

13.4.1.1 Accuracy and Precision

Model accuracy and precision will be assessed by comparing the "absolute distance" between modeled results and field measurements representing a similar time and location (positive and negative differences will be treated the same). For most parameters, notably temperature and DO, we will calculate the root mean square error (RMSE) between paired modeled and observed results to assess accuracy, as well as the centered RMSE to assess precision, which first subtracts the means of observations and predictions from the values before calculating the RMSE. We will also calculate the average mean error (AME).

13.4.1.2 Bias

Bias is also usually assessed by comparing modeled results to field measurements from a similar time and location. However, bias is indicated by the average shift between the two (positive and negative differences "cancel out"), which helps determine how much precision deviates from being equally balanced.

This project will use the mean error (average of paired observed-modeled values) to assess model bias for the QUAL2Kw models and relative percent difference to evaluate bias in the HSPF model.

13.4.1.3 Representativeness

To assess whether model results represent the system and sample population for a given constituent, they will be compared to representative field data and observations. A model that represents the system well will have adequate performance and effectively capture patterns under a wide range of hydrologic, seasonal, and daily conditions.

13.4.1.4 Qualitative assessment

Calibration will utilize different graphic plots to assess qualitative model fitness, including:

- Longitudinal plots across the spatial extent of the model of daily minimums, means, and maximums for several days representing critical or important conditions (low flow, end of supplemental spawning, first flush storm, etc.).
- Hourly fluctuations over the course of a day (diel plots) at observed downstream locations on critical or important days.
- Time series plots for the entire model period, annually, seasonally, monthly, or during important weeks or days, as necessary to adequately assess temporal patterns.
- Cumulative frequency or histograms to evaluate observed vs predicted data distribution.
- Observed versus predicted scatterplots with fitted linear regressions and r correlation values.

13.4.2 Analysis of sensitivity and uncertainty

We will test model sensitivity to a range of input values for key parameters that affect temperature, DO, and *E. coli* bacteria in the model. RMSE and plots will be used to evaluate how fitness and model results change when parameters or key inputs are changed within a reasonable range. This may include, but is not limited to:

- Temperature: We will assess daily heat fluxes for critical dates in the model to help determine sensitivity parameters. Examples of potential sensitivity tests include:
  - Groundwater input temperature (range of monitoring results)
  - Percent effective shade (± 10% effective shade)
  - Longwave radiation model selected.
  - Hyporheic flow fraction (± 5 – 10% in reaches where used)
- Dissolved oxygen: We will assess daily oxygen fluxes for critical dates in the model to help determine sensitivity parameters. Potential sensitivity tests:
  - 25^{th} and 75^{th} percentiles of 'Rate Sheet' parameters for calibrated QUAL2Kw models from the western U.S.
  - Groundwater DO concentrations (range of monitoring results)

    - Reaeration model selected and user reaeration coefficients (if user model is selected for calibrated model).
- *E. coli* bacteria:
    - Range of die-off rates from appropriate literature.
    - Range of bacteria concentrations in groundwater and stormwater.

See Section 13.4.2 of the Programmatic QAPP (McCarthy and Mathieu 2017) for a more detailed discussion of potential uncertainty analyses and resources. The final report will contain a qualitative analysis and discussion of uncertainty and a quantitative analysis or discussion of sources of uncertainty where it is feasible to provide some level of quantitative assessment.

We will explore two methods for Monte Carlo simulations to further evaluate QUAL2Kw model parameter sensitivity and uncertainty:

- The use of the YASAIw Excel plug-in (Pelletier 2009) coupled with the Excel version of the QUAL2Kw model. Stuart (2020) provides a good example of how YASAIw might be used.
- Available R software statistical packages and base functions combined with the rQUAL2Kw R package for running QUAL2Kw.

The general process involves varying model inputs/parameters randomly around the mean of the original parameter/input value within a probability distribution; a model simulation is run, model output summary and error statistics are calculated, and the process is repeated hundreds or thousands of times.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

See Section 14 of the Programmatic QAPP (McCarthy and Mathieu 2017).

14.2 Treatment of non-detects

See Section 14 of the Programmatic QAPP (McCarthy and Mathieu 2017).

14.3 Data analysis and presentation methods

See Section 14 of the Programmatic QAPP (McCarthy and Mathieu 2017).

14.4 Sampling design evaluation

See Section 14 of the Programmatic QAPP (McCarthy and Mathieu 2017).

14.5 Documentation of assessment

See Section 14 of the Programmatic QAPP (McCarthy and Mathieu 2017).

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16.0 Appendices

Appendix A. Historical data plots

Historical Streamflow Data

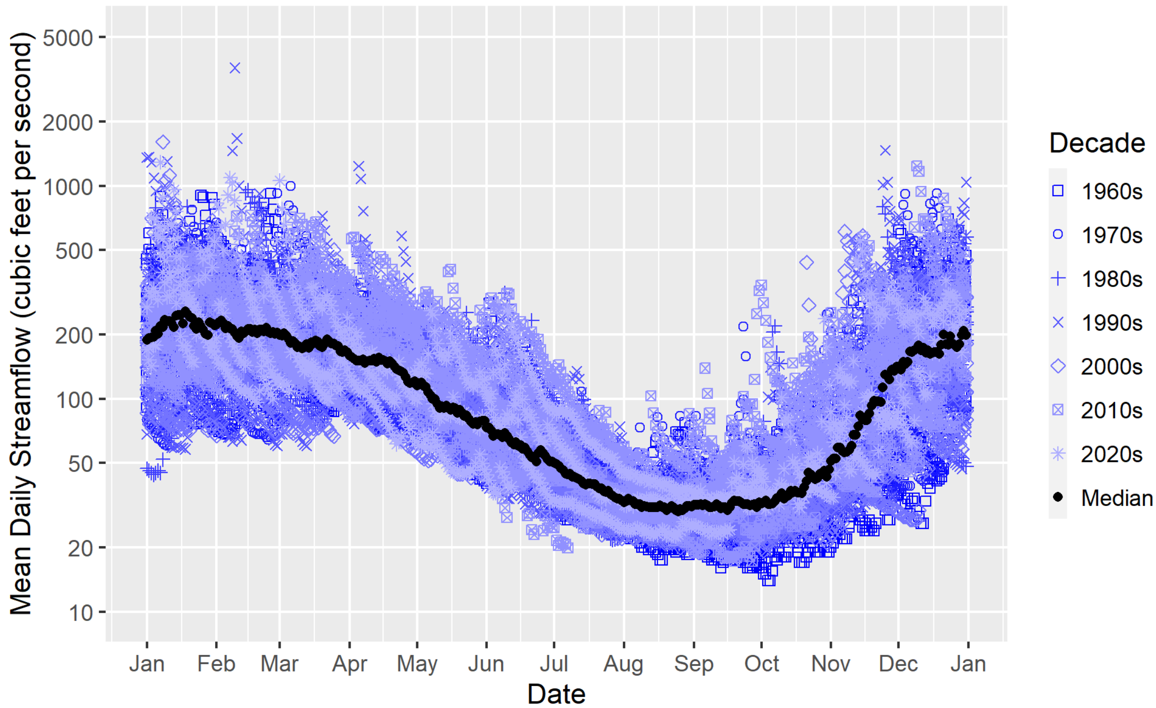

Figure A-1. Big Soos Creek at USGS gage 12112600 near creek mile (CM) 1.1.

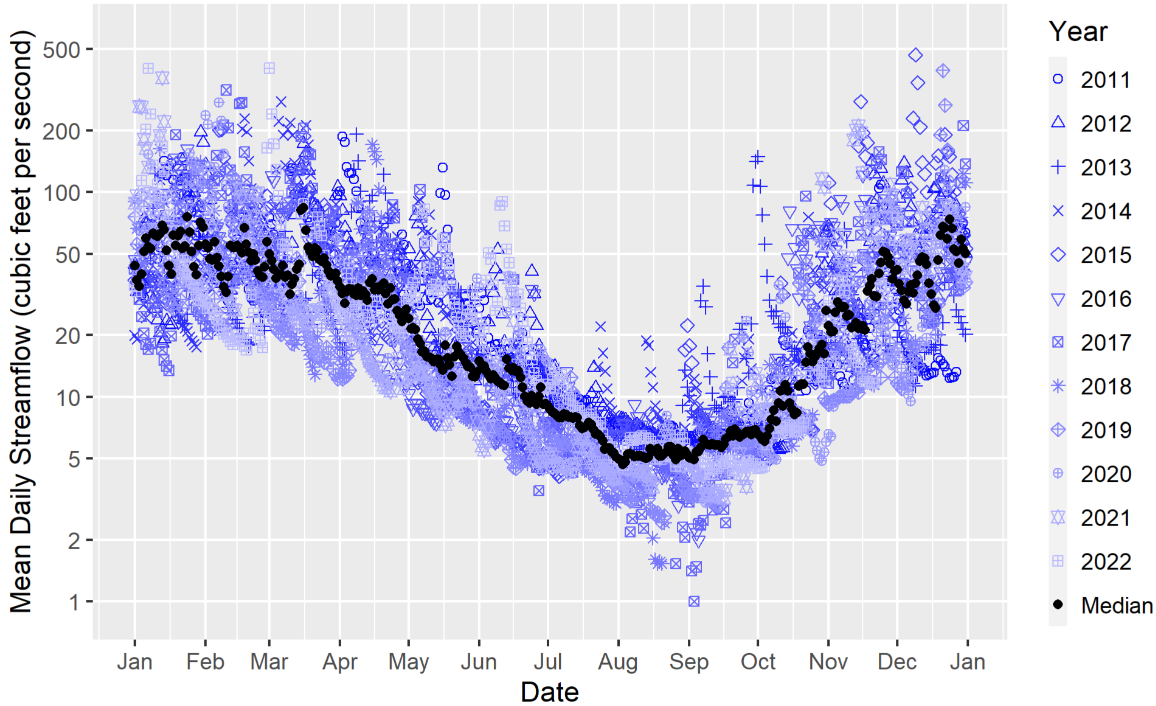

Figure A-2. Big Soos Creek at King County gage 54j near creek mile (CM) 4.6.

