



Icicle Creek Tributary Streamflow Monitoring and Dye Tracer Study

Quality Assurance Project Plan

Office of Columbia River

Washington State Department of Ecology
Central Regional Office
Union Gap, Washington

June 2026, Publication 26-12-014

Publication Information

This document is available on the Department of Ecology's website at:

<https://apps.ecology.wa.gov/publications/summarypages/2612014.html>

Prepared for:

The Washington State Department of Ecology and Chelan County Department of Natural Resources.

Funded through the following grant from the Washington State Department of Ecology Office of Columbia River: WROCR-2527-ChCoNR-00068 and Bureau of Reclamation WaterSMART Grant No. R25AS00013

Project EIM ID: WROCR-VER1-00015

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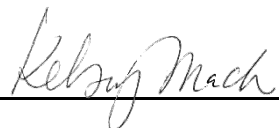
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Background and Project Description

The multi-stakeholder Icicle Working Group (IWG) comprised of diverse agricultural, conservation, and recreational interests; tribal governments; and local, state, and federal agencies, developed the Icicle Creek Water Resource Management Strategy (Icicle Strategy).^{2,3} The Icicle Strategy was developed by consensus of IWG members and established several guiding principles, including improvement of instream flow in Icicle Creek. The Icicle Strategy outlines several actions intended to support an instream flow target in lower Icicle Creek of 100 cubic feet per second (cfs) during low-flow periods in non-drought years and 60 cfs in drought years. The instream flow target is measured at the Leavenworth National Fish Hatchery (LNFH, 2025) Structure No. 2, located at River Mile (RM) 3.7 within what is referred to as the “historic channel.”

One of the key projects established as a part of the Icicle Strategy for meeting the instream flow target is the Alpine Lakes Reservoir Optimization, Modernization, and Automation Project (Alpine Lakes Project). The Alpine Lakes Project intends to improve management of lake releases from Icicle-Peshastin Irrigation District (IPID) and United States Fish and Wildlife Services (FWS) lakes located in the Alpine Lakes Wilderness where the lakes are situated. The alpine lakes consist of Colchuck, Eightmile, Klonauqua, and Square Lakes (IPID-managed) as well as the Snow/Nada Lake complex (FWS-managed). The IWG members on the Streamflow Management Subcommittee are preparing an update to the existing Lake Release Management Protocols document intended to guide implementation and long-term management of the Alpine Lakes Project.

To improve the management of lake releases, the lake release protocols must be informed by high quality data. Streamflow measurements and dye tracer studies, used in combination with other existing data sources, will provide a more complete conceptual hydrologic model. While there have been streamflow studies within the Icicle Creek basin, additional data is needed to refine our understanding of the timing, dispersion, and dilution of lake releases between the release points and the critical low-flow reach of the historic channel. The extent to which lake water is lost to transient and long-term storage in transit to the historic channel is difficult to understand from stream gage data alone. Understanding of the fate of lake releases can be improved by developing flow records for major Icicle Creek tributaries in tandem with dye tracer studies to record travel time and dispersion of water released from the lakes. This study is meant to capture flow patterns during lake release season during the late summer when the low-flow instream requirements in the Icicle historical channel are most challenging to meet.

Previous efforts to understand the response in the Icicle Creek system to lake releases have attempted to rely solely on streamflow data in the Icicle mainstem but have not been able to come to a complete understanding of the complex natural flow, artificial flow from reservoir releases, and diversions (Geosyntec, 2026a). The magnitude of short-term surface storage (side

² <https://apps.ecology.wa.gov/publications/documents/1812016.pdf>

³ <https://iciclestrategy.com/>

channels, eddies), shallow groundwater losses, and deep groundwater percolation can be better predicted through a tracer study than through conventional flow measurements alone.

Tracer studies provide the most accurate and definitive method of understanding travel time of lake releases. Additionally, measuring the percentage of dye mass recovered at monitoring points downstream of dye injection will aid in quantifying the magnitude of water losses to transient and long-term storage. While rhodamine dye can be adsorbed to the streambed and banks, making dye mass recovery an imperfect quantitative metric of storage losses (Runkel, 2015), mass recovery will provide a line of evidence for understanding storage losses in addition to analysis of flow measurements.

Lastly, the duration of the dye tracer curves and their tailing edge can help fill in knowledge gaps that hydrograph comparison alone cannot. These knowledge gaps include how long lake releases take to fully enter the historic channel, and how much flow in the historic channel is made up of lake release water versus direct surface runoff and inflow from ungaged tributaries. Physical models can be used to estimate stream processes such as groundwater storage and evaporation but are often unreliable in steep headwater streams with complex flow characteristics such as Leland and Eightmile creeks (Jacobson et al., 2026). Thus, dye tracing is a more effective method to quantify losing stream interactions. The justification for conducting a dye study has been vetted, approved, and funded by the United States Bureau of Reclamation (USBOR) and endorsed by Chelan County and the Icicle Working Group as worthwhile to advance understanding of flow in the Alpine Lakes-Icicle Creek system. The knowledge gained from this study is fundamental to the successful implementation of the Icicle Strategy.

This Quality Assurance Project Plan (QAPP), for the Icicle Creek Streamflow Monitoring and Dye Tracer Study (Study), outlines procedures for measuring streamflow within French Creek, Leland Creek, and Eightmile Creek during a season of releases from Square, Klonaqua, and Colchuck Lakes (July-October). This QAPP also describes the implementation of two dye tracer studies with dye injections downstream of the Square and Colchuck Lake outlets and downstream monitoring of the dye concentrations along the Icicle Creek study reach. The results of this study will inform the lake release protocols, annual alpine lakes trust donations, and the development of a future Icicle Creek Hydrologic Modelling QAPP.

As detailed in this QAPP, the proposed data collection and analysis methods described above aim to accomplish the following:

- Collect continuous and discrete streamflow measurements and stage readings at three locations along alpine lake tributary creeks during a full season of lake releases.
- Complete two dye tracer studies, one at the uppermost and one at the lowermost IPID alpine lakes.

The efforts under this QAPP are funded by Grant Number WROCR-2325-ChCoNR-

00050 and WROCR-2527-ChCoNR-00068 from the Washington State Department of Ecology (Ecology) Office of Columbia River (OCR), and a WaterSMART grant through the USBOR.

Study Area and Project History

The study area consists of the Icicle Creek watershed located in Chelan County, Washington, in the Wenatchee Basin (WRIA 48). This Study is a part of the ongoing Decision Support Tool project being performed under the Icicle Strategy. As a part of this project, graphs are prepared throughout the lake-release season to document lake release events. Lake release quantities and continuous flow at the lake outlets are measured. Releases are compared to the downstream gages on Icicle Creek in relation to the established instream flow guiding principles. An example graph is included below as Figure 1. These graphs are intended to help inform lake release management for improving instream flow. This Study aims to build upon ongoing and previous efforts performed within the Icicle Creek watershed under the Icicle Strategy.

Washington Department of Fish and Wildlife (WDFW) measured streamflow in both French and Leland Creeks between 2017 and 2021 (WDFW, 2020; WDFW, 2021; WDFW, 2022). Additional discrete streamflow measurements were made in Leland Creek during 2023 (WDFW, 2024). While streamflow measurements are helpful, use of these datasets to address the goals of this Study is limited because continuous lake releases from Klonauqua and Square Lakes were not monitored during the period of study. Thus, the relationship between tributary flows and lake releases is still an open question.

Periodic lake release measurements were collected in 2016, 2017, and 2019 by Aspect Consulting, LLC (now Geosyntec Consultants, Inc. [Geosyntec]) for a series of pilot lake release studies at Klonauqua, Square, and Colchuck Lakes (Aspect, 2016; Aspect, 2017; Aspect, 2018; Aspect, 2019). Further monitoring on the same lakes began in 2025 to measure reservoir stage and continuous lake releases (Aspect, 2025) and will continue into 2026⁴. These data will inform our interpretation of the dye concentration curves and tributary flow measurements to meet the Study goals.

It should be noted that in 2026, Chelan County plans to collect data under the Icicle Creek Synoptic Flow Study, which entails collection of discrete discharge measurements at up to five locations between the United States Geological Survey (USGS) gage upstream of Structure No. 2, and the Ecology gage downstream of Structure No. 2. This Study is not dependent on the results of the Icicle Creek Synoptic Flow Study (Geosyntec, 2026a) ⁵, but both should be coordinated to the extent feasible for efficiency.

⁴ [Ecology publication number 25-12-006; addendum 25-12-001](#)

⁵ [Ecology publication number 26-12-010](#)

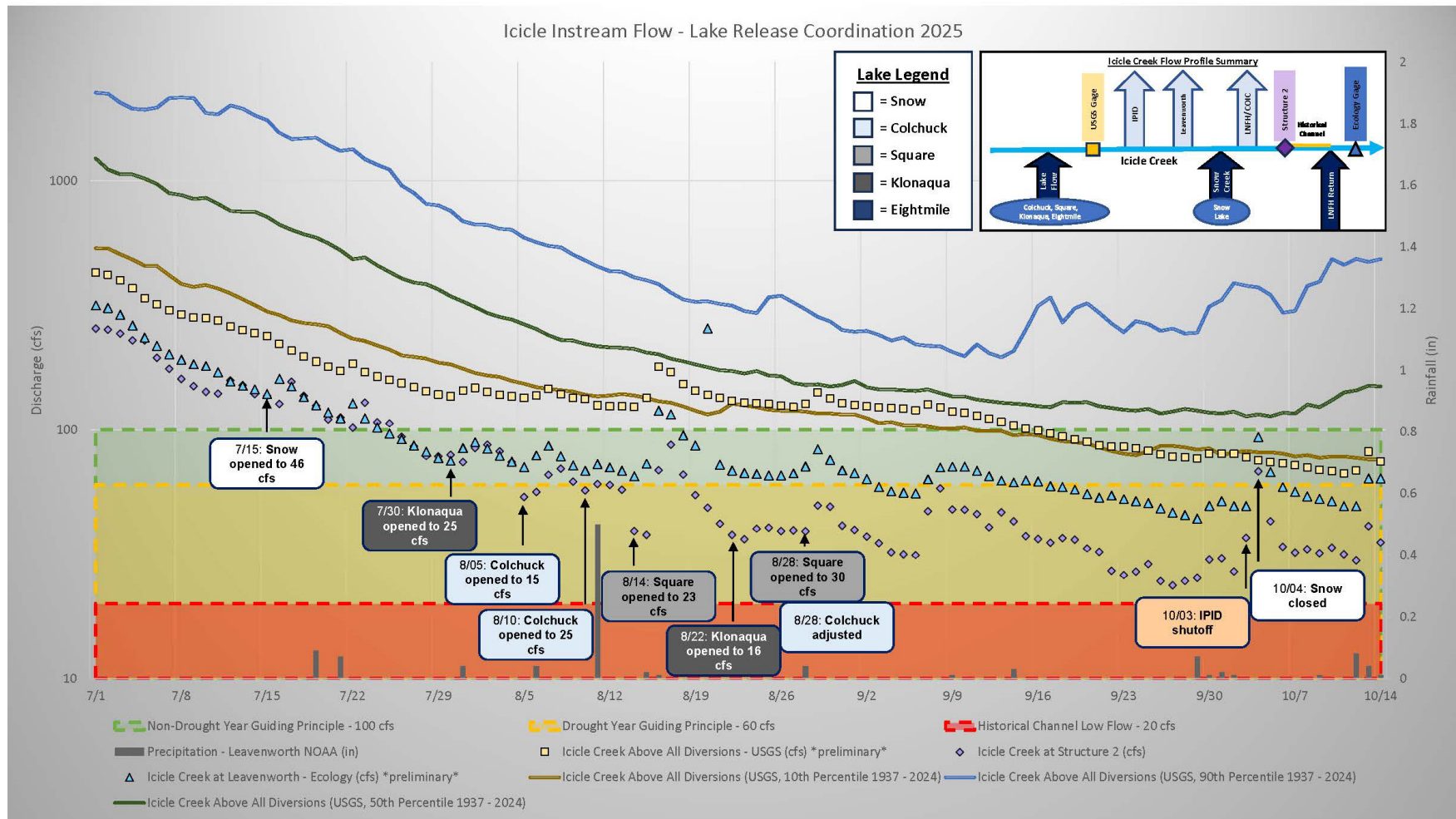


Figure 1. Daily Time Series of Lake Releases and USGS 12458000 Flow Data from Icicle Instream Flow Monitoring (Aspect, 2025)

Instrumentation and Monitoring

This section describes the instrumentation and monitoring plan for the tributary streamflow monitoring and dye tracer studies.

Tributary Streamflow Monitoring

Under this QAPP, proposed tributary streamflow monitoring entails installation of temporary streamflow gages for collection of continuous discharge measurements. Streamflow monitoring is proposed to occur at up to three locations on Leland, French, and Eightmile Creeks, tributary creeks to Icicle Creek, or alternative locations on the Icicle Creek mainstem (Alternative Locations 1 and 2; see Figure 4 in Section 4). Discrete streamflow and stage measurements will be collected to develop stage-discharge relationships for the three monitoring locations. Additionally, stilling wells will be installed at each location with a pressure transducer datalogger to collect continuous stream stage measurements. Staff plates will be installed at each location to calibrate and validate pressure transducer data. The stage-discharge curves will be used to convert the continuous stage readings into continuous discharge records.

