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Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticides TMDL

2019 Effectiveness Monitoring for TSS and Turbidity TMDL Targets

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COVER PHOTO: Jim Carroll canoeing on the Yakima River near the Nelson-Siding background site. Taken on June 29, 2019 by Evan Newell.

Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticides TMDL

2019 Effectiveness Monitoring for TSS and Turbidity TMDL Targets

by

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Abstract

Located in Kittitas and Yakima Counties, the upper Yakima River basin extends from headwater areas near Snoqualmie Pass, downstream to the more arid regions near the Cities of Ellensburg and Selah. Three large reservoirs store some of the headwater snowmelt for later release during the irrigation season. Canals also convey water for irrigation, a portion of which returns to the Yakima River.

In 2002, Ecology established a Total Maximum Daily Load (TMDL) for suspended sediment, turbidity, and organochlorine pesticides in the upper Yakima River basin. Turbidity targets and total suspended solids (TSS) load allocations were established as part of this TMDL. The TMDL also included a detailed implementation plan to improve water quality in the basin. Implementation has been in effect since the early 2000s:

- Reduced turbid agricultural return flows to streams
- Protected streambanks and restored riparian vegetation
- Reduced erosion from unpaved roads

In 2019, Ecology conducted extensive monitoring to see if the levels of TSS and turbidity in the upper Yakima River basin were meeting the final target levels set by the TMDL. Drought during 2019 resulted in low-flow conditions in the Yakima River and its tributaries, especially during the early part of the TMDL season (April-June). There was reduced sediment delivery in 2019 from the upper basin, particularly from the Teanaway River, due in part to low snowpack. Flow conditions in the Yakima River and selected irrigation returns during the latter part of the TMDL season (July-October) were more similar to the original TMDL flow conditions.

This study found that the Yakima River and most of its tributaries met the TMDL targets for turbidity and TSS load allocations for the critical period of April-October, 2019. These results indicated that TMDL implementation showed success, but Wilson Creek and Sorenson/Fogarty sub-basins continue to need additional improvement.

Background

The Clean Water Act requires that Ecology develop a Total Maximum Daily Load (TMDL) for each river or stream in Washington State that is on the 303(d) list, a list of river and streams that do not meet water quality standards. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water.

Ecology placed parts of the upper Yakima River and Cherry Creek on the 1998 303(d) list for violating water-quality standards for high levels of organochlorine pesticides measured in the 1980s. Rogowski (2000) confirmed that fish tissue from the Yakima River basin collected in 1999 remained at concentrations that indicate an impairment to designated uses, including fish harvesting use[1].

Although the 1998 303(d) list did not include suspended sediment in the upper Yakima River watershed, the 1999 TMDL study investigated suspended sediment because of its established relationship with organochlorine pesticides in the lower Yakima River watershed (Joy and Patterson 1997). DDT (see Glossary for definition) and organochlorine pesticides are known to attach to soil particles.

Using the suspended sediment and organochlorine pesticide data collected in 1999, Ecology established an *Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticide TMDL* in 2002 (Joy, 2002; Creech and Joy, 2002).

As follow-up to the TMDL, Ecology worked with the local community and stakeholders to develop a detailed implementation plan to reduce suspended sediment from entering the river and its tributaries (Creech, 2003). TMDL implementation in the upper Yakima River began in 2003 with efforts to reduce agricultural runoff and erosion in the Upper Yakima River basin, and included implementing some of the following actions:

- Changes to irrigation practices.
- Riparian fencing and re-vegetation.
- Road improvements by the forestry industry.
- Outreach and education.

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[1] Tissue sample collected in 1999 exceeded Fish Tissue Equivalent Concentrations (FTECs) for dieldrin and DDT breakdown products. The FTEC is a former tissue threshold concentration developed by Ecology and calculated using the National Toxics Rule criteria and chemical-specific tissue bio-concentration factors. The FTEC infers a long-term average of a chemical in the waterbody from which fish are collected. Washington no longer uses the FTEC method for determining impairment, but instead uses a Tissue Exposure Concentration (TEC) derived from fish consumption rates and risk factors consistent with current Washington State human health criteria for toxics.

The *Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticide TMDL* also included a post-monitoring schedule (Creech and Joy, 2002) to check on the effectiveness of the implementation actions, and a timetable of dates to meet interim and final targets (limits) for suspended sediment in the Yakima River basin's waters. Following is a brief outline of the *Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticide TMDL* history and timeline.

TMDL History and Timeline

- 1999 Ecology started the TMDL as a field study to collect TSS, turbidity and organochlorine pesticide samples in the upper Yakima River basin. Field studies followed a project plan as outlined in Quality Assurance Project Plan (Dickes and Joy, 1999).
- 2000 Ecology confirmed that fish tissue from the Yakima River basin collected in 1999 remained at concentrations that indicate an impairment to designated uses, including fish harvesting use (Rogowski, 2000).
- 2002 Ecology published the TMDL technical study (Joy, 2002) analyzing the results of the 1999 monitoring data and establishing load allocations and waste load allocations for TSS and turbidity in the basin. Ecology published, and the EPA approved, a TMDL Submittal Report for the TMDL (Creech and Joy, 2002). The TMDL established future interim and final target levels for TSS loads and turbidity levels in order to meet the water quality standards.
- 2003 Ecology published a Detailed Implementation Plan for the TMDL (Creech, 2003) outlining specific steps to take in order to reduce TSS and turbidity levels and achieve cleaner water in the upper Yakima River basin.
- 2006 Ecology coordinated a monitoring study with local assistance to collect TSS and turbidity samples in the upper Yakima River and tributaries to see if TSS and turbidity levels were reduced enough to meet the interim targets set in the 2002 TMDL implementation plan. The Quality Assurance Project Plan (Creech, 2009) described the monitoring plan.
- 2007 Ecology published a technical study showing the fish tissue collected from the Yakima River in 2006 confirmed that dieldrin and DDT concentrations in fish tissue still indicated impairment to designated uses in the Yakima River basin (Johnson et al., 2007).
- 2008 Ecology published a water quality effectiveness monitoring report (Anderson, 2008) describing the results of the 2006 TSS and turbidity monitoring. The report concluded that as of 2006, implementation of the TMDL was showing some success, but while TSS and turbidity values were lower than in 1999, not all interim targets of the TMDL had been met.
- 2011 Ecology's Water Quality Program extended the deadline date to meet the final TMDL target reductions from 2011 to 2016. (Because of budgetary constraints, Ecology postponed the monitoring to check the final TSS and turbidity targets until 2019).
- 2014 Ecology checked to see if organochlorine pesticide levels were improving in Cherry Creek and Wipple Wasteway. As reported in the *Upper Yakima River Watershed DDT and Dieldrin Monitoring, 2014: Status Monitoring for TMDL* (Friese, 2015), though final TMDL targets were not met, sample results showed that some progress has been made

towards lowering DDT and dieldrin concentrations. Except for one sample event, aquatic toxicity criteria were met for all other dieldrin and DDT/ metabolite samples collected at Wipple Wasteway. Cherry Creek and Wipple Wasteway consistently met the aquatic toxicity criteria for dieldrin but exceeded the human heath criteria throughout the irrigation season.

- 2016 Ecology published an additional technical study showing that fish tissue collected from the Yakima River in 2014 still violated water quality standards for DDE (breakdown product of DDT) and dieldrin (Seiders et al., 2016).
- 2017 Ecology established a reserve capacity for suspended sediment and modified the final TMDL tributary-based TSS load allocation target for the site at the Yakima River at Umtanum Creek footbridge, as described in the published TMDL addendum (Creech, 2017).
- 2019 Ecology conducted extensive monitoring to see if the levels of TSS and turbidity in the upper Yakima River basin were meeting the final target levels set by the TMDL. Data were collected under a Quality Assurance Project Plan (Carroll and Urmos-Berry, 2019)
- 2021 Current study published (this report), describing the 2019 monitoring results. This report evaluated the 2019 data to see whether the final TMDL targets were met for TSS and turbidity levels in the Upper Yakima River basin.

2019 Status of TMDL Implementation

As mentioned, Ecology wrote a detailed implementation plan for the TMDL (Creech, 2003) which identified sources of suspended sediment and turbidity to the Upper Yakima River. Sources included streambank erosion, turbid agricultural return flows into local waterbodies, and erosion from unpaved roads. The implementation plan outlined numerous specific actions to reduce sources of turbidity and suspended sediment from these sources. Since 2003, implementation actions have included:

- **Reduced turbid agricultural return flows to streams.** Appropriate best management practices (BMPs) have been implemented to prevent entry of sediment-laden agricultural return flows into area waterways. A key BMP has been the upgrading irrigation methods to reduce erosion of agricultural fields (Figure 1); upgrades have included switching from flood, furrow, or rill irrigation to sprinklers and drip irrigation (Figure 2). Also, the use of polyacrylamide (PAM) on furrow or rill irrigated fields has helped prevent erosion caused by irrigation, by causing soil to drop out of suspension.
- **Protected streambanks and restored riparian vegetation.** Healthy riparian vegetation can filter overland runoff and trap sediment before it reaches waterways. Additionally, riparian vegetation also helps to increase streambank stability and prevent bank sloughing. Livestock management BMPs like fencing can help prevent streambank destabilization and erosion from livestock use along streams.
- **Reduced erosion from unpaved roads.** Forest management BMPs including improved forest road maintenance and low-impact timber harvest practices have helped prevent sediment from roads and ditches from getting into area waterways.

Figure 1. Sediment-laden runoff from rill irrigated field.

Figure 2. Two types of sprinkler irrigation systems in the Kittitas Valley.
Top: Wheel line sprinklers. Bottom: Linear irrigation system.

In addition to these actions, the TMDL implementation plan called for the administration of public education programs for irrigators, landowners and resource users, as well as continued monitoring to track and evaluate the progress toward meeting TMDL targets and water quality criteria.

Many partner groups and organizations have contributed to the implementation actions to reduce sediment and turbidity levels in the upper Yakima River and its tributaries, including:

- **Natural Resources Conservation Service (NRCS)**

  The NRCS directs several essential federal funding programs that assist agricultural producers, including the Environmental Quality Incentives Program. The NRCS also supplies technical assistance to growers, to help them improve water quality while maintaining essential growth of crops.

- **Kittitas County Conservation District (KCCD)**

  The KCCD provides agricultural producers with financial and technical assistance, to fund agricultural BMPs and promote water quality. In 2007, Ecology presented the KCCD with an Environmental Excellence Award, in recognition of the many years of service to the environment and the community.

  In 2016, the KCCD and the Yakama Nation secured funding through the USDA's Regional Conservation Partnership Program, via a joint project titled, "Yakima Integrated Plan – Toppenish to Teanaway." Of the total funding award, more than $6.2 million is dedicated to Kittitas County programs and projects in irrigated croplands and grazing areas, where the funds are used primarily for irrigation upgrades and piping.

  Working in concert with the NRCS on numerous projects, the KCCD has helped fund many irrigation upgrade projects with minimum expense to growers, allowing improvements to proceed more quickly. Due to the diligent work of the KCCD and NRCS, almost 30% of the irrigated land in Kittitas County has sprinkler or drip irrigation in 2019, an increase from only 8.5% in 2004 (Table 1).

  Additionally, KCCD has completed numerous riparian planting projects, many associated with fish screen upgrades and installations, while also administering various public education programs for Kittitas Valley irrigators, landowners and resource users. In 2019, the KCCD provided cost-share funding for polyacrylamide (PAM) use on 1,056 acres in Kittitas County. PAM can significantly reduce soil erosion on fields that use rill or furrow irrigation. KCCD also manages the Kittitas County's Voluntary Stewardship Program, which offers incentives to improve the water quality of agricultural runoff.

Table 1. Changes in use of sprinkler and drip irrigation in Kittitas County, 2004-2019.

	2004	**2019**
Total irrigated acres in Kittitas County	97,360	94,590
Acres of sprinklers and drip irrigation	8,260	27,320
Percent of total irrigated acres in sprinklers and drip irrigation	**8.5%**	**28.9%**

- **Kittitas County Water Purveyors (KCWP)**

  The KCWP is a consortium of irrigation districts and companies in Kittitas County. The KCWP have implemented many sediment-reducing projects, such as sediment settling ponds and waterway fencing. Additionally, the KCWP has an active turbidity monitoring program, used to give feedback to landowners after BMP implementation actions.

  In 2014, Ecology developed a memorandum of agreement with the KCWP to allow KCWP to take the lead on responding to high turbidity and suspended sediment exceedances in local waterways, with Ecology providing an enforcement backup if needed. Each year KCWP reports high turbidity violations to Ecology.

- **Teanaway Community Forest**

  In 2013, Washington State purchased over 50,000 acres of private timberland in the Teanaway River watershed. This publicly owned forest is now known as the Teanaway Community Forest (TCF). The TCF immediately adjoins national forest lands, managed by the US Forest Service. The TCF is jointly managed by the Washington State Departments of Natural Resources and Fish and Wildlife, guided by an advisory group. The TCF management plan includes numerous actions to reduce sediment input into the Teanaway River system, including improved livestock management, closure of unneeded earthen roads, improved maintenance of remaining roads, utilizing low-impact timber harvest techniques, and sediment-reductions guidance for recreational users.

- **Kittitas County**

  Kittitas County administers the Critical Area Ordinances and Shoreline Master Programs in the county. In 2014, Kittitas County passed a grade and fill ordinance, to control erosion during land development. The provisions of the ordinance are designed to minimize adverse impacts, protect water quality, and ensure erosion control activities during and after grading activities.

- **Washington State Department of Natural Resources (DNR)**

  The DNR administers forest practices regulations on DNR lands throughout the Upper Yakima watershed, including BMPs that reduce erosion and other sediment-reduction actions on DNR lands.

- **US Forest Service (USFS)**

  The Cle Elum Ranger District of the USFS implements forest management practices, including road improvements and maintenance on Wenatchee National Forest lands in the upper Yakima River basin. The USFS promotes water quality protection and restoration guidance as dictated in the Okanogan-Wenatchee National Forest Plan.

- **Yakima Basin Integrated Plan (YBIP)**

  The Yakima Basin Integrated Plan (YBIP) is a 30-year plan to resolve decades of water conflicts in the Yakima River watershed, by responding to drought and changing climate, assuring water is clean and ample, and lands are both protected and productive for growing communities and the natural environment. The YBIP is a collaborative partnership between the Yakama Nation, irrigation districts and companies, state and federal resource agencies and conservation groups, as well cities and counties throughout the greater Yakima watershed. One of YBIP's stated goals is to conserve up to 170,000 acre feet of water through irrigation system upgrades, with much of this work occurring in Kittitas County. These irrigation upgrades have helped reduce sediment input to the Upper Yakima River and its tributaries. As global warming proceeds, increased emphasis on water conservation in the upper Yakima watershed, additional efforts are made each year to upgrade more agricultural irrigation practices to sprinklers.

- **Yakima Tributary Access and Habitat Program (YTAHP)**

  The YTAHP provides assistance to landowners to restore critical salmon habitat by implementing projects that protect, restore, and enhance riparian and floodplain habitat used by salmon. Program objectives include reducing bank erosion, screening irrigation diversions, removing man-made barriers (e.g., dams, culverts), and restoring fish passage.

2019 Status Monitoring to Check TMDL Final Targets

Study area and land use

Earlier TMDL publications describe the study area and basin characteristics in detail (Joy, 2002; Creech and Joy, 2002; Creech 2003; Anderson, 2008). The study area for the 2019 status monitoring mimicked the earlier 1999 TMDL work in the Upper Yakima River basin.

In brief, the 2019 study area consists of the mainstem Yakima River and its major tributaries from RM 121.7 (Harrison Bridge, near the town of Selah) upstream to RM 202.4 (just below Lake Easton).

The Yakima River basin is located in south-central Washington State. The Yakima River flows 215 miles from the dam outlet of Lake Keechelus, southeasterly to its confluence with the Columbia River. The upper portion of the Yakima River basin drains 2,139 square miles on the eastern slope of the Cascade Mountains. Below Lake Keechelus, the main tributaries to the Upper Yakima River are the Kachess River, Cle Elum River, and Teanaway River, as well as many smaller tributaries, including Taneum Creek, Manastash Creek, Wilson Creek, and Wenas Creek (Creech and Joy, 2002).

Land uses in the basin include forestland, rangeland, irrigated agriculture, and urban areas. A large network of irrigation supply canals, diversions, and irrigation return drains are located throughout the Upper Yakima River basin but are especially concentrated in the lower Kittitas Valley. Several irrigation districts divert water from the Yakima River and the streams flowing through the basin (Creech and Joy, 2002).

TMDL turbidity targets and TSS load allocations

Suspended Sediment TMDLs for the lower and upper portions of the Yakima River Basin were established to protect aquatic organisms from the chronic effects (i.e., injury or death from long periods of exposure) of suspended sediment (Joy and Patterson, 1997; Joy, 2002). The TMDLs presented documentation from the scientific literature showing that turbidities and TSS concentrations become detrimental, or lethal, to aquatic life at varying concentrations, depending upon the species of organism, and the duration of exposure.

The *Upper Yakima River Basin Suspended Solids and Organochlorine Pesticides TMDL* (Creech and Joy, 2002) established turbidity targets for the mainstem upper Yakima River and tributaries. The targets were intended to reduce suspended sediment loads in the upper basin (and therefore the lower basin, as well), and to reduce the likelihood of organochlorine pesticide transport in the aquatic environment.

Turbidity targets

The TMDL turbidity targets were based on the Washington State freshwater turbidity criteria to protect aquatic life (WAC 173-201A-200; Ecology, 2019). The following turbidity criteria apply for all areas of the Upper Yakima River basin:

- Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or
- Turbidity shall not exceed more than a 10% increase when the background is more than 50 NTU.

The original 1999 TMDL used the median and 90th percentile statistics to compare to background values, to allow variation from natural short-term peak turbidity events (Joy, 2002). Background sites for the 2019 Status Monitoring were chosen to mimic other TMDL work in the basin (Joy, 2002 and Anderson, 2008).

The 2019 Status Monitoring compared the median or the 90th percentile statistic to the final TMDL turbidity targets as shown in Table 2.

Table 2. TMDL turbidity targets for 2019 monitoring.

Sites	TMDL Submittal Report	Turbidity Target
Teanaway River Taneum Creek Manastash Creek Sorenson Creek at Fogarty Wilson Creek Wenas Creek	"The 90th percentile of the turbidity values collected at the mouths of the Teanaway River, Manastash Creek, Sorenson Creek at Fogarty Ditch, Wilson Creek below Cherry Creek, Taneum Creek, and Wenas Creek will not exceed 5 NTU over the 90th percentile background value."	90th percentile ≤ 5 NTU over 2019 background
Packwood Ditch	"The geometric mean turbidity at the mouth of Packwood Ditch will not exceed 5 NTU over the geometric mean turbidity of the background site."	Geometric mean ≤ 5 NTU over 2019 background
Yakima River at Umtanum Creek Yakima River at Harrison Bridge	"The 90th percentile of the turbidity values collected at the Yakima River at Umtanum Creek (RM 139.8) and the Yakima River at Harrison Bridge (RM 121.7) will not exceed 5 NTU over the 90th percentile turbidity value of samples collected from the Yakima River at Nelson (RM 191)."	90th percentile ≤ 5 NTU over 2019 background

TSS load allocations

Unlike turbidity, no water quality standards for suspended sediment currently exist in Washington State for protecting fresh water aquatic life.

The TMDL set load allocations for suspended sediment loads at several sites, including most tributaries and several mainstem sites (Joy, 2002). Allocations were set as seasonal limits (April through October) expressed as daily loading unit of tons of TSS per day (Table 3). Sites where the TSS load allocation is equal to the 1999 TSS load were either background sites or sites which met the turbidity criteria. For other sites, TSS load allocations were based on calculated TSS load reductions for the tributaries to meet turbidity standards (5 NTU over background)

Two downstream Yakima River sites (at Umtanum Creek and at Harrison Bridge) were assigned total load allocations based on the sum of the TSS load allocations for upstream sources (headwaters, non-point sources, point sources and tributaries).

In 2017, Ecology slightly modified the tributary-based total load allocation target for the Yakima River at Umtanum Creek. The sum of the TSS load allocations from upstream sources was reduced by 10 tons/day to build a reserve capacity in the TMDL so the Yakama Nation could build a new fish hatchery, completed in 2020. The new hatchery discharges a few miles upriver from Ellensburg.

Table 3. TMDL load allocations of suspended sediment (as TSS) for the mainstem and tributaries of the upper Yakima River basin for the Apr-Oct irrigation season.

Site	1999 TSS Load (tons/day)	TSS Load Allocation (tons/day)
Yakima River at Nelson	14	14
Cle Elum River	5.8	5.8
Crystal Creek	0.03	0.03
Cle Elum POTW	0.12	0.16*
Teanaway River	77	28
Swauk Creek	6.4	6.4
Taneum Creek	4.1	2.6
Dry Creek	0.11	0.11
Packwood Ditch	1.2	1
Manastash Creek	4.4	2.7
Ellensburg POTW	0.05	0.44*
Reecer Creek	0.5	0.5
Sorenson Creek at Fogarty	3.2	1.8
Wilson Creek	71	26
Wenas Creek	3.9	3.7
Yakima River at Umtanum	215	110**
Yakima River at Harrison Bridge	131	75

POTW = Publicly-Owned Treatment Works (wastewater treatment facility)
*Wasteload allocations based on 1999 NPDES permit limits
**Load allocation changed from 120 to 110 (tons/day) with TMDL revision in 2017 (Creech, 2017)

Additional TMDL water quality concerns

The 1999 TMDL (Joy, 2002) documented TSS and turbidity high enough to harm aquatic communities, specifically salmonids, due to the duration of exposure (> 30 days) to high levels (beginning around 7 – 100 mg/L TSS or 10 – 50 NTU turbidity). Joy (2002) showed that the TMDL TSS load allocations should alleviate aquatic life exposure to high TSS levels.

In addition, the TMDL advised against exceeding a concentration threshold range of 20 – 35 mg/L TSS in Cherry Creek and Wipple Wasteway, as this range is a surrogate for the presence of pesticides in water, based on the sample data from 1999.

Scope of work for the 2019 TMDL monitoring study

Ecology's 2019 monitoring study assessed the TMDL turbidity targets, TSS load allocations, and additional concerns listed above. The 2019 study focused on monitoring the two mainstem Yakima River sites and eight tributaries that were assigned TMDL turbidity targets. The 2019 monitoring study assessed these sites to see if they were meeting their final turbidity targets after nearly two decades of TMDL implementation.

In addition, the 2019 monitoring study also collected data to address monitoring needs and recommendations identified during the course of the original TMDL evaluation and recommended for inclusion in final TMDL monitoring plans (Joy, 2002; Creech and Joy, 2002):

- Intensive site placement and monitoring between the Yakima River at Nelson and the USBR Yakima River at Ellensburg gage to identify sources of suspended sediment.
- Collecting necessary data to construct a spatial model that simulates sediment transport in irrigated and non-irrigated areas of the basin.

By collecting flow and TSS data for second item above, the 2019 study was able to develop a simple mass balance of TSS for the upper Yakima River and also address whether or not sites were meeting the TSS load allocations established by the 1999 TMDL (Joy, 2002; Creech and Joy, 2002).

The 2019 monitoring study also analyzed the duration of elevated suspended sediment in regards to impairment levels that could harm fish, and assessed Cherry Creek in regards to high concentrations of TSS related to potential levels of organochlorine pesticides.

Ecology notes that the following two effectiveness monitoring elements of Ecology's TMDL water quality clean-up plan (Creech and Joy, 2002) and the TMDL Detailed Implementation Plan (Creech, 2003) were previously addressed (Friese, 2015; Seiders et al 2016):

- Cherry Creek and Wipple Wasteway water column concentrations of individual DDT compounds, total DDT, and dieldrin will not exceed human health criteria (0.00059 ug/L DDT or DDE compounds, or total DDT, 0.00083 ug/L DDD, and 0.00014 ug/L dieldrin).
- Dieldrin concentrations in fish fillet samples will make substantial progress toward meeting a compliance target of 0.65 ug/Kg wet weight in the upper Yakima basin.

Goals and Objectives

Project goals

The goal of this study is to measure suspended sediments and turbidity and to determine whether 2019 levels were meeting the final targets as specified in the *Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticide TMDL* (Creech and Joy, 2002).

Project objectives

Field work was conducted from February 2019 through November 2019. The assessment of whether final targets have been achieved was made by evaluating the sample results during the critical season of April through October, as established by the TMDL (Joy, 2002).

Specific objectives of the study are to:

- Collect biweekly samples of TSS and turbidity in the Upper Yakima River mainstem and priority tributaries.
- Install continuous turbidity monitoring stations at upstream and downstream boundaries on the Yakima River, and in the Teanaway River and Wilson Creek.
- Obtain streamflow data from U.S. Bureau of Reclamation (USBR), U.S. Geological Survey (USGS), Ecology, and other sources.
- Conduct an evaluation of the data generated from sampling, continuous monitoring, and streamflow measurements.
- Summarize the results of the evaluation in a published report.

Field Methods and External Data Sources

Field Activities

The Washington State Department of Ecology (Ecology) collected turbidity and suspended solids data in the upper Yakima River basin during February-November 2019. Ecology followed a Quality Assurance Project Plan (QAPP); see Carroll and Urmos-Berry (2019). Ecology measured turbidity with in-situ measurement using turbidity sensors and data loggers and collected water samples to analyze for turbidity TSS. Additionally, Ecology measured streamflow and gaged some streams to supplement flow gaging already present in the basin.

The QAPP sampling dates, methods, site locations, and data analysis techniques were chosen to mimic those used in the initial TMDL evaluation by Joy (2002).

Table 4 shows the 2019 study sampling dates. This study included sample dates that preceded and extended after the TMDL critical season, as shown in the table. As in previous TMDL studies, TMDL target analysis was limited to the April-October critical season. Consistent with previous studies, Ecology collected water samples every other week.

Table 4. Sampling dates for 2019 monitoring.

Sample Dates (2019)	Feb 25-27	Mar 11-13	Mar 25-27	Apr 8-10	Apr 22-24	May 6-8	May 20-22	Jun 3-5	Jun 17-19	Jun 30-Jul 2	Jul 15-17	Jul 29-31	Aug 12-14	Aug 26-28	Sep 9-11	Sep 23-25	Oct 7-9	Oct 21-23	Nov 4-6
Week #	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
TMDL critical season				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Sampling locations for 2019 are shown in Figure 3; flow and turbidity gaging locations are shown in Figure 4. Most monitoring site locations for this study coincided with the original TMDL study sites (including background sites), but some sampling sites were relocated to slightly different locations due to site access or safety issues. Ecology also added several sites, not included in original TMDL study, to improve spatial resolution and reduce data gaps. The original TMDL had its uppermost Yakima River site located at Nelson (YKNS), but this study added an additional upstream site (YKEA) just below Lake Easton at a USBR streamflow gage location (see Figure 4).

Table 5 provides details about the 2019 sampling locations, including the types and time periods of data collection activities.

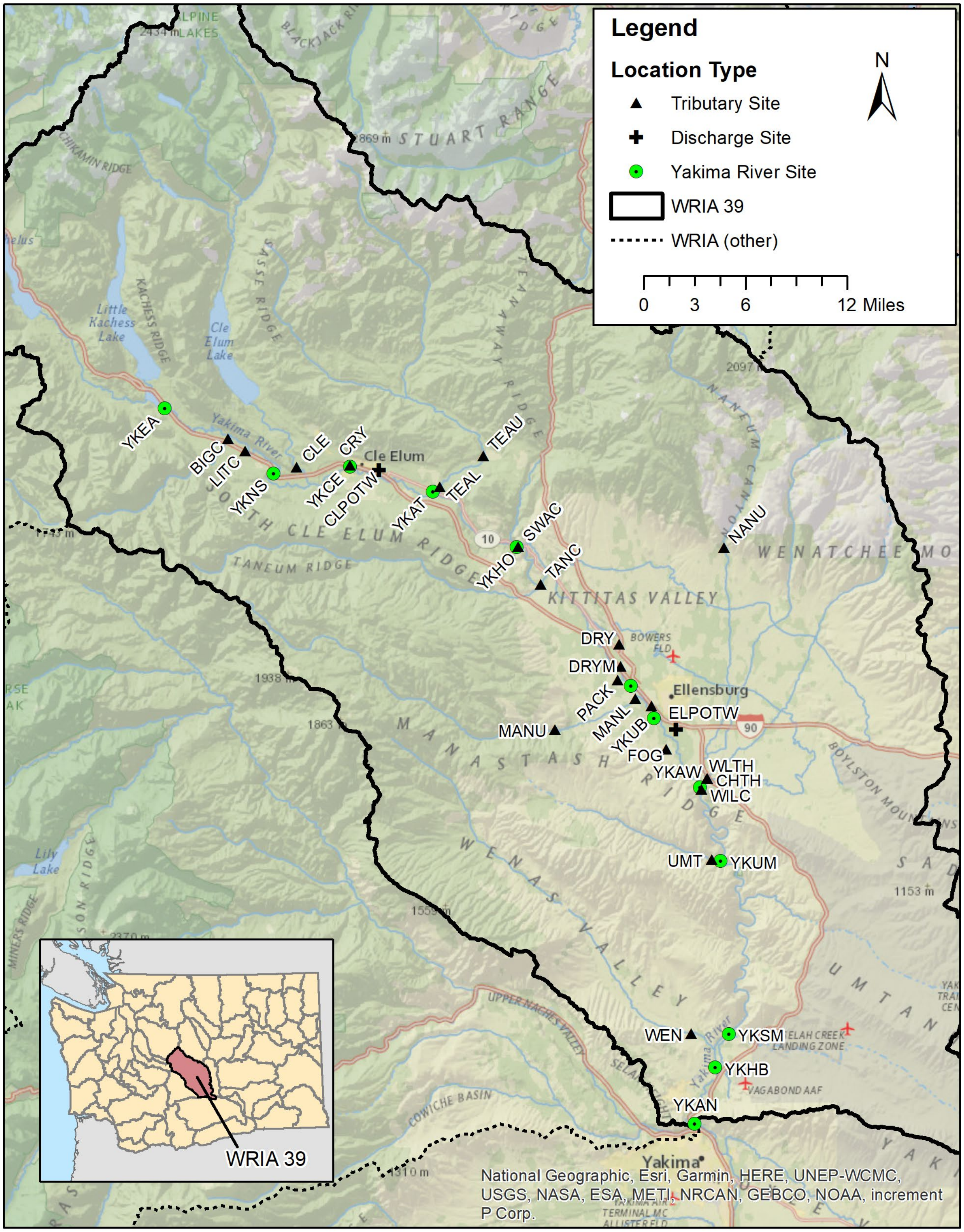

Figure 3. Sampling site locations for 2019 monitoring.

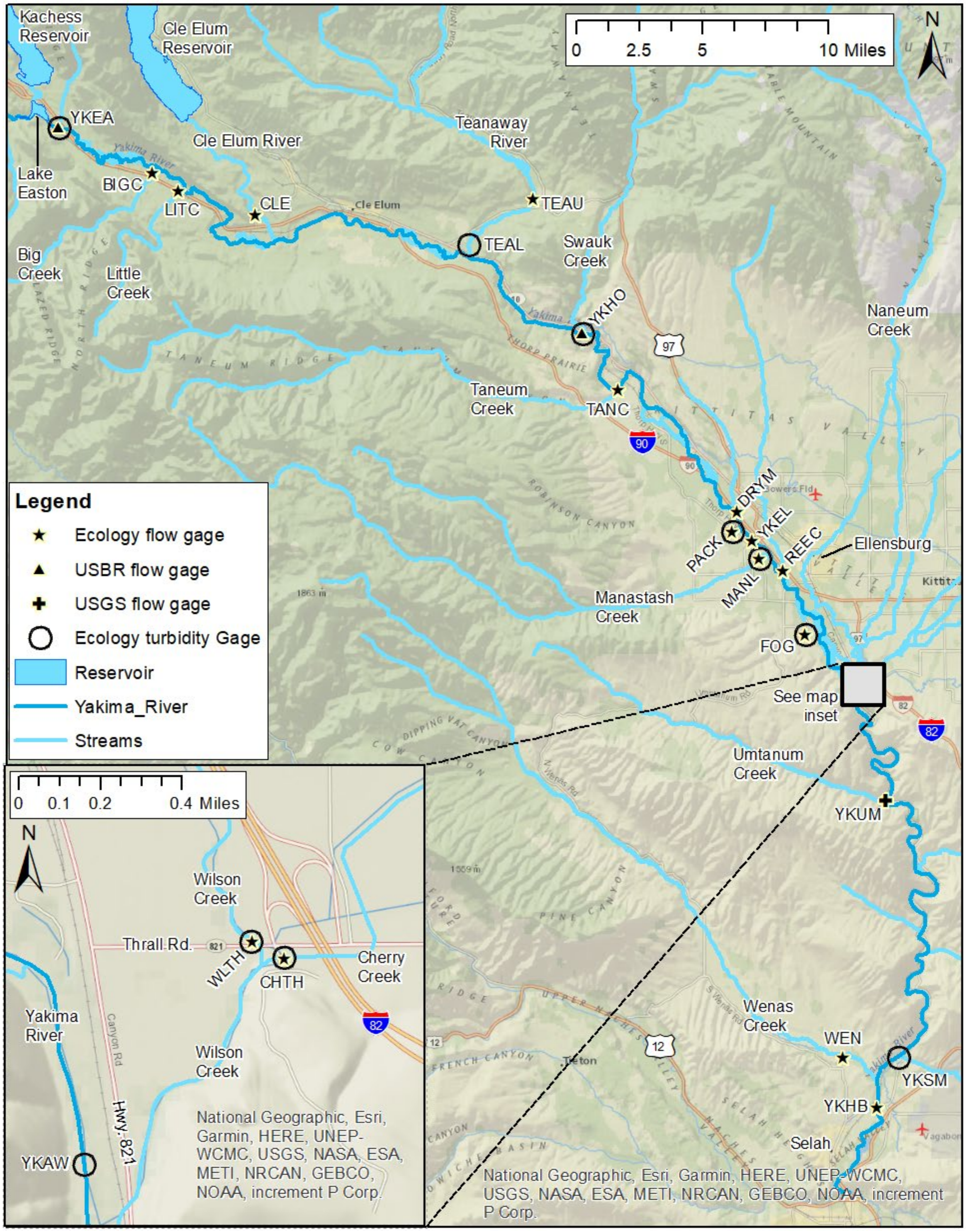

Figure 4. Flow and turbidity gage locations for 2019 monitoring.

Table 5. Site locations plus data collection types and durations for 2019 monitoring.

