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State of Washington

Quality Assurance Project Plan

Icicle Creek Alluvial Water Storage Project Monitoring

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COVER PHOTO: Doctor Creek landslide debris providing alluvial water storage benefits. PHOTO BY BRYAN MALONEY.

Quality Assurance Project Plan
Icicle Creek Alluvial Water Storage

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EAP: Environmental Assessment Program

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2.0 Abstract

In 2022, the Chelan County Natural Resources Department (CCNRD) received a grant from Office of Columbia River entitled Icicle Strategy (WROCR-2123-ChCoNR-00025). CCNRD was also awarded a Drinking Water Providers Partnership grant from the U.S. Forest Service entitled Icicle Creek Floodplain Restoration and Sediment Reduction Conceptual Design Project (22-PA-11061700-039). This project is a continuation of Chelan County's efforts to address Category 4 303(d) listings for temperature, dissolved oxygen (DO), and water quantity in the Wenatchee Watershed.

A component of both grants is to design Alluvial Water Storage (AWS) restoration treatments to increase subsurface and surface water storage in the floodplain, with potential subsequent contributions of colder groundwater to low summer baseflows. AWS restoration projects rely on treatment techniques that raise the channel bed elevation through natural or constructed aggradation, such as installation of engineered log jams, construction of beaver dam analogs, or re-grading of the channel and floodplain. The anticipated effects of reversing channel incision include: (1) an increase in the frequency of overbank flow, which recharges groundwater and lengthens the hydroperiod of floodplain water bodies and (2) a reduction in lateral hydraulic gradients toward the channel, which reduces the rate at which groundwater drains into the channel. Together these effects increase the volume and duration of alluvial water storage.

This Quality Assurance Project Plan (QAPP) will cover monitoring associated with the AWS component of this grant (WROCR-2123-ChCoNR-00025), which includes nine sites within the Icicle watershed. This QAPP describes the AWS monitoring program designed to quantify the effect of restoration actions on the channel bed elevation of incised streams and the groundwater storage effects that are expected to result from reconnecting an incised stream to its floodplain. Monitoring will include observational data collection of channel bed elevations, groundwater and surface water elevations, water temperature, and stream discharge. The anticipated effects of prospective restoration actions include increases in channel bed elevations and an associated increase in surface water elevations. Consequently, an increase in the magnitude of groundwater elevations as well as the duration of the elevated groundwater table, which are indicative of increased groundwater storage volume, are anticipated. We speculate that this approach could ultimately lower stream temperatures and increase baseflow. However, we do not anticipate that those effects will be large enough to be beyond the margin of measurement errors for the planned restoration and monitoring approach.

3.0 Background

3.1 Introduction and problem statement

This QAPP covers effectiveness monitoring for an Alluvial Water Storage (AWS) project in the Icicle Creek Basin, Chelan County, Washington. This project aims to restore natural water storage functions of the floodplain through designing restoration actions to reverse historic channel incision (i.e., down-cutting). The monitoring aims to measure changes in both geomorphology and hydrology as a result of future restoration actions. The anticipated effects of AWS restoration actions include increases in channel bed, surface water, and groundwater elevations, all of which are conceptually well-supported by the scientific literature but which are largely untested outside of montane meadow environments (Montgomery et al., 2003, Tague et al., 2008, Hunt et al., 2018). This project includes five sites in this study located in the Icicle Creek watershed (Figure 1). The potential for hydrologic effects from restoration actions is of high interest in Icicle Creek because it provides water supply for the Leavenworth National Fish Hatchery, Icicle-Peshastin Irrigation District, Cascade Orchard Irrigation Company, and City of Leavenworth domestic water intake. Icicle Creek has class 4 instream flow, temperature, and dissolved oxygen water quality 303(d) listings which directly affect instream habitat quality.

Icicle Creek has been affected by a legacy of impacts that have resulted in incision of the stream bed relative to its floodplain, as well as a loss of complex aquatic habitat such as pools, log jams, and side channels. Channel incision disconnects surface water from the floodplain and reduces both groundwater recharge and groundwater storage. Streams that flow within incised channels overflow their banks less frequently, which diminishes groundwater recharge through overbank flow and reduces contributions to floodplain water bodies. Channel incision also results in a lowered surface water elevation during the drier summer season, which increases the lateral hydraulic gradient for groundwater flow toward the channel and induces earlier and more rapid groundwater drainage. The overall result is that less water is stored in the shallow alluvial aquifer, which drains earlier and faster than under un-incised conditions. The reduction in the magnitude and duration of groundwater storage subsequently results in less water availability for riparian plants, and less groundwater contribution to dry season streamflow.

The cumulative effect of channel incision and the consequent loss of natural water storage functions of floodplains is substantial in the Icicle Creek watershed (CCNRD & NSD 2022). In addition to legacy impacts that impair natural functions (e.g., logging), contemporary management of the Icicle Creek watershed for domestic, agricultural, and fish propagation purposes degrades ecological functioning (IVCTU & TWC 2005). Cumulatively, these impacts result in lower and warmer summer baseflow and pose a threat to the lower Icicle Creek. Lastly, since climate change projections suggest that summer flows will become lower and warmer due to diminishing snowpacks and warming air temperatures, the current water shortages and impairments to habitat quality are only expected to worsen under future conditions (Mauger et al., 2017).

The project included in this QAPP aims to design AWS restoration treatments to (1) reverse channel incision and raise channel bed elevation, and (2) increase groundwater recharge and reduce groundwater drainage. The restoration methods will vary by site, including techniques such as engineered log jams and constructed riffles. All treatment approaches are designed for the goal to raise channel bed and surface water elevation and increase the magnitude and duration of groundwater storage in the shallow alluvial aquifer that extends under and across a riverine floodplain. As outlined in this QAPP, CCNRD plans to monitor the effectiveness of AWS restoration through the monitoring of the following before and after implementation:

- Channel Bed Elevation (repeat topographic surveys of cross-sections)
- Stream Stage (continuous level logger data and occasional manual measurements)

- Groundwater Elevation (continuous level logger data and occasional manual measurements)
- Surface Water Discharge (continuous stage data with a rating curve developed from manual discharge measurements)
- Surface and Groundwater Temperature (continuous temperature logger data)