Two of the three proposed monitoring locations (French and Leland Creeks) are downstream of Klonoqua and Square Lakes, accordingly. These two proposed monitoring sites are within the federally protected and managed Alpine Lakes Wilderness Area (ALWA) and will require special use permits from the US Forest Service (USFS). The third proposed monitoring location is on Eightmile Creek, a tributary to Eightmile and Colchuck lakes, near the confluence with Icicle Creek. This location will not require a USFS permit. The proposed locations were chosen because they are close to past monitoring locations established by the WDFW, and they allow for greater comparability with the previous studies. If USFS permits are not granted for the monitoring locations on French and Leland Creeks, two alternative locations on Icicle Creek outside of the ALWA are proposed (Figure 4; Section 4). The alternative streamflow measurement locations would not directly capture tributary inflows to Icicle Creek during lake releases but would provide useful information about Icicle Creek flow patterns during releases. The alternative locations are near the midway point of the flow path between lake releases and the historic channel. Flow in this portion of Icicle Creek is not gaged, and flow trends are not well understood. Paired with travel time, dispersion, and mass recovery data from the dye tracer studies, these streamflow data will inform the fate of lake release water.

The Chelan County Natural Resources Department (CCNRD) will use existing or rented equipment where available. To collect discrete flow measurements, field personnel will use a SonTek FlowTracker2, acoustic doppler velocimetry (ADV) meter or equivalent (Figure 2). ADVs will be deployed on a topset rod and measurements will be collected by wading across the transect as shown on Figure 3 below. The flow monitoring instrument should be selected based on site conditions and ability to collect accurate measurements based on observed site conditions (i.e., stream depth and velocity) to meet quality objectives. For locations where wading is unsafe, a SonTek RS5 Acoustic Current Doppler Profiler (ADCP) meter or equivalent (Figure 3) will be

deployed via a tethered system across the stream on a structure like the SonTek RS5 Torrentboard TBX.



Figure 2. SonTek FlowTracker2, Hach FH950 ADV meters (left, middle) and Sontek RS5 ADCP (right)



Figure 3. FlowTracker2 Monitoring Setup

Dye Tracer Studies

Two dye tracer studies will be conducted on releases from Square Lake and Colchuck Lake. The approximate paths of the two dye studies are shown on Figure 5 (Section 4). Data collected during the dye tracer studies will be used to further understand the time it takes released water to travel from the lake outlets to the historic channel of Icicle Creek, and how the dye cloud

evolves during transport. Data will include peak concentration, plume duration/width, and percentage of dye mass recovery at downstream monitoring locations.

These results will be evaluated concurrently with flow measurements at the tributary gages and the USGS gage to support interpretation of transport behavior. Additionally, discrete flow measurements will be taken during the dye tracer studies on the Icicle Creek mainstem (upstream of Leland Creek and upstream of Eightmile Creek). Gaining an understanding of how long lake release water takes to enter and pass through the historic channel, as well as a qualitative understanding of how much water is lost to storage (based on dye mass recovery percentage) will help fill key knowledge gaps. Previous analysis of the Icicle Creek system based solely on streamflow has been unable to provide a complete understanding of the contributions of natural streamflow and artificial flow from lake releases and diversions to flow measured in the historic channel. Pairing data from the dye tracer studies with streamflow data will improve future hydrologic models and lake release management. The USGS gage was selected as the downstream monitoring location as it is above the major diversions on Icicle Creek, proximal to the historic channel, and has continuous telemetered streamflow measurements.

Although these studies will use Ecology Standard Operating Procedure (SOP) EAP037 (Ecology, 2022) as guidance for study planning and travel-time monitoring practices (slug injection concept, steady-flow requirements, deployment considerations, and notification/safety), the Study objectives extend beyond the Ecology SOP EAP037 “low-level” travel-time focus because the Study also aims to characterize the shape of the dye time-concentration response (peak and duration/width) and estimate mass recovery. Accordingly, project methods will also follow relevant USGS guidance for time-concentration curve concepts, plume timing definitions (leading edge, peak, trailing edge, centroid), and interpretation of response curves (Kilpatrick and Wilson, 1989; Jobson, 1997).

Inert rhodamine WT dye will be injected at each lake outlet or directly downstream during a period of release. The location of the dye injection points is contingent on approval of a special use permit from USFS to operate within the ALWA. If we are unable to get USFS approval, then the dye for the first study will be injected at an alternative location downstream of the Colchuck Lake release location outside of the ALWA for Study 1. For Study 2, the alternative location will be downstream of the Square Lake outlet outside of the ALWA. Dye injection at these alternative locations would still allow the studies to cover a significant portion of the Icicle Creek basin, providing travel time, dispersion, and estimates of storage losses for flow along the Icicle mainstem. The use of the alternative release locations would not provide information on tributary flow characteristics for Study 2; however, data on mainstem flow patterns would still be valuable in understanding the contribution of lake releases to historic channel flow.

Rhodamine WT dye will be purchased from an Ecology-approved vendor. The dye injections will be conducted as slug releases consistent with the general approach described in Ecology SOP EAP037 (peak tracking concept) and USGS dye-tracing guidance (time-concentration response).

The two proposed dye tracer studies (Dye Tracer Study 1 [Colchuck Lake Release] and Dye Tracer Study 2 [Square Lake Release] are described below. For both studies, continuous rhodamine WT dye measurements will be collected from deployed sondes at two to three monitoring locations.. Kilpatrick and Wilson (1989) specify that a minimum of two monitoring locations are required for a tracer study, and budget for the project allows for up to three monitoring probes. The locations of the monitoring were selected to capture the anticipated variation in travel time and flow characteristics in Leland Creek, Eightmile Creek and in the Icicle Creek mainstem. Continuous or discrete turbidity measurements will be taken at the monitoring locations to provide quality control for dye concentration data.

Dye Tracer Study 1 (Colchuck Lake Release)

Dye will be injected at or directly downstream of the Colchuck Lake release outlet to Mountaineer Creek, which joins Eightmile Creek before flowing into Icicle Creek. In-Situ Aqua TROLL water quality sondes (or similar) equipped with rhodamine WT dye probes and connected to Campbell Scientific dataloggers (or internal datalogging capability) will be deployed at the following monitoring locations from upstream to downstream:

- **Tracer Study 1, Monitoring Point 1:** Eightmile Creek upstream of the confluence with Icicle Creek
- **Tracer Study 1, Monitoring Point 2:** USGS gage on Icicle Creek

Dye Tracer Study 2 (Square Lake Release)

Dye will be injected at or directly downstream of the Square Lake release outlet to Prospect Creek, which joins Leland Creek before flowing into Icicle Creek. Similar sondes to those in Dye Tracer Study 1 will be deployed at the following monitoring points:

- **Tracer Study 2, Monitoring Point 1:** Leland Creek upstream of the confluence with Icicle Creek
- **Tracer Study 2, Monitoring Point 2:** Icicle Creek upstream of the confluence with Eightmile Creek
- **Tracer Study 2, Monitoring Point 3:** USGS gage on Icicle Creek

Discrete flow measurements will be collected at the following locations during each dye tracer study:

- Each dye concentration monitoring location at the time of deployment and at a time close to the estimated dye plume arrival.
- Icicle Creek upstream of the target-tributary to aid in interpretation of downstream dye concentrations and characterize flow contributions upstream of the tributary input. Flow measurements should be collected at a time close to the estimated dye plume arrival at the tributary outlet.

- The dye injection point prior to injection, consistent with Ecology SOP EAP037 requirements.

Discrete flow measurements collected for the dye tracer studies will use the same methodology described above (ADV or ADCP meter).

To the extent feasible, the tracer studies will be completed during periods of steady flow in the tributary creeks (Leland and Eightmile Creeks) and Icicle Creek in accordance with USGS guidelines. Accordingly, 1 to 2 days following the initial lake release will be required for flow conditions to become steady as the lake outlet channels, side channels, and downstream wetlands refill. Steady flow conditions are important for interpreting travel time and response curves and will be evaluated using real-time telemetered flow data at the USGS gage, precipitation data, communication with lake outlet operators, and forecasts from the National Weather Service (NWS) weather station at Leavenworth, Washington (LVN11).

Dye Tracer Study 1 is expected to require approximately 3 to 5 days after dye injection to capture passage and the tail of the plume across monitoring sites, while the second study may last approximately 1 week due to the longer travel distance and additional dilution between the release point and the furthest downstream monitoring location at the USGS gage. These estimates are based on past observations, which indicate a 1 to 2 day travel time for initial signature of released water from Square and Colchuck Lakes at the USGS gage.

Dye Tracer Study 2 will be conducted after a waiting period of 3 to 5 days following the first study to reduce the potential for residual dye to interfere with the subsequent tracer response. Monitoring data from Study 1 will be reviewed to confirm that optical dye concentrations have returned to near background levels before Study 2 begins. If field logistics allow, travel time estimates will be refined based on the results of Study 1 prior to initiation of Study 2. Estimates will also be informed by velocity and discharge data at the monitoring locations and the USGS gage.

Ecology SOP EAP037 emphasizes that notification is important because the public may observe dye in the stream and contact local authorities. It also identifies a precautionary guideline that dye concentrations near drinking water intakes should remain below 10 micrograms per liter ($\mu\text{g/L}$). The dye concentration at the release point will be selected using the recommended methodology provided in Ecology and USGS guidance and informed by discrete flow measurements collected prior to dye release (Kilpatrick and Wilson, 1989). This methodology is described in Section 4.2.4.

The peak dye concentration planned at the downstream monitoring location is $2.5 \mu\text{g/L}$, which is well below the Ecology and EPA-recommended concentration of $10 \mu\text{g/L}$, and adequately larger than the detection limit of the dye probes ($0.5 \mu\text{g/L}$). Aiming for this concentration at the furthest downstream monitoring location should provide sufficient tracer data to satisfy the quality objectives described in Section 3. Prior to dye release, Chelan County will coordinate with staff at major downstream diversion locations on Icicle Creek (including IPID, LNFH, Cascade Orchard Irrigation Company (COIC), and the City of Leavenworth intake for their municipal water system),

along with local law enforcement, USFS park rangers, Ecology spills personnel and Ecology project management. Clear communication will be a critical component of the dye tracer studies.

Organization and Schedule

The following key individuals will be involved in planning for and conducting the data collection efforts:

- **Kelsey Mach, Geosyntec Project Manager:** Kelsey has supported CCNRD with technical and project management support for the Icicle Strategy and other projects over the last 4 years. Kelsey will serve in a project management role, overseeing Geosyntec technical support staff and facilitating coordination between Geosyntec and CCNRD.
- **Bryan Berkompas, Geosyntec Technical Lead:** Bryan is a Principal Hydrologist at Geosyntec and has over 25 years of experience collecting and analyzing stream discharge measurements, including 3 years with the FlowTracker2 and experience with other ADCP flow meters. Bryan will be trained in the release and monitoring procedures for the dye tracer studies, will direct data collection activities and data analysis, and will perform senior technical review prior to reporting.
- **Josh Gottlieb, Geosyntec Field Staff:** Josh is a technical support staff at Geosyntec with experience performing and analyzing stream discharge measurements, including with the FlowTracker2. Josh has experience analyzing and modeling data collected from dye tracer studies. He will be trained on the release and monitoring procedures for the dye tracer studies and support CCNRD as needed for field data collection and analysis.
- **Matt Holland, CCNRD Field Staff:** Matt has several years of experience collecting hydrologic data including stream discharge measurements using a variety of methodologies including the Sontek RS5 and FlowTracker2. Matt will support the field data collection and analysis for this study.
- **Mary Jo Sanborn, CCNRD Project Lead:** Mary Jo will oversee study efforts on behalf of CCNRD as the Icicle Strategy grant project lead.
- **Ingrid Ekstrom, Ecology Grant Manager:** Ingrid will provide review of the project final reporting and will be informed prior to the implementation of the dye tracer studies.
- **Robert Granger, WDFW:** Robert is the main point of contact at WDFW and was the primary author on the Leland Creek and French Creek flow monitoring studies completed by WDFW between 2017 and 2021.
- **Andi Zontek-Backstrum, City of Leavenworth Public Works Director:** Andi is the main point of contact for the City of Leavenworth and will be informed prior to the implementation of the dye tracer studies.
- **Tim Walsh, COIC Board President:** Tim is the main point of contact for COIC and will be informed prior to the implementation of the dye tracer studies.
- **Mat Maxey, LNFH Hatchery Manager:** Mat is the main point of contact at the LNFH. Geosyntec staff will coordinate with LNFH on timing of flow releases and implementation of the dye tracer studies.

- **Levi Jantzer, IPID Manager:** Levi is the main point of contact at IPID. Geosyntec staff will coordinate with IPID on timing of flow releases and implementation of the dye tracer studies.
- **Erica Taecker, USFS District Ranger:** Erica is the main point of contact at USFS and will be informed prior to the implementation of the dye tracer studies. The Chelan County will also coordinate with Erica for the USFS special use permit application.
- **Mike Morrison, Chelan County Sheriff:** The sheriff's office will be notified prior to the implementation of the dye tracer studies.
- **Seth Benge, Ecology Central Regional Office Lead Spill Responder:** The Ecology's CRO Spill Prevention, Preparedness, and Response program will be notified prior to the implementation of the dye tracer studies at the following contact information: seth.benge@ecy.wa.gov and 509-406-2571.