Study Location ID	Type	Location Name	Latitude	Longitude	EIM Location ID	TSS and Turbidity Samples	Gaged Turbidity	Measured Flow	Gaged Stage or Flow
YKEA	Background	Yakima River below Lake Easton	47.2403	-121.1817	YKEA	Feb-Nov	Feb-Nov	USBR	USBR
YKNS	Background	Yakima River at Nelson Siding	47.1857	-121.0445	39A090	Feb-Nov	---	Feb-Nov	May-Nov
YKCE	Mainstem	Yakima River at S. Cle Elum Way	47.1918	-120.9489	39A080	Feb-Nov	---	Mar-Nov	Jun-Nov
YKAT	Mainstem	Yakima River above Teanaway	47.1709	-120.8448	YKAT	Apr-Nov	---	---	---
YKHO	Mainstem	Yakima River at Horlick	47.1239	-120.7394	YKHO	Feb-Nov	Feb-Nov	USBR	USBR
YKEL	Mainstem	Yakima River near Ellensburg	47.0052	-120.5962	03-YKKO	Feb-Nov	---	Mar-Nov	USBR/Ecology
YKUB	Mainstem	Yakima River at Irene Rinehart park	46.9777	-120.5674	04-YKIR	Feb-Nov	---	---	---
YKAW	Mainstem	Yakima River above Wilson Creek	46.9185	-120.5100	YKAW	Feb-Nov	Feb-Nov	---	---
YKUM	Mainstem	Yakima River at Umtanum Creek Bridge	46.8557	-120.4842	05-YKUM	Feb-Nov	---	---	USGS
YKSM	Mainstem	Yakima River at Selah Moxee diversion	46.7081	-120.4742	YKSM	Mar-Nov	Feb-Nov	---	---
YKHB	Mainstem	Yakima River at Harrison Bridge	46.6795	-120.4912	39A050	Feb-Nov	---	---	USBR & USGS
YKAN	Mainstem	Yakima River Above Naches	46.6312	-120.5169	---	---	---	Apr-Nov	---
CLPOTW	Discharge	Cle Elum POTW effluent	47.1889	-120.9126	FSID 8169652	Jun-Oct	---	---	---
ELPOTW	Discharge	Ellensburg POTW effluent	46.9681	-120.5402	FSID 12235	Jun-Oct	---	---	---
TEAU	Background	Teanaway River at Red Bridge Rd	47.2013	-120.7816	TEAU	Feb-Nov	---	Mar-Sept	Feb-Nov
NANU	Background	Naneum Creek at Naneum Road	47.1235	-120.4799	26-NN	Feb-Nov	---	Aug-Oct	---
MANU	Background	Manastash Creek at Manastash Road	46.9681	-120.6913	01-MAN	Mar-Nov	---	---	---
BIGC	Tributary	Big Creek at I-90	47.2150	-121.1021	BIGC	Feb-Nov	---	Feb-Nov	Apr-Nov
LITC	Tributary	Little Creek at Hundley Rd.	47.2047	-121.0804	LITC	Feb-Nov	---	Feb-Nov	May-Nov
CLE	Tributary	Cle Elum River at Bullfrog Rd bridge	47.1911	-121.0156	39B090	Feb-Nov	---	Mar-Nov	Apr-Nov
CRY	Tributary	Crystal Creek near mouth	47.1931	-120.9489	08-CRY	Feb-Oct	---	Feb-May	---
TEAL	Tributary	Teanaway River at Lambert Road	47.1749	-120.8361	39D075	Feb-Nov	---	May-Sep	---
SWAC	Tributary	Swauk Creek at mouth	47.1242	-120.7379	39SWA00.1	Feb-Nov	---	Feb-Nov	Ecology
TANC	Tributary	Taneum Creek at mouth	47.0919	-120.7093	11-TAN	Feb-Nov	---	Feb-Nov	May-Nov
DRY	Tributary	Dry Creek at Hwy 10	47.0408	-120.6115	14-DRY	Feb-Apr	---	Feb-Apr	---
DRYM	Tributary	Dry Creek at Mouth (new location)	47.0220	-120.6092	DRYM	May-Nov	---	May-Oct	Apr-Oct
PACK	Tributary	Packwood Ditch at S. Thorp Hwy	47.0106	-120.6130	YAK-49	Mar-Nov	Jul-Oct	Mar-Aug	Apr-Oct
MANL	Tributary	Manastash Creek at Brown Rd	46.9946	-120.5908	YAK-46	Mar-Nov	Jul-Oct	Jun-Oct	Jun-Nov
REEC	Tributary	Reecer Creek in Irene Rinehart Park	46.9881	-120.5707	15-REE	Feb-Nov	---	Feb-Nov	Apr-Nov
FOG	Tributary	Sorenson/Fogarty at Riverbottom Road	46.9514	-120.5522	16-FOG	Mar-Nov	Jul-Oct	Mar-Nov	May-Nov
WLTH	Tributary	Wilson Creek at Thrall Road	46.9263	-120.5017	YAK-48	Feb-Nov	---	Feb-Nov	USBR
CHTH	Tributary	Cherry Creek at Thrall Road	46.9263	-120.5006	39CHE00.2	Feb-Nov	---	Feb-Nov	USBR
WILC	Tributary	Wilson Creek at Hwy 821	46.9172	-120.5081	17-WIL	Feb-Nov	---	---	---
UMT	Tributary	Umtanum Creek	46.8573	-120.4957	39UMT00.2	Feb-Nov	---	Feb-Jun	---
WEN	Tributary	Wenas Creek at Wenas Rd.	46.7085	-120.5203	WENAS-1	Feb-Oct	---	Feb-Oct	Mar-Jul

Field and Laboratory Methods

Ecology conducted the following data collection activities.

- Water samples – laboratory analysis of bi-weekly turbidity and TSS water samples (analyzed by MEL).
- Gaged turbidity – logged in-situ turbidity measurements (15-minute interval).
- Measured flow – stream discharge measured by Ecology, USGS, or USBR.
- Gaged stage or flow – stream discharge by rating curve (either rated by Ecology or downloaded from USBR or USGS – 15- or 30-minute intervals)

The QAPP (Carroll and Urmos-Berry, 2019) describes the field activities and methods. A brief summary is presented below.

Water samples

During February-November 2019, Ecology collected water samples bi-weekly (every two weeks), occasionally missing sites due to poor site accessibility, dry channel, or ice. Ecology sent water samples to Manchester Environmental Laboratory (MEL) for analysis. Most samples arrived at MEL in good condition at proper holding temperature. See Appendix B for details.

Water samples were collected using a grab-sampler plunged into the water column. Samples were sometimes width integrated, depending on stream cross-sectional width and flow characteristic. Multiple point samples were composited in a churn-splitter for mixing and distribution into sample bottles. Tables A1 and A2 (Appendix A) show the type of samples taken at each location for each sample event.

Ecology also collected additional depth-integrated samples at several sites. Appendix B provides a comparison between the depth-integrated and grab sample pairs collected in 2019. Ecology observed no systematic bias between grab sample results versus depth integrated sample results. Unless stated otherwise, analyses in this report used grab sample results.

Continuous turbidity

Ecology installed telemetered stream turbidity stations at four mainstem and three tributary sites. Factory-calibrated FTS® DTS-12 in-situ turbidity sensors measured turbidity at continuous stations. The sensors measured turbidity at 15-minute intervals throughout the study period (Feb-Nov). Ecology also installed portable, non-telemetered turbidity stations at three tributary locations, operated July-October.

Field checks on turbidity were made at each turbidity gage during sampling visits, using Hach portable turbidity meters (models 2100P and 2100Q). If significant differences were observed between the portable meters and the turbidity gage, then the turbidity sensor was removed for inspection and cleaning using de-ionized water.

Streamflow

Ecology measured streamflow at several mainstem Yakima River and multiple tributary locations. For many sites, Ecology relied on permanent stream gaging stations for either continuous flow or continuous stage data. These included gages operated by Ecology, USBR, and USGS.

Ecology also gaged flow at additional sites using Hobo® stand-alone pressure transducer data loggers with a recording interval of 30 minutes.

Additional streamflow data

Ecology used a number of different sources of information for flow entering and leaving the Yakima River. These sources of information allowed Ecology to construct a relatively complete water budget for the upper Yakima River basin below Lake Easton. This budget is important for loading calculations. Ecology obtained data from the following organizations, see Appendix C for details.

- USBR
- USGS
- Ecology's Freshwater Monitoring Unit
- Washington Department of Fish and Wildlife
- Kittitas Conservation District
- Cascade Irrigation District
- Kittitas Reclamation District
- Final Water Rights adjudication
- Ecology's PARIS database

Data Usability Assessment

Ecology assessed the quality of all data collected and used in this study against the objectives specified in the QAPP (Carroll and Urmos-Berry, 2019). Appendix B provides the details of this data quality assessment. All data are of adequate quality for their intended use in this project. Ecology has taken data quality and qualifications into account in developing results and recommendations.

Analysis Methods

Turbidity Gage Results

Ecology first converted the raw 15-minute turbidity monitoring data to hourly averages. Prior to hourly averaging, 15-minute data were reviewed and suspicious readings were flagged for removal. Suspicious readings were identified as sudden short term peaks in turbidity which cannot be confirmed by other stations. These peaks indicate the possibility of either sensor interference by debris in the water or near shore disturbances which are not representative of the water body.

Ecology next applied linear corrections to the hourly turbidity data, based on factory calibration checks performed post-study (see Figure A5 in Appendix A). Turbidity gage sensors were calibrated before and after the 2019 study.

After removing flagged data and applying a linear correction, the hourly gage turbidity data were loaded to EIM.

TMDL Turbidity Target Statistics

Ecology used both water sample results as well as turbidity gage results for calculating TMDL turbidity target statistics. Because no turbidity gages were available at most tributary background sites, Ecology used the water sample results to calculate statistics for all tributary sites. For the mainstem Yakima River, statistics were calculated using the turbidity gage results.

For calculating TMDL turbidity target results based on water samples, Ecology evaluated TMDL turbidity targets using analysis methods similar to past studies (Joy, 2002 and Anderson, 2008). Ecology applied the following steps for evaluating 2019 TMDL turbidity target comparisons:

1. Verify log-normal distribution assumption using the Shapiro-Wilk test (as appropriate by site).
2. Calculate statistics (90th percentiles or geometric means, as appropriate by site) at both target and background sites.
3. Calculate differences in statistics by subtraction (target site statistic – background site statistic).
4. Compare these differences against the turbidity targets (see Table 2).

Like past studies (Joy, 2002 and Anderson, 2008), Ecology calculated 90th percentiles for water samples by assuming a log-normal distribution. This assumption was applied only when calculating 90th percentiles for grab water samples, not for calculating 90th percentiles of turbidity gage monitoring data. The turbidity gage data did not require this assumption due to nearly complete and continuous monitoring of turbidity over the TMDL season. The completeness of gage monitoring data eliminates the need for the lognormal assumption.

For the mainstem Yakima River, turbidity time series were calculated based on linear regression at two Yakima River target sites (Umtanum and Harrison Bridge), as described below. Regression adjustment was not applied to the turbidity gage data from the background site, since the gage and samples were collected at the same location.

For calculating TMDL turbidity target results based on gage measurements, Ecology evaluated TMDL turbidity targets using the following method:

1. Download turbidity gage data from EIM and calculate daily average values.
2. Calculate turbidity gage time series at target sites based on linear regression between the water sample turbidity (at target site), versus average daily turbidity (at proxy gage site).
3. Calculate 90^{th} percentiles at both target and background sites.
4. Calculate differences in 90^{th} percentiles by subtraction (target – background).
5. Compare these differences against the turbidity targets (see Table 2).

The linear regression adjustment (step 2 above) was applied to reflect the differences between the water sample turbidity (target site) and the gage turbidity (proxy site).

For both the water sample and gage methods, the differences in statistics are called point estimates (Helsel et al., 2020), and these are the values Ecology relied on to determine whether TMDL targets were met.

By themselves, point estimates do not convey any uncertainty. For sample results, the main source of uncertainty is the two-week interval between samples. For gage results, the main source of uncertainty is the regression adjustment applied to the gage data. To communicate uncertainty around our point estimates, Ecology calculated confidence intervals, as discussed in the next section.

Confidence intervals for TMDL turbidity target statistics

Uncertainty in the TMDL turbidity target results is expressed as confidence intervals for both the water sample results as well as turbidity gage results.

For the water sample method, Ecology calculated the confidence interval based on the differences between the 90% upper confidence limits (UCL_{90}) and the 90% lower confidence limits (LCL_{90}). The UCL_{90} estimates the largest expected value at the 90% confidence level; the LCL_{90} similarly estimates the smallest expected value. Confidence intervals were calculated as differences between UCL_{90} and LCL_{90} at the target and background sites as follows:

- Top of confidence interval = UCL90.target – LCL90.background
- Bottom of confidence interval = LCL90.target – UCL90.background.

For the turbidity gage method, Ecology calculated a 90% confidence interval for the linear regression line. Upper and lower bounds for the regression line were then used to calculate upper and lower bounds for the turbidity gage adjustment. Finally, the confidence interval for the TMDL turbidity target result was calculated based on the differences between 90^{th} percentiles for the upper and lower bounds of the adjusted turbidity gage data, versus the background site 90th percentile.

If the confidence interval lies completely above or completely below the target, then Ecology assigns a >90% confidence level to the TMDL target result. Ecology reports the "level of confidence" for this approach as >90%, since it is based on differences in upper and lower 90% confidence limits.

The following functions in R statistical software were used to calculate 90th percentiles and geometric means of the 2019 turbidity samples and turbidity gage data, along with UCL_{90}s and LCL_{90}s:

- Shapiro-Wilk test: function shapiro.test [stats package]
- 90th percentile (water samples): function "eqlnorm" [EnvStats package]
- 90th percentile (water samples which included non-detect results): function "eqlnormCensored" [EnvStats package]
- 90th percentile (gage daily averages): function "quantile" (stats package)
- Geometric mean (water samples): function "Gmean" (DescTools package)
- Linear regression (water samples vs turbidity gage): function "lm" [stats package]
- Linear regression confidence interval: function "confint" [stats package]

The following versions of R software and packages were used in the calculations: R (version 3.6.1); EnvStats (version 2.3.1); DescTools (version 0.99.35). Default options were accepted for all functions. Quantiles calculated for the gage daily averages used the default type=7, which is equivalent to the Excel® "PERCENTILE.INC" function.

Illustrative example of turbidity target statistics and confidence intervals

As an aid to understanding the turbidity target assessment presented below in the Results section (Figure 7 and Table 6), Ecology provides an illustration example for a target/background site pair, shown in Figure 5 below.

For this example (using 2019 sample data), the target site is Wilson Creek at Highway 821 (WILC) and the background site is Naneum Creek (NANU). For this target site, the TMDL turbidity target states: "the 90th percentile of the turbidity values collected at Wilson Creek will not exceed 5 NTU over the 90th percentile turbidity value of samples collected from the background site at Naneum Creek".

In this example figure, the difference in 90th percentiles calculated at the target and background site is 9.0 NTU (center vertical arrow). This difference (also called the point estimate) is then compared to the TMDL turbidity target. Because 9 NTU exceeds the 5 NTU difference allowed in the TMDL turbidity target, Wilson Creek (WILC) did not meet the TMDL turbidity target in 2019.

The confidence interval bounds are also shown on this figure. In this example, the >90% confidence interval is 1.2 to 19.8 NTU:

- 1.2 NTU (the smallest difference = LCL90 at Wilson Creek – UCL90 at Naneum Creek). Shown as the left vertical arrow.
- 19.8 NTU (the largest difference = UCL90 at Wilson Creek – LCL90 at Naneum Creek). Shown as the right vertical arrow.

Because the 5 NTU turbidity criterion falls within the confidence interval (1.2 to 19.8 NTU), Ecology cannot not assign >90% confidence to the TMDL turbidity target result at Wilson Creek.

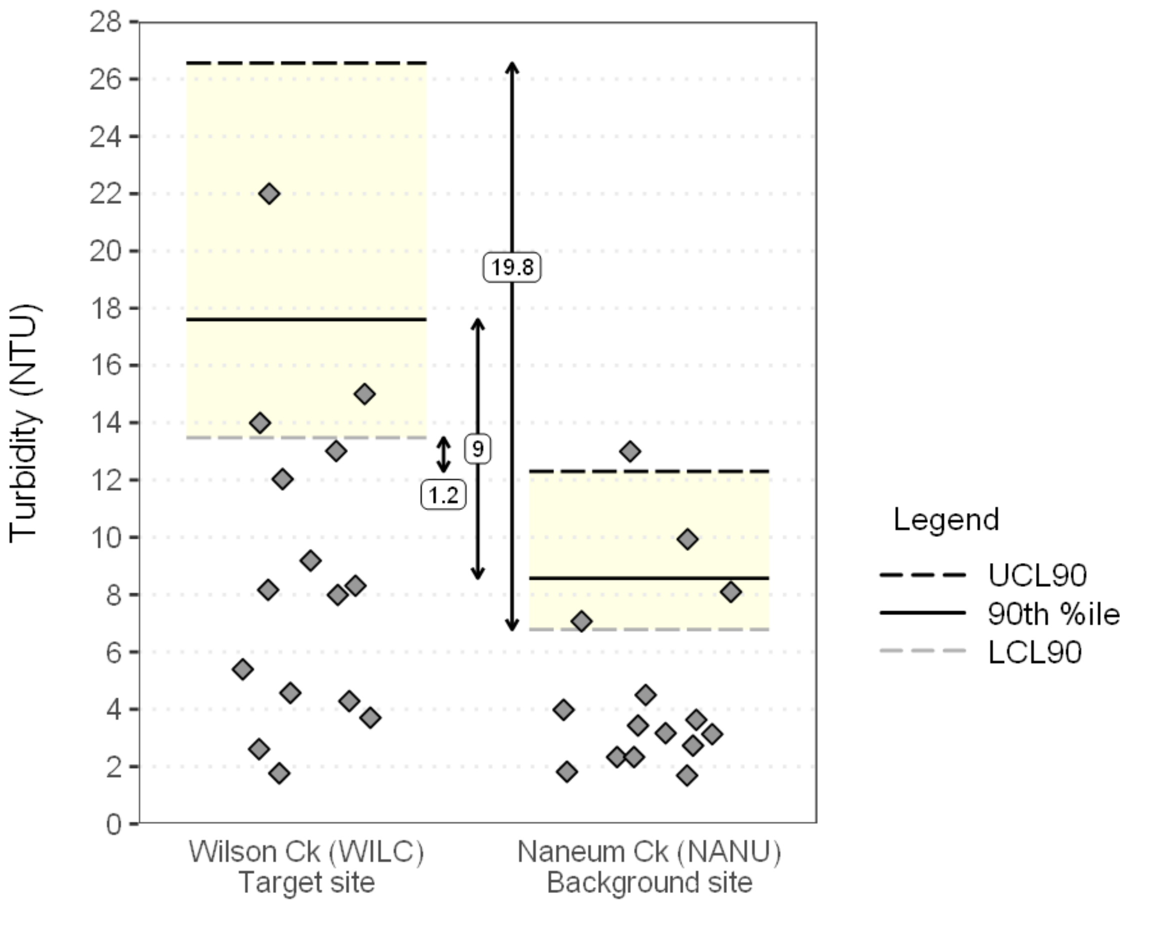

Figure 5. Example of calculated turbidity target result and confidence intervals.

Figure 5 shows the turbidity sample results for April-October 2019, along with the 90th percentile, UCL_{90}, and LCL_{90} (as indicated in the legend).
Laboratory turbidity results are shown as diamonds.
As a visual aid, yellow shading highlights the range between LCL_{90} and UCL_{90}.

Calculating Sediment Loads

Ecology used several different calculation methods for estimating 2019 sediment loads (see Appendix A for calculation details):

1. **Beales**: Beales ratio estimator from Principles of Surface Water Quality Modeling and Control by Thomann and Mueller (1987) provides a mass load estimate of a pollutant. The formula for the unbiased stratified ratio estimator is used when continuous flow data are available for sites with less frequent pollutant sample data.
2. **Interpolation**: TSS concentrations were first estimated by interpolation between sample results. TSS loads were then calculated by using TSS concentrations and streamflow.
3. **Gage**: TSS concentrations were calculated based on simple linear regression of TSS sample results versus gage turbidity values. TSS loads were then calculated by using TSS concentrations and streamflow.

Each method provided a different way to assess the sediment load. Beales was used in the original TMDL. Interpolation was useful in calculating monthly loads. The Gage method was appropriate for the use of the continuous turbidity data that was collected in the 2019 study, allowing improved resolution. Comparing results from the three methods provided a measure to assess uncertainty in calculating the load.

Results

Streamflow, Sample Results, and Gaging

Ecology presents basic laboratory analysis results, turbidity gaging results, data quality analysis, and flow data within four appendices, briefly described below. Laboratory and turbidity gage results were loaded into EIM. Flow data and ratings were loaded into Ecology's HYDSTRA database.

Appendix A

- Sampling methodology used by Ecology at different sites and dates (Tables A1 and A2).
- Laboratory results for turbidity, TSS and TNVSS (Figures A1-A2 and Tables A3-A6).
- Gage turbidity time series plus portable turbidity meter checks and laboratory results (Figures A3-A4).
- Corrections made by Ecology to gage turbidity based on factory calibration post-checks (Figure A5 and Table A7).
- Simple linear regressions used for converting gage turbidity to TSS used for loading analysis (Figure A6).
- Detailed balance tables for both flow (Table A8) and TSS loads (Table A9-A11), showing both the monthly and TMDL season (Apr-Oct) values.
- Correlations between laboratory results for turbidity vs TSS (Figure A7-A8).
- Turbidity statistics from samples at both TMDL target and non-target sites (Tables A12-A13).

Appendix B

Data quality analysis, including depth integrated replicates (Tables B1-B5).

Appendix C

- Figures showing time-series for flow ratings and measurements, plus statistics (Figures C1-C7, Table C1).
- Figures showing time series for various diversions from the Yakima River (Figures C8-C10).
- Figure for stream supplementation rates, courtesy of Kittitas Reclamation District (KRD) (Figure C11).
- Figures showing the flow rating curves used at several sites where the available data was not adequately high quality for HYDSTRA (Figures C12-C15).

Appendix D

Information about how turbidity targets were assessed for the Yakima River at Umtanum Creek (YKUM) and Harrison Bridge (YKHB).

Comparing 2019 Flow to 1999 TMDL Flow

To help understand the turbidity and loading results, this section compares 2019 flow to the flow during the 1999 TMDL study. Background turbidity and suspended sediment loads vary from year to year due to differences in precipitation, snowpack, streamflow, and other climate-associated forces. Drought and low snowpack were experienced in 2019, which impacted both turbidity and sediment in the river. On April 1, 2019 snowpack (snow-water equivalent) was at 73% of the 1981-2010 average for the upper Yakima basin (USDA-NRCS, 2020).

Figure 6 below shows flow and 50% seasonal discharge volume (50% volume) at Yakima River at the Umtanum Creek footbridge (study site YKUM, data from USGS Station ID 12484500). The figure shows how flow and 50% discharge volume compare between 1999 and 2019, as well as providing an overall perspective of past years (1990-2019), including the 2006 study year.

The top half of the figure shows flow; the bottom half of the figure shows 50% volume. Both are divided into two time periods: March 15-June 30 (early) and July 1-October 15 (late). The horizontal axis in the bottom half of the figure shows the timing when the 50% volume was reached. The 50% volume can be considered a proxy for precipitation effects (amount of water) while the timing can be considered a proxy for temperature effects (how early the water is released).

Figure 6 shows that, year to year, flow and 50% volume tend to be highly variable during the early time period and remarkably stable during the late time period. The stable flow and 50% volume during the late time period are due to USBR's managed release of water from the reservoirs in the upper Yakima Basin (known as "storage control"), that generally begins in July. The dip in flow during September is due to the USBR's annual reduction in water released from the upper reservoirs (colorfully referred to as "flip-flop").

Figure 6 (top) shows lower flow in the early time period during 2019 compared to 1999 (<5,000 vs <8,000 cfs, respectively).

Figure 6 (bottom) shows lower 50% volume in the early time period during 2019 compared to 1999 (<300,000 vs >400,000 acre-ft, respectively). The figure also shows the 50% volume timing occurred earlier during 2019 compared to 1999 (May 3 vs May 21, respectively).

One of the reasons that 50% volume timing occurred later during 1999 is that temperatures were much cooler in April and May. Monthly average temperatures at Stampede Pass were approximately 6°F cooler in March and 11°F cooler in April during 1999 than in 2019 (based on data from the National Weather Service station STMP).

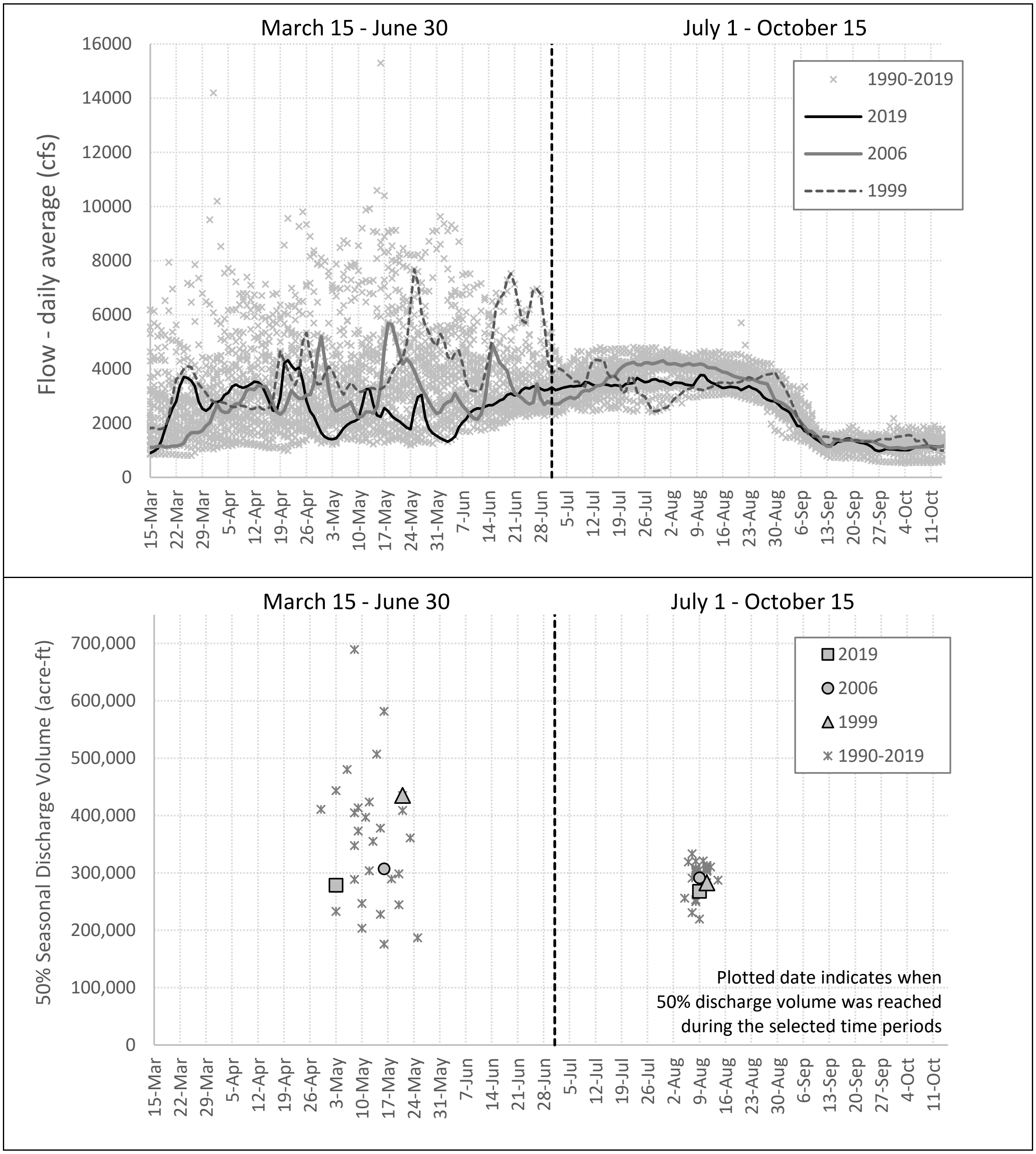

Figure 6. Yakima River flow and volume statistics (1990-2019) for USGS flow gage Yakima River at Umtanum Creek (Station ID 12484500) for two selected time periods across the irrigation season.

Time periods selected for this figure are March 15-June 30 (approx. first half of irrigation season) and July 1 – October 15 (approx. second half of irrigation season).
Top half of figure shows daily average flow in cfs; lower half shows date and amount when 50% volume has passed at this station (similar to Kormos et al., 2016) during each of the selected time periods. Study years (1999, 2006, and 2019) are highlighted.

TMDL Turbidity Target Results for 2019

Creech and Joy (2002) set TMDL turbidity targets as described in Table 2 in the Background section above. TMDL targets are based on the difference between statistics calculated separately for both the target site and the background site. The TMDL turbidity targets have a built-in annual adjustment that accounts for annual background variation; each year uses a different background turbidity level. This accounts for varying background turbidity from different hydrologic years. Heavy runoff years with higher turbidity levels will have higher background levels and therefore the difference between target and background sites are adjusted proportionally, but still allow no greater than 5 NTU increase relative to background.

As designated in the TMDL submittal (Creech and Joy, 2002), two different statistics were defined in the TMDL targets:

- Packwood Ditch (PACK) was evaluated based on difference in geometric mean (geomean).
- All other target sites were evaluated using differences in 90th percentiles.

Ecology calculated point estimates and confidence intervals for each site as described in the Methods section above. Appendix A (Table A12) presents the full calculation details. The point estimates for the two Yakima River target sites (at Umtanum and Harrison Bridge) were calculated using continuous turbidity gage data. See Appendix D for the turbidity target evaluation of these sites.

Figure 7 below presents the 2019 turbidity results compared to the final turbidity targets for all TMDL target sites. Point estimates are shown as symbols and confidence intervals are shown as error bars. The solid blue line shows the final target and the dashed blue line shows the interim target. The target is met for a site if the point estimate is less than or equal to the target. If the confidence interval (error bars) does not cross the target line, then Ecology assigns >90% confidence level to the final target comparison.

Table 6 tabulates the target results shown in Figure 7. This table indicates “Yes” or “No” whether or not the site met the final target, and whether or not Ecology found >90% confidence in the point estimate based on our confidence interval. Background site locations shown in this table are consistent with those used by Joy (2002) and Anderson (2009), except for the Teanaway River (TEAL) which used a background site at Red Bridge Rd (TEAU), instead of Teanaway River at North Fork.

Table 6 shows that six out of the nine TMDL target sites met the turbidity targets in 2019. Ecology found >90% confidence in these results for three of the sites meeting the targets, based on the confidence intervals which are shown in Figure 7 above, as well as in this table.

The TMDL turbidity results are encouraging evidence that the implementation of this TMDL may have improved water quality in parts of the upper Yakima Basin. However, Sorenson/Fogarty (FOG), Wilson Creek (WILC), and Yakima River at Umtanum Ck (YKUM) still need additional reductions in turbidity. Notably, Sorenson/Fogarty (FOG) did not even meet the interim TMDL turbidity target that was set as an early implementation goal. The post-TMDL monitoring study in 2006 showed FOG meeting both the interim and final TMDL turbidity targets (Anderson, 2008), so there appears to be need for more water quality improvements in the FOG sub-basin.

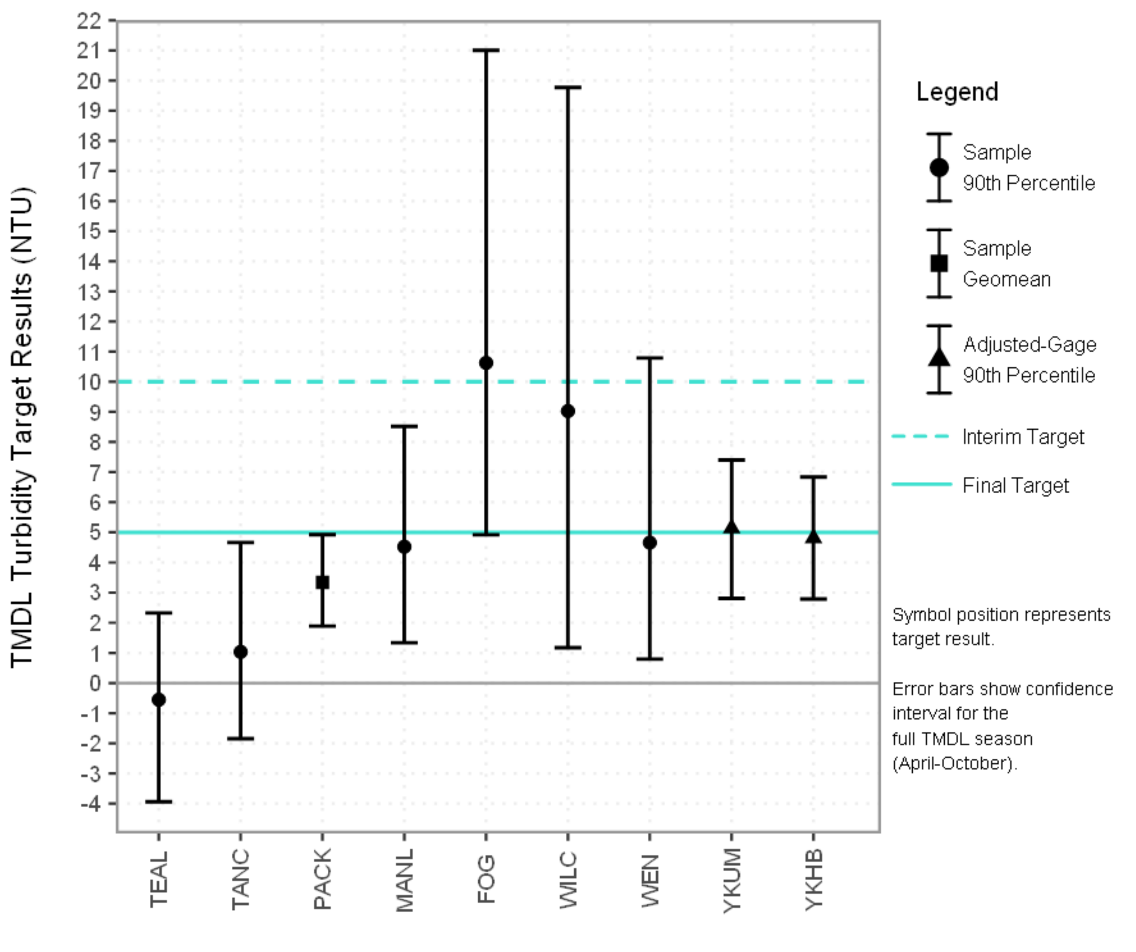

Figure 7. TMDL turbidity results for 2019 compared to TMDL targets.

See Table 6 for site names associated with the 4-letter codes above. The TMDL final target was met if the symbol falls onto or below the final target line (solid blue). If neither of the error bars cross the final target line, there is at least a 90% confidence level in the result.

Table 6. TMDL final target turbidity results for Apr-Oct 2019.

Site Name	Site Code	Final Target Met	Confident at > 90% level	Difference (NTU)	Confidence Interval (NTU)	Background Site
Teanaway River at Lambert Rd.	TEAL	Yes	Yes	-0.6	-3.9 to 2.3	TEAU
Taneum Creek	TANC	Yes	Yes	1.0	-1.8 to 4.7	MANU
Packwood Ditch	PACK[2]	Yes	Yes	3.3	1.9 to 4.9	MANU
Manastash Creek	MANL	Yes	No	4.5	1.3 to 8.5	MANU
Sorenson/Fogarty	FOG	No	No	10.6	4.9 to 21.0	MANU
Wilson Creek at Hwy 821	WILC	No	No	9.0	1.2 to 19.8	NANU
Wenas Creek	WEN	Yes	No	4.7	0.8 to 10.8	MANU
Yakima R. at Umtanum Ck	YKUM	No[1]	No	5.1	2.8 to 7.4	YKEA
Yakima R. at Harrison Bridge	YKHB	Yes[1]	No	4.8	2.8 to 6.8	YKEA

Yellow highlighting added to “Yes” cells as a visual aid.

[1]Target was evaluated using continuous gage data collected at YKSM and YKEA (background). See Appendix D for the turbidity target evaluation of these sites.

[2]Site PACK used differences in geometric means; all other sites used differences in 90th percentiles.

TMDL TSS Load Allocation Results for 2019

Creech and Joy (2002) also established TMDL load allocations for TSS (see Table 3). As described in Joy (2002), these load allocations were established based on calculated TSS load reductions from the tributaries to meet turbidity standards (5 NTU over background).

Ecology assessed the 2019 TSS data using three different methods to calculate TSS loads (as described in the Analysis Methods):

- Beales – using the Beale’s ratio estimator
- Interpolation – using linear interpolation between TSS samples
- Gage – using turbidity gage regression for TSS.