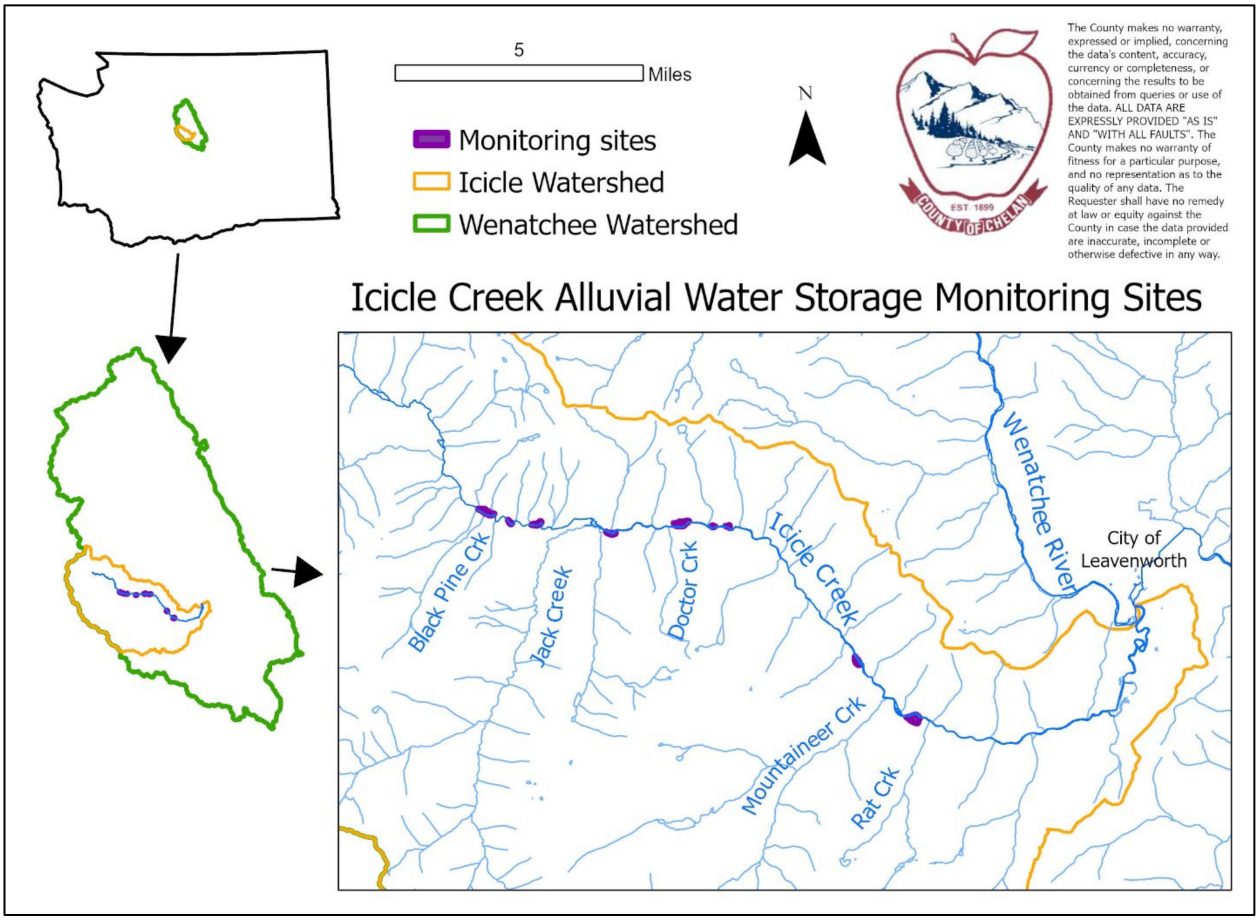


Figure 1. Map of Icicle Creek AWS study sites within the Icicle and Wenatchee watersheds.

3.2 Study area and surroundings

The Icicle Creek watershed is located in central Washington on the eastern slope of the Cascade Mountains, near Leavenworth, WA. The Icicle Creek basin spans 136,916 acres and is the largest sub-watershed in the Wenatchee River watershed (WWPU 2006). Icicle Creek contributes 20% of the Wenatchee River's annual flow at the confluence at RM 25.6 on the Wenatchee River (Bilhimer et al. 2002). Of the entire Icicle Creek basin, 87% of the land is managed by the U.S. Forest Service and 74% of the land is contained within the Alpine Lakes Wilderness (Andonaegui 2001). Icicle Creek and tributaries support steelhead (*Oncorhynchus mykiss*), Chinook salmon (*O. tshawytscha*), bull trout (*Salvelinus confluentus*), and cutthroat trout (*O. clarkii*) (WWPU, 2006). The study area for this project includes floodplains along the mainstem of Icicle Creek. Steelhead, bull trout, and cutthroat trout are all present in the study reach of Icicle Creek (Ecology & CCNRD, 2019).

This study will collect data on nine Alluvial Water Storage (AWS) project sites along the Icicle Creek mainstem (Table 1).

Table 1. Project site details.

Site Name	Approximate Reach Length (miles)	Approximate River Mile (RM)
1	0.56	RM 20
2	0.25	RM 19.5
3	0.37	RM 18.5
4	0.28	RM 16.5
5	0.56	RM 15.5
6	0.12	RM 14.6
7	0.16	RM 14.3
8	0.31	RM 10
9	0.47	RM 8.3

3.2.1 History of study area

The Icicle Creek watershed provides important water for nearby communities. The City of Leavenworth, Icicle-Peshastin Irrigation District, Cascade Orchards Irrigation Company, and Leavenworth National Fish Hatchery all divert water from the lower 5 miles of Icicle Creek. This Icicle Creek water is used for domestic, agricultural, and fish propagation purposes. Within the Alpine Lakes Wilderness Area, Colchuck, Eightmile, Klonaqua, Square, Lower Snow, Upper Snow, and Nada Lakes are all managed to provide water to the lower reaches of Icicle Creek in dry times of the year.

Other impacts to Icicle Creek include historic resource extraction and contemporary recreation. Sheep herding, mining, and logging have all occurred in the Icicle watershed. Currently, the Icicle Creek watershed provides valuable recreation opportunities for campers, backpackers, hikers, rock climbers, and kayakers.