Monitoring will occur over the lake release season (July through October). The anticipated schedule for the study period is provided below as Table 1. Depending on the timing of QAPP approval and USFS permitting, data collection may be required to begin in 2027, in which case the anticipated schedule would project forward one year.

Table 1. Anticipated Schedule for Study Period

Month	Activity
March 2026 to July 2026	• Finalize QAPP • Acquire or rent equipment • Coordinate with stakeholders • Acquire USFS permitting
July to October 2026	Data Collection: • Deploy tributary streamflow gages with staff plates and pressure transducers (3) • Collect periodic discrete streamflow measurements at tributary monitoring locations • Dye Tracer Study 1 for Colchuck Lake (3-5 days; 3-5 additional days of waiting to allow dye to settle out before beginning Dye Tracer Study 2) • Dye Tracer Study 2 (Square Lake) release (4-7 days)
October to December 2026	• Data Entry • Verification and Analysis
January 2027	• Ecology's Environmental Information Management Submittal • Final Report Submittal

Schedule Constraints

Site selection for the flow monitoring locations is contingent on securing a special use permit from the USFS. Schedule constraints include approval of the QAPP, funding from the Reclamation WaterSMART program, approval of the USFS special use permit, coordination with downstream diverters (COIC, IPID, City of Leavenworth, and LNFH) during the tracer study, wildfire and air quality conditions, precipitation events, acquiring equipment from vendors, and flow conditions in the stream.

Real-time streamflow data from the USGS Icicle Creek gaging station (USGS 12458000) and the NWS Leavenworth (LVN11) weather station will be used to verify steady-flow conditions prior to each dye tracer study. Timing of lake releases will be coordinated with the Lake Release Subcommittee which includes IPID, Ecology, WDFW and LNFH. Flow conditions will be considered steady when the following occur:

- The hourly flow hydrograph at the USGS gage is free from significant variation.
- 1 to 2 days have elapsed since the onset of lake release.
- No or minor measurable precipitation has occurred for at least 24 hours preceding field activities.
- No or minor measurable precipitation is forecasted for the next 7 days.

Quality Objectives

Data Quality Objectives

The data quality objectives (DQOs) for this project are to:

- Collect reliable and continuous streamflow records for Leland, French and Eightmile Creeks or alternative locations on the mainstem Icicle outside of the ALWA.
- Gather dye tracer data that consists of well-defined tracer curves for determining travel time, dye plume characteristics including peak concentration and duration, and dye mass recovery percentage.
- Confirm the collected streamflow and dye tracer data are of known and documented quality such that analysis of the fate and travel characteristics of lake water releases can be assessed.

These DQOs are supported by the Measurement Quality Objectives (MQOs) described below, which establish quantitative and qualitative acceptance criteria for individual data quality indicators.

Measurement Quality Objectives

The analysis will use standard methods to obtain data that meet the MQOs described below and that are comparable to previous and future study results. MQOs include procedures to address the following measurement quality categories, with additional details provided in further sections of this QAPP:

- **Precision**
Precision describes the agreement among replicate measurements and reflects random variability in the data. Precision is evaluated in this study using duplicate measurements and expressed using Relative Percent Difference (RPD).
- **Bias**
Bias is the systematic difference between measured values and the true value. Bias is minimized in this study through instrument calibration, use of standards and reference checks, and comparison of independent measurements.
- **Sensitivity**
Sensitivity refers to the ability of a method or instrument to detect and reliably measure a parameter at low concentrations or small magnitudes. Sensitivity is addressed in this study by selecting sensors with appropriate detection limits and measurement resolution.

- **Comparability**

Comparability is the degree to which data can be consistently compared across studies, locations, or time periods. Comparability is achieved in this study through the use of standardized methods, procedures, and protocols.

- **Representativeness**

Representativeness describes how well the collected data reflect actual environmental conditions at the time and location of sampling. Representativeness is addressed in this study through site selection, sampling design, and field condition requirements.

- **Completeness**

Completeness is the proportion of valid and usable data obtained relative to the planned data collection effort. It is a measure of whether sufficient data were collected to meet study objectives. The proposed methodology is intended to maximize the likelihood that adequate data is collected to meet study objectives.

The accuracy and sensitivity specifications for field instrumentation used in this project are provided in Table 2.

Table 2. Monitoring Field Equipment Information

Parameter	Equipment/Method	Accuracy	Resolution	Range	Detection Limit
Velocity	ADCP Meter (SonTek-RS5)	1% or +/-0.007 ft/s	0.003 ft/s	+/-16.4 ft/s	NA
Water Level	ADCP Meter (SonTek-RS5)	1% or +/-0.016 ft	--	0.328-19.7 ft	NA
Velocity	ADV Meter (FlowTracker2)	±1.0% of measured velocity	0.0003 ft/s	±0.003 to 13 ft/s	NA
Water Level		0.1 ft (rod)	0.1 ft (rod)	--	NA
Water Pressure (height of water column)	Van Essen TD-Diver DI801	±0.02 ft	0.007 ft	0 - 32.8 ft	NA
Water Stage	Staff Plate	0.02 ft	0.02 ft	--	NA
Rhodamine WT Dye	Rhodamine Dye Probe (In-Situ)	NA	0.001 RFU6	0-100 RFU 0-1000 µg/L	0.5 µg/L

⁶ Relative Fluorescence Unit

Parameter	Equipment/Method	Accuracy	Resolution	Range	Detection Limit
Turbidity	Turbidity Probe (In-Situ)	$\pm 2\%$ of reading or ± 0.5 NTU, whichever is greater	0.01 NTU from 0-1000; 0.1 NTU from 1000-4000	0-4000 NTU	NA

Notes:

ft = feet

ft/s = feet per second

$\mu\text{g/L}$ = micrograms per liter

NTU = Nephelometric Turbidity Unit

RFU = Relative Fluorescence Units

Details on how MQOs will be met for streamflow, stage, and dye concentration measurements are included in the following sections.

Streamflow

The MQOs for the proposed streamflow discharge measurements will consist of qualitative and quantitative assessments. The qualitative assessment is intended to be consistent with Ecology (SOP EAP056) and USGS Techniques and Methods 3-A8 and is based on factors like channel condition at the transect, velocity patterns, change in stage during measurement, wind and weather conditions, number of measurement points, etc. The qualitative assessment will determine if the physical conditions within the transect at the time of the measurement were “excellent,” “good,” “fair,” or “poor.” The sites will be located far enough upstream of confluences to prevent disturbances in the stage-discharge relationship. Stable stream controls free of debris or vegetation will be used in selecting gage locations, following guidance in Ecology SOP EAP024 (Ecology, 2026; unpublished). Discharge measurements will be taken in transects close to the stage sensors to confirm the stage-discharge curves are representative of instream conditions.

The quantitative assessment will make use of internal uncertainty calculations performed by the FlowTracker2 and RS5 and replicate measurements at one of the monitoring locations during each field event. Bias will be evaluated by performing routine calibration checks on the flow meters. Both the FlowTracker2 and RS5 use International Organization for Standardization (ISO) 748 (2007) to estimate an overall measurement uncertainty percentage. Uncertainty of 5 percent or less would be considered excellent, and between 5 percent and 10 percent would be considered usable. If the uncertainty is greater than 10 percent, the measurement should be discarded and repeated in the field, adjusting the transect or methods as needed to reduce the uncertainty.

Precision will be addressed by taking replicate flow measurements. A replicate measurement will be compared with the initial measurement using the relative percentage difference (RPD). A RPD of 5 percent or less represents a “good” rating. An RPD between 8 percent and 10 percent will be “qualified” but still deemed usable for the purpose of this study, although a replicate should be recollected if time allows to get a better reading. Data with an RPD of greater than 10 percent will be deemed invalid and the replicate should be re-collected as needed with the goal of collecting a higher quality measurement.

Stage

The MQOs for stream stage measurements collected using staff plates and pressure transducer dataloggers (Van Essen TD-Diver DI801, or equivalent) are intended to confirm that continuous stage data are accurate and stable over time. Stilling wells will be used to dampen surface unsteadiness and provide a stable hydraulic connection between the stream and the pressure transducer sensor. Pressure transducer performance will be verified using pre- and post-deployment sensitivity checks using the two-depth bucket method described in Ecology SOP EAP024 (Ecology, 2026; unpublished). These checks will confirm that the sensitivity of the sensors is acceptable and detect potential bias in readings.

Staff plate readings will be recorded during each site visit and used to verify the continuous pressure transducer record (including evaluation of potential drift) consistent with Ecology guidance (EAP042) for gage height measurement and correction of continuous stage records. Staff plate readings will be recorded to the nearest 0.01 ft. Pressure transducers will be inspected during each site visit; data will be downloaded and reviewed for gaps or anomalies and compensated with barometric pressure datalogger data. Inspecting the downloaded files will confirm comprehensiveness of the data. Any corrections applied to the continuous stage record (e.g., drift correction) will be documented as part of data verification and validation. To confirm representativeness of stage data, care will be taken to redeploy pressure sensors in the same position following each download. Additionally, sensors will be deployed close to the locations selected for streamflow measurements, and near (or attached to) the staff plates.

Rhodamine WT Dye Concentration

Consistent with Ecology SOP EAP037 and USGS guidance, interpretability and consistency of dye response curves are prioritized over strict numerical precision for travel time and dispersion studies (Kilpatrick and Wilson, 1989; Wilson et al., 1986); however, dye probes will be calibrated to confirm accuracy following U.S. Environmental Protection Agency (USEPA) guidance (2017), in addition to procedures provided by the instrument manufacturer. Calibration procedures for the dye probes are described in Section 5.3.2.1.

The objective of the dye tracer studies is to collect dye concentration time series data that clearly resolves dye arrival, peak concentration, and recession at each downstream monitoring location. These data will be used to evaluate travel time, plume dispersion characteristics, and relative dye mass recovery. Under steady flow conditions, the time concentration response at a fixed downstream monitoring location is expected to approximate a unimodal, positively skewed

distribution, characterized by a rapid leading edge, a distinct peak concentration, and a longer trailing edge. This response shape is well documented in dye tracer literature and forms the basis for interpretation of travel time, dispersion, and plume duration metrics (Kilpatrick and Wilson, 1989; Wilson et al., 1986).

Dye concentration time series meeting the objectives of this Study shall exhibit a single, well-defined peak above background fluorescence, with a coherent rising and falling limb consistent with expected transport behavior. The plume response should be sufficiently resolved to identify the time of first arrival, time of peak concentration, and effective plume duration. Minor deviations from ideal plume characteristics are expected due to channel complexity, transient storage, and longitudinal dispersion, and they will not invalidate the data. If these qualitative conditions are met, the data will be considered suitable for travel time and dispersion analysis.

To produce a clear peak concentration, the volume of dye to be injected will be calculated following the procedure described in Section 4.2.4. Initial estimates of required dye to be injected are shown in Appendix B. Aiming for a peak concentration of 2.5 µg/L at the downstream monitoring station should confirm that the dye concentration is significantly above the detection limit of the rhodamine probes. This will allow sufficient resolution in the dye curves to locate a clear peak concentration and trace the arrival and passage of dye. Meeting the quality objectives for this study will provide data on the exact passage of lake release water into the historic channel. This will explain the extent of dispersion of the water released from the lakes, and the particular portion of the flow record at the USGS gage which is influenced by lake releases during the studies. A well-defined set of tracer curves will also allow for calculation of the percentage of dye mass recovered (Equation 5; Section 8.2). Dye mass recovery will be analyzed in conjunction with streamflow data to assess the extent to which lake release water may be lost to storage in transit to the historical channel.

Background signal, (i.e., positive dye concentration readings in the absence of injected dye), may arise from natural organic matter, turbidity, scattered light, or other fluorescent materials commonly present in streams (Wilson et al., 1986). Background signal will be minimized through careful deployment so that representativeness of the dye concentration data is achieved. The sondes will be deployed using PVC casings to protect and shade the sensor. Deployment locations will be selected to provide shade, avoiding sun-exposed reaches.

Turbidity will be measured using turbidity probes attached to the water quality sondes to assess the potential for interference with optical rhodamine fluorescence measurements or using handheld turbidity meters. Turbidity measurements will be taken at each monitoring location continuously throughout each field deployment or at least every visit to the monitoring location. Bias in the turbidity measurements will be addressed by calibrating turbidity probes before and after field deployment, and by performing mid-deployment field checks with a reference probe as described in Ecology SOP EAP129 (Ecology, 2019d).

Outside Data

Data from previous studies conducted by WDFW on Leland and French Creeks will be used to inform elements of the proposed study design (WDFW, 2020; WDFW, 2021; WDFW, 2022; WDFW, 2024). Collectively, these WDFW efforts evaluated streamflow conditions, channel geometry, and hydraulic relationships in Icicle Creek and key tributaries, including French and Leland Creeks, using a combination of field measurements, hydraulic analyses, and empirical relationships across a range of discharge rates. Where relevant, stage-discharge relationships developed in these reports will be reviewed in relation to the results of the present Study.