Figure 8 compares the 2019 TSS load calculations from these three methods against the TMDL TSS load allocations. TSS loads from the 1999 and 2006 monitoring are included in this figure for comparison.

Symbols falling within the gray bars in this figure meet the TMDL TSS load allocation. Sites were grouped as "large/medium/small" for purposes of plotting. Loading calculation methods are indicated by symbol shapes, while study years are indicated by color.

Table 7 compares the 2019 TSS loads and TMDL load allocations shown in Figure 8. Table 7 indicates "Yes" or "No" whether or not the 2019 TSS loads met the TMDL load allocations.

Figure 8 and Table 7 show that 15 out of 17 TMDL target sites met the TSS load allocations in 2019. These results provide additional encouraging evidence that the implementation of the TMDL may be improving water quality in the upper Yakima River Basin; however, additional improvements in TSS loading are still needed for two locations:

- Dry Creek (DRYM): The 2019 TSS load did not meet the 1999 TMDL load allocation. The TMDL load allocation did not include inputs of irrigation flow which occur downstream of the original TMDL site. In 2019, this site was moved closer to the mouth to include irrigation return flow and better represent loading to the Yakima River. The additional water from these irrigation inputs are likely the reason why this site did not meet the TSS load allocation.
- Packwood Ditch (PACK): The 2019 TSS load did not meet the TMDL load allocation, but did meet the turbidity TMDL target for geometric mean (although, as noted above, the site would not have met a 90^{th} percentile turbidity target).

The following two locations were unique in that they met their TSS load allocations but did not meet their TMDL turbidity targets:

- Wilson Creek (WILC): The three calculated 2019 TSS loads straddled the TMDL load allocation, with the Beales method exceeding the TMDL load allocation. Ecology considers the Gage method as the most accurate method because it is not limited to samples collected every 2 weeks, but rather, used continuous data. The 2019 TSS load calculated with the Gage method just barely met the TMDL load allocation. Even though there was marked improvement from 1999 TSS loading, Wilson Creek still did not meet its TMDL turbidity target.
- Sorenson/Fogarty (FOG) also met the TMDL load allocation but did not meet its final or interim TMDL turbidity target.

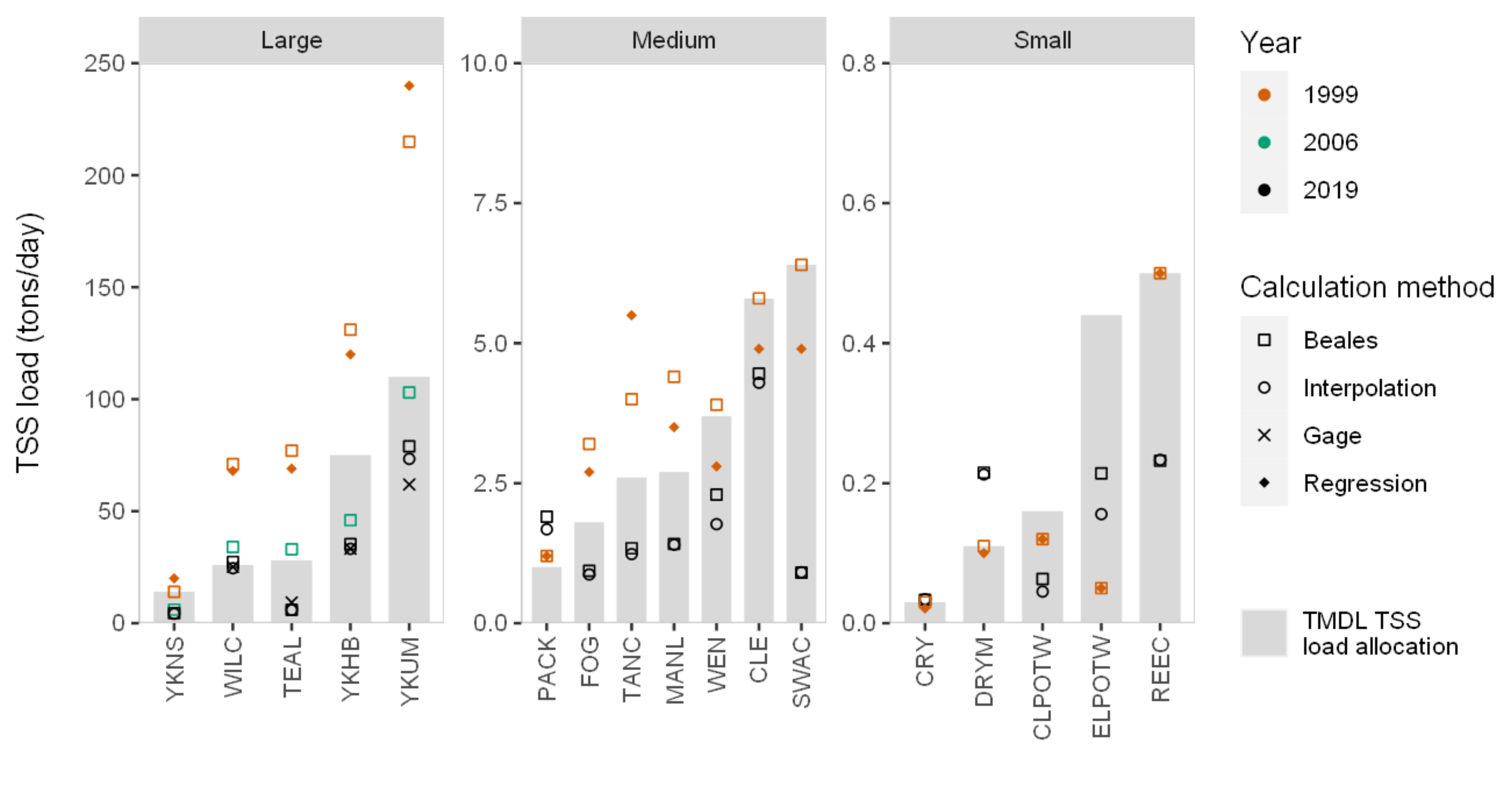

Figure 8. Mean TSS loads for the full season (Apr-Oct) for 1999, 2006, and 2019 versus TMDL load allocations.

See Table 7 for site names associated with the 4-letter codes above.
Symbols plotted within the gray bars met the TMDL TSS load allocations.
The "Regression" method shown in this figure was used in the 1999 TMDL study (Joy, 2002).

Table 7. TSS loads during Apr-Oct 2019 versus TMDL TSS load allocations.

Location Name	2019 Site Code	TMDL TSS Load Allocation[1] (tons/day)	2019 TSS Load (Interpolation)	2019 TSS Load (Gage)	2019 TSS Load (Beales)	TSS Load Allocation Met?	Note
Yakima River at Nelson	YKNS	14	2.6	---	2.7	Yes	2019 had low Cascade runoff
Cle Elum River	CLE	5.8	4.3	---	4.5	Yes	2019 had low Cascade runoff
Crystal Creek	CRY	0.03	0.03	---	0.03	Yes	
Cle Elum WWTP	CLPOTW	0.16	0.05	---	0.06	Yes	Based on design flow of 3.6 million gallons/day
Teanaway River	TEAL	28	5.9	9.2	5.9	Yes	2019 had low Cascade runoff
Swauk Creek	SWAC	6.4	0.91	---	0.90	Yes	
Taneum Creek	TANC	2.6	1.2	---	1.3	Yes	
Dry Creek	DRYM	0.11	0.21	---	0.22	No	1999 load allocation calculated for a different site location.
Packwood Ditch	PACK	1.0	1.7	---	1.9	No	
Manastash Creek	MANL	2.7	1.4	---	1.4	Yes	
Ellensburg WWTP	ELPOTW	0.44	0.16	---	0.21	Yes	Based on design flow of 8.0 million gallons/day
Reecer Creek	REEC	0.5	0.2	---	0.2	Yes	
Sorenson/Fogarty	FOG	1.8	0.87	---	0.93	Yes	
Wilson Creek	WILC	26	25	25	27	Yes	2019 loading was very close to the load allocation.
Wenas Creek	WEN	3.7	1.8	---	2.3	Yes	
Yakima River at Umtanum Cr	YKUM	110[2]	73	62	79	Yes	
Yakima River at Harrison Br.	YKHB	75[3]	33	33	35	Yes	

[1]TSS load allocations are from Table 11 in TMDL Submittal (Creech and Joy, 2002) unless otherwise specified.
[2]TSS load allocation for this site was revised August 2017 (Table 2 in TMDL Submittal Addendum #1, Creech and Joy, 2017).
[3]TSS load allocation from Table 10 in TMDL Submittal (Creech and Joy, 2002).

Flow and TSS Load Results for 2019

2019 April - October flow volume and TSS load balances

Table 8 shows an overall balance of 2019 flow volume (thousands of acre-ft) at several sites along the Yakima River. The full season volume (Apr-Oct) at each Yakima River site is listed in the first row. The next row shows the volume of water entering the Yakima River from tributaries between the site and the next upstream site. Upstream diversions are shown in the third row. The fourth row shows the unaccounted volume of water for each Yakima site (the residual of the mass balance). Finally, the unaccounted amount is shown as a percentage of the total volume of water at each Yakima River site.

Table 8. Yakima River seasonal flow volume balance (Apr-Oct 2019) in thousands of acre-ft.

	Below Lake Easton (YKEA)	Horlick (YKHO)	Ellensburg (YKEL)	Umtanum Creek footbridge (YKUM)	Selah Harrison bridge (YKHB)
Yakima River	169	869	851	1,046	513
Upstream tributary contribution	n/a	669	51	194	13
Upstream diversion reduction	n/a	0	-106	0	-546
Unaccounted volume	n/a	32	37	1	unknown
Unaccounted volume %	n/a	3.7%	4.3%	0.1%	unknown

n/a = not available. Table values were rounded to the nearest thousand acre-ft.

Balance calculations for volume (thousands of acre-ft):

YKHO = YKEA + upstream trib – upstream diversion + unaccounted
869 = 169 + 669 – 0 + 32

YKEL = YKHO + upstream trib – upstream diversion + unaccounted
851 = 869 + 51 – 106 + 37

YKUM = YKEL + upstream trib – upstream diversion + unaccounted
1046 = 851 + 194 – 0 + 1

YKHB = YKUM + upstream trib – upstream diversion
513 = 1046 + 13 – 546

Ecology included as many diversions and tributaries as possible in the above balances, but could not account for everything. Zero diversion amounts in the table above does not necessarily mean that no diversions exist. It just means that Ecology did not assess them in this balance because adequate data to quantify them was not collected. The unaccounted percentage in the flow balance is low overall (under 5%).

Table 9 shows a similar balance but for TSS loads (tons/day) at several sites along the Yakima River. The full season TSS load (April – October) at each Yakima River site is listed in the first row. The next row shows the TSS load entering from tributaries between the site and the next upstream site. Similarly, diversions are shown in the third row. Finally, the unaccounted load is shown both as a volume and also as a percentage of total load.

Table 9. Yakima River sediment load balance as TSS (Apr-Oct 2019) in tons/day.

	Below Lake Easton (YKEA)	Horlick (YKHO)	Above Wilson Creek (YKAW)	Umtanum Creek footbridge (YKUM)	Selah Harrison bridge (YKHB)
Yakima River	0.9	23.3	36.7	61.9	33.3
Upstream tributary contribution to load	n/a	14.2	6.7	25.2	1.8
Upstream diversion of load	n/a	0.0	-2.1	0.0	-29.6
Unaccounted load	n/a	8.1	8.9	0.0	-0.8
Unaccounted load % of mainstem load	n/a	35%	24%	0%	-3%

n/a = not available. Table values were rounded to the nearest 0.1 tons/day.

Balance calculations for sediment loads (tons/day):

YKHO = YKEA + upstream trib – upstream diversion + unaccounted
23.3 = 0.9 + 14.2 – 0 + 8.2

YKEL = YKHO + upstream trib – upstream diversion + unaccounted
36.7 = 23.3 + 6.5 – 2.1 + 9.0

YKUM = YKEL + upstream trib – upstream diversion + unaccounted
61.9 = 36.7 + 25.2 – 0 + 0

YKHB = YKUM + upstream trib – upstream diversion + unaccounted
33.3 = 61.9 + 1.8 – 29.6 – 0.8

In the Yakima Canyon stretch, the full season TSS load balance had no unaccounted TSS load between Yakima River above Wilson (YKAW) and Yakima River at Umtanum (YKUM) and only 0.8 tons/day of unaccounted TSS load (loss) for in the rest of the canyon from Umtanum (YKUM) to the Harrison Bridge (YKHB) in Selah.

In the upper portion of the basin, there was an unaccounted TSS load (8.1 tons/day) in the Cle Elum sub-basin from Easton (YKEA) to Horlick (YKHO). There was also an unaccounted TSS load (8.9 tons/day) in the Kittitas sub-basin from Horlick (YKHO) to above Wilson Creek (YKAW). The unaccounted flow balance for both of these sub-basins was only about 4%, so increased TSS concentrations are the only explanation for the unaccounted increase in TSS loads. The unaccounted loads in the upper basin most likely indicate the presence of unmeasured nonpoint sources in the Cle Elum and Kittitas sub-basins, such as from channel erosion, sediment resuspension, and unmeasured discharges in the Yakima River.

The full season balance presents an overall view of flow and TSS loading during the 2019 study year, and shows that the Ecology monitoring successfully accounted for the major sources and losses during the full season.

2019 average monthly flow and TSS loads

Figure 9 shows a monthly breakdown of 2019 flow (cfs) and TSS loads (tons/day), as well as the average monthly TSS concentration (mg/L) for the months of April thru October (the TMDL season). The top figure shows Yakima River sites, including the headwater location at Easton (YKEA); the lower figure shows two major headwater tributaries (Cle Elum River and Teanaway River), Wilson Creek, plus all other tributaries combined as “Other”.

Flow was already high in the Yakima River in April (due to snowmelt runoff from all headwaters sources) and would have declined if not for large releases from Cle Elum Reservoir (June – August) and Lake Easton in August. The Teanaway River contributed very little flow after April and May. There was a notable drop off in Yakima River flow starting in September due to the annual “flip flop” (also shown in Figure 6). The consistent lower monthly flow at YKHB was due to Roza Canal diversions.

Figure 9 shows that the highest TSS loads in the Yakima River occurred in April and decreased through the rest of the season. In general, TSS loads in the Yakima River increased from upstream to downstream each month due to additive loading from tributaries. The increased loads at Umtanum (YKUM) each month was due to the large TSS loads coming from Wilson Creek. Again, the monthly drops at YKHB were due to Roza Canal diversions. The Easton headwater site (YKEA) provided practically no monthly loads for the entirety of the season.

The average monthly TSS concentrations in the Yakima River were highest in April and May, at the same time when the tributaries (particularly Wilson Creek) were highest.

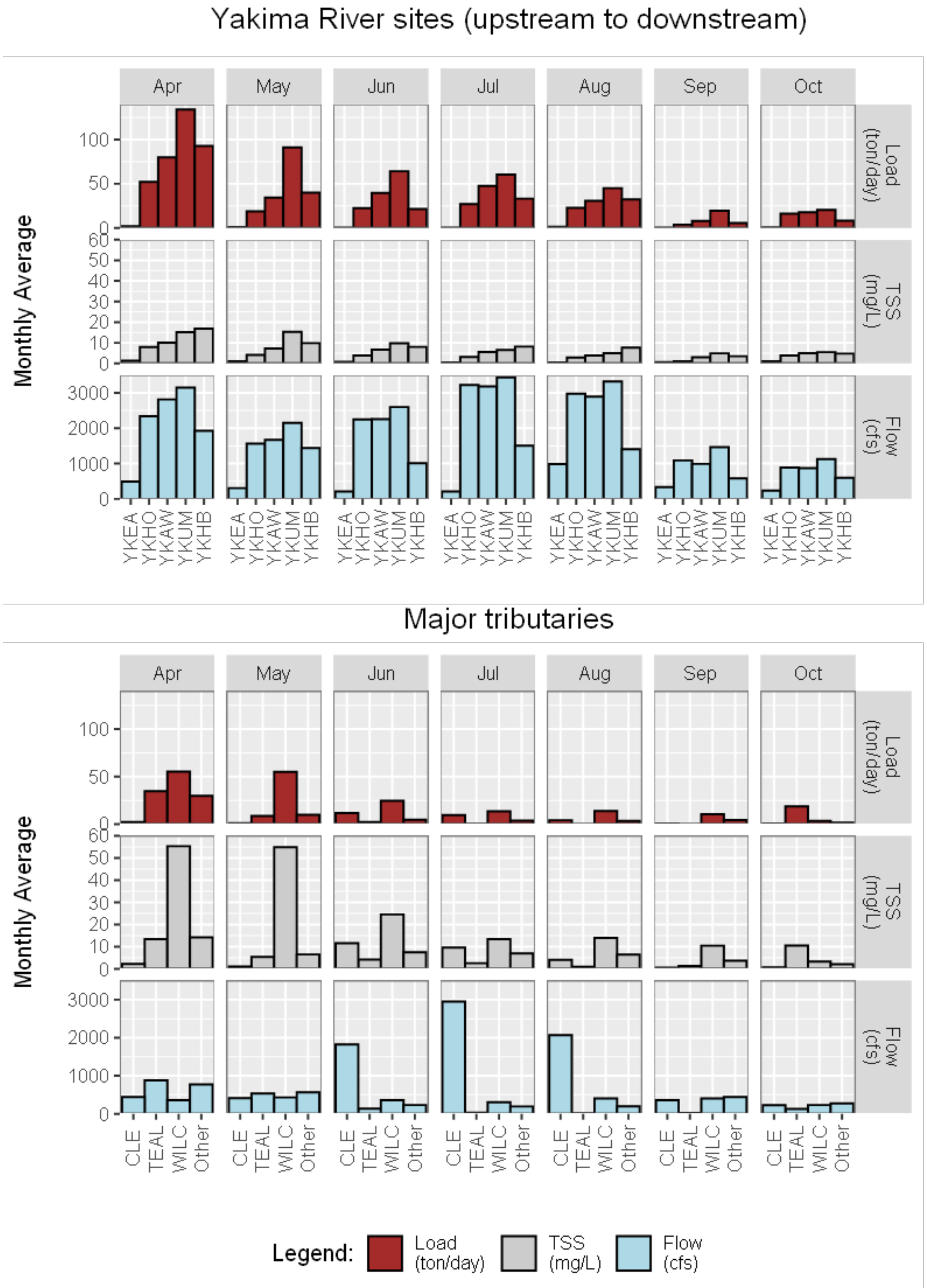

Figure 9. Monthly (Apr-Oct) averages of TSS load, TSS concentration, and flow at Yakima River and selected tributaries for 2019.

Yakima River sites are ordered from upstream to downstream. YKEA=Easton, YKHO=Horlick, YKAW=above Wilson Ck, YKUM=Umtanum footbridge, YKHB=Harrison Bridge. Tributaries are CLE=Cle Elum, TEAL=Teanaway, WILC=Wilson at Hwy 821.

Comparing 1999 TMDL TSS loads to post-TMDL monitoring years (2006 and 2019)

The TMDL (Joy, 2002) split the 1999 TSS load balance into an early season (Apr-Jun) and late season (July-Oct). This split roughly corresponds to the two time periods depicted in Figure 6. Figure 6 shows, from 1990 to 2019, highly variable flow in the "early period" (Mar 15- Jun) and stable flow in the "late period" (Jul-Oct 15) year-to-year. Figure 6 shows large differences between 1999 and 2019 in the amount and timing of flow in the early period (season).

As discussed, headwater sources of turbidity and suspended sediment loads vary from year to year due to differences in precipitation, snowpack, streamflow, and other climate-associated forces. The Cascades experienced low snowpack in 2019, while 1999 was an exceptional heavy snow year. Using the snow water-equivalent (SWE) data from the Stampede Pass for April 1, 1999 ranked 2nd highest in SWE in the last 39 years (1983-2021), while 2019 ranked 36th in SWE (USDA-NRCS, 2021).

Figure 10 provides a comparison between early vs. late season flow and TSS load for 1999 and 2019. The early season has large differences in between the two years; the late season, in contrast, shows a lot of similarity in flow between the years. The text notations shown on this 4-panel figure are elaborated below:

1. *"Higher flow Early 1999"* (top-left panel): Due to high snow-pack, early season flows were higher across the board in 1999. The major headwater sources to the system are Yakima-Nelson/Cle-Elum/Teanaway. Two of these headwater sources (Yakima-Nelson and Cle-Elum) are managed by reservoir outflows, while Teanaway River has no reservoir which results in "flashy" flow. Wilson Creek also shows higher flow in the early season 1999 which was likely due to a combination of increased flow from background tributaries (such as Naneum Creek) and also increased irrigation canal flow (for example Town and Cascade Canal). Early season irrigation flow in Town and Cascade canals was 20% and 40% higher during early 1999 vs. 2019, respectively.
2. *"Similar flow both years Late Season"* (top-right panel): Late season flows are more similar overall for both study years. Flows were just slightly higher in 1999, with one exception at the headwater source site, Yakima River at Nelson. The Teanaway River in particular experienced low flow during late season 2019. Overall, the late season flow similarity is due to managed flows for storage control, implemented by the USBR every year (also as shown in Figure 6 above). Cle Elum River had the largest flow during late seasons in both years due to this managed flow regime (see also the 2019 Cle Elum monthly flow averages in Figure 9 above).
3. *"Higher TSS load Early 1999"* (bottom-left panel): TSS loads were dramatically higher for the Teanaway River and Wilson Creek in early 1999. Loads were also higher in 1999 for the background site Yakima-Nelson as well as other tributaries (combined). Conversely, TSS loads were lower in early 2019, but it is not clear if this was due exclusively to lower flow or if implementation actions may also have provided benefits to decrease loading. Finally, despite high flow in the Cle Elum River, the TSS load here remained low compared to other sites, because of the low TSS concentrations.

4. *“Wilson Creek decreased TSS load Late 2019”* (bottom-right panel): The late season 2019 TSS load decreased significantly at Wilson Creek for roughly similar late season flow to 1999. This decrease in load was due to decreased TSS concentrations at Wilson Creek, see the Discussion section. For both years, the TSS load is much lower during the late season than it is during the early season. The Teanaway River does not contribute any significant load during the late season for either year.

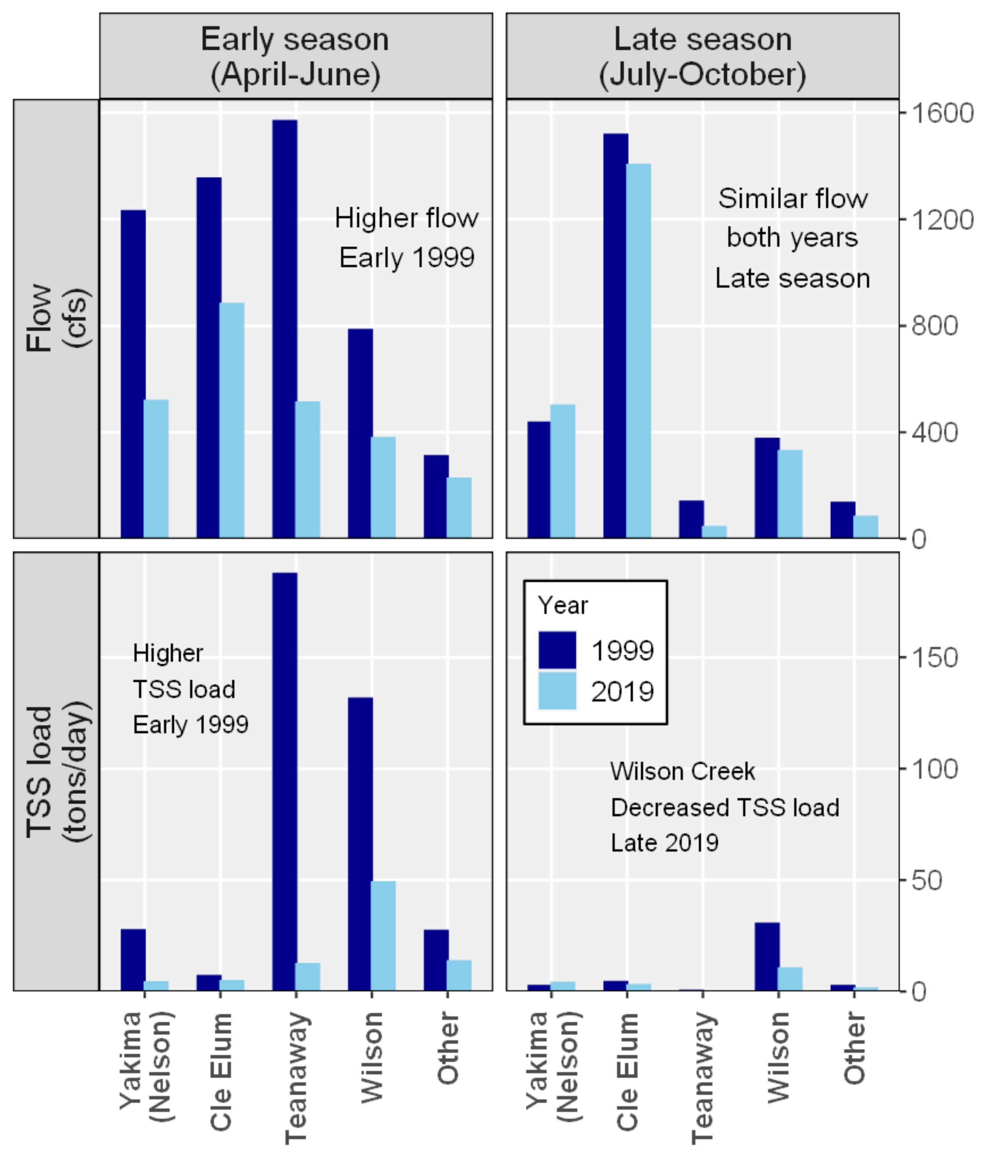

Figure 10. Early season (Apr-Jun) and late season (Jul-Oct) comparison of flow and TSS loads for 1999 and 2019.

Figure 10 used Beales calculation method for TSS load to compare 1999 (Joy, 2002) and 2019 TSS loads.
Sites: Yakima River at Nelson (YKNS); Cle Elum River (CLE);Teanaway River (TEAL); Wilson Creek near mouth (WILC).
"Other" is sum of flow and TSS load for all other tributaries.

Figures 11 and 12 below provide further analysis of the TSS loading comparison between the 1999 TMDL and the post-TMDL monitoring years (2006 and 2019). For both figures, loads are shown by season (early and late). As shown in the legend, symbol shape indicates calculation method; symbol color indicates year.

- Figure 11 presents seasonal comparisons of longitudinal TSS loading (from upstream to downstream) in the Yakima River.
- Figure 12 presents seasonal comparisons of TSS loads for the main tributaries to the upper Yakima River.

Figure 11 (left panel) shows the early season TSS loading in the Yakima River. It shows that the highest TSS loads occurred in 1999, with lower loads in 2006 and 2019. Flow was much higher during the early season of 1999, as discussed above (see Figures 5 and 9). The two biggest TSS load contributions to the Yakima River during the early season came from the Teanaway River and Wilson Creek. On this figure, these tributaries enter the Yakima River downstream of "Nelson-Siding" (YKNS) and "above Wilson" (YKAW), respectively.

Figure 11 (right panel) shows the late season TSS loading in the Yakima River. It shows that TSS loads above Wilson Creek were similar overall between all three years, again due to managed storage control by USBR. Below Wilson Creek, Umtanum (YKUM) is apparently showing noticeable improvements during the late season due to reduced TSS loads from Wilson Creek. Umtanum (YKUM) had higher loads in 1999 than the other two years. As shown above in Figure 10, the TSS load in Wilson Creek was 2-3 times higher in 1999 compared to 2019, even though the flows were about the same.

For both seasons in Figure 11 (both panels), the TSS load in the Yakima River generally increases in a downstream direction, except for a significant reduction between Umtanum (YKUB) and Harrison bridge (YKHB) due to water (and associated TSS load) being diverted into irrigation canals at Roza and Selah-Moxee. For the late season, there also appears to be a minor load reduction from Ellensburg (YKEL) to above Wilson Creek (YKAW) in 2019. However, this may have been due to sampling from the stream bank at YKAW, instead of from the center of the thalweg off a bridge.

The reduced TSS loads from the headwater sources in the early season of 2019 helped meet the TMDL load allocations, due to drought conditions. Early season TSS loading highly affects the ability to meet the TMDL TSS load allocations in the Yakima River. These load allocations are based on a full season (April-October), which is essentially an average of the early and late seasons. Early season TSS loading tends to be highly variable between years, while late season loading tends to be stable. The early season variability is driven by TSS loads from headwater sources, particularly the Teanaway River.

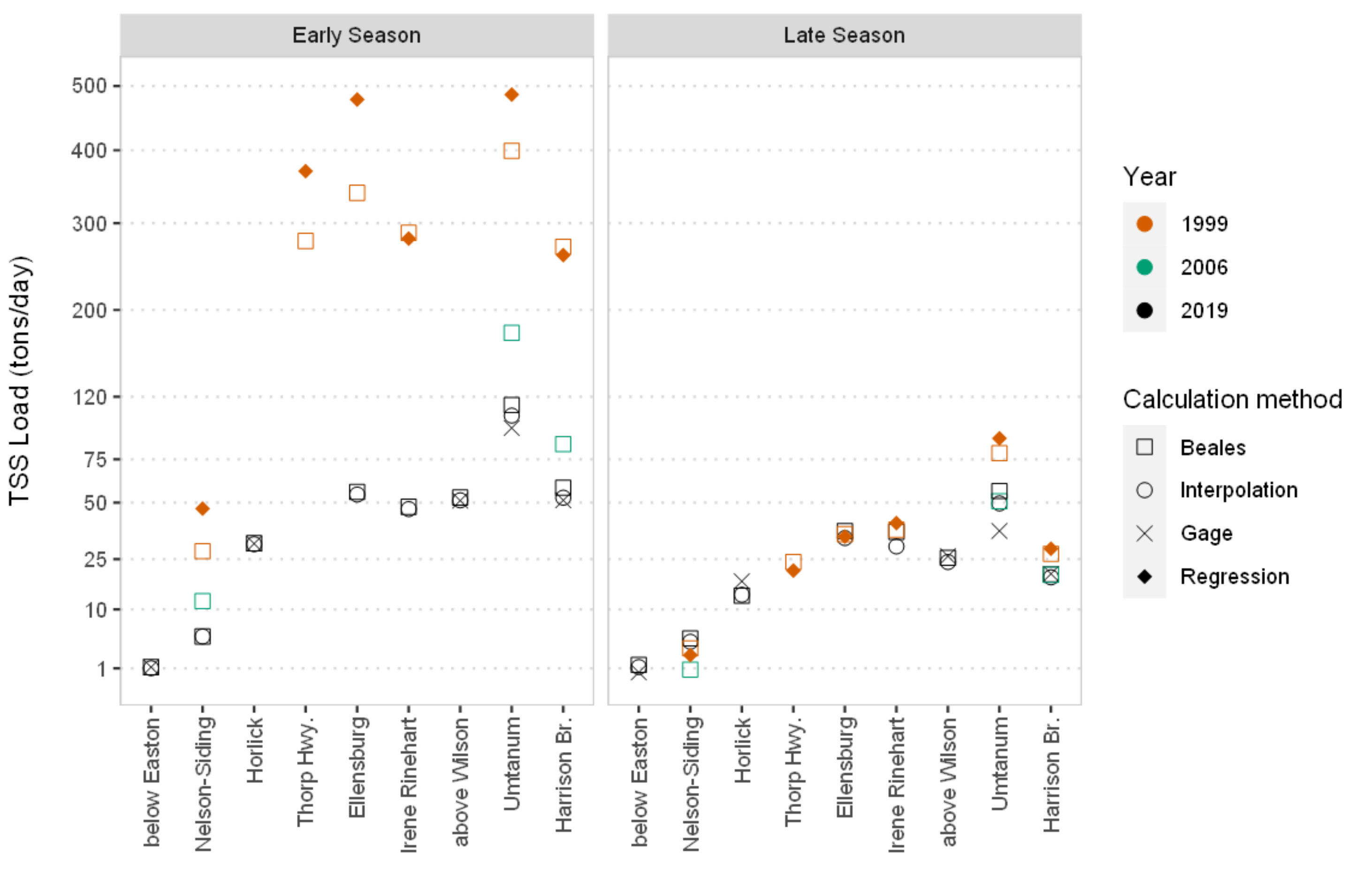

Figure 11. TSS load comparison for the Yakima River sites by season and study year.

Early season is April-June; late season is July-October. Yakima River sites are ordered from upstream to downstream. YKEA=Easton, YKNS=Nelson Siding, YKHO=Horlick, YKTH=Thorpe Rd., YKEL=Ellensburg, YKUB=Irene Rinehart, YKAW=above Wilson Ck, YKUM=Umtanum footbridge, YKHB=Harrison Bridge in Selah.
The "Regression" method from the 1999 TMDL study (Joy, 2002).

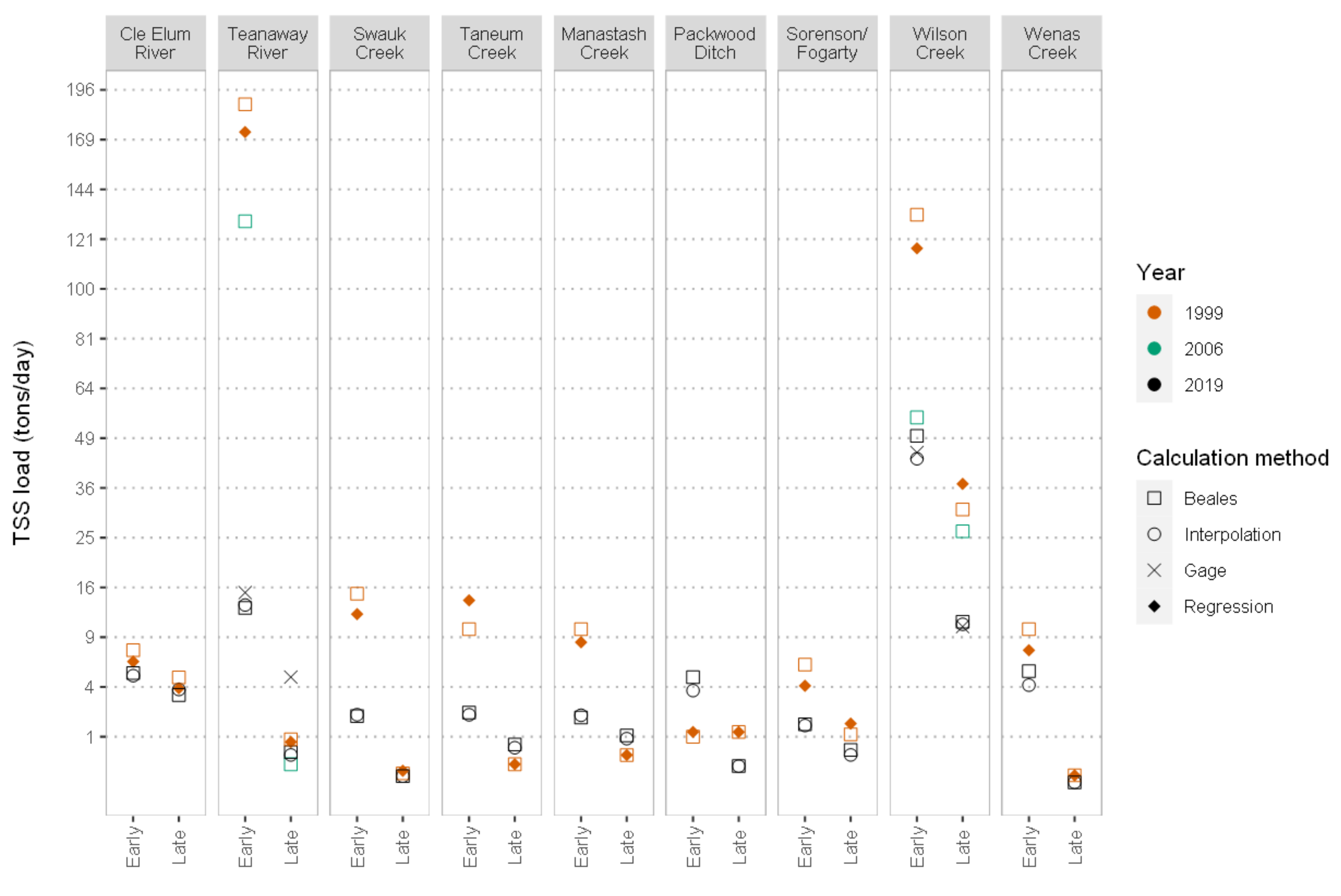

Figure 12. TSS load comparison for selected tributaries by season (early and late) and study year.