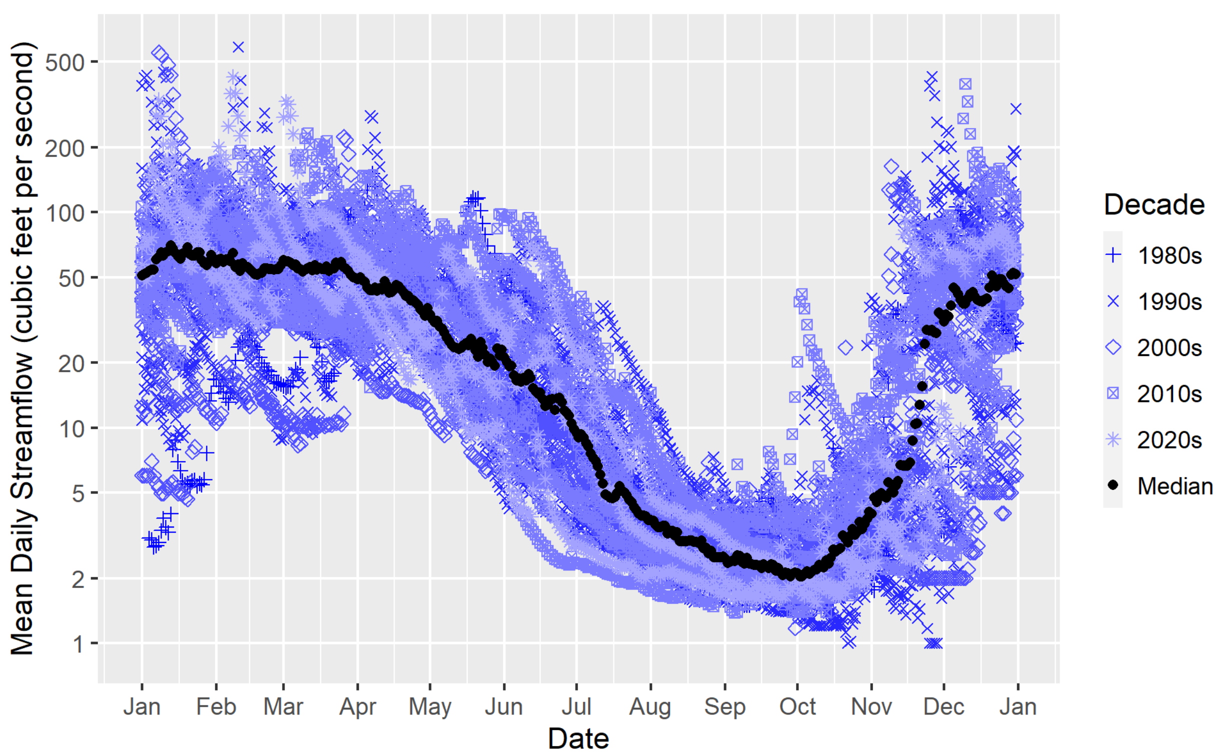

Figure A-3. Covington Creek at King County gage 09a.

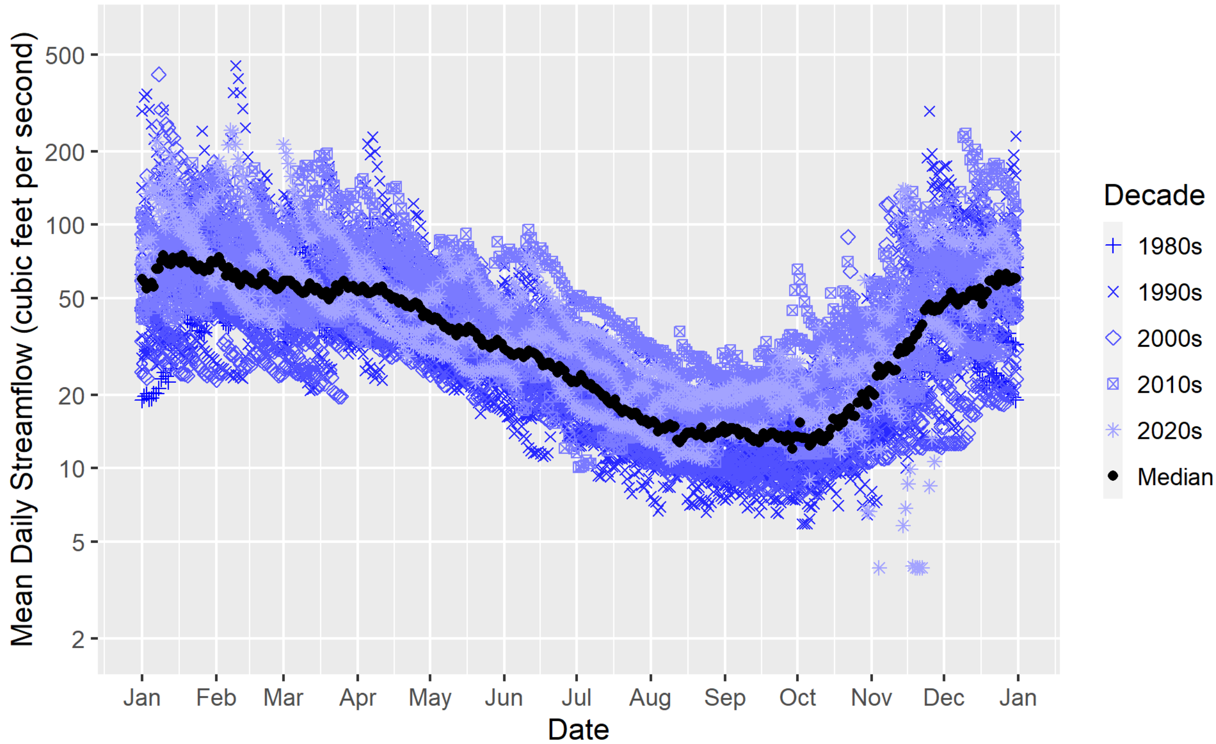

Figure A-4. Jenkins Creek at King County gage 26a.

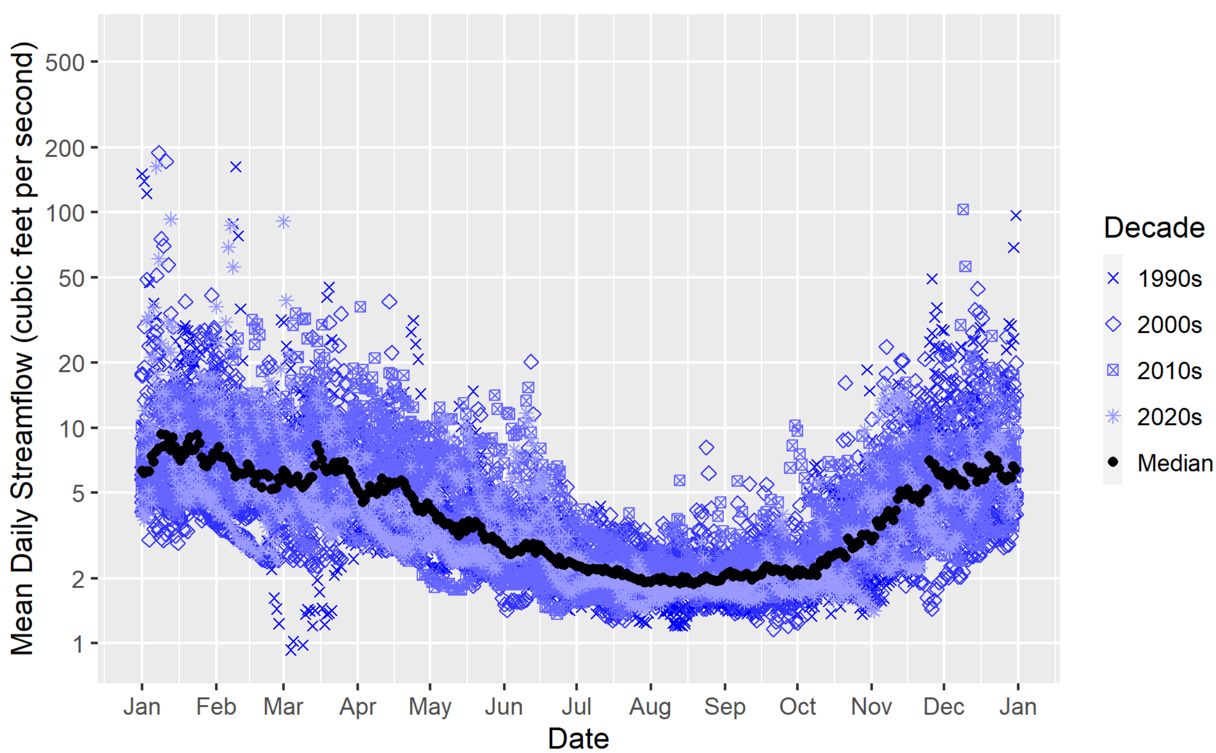

Figure A-5. Little Soos Creek at King County gage 54i.

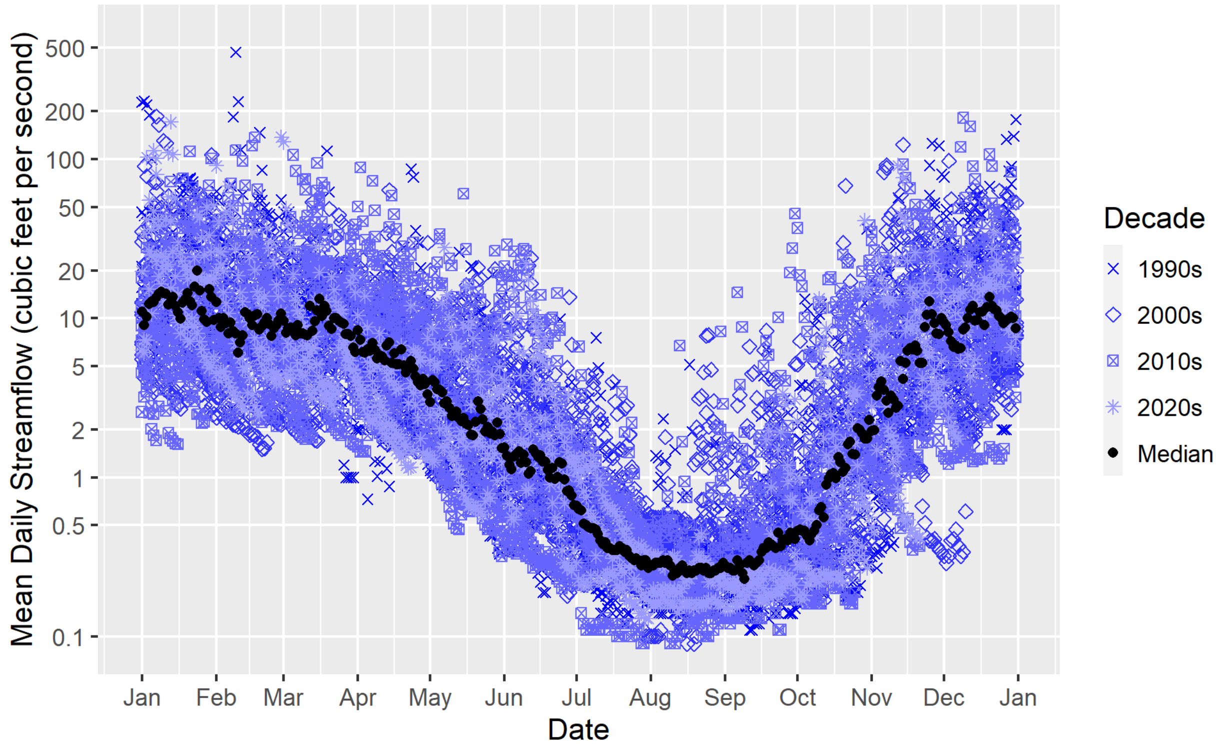

Figure A-6. Soosette Creek at King County gage 54h.

Historical Water Quality Data

Figures A-7 through A-11. Water quality plots for King County monitoring on Big Soos Creek at site A320 near CM 1.1.

Figure A-7. Ammonia at on Big Soos Creek at site A320 near CM 1.1.