This project will also use data from the ongoing Alpine Lakes Flow Augmentation study being funded by Ecology and led by Chelan County (Aspect, 2025), which will include continuous discharge measurements downstream of release points. Lake release measurements collected concurrently as part of the Alpine Lakes Flow Augmentation study⁷ (Aspect, 2025) will be used to inform this Study. In addition, results from earlier Alpine Lakes Flow Augmentation studies may be referenced to provide supporting context and comparison for interpreting streamflow and dye tracer measurements, where appropriate (Aspect, 2016; Aspect, 2017; Aspect, 2019; Aspect, 2025).

The Icicle Creek Synoptic Flow Study is anticipated to occur concurrently with this Study (Geosyntec, 2026b). Data from the Icicle Creek Synoptic Flow Study will include continuous flow records at numerous locations along the Icicle Creek mainstem between the USGS gage and Ecology gage. To the extent feasible, field activities for both studies will be coordinated so that lake release data is collected during the streamflow and dye tracer studies.

Streamflow data from the USGS gaging station on Icicle Creek (USGS gage 12458000 at River Mile 5.8) will be used to characterize background hydrologic conditions, assess steady-flow assumptions during dye tracer studies, and will be key to analysis of the travel time and characteristics of released lake water. USGS streamflow data are collected and managed in accordance with the Surface-Water Quality Assurance Plan of the USGS Washington Water Science Center (Mastin, 2017). The Surface-Water Quality Assurance Plan documents established procedures for gage operation, calibration, data review, and validation.

⁷ [Ecology publication number 25-12-006; addendum 25-12-001](#)

Study Design

This section describes the design of the streamflow and dye tracer studies that will occur over the course of this Study. A map of the proposed sampling locations is included as Figures 4 and 5 below.

Tributary Streamflow Monitoring

This section describes the Study design for the tributary streamflow monitoring.

Sampling Locations and Frequency

Temporary streamflow gages will be installed at three Alpine Lake tributary locations throughout the Study period on Leland, French, and Eightmile Creeks, or the alternative locations. The continuous flow data will be analyzed with the release discharge measurements from the Alpine Lakes Flow Augmentation study (Aspect, 2025) to inform the travel time and gain/loss of released lake water. The Study area and streamflow monitoring locations are shown below on Figure 4. Exact flow monitoring transect locations may be slightly upstream or downstream of the locations shown on Figure 4, and will be selected following guidance in SOP EAP056 and USGS Techniques and Methods 3-A8 as described in Section 3 above.

The proposed monitoring locations near the mouths of Leland and French Creek are dependent on gaining a special use permit from USFS for the federally-managed ALWA. Two alternative measurement locations are proposed in the event that a special use permit is not received in time for the monitoring season. The alternative measurement locations would provide useful data for flow responses on the mainstem Icicle Creek during lake releases. While utilizing these alternative locations would not provide direct flow measurements of Leland and French Creek, measuring flow in Icicle Creek downstream of these tributaries and upstream of the stream gage on Eightmile Creek would capture flow in key reaches of the system where flow patterns are currently unrecorded. Alternative Location 1 is intended to capture flows from the upper basin tributaries including Leland and French Creek. Alternative 2 is intended to provide an additional flow measurement along the Icicle Mainstem and inform tributary inflows and losses downstream of Alternative 1 monitoring location. In concert with dye tracer data, the flow data will provide information on how long it takes lake releases to travel through the system and how much water is lost in transit to the historic channel.

During the initial site visit to each location, field staff will install a stilling well with a pressure transducer for measuring continuous stream stage, along with a staff plate for manual stage readings. A barometric pressure transducer will be installed at each location for compensation of the stage pressure transducer readings. Field staff will also collect a discrete flow measurement using an ADV or ADCP meter. The coordinates of each flow sampling location will be recorded,

along with relevant site conditions. Survey flags may be used to mark the locations for future reference and ease of access.

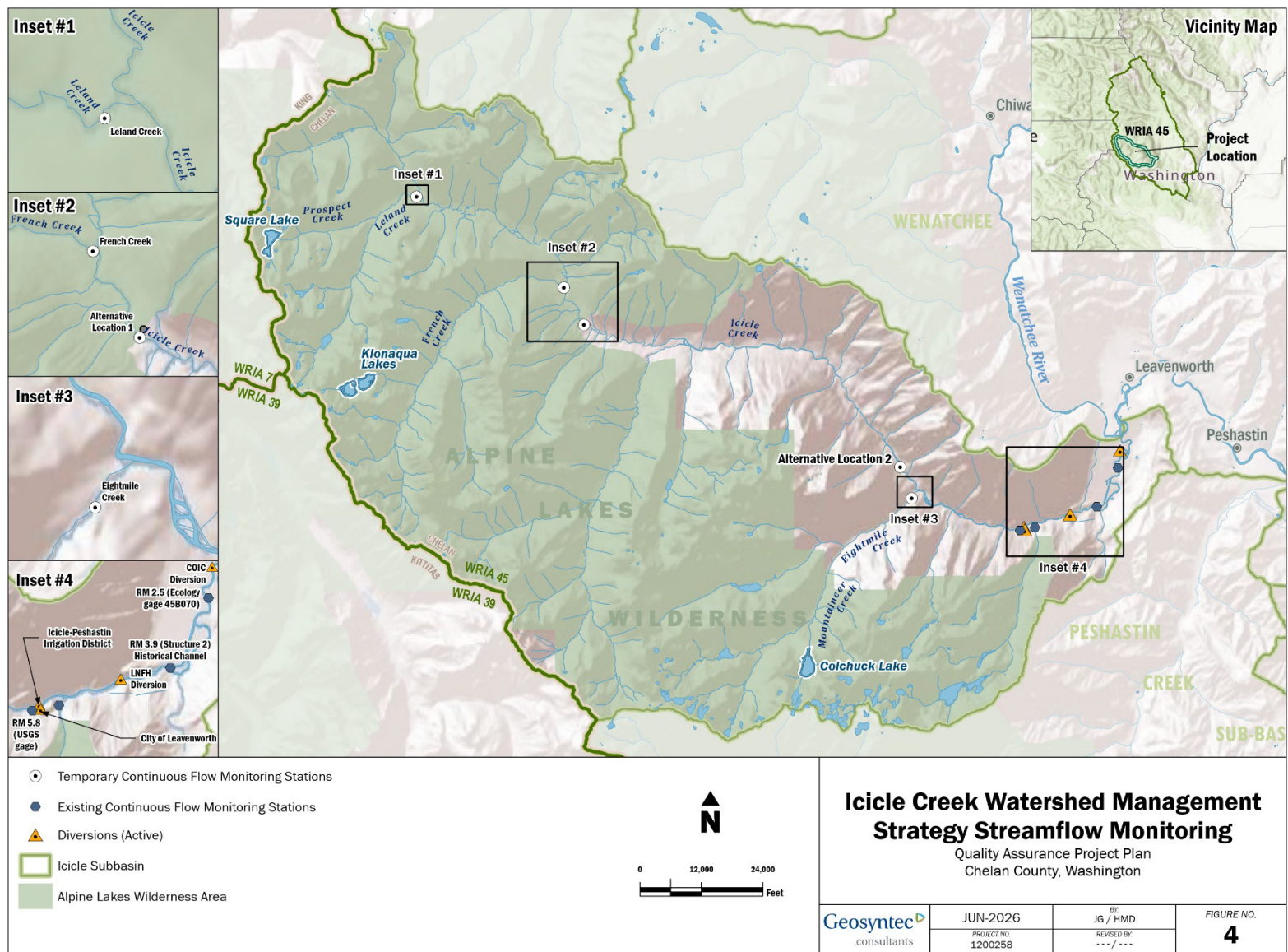


Figure 4. Map of Study Area for Streamflow Monitoring

The USGS recommends 10 measurements over the course of a year to establish a stage-discharge curve covering both high-flow and low-flow seasons. Given the remote location and limited access of the monitoring sites, monthly visits throughout the Study period are proposed in order to collect discrete flow and stage measurements. This frequency is similar to recommendations from the USGS of one measurement every 5 to 6 weeks (Rantz, 1982). The aim of this study is to capture flow patterns during a lake release season, not an annual hydrograph. Therefore, monthly discharge measurements are thought to be adequate for the purpose of this Study to establish stage-discharge curves for converting continuous stage measurements to continuous flow.

At each site visit, stage measurements will be recorded from the staff plate and data from the pressure transducers will be downloaded. All data collection procedures will adhere to standard operating procedures to confirm consistency and reliability. The location of the proposed and alternative streamflow monitoring sites are listed in Table 3.

Table 3. Tributary Streamflow Monitoring Sites (Alternative Locations Shown in Orange)

Name	Latitude, Longitude	River Mile	Monitoring Equipment
French Creek	47.62835, -120.96325	4.3	Pressure transducers and the staff plate installed for continuous monitoring; ADV for discrete measurements
Icicle Creek Alternative Location 1	47.61515, -120.95322	21.1	Pressure transducers and the staff plate installed for continuous monitoring; ADV or ADCP for discrete measurements
Leland Creek	47.66134, -121.04273	0.1	Pressure transducers and the staff plate installed for continuous monitoring; ADV for discrete measurements
Icicle Creek Alternative Location 2	47.56380, -120.78411	10.2	Pressure transducers and the staff plate installed for continuous monitoring; ADV or ADCP for discrete measurements
Eightmile Creek	47.55252, -120.77798	0.3	Pressure transducers and the staff plate installed for continuous monitoring; ADV for discrete measurements

Dye Tracer Studies

Two dye tracer studies will be conducted during the Study period. The studies are designed to evaluate travel time, plume characteristics (peak concentration, duration), and relative dye mass recovery for water released from Square and Colchuck Lakes traveling downstream to the USGS gage. The proposed locations and path of dye release, alternative dye injection locations, and downstream measurement locations for dye plumes are shown on Figure 5 below. If a permit is not obtained to inject dye at the primary locations within the ALWA dye will be injected at the alternative locations listed in Table 4.

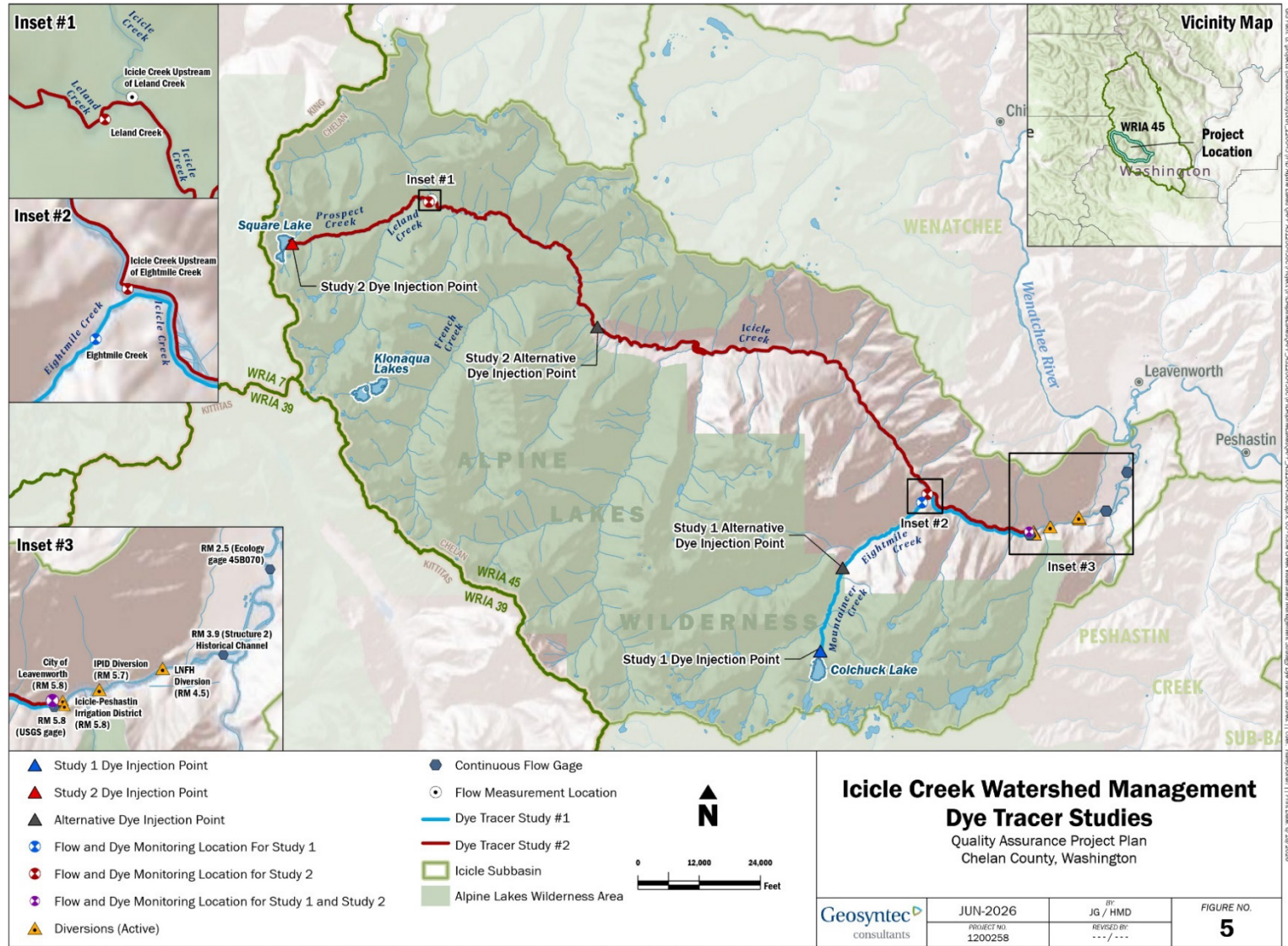


Figure 5. Map of Study Area for Dye Tracer Studies

The USGS gage was selected as the downstream monitoring point because it is upstream of major diversions and the Snow Lake tributary, proximal to the historic channel, and has available real-time streamflow data. Previous studies relying on streamflow alone to understand the transport and loss of lake release water in transit to the historic channel have not been able to capture the hydrologic dynamics of the Icicle system. The tracer study will provide information on exactly how long it takes lake release water to travel to the historic channel. By tracing the lake water, the response of the USGS hydrograph during dye passage can be used to measure exactly how much flow from the lake makes it to the historic channel. The recovery percentage of the dye at the USGS gage will also provide evidence to support understanding of how much lake water may be lost to transient and long-term storage in groundwater, backwater, and wetlands. This information will inform lake release management by providing evidence for how much lake water must be released to meet instream flow requirements.