Early season is April-June; late season is July-October. Tributaries to the Yakima River are ordered from upstream to downstream. The "Regression" method is from the 1999 TMDL study (Joy, 2002).

Figure 12 shows the comparative TSS load results for individual tributaries:

- Cle Elum River (CLE) has fairly low TSS loads during both early and late season, regardless of year to year changes in flow due to snowpack.
- Teanaway River and Swauk Creek (TEAL and SWAC) – early season loads were highest here in 1999; late season loads are similar overall.
- Taneum Creek (TANC) and Manastash Creek (MANL) – for both creeks, early season loads were higher in 1999, with minor increases in 2019 late season TSS loading, probably due to the additional water added to the creek as part of stream supplementation.
- Packwood Ditch (PACK) –the 2019 study showed a higher load during the early season which may have been driven by one high TSS sample result on April 9, 2019 (estimated 185 mg/L). Flow was lower in 2019 than 1999.
- Sorenson/Fogarty (FOG) – TSS loading was lower during both seasons in 2019, compared to 1999. During 2019, the highest TSS concentrations were observed in the early season (April-June).
- Wilson Creek at Hwy 821 (WILC) – early season TSS loading was highest in 1999. Late season TSS loading was lowest in 2019, due to decreased TSS concentrations in this creek (see Discussion section for further information about decreased TSS concentration).
- Wenas Creek (WEN) – early season loading was lower in 2019 than 1999, with similar loading during late season.

The three different calculation methods[2] for 2019 TSS loads agree overall in both Figures 11 and 12, although in some cases (such as Teanaway River) the Gage method differed from the other methods but was considered more reliable due to continuous monitoring instead of sampling every 14 days.

Additional Results

In addition to reporting on the 2019 status of meeting TMDL turbidity targets, TMDL TSS allocations, and comparing annual TSS loads, Ecology looked also looked at two elevated TSS concentration thresholds:

- 30-day duration of TSS affecting aquatic life in the Yakima River basin (Joy, 2002).
- TSS threshold for indicating Total DDT and Dieldrin transport in Cherry Creek (Joy, 2002; Creech and Joy, 2002).

As described in the Methods section, Ecology collected full-season continuous TSS concentration data for four Yakima River sites and four tributaries where Ecology monitored continuous turbidity levels in 2019. Continuous records of TSS levels were regressed from the continuous turbidity records measured at each site, based on the relationship of discrete TSS measurements to simultaneous turbidity levels from continuous turbidity data as shown in

[2] Interpolation, Beales, and Gage method

Appendix A, Figure A-6. The regressions between TSS and turbidity turned out to be linear and highly correlated.

Wilson Creek near the mouth (WILC) did not have a continuous turbidity gage, but instead was based on a mass balance of turbidity and flow at two upstream sites (WLTH and CHTH) as described in Appendix A. In addition, the TSS sample results from Harrison Bridge were regressed against turbidity gage data from 2.4 river miles upstream of the site at Yakima River at Selah Moxee diversion (YKSM).

Figure 13 presents the TSS concentrations at the sites. Overall, TSS concentrations at all sites followed a pattern of having peak concentrations in March and then gradually declining the rest of the season, apart from singular precipitation events in August and October:

- A brief spike in TSS at YKHB during August was due to a flash precipitation event in the Yakima River Canyon.
- A large precipitation event during late October caused increased TSS in the Teanaway River and also in the Yakima River below the Teanaway River confluence. The TSS concentrations in the Yakima River from this event can be observed to decrease in a downstream direction from YKHO to YKAW to YKSM, as the TSS dispersed in the river.

The increase in TSS concentration between Easton and Horlick is primarily due to the Teanaway River. There was no elevated TSS in the Yakima River at Easton (YKEA) in 2019 (Apr-Oct). The other headwater source at Cle Elum had no elevated TSS (as shown in Appendix A, Figure A-2), leaving the Teanaway River as the source for most of the increased TSS in the Yakima River at Horlick (YKHO).

Also shown in Figure 13 are two TSS thresholds:

- **30-day Duration of Elevated TSS**

  Duration of TSS levels in the Yakima River and its tributaries was a reported element in the original TMDL study. Joy (2002) identified a threshold range of concern for TSS concentrations starting between 7-100 mg/L. Concentrations in that range, occurring for more than 30 days, can potentially harm salmon eggs and emergent fry, as well as degrade aquatic habitat.

  Figure 13 shows the 30-day moving average TSS concentration as gradations of blue (as described in the legend). The darker the blue, the higher the 30-day TSS concentration.

  Overall, the 30-day average TSS levels were low in the Yakima River sites, partly due to the low runoff in 2019. Cherry Creek (CHTH) showed consistently high 30-day TSS levels from March through mid-July 2019. Overall, Cherry Creek had the highest levels and longest duration of elevated TSS for the 2019 study, and greatly impacted the downstream site at Wilson Creek at the mouth (WILC).

- **TSS Threshold for Pesticide Transport in Cherry Creek**

  The 1999 TMDL indicated a threshold for total DDT and dieldrin appearance in Cherry Creek occurring at 20-35 mg/L TSS (Joy, 2002). This TSS threshold range is compared to the 2019 TSS data from CHTH in Figure 13, plotted as a transposed box over the TSS concentration data.

During 2019, Cherry Creek (CHTH) exceeded the lower threshold of the range (20 mg/L) from late March through mid-August, and exceeded the higher threshold of the range (35 mg/L) from late March through at least early July. If the 1999 relationship between TSS concentration and pesticides is still valid, then the 2019 data shows that Cherry Creek was still transporting DDT and dieldrin downstream to the Yakima River, for at least three months of 2019.

While Ecology did not monitor pesticides in 2019, a study looking specifically at the status of pesticides in Cherry Creek in 2014 (Friese, 2015), did report that Cherry Creek was not meeting the final TMDL targets for pesticide reductions, even though progress had been made towards lowering DDT and dieldrin concentrations from higher 1999 levels.

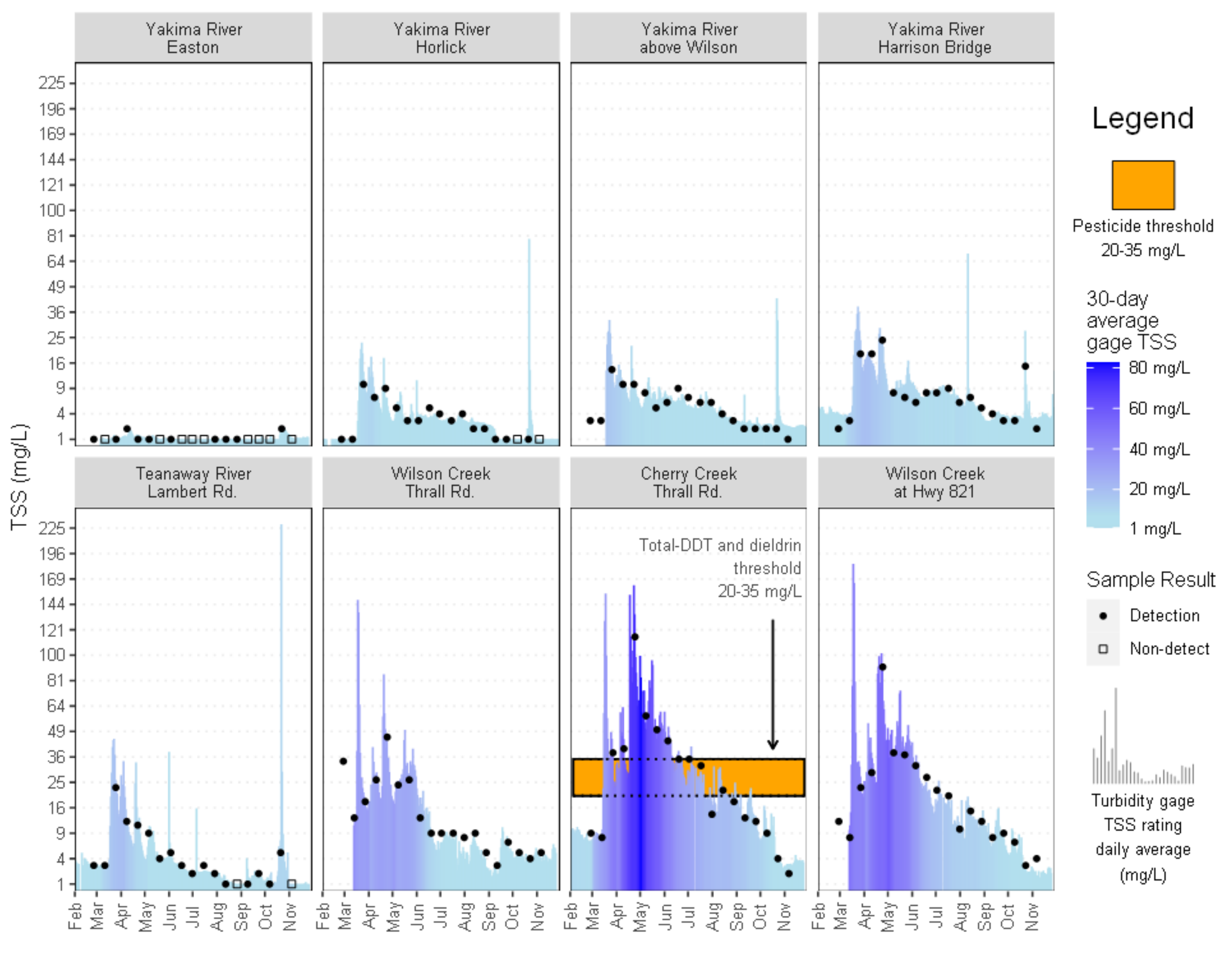

Figure 13. TSS concentrations for 2019 time series (daily and 30-day average – as calculated from relationship with turbidity) and sample results.

Joy (2002) identified TSS concentrations of concern as 7-100 mg/L for more than 30 days, plus a pesticide threshold range for TSS concentrations starting between 20-35 mg/L for Cherry Creek (associated with detections of total-DDT and dieldrin in that waterbody).

Discussion

The 2019 monitoring study took place 20 years after the original 1999 TMDL study year, giving enough time for implementation in the basin to show improvements. In essence, the comparison of the 2019 monitoring data to TMDL targets is a "report card", measuring the progress made towards improving water quality in the basin.

Did TMDL implementation over the past 20 years make a difference?

- Most turbidity targets were met in 2019, which is good news and points to success in the TMDL implementation progress. The TMDL turbidity targets are a robust measure of progress because they adjust for background levels year to year. However, two sub-basins showed improvement but did not meet their turbidity targets: Wilson Creek and Sorenson/Fogarty. The Yakima River at Umtanum also needs more improvement, but this site is just downstream of Wilson Creek and will reflect future progress made in Wilson Creek.
- Most TMDL sites met their TSS load allocations in 2019, also showing success in TMDL implementation. Progress was more clear in the late season (July-Oct) and less clear in the early season (Apr-June):
    - During the early season, reduced TSS loads were likely due to a combination of both TMDL implementation as well as low runoff in 2019. The TMDL load allocations were based on 1999 conditions, which had high runoff in the early season. The TSS load allocations do not adjust for different background levels year to year, like the turbidity targets.
    - During the late season, reduced TSS loads in the Yakima River and Wilson Creek were clearly due to TMDL implementation. Late season flow has been remarkably stable (1999-2019) in the Yakima River, which allows for a more direct comparison between years.

Below we present an assessment of TMDL progress for two important tributaries (Teanaway River and Wilson Creek):

Teanaway River

The Teanaway River met both its turbidity target and TSS load allocation in 2019. The Teanaway River was identified in the 1999 TMDL as one of the tributaries with the highest TSS loads and impact to the Yakima River. In 1999, the Teanaway River contributed 36% of the seasonal TSS load to the Yakima River at Umtanum (YKUM), compared to only 15% in 2019. As shown above in Figure 10, low snow pack in 2019 reduced the TSS load from the Teanaway River to just a fraction of its 1999 TSS load. Every year, nearly the entire TSS load from the Teanaway River occurs in the highly variable early season. Due to year-to-year hydrologic differences in the early season, it is not possible to distinguish between TSS load reductions due to hydrologic differences and reductions due to improvements in management practices in the Teanaway River basin.

Wilson Creek

Wilson Creek did not meet its turbidity target and barely met its TSS load allocation in 2019. Wilson Creek was identified in the 1999 TMDL as another tributary with the highest TSS loads and impact to the Yakima River.

However, there are several lines of evidence to show there have been improvements in Wilson Creek TSS loading in the late season (July-October):

- Figure 10 shows that the late season 2019 TSS load decreased significantly at Wilson Creek (for roughly similar flows).
- Figure 12 shows consecutive decreases in TSS loads from 1999 to 2006 to 2019, for both the early and late seasons.
- Figure 14 (see below) shows decreasing TSS concentrations over the past 20 years (1999-2019) near the mouth of Wilson Creek (WILC).
- Figure 11 shows that the Yakima River late season TSS loads downstream of Wilson Creek have decreased since 1999, due to improvements in Wilson Creek.

Decreasing TSS loads in the late season for Wilson Creek is encouraging and shows success in TMDL implementation. However, the 2019 data also indicate water quality must still be improved in the Wilson Creek watershed:

- Figure 7 shows that Wilson Creek did not meet the turbidity target in 2019, a dry year, clearly showing that additional improvements need to be made in the basin.
- Figure 8 and Table 7 show that Wilson Creek barely met the TSS load allocation in 2019, even though it was a dry year with lower flow.
- Figure 13 shows that Wilson Creek exceeded the greater-than 30-day TSS concentrations of concern.
- Figure 13 also shows that TSS concentrations in Cherry Creek during 2019 remained above the pesticide threshold concentration, indicating that total DDT and dieldrin may continue to be released into the Yakima River from Cherry Creek.

Wilson Creek represented 41% of the 2019 TSS load in the Yakima River at Umtanum, clearly making it for a priority for further BMP actions. Cherry Creek represented greater than 75% of the Wilson Creek TSS load, so most of the focus should be within the Cherry Creek sub-watershed.

Did TMDL implementation over the past 20 years make a difference? Yes, overall, TMDL implementation has shown improvements to water quality in the upper Yakima River basin to date, and should be continued in order to provide additional benefits.

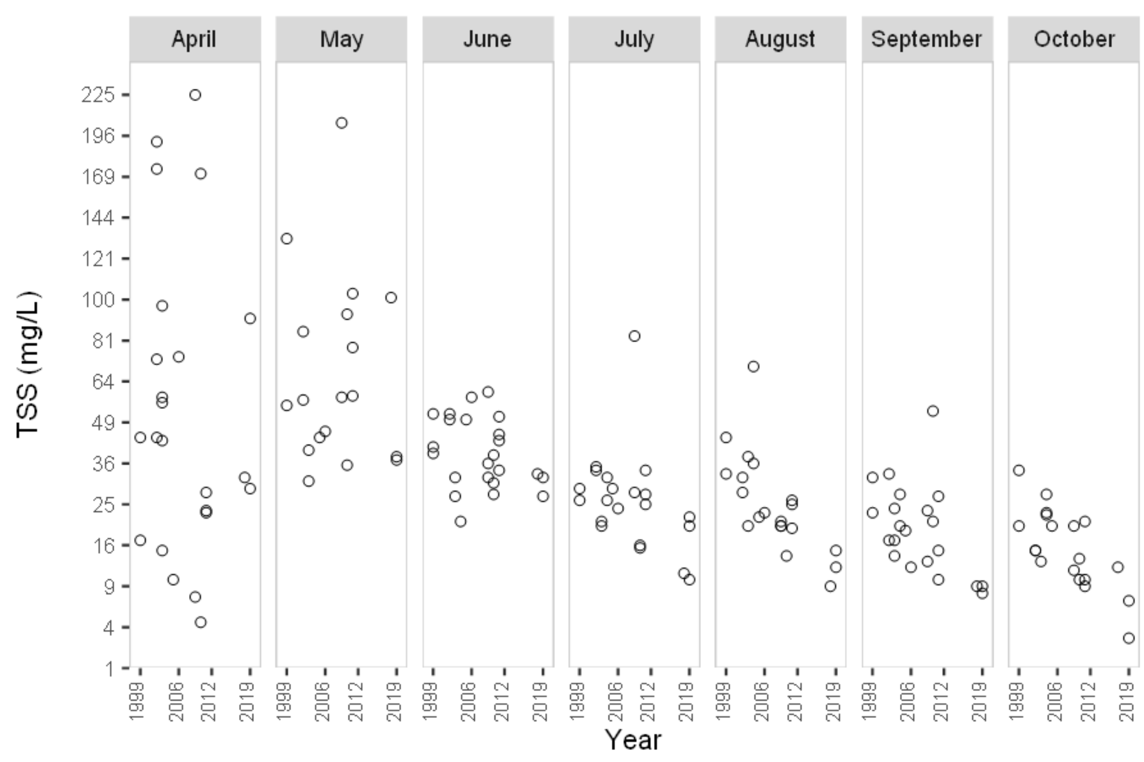

Figure 14. TSS concentrations over time (1999-2019) at Wilson Creek near the mouth (WILC).

TSS concentrations at Wilson Creek (WILC) have decreased in later irrigation months (June-October) since implementation of the TMDL. This can be seen on this figure as consistently decreasing TSS concentrations in each of these months. On the other hand, maximum TSS concentrations at Wilson Creek typically occur during April and May, although concentrations appear variable and include low concentrations as well.
Ecology downloaded verified data for this figure from Ecology's Environmental Information Management database (EIM).

Summary of 2019 Status Monitoring for TMDL Turbidity Targets and TSS Load Allocations

Many of the sites in this study met the turbidity targets and TSS allocations established in the TMDL (Creech and Joy, 2002). Table 10 summarizes the 2019 results by site.

Table 10. Summary of 2019 status monitoring for TMDL turbidity targets and TSS allocations.

Location Name	Site	Turbidity Target Met?	TSS Allocation Met?
Yakima River at Nelson Siding	YKNS	---	Yes
Cle Elum River at Bullfrog Rd. Bridge	CLE	---	Yes
Crystal Creek near mouth	CRY	---	Yes
Cle Elum POTW effluent	CLPOTW	---	Yes
Teanaway River at Lambert Rd.	TEAL	Yes	Yes
Swauk Creek at mouth	SWAC	---	Yes
Taneum Creek at mouth	TANC	Yes	Yes
Dry Creek at mouth (new location)	DRYM	---	No[1]
Packwood Ditch at S. Thorp Hwy	PACK	Yes	No
Manastash Creek at Brown Rd.	MANL	Yes	Yes
Ellensburg POTW effluent	ELPOTW	---	Yes
Reecer Creek in Irene Rinehart Park	REEC	---	Yes
Sorenson/Fogarty at Riverbottom Road	FOG	No	Yes
Wilson Creek at Hwy 821	WILC	No	Yes[2]
Wenas Creek at Wenas Road	WEN	Yes	Yes
Yakima River at Umtanum Creek Bridge	YKUM	No[3]	Yes
Yakima River at Harrison Bridge	YKHB	Yes[3]	Yes

Dashes in cells (---) indicate that no TMDL turbidity target exists for the site.
Yellow highlighting added to "Yes" cells as a visual aid.

[1]Site DRYM lies downstream of the original TMDL site for Dry Creek (DRY). Site DRYM receives irrigation return flow, which was not considered in the calculation of the original TMDL TSS loading allocation for this site.
[2]Wilson Creek 2019 TSS loading was very close to the TMDL TSS load allocation.
[3]Target was evaluated using continuous gage data collected at YKSM and YKEA (background). See Appendix D for the turbidity target evaluation of these sites.

Conclusions and Recommendations

Conclusions

Results of this 2019 effectiveness monitoring study support the following conclusions:

- TMDL implementation has shown improvements to water quality in the upper Yakima River basin to date, and should be continued in order to provide additional benefits.
- Most turbidity targets were met in 2019, which is good news and points to success in TMDL implementation progress. The TMDL turbidity targets are a robust measure of progress because they adjust for background levels year to year. Wilson Creek (WILC) showed improvement from 1999 but did not meet its turbidity target. Sorenson/Fogarty (FOG) also did not meet its turbidity target. The Yakima River at Umtanum (YKUM) needs more improvement, but this site is just downstream of WILC and will reflect future progress made there.
- Most TMDL sites met their TSS load allocations in 2019, also showing success in TMDL implementation. It is clear that low flow due to low snowpack in 2019 helped reduce TSS loads in the early season (Apr-June). Progress from BMP implementation was evident in the late season (July-Oct) when more stable flow conditions allowed comparison between years.

Recommendations

Results of this 2019 effectiveness monitoring study support the following recommendations.

- Overall, the TMDL implementation showed success. Further implementation throughout the watershed will continue to improve water quality. Additional technical and financial assistance for irrigation improvements should be made available to producers in the TMDL project area.
- Prioritized clean-up activities are recommended for the following locations:
    - Wilson Creek – While showing improvement, the turbidity target was not met. High levels of TSS and turbidity continue to come from the Cherry Creek sub-basin. During the 2019 monitoring study, Cherry Creek had the highest levels and longest duration of elevated TSS, and represented greater than 75% of the TSS load at Wilson Creek at the mouth (WILC), so the Cherry Creek sub-basin should be prioritized for further clean-up.
    - Sorenson/Fogarty – This sub-basin did not meet the interim or final TMDL turbidity target in 2019. This basin should be prioritized for clean-up in order to improve water quality conditions.
    - Packwood Ditch – TSS load allocation not met. Ecology noted early season high flow and TSS, which was reportedly attributed to Robinson and Fogey Creek, which drain into this ditch.

    - Prioritized clean-up activities are recommended for the Yakima River at Umtanum too, but this would mainly entail further clean-up of Wilson Creek sub-basin.
- Future effectiveness monitoring studies looking at suspended sediment in the upper Yakima River basin should use continuous turbidity monitoring in combination with the 2-week sampling programs so that the distribution of turbidity levels is more accurately assessed at target sites. Turbidity gages should also be installed at background sites.
- Consideration should be given to establishing variable TSS load allocations that take into account inter-annual hydrologic variation, particularly in the early season.
- The 2019 monitoring station at the mouth of Dry Creek (DRYM) needs a new TSS load allocation because it is a new sampling site with additional sources that were not accounted for in the original TMDL load allocation.
- Future monitoring and analysis should consider the potential impacts from climate change. Climate change is reducing winter snowpack, with more rain and earlier snowmelt, and potential drought conditions during the TMDL season. This may shift high turbidities to earlier in the year, maybe even before the TMDL season.
- Because there is so much annual variation in flow and suspended sediment delivery, strategic continuous turbidity monitoring in conjunction with continuous flow monitoring could be implemented at the following sites: YKEA, YKHO, YKAW, YKUM, and YKSM to better understand inter-annual TSS loading within the upper Yakima River basin.
- Any shortcomings in meeting the TMDL targets will need to be addressed in a new TMDL implementation strategy, adjusted and changed through a public process including the community stakeholders and Ecology.

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Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Basin: 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.

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.

Confidence Interval: Statistical interval designed to bound the true value of a population parameter such as the mean or an upper percentile.

DDT: Dichlorodiphenyltrichloroethane. In this report, DDT refers to this compound and its breakdown products or metabolites.

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

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

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

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

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.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

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

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.

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

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

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting 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.

Lower confidence limit at 90% (LCL_{90}): This represents the value, above which we are 90% confident, lies the true value of a statistic.

Lower confidence limit at 90% (UCL_{90}): This represents the value, below which we are 90% confident, lies the true value of a statistic.

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

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

BMP	Best management practice
DDT	Dichlorodiphenyltrichloroethane
DNR	Washington State Department of Natural Resources
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
HUC	Hydrologic Unit Code
KCCD	Kittitas County Conservation District
KCWP	Kittitas County Water Purveyors
KRD	Kittitas Reclamation District
MEL	Manchester Environmental Laboratory
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PAM	Polyacrylamide
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedure
TCF	Teanaway Community Forest
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USBR	United States Bureau of Reclamation
USFS	United States Forest Service
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
NTU	nephelometric turbidity units
tons/day	tons per day

Appendices

Appendix A. Laboratory Results and Turbidity Gaging

Appendix A presents details about sampling methods, laboratory results, turbidity gage results, as well as detailed balances for flow and TSS loading. This appendix is organized as follows:

- Table A1 presents details about water sample collection methods in 2019.
- Table A2 presents sample collection methods for sites which were re-sampled using a different method.
- Figures A1-A2 present sampling results for turbidity and TSS, respectively. Table A3 presents sampling dates and week numbers for reference to these figures.
- Table A4 describes the laboratory qualifiers associated with turbidity and TSS sampling results, and Tables A5 and A6 present sampling results for turbidity and TSS.
- Figure A3 presents corrected continuous turbidity gage results as daily averages compared against portable turbidity gage checks, and Figure A4 presents 30-day averages of corrected continuous turbidity gage results compared against laboratory results.
- Figure A5 presents the difference and slope between hourly turbidity gage readings versus both factory calibration checks and portable turbidity gage checks. Table A7 presents how the slope was used for correcting turbidity values.
- Figure A6 presents the linear regression used for converting hourly gage turbidity readings to TSS concentrations.
- Tables A8-A11 presents detailed flow and load balances. The calculation method for load balances is described in the text above these tables.
- Figures A7-A8 shows correlation between TSS and turbidity water sample results.
- Table A12 and A13 presents details on turbidity target statistics. Table A12 presents the turbidity statistics for the TMDL target sites. Table A13 presents turbidity statistics for non-target sites.

Table A1. Water sample collection method details for TSS and turbidity (see abbreviation key below Table A2).

Study Location ID	Location Name	Feb 25-27	Mar 11-13	Mar 25-27	Apr 8-10	Apr 22-24	May 6-8	May 20-22	Jun 3-5	Jun 17-19	Jun 30-Jul 2	Jul 15-17	Jul 29-31	Aug 12-14	Aug 26-28	Sep 9-11	Sep 23-25	Oct 7-9	Oct 21-23	Nov 4-6
YKEA	Yakima River below Lake Easton	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKNS	Yakima River at Nelson Siding	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc
YKCE	Yakima River at S. Cle Elum Way	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
YKAT	Yakima River above Teanaway	NS	NS	NS	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKHO	Yakima River at Horlick	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKEL	Yakima River near Ellensburg	LB	LB	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc
YKUB	Yakima River at Irene Rinehart Rd bridge	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKAW	Yakima River above Wilson Creek	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKUM	Yakima River at Umtanum Creek Bridge	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc	3Xc
YKSM	Yakima River at Selah Moxee diversion	NS	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
YKHB	Yakima River at Harrison Bridge	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc	2Xc
CLPOTW	Cle Elum POTW	NS	NS	NS	NS	NS	NS	NS	NS	24c	NS	24c	24c	24c	24c	24c	24c	24c	24c	NS
ELPOTW	Ellensburg POTW	NS	NS	NS	NS	NS	NS	NS	NS	24c	NS	24c	24c	24c	24c	24c	24c	24c	24c	NS
TEAU	Teanaway River at Red Bridge Rd	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
NANU	Naneum Creek at Naneum Road	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
MANU	Manastash Creek at Manastash Road	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
BIGC	Big Creek at I-90	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB
LITC	Little Creek at Hundley Rd.	1Xc	ICE	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
CLE	Cle Elum River at Bullfrog Rd bridge	2Xc	2Xc	2Xc	2Xc	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
CRY	Crystal Creek near mouth	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	DRY	DRY	DRY	DRY	DRY	LB	LB	DRY
TEAL	Teanaway River at Lambert Road	2Xc	2Xc	2Xc	2Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
SWAC	Swauk Creek at mouth	RB	RB	RB	RB	RB	RB	RB	RB	RB	1Xc	RB	LB	RB	1Xc	RB	1Xc	1Xc	LB	RB
TANC	Taneum Creek at mouth	LB	LB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB	RB
DRY	Dry Creek at Hwy 10	1Xc	1Xc	1Xc	1Xc	1Xc														
DRYM	Dry Creek at Mouth (new location)						LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
PACK	Packwood Ditch at S. Thorp Hwy	NS	NS	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
MANL	Manastash Creek at Brown Rd	NS	NS	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
REEC	Reecer Creek in Irene Rinehart Park	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
FOG	Sorenson/Fogarty at Riverbottom Road	NS	NS	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
WLTH	Wilson Creek at Thrall Road	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
CHTH	Cherry Creek at Thrall Road	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
WILC	Wilson Creek at Hwy 821	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB
UMT	Umtanum Creek	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc	1Xc
WEN	Wenas Creek above mouth	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	DRY	DRY	LB	LB	LB	NS

Table A2. Sample collection method details for sites that were re-sampled for TSS and turbidity with a different sampling method (see abbreviation key below).

Study Location ID	Location Name	Feb 25-27	Mar 11-13	Mar 25-27	Apr 8-10	Apr 22-24	May 6-8	May 20-22	Jun 3-5	Jun 17-19	Jun 30-Jul 2	Jul 15-17	Jul 29-31	Aug 12-14	Aug 26-28	Sep 9-11	Sep 23-25	Oct 7-9	Oct 21-23	Nov 4-6
TEAL	Teanaway River at Lambert Road	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS
PACK	Packwood Canal at S. Thorp Hwy	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	3Xdc	NRS	NRS	NRS	NRS	NRS
MANL	Manastash Creek at Brown Rd	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS
FOG	Sorenson/Fogarty at Riverbottom Road	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	NRS
CHTH	Cherry Creek at Thrall Road	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	3Xdc	NRS
YKUM	Yakima River at Umtanum Creek Bridge	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	3Xdc	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS
WEN	Wenas Creek at mouth	NRS	NRS	NRS	NRS	NRS	NRS	NRS	3Xdc	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS	NRS

Abbreviation Key for Tables A1 and A2:

1Xc = 1-point sample centered on the thalweg

2Xc = 2-point sample composite (2 grab sample composite)

3Xc = 3-point sample composite (3 grab sample composite)

3Xc-d = 3-point depth-integrated sample composite (DH-76 sampler or hand-held DH-48 sampler)

NS = not sampled

ICE = not sampled (frozen)

DRY = not sampled (dry or not enough water to sample)

RB = right bank sample

LB = left bank sample

[blank] = site not visited during survey

NRS = not re-sampled

Laboratory turbidity results over time (in terms of week number, where week number is the number of weeks since the start of calendar year 2019) are presented in Figures A1 and A2; week numbers are shown by sampling dates in Table A3 as a reference for these figures.

Table A3. Sampling dates (2019) expressed in terms of week number, where week number is the number of weeks since the start of calendar year 2019.

Sample Dates (2019)	Feb 25-27	Mar 11-13	Mar 25-27	Apr 8-10	Apr 22-24	May 6-8	May 20-22	Jun 3-5	Jun 17-19	Jun 30-Jul 2	Jul 15-17	Jul 29-31	Aug 12-14	Aug 26-28	Sep 9-11	Sep 23-25	Oct 7-9	Oct 21-23	Nov 4-6
Week #	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45

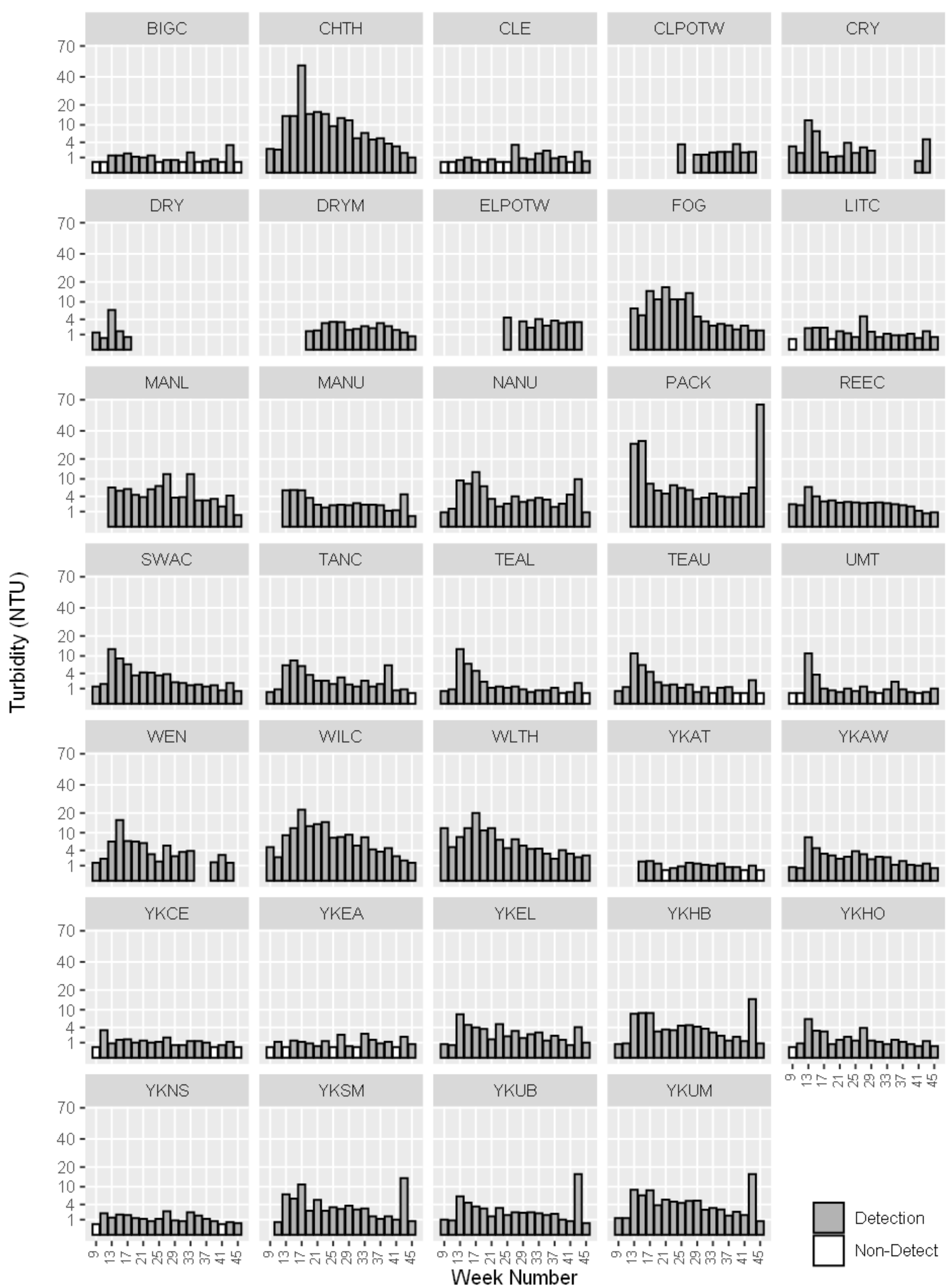

Figure A1. 2019 Turbidity water sample analysis results (NTU) vs. week number.