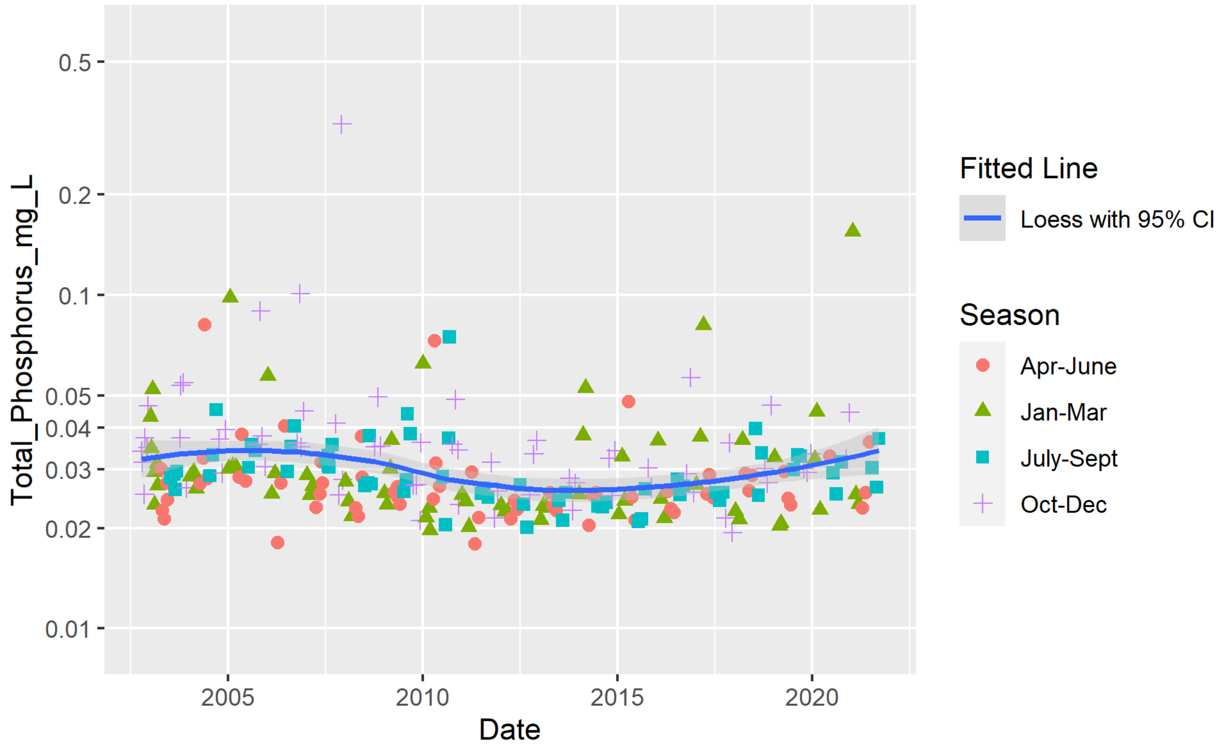

Figure A-8. Total Phosphorus at on Big Soos Creek at site A320 near CM 1.1.

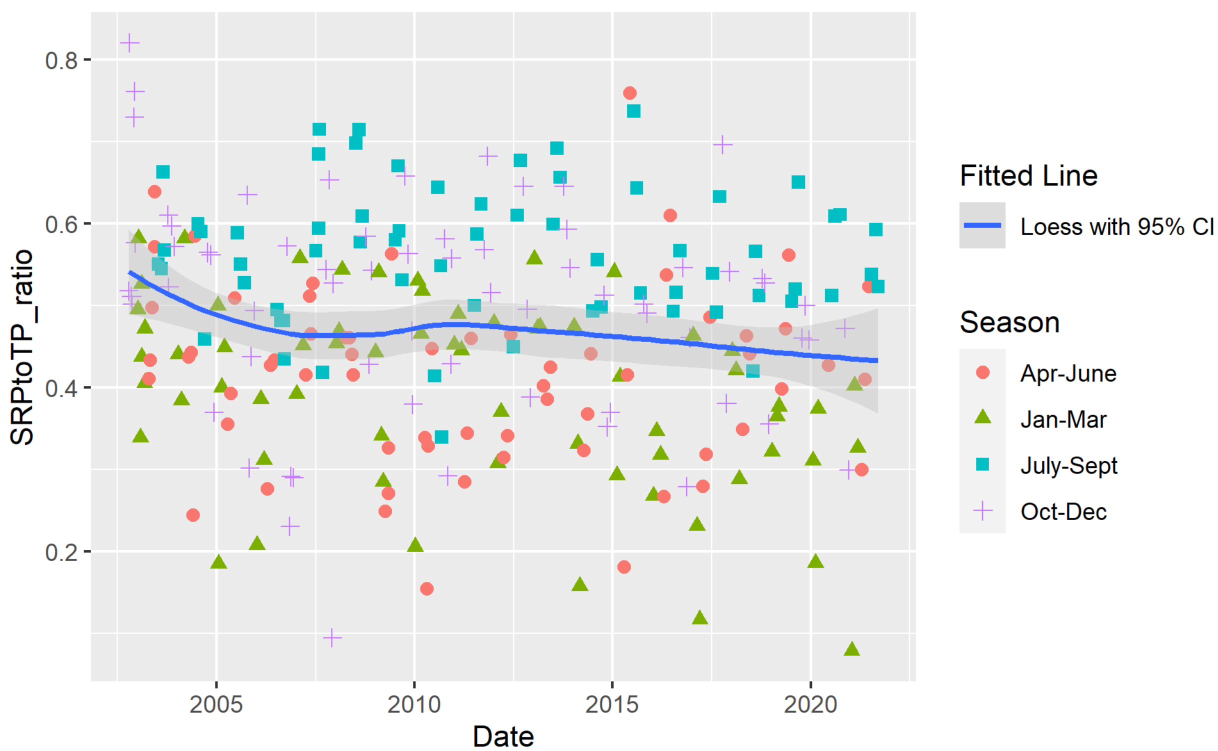

Figure A-9. Soluble Reactive Phosphorus to Total Phosphorus ratio at on Big Soos Creek at site A320 near CM 1.1.

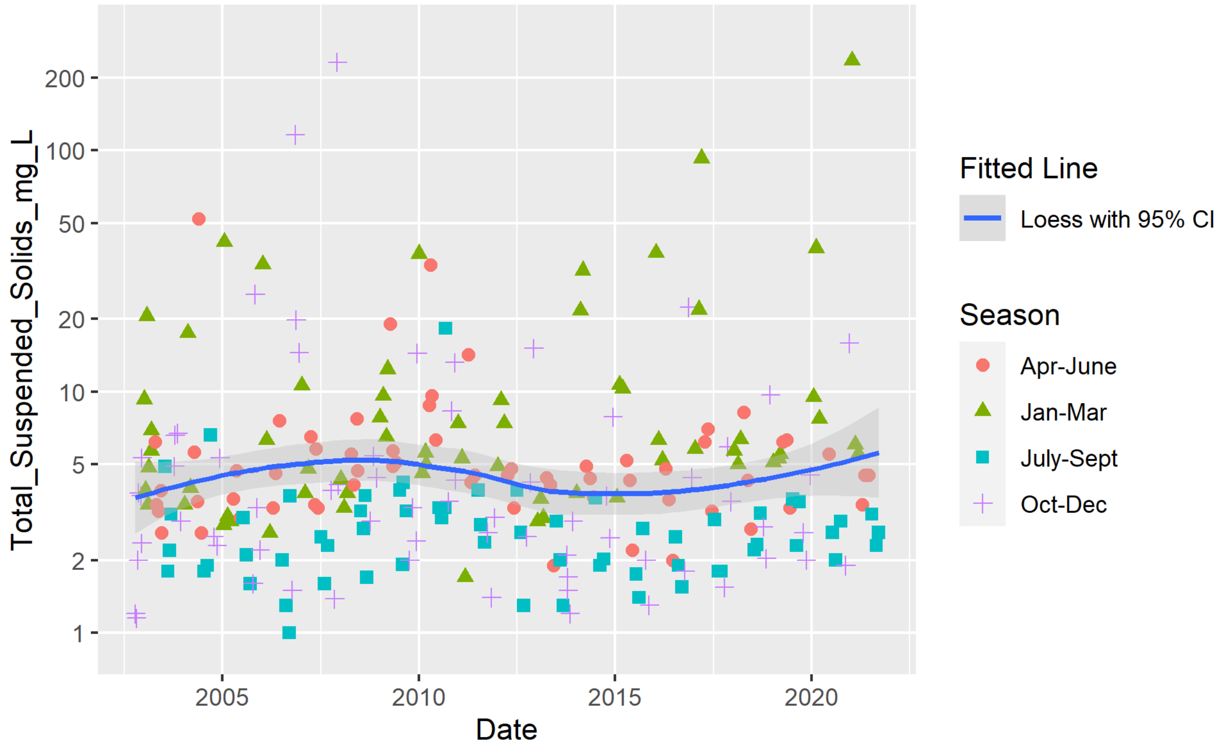

Figure A-10. Total Suspended Solids at on Big Soos Creek at site A320 near CM 1.1.

Figure A-11. Turbidity at on Big Soos Creek at site A320 near CM 1.1.

Figures A-12 through A-21. Water quality plots for King County monitoring on Jenkins Creek at site D320.

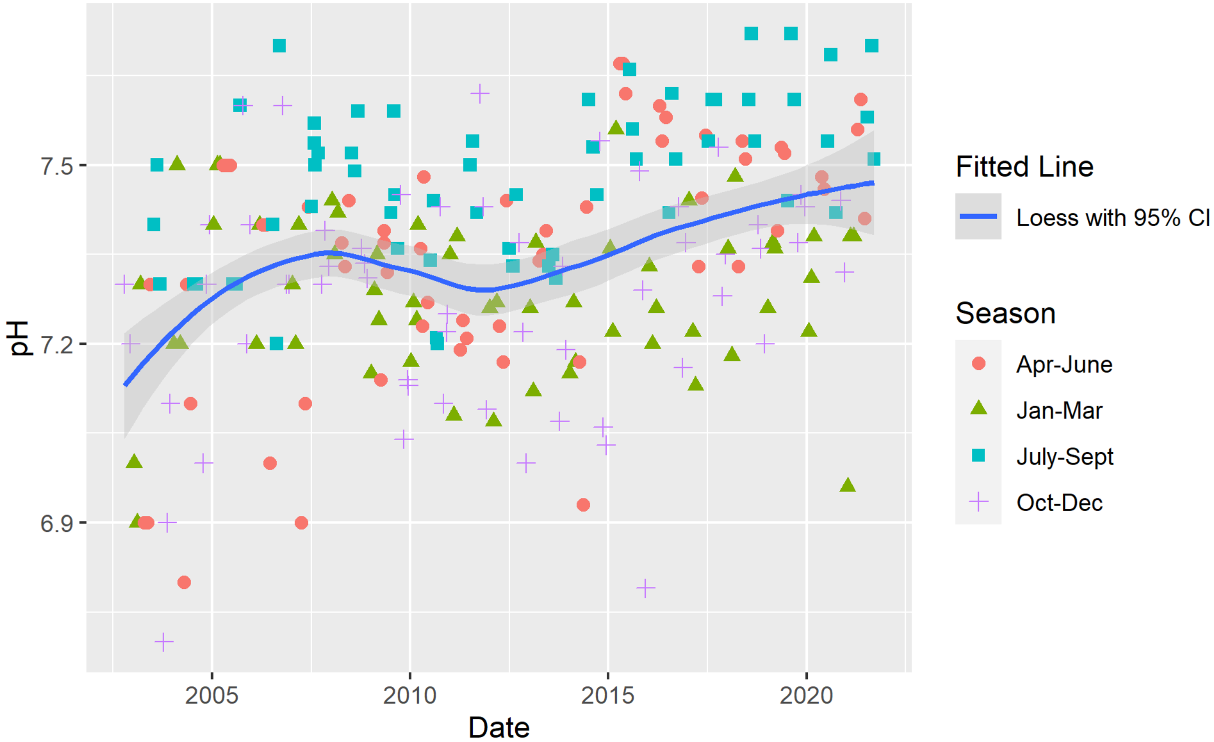

Figure A-12. King County pH at Jenkins Creek at site D320.