Each study will consist of a single slug injection of inert rhodamine WT dye in the thalweg (fastest moving section) of the stream at or downstream of the lake release point, with continuous downstream monitoring of dye concentration coordinated with concurrent lake release and streamflow measurements as described in detail below.

1.1.1 Sequencing

Dye Tracer Study 1 will occur during a controlled release from Colchuck Lake and will be followed by Dye Tracer Study 2 that will occur during a release from Square Lake. Dye will be released in the thalweg of the stream by a field staff. GPS coordinates of the dye release location will be recorded. The proposed sequencing will allow sufficient time for residual dye from the first study to attenuate and settle prior to the injection for the second study, consistent with USGS and Ecology guidance (Ecology, 2022; Kilpatrick and Wilson, 1989). Each study will extend over multiple days to allow full capture of dye plume arrival, peak concentration, and recession (tailing) at all monitoring locations.

Dye Concentration Monitoring

Two to three downstream monitoring locations will be established for each tracer study. Each location will be monitored using a water quality sonde equipped with a rhodamine WT sensor and installed within the approximate center of the stream. The sondes will either log data internally at a set interval or be connected to a datalogger for continuous recording. Water quality monitoring equipment will be deployed prior to initiation of the dye release to monitor background fluorescence. Installation will take place during a streamflow site visit, or as a separate field event. Deployment timing will be based on coordination with IPID staff on lake release scheduling, weather forecasts, and steady flow conditions at the downstream USGS gage. Dye monitoring at each location will continue through recession of the dye signal, defined by the background fluorescence concentration or concentrations near the instrument detection limit (0.5 µg/L). At minimum, the locations will include monitoring at the mouth of Eightmile and Leland creeks and the USGS gage on Icicle Creek (the furthest point downstream). Exact monitoring locations will be selected to perform the following:

- characterize dye transport within tributary creeks downstream of lake releases,
- measure dye transport through Icicle Creek upstream of major diversions, and
- support interpretation of dilution and relative mass recovery by pairing dye concentration measurements with concurrent flow measurements.

An additional intermediate dye concentration monitoring location is proposed for the Dye Tracer 2 Study (Square Lake), given the length of stream between the release point and downstream monitoring point.

Selection of monitoring locations will balance spatial coverage with Study goals, logistical constraints, and permitting constraints, and will avoid backwater conditions, eddies, or hydraulic controls that could bias measurements. Turbidity will be measured continuously using turbidity probes attached to the sondes during the studies or with handheld turbidity meters. These turbidity data will help establish any potential patterns of interference with the optical rhodamine probes. Proposed locations for field monitoring, associated field activities, and equipment details for the two dye tracer studies are provided in Table 4 below.

If the alternative injection location is used for Tracer Study 1, the dye monitoring stations will stay the same. For Tracer Study 2, if the alternative injection point is used, the dye monitoring stations will not include the Leland Creek location, but the other monitoring locations will remain the same.

Flow Measurements During Dye Studies

The dye tracer studies will be scheduled to coincide with monthly tributary streamflow measurement events to the extent feasible. Additional discharge measurements will be collected during each dye tracer study at the dye monitoring locations; upstream of the corresponding tributary mouths on Icicle Creek; and dye release points (at time of release) to characterize flow conditions during tracer transport. If the alternative injection location is used for Tracer Study 1, the flow monitoring stations will stay the same. For Tracer Study 2, if the alternative injection point is used, the flow monitoring stations will not include the Leland Creek location or upstream of Leland Creek on Icicle, but the other monitoring locations will remain the same.

At each dye monitoring location, at least two discrete discharge measurements will be taken over the course of each study: during sonde deployment, and near the time when the dye plume is estimated to arrive. The discharge measurements taken upstream of the mouth of the corresponding tributaries on Icicle Creek will aid in interpretation of downstream dye concentrations and help characterize flow contributions upstream of the tributary input.

Dye Injection Volume Estimation

The volume of 20% rhodamine WT dye solution will be estimated using the following relationship (Kilpatrick and Wilson, 1989):

Equation 1

$$V_s = 3.4 \times 10^{-4} \left[\frac{Q_m L}{v} \right]^{0.94} C_p$$

where:

V_s = volume of 20 percent rhodamine WT dye solution (liters)

Q_m = maximum stream discharge at the USGS monitoring location (cfs), based on real-time USGS gage data at the time of release

L = distance from injection point to downstream monitoring location (miles)

v = mean stream velocity (ft/sec)

C_p = target peak dye concentration at the downstream monitoring location (2.5 µg/L). This will help record a measurable signal, while keeping concentrations below the USGS recommended upper limit for drinking water intakes of 10 µg/L (Kilpatrick and Wilson, 1989).

Calculated estimates for dye concentrations at key points along the study reaches (using Equation 1) are shown in Appendix B. These estimates will be refined based on velocity and streamflow readings taken during field events preceding the dye studies. Stream velocity measurements taken at the USGS gage for the discrete flow measurements will be averaged with velocity measured at the applicable tributary monitoring location (i.e., Eightmile Creek for Colchuck Lake study, Leland Creek for Square Lake study) and weighted based on stream segment length to develop mean stream velocity. In both cases, velocities measured in the middle of the stream transect will be taken as representative values. Based on the range of expected flows and stream velocities, we expect 2 to 8 liters (L) of 20 percent rhodamine dye will be needed to reach the target concentrations at the USGS gage for each study.

Mixing Considerations

Adequate lateral and vertical mixing is required for measured dye concentrations taken in the center of the channel to be representative of the full channel cross section. Monitoring locations have been selected so that their distances downstream of injection points and tributary confluences exceed estimated mixing lengths, consistent with USGS guidance. Vertical mixing occurs more rapidly than lateral mixing, so distances between monitoring locations will be confirmed to meet requirements for lateral mixing. Requisite lateral mixing lengths will be estimated using the relationship presented by Kilpatrick and Wilson (1989):

Equation 2

$$L_m = 0.1 \frac{W^2 U}{E_z}$$

where

L_m = length of channel required for optimal lateral mixing (ft),

W = average channel width (ft),

U = mean stream velocity (ft/s), and

E_z = lateral mixing coefficient (ft²/s).

The same average velocity calculated for Equation 1 above will be used for Equation 2. The lateral mixing coefficient E_z can be estimated using the depth and slope of the stream. Monitoring locations will be placed at distances greater than the estimated lateral mixing length where feasible to minimize bias associated with incomplete mixing.

Duration of Field Activities

Estimated travel times and duration of the tailing end of the plume will determine the required duration of field monitoring for each tracer study. Each study is anticipated to take between 3 days to 1 week, with at least 3 days between each study. Measurement of background fluorescence will occur during the deployment of the water quality sondes. Additional background fluorescence measurements may be taken prior to the start of Study 1 during field deployments to measure stream flow and set up the stream gage stations. Following Study 1, additional background measurements at each dye monitoring location will be taken to confirm that dye concentrations have returned to near pre-study background fluorescence levels. Water quality sondes will remain deployed for the full duration of plume passage to capture first arrival, peak concentration, and recession at each monitoring location.

Table 4. Monitoring Locations for Dye Tracer Studies (Alternative Locations Shown in Orange)

Name	Study	Latitude, Longitude	River Mile	Monitoring Equipment	Field Activities
Tributary to Mountaineer Creek - Colchuck Lake Release	1	47.498969, -120.832552	2.9	Rhodamine WT dye and flow meter	Take flow measurement prior to dye release. Release rhodamine dye.
Study 1 Alternative Release Location	1	47.526988, -120.821709	0.7	Rhodamine WT dye and flow meter	Alternative location for dye release for Dye Tracer Study 1 (in Mountaineer Creek) if USFS permit is not granted. Take flow measurement prior to dye release. Release rhodamine WT dye.
Eightmile Creek - Mouth	1	47.55252, -120.77798	0.3	Flow meter, Rhodamine WT dye sensor, turbidity sensor	Install water quality sonde prior to dye release. Take flow measurement during sonde deployment and near time when dye plume will reach the location. Record turbidity and rhodamine measurements continuously during each deployment. Perform field check using a reference turbidity probe during at least one site visit.
Icicle Creek - USGS Gage	1, 2	47.5409214 7, - 120.720059	6.4	Flow meter, Rhodamine WT dye sensor, turbidity sensor	Install water quality sonde prior to dye release. Take flow measurement during sonde deployment and near time when dye plume will reach the location. Record turbidity and rhodamine WT dye measurements continuously during each deployment. Perform field check using a reference turbidity probe during at least one site visit.
Prospect Creek – Square Lake Release	2	47.646580, -121.116173	2.7	Rhodamine WT dye and flow meter	Take flow measurement prior to dye release. Release rhodamine WT dye.
Study 2 Alternative Release Location	2	47.61515, -120.95322	21.1	Rhodamine WT dye and flow meter	Alternative location for dye release for Dye Tracer Study 2 (in Icicle Creek) if USFS permit is not granted. Take flow measurement prior to dye release. Release rhodamine WT dye.
Icicle Creek - Upstream of Eightmile Creek Confluence	2	47.555562, -120.775098	9.5	Flow meter, Rhodamine WT dye sensor, turbidity sensor	Install water quality sonde prior to dye release. Take flow measurement during sonde deployment and near time when dye plume will reach the location. Record turbidity and rhodamine WT dye measurements continuously during each deployment. Perform field check using a reference turbidity probe during at least one site visit.

Leland Creek - Mouth	2	47.66134, -121.04273	0.1	Flow meter, Rhodamine WT dye sensor, turbidity sensor	Install water quality sonde prior to dye release. Take flow measurement during sonde deployment and near time when dye plume will reach the location. Record turbidity and rhodamine WT dye measurements continuously during each deployment. Perform field check using a reference turbidity probe during at least one site visit only if USFS permit is received.
Icicle Creek Upstream of Leland Creek Confluence	2	47.662180, -121.041213	28.6	Flow meter	Take flow measurement prior to dye release.

Possible Challenges and Contingencies

Logistical problems beyond the control of Geosyntec and Chelan County that interfere with data collection may occur given general equipment challenges and the particularly remote and difficult to access monitoring locations. These problems include the following:

- **Site Access:** Adverse weather or logistical constraints may impede access to certain remote monitoring locations. Field teams will monitor conditions and adjust the schedule as needed.
- **Equipment Functionality:** Technical issues with pressure transducers, dye probes, or flow meters may arise. Equipment will be tested and calibrated prior to deployment. Backup pressure transducers will be included in the field kit.
- **Permitting:** Inability to obtain a special use permit from USFS will result in using the alternative locations (outside of the ALWA) to measure flow on the Icicle Creek mainstem. This would also require an updated injection point for the dye studies.
- **Flow Conditions:** Steady flow is required for the dye tracer studies, and the studies will be defined by hourly flows reported at the USGS gage, no or minor measurable precipitation for 24 hours preceding each study, as well as 7 days with no or minimal forecasted precipitation.
- **Reliable Dye Concentrations:** Dye dispersion can lead to weak or atypical optical measurements at downstream monitoring locations, particularly for long study reaches. Intermediate monitoring stations between the dye release points and the USGS gage are proposed to improve the likelihood of collecting usable data.
- **Timing of Discrete Flow Measurements During Dye Studies:** USGS guidance (Kilpatrick and Wilson, 1989) specifies that discharge should be measured during dye passage. Since we will have continuous flow gages established during the dye tracer studies, we will have data on flow at those locations if a live reading of discharge during plume passage is not obtained.

Any issues encountered will be documented by the field team, and additional site visits may be scheduled if deemed necessary to confirm completeness and representativeness of the data. The dye tracer studies will need to be completed during the lake release period during the late summer, in order to target the fate of released water, and capture low flow dynamics.

Field Procedures

This section outlines general procedures to be followed for field deployments of streamflow monitoring equipment and monitoring probes for the dye tracer studies.

Invasive Species Evaluation

Field staff will follow Ecology's SOP EAP070 (publicly available in digital format on Ecology's website), minimizing the spread of invasive species (Ecology, 2024). At the end of each field visit, field staff will clean field gear in accordance with SOP EAP070 to minimize the spread of invasive species for areas of both moderate and extreme concern.