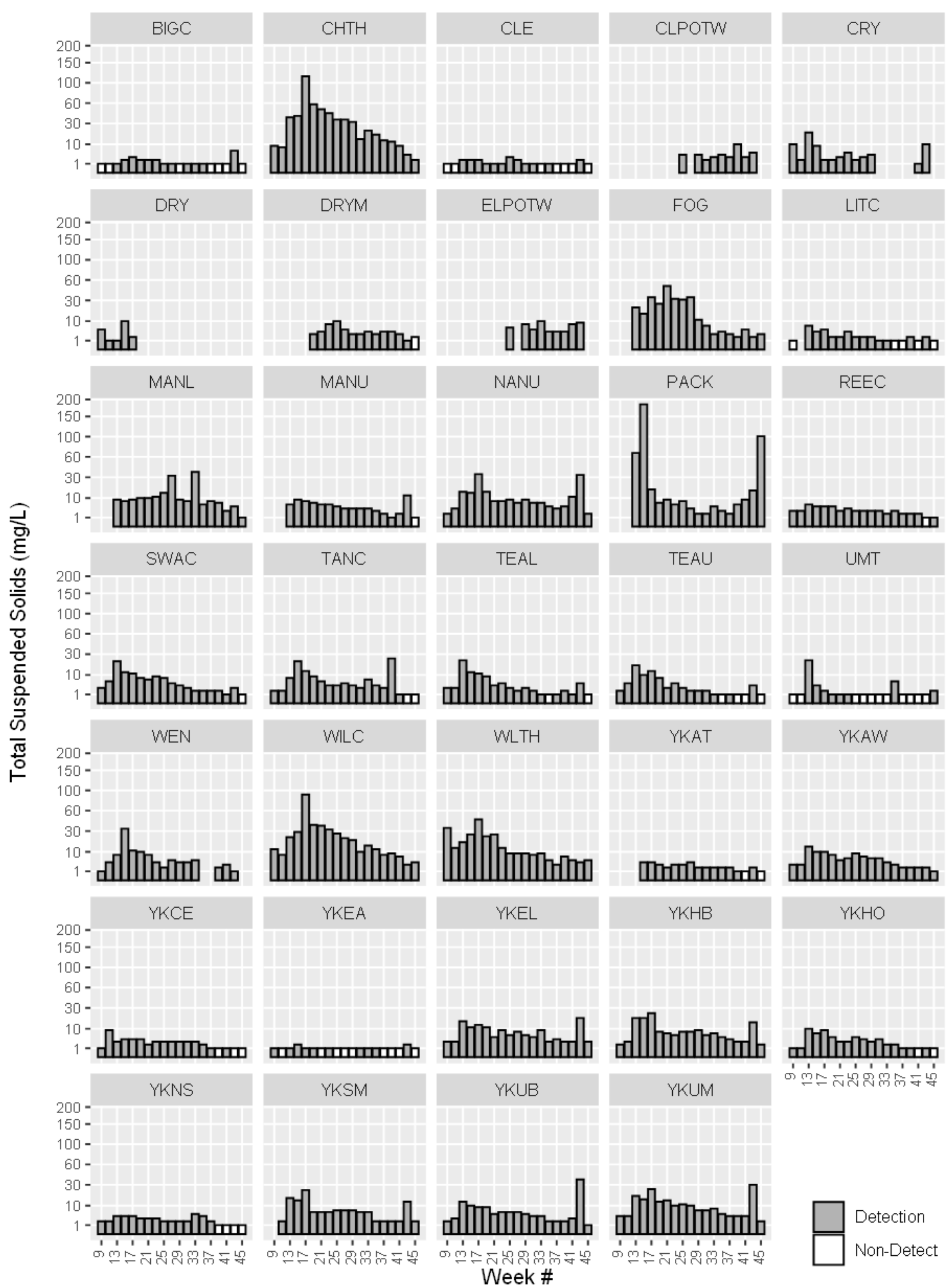

Figure A2. 2019 total suspended solids (TSS) water sample analysis results (mg/L) vs. week number.

Data qualifiers for laboratory data are listed in Table A4, and laboratory results for water samples are presented in Tables A5-A6.

Table A4. Data qualifiers for laboratory results.

Qualifier	Qualifier Description
U	The analyte was not detected at or above the reported result.
UJ	The analyte was not detected at or above the reported estimated result.
J	The analyte was positively identified. The associated numerical result is an estimate.

Table A5. 2019 Turbidity sample results (NTU) and qualifiers.

Site	Feb 25-27 (week-09)	Mar 11-13 (week-11)	Mar 25-27 (week-13)	Apr 8-10 (week-15)	Apr 22-24 (week-17)	May 6-8 (week-19)	May 20-22 (week-21)	Jun 3-5 (week-23)	Jun 17-19 (week-25)	Jun 30-Jul 2 (week-27)	Jul 15-17 (week-29)	Jul 29-31 (week-31)	Aug 12-14 (week-33)	Aug 26-28 (week-35)	Sep 9-11 (week-37)	Sep 23-25 (week-39)	Oct 7-9 (week-41)	Oct 21-23 (week-43)	Nov 4-6 (week-45)
BIGC	0.5 U	0.5 U	1.3	1.3	1.6	1.1	1	1.3	0.5 U	0.7	0.7	0.5 U	1.8	0.5 U	0.6	0.8	0.5 U	3.3	0.5 UJ
CHTH	2.5	2.3	14	14	50	15	16	15	9.4	13	12	5.2	6.9	4.8	5.2	3.7	3	1.7	1
CLE	0.5 U	0.5 U	0.7	1	0.7	0.5 U	0.8	0.5 U	0.5 U	3.4	0.9	0.8	1.6	2.1	0.9	1.1	0.5 U	1.9	0.6 J
CLPOTW									3.5		1.4	1.4	1.8	1.9	1.9	3.6	1.8	1.9	
CRY	3	1.7	12	7.5	1.8	1.1	1.2	3.9	1.7	2.8	2.1						0.6	4.9	
DRY	1.3	0.6	6.9	1.5	0.7														
DRYM						1.5	1.6	3.1	3.4	3.3	1.7	1.9	2.4	2	3.1	2.4	1.7	1.3	0.8
ELPOTW									4.5		3.5	2.1	4.1	2.5	3.7	3.1	3.3	3.3	
FOG			7.4	5.2	15	11	17	11	11	14	4.8	3.5	2.5	2.9	2.6	1.8	2.5	1.6	1.6 J
LITC	0.5 U		2	2.1	2.1	0.5 U	1.5	1.2	0.7	4.9	1.4	0.7	1.1	0.9	0.9	1.1	0.6	1.5	0.7
MANL			6.7	5.6	6.2	4.4	3.8	6.1	7.2	12	3.7	3.8	12	3	3	3.4	1.8	4.2	0.6 J
MANU			5.8	5.9	5.8	3.6	2.1	1.6	2	2.1	2	2.4	2.1	2.1	2	1.1	1.2	4.6	0.5 J
NU	0.9	1.4	9.3	8.1	13	7.1	3.4	1.8	2.3	4	2.7	3.1	3.6	3.2	1.7	2.3	4.5	9.9	0.9 J
PACK			30	32	8.1	5.7	4.8	7.5	6.5	5.9	3.4	3.7	4.8	4	3.8	3.8	4.8	6.7	65 J
REEC	2.2	2	6.9	4	2.8	3	2.5	2.7	2.6	2.4	2.5	2.6	2.4	2.2	2	1.8	1.1	0.8	0.9 J
SWAC	1.3	1.7	13	8.9	6.8	3.5	4.3	4.2	3.5	3.8	2	1.9	1.5	1.6	1.3	1.5	0.8	1.9	0.7
TANC	0.6	0.9	6.4	8.1	6.2	3.6	2.3	2.3	1.7	3	1.6	1.3	2.3	1.3	1.7	6.4	0.8	0.9	0.5 UJ
TEAL	0.7	0.9	13	7	4.7	2.1	1.1	1.3	1.1	1.3	0.9	0.6	0.8	0.8	1.1	0.5 U	0.6	1.9	0.5 U
TEAU	0.7	1.2	11	6.5	4.4	2	1.5	1.6	1.1	1.6	0.6	1.2	0.5 U	1.1	1.2	0.5 U	0.5 U	2.4	0.5 U
UMT	0.5 U	0.5 U	11	3.7	1	0.8	0.6	1	0.7	1.3	0.6	0.5 U	0.9	2.1	0.9	0.6	0.5 U	0.6	1 J
WEN	1.4	2.1	6.7	16	6.9	6.7	6.2	3.1	1.6	5.4	2.6	3.6	3.9			1.5	2.9	1.4	
WILC	4.9	2.4	9	12	22	13	14	15	8	8.3	9.2	5.4	8.2	4.3	3.7	4.6	2.6	1.8	1.4
WLTH	12	4.9	8.3	12	20	11	12	7.3	4.6	7.5	5.4	4.4	4.5	3.2	2.1	4.1	3.2	2.4	2.8
YKAT				1.6	1.7	1.3	0.5 U	0.7	0.9	1.4	1.3	1.1	1	1.3	0.8	0.8	0.5 U	1	0.5 U
YKAW	0.8	0.7	8.2	4.6	3.2	2.8	2.1	2.5	3.8	3.1	2	2.5	2.4	1.1	1.7	1.1	1	1.3	0.7
YKCE	0.5 U	3.3	0.9	1.4	1.5	1	1.3	1	1.1	1.8	0.7	0.7	1.2	1.2	1	0.5 U	0.7	1.1	0.5 UJ
YKEA	0.5 U	1.1	0.5 U	1.3	1.1	0.9	0.6	1.2	0.5 U	2.3	0.6	0.5 U	2.5	1.4	0.9	1.1	0.5 U	1.9	0.8 J
YKEL	0.8	0.7	8.2	4.7	4	3.6	1.5	4.9	2	3.1	1.7	2.4	2.8	1.3	2.1	1.4	0.7	4.1	1 J
YKHB	0.8	0.9	8.4	8.7	8.7	3	3.5	3.3	4.5	4.6	4.2	3.7	2.8	2.1	1.3	1.9	1.2	15	0.9 J
YKHO	0.5 U	0.9	6.5	3.2	3	0.8	1.4	1.9	1.3	3.9	1.3	1.1	0.8	1.4	1.1	0.8	0.6	1.2	0.6
YKNS	0.5 U	2	1.3	1.8	1.7	1.2	1.1	0.8	1.1	2.4	0.9	0.8	2.2	1.6	1.1	0.8	0.5 U	0.7	0.6 J
YKSM		0.7	7.1	5.7	11	2.5	5.3	2.5	3.3	2.9	3.7	2.8	3	1.5	1.1	1.5	1	14	0.8
YKUB	1	0.9	6.4	4.5	3.5	3	1.5	3.1	1.7	2.2	2.1	2.2	2	1.7	1.9	1	0.8	16	0.6
YKUM	1.2	1.2	8.8	6.8	8.6	3.8	5.4	4.8	4.4	5	5.1	2.7	3.1	2.8	1.6	2.3	1.7	16	0.8

Blank cells indicates no samples collected at that location/time.

Table A6. 2019 total suspended solids (TSS) sample results (mg/L) and qualifiers.

Site	Feb 25-27 (week-09)	Mar 11-13 (week-11)	Mar 25-27 (week-13)	Apr 8-10 (week-15)	Apr 22-24 (week-17)	May 6-8 (week-19)	May 20-22 (week-21)	Jun 3-5 (week-23)	Jun 17-19 (week-25)	Jun 30-Jul 2 (week-27)	Jul 15-17 (week-29)	Jul 29-31 (week-31)	Aug 12-14 (week-33)	Aug 26-28 (week-35)	Sep 9-11 (week-37)	Sep 23-25 (week-39)	Oct 7-9 (week-41)	Oct 21-23 (week-43)	Nov 4-6 (week-45)
BIGC	1 U	1 U	1	2	3	2	2	2	1	1	1 U	1	1	1	1 U	1 U	1 U	6	1 U
CHTH	9	8	38	40	115	58	50	44	35	35	32	14	22	18	13	12	9	4	2
CLE	1 U	1 U	2	2	2	1	1	1	3	2	1	1	1 U	1	1 U	1 U	1 U	2	1 U
CLPOTW									4		4	2	3	4	3	10	3	5	
CRY	10	2	20	9	2	2	3	5	2	3	4						1	10	
DRY	5	1	1	10	2														
DRYM						3	4	8	10	5	3	3	4	3	4	4	3	1	2 U
ELPOTW									6		8	5	10	4	4	4	8	9	
FOG			22	16	34	26	50	32	31	34	11	7	3	4	3	2	5	2	3
LITC	1 U		7	4	5	2	2	4	2	2	2	1	1	1 U	1 U	2	1 U	2	1 U
MANL			9	8	9	10	10	11	14	32	9	8	37	6	8	7	3	5	1
MAN U			6	9	8	7	6	6	5	4	4	4	4	3	2	1	2	12	1 U
NAN U	2	4	15	14	34	15	8	8	9	7	9	7	7	5	4	5	11	33	2
PACK			67	185 J	17	7	9	6	8	4	2	2	5	3	2	6	9	16	101
REEC	3	3	6	5	5	5	3	4	3	3	3	3	2	3	2	2	2	1 U	1
SWAC	3	6	22	12	11 J	8	7	9	8	5	4	3	2	2	2	2	1	3	1 U
TANC	2	2	8	22	13	9	6	4	4	5	4	3	7	4	3	25	1	1 U	1 U
TEAL	3	3	23 J	12	11	9	4	5	3	2	3	2	1	1 U	1	2	1	5	1 U
TEA U	2	5	18	10	13	8	3	5	3	2	2	2	1	1 U	1	1 U	1 U	4	1 U
UMT	1 U	1 U	23	4	2	1	1	1	1 U	1 U	1 U	1 U	1 U	6	1 U	1 U	1 U	1 U	2
WEN	1	4	8	33	11	10	8	4	2	5	4	4	5			2	3	1	
WILC	12	8	23	29	91	38	37	32	27	22	20	10	15	12	8	9	7	3	4
WLTH	34	13	18	26	46	24	26	13	9	9	9	8	9	5	3	7	5	4	5 J
YKAT				4	4	3	2	3	3	4	2	2	2	2	2	1	1 U	2	1 U
YKAW	3	3	14	10	10	8	5	6	9	7	6	6	4	3	2	2	2	2	1
YKCE	1	9	3	4	4	4	2	3	3	3	3	3	3	2	1	1 U	1	1 U	1 U
YKEA	1	1 U	1	2	1	1	1 U	1	1 U	1 U	1 U	1	1	1	1 U	1 U	1 U	2	1 U
YKEL	3	3	16	11	13	11	5	9	6	8	6	5	9	3	4	3	3	19	3
YKHB	2	3	19	19	24	8	7	6	8	8	9	6	7	5	4	3	3	15	2
YKHO	1	1	10	7	9	5	3	3	5	4	3	4	2	2	1	1	1 U	1	1 U
YKNS	2	2	4	4	4	3	3	3	2	2	2	2	5	4	2	1 U	1 U	1 U	1 U
YKSM		2	16	14	24	6	6	6	7	7	7	6	6	2	2	2	2	13	2
YK UB	2	3	13	10	9	9	5	6	6	6	5	4	4	2	2	2	3	37	1
YK UM	4	4	18	15	25	13	14	10	11	10	7	7	8	5	4	4	4	30	2

Blank cells indicates no samples collected at that location/time.

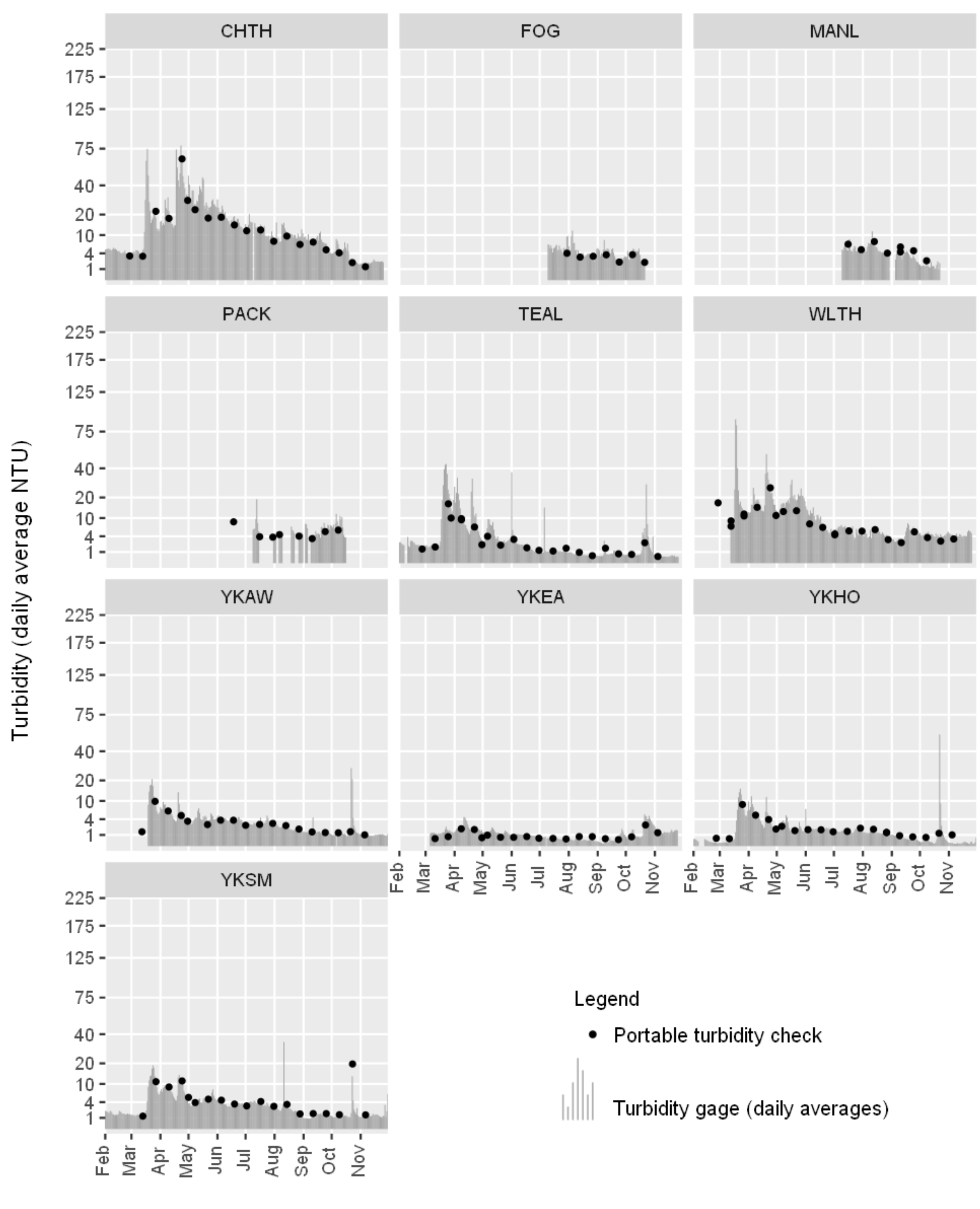

Figure A3. 2019 continuous turbidity gage results (daily average) plus field checks using portable turbidity meter.

Figure A4. 2019 gage turbidity (daily average with shading to indicate 30-day average) versus laboratory sample results.

Ecology corrected continuous turbidity gage results (hourly) based on post-study factory calibration measurements (Figure A6 and Table A7). No corrections were applied at three sites because they had incomplete records and no post-calibration data and were therefore qualified as estimates in EIM: Packwood Ditch (PACK), Sorenson/Fogarty (FOG) or Manastash Creek at Brown Road (MANL). Turbidity gage data at these three sites were not relied upon for any conclusions in the report body.

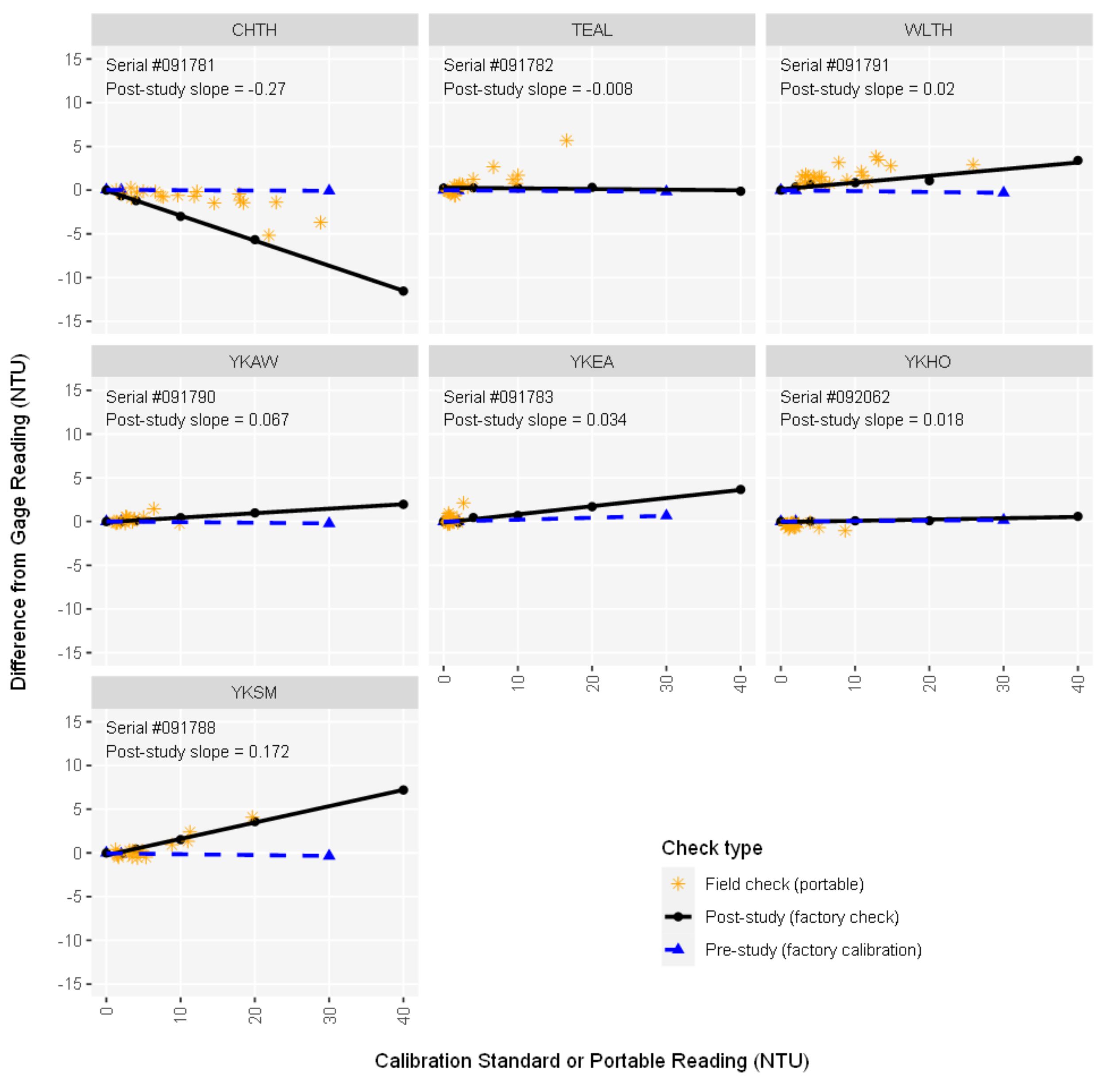

Figure A5. Difference and slope between hourly turbidity gage readings versus both factory calibration checks and portable turbidity gage checks.

Figure A5 compares un-corrected turbidity gage data against factory calibration and field QC checks.

Table A7. Correction slope, average and largest daily corrections applied to 2019 gage turbidity.

Site	Correction slope	Average daily correction amount (NTU)	Largest daily correction amount (NTU)
CHTH	-0.271	3.0	16.7
TEAL	-0.008	0.0	1.8
WLTH	0.02	-0.2	-1.8
YKAW	0.067	-0.2	-2.0
YKEA	0.034	0.0	-0.2
YKHO	0.018	0.0	-1.0
YKSM	0.172	-0.7	-7.0

Corrected value = (Uncorrected value) - slope * (Uncorrected value)

Figure A7 below presents linear regressions for converting hourly turbidity gaging results (NTU) to TSS concentrations (mg/L). Ecology calculated these regressions based on samples collected from the same location as the turbidity gage, with the following two exceptions:

- Wilson Creek near mouth (WILC): TSS samples collected at this site were regressed using turbidity time-series which was calculated based on flow and turbidity gaging at the two upstream sites: Wilson Creek at Thrall Rd. (WLTH) and Cherry Creek at Thrall Rd. (CHTH). This calculation used a mass balance approach (flow-weighted mass balance of turbidity), which is justified based on the strong relationship in 2019 between turbidity and suspended sediment at all three of these sites.
- Yakima River Harrison bridge (YKHB): TSS samples collected at this site were regressed using turbidity gaging data collected approximately 2.4 miles upstream at Yakima River at Selah-Moxee (YKSM). Ecology generally considered YKSM as a proxy site for YKHB. The tributary Wenas Creek (WEN), which dried up in early July, enters the Yakima River between these two sites.

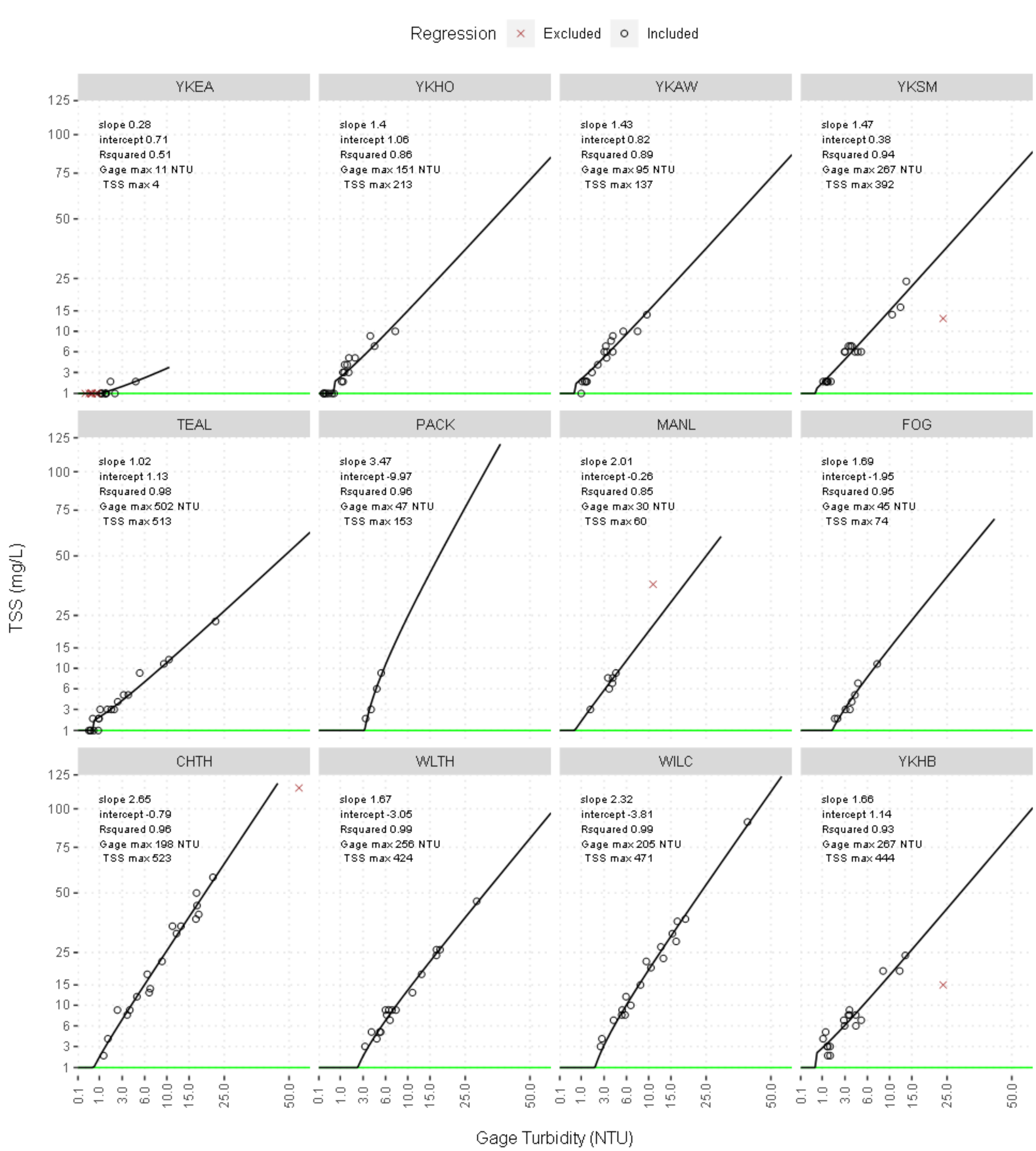

Figure A6. Linear regression for converting gage turbidity (NTU) into TSS concentration (mg/L) using 2019 data.

Lines appear curved in this figure because of square-root transformed axes (to show the full range of data). Some data points were excluded from the regression fit due to their strong influence on the linear fit. Ecology focused on finding the best fit day-in/day-out for converting turbidity gage data to TSS. Horizontal line at 1 NTU shows the laboratory reporting limit.

Flow and load balances are shown in Tables A8-A11 below. Non-detect values were substituted at one-half of the reporting limit for all loading calculations. Calculation methods for these tables are described below:

For the "Beales" calculation method above, Ecology used the function "beale.ratio" from the RiverLoad package version 1.0.2 in R statistical software version 3.6.1 (R Core Team, 2019).

For the "Interpolation" and "Gage" calculation methods (described in the main report), Ecology calculated loads as follows:

1. Calculate daily average of hourly TSS concentrations (mg/L) using two different methods:
   a. linear interpolation between TSS sample results ("Interpolation" method)
   b. linear regression of gage turbidity versus TSS sample results ("Gage" method)
2. Calculate daily averages for flow (cfs).
3. Calculate daily volumes of water (L and acre-ft) based on daily flow, using the following conversion factors:
   a. volume (L) = daily average flow (ft^3/s)*28.32 (L/ft^3)*24(h/day)*3600(s/h)*1day
   b. volume (acre-ft) = volume (ft^3) / 43560 (ft^3/acre-ft)
4. Calculate daily load in tons by multiplying daily volumes multiplied by estimated daily TSS concentrations (calculated in Step 1 above), using the following conversion factors:
   a. load (tons) = TSS (mg/L) * volume (L) * 10^{-6} (kg/mg) * 0.001102 (tons/kg)
5. Sum volumes and loads (tons) by month and season.
6. Calculate average monthly or seasonal flow rate (cfs) by dividing volumes (ft^3) by the number of seconds in the month or season.
7. Calculate average monthly or seasonal load (tons/day) by dividing load sums by the number of days in the month or season.
8. Compare the full season (Apr-Oct) loads (tons/day) against TMDL loading targets.

Daily TSS loading was calculated for the Yakima River at Umtanum Creek (YKUM), however no turbidity gage was present at this site. Gage turbidity was calculated at YKUM based on a mass balance calculation by adding the two upstream sources where data were available:

$$\text{TSS\_YKUM}^{3} = \frac{\text{Flow\_YKAW}*\text{TSS\_YKAW} + \text{Flow\_WILC}*\text{TSS\_WILC}}{\text{Flow\_YKAW}+\text{Flow\_WILC}}$$

Loads were then calculated based on this calculated daily average TSS concentration at YKUM multiplied by flow at YKUM (which was based on the gaged flow at YKEL plus tributaries).

[3] Turbine ditch and Umtanum Creek were not included in this calculation. This is because no measurements of TSS were made in Turbine Ditch and also because Umtanum Creek enters the Yakima River on the right bank at the footbridge sampling location and is therefore not yet mixed into the Yakima River.

Table A8. Flow (cfs) averages by month and season for 2019.

Site	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Apr-Jun	Jul-Oct
KTCW	-197	-811	-878	-1030	-1040	-863	-285	-729	-631	-803
YKEA	491	306	213	214	984	334	233	397	336	442
SILV	48	36.2	7.29	0	0	0	4.09	13.6	30.6	1.03
TUCK	14.4	9.05	4.97	3.72	3.5	3.52	3.61	6.09	9.47	3.59
BIGC	139	108	29.3	11.3	9.95	9.96	22.2	46.9	92.3	13.4
LITC	48	36.2	16.1	12.5	10.3	10.2	11.2	20.6	33.5	11.1
YKNS	740	525	305	285	1020	391	321	512	523	504
TILM	14.4	9.05	1.94	1.89	4	4.02	2.04	5.32	8.47	2.98
CLE	442	410	1820	2950	2070	355	229	1190	887	1410
YKCE	NA	NA	NA	3250	2950	752	591	NA	NA	1900
CRY	10.3	1.31	0	0	0	0	0	1.64	3.85	0
CLPOTW	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57
YKAT	NA	NA	NA	3250	2950	752	591	NA	NA	1900
TEAU	878	535	136	30.6	12.6	20.3	129	247	516	48.4
TEAL	878	535	136	30.6	12.6	20.3	129	247	516	48.4
KESW	0	0	0	0	0	222	108	46.8	0	81.5
YKHO	2340	1570	2250	3220	2970	1090	890	2050	2050	2050
SWAC	138	65.6	16.9	7.72	3.34	3.44	9.26	34.7	73.5	5.96
WESW	-22.9	-89.4	-81.6	-93.2	-75.8	-58	-18.2	-62.8	-64.9	-61.3
TANC	102	82.7	20	13.6	18.6	47.2	29.7	44.6	68.3	27.1
ETCW	-37.2	-108	-103	-113	-121	-97	-38.9	-88.4	-82.9	-92.5
CIDM	-10.7	-90.4	-89	-109	-95.7	-89.4	-38.3	-74.8	-63.7	-83.1
CIDS	-0.392	-2.56	-2.69	-2.71	-2.42	-2.07	-1.07	-1.99	-1.89	-2.07
CIDC	-0.291	-1.74	-1.34	-1.58	-1.66	-1.31	-0.735	-1.24	-1.13	-1.32
DRYM	14.6	17.3	17.4	21.2	19.9	20.1	14.5	17.9	16.5	18.9
PACD	-23.5	-23.5	-23.5	-21.8	-21	-21	-7.45	-20.2	-23.5	-17.8
PACK	33	30.1	24.2	24.3	22.4	16.8	3.69	22	29.1	16.8
YKEL	2650	1530	2190	3110	2810	911	825	2010	2120	1920
MANL	114	93.9	21.5	22.8	29.6	34.9	17.7	47.6	76.6	26.2
REEC	34.9	31.2	28.2	28	23	24	14.3	26.2	31.4	22.3
YKUB	2800	1660	2240	3160	2870	969	857	2080	2220	1970
ELPOTW	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
FOG	15	17	18.6	22.3	27.2	21.1	13.8	19.3	16.8	21.1
YKAW	2810	1670	2260	3180	2890	990	870	2100	2240	1990
WLTH	188	205	122	102	124	121	71.9	133	172	105
CHTH	171	226	235	200	277	283	159	222	211	229
WILC	360	431	357	303	401	404	231	355	383	334
TURB	3.68	5.7	5.25	4.31	4.66	4.31	0	3.98	4.89	3.31
UMT	23.6	3.58	1.2	0.9	0.9	0.9	0.9	4.51	9.4	0.9
YKUM	3150	2150	2600	3440	3320	1470	1130	2460	2630	2350
RZCW	-1360	-663	-1520	-1860	-1840	-824	-509	-1220	-1180	-1260
YKSM	-47.1	-74.5	-75.9	-77.5	-73	-63.5	-22.2	-61.9	-65.9	-59
WEN	188	27.3	3.28	0.799	0	1.22	2.18	31.4	72.3	1.05
YKHB	1930	1440	1010	1500	1410	581	600	1210	1460	1030

NA = missing value (not available)

All sites with negative flows are diversions from the river. Site KTCW is the diversion from Lake Easton for the Kittitas Canal.

Table A9. TSS Load (tons/day) for 2019, calculated by Interpolation method.