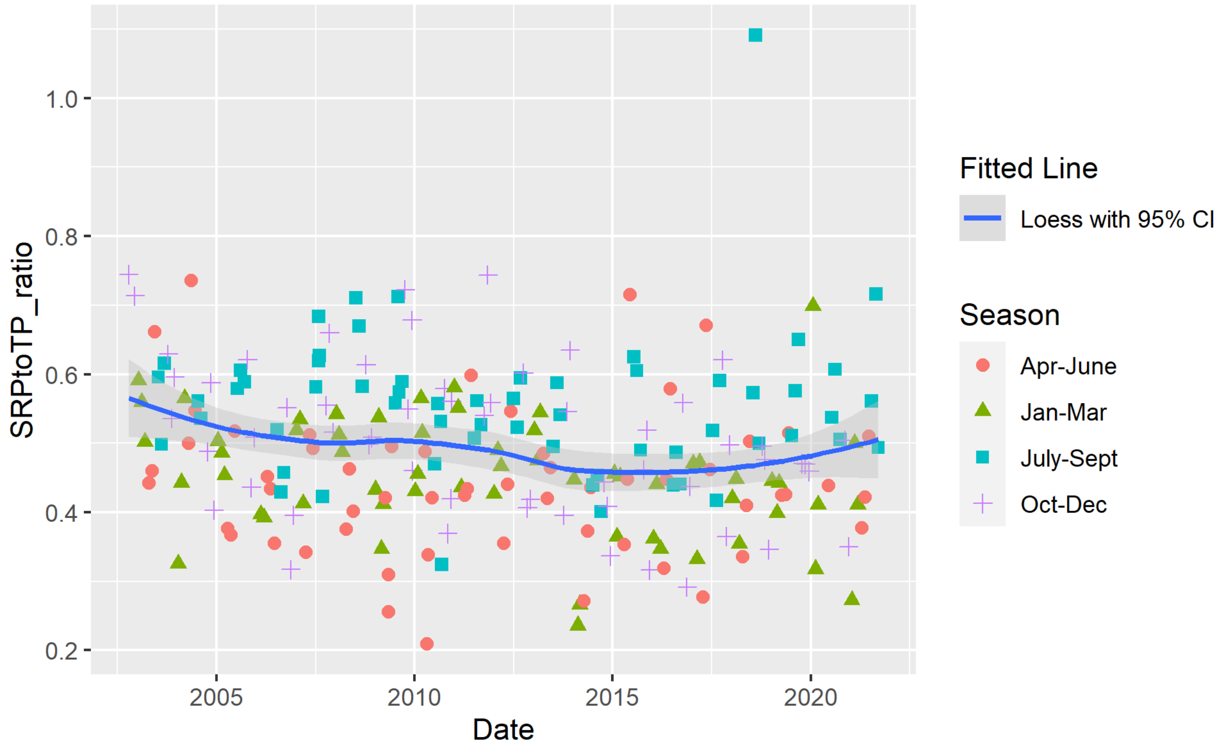

Figure A-13. King County SRP to TP ratio at Jenkins Creek at site D320.

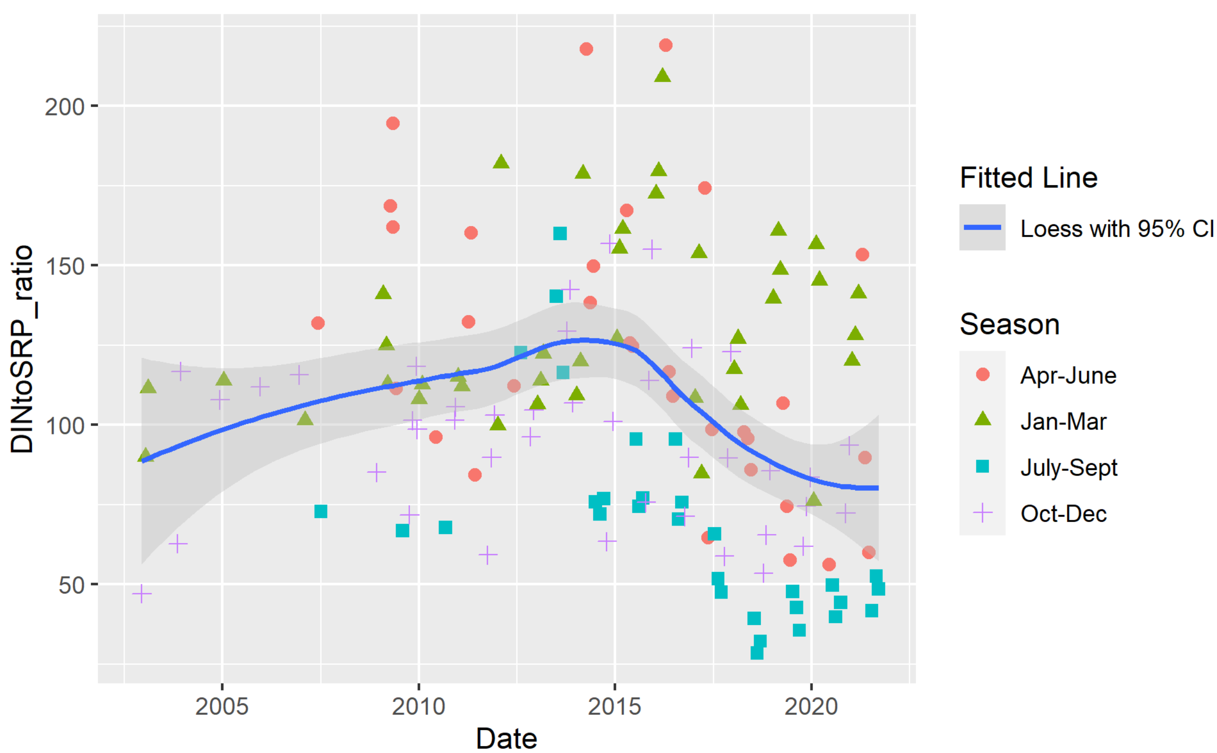

Figure A-14. King County DIN to SRP ratio at Jenkins Creek at site D320.

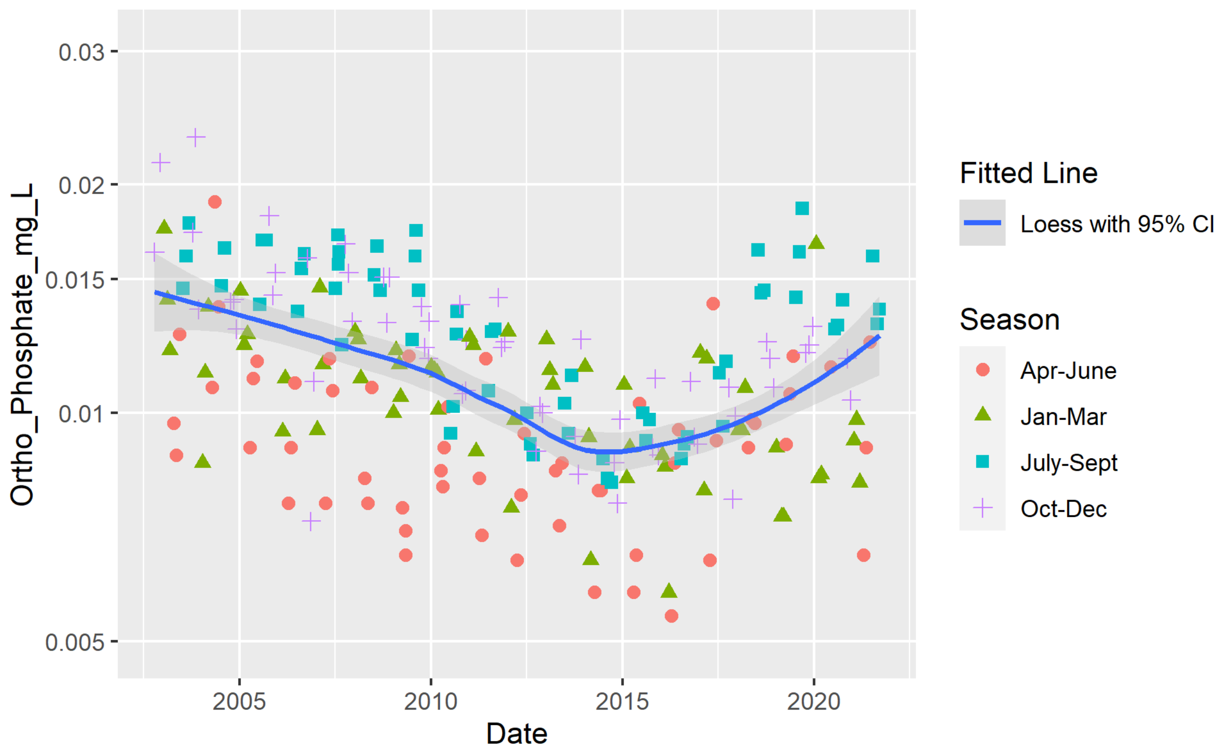

Figure A-15. King County Orthophosphate data at Jenkins Creek at site D320.

Figure A-16. King County Total Phosphorus data at Jenkins Creek at site D320.

Figure A-17. King County Ammonia data at Jenkins Creek at site D320.

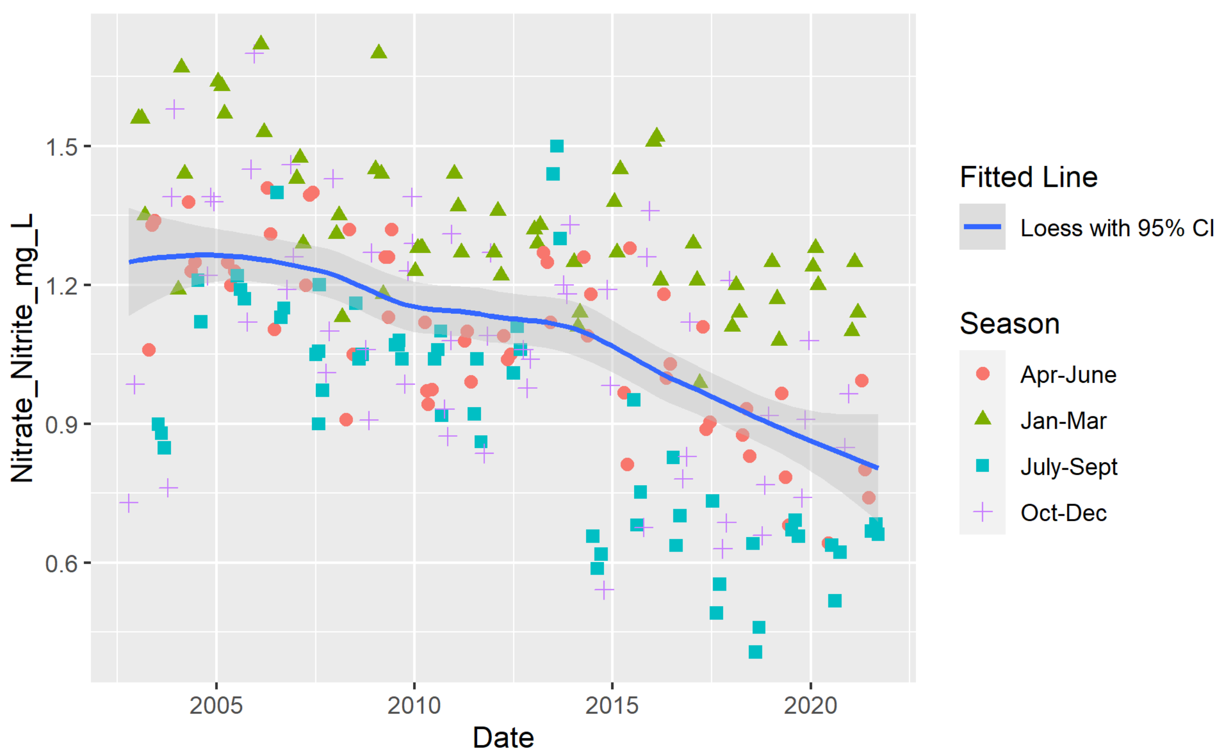

Figure A-18. King County Nitrate-Nitrite data at Jenkins Creek at site D320.