Field staff will minimize the spread of invasive species after conducting field work by inspecting and cleaning all equipment, removing any visible soil, vegetation, vertebrates, invertebrates, plants, algae, or sediment. Then, if necessary, a scrub brush and clear water will be used to rinse all equipment that was brought from the site or for cleaning. This process will continue until all equipment is clean.

Measurement and Monitoring Procedures

This section details measurement and monitoring procedures for streamflow/stage measurements and dye concentration monitoring. Appendix A includes a field procedures checklist for the FlowTracker2 and RS5.

Streamflow Monitoring

Procedures for installing stage measurement equipment, taking streamflow measurements, and recording measurement data will follow Ecology and USGS SOPs and guidance. SOPs to be followed are publicly available in digital format online and include the following:

- Standard Operating Procedure EAP024, Version 4.0: Measuring Streamflow for Water Quality Improvement Studies (Ecology, 2026; unpublished)
- Standard Operating Procedure EAP042, Version 1.2 – Measuring Gage Height of Streams (Ecology, 2018a)
- Standard Operating Procedure Ecology EAP056, Version 1.3 – Measuring and Calculating Stream Discharge (Ecology, 2018b)
- Standard Operating Procedures EAP057, Version 1.2 – Conducting Stream Hydrology Site Visits (Ecology, 2019a)
- Standard Operating Procedures EAP058 Operation of the SonTek® FlowTracker® Handheld ADV® (Ecology, 2018c)
- Quality Assurance Monitoring Plan Streamflow Gaging Network, Publication No. 05-03-204, (Ecology, 2007)

- Standard Operating Procedure EAP074, Version 1.2 – Use of Submersible Pressure Transducers During Groundwater Studies (Ecology, 2019b).
- Standard Operating Procedure EAP082, Version 1.2 – Correction of Continuous Stage Records Subject to Instrument Drift (Ecology, 2019c)
- Quality-Assurance Plan for Discharge Measurements Using Acoustic Doppler Current Profilers, Scientific Investigations Report 2005-5183, (Oberg et. al., USGS, 2005)
- Discharge Measurements at Gaging Stations, Techniques and Methods 3-A8, (USGS, 2010)
- Surface-Water Quality-Assurance Plan for the U.S. Geological Survey Washington Water Science Center Open-File Report 2016–1020, (Mastin, 2017)

Flow measurements in Leland, French and Eightmile Creeks will be made by wading, using a rod-mounted ADV to measure velocity in stream transects, following Ecology SOP EAP056. Flow measurements in Icicle Creek may be made by wading if stream velocity and water level is safe. Field staff will use general caution, following safety guidelines laid out in the Ecology SOPs to decide if wading measurements can be taken. If wading is determined to be unsafe, flow measurements will be taken using a SonTek RS5 ADCP Meter deployed on a floating platform and attached to a tethering cable. Procedures specific to the Sontek FlowTracker2 ADV and SonTek RS5 ADCP meter are detailed below.

Frequency and location of streamflow monitoring activities for this Study are described above.

SonTek FlowTracker2

The methodology described here is specific to the Sontek FlowTracker2 ADV, but a similar instrument may be used. Discharge will be measured using the mid-section method, the default discharge equation applied in FlowTracker2. The FlowTracker2 defaults to using the 0.6 method, which assumes that the mean vertical velocity occurs at 60 percent of depth below the surface but can be adjusted to measuring at 0.2 and 0.8 depths as well.

The 0.6 method will be used for depths less than 2.5 feet and the 0.2/0.8 method will be used for depths of 2.5 feet or greater. Stream velocity is measured at a minimum of 20 stations across the channel. A reel tape marked in tenths of feet should be used for measuring station locations across the channel section. The tape should begin on the left bank looking downstream. Velocity measurements should be taken from left to right and set to average values recorded over a 40-second interval. The left bank measurement location will be identified at the initial station location, while the right bank measurement location will be identified at the final station location. Each bank edge measurement (i.e., distance to the bank) should be entered with the corresponding water depth. All instances when a measurement could not be performed within the established transect should be recorded on the field sheet.

Transect locations should be selected to minimize turbulence, avoid eddies, and be wadable for the stream conditions encountered. Locations where water flows beneath an overhanging stream bank should also be avoided. The location along the reel tape and the corresponding water depth will be entered into the FlowTracker2 prior to each measurement. A minimum of 20 velocity measurements should be collected within the channel section.

Following collection of all velocity and depth measurements along the stream, discharge will be calculated by the FlowTracker2 using the Mid-Section Method (Rantz, 1982), demonstrated below from the FlowTracker2 user manual⁸.

Equation 3

$$Q = \sum \bar{v}_0 d_0 \left(\frac{b_1 - b_0}{2} \right) + \bar{v}_1 d_1 \left(\frac{b_2 - b_0}{2} \right) + \bar{v}_n d_n \left(\frac{b_{n+1} - b_{n-1}}{2} \right)$$

Edge	Open water	Open Water
------	------------	------------

where, $\bar{v}$ is the average velocity in the vertical or at the station,
 d is the water depth measured at the station,
 b is the location of the station.

SonTek RS5 ADCP Meter

The SonTek RS5 is a compact, high-frequency ADCP meter designed for measuring water velocity and discharge in open channel environments as demonstrated on Figure 6 below.

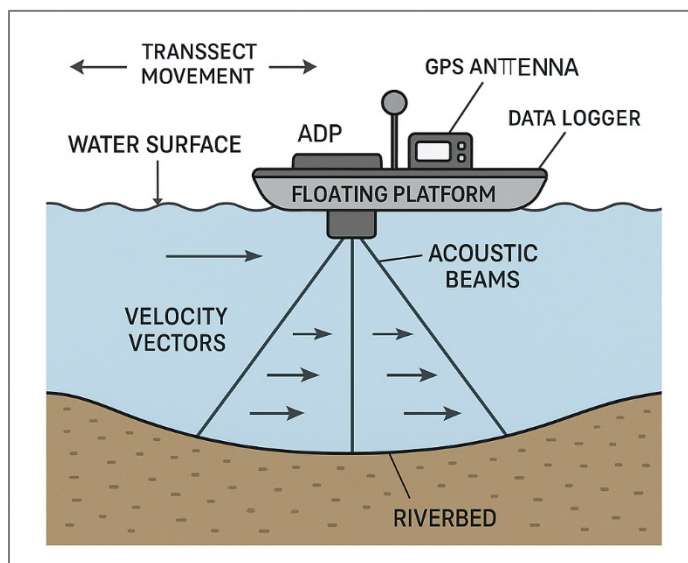


Figure 6. Illustration of SonTek RS5 ADCP Meter

⁸ geotechnenv.com/Manuals/SonTek_Manuals/sontek_flowtracker2_manual.pdf

The unit combines data from multiple sensors including multi-beam Doppler velocity measurements and depth data. The SonTek RS5 is typically deployed on a floating platform, such as the HydroBoard II Micro, and operated using SonTek's RSQ software.

The SonTek RS5 uses five acoustic beams, four slanted for velocity profiling and one vertical for depth measurement, operating at 3.0 MHz. The sensor employs SmartPulse+® technology to dynamically adjust between broadband and pulse-coherent processing, optimizing data quality across a range of flow conditions. The SonTek RS5 is a monostatic system, using the same transducers for both transmitting and receiving acoustic signals. Water velocity is calculated from Doppler shifts, with sound speed corrections based on internal temperature sensors and user-defined salinity (assumed negligible in freshwater systems).

Antennas and sensors will be securely connected, and a Bluetooth connection will be established with the laptop and RSQ software. Operators will verify system diagnostics, GPS signal strength, and compass calibration using RSQ's SmartPage interface. The SonTek RS5 will be deployed at each monitoring point using a tethered system attached to the non-motorized flotation device securing the ADCP. Two field personnel, one stationed on each bank, are required to maintain the SonTek RS5's position throughout the measurement. During deployment, the SonTek RS5 is moved across the channel in a series of transects, with real-time data collected and visualized in RSQ software.

Outlier Resolution

Outliers may be observed in individual velocity measurements collected across a given stream transect. If outliers in velocity (i.e., significantly greater or lower velocity measurements at a given location across the transect) are observed based on professional judgement and prior flow monitoring experience, field personnel should modify to the 0.2/0.8 method to capture the mean velocity (as detailed above), move the sensor slightly left or right along the cross section, or consider moving the cross section up or downstream if feasible.

Stream Stage

Stream stage measurements will be collected consistent with applicable sections of SOPs EAP042, EAP024 and EAP074 (Ecology, 2018; Ecology 2026 (unpublished); Ecology, 2019a). Pressure transducers and barometric pressure dataloggers will be deployed at each temporary streamflow monitoring gage location and be programmed to collect at continuous 15-minute intervals. The user manual for the proposed pressure transducer make and model (Van Essen Instruments Divers) should be used as a reference. The clock on the stream stage pressure transducer and corresponding barometric pressure logger will be synced and will match pacific standard time. The pressure transducer should be deployed such that it is below the lowest anticipated stream level and should be installed within a stilling well pipe that is secured to the ground or another solid structure to avoid instrument drift.

Each pressure transducer will be connected to a download cable that will allow for data retrieval.

Following deployment, during each field event the data will be downloaded onto a laptop or field computer from both the pressure transducer and barometric pressure loggers. Additionally, the datalogger remaining battery life and storage should be checked, along with datalogger time against computer time to check for drift. If time drift has occurred, both the stream stage and barometric pressure datalogger times should be reset. Extra dataloggers should be brought during each deployment. If battery life or storage is noted as being low, those dataloggers should be replaced with extra dataloggers. It is anticipated that datalogger battery and storage should last for the full Study period.

Staff plates will be installed at each temporary stream gage monitoring location in a manner that limits the likelihood of movement throughout the Study period. Readings will be collected during each deployment, downloaded to verify the pressure transducer stream stage record, and corrections will be applied where needed (e.g., drift or offset adjustments).

Outlier Resolution

Pressure transducer stage measurements will be compared to manual measurements taken on the staff plates during field events. If readings from a pressure transducer shows consistent differences from staff plate readings the data will be adjusted following Ecology SOP EAP082 for the correction of continuous stage records subject to instrument drift (Ecology, 2019c).

Dye Tracer and Turbidity Monitoring

Dye tracer monitoring activities will be conducted in accordance with applicable Ecology, USGS, and U.S. Environmental Protection Agency (EPA) standard operating procedures and guidance documents, as well as manufacturer documentation for deployed instrumentation.

Procedures and guidance documents to be adhered to include the following:

- Standard Operating Procedure EAP037, Version 2.2 – Time-of-Travel Studies in Freshwater Using a Dye Tracer (Ecology, 2022).
- Standard Operating Procedure EAP129, Version 1.0 – Short-term Continuous Data Collection with a Multiparameter Sonde, Part 1: Field Procedures (Ecology, 2019d).
- Standard Operating Procedure EAP130, Version 1.0: Short-term Continuous Data Collection with a Multiparameter Sonde, Part 2: Data Processing (Ecology, 2019e).
- Techniques of Water-Resources Investigations, Book 3, Chapter A9 – Measurement of Time of Travel in Streams by Dye Tracing (Kilpatrick and Wilson, 1989).
- Techniques of Water-Resources Investigations, Book 3, Chapter A12 – Fluorometric Procedures for Dye Tracing (Wilson, et al., 1986).
- Journal of Hydraulic Engineering – Predicting Travel Time and Dispersion in Rivers and Streams (Jobson, 1997).
- USEPA SEDS Operating Procedure SEDSPROC-514-R2 – Dye Tracer Measurements (Effective July 27, 2017).
- In-Situ Aqua TROLL® 600 Water Quality Sonde – Operator’s Manual and calibration guidance for rhodamine WT fluorescence sensors

Fluorescent dye concentrations shall be measured at all monitoring locations using In-Situ Aqua TROLL water quality sondes (or similar instruments) equipped with rhodamine WT fluorescence sensors. Instruments will be deployed in the center of the stream, in one of two configurations to record continuous dye concentration measurements

- internal sonde datalogging, using the internal memory and logging functions of the sonde; or
- external datalogging, where the sonde is connected to a Campbell Scientific datalogger.

The selected logging configuration for each monitoring location shall be documented in the field logbook, including instrument serial numbers, datalogger model (if applicable), logging interval, and clock synchronization method.

Logging intervals shall be selected to adequately resolve dye plume arrival, peak concentration, and recession (tail of plume), and shall typically range from 5 to 30 minutes based on storage capacity of the instrument and estimated arrival time of the plume.

Turbidity will be measured using turbidity probes attached to the water quality sondes to assess the potential for interference with optical rhodamine fluorescence measurements or using hand-held turbidity meters. Turbidity measurements will be taken at each monitoring location continuously throughout each field deployment or at least every visit to the monitoring location.

Instrument Deployment Procedures

Water quality sondes will be deployed at fixed monitoring locations downstream of dye injection points as shown on Figure 5. Deployment methods will generally follow Ecology SOP EAP129 for short term continuous data collection with a multiparameter sonde. Instruments will be positioned in the center of the stream so that continuous submergence and representative sampling of the flowing water column is achieved, avoiding stagnant zones, backwater conditions, or localized eddies.

The sondes will be secured in the channel using a PVC casing to protect and shade the sensor and anchored to a concrete block or other suitable weight (Figure 7). Deployment methods may be adjusted based on site conditions to maintain sensor stability and representative exposure to the passing plume. Instruments will be deployed in advance of dye release. Deployment and retrieval times will be recorded in the field logbook.