3.2.2 Summary of previous studies and existing data

In-stream wood has two important hydrologic influences. It can slow flow velocities and downstream routing resulting in spreading out the hydrograph and storage of large volumes of alluvium within stream valleys (Abbe 2000). In forested channel networks, wood can also be the dominant control on grade and shear stress partitioning (Abbe et al. 2003). In these systems a loss of wood triggers channel incision that results in a lowering of alluvial groundwater tables and loss of water storage within a watershed. It also speeds up the routing of water out of channel network. Channel incision leads to a substantial reduction or even complete loss of subsurface water storage capacity by lowering water tables and evacuating alluvial sediment. Shields et al. (2009) report that 60-90% of sediments leaving many watersheds are due to channel incision.

Restoration actions that implement channel-spanning structures or barriers constructed from natural materials are designed to re-aggrade the channel bed through the trapping of sediments and improve hydrologic connectivity between the channel and the surrounding floodplain. Approaches range from installing engineered log jams (Abbe et al. 2003, Abbe and Brooks 2011) to beaver dam analogs (Pollock et al. 2012) to creation of small earthen dams (i.e., 'pond and plug') (Wilcox 2005), but the underlying concept is similar: partially block the channel to increase hydraulic roughness, slow and impound streamflow, and capture and store sediment.

Recent research has demonstrated that increasing water storage through stream restoration is a sustainable strategy to address water scarcity into the future (Tague et al. 2008, Hunt et al. 2018). When compared to traditional water storage approaches, stream restoration can offer a multi-benefit approach to increase natural water storage while providing benefits to riparian/wetland function, fish and wildlife habitat, water quality, fire resilience, and climate change adaptation (Tague et al. 2008).

Monitoring the effects of restoration on mountain meadows within the Sierra-Nevada Mountains of California show positive results for groundwater storage as well as increases to baseflows. Utilizing similar methods to those proposed in this QAPP, researchers quantified the increase in groundwater elevation following restoration with groundwater wells along the treatment reach, in some places raising the water table by as much as 0.6 feet (Hunt et al. 2018). Additionally, through monitoring continuous discharge data at the inlet to the restored area and outlet of the meadow, researchers quantified changes in the timing and quantity of baseflow. Despite sustained drought conditions, the study determined over several years of study that summer baseflow increased by 5-12 times the pre-restoration baseflows (Hunt et al. 2018).

Since 2018, Chelan County Natural Resources Department (CCNRD) has worked collaboratively with Natural Systems Design (NSD) to model estimated effects of stream restoration on water storage throughout the Wenatchee watershed in Chelan County (CCNRD & NSD 2022). CCNRD and NSD developed a GIS-based screening framework that utilizes LIDAR data and GIS tools to compute the restorable sub-surface water storage and associated streamflow contribution per restored river mile derived from reach-scale valley widths, extents of incision, and stream gradients. From this model, CCNRD has prioritized several locations for developing AWS projects including the projects to be monitored under this QAPP.

In 2018, CCNRD's conducted an AWS pilot study on a section of Poison Creek in the Mission Creek sub-basin in the Wenatchee Watershed. Initial monitoring results show successful aggradation of alluvial sediments behind structures and a positive groundwater response in adjacent floodplain wells. Because of the small size of the drainage, above and below treatment discharge stations recorded suspect in-stream data (<0.15 CFS) that has been deemed insufficient to draw conclusive results. Nonetheless, both qualitative and quantitative evidence within the treatment area that suggest aggradation has successfully reconnected the channel to the floodplain, and thus have increased storage volume.

CCNRD and NSD have presented work related to AWS and potential for instream flow benefits at various conferences. Some of the conference presentations are included here as reference:

- Can wood placement in degraded channel networks result in large-scale water retention (Abbe et al. 2019).
- Channel incision and the loss of water storage in drainage networks presented at the 2019 RCO Salmon Recovery Conference (Abbe and Dickerson-Lange, 2019).
- Identifying and Quantifying Restorable Water Storage in the Wenatchee presented at the 2019 RCO Salmon Recovery Conference (Dickerson-Lange et al. 2019).
- Restoring Fluvial Corridors to Buffer Hydrologic Impacts of Climate Change presented at North West Climate Conference (Dickerson-Lange et al. 2017).

3.2.3 Parameters of interest and potential sources

The parameters of interest for monitoring are environmental indicators of the anticipated changes, due to prospective restoration treatments, in channel bed and surface water elevation and the magnitude and duration of groundwater storage in the shallow alluvial aquifer. Based on previous investigations we speculate that extensive implementation of this approach could contribute colder groundwater to baseflow, however the magnitude of the anticipated effect is likely to be below the measurement accuracy for the planned monitoring approaches based on project scale. As such, we plan to monitor discharge and water temperature to characterize hydrologic conditions, but do not anticipate detection of a change resulting from any restoration treatments.

The parameters of interest are:

- Channel bed elevation and channel morphology
- Surface water stage (elevation)
- Groundwater elevation
- Surface water discharge
- Stream temperature

Channel Bed Elevation and Channel Morphology
Changes in channel bed elevation are indicative of local aggradation or degradation. Aggradation of sediments in an incised channel raises the surface water elevation, reduces the lateral hydraulic gradient between the shallow groundwater and the in-channel surface water, and therefore slows the lateral drainage of the shallow groundwater reservoir (Beechie et al. 2012).

Surface Water Stage
The elevation of the surface water during a given discharge varies with channel bed elevation, channel morphology, and instream hydraulic roughness (Montgomery et al. 2003). Observations

of surface water elevation are required to assess the connectivity between surface water and ground water elevations, for computing hydraulic gradient, and for estimating discharge. The measurement of stream stage is typically referenced to a staff plate that is installed in the wetted channel. This staff plate is surveyed to link it to a nearby absolute or relative datum and determine the water surface elevation in comparison to other elevation measurements.

Groundwater Elevation

The elevation of the groundwater in an alluvial valley reflects the local water table, which is typically influenced by the surface water elevation in the stream. This elevation varies both laterally and longitudinally, and the groundwater table elevation contours can be estimated from point measurements spread out through the floodplain. We will measure groundwater elevation, using shallow wells that are installed approximately 6-10 feet deep in the alluvial floodplain to test how changes in stream bed elevation and surface water elevation due to restoration treatments influence the time series of local groundwater elevations. We will also use groundwater elevations to compute hydraulic gradients.