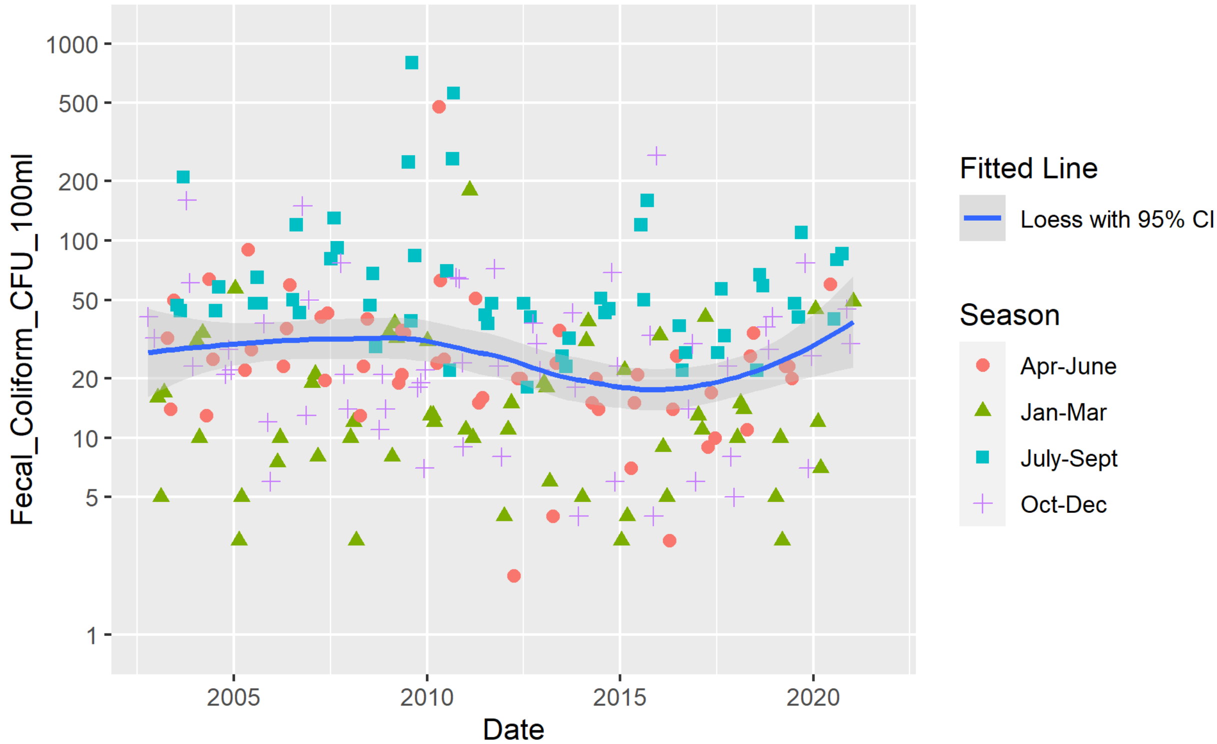

Figure A-19. King County Fecal Coliform data at Jenkins Creek at site D320.

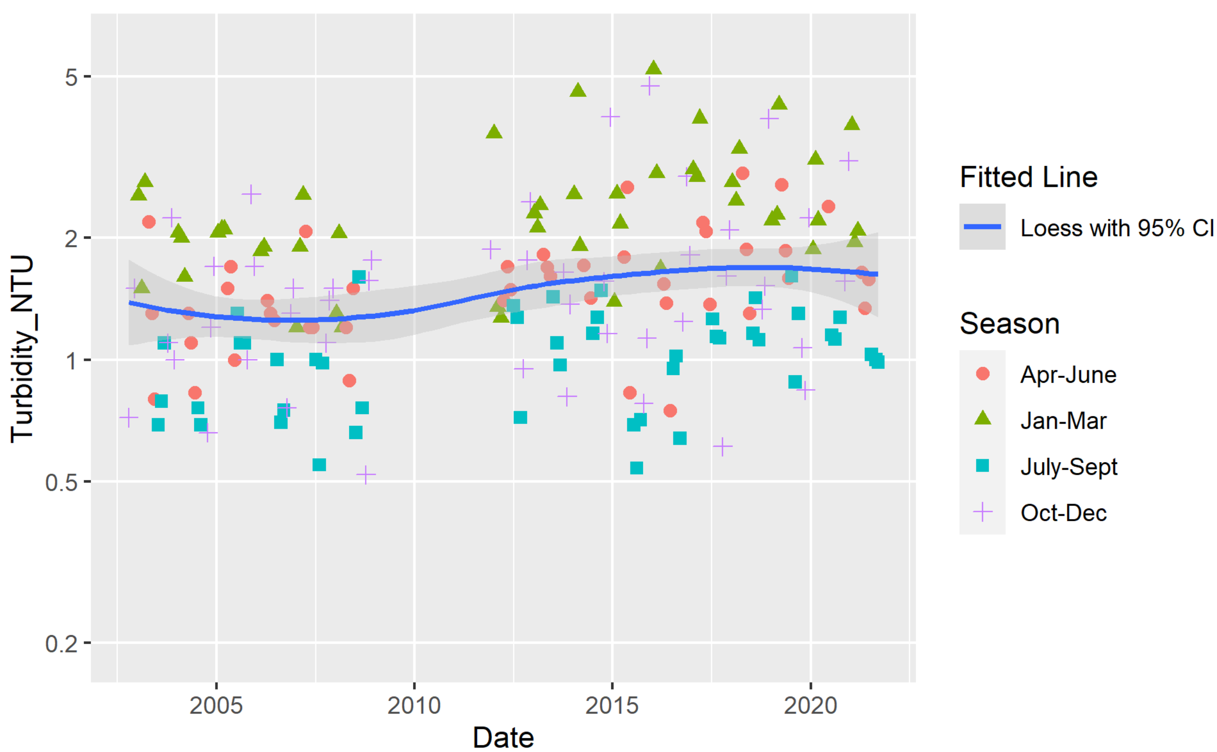

Figure A-20. King County Turbidity data at Jenkins Creek at site D320.

Figure A-21. King County Total Suspended Solids Data at Jenkins Creek at site D320.

Figures A-22 through A-31. Water quality plots for King County monitoring on Covington Creek at site C320.

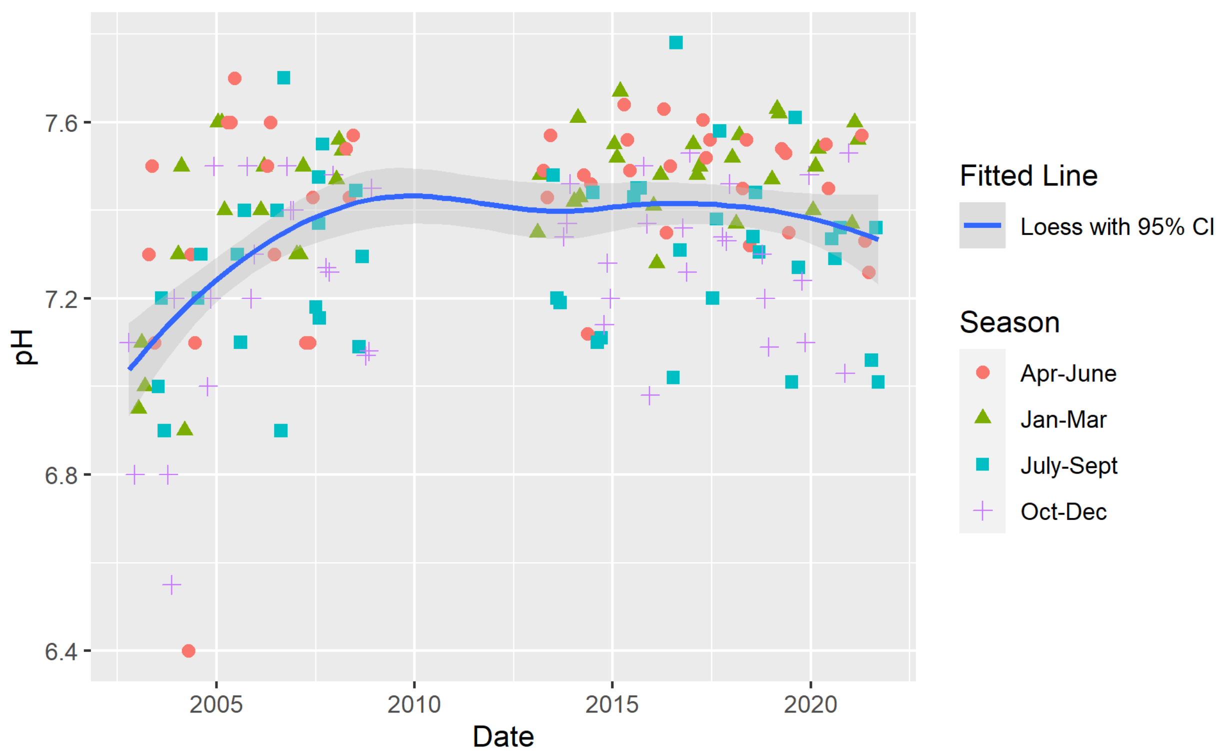

Figure A-22. King County pH at Covington Creek at site C320.