Figure 7. In-Situ Aqua TROLL 600 Water Quality Sonde and an Example Deployment System for Monitoring Dye Concentration.

Estimated arrival times for the dye plumes at the monitoring locations will be developed based on review of stream stage data at the monitoring locations. The time it takes for the spike in stage record after water is released from the lakes will provide a basis of estimate for plume travel time. Travel times of initial water releases are expected to be longer than plume travel times once the basin is wetted out and steady state flow conditions are achieved. Therefore, field visits to measure discharge near the time of plume arrival will be scheduled conservatively, with staff arriving multiple hours in advance of the estimated travel time. These estimates will aid in scheduling of field activities and determine the approximate time of plume arrival for discrete discharge measurements.

Final travel times will be determined from the observed dye time-concentration records at each monitoring station using the timing of plume features (leading edge and peak), consistent with USGS definitions of response curves and travel-time metrics (Kilpatrick and Wilson, 1989). The water quality sondes will remain instream after plume passage to collect a complete dye time series for analysis of peak, duration/width, and recovery.

Prior to dye release, background fluorescence levels shall be recorded to establish baseline conditions. Monitoring shall continue through plume arrival, peak concentration, and recession until fluorescence values return to near-background levels. To evaluate potential interference with optical rhodamine WT sensor readings, turbidity probes will be attached to the water quality sondes alongside the dye fluorescence robes. Turbidity readings will be collected continuously during sonde deployment, and checked during field measurements, timed as close as practicable to plume passage, and upon retrieval of the sondes. The turbidity probes will be calibrated

following procedures outlined in Ecology SOP EAP129 and EAP130. Staff will perform field checks on turbidity values during deployment using a calibrated reference probe (Ecology, 2019e).

Dye tracer and turbidity data will be downloaded following each site visit and reviewed for completeness, time continuity, and sensor performance. Data screening will include a qualitative evaluation of baseline stability, peak definition, potential sensor drift, and anomalous values associated with fouling or exposure. All deviations from planned procedures, equipment issues, or data quality concerns will be documented.

Outreach to Key Personnel

Outreach to key personnel (listed in Section 2) will be completed in advance of dye studies. These personnel will be notified prior to the onset of the dye studies, during the studies as plume concentrations are monitored, and after the studies are completed. Where requested by the Sherriff's Office and other agencies, press releases or other public communication will be provided by Chelan County.

Data Verification and Validation

This section provides data verification and validation considerations for the streamflow monitoring and dye concentration measurements.

Streamflow Monitoring

Data verification for stream stage and flow measurements will occur during each site visit. Measurements will be reviewed in real-time via the equipment screen or field laptop to observe for outliers or errors given by the equipment software. Validation will be achieved by performing at least one replicate flow measurement in the field at one location for each deployment, immediately after the initial flow measurement. Validation will also include documentation of real-time conditions via notes and photographs during each measurement to be able to understand if changes in conditions may have impacted data quality. Stage measurements will be downloaded from pressure transducer data loggers during each field visit and checked against manual staff plate measurements.

Where measurements are collected using the RS5, validation will be performed by comparing individual transect flow measurements to the average of those flow measurements. Replicate flow measurements are further described in Section 6.2. Electronic flow data will be downloaded during each site visit and checked for completeness and appropriate metadata.

Dye Tracer and Turbidity Monitoring

Dye concentration time series data should be downloaded during each site visit to verify data collection, and to confirm the instrument is working properly. The instruments will be calibrated before deployment in accordance with the procedures outlined below. If significant background fluorescence is observed, the meter may need to be recalibrated or repositioned, and these activities should be documented in the field notebook. Upon completion of dye tracer study,

instruments will undergo an end check verification using a dye standard to confirm calibration stability. Results of post deployment verification will be documented in the field logbook.

Continuous turbidity measurements collected with the turbidity probe installed on each water quality sonde should be downloaded during each site visit. Readings should be compared to previous visits to establish whether turbidity conditions are stable. Both the deployed and field instruments will be checked against calibration standards following the study to confirm the validity of data (Ecology, 2019d).

After the studies are completed, data review will include evaluation of deployment and retrieval records, confirmation of clock synchronization, inspection of calibration and end-check results, inspection of turbidity readings and field QC checks. Data will be analyzed to verify that continuous logging occurred for the full duration of plume passage. Field logs, photographs, and site notes will be reviewed alongside the data to document deployment conditions, flow conditions, and any deviations from planned procedures.

Calibration Procedures

Because this study will evaluate plume metrics (including peak concentration and mass recovery), the rhodamine WT probes will be calibrated and verified in accordance with manufacturer specifications and established EPA and USGS guidance prior to field deployment and following completion of measurements (USEPA, 2017; Wilson et al., 1986). EAP037 notes that calibration to absolute concentration is not required for low-level peak-timing studies; however, this project's broader analysis objectives require defensible concentration data for plume characterization and mass recovery calculations.

Calibration shall therefore meet the following requirements:

- Instrument readings must agree within ± 10 percent of calibration standards.
- If readings do not meet the ± 10 percent criterion, the instrument shall be recalibrated, repaired, or replaced prior to use.
- Calibration and verification activities will be documented in the field investigator's logbook, including date, time, standard concentration, temperature (if applicable), and instrument identification.
- Alternatively, calibration performed by equipment managers (i.e., equipment rental companies) should be documented according to appropriate standards and will be reviewed by the study team.
- Deionized (DI) water will be used as a blank during calibration (USEPA, 2017).

Dye concentrations may be reported as tracer concentration or true dye concentration, depending on instrument specifications. For rhodamine WT supplied as a 20 percent solution, tracer concentration may be converted to true dye concentration by dividing the tracer concentration by five (USEPA 2017). Following calibration, instruments will be thoroughly rinsed with DI water or background water prior to sample measurements.

Turbidity probes should be calibrated following manufacturer guidelines. Field checks with a reference probe should be performed during deployment following procedures detailed in Ecology SOPs EAP129 and EAP130. These field checks should include readings before and after field staff clean the probes. If the post-cleaning readings deviate from the calibrated reference probe readings by greater than 10 percent or 1 Nephelometric Turbidity Unit (NTU) (whichever is greater), then recalibration of the field sonde should be performed using National Institute of Standards and Technology-certified standard solutions.

Data Quality (Usability) Assessment

Streamflow Monitoring

A data usability assessment will occur in the field by looking for outliers in flow values (as described above), observing error messages provided by the equipment software, and comparing replicate flow measurements in real-time as described in Section 6.

Dye Tracer Concentrations

The quality of the dye concentration data will be determined primarily through qualitative assessment of the concentration curve overtime. The shape of dye concentration time series will be assessed during each field visit to identify whether there is a clear peak concentration, and the expected skewed, Gaussian shape that is characterized by a rapid leading edge and a longer trailing tail. Minor deviations from ideal plume symmetry are expected due to channel complexity, transient storage, and longitudinal dispersion and will not invalidate the data (Kilpatrick and Wilson, 1989; Wilson et al., 1986).

Quality Control

This section describes the actions that will be taken before and during a field event to evaluate quality control. These actions are both quantitative and qualitative. Data collected in the field will be reviewed during measurements, and after deployment to confirm equipment is functioning as expected and measurements are in line with the MQOs. If equipment is not functioning as expected, troubleshooting will occur in the field and equipment will be calibrated, fixed, or replaced during the subsequent field event.

Specific quality control procedures, both in field and out of field, along with corrective actions for each data collection method are described below and summarized in Table 5.

Table 5. Quality Control Procedures

Data Type	Out of Field		In Field	
	Action	Frequency	Action/Correction	Frequency
Flow Measurements	Check equipment battery level and functionality. Charge batteries and replace equipment as needed.	Prior to each mobilization	Perform replicate flow measurement of discharge. If RPD >8%, troubleshoot equipment, collect third measurement. If third measurement has an RPD >8% of both other measurements, troubleshoot cross section location/geometry and use alternative instrumentation if feasible.	One monitoring location, once each deployment for mid-section method only.
			Compare individual transect measurements to average. If a single measurement is >5% of average, perform four additional transect measurements.	For RS5 measurement locations
			Look for outliers in individual velocity measurements based on professional judgement. If outliers are observed, measurements should be recollected. For the FlowTracker2, where velocity outliers are observed, mean velocity measurements should be collected using the 0.2/0.8 method for that location, or the location should be adjusted slightly left or right. If outliers are thought to be related to cross section conditions, move the cross section upstream or downstream if feasible.	Each individual measurement along a transect.
			Perform beam check.	Each site visit.

Data Type	Out of Field		In Field	
	Action	Frequency	Action/Correction	Frequency
	Upgrade firmware and check flow meters	Per manufacturer recommendations	Review Quality assurance/quality control functions in software. If errors are flagged, investigate and correct as needed in accordance with user manual.	Throughout data collection
Water Level	Check barologger and pressure transducer battery life. Prepare backup sensors.	Before deployment	Check battery levels, photograph staff plate position to monitor for shifting, document site conditions. Replace faulty or depleted loggers.	During each site visit
			Sensitivity QC check of pressure transducer loggers using the two-depth bucket method described in Ecology SOP EAP024	Before deployment and after retrieval
	Compare pressure transducer readings to staff plate readings.	After each site visit	Perform a replicate measurement. If replicate is $> \pm 0.02$ feet of the reading, take a third replicate measurement.	For each staff plate reading
			View raw pressure transducer data in the field in graphic and tabular format to observe for any outliers in reading values or missing data. If equipment malfunction is observed, the datalogger should be replaced at the time of the field visit, and notes should be made regarding the new datalogger serial number and installation date/time/location.	During deployments and during each site visit
			Check staff plate for obvious damage. If staff plate has been moved, make note in field log and repair and resurvey at the next visit.	Each site visit
Rhodamine Dye Measurements	Check battery level and functionality of water quality sondes.	During deployments and during each site visit	Observe background fluorescence in live readings during deployment. Look for outlying data points or spikes. If spikes in dye concentrations are noted, take live readings to troubleshoot. If issue appears to be related to the deployment location, (i.e., because of optical interference), consider deploying sonde in a different location.	During deployment/ Each site visit
			Perform field checks on turbidity values using a calibrated reference sonde. Recalibrate the field turbidity probe if the values deviate by greater than 10 % or 1 NTU, whichever is greater.	During a site visit after the sondes are deployed

Data Type	<i>Out of Field</i>		<i>In Field</i>	
	Action	Frequency	Action/Correction	Frequency
	Perform calibration on rhodamine WT probe.	Pre-deployment and post-retrieval	Check battery life and storage capacity to confirm that sondes can store data for full duration of the Study.	Each site visit
	Perform calibration and QC checks of turbidity probe using NIST standard solutions.	Pre-deployment and post-retrieval	Take turbidity reading to pair with optical rhodamine dye measurements.	Each site visit
	Review dye concentration time series for each monitoring location. Look for characteristic bell-shaped curve with clearly defined peak.	Post-data retrieval		

Notes:

NTU = Nephelometric Turbidity Unit

Quality Control Steps in Preparation of Field Work

The following are steps to be taken prior to field deployment to collect quality data using the proposed instrumentation. This list is not exhaustive, and it is incumbent on field staff to plan ahead, checking equipment availability and functionality.

1. Equipment Inspection

- Inspect the equipment for physical damage or wear.
- Check cables, connectors, and mounting hardware (e.g., HydroBoard II Micro).
- Check that the GPS antenna and Bluetooth module for the ADCP are intact and functional (where relevant).
- Check O-ring on water quality sonde for watertight seal.
- Check the PVC encasement for sonde (and other deployment equipment) for integrity and fouling.
- Inspect the wiper on the sonde (if it has one) for function.

2. Battery and Power

- Fully charge the SonTek RS5's 18650 lithium-ion battery.

- Bring spare batteries (AA for FlowTracker2) and a charger for SonTek RS5 if extended use is expected.
- Check the battery life on the water quality sonde and bring spare D batteries.
- Check battery life on laser level and/or GPS unit.

3. Software/Firmware Setup

- Install or update RSQ software and FlowTracker software on field laptop or tablet.
- Verify that the SonTek RS5 and FlowTracker2 firmware is up to date and compatible with software.
- Connect to the sonde using the VSITU mobile app or desktop configuration. Check the LCD screen for logs statuses and/or errors. Make sure data is able to be acquired.

4. System Configuration

- Connect to the SonTek RS5 via Bluetooth using RSQ software.
- Check storage and set logging interval on sonde.

5. Field Documentation

- Prepare field data sheets or digital forms.
- Download GPS-enabled photo application for phone (e.g., Solocator) to take site photos with location and orientation stamps.

6. Safety and Logistics

- Check weather forecasts and seasonal access windows.
- Pack personal protective equipment (PPE) and communication devices.

7. Backup and Redundancy

- Bring a backup data storage device (e.g., USB drive or external hard drive).
- Bring an extra field laptop.
- Pack a replacement staff plate in case of damage.
- Bring a replacement barologger and pressure transducer in case of damage or instrument malfunction.
- Bring an extra cable reader for datalogger.