Stream Discharge

The timing and magnitude of stream discharge reflects local precipitation, runoff, and evapotranspiration, and reflects how water is stored and released from the local groundwater aquifer. We will measure stream discharge upstream and downstream of the monitoring sites, if feasible and safe to do so. Measuring stream discharge in Icicle Creek may be difficult, due to water velocity and depth. Conceptually, we anticipate the restoration actions to contribute to a change in the relationship between the two gages due to the potential increased residence time of water in the treatment reach. For example, observational and modeling studies have demonstrated that re-aggradation of incised reaches can result in a 10 to 20 percent increase in baseflow early in the dry season (Tague et al. 2018, Ohara et al. 2014), and one empirical study showed a 35-90% increase in baseflow contribution in the three years following restoration (Hunt et al. 2018).

However, we estimate the magnitude of the anticipated effect in these limited pilot project areas to be smaller than the uncertainty associated with measuring discharge. For this study, stream discharge will be used primarily to characterize local hydrologic conditions and to characterize how stream stage through the project reaches vary with discharge.

Water Temperature

Temperature in streams fluctuates over the day and year in response to changes in solar energy inputs, meteorological conditions, streamflow, groundwater inputs, and other factors. Temperature in the groundwater is relatively constant compared to surface water temperature fluctuations. Within the surficial zone, temperature of groundwater is influenced by seasonal heating and cooling of the land surface. Surficial groundwater temperatures are typically cooler than surface water temperatures during the critical low flow period.

For this study, stream temperature will be measured to characterize existing conditions related to surface water and groundwater temperature. Conceptually, we anticipate the restoration actions to contribute colder groundwater to baseflow and potentially even depress surface water temperatures (e.g., Loheide and Gorelick, 2006); however, given heterogeneous mixing of groundwater and surface water, the magnitude of the anticipated effect is estimated to be too small to measure with sparse point observations.

3.2.4 Regulatory criteria or standards

Not applicable.

3.3 Water quality impairment studies

Not applicable.

3.4 Effectiveness monitoring studies

Not applicable.

4.0 Project Description

4.1 Project goals

The overall goal of monitoring alluvial water storage projects is to test the effectiveness of stream restoration actions to restore floodplain water storage functions that are impaired where the stream has vertically incised into its floodplain. In particular, the monitoring effort aims to track the following, both before and after project implementation:

- Detect geomorphic (e.g., elevated channel bed) and hydrologic (e.g., elevated surface water elevation) changes that are indicative of increased groundwater recharge from overbank flow and bank flow, and increased magnitude and duration of groundwater storage in the floodplain.
- Characterize hydrological conditions through time including the timing and magnitude of streamflow in comparison to groundwater elevations.
- Characterize surface water temperatures in comparison to groundwater temperatures.

Elevated channel bed and surface water elevations would be the first indication of increased vertical hydrologic connectivity with the surrounding floodplain and decreased lateral hydraulic gradients toward the channel. Both of these effects are likely to result in increased magnitude and duration of groundwater storage, as quantified by time series observations of groundwater elevations.

4.2 Project objectives

To test the effectiveness of stream restoration actions that aim to restore floodplain water storage functions, the monitoring efforts will be set up as “Before-After Control-Impact” studies. Using this approach parameters will be monitored both before and after restoration implementation at a control reach (i.e., no change) and a treatment reach, which are geomorphically and hydrologically similar. This approach aims to isolate geomorphic and hydrologic changes that result from restoration treatment from natural variability in climate and streamflow.

The objectives of this monitoring program are to measure:

- Changes to stream bed and surface water elevation between a control and treatment reach.
- Changes to the magnitude and timing of groundwater elevations in relationship to surface water elevation at both a control and treatment reach.
- Atmospheric pressure and temperature at the project site, which will be used to derive water levels and to characterize local air temperature.
- Discharge at the upstream and downstream ends of the treatment and control reaches.
- Groundwater and surface water temperatures at both a control and treatment reach.

4.3 Information needed and sources

We assemble various available geospatial data to identify potential locations for monitoring, to include a control reach, a treatment reach, and the upstream and downstream ends of the project. These geospatial data will include digital elevation models and associated derivatives (e.g., flow accumulation raster, relative elevation model), National Hydrography data including stream network and water bodies, and restoration project plans if available. These data were used to identify general locations for monitoring. We then probed soils in the prospective monitoring locations to assess feasibility. However, specific locations will need to be adjusted during field deployment of instruments to accommodate on-site conditions.

New data to be collected include:

- Topographic survey of channel bed elevations (e.g., cross sections), staff plates, and a standardized groundwater well measuring point at the top of casing (TOC). Ground water well measuring points at TOC are surveyed as the elevation of the bolt from which the transducer is suspended
- Barometric pressure and air temperature
- Groundwater well data (temperature and water surface elevation, derived from water pressure) collected both continually and through discrete manual measurements with an electric water level meter.
- In-stream stage data from reading staff plates visually, either in-person or from timelapse photographs
- In-stream well data (temperature and water surface elevation, derived from water pressure)
- Manual discharge measurements and subsequent development of rating curves at discharge stations

4.4 Tasks required

Tasks required to collect necessary data outlined in section 4.3 include:

- Establishment of channel bed elevation cross sections, including locations of end points (monumented by marked wood stake or rebar) and establishment of vertical datum to be used
- Installation of groundwater wells and/or piezometers, including survey of top of casing and measurement of water level

- Installation of stilling wells and staff plates to measure stream stage, including survey of top of casing and staff plates
- Installation of timelapse cameras, where used to monitor stream stage in conjunction with a staff plate

Field instruments that are used for continuous measurement will collect hourly (pressure transducers) to daily (timelapse cameras) data. CCNRD will visit monitoring sites a minimum of two times annually for data download, manual observations, and QA/QC. Survey tasks will occur approximately annually in addition to opportunistic survey following a low frequency peak flow event, such as a 10-year flood).

4.5 Systematic planning process

This QAPP represents the systematic planning process and include the key elements:

1. Description of the project, goals, and objectives.
2. Project organization, responsible personnel, and schedule.
3. Study design to support the project goals/objectives and procurement of data.
4. Specification of quality assurance (QA) and quality control (QC) activities to assess the quality performance criteria.
5. Data analysis, data storage, and reporting of acquired data.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2. Organization of project staff and responsibilities.