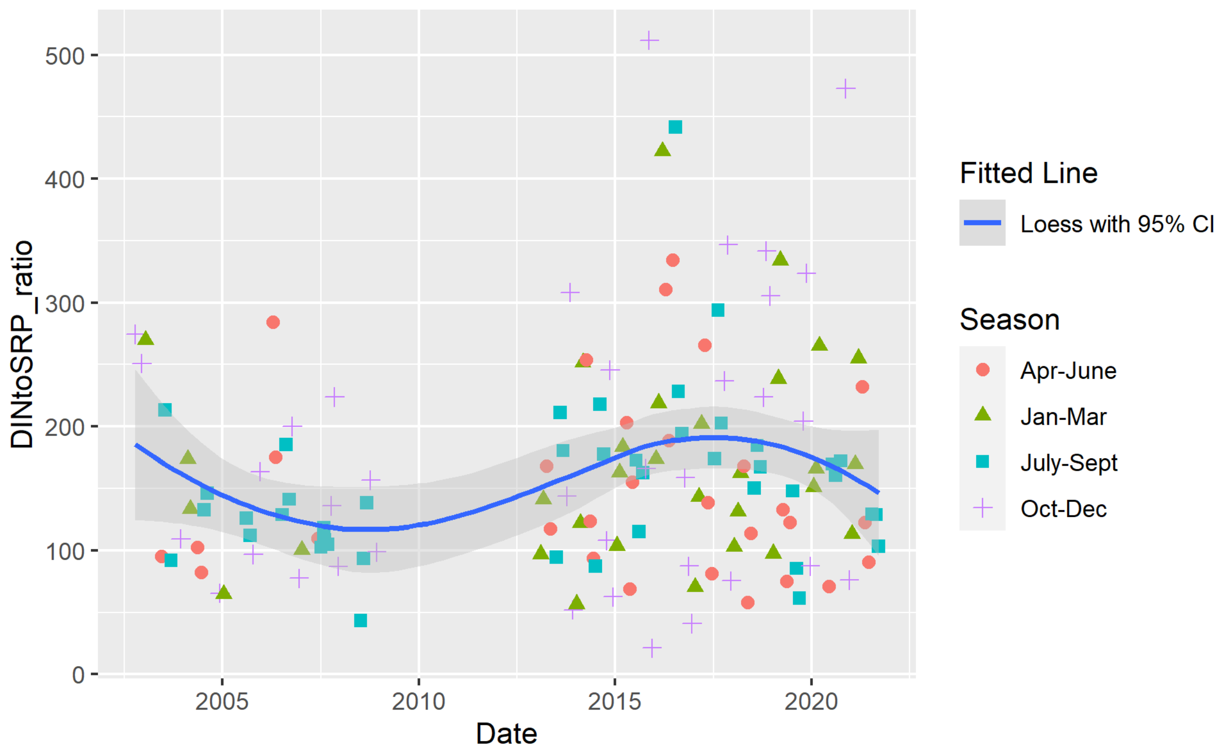

Figure A-23. King County DIN to SRP ratio at Covington Creek at site C320.

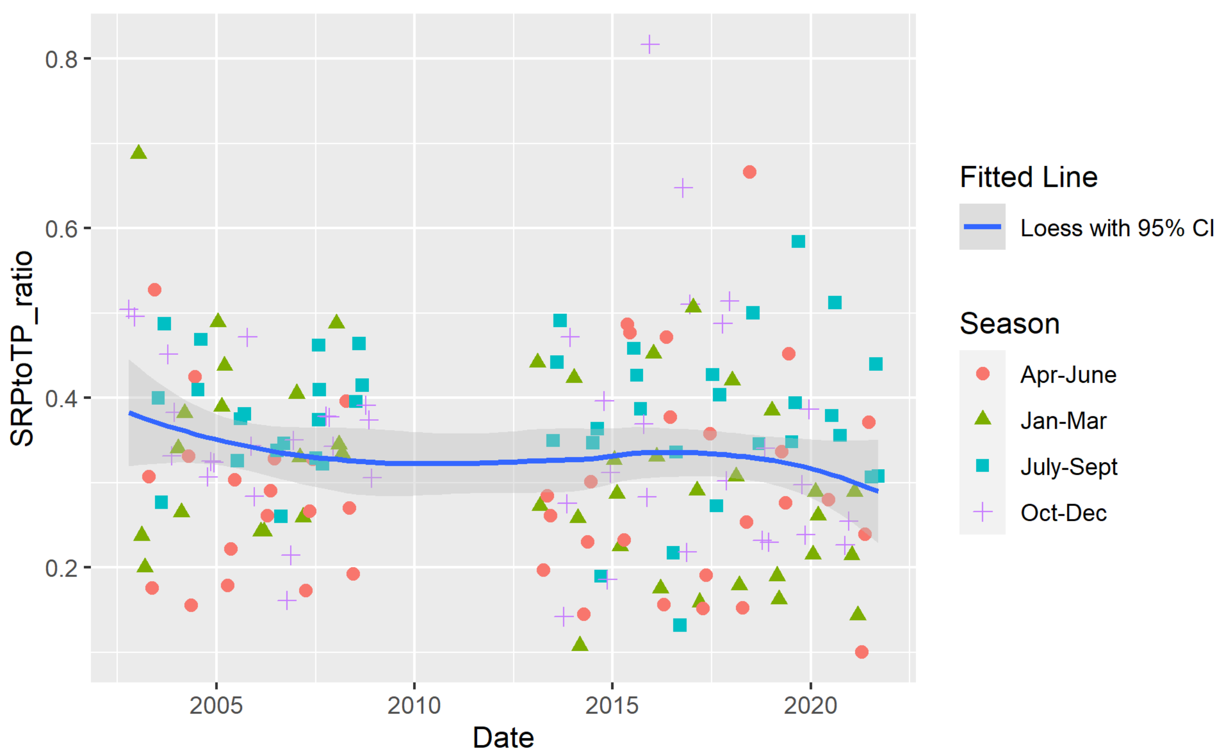

Figure A-24. King County SRP to TP ratio at Covington Creek at site C320.

Figure A-25. King County Ortho-Phosphate data at Covington Creek at site C320.

Figure A-26. King County Total Phosphorus data at Covington Creek at site C320.

Figure A-27. King County Ammonia data at Covington Creek at site C320.

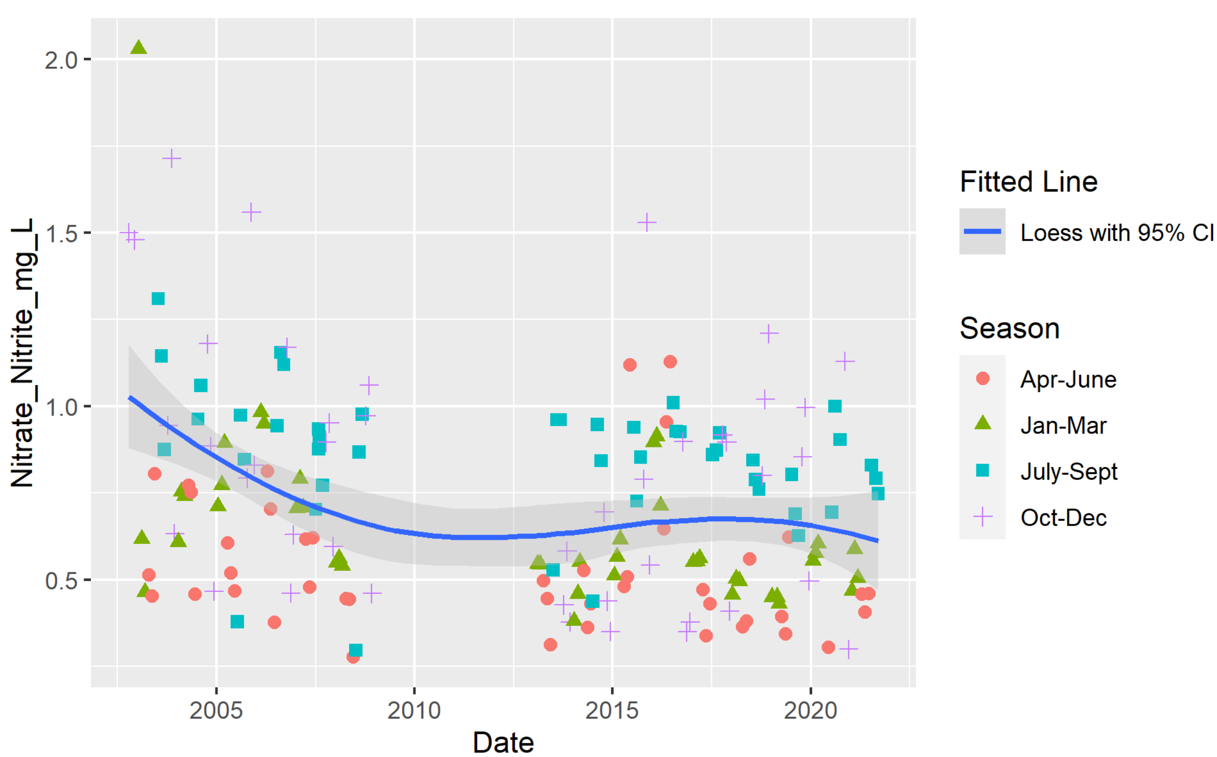

Figure A-28. King County Nitrate-Nitrite data at Covington Creek at site C320.

Figure A-29. King County Fecal Coliform data at Covington Creek at site C320.

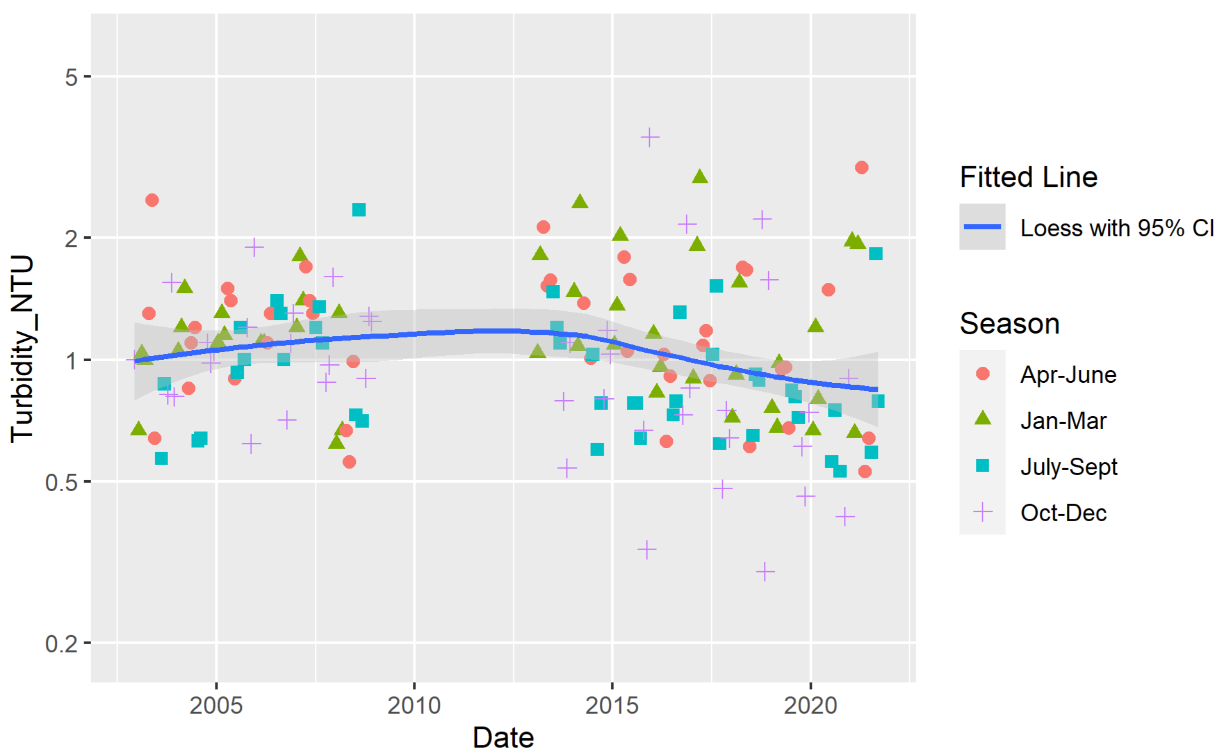

Figure A-30. King County Turbidity data at Covington Creek at site C320.