Site	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Apr-Jun	Jul-Oct
KTCW	-0.576	-1.69	-1.53	-1.82	-2.75	-1.28	-0.624	-1.47	-1.27	-1.62
YKEA	2	0.636	0.381	0.381	2.6	0.546	0.811	1.05	1	1.09
SILV	0.313	0.199	0.0331	0	0	0	0.061	0.0863	0.182	0.0154
TUCK	0.094	0.0499	0.0179	0.00777	0.00928	0.00516	0.0288	0.0303	0.0539	0.0128
BIGC	0.905	0.593	0.116	0.0233	0.0264	0.0144	0.229	0.271	0.539	0.0737
LITC	0.577	0.229	0.115	0.0581	0.0227	0.0316	0.0377	0.152	0.306	0.0376
YKNS	7.86	4.28	1.94	1.56	11.5	2.02	0.433	4.23	4.69	3.89
TILM	0.094	0.0499	0.00799	0.00429	0.0106	0.00589	0.00868	0.0258	0.0506	0.00738
CLE	2.29	1.13	11.6	9.6	4.17	0.58	0.738	4.29	4.96	3.8
YKCE	NA	NA	NA	26.3	20.9	2.12	1.08	NA	NA	12.7
CRY	0.234	0.00939	0	0	0	0	0	0.0341	0.0803	0
CLPOTW	NA	NA	0.0601	0.051	0.0483	0.0901	0.0672	0.0452	NA	0.0639
YKAT	NA	NA	NA	21.3	15.9	3.38	1.97	NA	NA	10.7
TEAU	27.8	8.38	1.41	0.165	0.0337	0.0373	1.01	5.49	12.5	0.315
TEAL	29.1	9.53	1.42	0.205	0.0337	0.0816	1.28	5.89	13.3	0.402
KESW	0	0	0	0	0	0.305	0.204	0.0722	0	0.126
YKHO	50.2	16.8	26	30.6	18.6	3.31	1.82	21	30.8	13.7
SWAC	4.52	1.38	0.362	0.085	0.0197	0.0178	0.0509	0.91	2.08	0.0435
WESW	-0.471	-0.976	-0.907	-0.884	-0.477	-0.163	-0.0313	-0.559	-0.787	-0.391
TANC	4.34	1.68	0.229	0.151	0.244	1.79	0.289	1.23	2.08	0.609
ETCW	-0.804	-1.16	-1.16	-1.07	-0.745	-0.279	-0.0727	-0.758	-1.05	-0.545
CIDM	-0.212	-0.98	-0.978	-1.03	-0.591	-0.26	-0.0651	-0.59	-0.726	-0.489
CIDS	-0.00771	-0.0276	-0.0299	-0.0257	-0.0151	-0.0059	-0.00183	-0.0163	-0.0218	-0.0122
CIDC	-0.00575	-0.0186	-0.015	-0.015	-0.0103	-0.00378	-0.00128	-0.01	-0.0132	-0.00763
DRYM	0.227	0.195	0.382	0.203	0.19	0.209	0.087	0.213	0.267	0.172
PACD	-0.501	-0.251	-0.262	-0.207	-0.129	-0.0598	-0.0149	-0.203	-0.337	-0.103
PACK	10.2	0.668	0.426	0.167	0.231	0.177	0.0928	1.68	3.72	0.167
YKEL	87.5	33.9	42.4	52.1	47.2	8.59	24.6	42.3	54.4	33.3
MANL	2.65	2.55	0.931	1.06	1.78	0.663	0.188	1.4	2.05	0.924
REEC	0.482	0.325	0.255	0.227	0.155	0.138	0.0578	0.233	0.354	0.144
YKUB	73.8	30.8	36.2	42.4	25.9	5.32	45.3	37.1	46.8	29.9
ELPOTW	NA	NA	0.208	0.229	0.227	0.143	0.28	0.156	NA	0.22
FOG	1.02	1.86	1.62	1.01	0.296	0.16	0.137	0.87	1.5	0.402
YKAW	77.8	29.5	47.2	53.6	31.5	5.83	4.39	35.6	51.3	24
WLTH	17.7	13.5	3.6	2.42	2.49	1.62	0.942	6.02	11.6	1.87
CHTH	37.2	32.4	24.5	15.8	14.3	10.1	3.15	19.6	31.4	10.9
WILC	58.3	44.4	27.4	15.1	14.1	9.72	3.56	24.6	43.4	10.6
TURB	0.0498	0.0619	0.0458	0.0348	0.0312	0.0243	0	0.0353	0.0526	0.0226
UMT	0.471	0.0106	0.00241	0.00121	0.00556	0.00295	0.00152	0.0695	0.16	0.00281
YKUM	164	79.4	74	72.7	61.2	16.6	47.2	73.4	105	49.7
RZCW	-70.2	-24.7	-43.2	-39.3	-33.6	-9.4	-22.7	-34.6	-45.8	-26.4
YKSM	-2.35	-1.41	-1.35	-1.41	-0.915	-0.343	-0.167	-1.13	-1.7	-0.712
WEN	11.9	0.65	0.0362	0.00927	0	0.00746	0.0114	1.77	4.15	0.00704
YKHB	107	31.1	20.3	32.4	23.6	5.9	13	33.2	52.7	18.8

NA = missing value (not available)

Site KTCW is the diversion from Lake Easton for the Kittitas Canal.

Table A10. TSS load (tons/day) for 2019, calculated by Beale's ratio method.

Site	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Apr-Jun	Jul-Oct
KTCW	-0.53	-1.64	-1.54	-2.09	-2.8	-1.16	-0.464	-1.43	-1.19	-1.6
YKEA	2.12	0.642	0.387	0.441	2.67	0.453	1.07	1.17	1.08	1.26
SILV	0.597	0.197	0.0732	0	0	0	0.0223	0.119	0.286	0.00551
TUCK	0.182	0.0501	0.0359	0.0157	0.00727	0.0122	0.0141	0.0448	0.0865	0.0121
BIGC	0.974	0.591	0.135	0.0254	0.0271	0.0136	0.327	0.318	0.562	0.138
LITC	0.605	0.2	0.122	0.053	0.0218	0.0358	0.0447	0.153	0.298	0.0386
YKNS	8.13	4.32	1.99	1.56	12.5	1.63	0.441	4.46	4.69	4.39
TILM	0.183	0.0504	0.0178	0.00564	0.00835	0.014	0.00557	0.0401	0.0811	0.00797
CLE	2.38	1.11	11.5	7.95	3.96	0.478	0.811	4.46	5.2	3.38
YKCE	NA	NA	19.5	26.6	19.8	1.74	1.17	NA	NA	12.8
CRY	0.229	0.00897	0	0	0	0	0	0.0333	0.0784	0
CLPOTW	NA	NA	0.0601	0.0451	0.0509	0.101	0.0601	0.0631	NA	0.0633
YKAT	NA	NA	NA	17.6	15.5	3.46	2.11	NA	NA	9.79
TEAU	28.2	8.95	1.56	0.171	0.0287	0.0393	1.25	5.71	12.5	0.37
TEAL	28	10.4	1.56	0.226	0.0286	0.0909	1.58	5.93	12.9	0.479
KESW	0	0	0	0	0	0.3	0.146	0.0629	0	0.109
YKHO	51.4	17.4	25.8	30.7	16.1	2.95	1.82	21.8	31.2	13.4
SWAC	4.4	1.39	0.367	0.0773	0.0185	0.019	0.0631	0.901	2	0.0427
WESW	0	-1.04	-0.891	-0.879	-0.412	-0.158	-0.0247	-0.525	-0.717	-0.362
TANC	4.65	1.72	0.221	0.161	0.246	2.37	0.0688	1.34	2.21	0.712
ETCW	-0.905	-1.19	-1.14	-1.07	-0.656	-0.262	-0.0602	-0.791	-1.06	-0.525
CIDM	0	-0.994	-0.917	-1.05	-0.517	-0.242	-0.0517	-0.567	-0.663	-0.467
CIDS	0	-0.0281	-0.029	-0.0255	-0.0131	-0.0056	-0.00145	-0.0156	-0.0202	-0.0113
CIDC	0	-0.0189	-0.0144	-0.015	-0.00896	-0.00354	-0.000994	-0.00967	-0.012	-0.00732
DRYM	0.234	0.166	0.42	0.21	0.195	0.217	0.0877	0.215	0.269	0.18
PACD	-0.509	-0.254	-0.254	-0.207	-0.114	-0.0568	-0.0151	-0.202	-0.322	-0.097
PACK	13.2	0.7	0.494	0.198	0.261	0.2	0.0934	1.9	4.82	0.169
YKEL	86.3	34.6	40.2	52.9	47.8	8.87	31.8	43.9	55.8	36.4
MANL	2.6	2.5	0.695	1.27	1.94	0.684	0.176	1.41	1.92	1.05
REEC	0.472	0.323	0.27	0.227	0.15	0.13	0.0648	0.232	0.349	0.146
YKUB	71.1	32	36.1	42.3	23.9	5.21	61.3	41	47.9	36.1
ELPOTW	NA	NA	0.2	0.217	0.226	0.138	0.284	0.214	NA	0.215
FOG	1.08	2.06	1.59	1.14	0.253	0.143	0.159	0.934	1.57	0.538
YKAW	76.3	30.1	49.9	54.6	27.9	5.38	4.73	36.1	52.7	25.5
WLTH	20.1	14.3	3.62	2.45	2.47	1.76	0.917	6.57	13	1.9
CHTH	43.1	31.9	24.9	15	14.9	9.57	3.28	21.4	35.1	11.2
WILC	69.3	44	28.6	14.6	14.8	9.44	3.63	27.3	49.7	11
TURB	0.0161	0.0117	0.00814	0.00829	0.0125	0.00578	0	0.00848	0.0113	0.00632
UMT	0.25	0.0106	0.0029	0.00133	0.00865	0.00133	0.00133	0.037	0.0841	0.00267
YKUM	174	78.4	75	74	59.6	15.9	63.1	79	114	56.2
RZCW	-73.5	-24.1	-43.7	-39.8	-32.1	-8.87	-31.3	-37.6	-49.2	-30.6
YKSM	-2.58	-1.2	-1.33	-1.39	-0.788	-0.342	-0.12	-1.11	-1.69	-0.71
WEN	15.4	0.724	0.0371	0.01	0	0.00711	0.0128	2.3	5.38	0.00673
YKHB	115	29.6	20.2	31.4	24.1	5.67	16.3	35.3	58	19.7

NA = missing value (not available)
Site KTCW is the diversion from Lake Easton for the Kittitas Canal.

Table A11. TSS load (tons/day) for 2019, calculated by Gage method.

Site	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Apr-Jun	Jul-Oct
YKEA	1.91	0.928	0.426	0.288	1.33	0.498	0.763	0.876	1.08	0.721
TEAL	34.8	8.64	2.35	0.227	0.0368	0.0812	18.8	9.24	15.2	4.84
YKHO	52.1	18.8	22.5	27.1	22.7	3.79	16.2	23.3	31	17.5
YKAW	79.9	34.3	39.6	47.6	30.7	7.94	17.7	36.7	51.1	26.1
WLTH	17.8	17.1	4.35	1.94	1.66	1.6	0.86	6.46	13.1	1.52
CHTH	36.1	37.4	23.2	14.2	15.8	11.8	3.9	20.3	32.3	11.4
WILC	55.4	54.9	24.6	13.5	13.9	10.5	3.36	25.1	45.1	10.3
YKUM	134	91.2	64.1	60.3	45	19.4	20.6	61.9	96.3	36.4
RZCW	-56	-28.3	-37.6	-32.5	-24.8	-10.8	-9.67	-28.5	-40.5	-19.5
YKSM	-1.8	-1.64	-1.32	-1.38	-1.18	-0.424	-0.151	-1.13	-1.59	-0.787
YKHB	92.7	40	21.5	33.1	32.3	5.47	8.3	33.3	51.3	19.9

Figures A7 and A8 show correlation between sample results for TSS and turbidity. The figures are divided into mainstem Yakima River sites and non-mainstem sites. Pearson's correlation (r) is shown on the figure, along with the linear regression line.

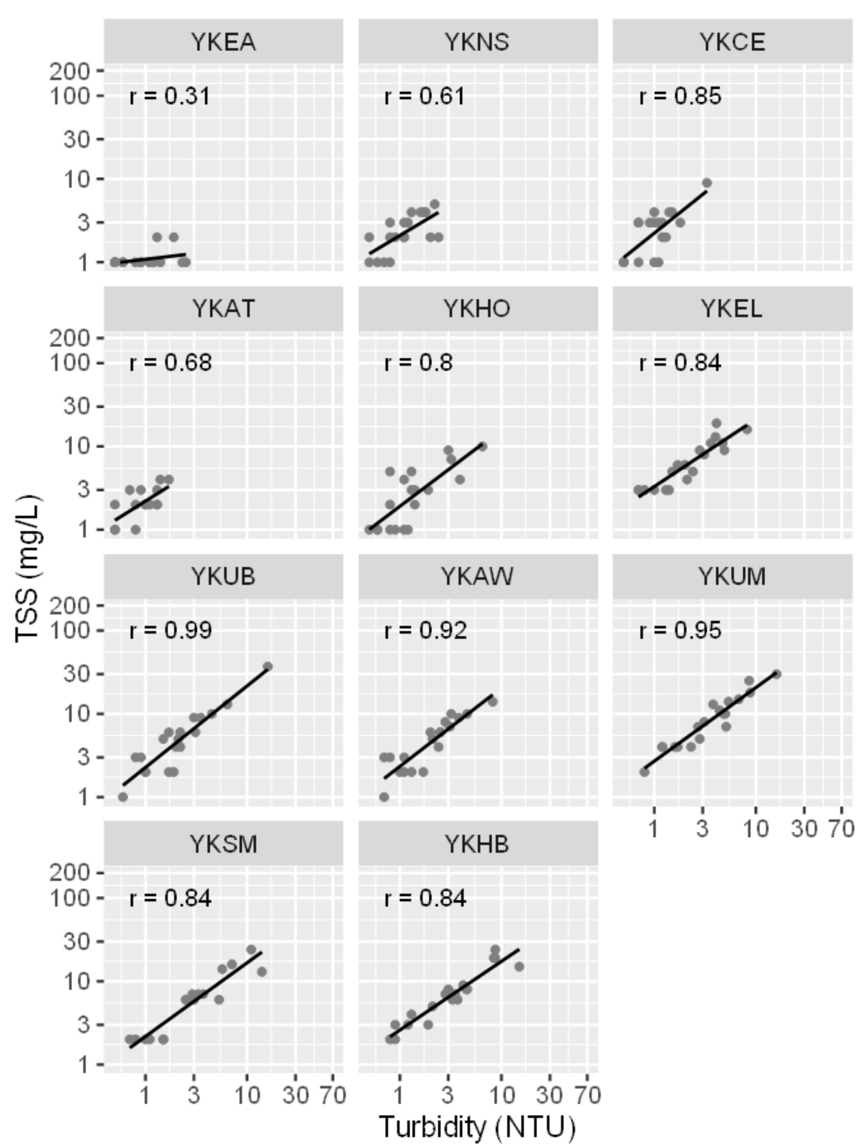

Figure A7. Correlation between grab samples for TSS and turbidity for mainstem Yakima River sites in 2019.

Axes show log-log relationships.

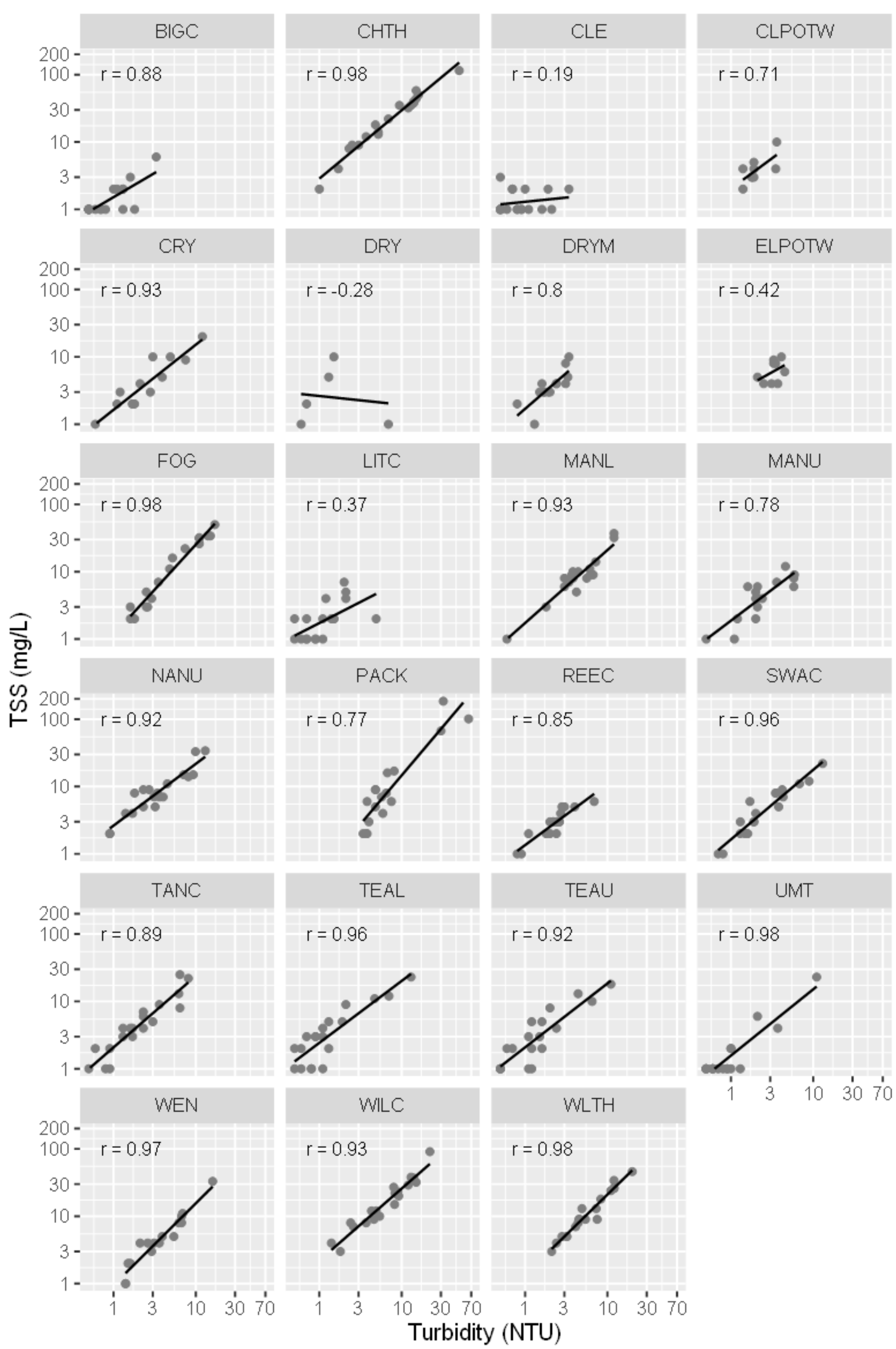

Figure A8. Correlation between grab samples for TSS and turbidity for non-mainstem sites in 2019.

Axes show log-log relationship.

Table A12. Turbidity target statistics (differences versus background) for 2019.

Target site code	Background site code	Target site statistic (NTU)	Background site statistic (NTU)	Difference (NTU)	Confidence interval for difference (NTU)
TEAL	TEAU	3.23	3.78	-0.55	[-3.95, 2.32]
TANC	MANU	5.59	4.56	1.03	[-1.85, 4.66]
PACK[1]	MANU	5.72	2.38	3.34	[1.89, 4.92]
MANL	MANU	9.08	4.56	4.52	[1.33, 8.52]
FOG	MANU	15.2	4.56	10.6	[4.92, 21.0]
WILC	NANU	17.6	8.58	9.03	[1.17, 19.8]
WEN	MANU	9.22	4.56	4.66	[0.8, 10.8]
YKUM[2]	YKEA	7.27	2.16	5.14	[2.81, 7.40]
YKHB[2]	YKEA	6.97	2.16	4.81	[2.79, 6.84]

[1]The turbidity target at PACK was based on differences in geometric mean; all other sites were based on differences in 90th percentiles.
[2]Target was evaluated using continuous gage data collected at YKSM and YKEA (background). See Appendix D for the turbidity target evaluation of these sites.

Table A13. Turbidity statistics (differences versus background) for non-target TMDL sites for 2019.

Site Code	Background Site Code	Difference (NTU)	Site Statistic (NTU)	Background Site Statistic (NTU)	Type of Statistic
BIGC	YKEA	-0.10	2.03	2.12	90th percentile
LITC	YKEA	0.36	2.48	2.12	90th percentile
CLE	YKNS	0.17	2.20	2.02	90th percentile
CRY	YKNS	3.64	5.66	2.02	90th percentile
SWAC	YKNS	4.00	6.03	2.02	90th percentile
DRYM	NANU	-5.21	3.36	8.58	90th percentile
REEC	NANU	-4.89	3.69	8.58	90th percentile
WLTH	NANU	4.40	12.97	8.58	90th percentile
CHTH	NANU	15.92	24.49	8.58	90th percentile
UMT	MANU	-2.74	1.82	4.56	90th percentile
YKCE	YKNS	-0.43	1.59	2.02	90th percentile
YKAT	YKNS	-0.44	1.59	2.02	90th percentile
YKHO	YKNS	0.73	2.75	2.02	90th percentile
YKEL	YKNS	2.79	4.81	2.02	90th percentile
YKUB	YKNS	3.65	5.68	2.02	90th percentile
YKAW	YKNS	1.87	3.89	2.02	90th percentile
BIGC	YKEA	0.76	0.87	-0.11	Geometric mean
LITC	YKEA	1.13	0.87	0.25	Geometric mean
CLE	YKNS	0.80	1.08	-0.29	Geometric mean
CRY	YKNS	2.14	1.08	1.06	Geometric mean
SWAC	YKNS	2.57	1.08	1.48	Geometric mean
DRYM	NANU	1.95	3.89	-1.94	Geometric mean
REEC	NANU	2.22	3.89	-1.67	Geometric mean
WLTH	NANU	5.63	3.89	1.74	Geometric mean
CHTH	NANU	8.31	3.89	4.42	Geometric mean
UMT	MANU	0.80	2.38	-1.58	Geometric mean
YKCE	YKNS	0.98	1.08	-0.10	Geometric mean
YKAT	YKNS	0.91	1.08	-0.18	Geometric mean
YKHO	YKNS	1.36	1.08	0.28	Geometric mean
YKEL	YKNS	2.36	1.08	1.27	Geometric mean
YKUB	YKNS	2.33	1.08	1.24	Geometric mean
YKAW	YKNS	2.13	1.08	1.04	Geometric mean

All calculations based on laboratory sample results; non-detect values substituted using half reporting limit.

References for Appendix A

R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
https://www.R-project.org

Appendix B. Data Quality

This appendix describes the quality of data that Ecology collected during 2019 for the Upper Yakima River Basin Suspended Sediment and Turbidity Status Monitoring. Ecology assessed data by comparing quality metrics such as replicate precision statistics to a target Measurement Quality Objective (MQO). EAP's programmatic QAPP for water quality impairment studies (McCarthy and Mathieu, 2019) and the project's QAPP (Carroll and Urmos-Berry, 2019) define the MQOs for this study. Ecology found all data to be acceptable for use in this study, unless otherwise noted in this section.

Sample collection and transport

During February-November 2019, Ecology collected water samples every two weeks, occasionally missing sites due to poor site accessibility, dry channel, or ice. Ecology sent water samples to Manchester Environmental Laboratory (MEL) for analysis. Most samples arrived at MEL in good condition at proper holding temperature. Two turbidity samples (collected Nov 6-8) were partially frozen or had ice in the container; these were qualified as estimates by MEL. Many of the turbidity samples from the Nov 6-8 batch were also analyzed after the recommended hold time and qualified as estimates by MEL (the November turbidity sampling data was not relied upon for this report).

Sample data quality

Ecology collected field replicate samples for laboratory parameter analysis. Field replicates consisted of two samples collected from the same location and as close to the same time as possible. Ecology collected field replicates to check the precision of sampling and analysis. Manchester Environmental Lab (MEL) checked the precision of the lab analysis by analyzing lab duplicates. Lab duplicates consisted of two subsamples taken from the same sample container and analyzed separately. Tables B1 and B2 presents the percentage of replicates and duplicates collected and the assessed field and lab sample precision.

The percentage of field replicates collected fell just short of the target levels of 20% of all samples (i.e. there were fewer replicate samples than what was planned), However, the precision for those field replicates expressed as relative standard deviation, met the targets set in the study's QAPP for all of the parameters. All the data is suitable for Ecology's analysis (Table B2). Ecology analyzes field replicates and laboratory duplicates with result values less than five times the reporting limit (RL) separately. Low-level sample results can have a higher relative variability than those with higher sample results.

MEL's manual (MEL, 2016) and Ecology's Programmatic QAPP, calls for duplicating a minimum of 5% of all samples (1/20 samples or 1/analytical batch). MEL met or exceeded that goal for all parameters analyzed (Table B1). The assessed precision, calculated as relative percent difference, also met the target levels set in the QAPP.

MEL assessed bias for the parameters of concern with the use of lab control samples and blanks. Lab control samples were within targets for all parameters (Table B1). Ecology submitted field blanks for analysis along with samples from nineteen sampling runs. In addition, MEL routinely ran lab blanks along with each analytical batch. Both field and lab blanks check for sample contamination in both the field and laboratory processes. All field and lab blanks resulted in no values above the reporting limit (Table B3).

Table B1. Lab Precision and Bias Results from 2019.

Parameter	# of Samples	# of Duplicates	% Duplicated	Lab Target Precision (% RPD)	% RPD		Lab Control Samples (% Spike Recovery)	
					<5X RL	≥5X RL	Target Range (%)	Actual Range (%)
Total Non-Volatile Suspended Solids*	584	76	13.0	<20	15.2	7.0	---	---
Total Suspended Solids	584	76	13.0	<20	7.3	4.5	80-120	81-100
Turbidity	584	60	10.3	<20	6.7	6.1	90-105	95-107

Results at the detection limit were excluded from consideration.
RPD = Relative Percent Difference
RL = Reporting Limit
% Spike Recovery = percent of recovered analyte of interest that was spiked into a sample
*No lab control samples were analyzed for this parameter.

Table B2. Field Precision Results from 2019.

Parameter	# of Samples	# of Replicates	% Replicated	Field Target Precision (% RSD)	Median % RSD[a]	
					<5X RL	≥5X RL
Total Non-Volatile Suspended Solids	584	55	9.4	<15	0.0	0.0
Total Suspended Solids	584	55	9.4	<15	0.0	2.9
Turbidity	584	55	9.4	<15	10.5	9.2

[a]Results at the detection limit were excluded from consideration.
RSD = Relative Standard Deviation
RL = Reporting Limit

Table B3. Field and laboratory blank results from 2019.

Parameter	# of Lab Blanks	# of Lab Blanks Results > RL	# of Field Blanks	# of Field Blanks Results > RL
Total Non-Volatile Suspended Solids	80	0	19	0
Total Suspended Solids	80	0	19	0
Turbidity	60	0	19	0

RL = Reporting Limit

Grab versus depth integrated sample comparison

Ecology compared TSS and turbidity sample results collected using two different sample collection methods: (1) grab samples and (2) depth-integrated samples. Beginning in June, depth-integrated samples were collected as field replicates at sites six sites: CHTH, MANL, FOG, PACK, TEAL, YKUM. Only sites CHTH and FOG were consistently sampled using depth integration.

Differences in turbidity results between the two methods is shown in Table B4 (aggregated across all sites). No consistent bias direction was evident for turbidity. Site CHTH had the largest differences in turbidity between grab and depth-integrated samples, but no consistent bias was evident for this site. For TSS and TNVSS, a potentially consistent bias direction was noted for TSS at higher concentrations, discussed below.

Table B4. Comparison of grab versus depth integrated collection method results from 2019 – *results are aggregated across all sites where paired data using both methods were available*.

Parameter	# of Replicates	Median % RSD (< 5X RL)	Median % RSD (> 5X RL)
Total Non-Volatile Suspended Solids	27	14.1%	3.6%
Total Suspended Solids	27	10.9%	3.5%
Turbidity	27	3.7%	7.2%

Differences in TSS results for higher concentrations (approximately ≥ 30 mg/L) showed consistent bias in four out of seven sample pairs (Table B4). For these four pairs, the TSS was consistently lower in the depth integrated result. For the other three pairs, no TSS difference was observed.

Table B5. Differences between 2019 depth integrated vs. grab sample pairs with TSS ≥ 30 mg/L at all sites.

Grab Result (mg/L)	Depth Integrated Result (mg/L)	Difference (mg/L)	RPD (%)	Site	Date
32	25	7	25%	CHTH	July 17
35	30	5	15%	CHTH	July 2
32	29	3	10%	MANL	July 1
34	31	3	9%	FOG	July 1
31	31	0	0%	FOG	June 18
32	32	0	0%	FOG	June 4
35	35	0	0%	CHTH	June 19

Overall it is unclear how grab sample collection methods impacted study results for 2019. Ecology could not collect depth integrated samples at most sites, due to high water velocity. Comparisons from a limited number of sites with lower water velocities do not show a consistent bias direction for turbidity.

References for Appendix B

Carroll, J. and E. Urmos-Berry. 2019. Quality Assurance Project Plan: Upper Yakima River Basin Suspended Sediment and Turbidity Status Monitoring. Publication 19-03-108. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/1903108.html

Manchester Environmental Laboratory (MEL), 2016. Laboratory Users Manual, 9th ed. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

McCarthy, S. and N. Mathieu, 2017. Programmatic Quality Assurance Project Plan: Water Quality Impairment Studies. Publication 17-03-107. Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/SummaryPages/1703107.html

Appendix C. Flow

Appendix C documents 2019 streamflow in the Yakima River and its tributaries. Ecology used streamflow for calculating TSS loads. Water entering the Yakima River contributes to the TSS load; water leaving the river for irrigation diverts TSS load away from the river.

Flow was calculated hourly, based on either rating curves or linear interpolation between measurements. The rating curve is a mathematical relationship between stage and flow. Ratings for most sites were calculated by Ecology's Stream Hydrology Unit using Hydstra® software. At several sites, ratings were developed outside of Hydstra®, and these ratings are documented at the end of this appendix. If a rating curve could not be developed, then linear interpolation between measurements was used.

Ecology measured streamflow following Ecology protocols (McCarthy and Mathieu, 2017). Flow measurements were made every two weeks using hand held velocity meters or acoustic-Doppler current profilers (ADCP) from rafts. Some measurements could not be made during high flows due to safety considerations. Ecology measured stage using pressure transducer data loggers, which were checked against staff gages, laser levels, tape downs and other reference points.

Plots of flow, withdrawal, and supplementation

Ecology presents the following figures and tables:

- Figures C1 through C7 show calculated hourly flow plus instantaneous flow measurements. Measurements shown on these figures were made by Ecology, unless indicated otherwise. Table C3 evaluates how closely flow ratings match the measurements.
- Figures C8 through C10 show irrigation withdrawals from the Yakima River, based on data obtained from the data sources listed in Table C2.
- Figure C11 show supplementation water provided to several streams to improve habitat and access (data and figure courtesy of Kittitas Reclamation District (KRD)).
- Figures C12 through C15 document flow ratings at several sites which could not be stored in Ecology's Hydstra® database.

To avoid confusion, these figures label flow in the Yakima River and tributaries as "discharge"; they label water diverted from the river as "withdrawal rate"; and they label water provided to tributaries as "supplementation rate".

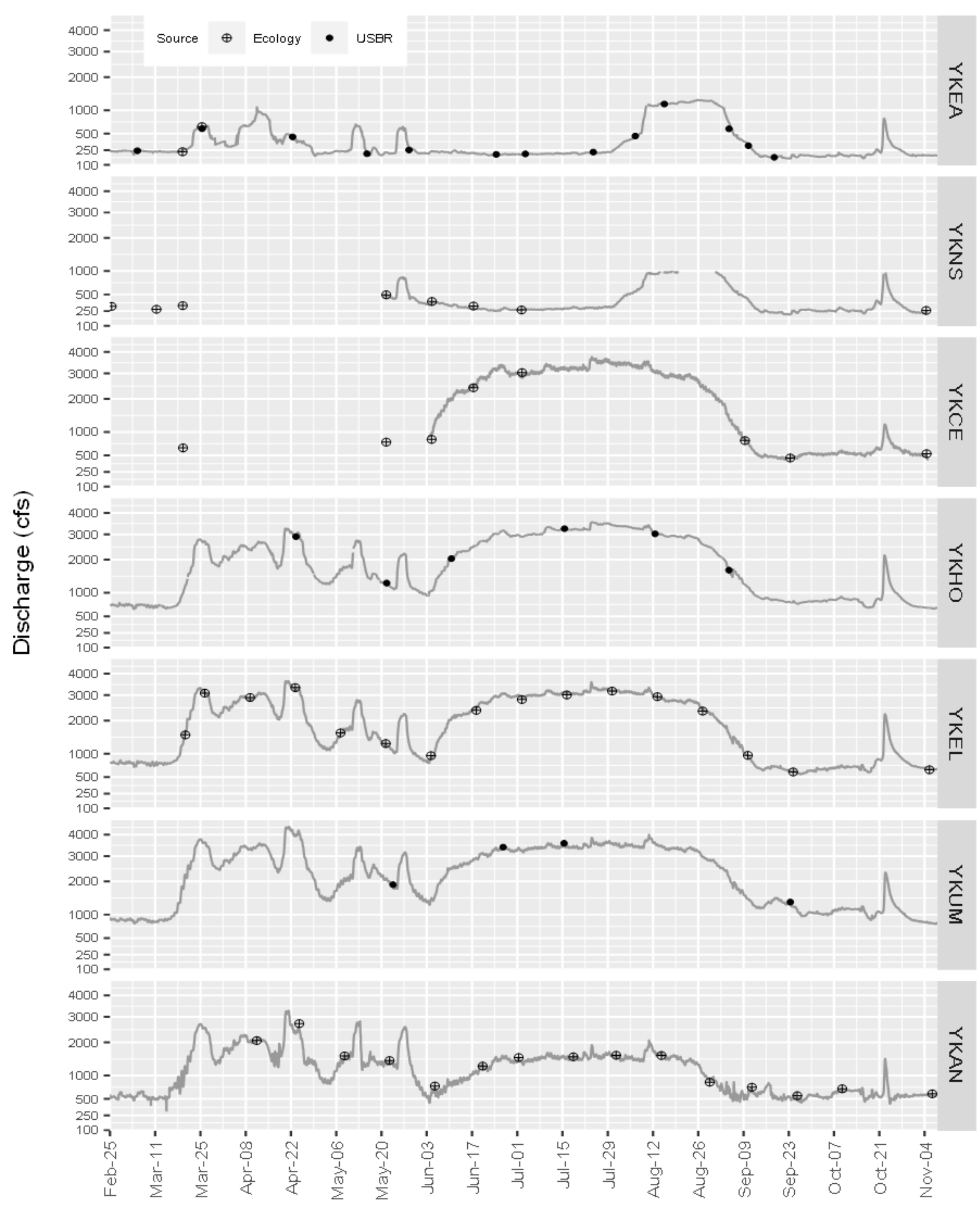

Figure C1. Discharge measurements and time-series (2019) for mainstem Yakima River sites.

Site locations along the Yakima River:
Below Lake Easton (YKEA), Nelson-Siding (YKNS), Cle Elum (YKCE), Horlick (YKHO), Ellensburg (YKEL), Umtanum Creek footbridge (YKUM) and above Naches River (YKAN).

The y-axis in this figure uses a square root transform to accommodate the wide range of flows.