Staff[1]	Title	Responsibilities
Bryan Maloney, CCNRD (509) 670-1772	Project Manager and Data Scientist	Project Scope. Internal and Final QAPP review and approval. Internal data review and approval.
Melissa Downes, Ecology (509) 454-4259	Ecology Project Manager	Final QAPP review and approval.
Matt Holland, CCNRD (509) 679-0085	Principal Investigator	Oversees field program. Plans/schedules field dates/logistics. Procures equipment. Ensures site access is safe and permission has been granted. Collects data, records field information, and has proper training.
Susan Dickerson-Lange Natural Systems Design (206) 480-1133	Licensed Hydrogeologist	Reviews and edits QAPP, provides technical assistance to monitoring staff.
Scott Tarbutton, Ecology (509) 867-6534	Ecology Quality Assurance Coordinator	Reviews and approves the draft QAPP and final QAPP

QAPP: Quality Assurance Project Plan

5.2 Special training and certifications

Bryan Maloney has 4 years of experience managing salmon recovery projects including developing, supervising, and monitoring projects from concept through completion. Matt Holland is proficient in several types of groundwater and surface water monitoring and has been the primary staff responsible for the installation, field monitoring, data analysis, and report writing of all AWS monitoring. Susan Dickerson-Lange is a hydrologist and geomorphologist with NSD and is licensed as a hydrogeologist in Washington state. Susan led the scientific and practical development of both the conceptual and actual methods of AWS projects including collaboration with CCNRD to develop a GIS-based screening framework to estimate water storage potential in the Wenatchee watershed, and to prioritize sites for additional restoration assessment.

5.3 Organization chart

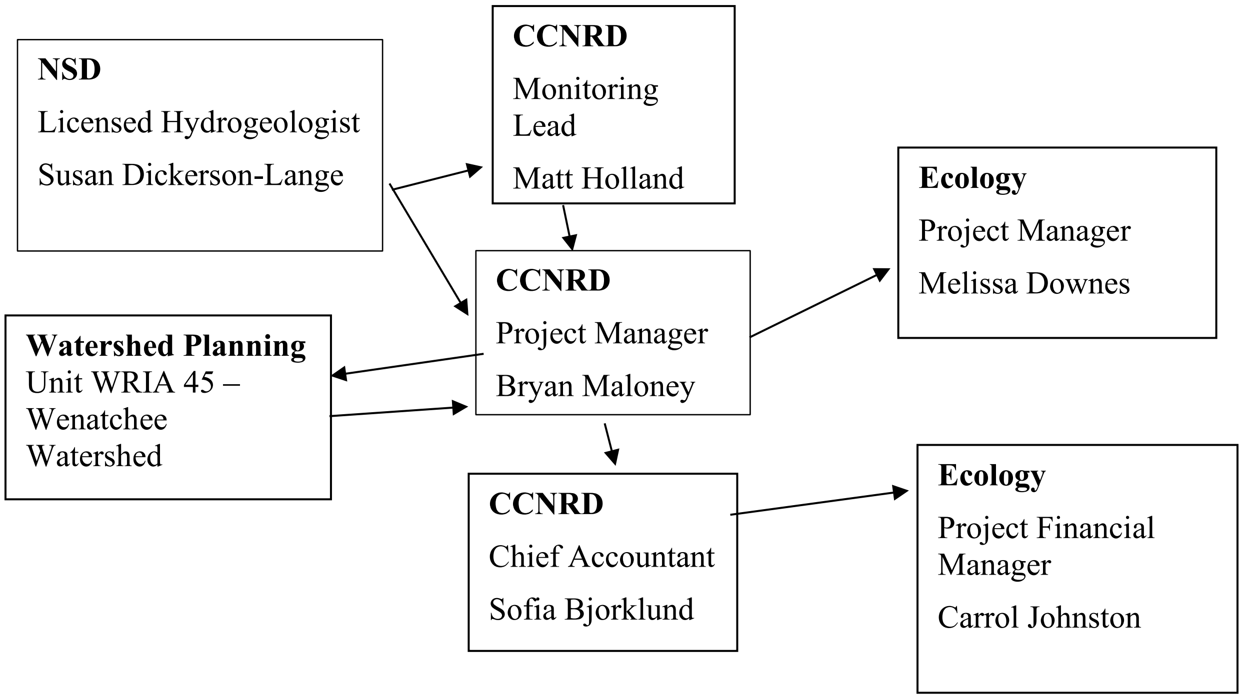


Figure 2. Organizational chart of Project staff

5.4 Proposed project schedule

This proposed project schedule includes all monitoring work under existing funding. However, monitoring will occur under this QAPP during and after restoration treatment implementation. We will pursue additional funding to continue monitoring under this QAPP during and after restoration treatment implementation. Any changes or additions would be captured in a QAPP addendum.

Table 3. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Work type	Due date	Lead staff
Field and laboratory work		
Equipment Installation	June 2023	Matt Holland
Field Visits	Bi-Monthly (Spring-Fall)	“ “
Field work completed	November 2024	“ “
Data analysis completed	February 2025	“ “
Environmental Information System (EIM) database		
EIM data loaded	December 2023-2024	Matt Holland
EIM data entry review	January 2024-2025	Bryan Maloney
EIM complete	February 2025	Matt Holland
Final report		
Draft due to supervisor	January 2025	Matt Holland
Draft due to client/peer reviewer	March 2025	“ “
Draft due to external reviewer(s)	April 2025	“ “
Final (all reviews done) due to publications coordinator	August 2025	“ “
Final report due on web	October 2025	“ “

5.5 Budget and funding

Funding for this monitoring project is provided by an Office of Columbia River (OCR) grant entitled 'Icicle Strategy' (WROCR-2123-ChCoNR-00025). The total value of monitoring funding within the grant is $76,470. We will pursue additional funding to continue monitoring during and after restoration treatment implementation.

Table 4. Project budget and funding.

Item	Quantity	Unity	Estimated Unit Cost	Total Eligible Cost
Staff Time & Travel				
Project Manager	80	hours	$44.92/hour	$3,594
Field Technician	435	hours	$48.90/hour	$21,272
Travel	500	miles	$0.55/miles	$276
Overhead		percent	20.5% of staff time	$5,098
Consultant Staff Time	202	hours	$175/hour	$35,400
Equipment				
Barometric Pressure Hobo	2	each	$310	$620
Water level loggers	25	each	$310	$7,750
PVC well/screen/casings/cable	20	each	$99	$1,980
Staff plates	5	each	$40	$200
T-posts	5	each	$5	$25
Sand (100 lbs)	12	each	$10	$120
Bentonite Chips (50 lbs)	1.5	Each	$90	$135
			TOTAL	$76,470

6.0 Quality Objectives

6.1 Data quality objectives

The main data quality objective (DQO) for this project is to collect channel bed elevation cross sections, surface water elevation, groundwater elevation, stream discharge, and groundwater and surface water temperature data representative of the project locations in a manner consistent with the measurement quality objectives (MQOs) described below and to analyze these data to determine effect of the project on channel morphology, stream stage, and groundwater storage.