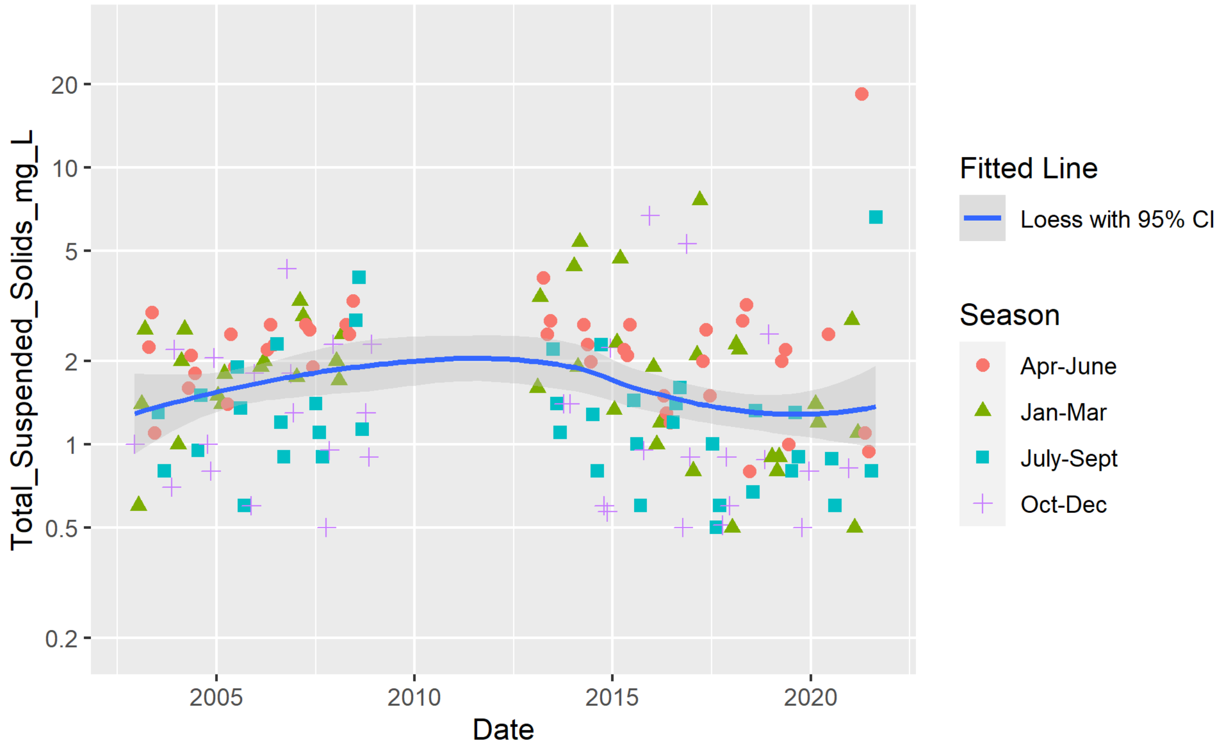

Figure A-31. King County Total Suspended Solids data at Covington Creek at site C320.

Figures A-32 through A-41. Water quality plots for King County monitoring on Little Soos Creek at site G320.

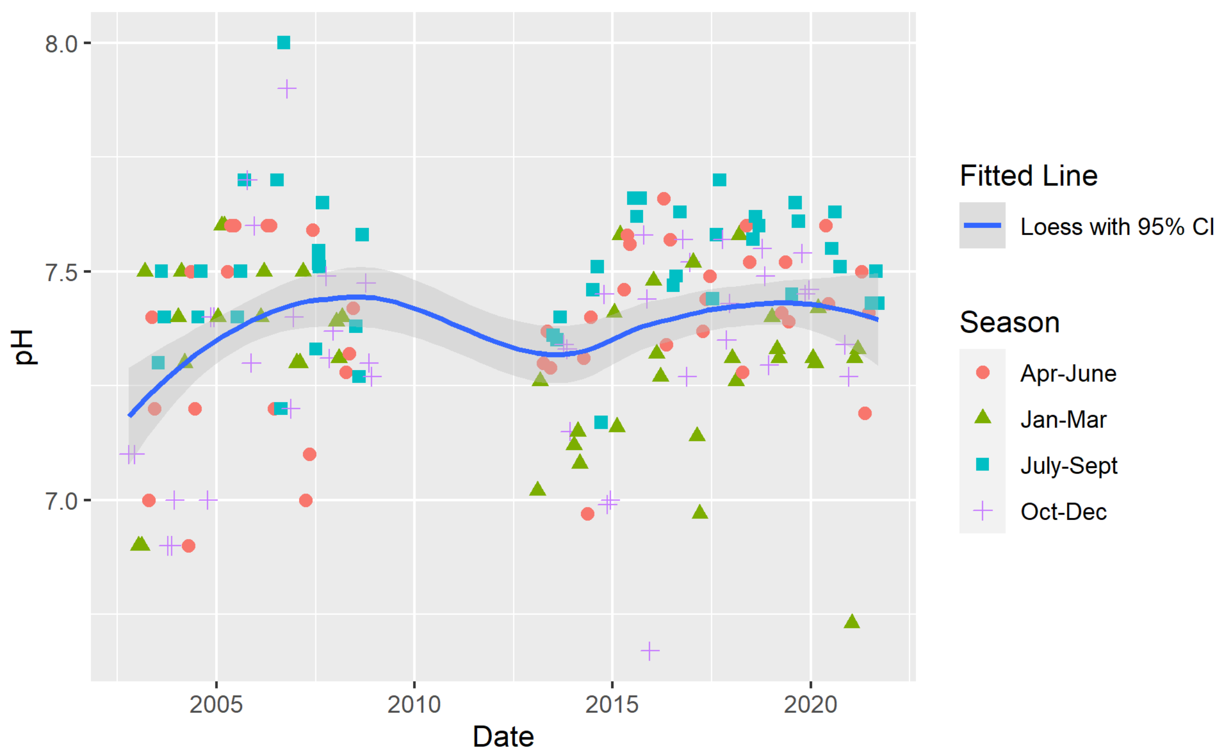

Figure A-32. King County pH at Little Soos Creek at site G320.

Figure A-33. King County DIN to SRP at Little Soos Creek at site G320.

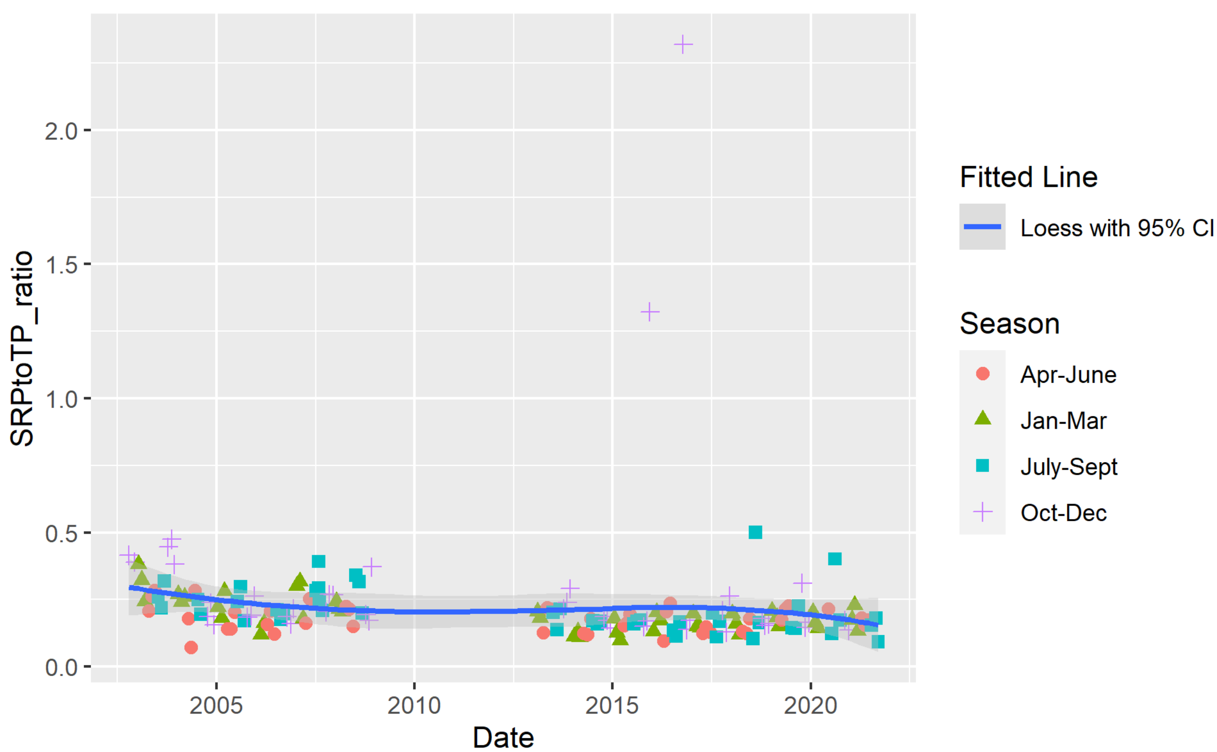

Figure A-34. King County SRP-TP ratio at Little Soos Creek at site G320.

Figure A-35. King County Orthophosphate data at Little Soos Creek at site G320.

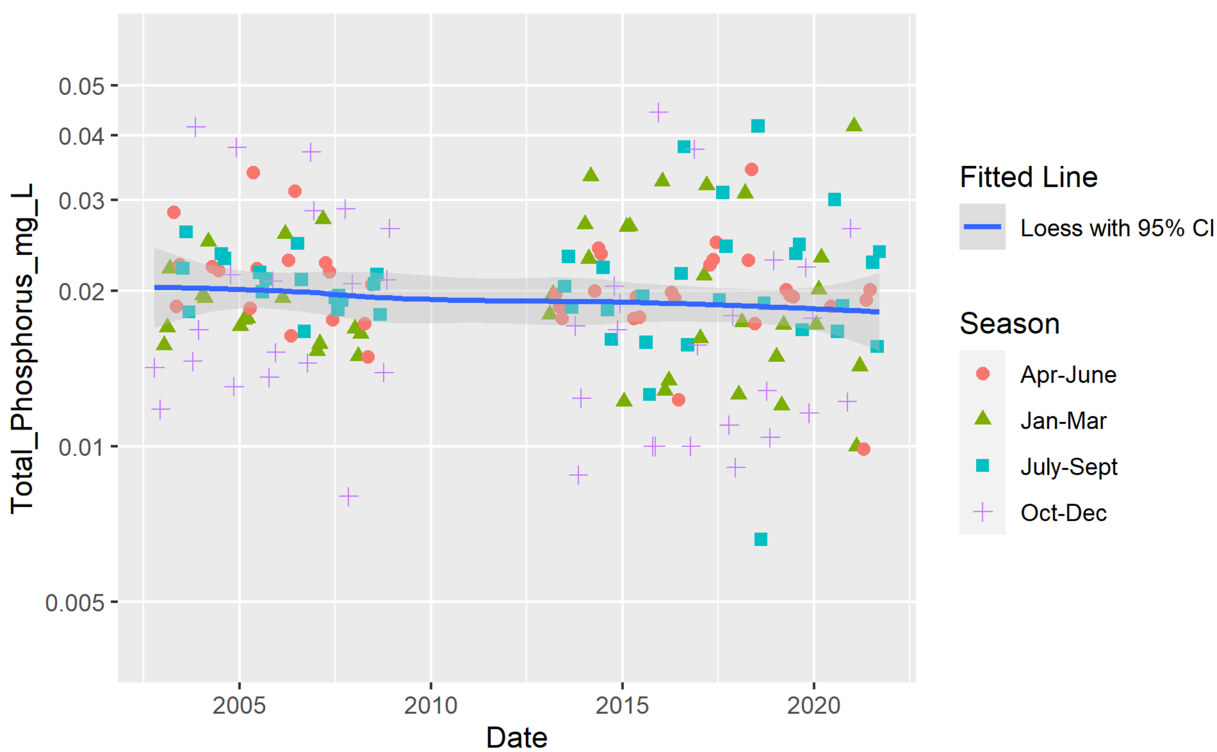

Figure A-36. King County Total Phosphorus data at Little Soos Creek at site G320.