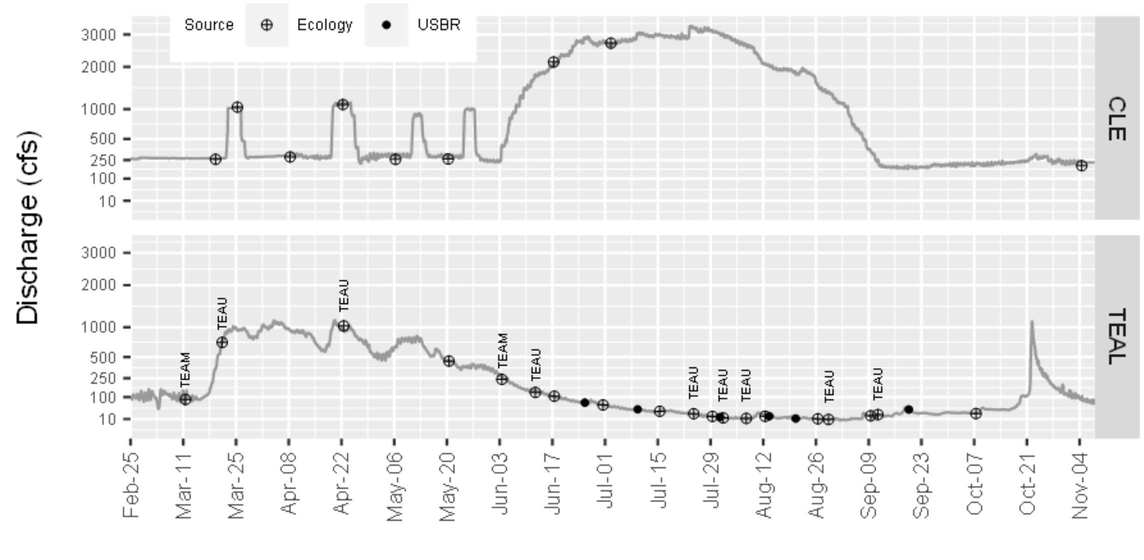

Figure C2. Discharge measurements and time-series (2019) for the Cle Elum at Bullfrog Rd. (CLE) and Teanaway River at Lambert Rd. (TEAL).

Measurements are labelled in this figure if they were not measured at the typical monitoring site. For Teanaway River above, additional measurements were taken at Red Bridge Rd. (TEAU) and near the mouth (TEAM).

The y-axis in this figure uses a square root transform to accommodate the wide range of flows.

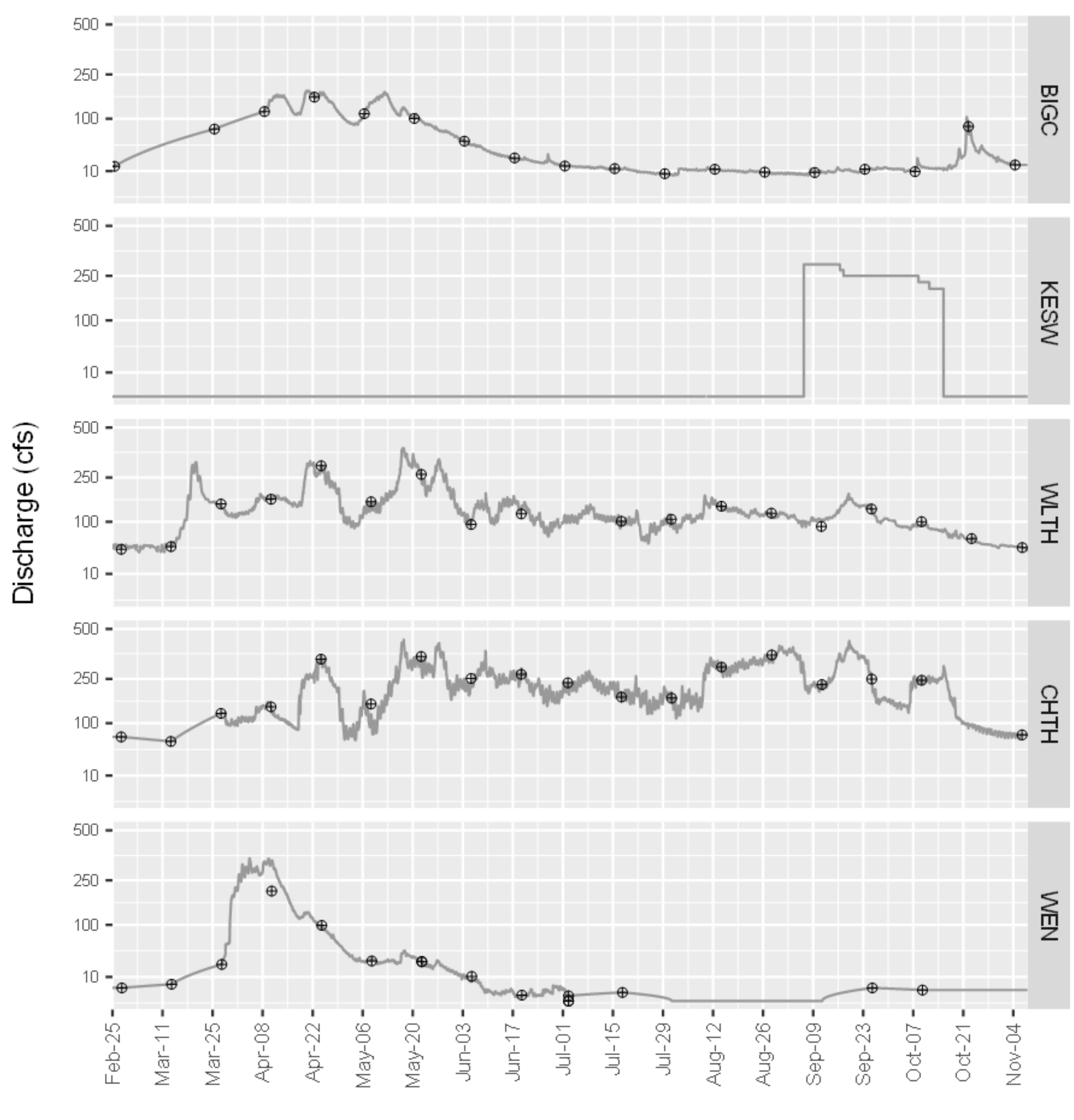

Figure C3. Discharge measurements and ratings (2019) for Big Creek (BIGC), KRD 1146 Drop (KESW), Wilson Creek at Thrall Rd. (WLTH), Cherry Creek at Thrall Rd. (CHTH) and Wenas Creek (WEN).

The y-axis in this figure uses a square root transform to accommodate the wide range of flows. KESW flows were downloaded from USBR, the drop operated only in Sept-Oct, and was otherwise dry.

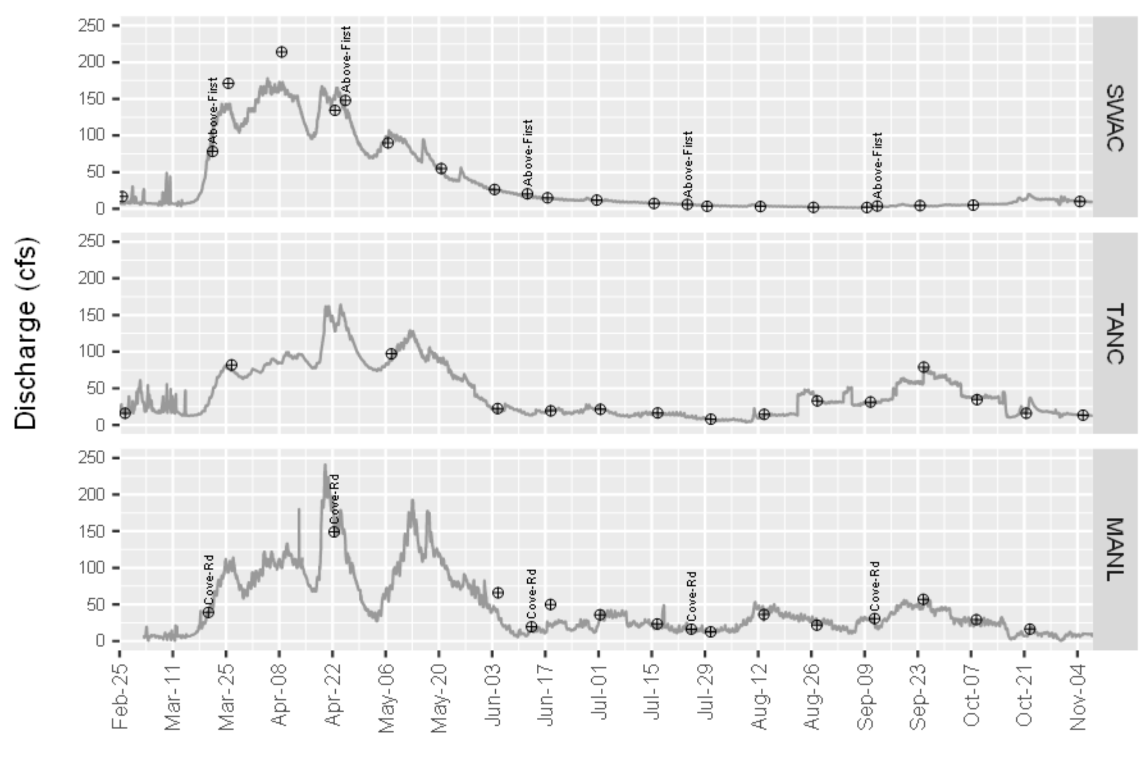

Figure C4. Discharge measurements and ratings (2019) for Swauk Creek (SWAC), Taneum Creek (TANC), and Manastash Creek at Brown Rd. (MANL).

Measurements are labelled in this figure if they were not measured at the typical monitoring site.
For Swauk Creek, the time series and some of the measurements were taken at the Ecology flow gage station above First Creek.
For Taneum Creek, some measurements were collected and the time series Feb-April was regressed based on the Ecology gage station at Brain Ranch.
For Manastash Creek, measurements also were taken at Cove Rd.

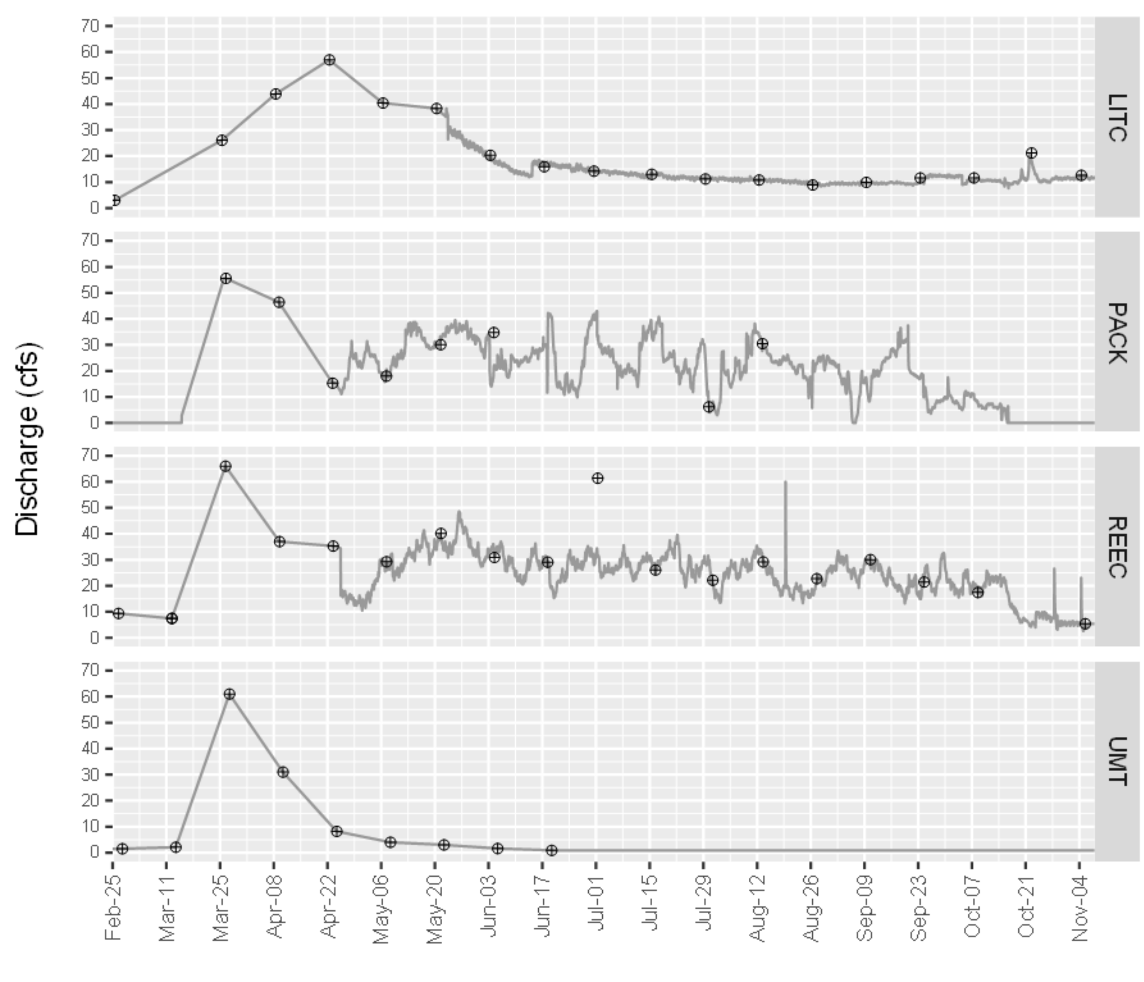

Figure C5. Discharge measurements and ratings (2019) for Little Creek (LITC), Packwood Ditch (PACK), Reecer Creek (REEC), and Umtanum Creek (UMT).

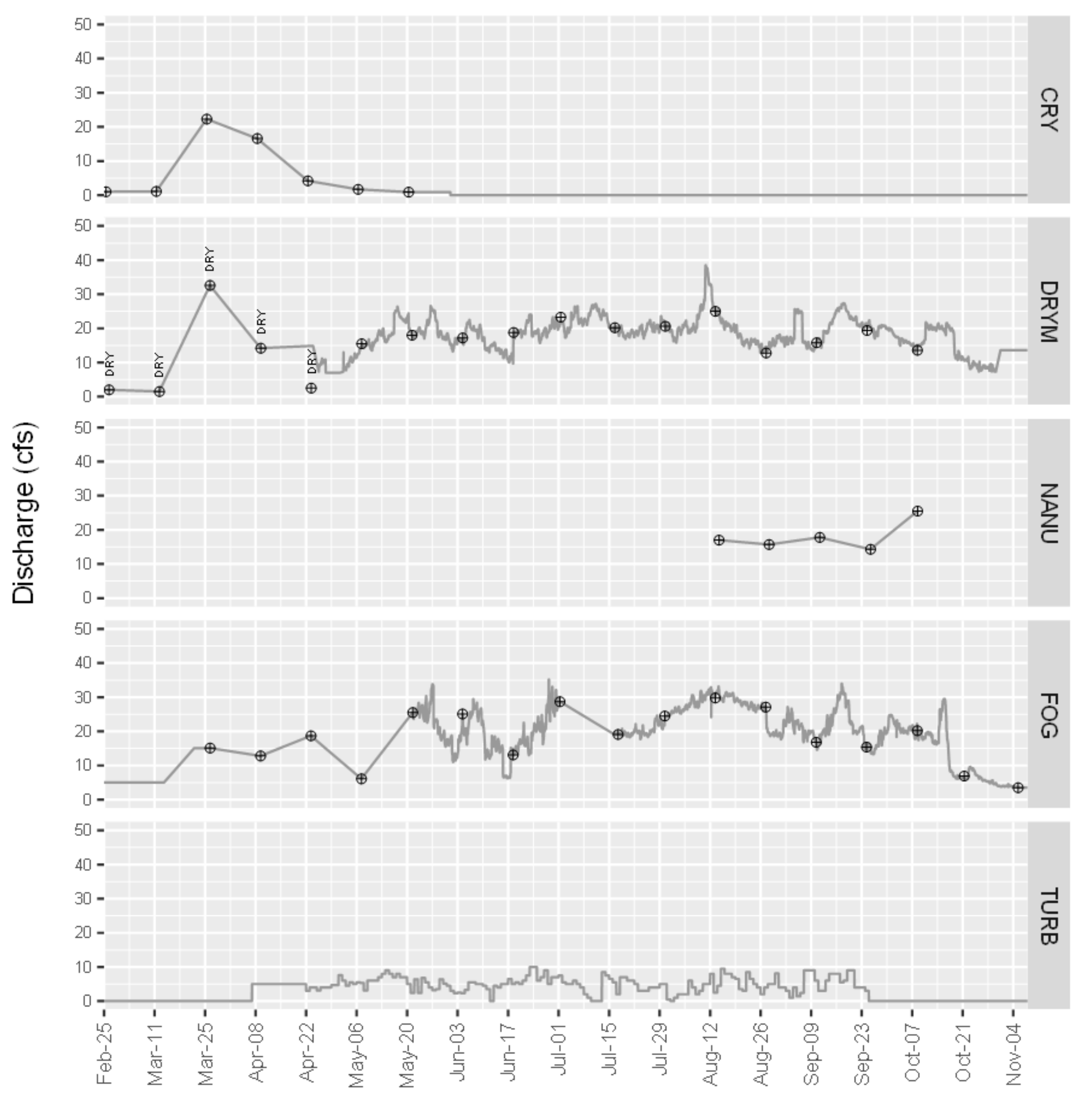

Figure C6. Discharge measurements and ratings (2019) for Crystal Creek (CRY), Dry Creek near mouth (DRYM), Naneum Creek (NANU), Sorenson/Fogarty Creek (FOG), and Turbine Canal return (TURB).

Measurements are labelled in this figure if they were not measured at the typical monitoring site. For Dry Creek, measurements were collected during the early season at an upstream site on McManamy Rd. (DRY), until this site went dry.

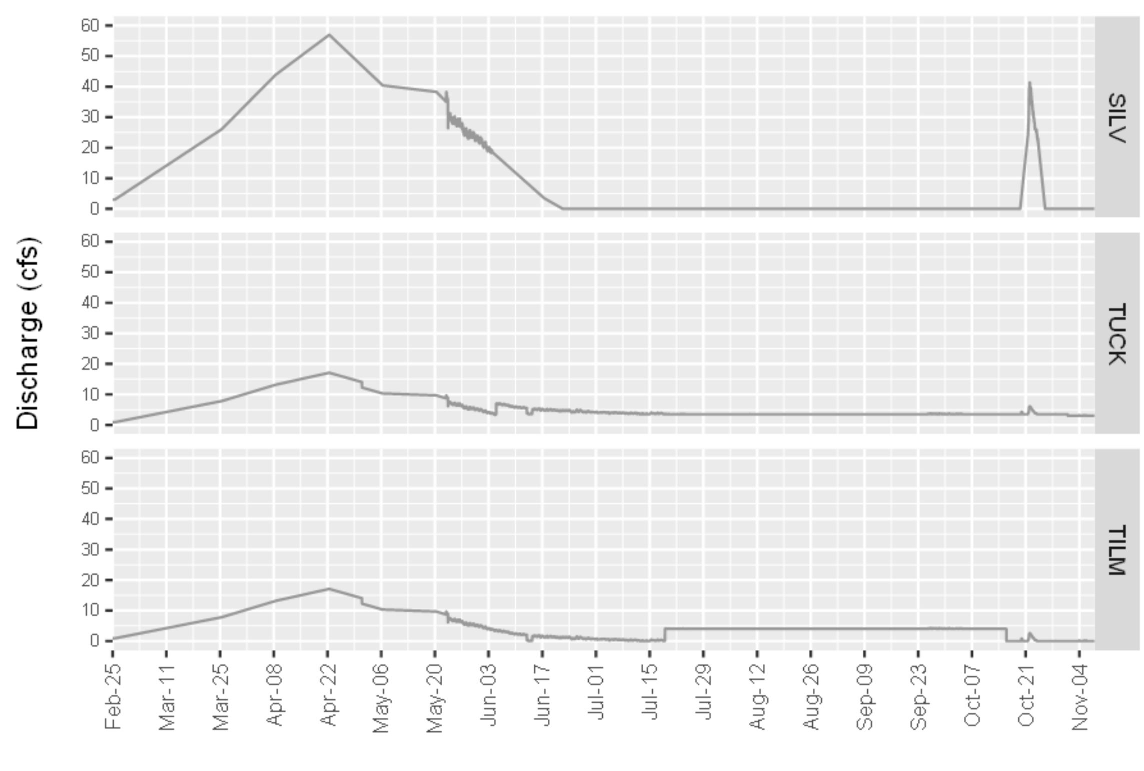

Figure C7. Discharge estimates (2019) for Silver Creek (SILV), Tucker Creek (TUCK) and Tillman Creek (TILM).

Silver Creek was based on field observations/estimates and set equal to Little Creek (LITC) until it went dry in June, with flow in October based on visual estimate.
Tucker and Tillman Creeks were supplemented by KRD.
Estimates for these creeks were made by adding their respective supplementation amounts to 30% LITC flow (after subtracting supplementation to Little Creek by KRD).

Table C1 presents bias and root mean squared error (RMSE) between flow ratings versus measurements. Bias is the average difference between flow rating and measurements. Root mean squared error (RMSE) is the square-root of the average of the squared differences.

Table C1. Bias and root mean squared error (RMSE) between flow ratings versus measurements for 2019.

Site code	Measurement count	Average of instantaneous flow measurements (cfs)	Bias (cfs)	RMSE (cfs)	Bias as percentage of average (%)	RMSE as percentage of average (%)
YKEA	2 + 13*	395	7.5	33.5	2%	8%
YKNS	5	344	-10.5	13.5	-3%	4%
YKCE	6	1340	-5.8	94.1	0%	7%
YKHO	6*	2350	9.1	28.5	0%	1%
YKEL	16	2100	9.9	56.8	0%	3%
YKUM	4*	2550	-67.5	70.2	-3%	3%
YKAN	15	1290	-26.8	91.2	-2%	7%
BIGC	16	47.2	-0.2	1.5	0%	3%
CHTH	16	231	-5.6	12.7	-2%	6%
CLE	9	915	0.2	29.8	0%	3%
DRYM	12	18.4	0.1	0.9	1%	5%
FOG	13	19.7	0	0.6	0%	3%
LITC	18	20.6	-0.3	0.9	-1%	4%
MANL	8	29.2	-2.4	5.1	-8%	17%
PACK	6	22.5	-1.3	5.7	-6%	25%
REEC	14	28.6	-2.8	8.2	-10%	29%
SWAC	17	45.4	-4.7	15.9	-10%	35%
TANC	15	33.6	-1.2	3.9	-4%	12%
TEAL	11 + 6*	72.8	2.5	8.7	3%	12%
WEN	16	27.3	7.5	30.5	27%	112%
WLTH	18	125	0.2	7.6	0%	6%

*Measurements provided by USBR

For ratings using linear interpolation, measurements will exactly match the rating (zero residual). Therefore. time periods using linear interpolation as the rating were not included in the statistics for any of the sites above.

For several sites. no statistics were calculated because linear interpolation was used as the rating for the full season (CRY, NANU, UMT)

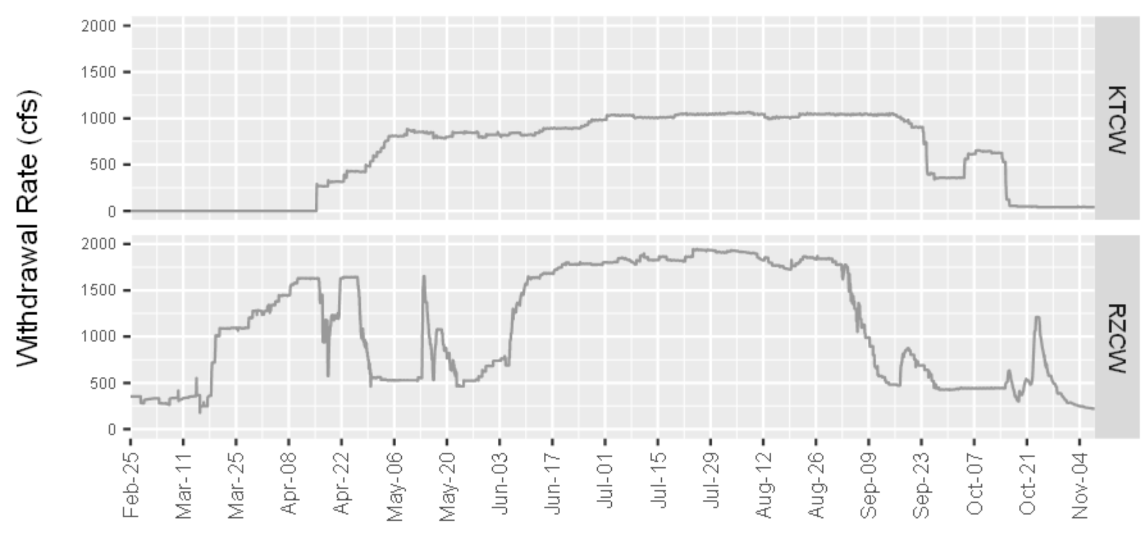

Figure C8. Withdrawal rates (2019) for Kittitas Canal (KTCW) and Roza Canal (RZCW).

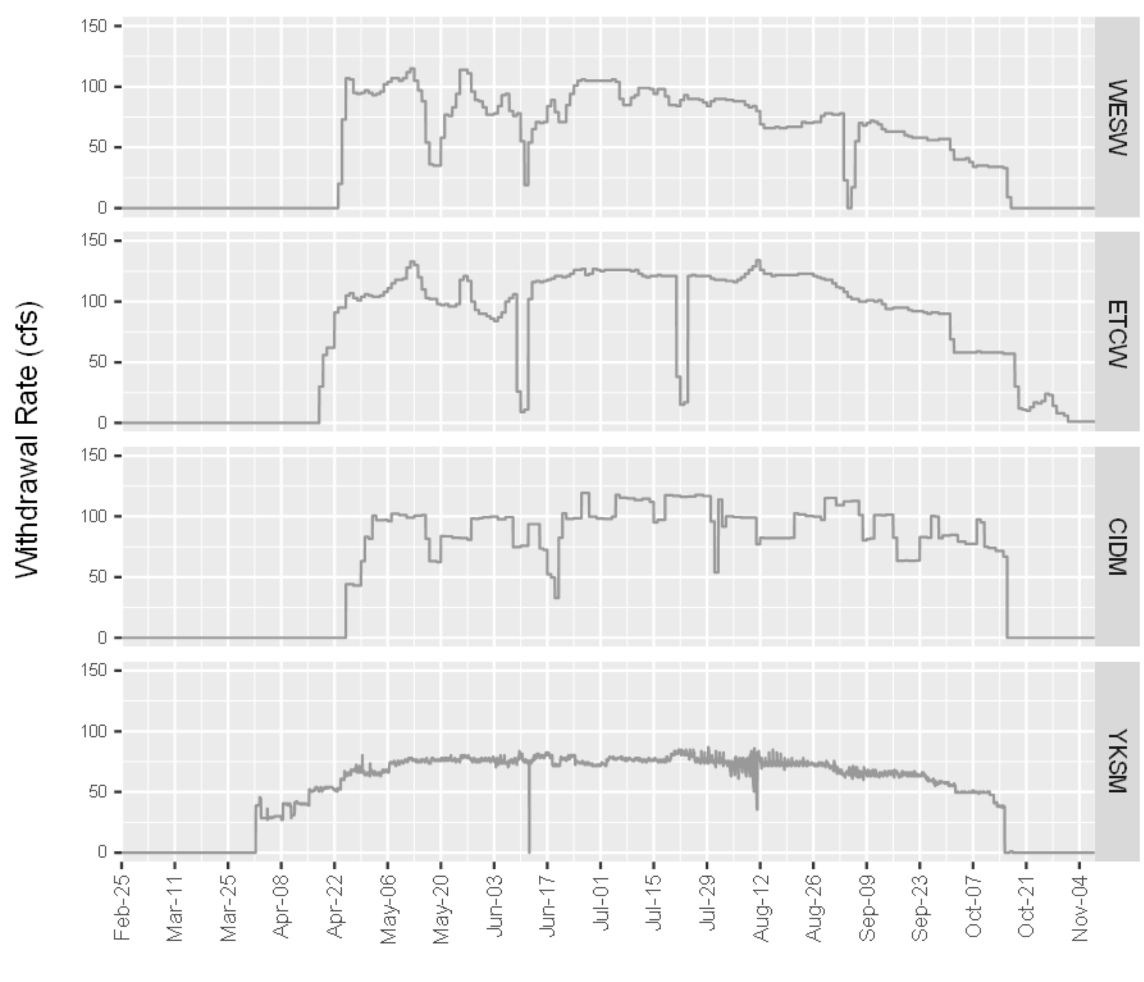

Figure C9. Withdrawal rates (2019) for Westside Canal (WESW), Ellensburg Town Canal (ETCW), Cascade Main Canal (CIDM), and Selah-Moxee Canal (YKSM).

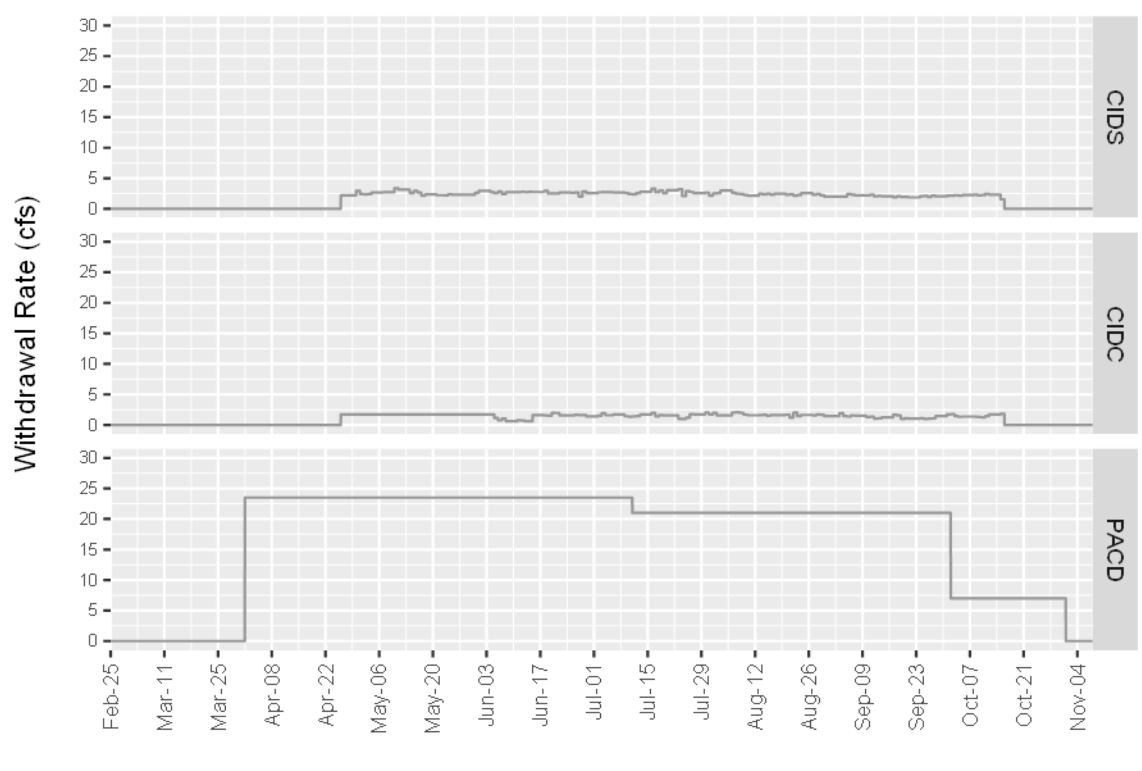

Figure C10. Withdrawal rates (2019) for Cascade-Strawberry diversion (CIDS), Cascade-Clark diversion (CIDC), and Packwood Ditch Diversion from the Yakima River (PACD).

Amount diverted from the Yakima River by Packwood Irrigation District was estimated based on their water rights in the Final Adjudication document (Superior Court of Yakima County, 2019).

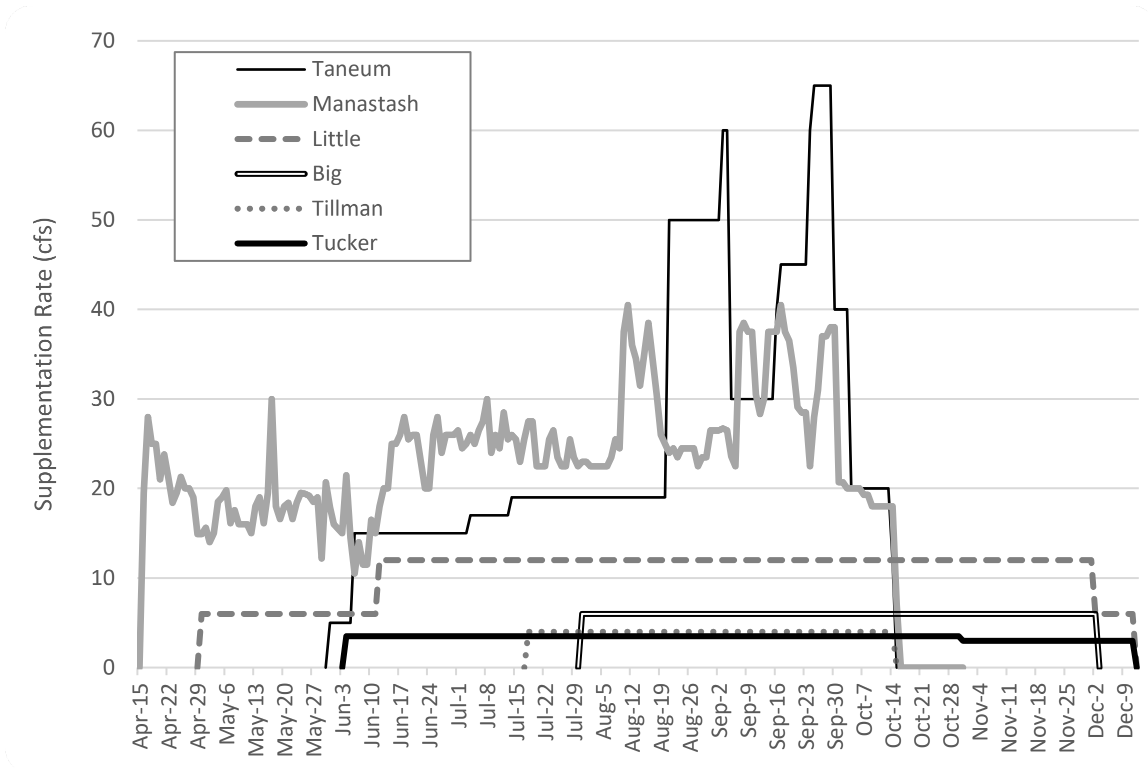

Figure C11. Supplementation rates (2019) by KRD to upper Yakima Basin creeks.

Stream water supplementation was provided to improve access for fish species in these creeks. Data and figure provided by KRD; figure modified to black and white.

Figures C12-C15 show the method of calculating rating curves or estimating flow at several sites which were not entered into Ecology's Hydstra® database.