6.2 Measurement quality objectives

Channel Elevation

The primary method for measuring temporal changes to channel bed elevation and channel morphology is through annual or biennial repeat topographic survey of cross-sections and longitudinal stream profiles. The MQO for tracking channel bed elevation are governed by the resolution of the approach and instrument being used, which can include Real-Time Kinematic (RTK) GPS, Total Station, laser level, and hand-level applications. Typically, measurements with survey grade instruments are recorded to 0.01 feet with an accuracy of +/-0.01 feet. Hand-level methods have an accuracy of +/-0.1 feet. At each cross section, the survey tool used will be selected based on the availability of adequate satellite coverage.

Water Level Monitoring

The primary instrument for continuously measuring water levels in both groundwater wells and surface water (i.e., stilling) wells is a pressure transducer with onboard datalogger, deployed in accordance with Ecology's SOP EAP074 (Use of Submersible Pressure Transducers During Groundwater Studies). We will also deploy a barometric pressure transducer at each project site in order to compensate measured total pressure data for the atmospheric pressure and therefore isolate water pressure. Accuracy varies by manufacturer. Table 5 provides accuracy and resolution for Onset HOBO Water Level Data Logger, Van Essen Baro-Diver, and TD-Diver pressure transducers typically used for shallow (less than 33-feet submergence) water depth deployments. It is our preference to use HOBO pressure transducers deployed in PVC well-screens/casings, but we may use smaller diameter Van Essen divers in drive-point piezometers if coarse substrate conditions preclude auguring.

In addition to stilling wells with pressure transducers to monitor surface water level, we will install staff gages to measure stage during occasional field visits. In addition, at some locations without pressure transducers we will visually record stage on a regular interval by using time lapse cameras programmed to take one or more photographs of the staff gage per day. Accuracy of this method varies with the distance from the camera to the staff gage and is typically +/-0.1 feet when determined by visual examination of each photograph.

The primary instrument for measuring instantaneous groundwater levels in the field is an electric water level meter, used in accordance with Ecology's SOP EAP052 (Manual Well-Depth and Depth-to-Water Measurements). These units have a steel probe connected to a clearly marked tape and emit a buzz when the probe hits water. The depth to water is read off of the tape by measuring to the bolt to which the logger is suspended from by a stainless-steel cable. A measuring point (MP) will be added to the top of casing of each location, using a file, paint, marker, or a cardinal direction. Field staff will use these manual measurements as an accuracy check of water level data loggers and for the conversions to water surface elevation. Electric tape manufacturers do not list accuracy of tapes, and assume accuracy is equal to the measuring tape resolution (0.01). On occasion, condensation on the interior casing wall and probe can prematurely trigger the electric-tape indicator, giving a false positive reading. In this situation it can help to center the tape in the well casing above the water level and lightly shake the tape to remove the excess water on the probe (SOP EAP052).

Streamflow gaging

Accuracy for individual discharge measurements is more difficult to quantify and is often given a more qualitative assessment. An example field form for assessing discharge measurement quality is located in Appendix B and is based on the factors affecting discharge measurement accuracy outlined by the USGS (Turnipseed and Sauer 2010). Based on these factors, staff will give the discharge measurement an accuracy rating of poor, fair, good, or excellent. Ecology's Standard Operating Procedure (SOP EAP056) for measuring and calculating discharge measurements recommends this type of accuracy rating and states: "Field staff must consider all the conditions and use professional judgement in rating a measurement" (Shedd 2018b). Thus, the quality rating will be completed in the field at the time of measurement and based on field staff's professional judgment of conditions. If methods, conditions, and equipment are good, a discharge measurement should be within five percent of the actual discharge at any given station. The accuracy of the continuous discharge data is a function of the accuracy of the stream stage measurement, the accuracy of the individual flow measurements, and the variability within the stage-discharge relationship and is extremely hard to quantify. As a general rule, the accuracy of the stage-discharge relationship will improve by increasing the number of flow measurements and the range of flows that are covered. Precision of flow velocity and discharge measurements will be additionally assessed and targets and methods are discussed below.

Temperature

The primary method for measuring continuous temperature is through pressure transducers which will measure water surface elevation as well as temperature on an hourly basis in both groundwater wells and instream wells. Accuracy varies by manufacturer. Table 5 provides accuracy and resolution for temperature values on the Onset HOBO Water Level Data Logger and the Van Essen Baro-Diver, which are typically used for shallow (less than 33-feet submergence) water depth deployments.

Table 5. Parameters measured with measurement instruments and their respective range, accuracy, and resolution.

Parameter	Equipment/ Method	Precision Field Replicates	Equipment Information			Expected Range
			Accuracy	Resolution	Range	
Continuous Air Monitoring						
Continuous Air Temp	Van Essen Baro-Diver	--	0.1°C	0.01°C	-10°C to 50°C	-7°C to 31°C
	Onset HOBO (U20L-01)	--	0.44°C	0.10°C	-20° to 50°C	
Continuous Barometric Pressure	Van Essen Baro-Diver	--	0.016 ft-H_2O	0.003 ft-H_2O	--	29 ft-H_2O to 33 ft-H_2O
	Onset HOBO (U20L-01)	--	0.03 ft-H_2O	0.007 ft-H_2O	--	
Continuous Water Monitoring						
Continuous Water Temp	Van Essen TD-Diver	--	0.1°C	0.01°C	0°C to 50°C	1°C to 25°C
	Onset HOBO (U20L-01)	--	0.44°C	0.10°C	-20° to 50°C	
	DGI Slope Indicator 3.5 bar VWP	--	0.04%FS	--	--	
Surface Water Stage	Van Essen Baro-Diver	--	0.016 ft-H_2O	0.003 ft-H_2O	max 4.9 ft-H_2O	0 ft-H_2O to 4 ft-H_2O
	Onset HOBO (U20L-01)	--	0.03 ft-H_2O	0.007 ft-H_2O	max 30 ft-H_2O	
Groundwater Level	Van Essen TD-Diver	--	0.016 ft-H_2O	0.007 ft-H_2O	max 32.8 ft-H_2O	0 ft-H_2O to 10 ft-H_2O
	Onset HOBO (U20L-01)	--	0.03 ft-H_2O	0.007 ft-H_2O	max 30 ft-H_2O	
Stream Discharge						
Discharge	SOP EAP056	10% RPD	--	--	--	0.01 to 200 cfs
Velocity	FlowTracker	5% RPD	<0.03 ft/s	0.01 ft/s	0.003 to 13 ft/s	0.01 to 10 ft/s
Groundwater Level Measurements						
Depth to Water Table	Electric Tape (SOP EAP 052)	--	0.05 ft	0.01 ft	0 to 100 ft--	0 to 10 ft
Topographic Cross Sections (in order of preferred alternatives, pending satellite coverage)						
Lat, Long, Elevation	Trimble R10-2 RTK	--	0.01 ft	--	--	2,000-2,800 ft (expected range)
Lat, Long, Elevation	Total Station	--	0.01 ft	--	--	2,000-2,800 ft (expected range)
Elevation, Horizontal Distance	Laser Level	--	0.1 ft	--	--	0-20 ft (relative heights)