Quality Control Steps Taken in Field

Streamflow Measurements

Field procedures developed to collect quality data are detailed in Section 5.2.1. Quality assurance/quality control (QA/QC) functions built into the software will be used as a quality control measure, as well as comparing individual velocity and depth measurements for outliers, and taking replicate discharge measurements. Outlier resolution is described in Section 5.2.1.3.

Selecting a Cross Section

As detailed in Section 3, a qualitative assessment should be completed for each cross-section location consistent with Ecology's SOP EAP056 and USGS Techniques and Methods 3-A8 to qualify the physical conditions within the transect at the time of the measurement as "excellent", "good", "fair", or "poor."

QA/QC Built-in Functions

The QA/QC functions built into the RSQ software are exhibited as warnings or errors under the following:

- System setup parameters
- Compass
- Stationary Moving-Bed Analysis (SMBA) method measurement
- Transect
- GPS
- System operation
- Post-processing

Field staff will check the RSQ software for these warnings or errors throughout the data collection process.

Where feasible, quality control checks on the flow meter's temperature reading will be done in the field using a reference thermistor to minimize impacts of any temperature bias on velocity readings.

Replicate Measurements

As close in time and location to the first measurement as possible, field personnel will repeat the same steps outlined in Section 5.2 to perform a replicate flow measurement in at least one of the monitoring locations for each deployment. Replicate measurements will only be collected at locations where the mid-point method is used. Using the original and replicate measurements, the RPD should be calculated using the equation provided below where M1 is the original measurement and M2 is the replicate measurement.

Equation 4

$$RPD = \frac{M1 - M2}{(M1 + M2)/2} \times 100\%$$

If the RPD is greater than 8 percent, the equipment should be checked for errors and monitoring location should be evaluated for potential conditions that might be interfering with flow measurements. Once equipment errors and monitoring setup issues have been corrected or ruled out, a third measurement should be collected. If the third measurement has an RPD greater than 8 percent of both the other two measurements, flow measurements should be collected

using the alternative method (SonTek RS5) if conditions allow, or the measurement cross section should be adjusted.

As detailed above, for locations where the SonTekRS5 is used (i.e., when the mid-point method is not used), discharge measurements for each transect should be within 5 percent of the mean of four measurements. If there is a known and unavoidable condition impacting the quality of the measurements, it should be noted in the field form. If any measurement differs by more than 5 percent, then four additional transects should be measured and all eight measurements averaged for the final flow.

1.1.1 Stream Stage Measurements

Pressure transducer performance will be verified using pre- and post-deployment sensitivity checks using the two-depth bucket method described in Ecology SOP EAP024 (Ecology, 2026; unpublished). These checks will confirm that the sensitivity of the sensors is acceptable and detect potential bias in readings.

For staff plate readings, duplicate measurements will be collected until two measurements in a row are within the MQO of error (0.02 ft). Any observed movements in staff plate position will be noted in the field log. Pressure transducers should be installed so that they will be fully submerged, and instruments specifications should be consulted so that a full range of submersion depths can be accurately measured. Data loggers should be suspended on a Kevlar cord or equivalent to avoid stretching. Raw pressure transducer data will be viewed in the field in graphic and tabular format to observe for any outliers in reading values or missing data. If equipment malfunction is observed, the datalogger should be replaced at the time of the field visit, and notes should be made regarding the new datalogger serial number and installation date/time/location. Additionally, confirmation measurements should be taken in the field by taking staff plate readings to check and correct for logger drift. Barometric pressure readings should be reviewed during field visits and will be used to compensate water level data.

Dye Tracer Concentrations

Field procedures for tracer studies are described in Section 5.2.2. QA/QC measures are built into the rhodamine dye probe and water quality sonde. These include integrated optical compensation to account for changes in the sensor's LED over time, and as a function of temperature. The qualitative MQOs described in section 3.2 will be supported by quality control features inherent to the deployed multiparameter sondes. Both the In-Situ Aqua TROLL 500/600 and Aquaread AP-2000-D sondes include automated stability checks that prevent data logging until sensor readings meet defined stability criteria. The sondes require successful completion of calibration routines before accepting measurements and generate error messages when readings are unstable, out of range, or when sensor performance is degraded.

Following Ecology guidance, the first dye study is planned downstream of the second study to allow time for dye to settle out and minimize potential for interference. Live readings of background fluorescence values will be a key quality control measure during this study and

readings should be taken during each site visit. Dye injection locations, volume of dye releases, and sonde deployment locations will be finalized based on velocity data and field assessment during deployment.

Steady flow conditions should be assessed prior to deployment. Flow will be considered steady, and dye study activities can commence when the hourly flow time series at the USGS gage is stable, 1 to 2 days have passed since the onset of lake water release, there has been no or minimal measurable precipitation for 24 hours, and there is no or minimal measurable precipitation forecast for the following 7 days.

Background fluorescence will be assessed at each monitoring location using sonde readings collected prior to dye injection and upon retrieval of the sondes. The peak dye concentration during plume passage should present as a clearly defined peak with tailing edge above background levels. While no minimum numerical value of the peak concentration for each curve will be required to validate the curve, the shape and consistency of the data making up each curve will be carefully evaluated. Elevated or variable background fluorescence does not invalidate dye tracer data provided the dye plume produces a distinct, interpretable response above background. Background fluorescence may change the peak concentrations and shape of the dye curve. If significant background fluorescence is detected, it will be subtracted from readings to establish an adjusted “zero-concentration” value for analysis of the dye-concentration curve characteristics (Kilpatrick and Wilson, 1989).

The dye tracer data should be reviewed qualitatively to determine whether there is a clear peak concentration, and whether the curve approximates a skewed Gaussian distribution with a shorter leading edge and a longer tailing edge. The shape of the curve may not match a skewed Gaussian shape exactly. In cases where dye curve data deviates significantly from the expected shape (e.g., the peak concentration is not clear), the data may be considered usable but will be qualified and tagged with descriptive comments.

Turbidity will be measured continuously or discretely and reviewed during each site visit to assess the potential for interference with the optical dye probes. Turbidity values tend to cause low bias in optical dye measurements, and mathematical corrections can sometimes be applied to compensate for interference (In-Situ, 2026). Turbidity values will be compared between site visits and across locations to establish any changes in stream conditions during the study and lake releases and aid in interpretation of dye concentration measurements.

Turbidity is expected to remain relatively stable over the duration of the study because tracer tests will be conducted under steady-flow and minimal precipitation conditions and the study reaches are characterized by coarse substrates (predominantly cobble and gravel) rather than fine-grained, sandy materials. Field checks using a reference sonde equipped with a turbidity probe will be used as the turbidity probe is deployed and after the dye tracer test to confirm quality of turbidity data. A field recalibration will be performed if readings between the field and reference probes deviate more than the specified threshold of 10 percent or 1 NTU (whichever is

greater) at deployment. Turbidity data will be qualified if the post-study calibration check deviates more than the specified threshold.

Data Management Procedures

This section describes the procedures that will be followed to manage data collected during streamflow monitoring and the dye tracer studies. All data collected under this QAPP will be submitted annually to Ecology's EIM database by January 31 of the following year, using Study ID: WROCR-VER1-00015. All data for this project will be saved in .csv format or equivalent and documented in field notes. All data will be reviewed for completeness and accuracy following each field event and prior to final analysis.

Streamflow/Stage Data

Data from streamflow measurements will include velocity across stream transects, cross sectional data provided by these transects, river stage from staff plates and pressure transducers, and flow measurements. Data from pressure transducers and barometric pressure loggers will be downloaded as .csv files or equivalent. The barometric pressure data will be used to compensate the pressure transducer readings using the appropriate software, spreadsheet, or scripted methodology, resulting in a measurement of feet of water column head over the pressure transducer. Pressure transducer readings will be corrected with staff plate readings and converted to flow using the stage-discharge curve developed for the specific transect (detailed in Section 8). Both discrete measurements and continuous time series data will be appended with metadata for each location and deployment. Metadata will include quality control flags, significant notes, time zone, and other important notes.

Dye Tracer Concentrations

Time series dye tracer concentrations at each location will be reported in units of $\mu\text{g/L}$ along with date/time of each reading. The metadata associated will also include quality control flags, time zone, and other important characteristics.

Reporting and Field Activity Assessments

This section describes the reporting and analysis proposed for this Study. Following the conclusion of the data collection, a comprehensive data compilation will be conducted in accordance with Section 7 and the schedule outlined in Section 2. All data collected under this QAPP will be submitted annually to Ecology's EIM database by January 31 of the following year, using Study ID: WROCR-VER1-00015.

Reporting and assessment of data collected in this Study will culminate in a final monitoring report, which will focus on documenting field activities, verifying data completeness, describing any processing and quality control measures, analyzing results, and summarizing findings as they relate to the Study goals.

Tributary Streamflow Monitoring Analysis

The streamflow data submittal will include the following components:

- SonTek RS5 ADP discharge measurements with qualifications where appropriate, average velocity profiles, and average stage.
- FlowTracker2 discharge measurements with qualifications where appropriate, depths, velocities, discharge and cross-sectional area (if used).
- Compensated and corrected datalogger readings and staff plate readings for each monitoring location converted to river stage.
- All field activities documented in field logs, including date, time, personnel, equipment used, and site-specific observations. These logs will be reviewed after each mobilization to assess data quality, identify any issues with equipment or procedures, and inform adaptive improvements for future fieldwork. Any deviations from standard procedures or anomalies encountered during data collection will be noted and addressed in the final data review and reporting process.

Stage-discharge rating curves will be developed for each tributary monitoring location (French Creek, Leland Creek, and Eightmile Creek or alternatives) by pairing discrete discharge measurements with concurrent stage readings from the staff plate and pressure transducer. Rating curves will be fit using an empirical best-fit relationship over the range of observed conditions. Extrapolation beyond the highest and lowest measured stages on the stage-discharge curves will be limited and clearly identified as estimated. If extensions are required for conversion of continuous stage data into discharge, they will be based on a best-fit extension of the measured relationship and qualified in reporting. Where relevant, existing stage-discharge measurements collected by WDFW (2017–2021) for French Creek and Leland Creek may improve coverage for development of the survey.

Streamflow time series developed for French Creek, Leland Creek, and Eightmile Creek will be evaluated in relation to continuous flow measurements at the USGS gage to evaluate the timing and magnitude of lake-release signals. This analysis will consider (1) the relative timing of observed increases in tributary discharge and corresponding responses at the USGS gage, and (2) the amount of increased flow measured at the USGS gage and tributary monitoring locations during lake release periods in relation to the released quantities.

Dye Tracer Study Analysis

Processing of dye tracer measured concentrations may include normalizing concentration values based on background fluorescence measurements and adjustments based on suspected interference from turbidity.

Following completion of each dye tracer study, the dye concentration time series data will be compiled and analyzed.

Reported dye tracer analysis is anticipated to include the following

- dye concentration time series plots for each monitoring location;
- estimated travel times between injection points and downstream monitoring locations based on observed plume arrival and peak timing;
- summary statistics describing plume characteristics, including peak concentration and plume duration (time elapsed between plume arrival and end of tailing edge); and
- estimates of relative dye mass recovery, interpreted in conjunction with concurrent discharge measurements and associated uncertainty.

For each monitoring location, dye concentration time series will be analyzed for completeness, and the presence of a distinct and interpretable dye plume response. Data will be evaluated for key plume features, including time of first arrival, time of peak concentration, and plume recession. Peak concentration will be defined as the highest measurement of fluorescence, excluding outliers. The time of first arrival will be defined as the first trace of signal with fluorescence values above background. The effective plume duration is the time elapsed between the time of first arrival and the point at which dye concentration returns to a value near background fluorescence measured before injection. The shape of the response curve will be reviewed for consistency with expected transport behavior under steady-flow conditions, recognizing that deviations from an idealized response may occur due to channel complexity, transient storage, and dispersion. Dye-concentration time series may be smoothed (i.e., time aggregated) to aid in estimating plume characteristics. All analysis steps will be clearly documented and included with the reported data. Both raw data values and processed data with clear documentation of processing steps will be provided in the report.

Dye tracer results will be interpreted in the context of concurrent streamflow measurements collected during each study, including tributary and mainstem discharge measurements and USGS gage data. Percent dye mass recovery will be evaluated alongside concurrent discharge measurements and travel-time results. Mass recovery calculations (Equation 5) rely on the

relationship between dye concentration and discharge integrated over time at a monitoring cross section (i.e., recovered mass estimated from concentration-discharge-time integration). Dye recovery is not a direct stand-alone measure of water loss due to adsorption; however, in combination with time-of-travel and flow measurements, these data will provide key information on the conceptual model of fate and transport of lake release water.

Equation 5

$$\text{Percent Dye Mass Recovery (\%)} = \frac{\sum_{\text{plume duration}} Q_i C_i dt}{M_{\text{injected}}} * 100$$

where:

Q_i = Flow at a timestep i during the passage of the dye plume (ft³/s)

C_i = Concentration at a timestep i during the passage of the dye plume (µg/ft³)

dt = Length of timestep i (s)

M_{injected} = Mass of dye injected (µg)

Any data limitations, anomalies, or quality concerns identified during data review will be documented in the reporting. If results from the dye tracer study are determined to be insufficient to meet study objectives due to data gaps, excessive background interference, equipment malfunction, or unanticipated flow variability, the need for a repeat tracer study will be evaluated.

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Appendices

- A Field Procedures Checklists
- B Calculated Estimates of Dye Volumes and Concentrations