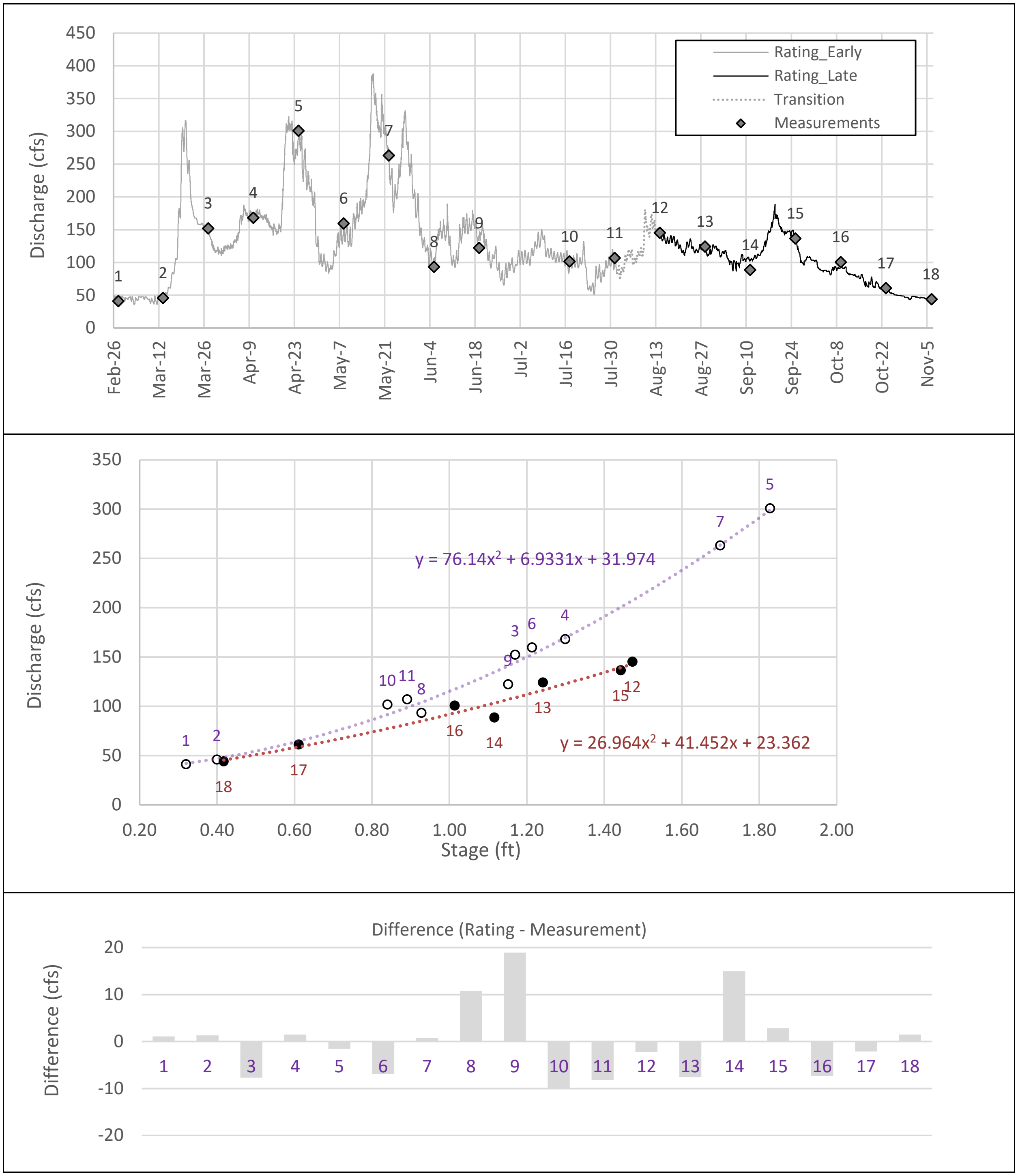

Figure C12. Flow rating used for Wilson Creek at Thrall Rd. (WLTH).
Time series of flow rating and measurements (top). Flow rating equations (center). Difference between flow rating and measurements (bottom).

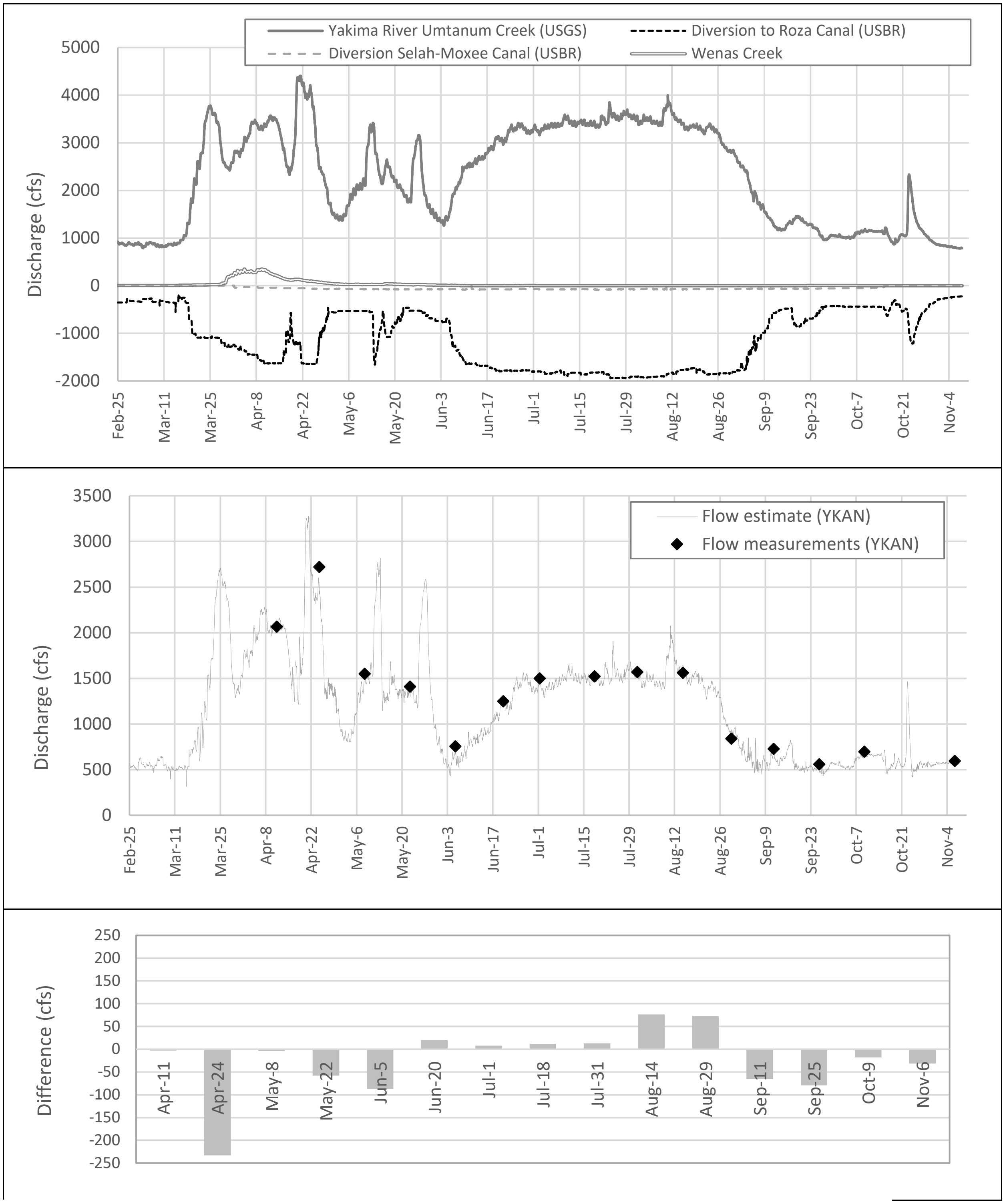

Figure C13. Flow estimation method for Yakima River above Naches River (YKAN).
Flow estimate input terms (top). Flow estimate (sum of input terms) and measurements (center). Difference between estimate and measurements in cfs (bottom).

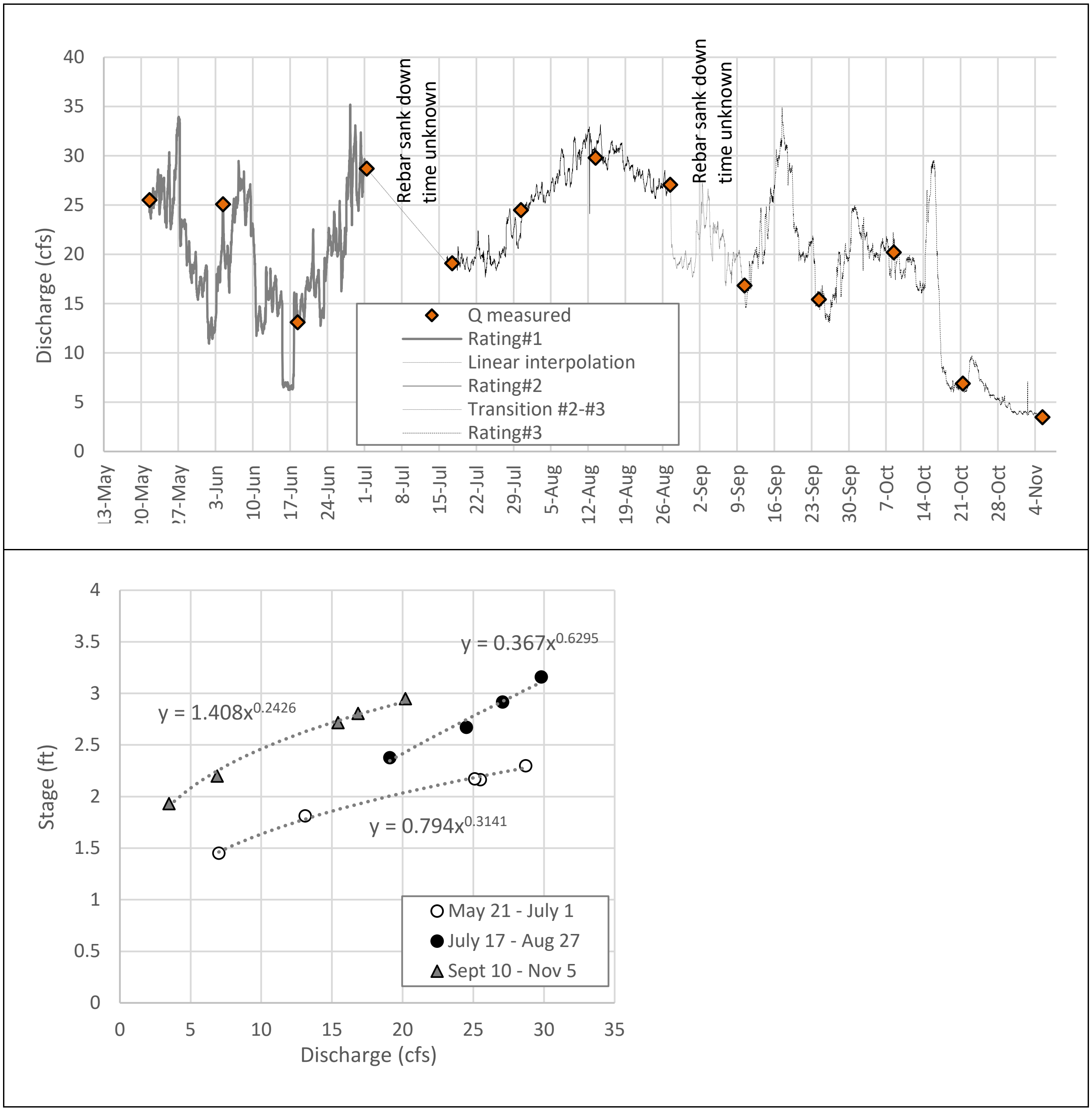

Figure C14. Estimated flow rating used for Fogarty/Sorenson (FOG).

Time series of flow rating and measurements (top). Flow rating equations (bottom).

Stage measurements were likely altered when the rebar holding the pressure transducer sank in muddy substrate. Rating is considered an estimate.

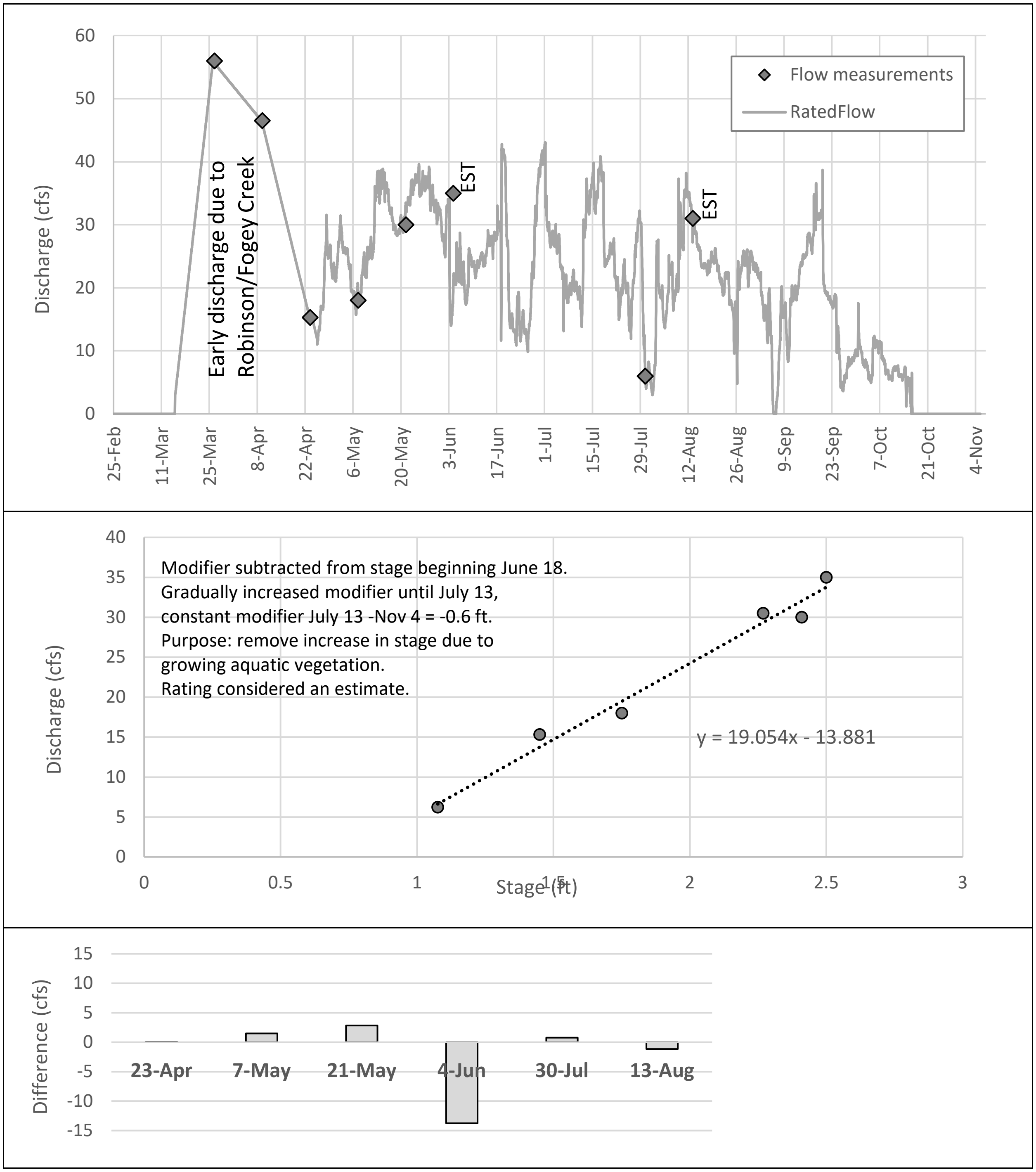

Figure C15. Estimated flow rating used for Packwood Ditch (PACK).

Time series of flow rating and measurements (top). Flow rating equations (center). Difference between estimate and measurements in cfs (bottom).

According to the Final Adjudication document (reference), water in Packwood Ditch includes water diverted from the Yakima River, Robinson Creek, and Fogey Creek.

References for Appendix C

McCarthy, S. and N. Mathieu, 2017. Programmatic Quality Assurance Project Plan: Water Quality Impairment Studies. Washington State Department of Ecology, Olympia, WA. Publication 17-03-107.
https://fortress.wa.gov/ecy/publications/SummaryPages/1703107.html

Superior Court of Yakima County, 2019. Final Schedule of Rights. State of Washington, Department of Ecology v. James J. Acquavella et al., Yakima County Cause No. 77-2-01484-5.

Appendix D. Turbidity Target Evaluation at Sites YKHB and YKUM

This appendix describes an alternate method to determine the TMDL turbidity target result for YKUM and YKHB. In the 2019 monitoring study, we used turbidity gage data to calculate the 90^{th} percentile for these two sites, instead of using turbidity sample data.

TMDL approach for setting turbidity targets for the Yakima River sites

The TMDL used the Washington State turbidity criteria of 5 NTU over background as guidance for setting TMDL targets for turbidity limits. For the upper Yakima River TMDL, two sites were established on the mainstem Yakima River to be evaluated for compliance:

- Yakima River at the Umtanum Creek footbridge – YKUM
- Yakima River at Harrison Bridge – YKHB.

The TMDL compared turbidity at these compliance sites to a single background site at Yakima River at Nelson Siding - YKNS, allowing a 5 NTU increase above background turbidity levels. The TMDL compared the 90^{th} percentile turbidity statistics of the sites instead of maximum values to allow for background seasonal variability, including natural short-term peak turbidity events. This approach was consistent with the lower Yakima River Suspended Sediment and Pesticides TMDL (Joy and Patterson, 1987). The 90^{th} percentile value is considered to support full beneficial use protection under USEPA policy (USEPA, 1995), and it is adequate for background definition under Ecology policy (Ecology, 1994, 1996a).

By basing targets on differences (relative to background) in 90^{th} percentiles, the TMDL focused on protecting the river from large increases in turbidity 90% of the time. For the April-October season (214 days), the 90^{th} percentile is the turbidity level that the river remains at or below 90% of the time (about 193 of 214 days). This approach allows for larger increases in turbidity during the remaining 21 days (10% of the time), yet still prevents long duration of increased turbidity.

Background site for turbidity on the mainstem Yakima River

The 1999 TMDL chose Yakima River near Nelson (YKNS) to represent the background condition for the Yakima mainstem. Lake Easton, as well as the upstream reservoirs at Kachess and Keechelus influence the initial suspended sediment at YKNS. The lake and reservoirs act as settling basins for upper watershed sediment loads, and reduce sediment transported to the river. In addition, Big Creek and Little Creek watersheds are located between Lake Easton and YKNS and may influence suspended sediment loads and turbidity at the Nelson site. YKNS is located above the Cle Elum River, the outlet to another significant reservoir, but available data shows that the Cle Elum River is not a significant source of sediment to the Yakima River, probably due to settling action within the large Cle Elum Reservoir.

To better quantify the natural contribution of TSS from background sources, the 2019 monitoring chose a new site to represent the background condition for the Yakima mainstem. Ecology installed a turbidity sensor near the outlet from Lake Easton (YKEA), about 11 river miles above YKNS. This location provided the best place to monitor continuous background turbidity below the two uppermost headwater reservoirs. The seasonal background characteristics of snowmelt and storm events coming from these headwaters were continuously monitored at YKEA every 15 minutes. An average daily turbidity time-series distribution (made from the 15 minute readings) was developed and used for the background turbidity for two downstream target sites on the Yakima River:

- Yakima River at Umtanum (YKUM)
- Yakima River at Harrison Bridge (YKHB).

Different datasets available for describing the 90th percentile turbidity at YKHB and YKUM

In addition to sampling data at the Yakima River target sites, the 2019 monitoring study measured continuous turbidity at a proxy site on the Yakima River at Selah-Moxee Canal diversion (YKSM). This proxy site was located in between the two TMDL turbidity target sites (YKUM and YKHB), approximately 2.4 miles upstream of YKHB. The turbidity measured at the YKSM gage site represented the culmination of all major tributary sources of turbidity affecting Yakima River at both the YKHB and YKUM sites.

Figure D1 shows the 2019 turbidity gage data collected at the proxy site YKSM, plus the portable turbidity checks made at the time of sampling. Due to short-term precipitation events, turbidity increased on August 11 and on October 23. As discussed below, one of the 2-week pre-scheduled sampling events coincided with and sampled the Oct. 23 spike.

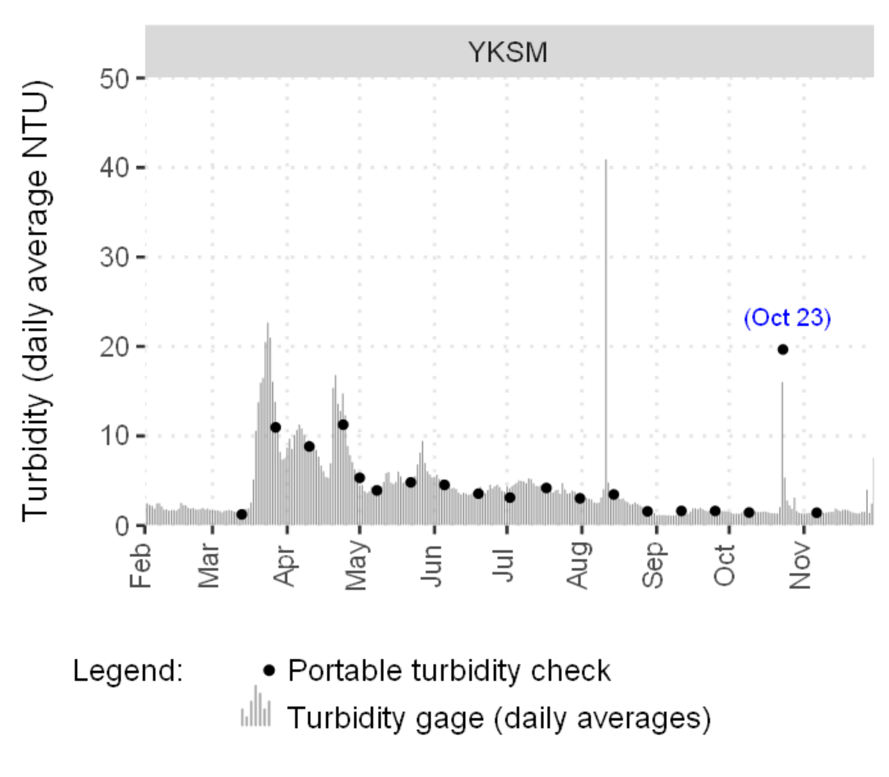

Figure D1. Turbidity at Yakima River at Selah-Moxee diversion (YKSM) from gage and portable checks.

Linear regression of gage time-series data to target sites

Linear regression was used to translate the turbidity gage time series at YKSM to target sites. The water sample turbidity (at target site) was regressed to the average daily gage turbidity (at proxy gage site). Translating the proxy times-series to each target site was necessary because of settling and diversion at Roza Dam that changed the turbidity levels between target sites.

Figure D2 shows the regressions used for translating the gage distribution to each target site. Ecology calculated a 90% confidence interval for the translated distributions by developing upper and lower bounds for each translation regression, which were then used to calculate upper and lower bounds for the turbidity gage time series.

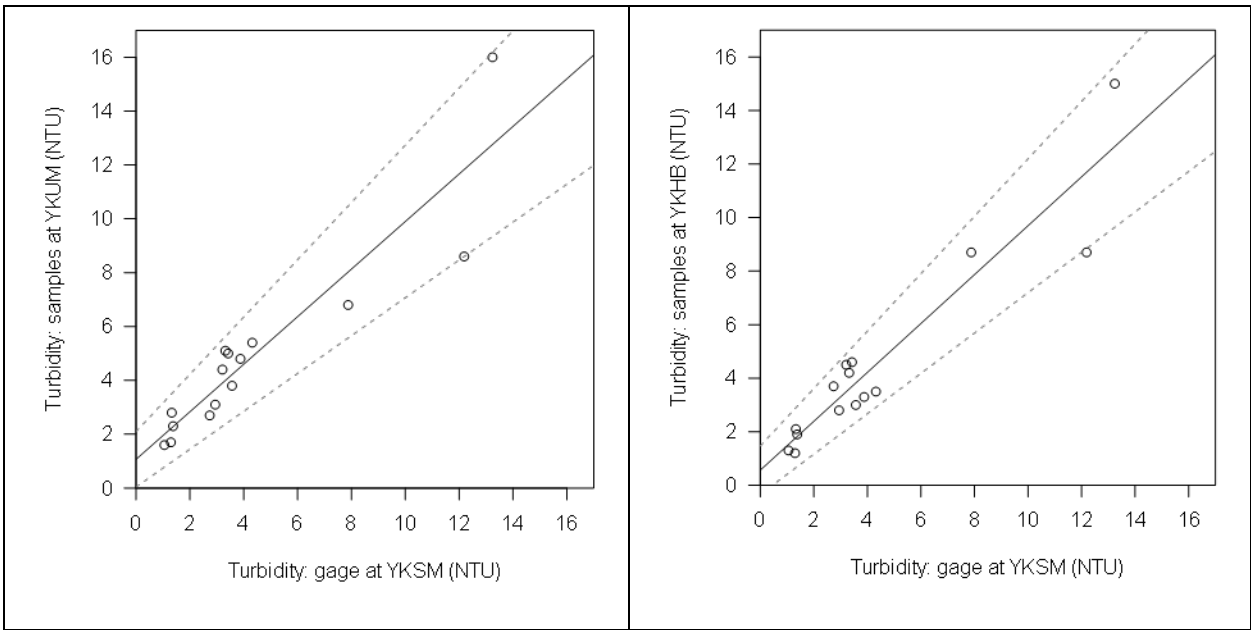

Figure D2. Regressions used to translate the proxy gage time-series to the Yakima River target sites at YKUM and YKHB.

Figure D3 shows the translated turbidity time series for YKUM and YKHB along with the 2-week samples. Likewise, to the YKSM location, the 2-week pre-scheduled sampling interval coincided with and sampled the short-term rise in turbidity on Oct 23, 2019 at both Yakima River target sites (YKUM and YKHB).

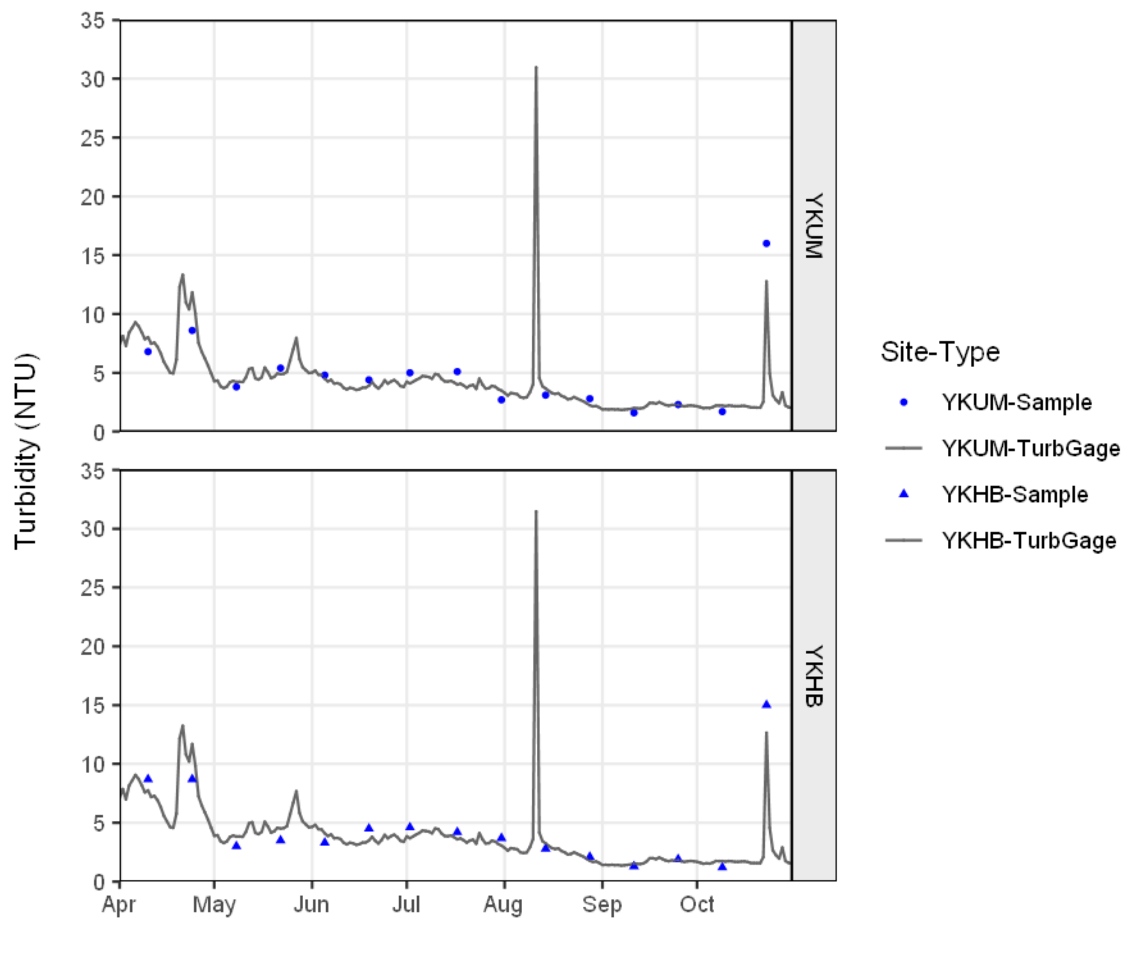

Figure D3. Turbidity time series (translated from the proxy gage data) for the Yakima River at Umtanum (YKUM) and Yakima River at Harrison Bridge (YKHB).

ECDF description of the different data sets at the target sites

Figure D4 shows the empirical cumulative distribution functions (ECDF) of two different distributions for the Yakima River target sites:

- The sample log-normal distribution (red line) was calculated using R-script (assuming a log-normal distribution) and developed from the 15 sample data points (shown as gray dots).
- The gage distribution (black line) is the ranked distribution developed from daily average turbidity readings for every day of the seasonal period (214 days). Again, the daily average turbidity was directly regressed from the YKSM proxy site.
- For reference only, the sample ECDF (gray line) is also shown without the log-normal assumption. The coarseness of this step-function is due to the small number of samples (15).

The 90th percentile is also shown as a green line on this figure, and the crossing point of the different distributions across this line indicates the 90th percentile predicted by that distribution.

As can be seen on this figure, the sample log-normal distribution (red line) predicts a higher 90th percentile (at both sites) than does the translated gage distribution (black line). For YKUM these distributions predict 90th percentiles of 9.0 vs 7.3 NTU, and for YKHB they predict 8.8 vs 7.0 NTU, respectively (see also Table D1 below).

Ecology determined that the sample log-normal distribution is over-predicting the 90th percentile at both sites. The reason is due to the influence of the October 23 sample, which was the maximum result at both sites, and represented a short-term (single-day) high turbidity event caused by precipitation. The data used for both distributions contain the short term event from October 23, but it represents a large proportion of the sampling results (1 sample out of 15 or about 7% of the sampling data), but only a small proportion of the translated gage results (1 daily average measurement out of 214 days, or 0.5% of the gage data).

Because the October 23 sample represents such a large proportion of the sampling results, the log-normal distribution is strongly influenced by this maximum value, causing an over-prediction of 90th percentiles at both sites. The translated gage distribution, on the other hand, provides a more accurate calculation of the 90th percentile because it is based on averages of monitoring data recorded every 15 minutes.

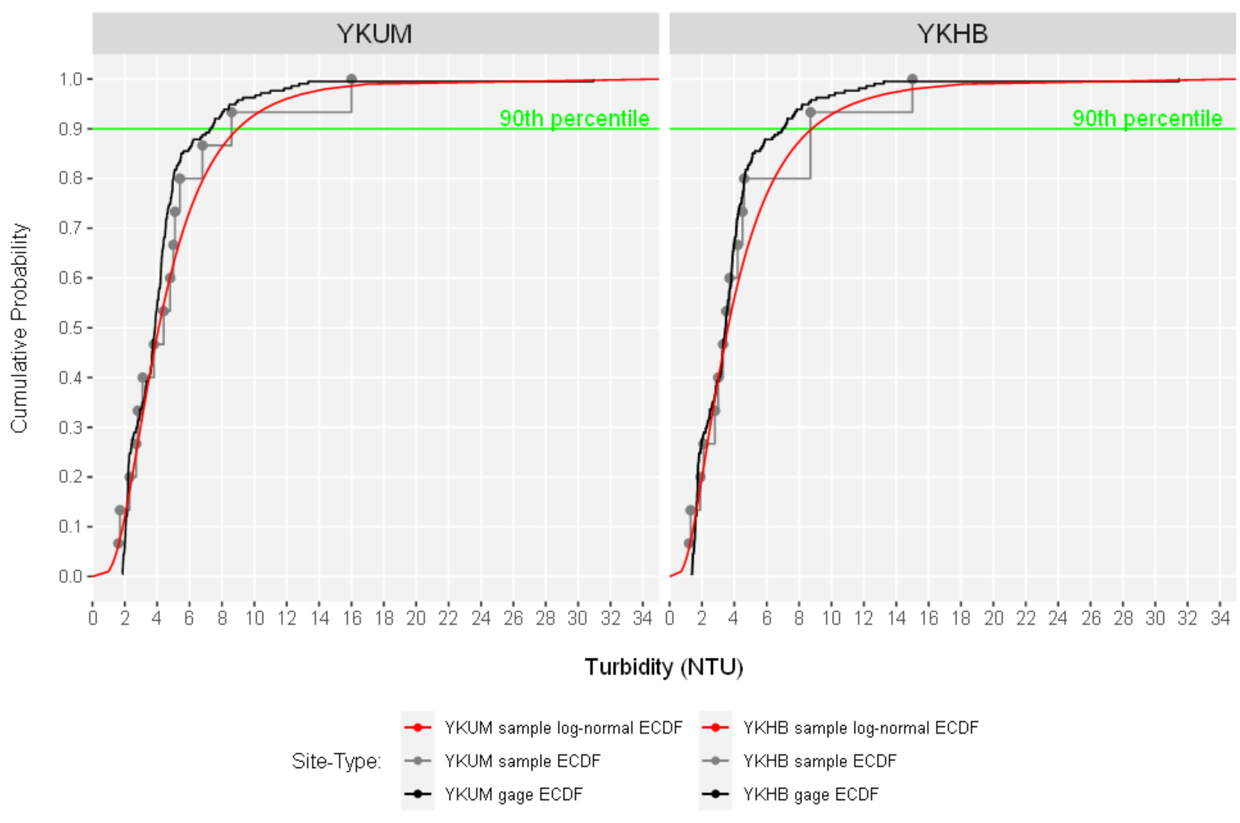

Figure D4. ECDFs of translated gage turbidity (black line) and sample log-normal turbidity (red line) for the Yakima River at Umtanum (YKUM) and the Yakima River at Harrison Bridge (YKHB).

For reference only, the sample turbidity step-ECDF (gray line) is also shown without the log-normal assumption.

Differences in target results

Table D1 shows the 2019 target results for both the translated gage data and the sample data for both Yakima River target sites. For YKUM, both target result differences show that the TMDL target was not met. For YKHB, the translated gage data shows YKHB met the TMDL target, while the sample data shows YKHB did not meet the TMDL target.

Table D1. Comparative turbidity target results for YKUM and YKHB based on gage translation and sample results for the 2019 monitoring study.

Site Code	Final Target Met?	Confident at > 90% level	Difference (NTU)	Confidence Interval (NTU)	Back-ground Site	Site 90th percentile (NTU)	Background 90th percentile (NTU)	Method
YKUM	No	No	5.1	[2.8, 7.4]	YKEA	7.3	2.2	gage translation
YKHB	Yes	No	4.8	[2.8, 6.8]	YKEA	7.0	2.2	gage translation
YKUM	No	No	6.9	[4.5, 11.1]	YKNS	9.0	2.0	sample log-normal
YKHB	No	No	6.8	[4.1, 11.5]	YKNS	8.8	2.0	sample log-normal

Conclusion

Ecology chose to use the 90th percentile from the translated gage data to develop the target results for both of the Yakima River target sites for the 2019 effectiveness monitoring study. Calculating the turbidity target for the Yakima River target sites using the YKSM gage data is the most accurate measurement of the distribution of turbidity over the course of the irrigation season because it was not limited by the 14-day sampling interval, but rather includes daily measurements.