6.2.1 Targets for precision, bias, and sensitivity

Precision

We will assess precision in channel bed elevation measurements via a minimum of one field replicate (e.g., repeated cross-section survey) during each field campaign. We will then plot repeated survey to visually assess for deviation of more than 0.1 feet at any single station and assess the data to determine whether mean elevation relative to the datum is within a margin of +/- 0.2 feet. If the replicated survey results deviate more than this margin, we will perform additional replicates to refine field methods until the field precision targets are met.

We will assess precision in water level measurements, recorded by the pressure transducer with onboard datalogger, via manual measurements of the distance between the top of casing and the water surface (i.e., tape down) at the time of downloading data and a minimum of 1x annually. If there is evidence of movement of a groundwater well, stilling well, or staff plate, the locations will be re-surveyed.

We will assess precision in discharge measurements by completing a minimum of three replicates per year. Precision for replicates is expressed as percent relative percent difference (%RPD) or absolute error and assessed following the MQOs outlined in Table 5.

Bias

Field staff will minimize bias in field measurements by calibrating instruments and following field measurement protocols. Potential sources of field bias in measurements include measurement procedure and calibration problems.

Sensitivity

Sensitivity is a measure of the capability of the field method and instrument used to detect a change. It is described by its range, accuracy, and resolution. This is usually reported for each instrument by the manufacturer. This information is provided Table 5.

For the purposes of this effort, sensitivity is assessed relative to the magnitude of expected changes in the measured parameter. Channel bed elevation measurements are expected to detect changes on the order of 0.1 feet, which is substantially smaller than changes on the order of 1 to 10s of feet that have been observed and documented around the region. Pressure transducers (i.e., water surface elevation and temperature loggers) have a factory-documented range, accuracy, and resolution for which data is collected (Table 5). Given that the documented accuracy and range are approximately 0.02-0.04 ft and <0.001 ft, respectively, the method is sufficiently sensitive to an anticipated change in water level on the order of 0.1 to 1 feet.

6.2.2 Targets for comparability, representativeness, and completeness

Comparability

Factors that influence comparability between studies can include the availability and extent of previous data, training of field staff, field data-collection similarities (location, duration, time of year, weather conditions, etc.), standard operation procedures (SOPs), and instrumentation. Field staff will adhere to common field protocols and all field measurements will follow SOPs to improve comparability between this and similar studies.

Within this monitoring effort, data will be comparable across various timeframes based on synchronous data collection timing (e.g., water level) and similar data collection timing relative to implementation (e.g., channel bed elevation measurements before and after implementation). Changes in channel bed elevation will be subject to the same bed-mobilizing peak flows across the project reach, so detection of changes due to project implementation in the treatment versus control sub-reach will be straightforward as long as the reaches are geomorphically similar.

Variations in annual climate make it difficult to compare water level data over a short timeframe, but the aim is that monitoring data collection before project implementation and for more than a year after project implementation in both a control and treatment reach will support the detection of implementation effects on surface water stage and groundwater storage that are beyond inter-annual climate variability.

<u>Representativeness</u>
Representativeness is a function of individual study design. For the purpose of these projects, a control reach and treatment reach are designated for monitoring in order to detect geomorphic and hydrologic changes that are outside of inter-annual variability in climate and peak flows. The reaches are assessed for their comparability to each other and for representativeness of the project area as a whole. This assessment for comparability includes consideration of tributary inflows, channel gradient, channel morphology, valley width, and presence and grain size of alluvial sediments.

<u>Completeness</u>
The U.S. Environmental Protection Agency (EPA) has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system to meet project objectives (Lombard and Kirchmer 2004). The goal for the physical habitat study is to correctly collect and analyze 100 percent of the samples for each project. However, problems occasionally arise during data collection, such as site access problems or equipment malfunction that cannot be controlled; thus, a completeness of 95% is acceptable for discrete measurements. If equipment fails, staff will attempt to recollect the data under similar conditions, such as the following day, if possible. In general, each project should be designed to accommodate some data loss and still meet project goals and objectives.

For continuous deployed measurements, additional variables can negatively impact completeness including vandalism/theft/tampering, equipment failure, unacceptable fouling or drift, and unpredictable hydrologic events (large storms or steep drops in water level between visits). For these reasons, a completeness of 80% is acceptable for continuous measurements. Given these difficulties, redundancy is an important component when designing studies with continuous data collection, particularly at important boundary conditions and within the most critical areas.
If completeness targets are not achieved, staff will determine whether the data that were successfully collected are sufficient to meet project needs. This will depend on a number of factors, such as the needs of the analysis framework, and the times and locations where data were lost. If successfully collected data are not sufficient, then one or a combination of the following approaches will be used:

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

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

6.3 Acceptance criteria for quality of existing data

No co-located groundwater and surface water data currently exist for these project areas. Existing survey data were collected in some locations, which will be accepted as pre-project survey data if the vertical and horizontal accuracy is greater than +/- 0.05 ft.

6.4 Model quality objectives

Not applicable.