Figure A-37. King County Ammonia data at Little Soos Creek at site G320.

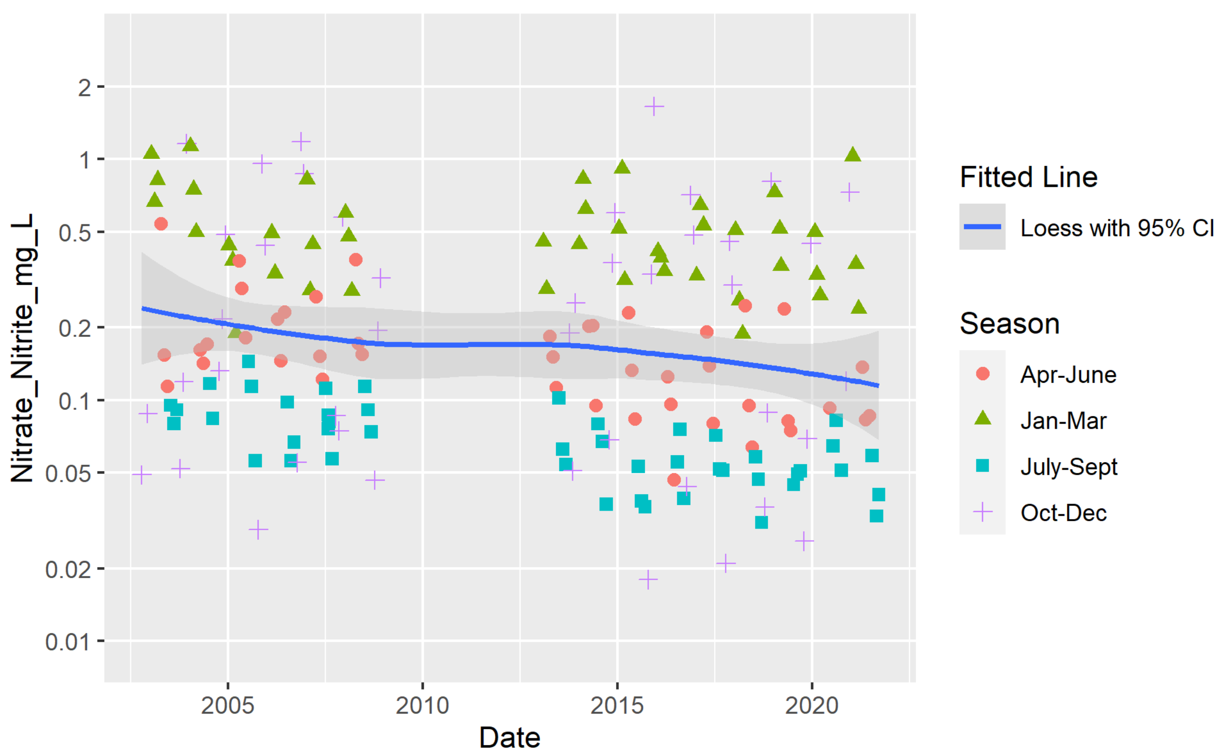

Figure A-38. King County Nitrate-Nitrite data at Little Soos Creek at site G320.

Figure A-39. King County Fecal Coliform data at Little Soos Creek at site G320.

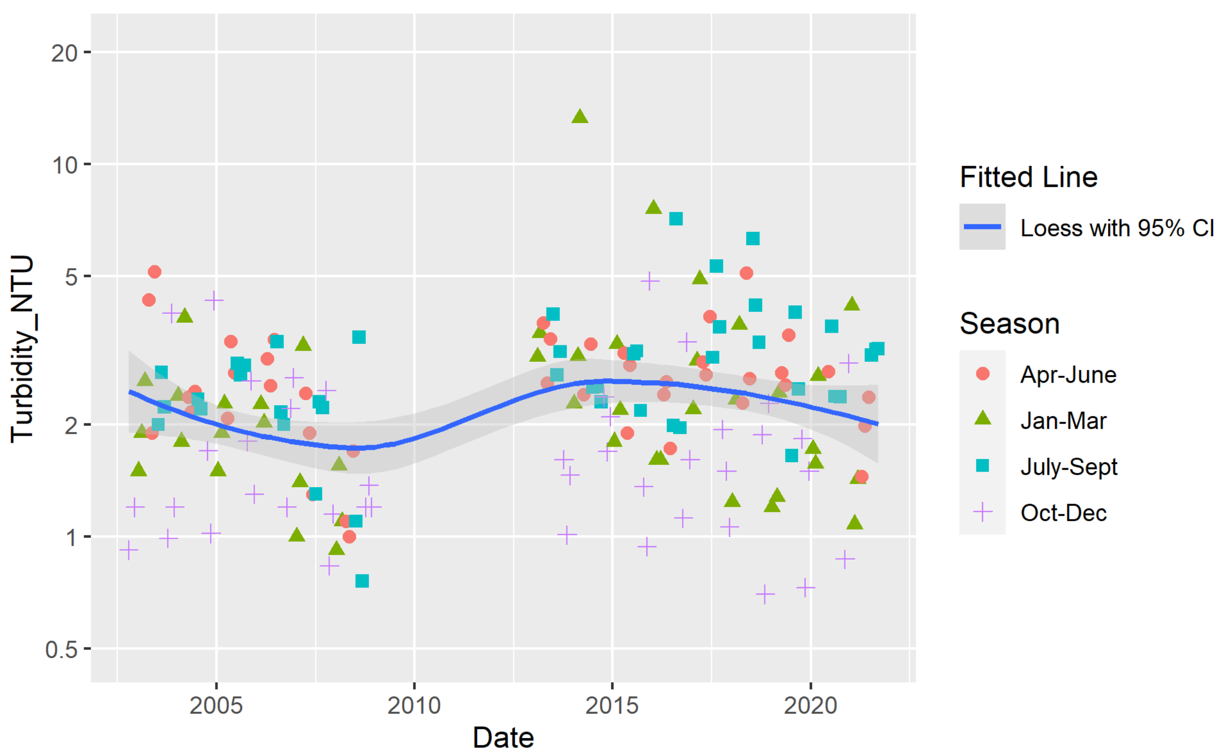

Figure A-40. King County Turbidity data at Little Soos Creek at site G320.

Figure A-41. King County Total Suspended Solids data at Little Soos Creek at site G320.

Appendix B. Considerations for natural conditions modeling checklist

Element	Current planned application
Boundary conditions	The forested/unimpacted HSPF watershed loading scenario will likely provide boundary conditions for inputs to the QUAL2Kw models, except for the headwaters to Big Soos Creek, where HSPF natural loads will most likely be coupled with a WetQual model first, then to QUAL2Kw headwater boundary. A backup option will be to use the 5^{th} – 25^{th} percentile of existing data or 50^{th} percentile of applicable reference data in a manner like other recent TMDL projects.
Channel morphology changes	We will explore potential changes to channel geometry (width, depth), slope, sinuosity, and hyporheic/floodplain connection and flow through historical research, particularly GLO plat survey maps/field notes and the academic work by Brian Collins at the University of WA. Changes will be implemented in the Qual2Kw models where sufficient evidence exists to support them.
Flow reductions or increases	We will add restored baseflow from estimated groundwater and surface water use back into the QUAL2Kw models where appropriate. Baseflow estimates will rely primarily on work completed by the Muckleshoot Indian Tribe for the bioassessment /fine sediment TMDL. Some additional water use estimates may be necessary for categories not represented in the MIT work. These estimates will utilize the methods from the Pilchuck TMDL.
Hydrologic modifications	The forested/unimpacted HSPF watershed model will remove the major source of hydrologic modifications: impervious surface and other land use changes and artificial stormwater drainage/routing. We will add wetland features to the HSPF model where reasonable estimates of impacts (draining, functional modification) can be derived. A backup option would be to use GLO notes and maps in combination with LIDAR data to adjust hydrologic modifications if represented in the existing framework.
Invasive species	Fieldwork will assess the extent of any disturbance of native riparian zone species or invasive aquatic plants or organisms in the creeks or sediment beds. The influence of any invasive plants will be removed in the Shade and Qual2Kw models to the extent practical. For example, reed canary grass will be removed from the wetland reaches of the shade model.
Microclimate	In the Qual2Kw models we will reduce air temperatures and increase dew point temperatures, based on literature and previous TMDL work, in areas that do not currently have full riparian corridors with mature trees.
Natural nutrient concentrations	The forested/unimpacted HSPF watershed model will be used to attain natural nutrient concentrations/loads. A backup option will be to use the 5^{th}-25^{th} percentile of existing data or 50^{th} percentile of applicable reference data in a manner like other recent TMDL projects.
Nonpoint sources	See natural nutrient concentrations for DO. See System Potential Shade for temperature.
Point source effluent	Remove Soos Creek Hatchery and any other point source discharges from QUAL2Kw models.
System potential shade	Composite system potential tree heights are estimated based on a combination of information, including site soil index percentages within the riparian zone, GLO survey notes on bearing trees, and LIDAR data for topography (floodplain vs uplands) and canopy height (in unimpacted areas of Puget Lowlands). System potential species and densities may be altered for different areas based on more detailed information (for example, Palustrine wetland channels with beaver activity). System potential shade applied to QUAL2Kw models.

Appendix C. Glossaries, acronyms, and abbreviations

Glossary of General Terms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

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

Reach: A specific portion or segment of a stream.

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

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

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

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

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

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

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

System potential: The design condition used for TMDL analysis.

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

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

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

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.

303(d) list: Section 303(d) of the federal Clean Water Act, requiring Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

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

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.

Acronyms and Abbreviations

BMP	Best management practice
CM	Creek mile
DO	Dissolved oxygen
DOC	Dissolved organic carbon
e.g.	For example
E. coli	*Escherichia coli* bacteria
Ecology	Washington State Department of Ecology

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
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NAF	New Approximation Flow
NPDES	(See Glossary above)
NSDZ	Near-stream disturbance zones
QA	Quality assurance
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
TMDL	(see Glossary above)
TOC	Total organic carbon
TSS	(see Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cfu	colony forming units
cms	cubic meters per second, a unit of flow
Dw	dry weight
Ft	feet
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mgD/L	milligrams Dry mass per liter
mg/L	milligrams per liter (parts per million)
mL	milliliter
NTU	nephelometric turbidity units
s.u.	standard units
µg/L	micrograms per liter (parts per billion)

Quality Assurance Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examples of data types commonly validated would be:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pearson Correlation Coefficient (r): a measure of linear correlation between two sets of data. It is the ratio between the covariance of two variables and the product of their standard deviations; a normalized measurement of the covariance, such that the result always has a value between −1 and 1.

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).

Root Mean Square Error (RMSE): The square root of the mean of the squared difference between observed and simulated values. The RMSE is defined as:

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

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

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

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

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

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

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

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

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

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

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

References for QA Glossary

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