7.0 Study Design

7.1 Study boundaries

The study will occur within the Icicle Creek watershed and in Chelan County. The study will include nine discrete project locations (Table 1, Figure 1) on different floodplains of Icicle Creek (Figure 3).

7.2 Field data collection

All alluvial water storage monitoring locations are on Icicle Creek floodplains (Figure 3). We have identified approximate well locations at all Icicle Creek locations, but those wells have not yet been installed (Figure 3).

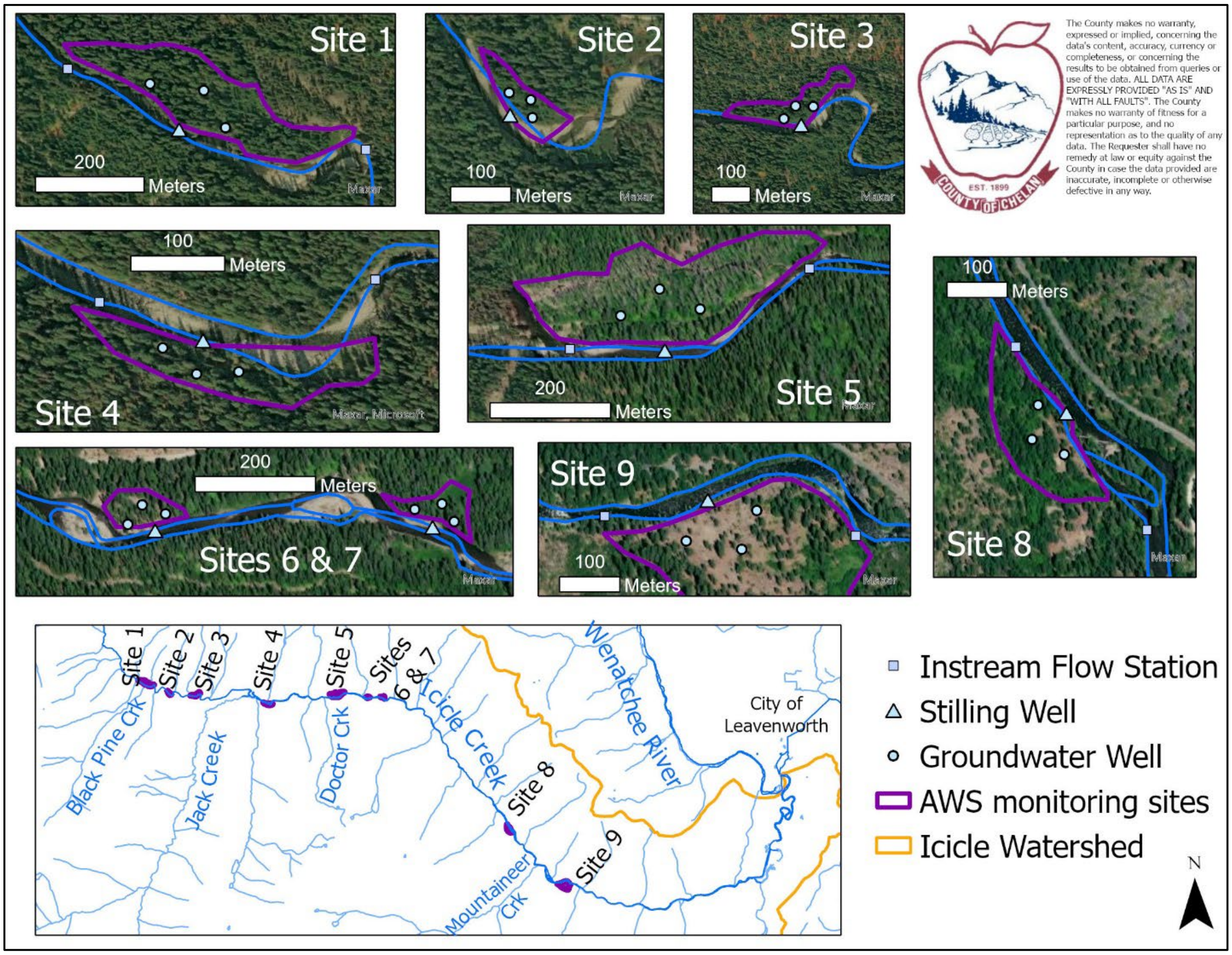


Figure 3. Icicle Creek monitoring locations and proposed well locations.

7.2.1 Sampling locations and frequency

The study design for all projects follows a Before After Control Impact (BACI) experimental design. The BACI design is used here as an approach to detect geomorphic and hydrologic change within a treatment reach relative to an untreated reach (i.e., the control reach). By collecting data both before and after restoration treatment at both reaches, change that is linked to the restoration actions, which occur in the treatment reach only, can be isolated from natural variability in climate and streamflows that influences the geomorphology and hydrology within both reaches. This study design is considered statistically powerful enough to isolate the effect of the stream restoration from natural variability when the timing and location of the treatment is known, and adequate pre-treatment data are collected (Smokorowski 2017).

The project size and treatment approach along with the monitoring extent for individual alluvial water storage projects will vary. This QAPP covers the general study design elements but specific monitoring locations and sampling density will vary with project site conditions. Generally, monitoring design will include groundwater wells strategically located within the treatment area to monitor changes to groundwater elevation in the unconfined, alluvial aquifer as channel bed elevation changes through time. In-stream level loggers will record simultaneous surface water elevation data at in-stream monitoring stations (termed stilling or instream wells, Figure 3) placed within the same reach. Additionally, all projects will have a surface water discharge station above and below treatment to monitor the hydrologic conditions in the project reach in conjunction with changes to surface water and groundwater elevations.

In some cases, particularly in larger scale projects, the floodplain groundwater wells may be arranged in a triangular or diamond pattern between the inset and upland floodplain straddling the in-stream logger. This orientation aims to capture a 3-dimensional (x, y, z, where z = elevation) representation of the hydraulic gradient and the changes that occur to it after treatment is applied. For smaller scale treatment areas, a simpler design may be implemented with fewer wells used, capturing a 2-dimensional water surface elevation (x, z, where x = distance from stream center and z = elevation). Whereas a transect of wells is sufficient to observe the lateral hydraulic gradient, more wells are preferred in wider alluvial valleys for redundancy and for computing flow vectors rather than just the lateral hydraulic gradient. The number of wells and arrangement will depend on both the valley width and the relative elevation of the valley bottom surface, along with the feasibility of installing wells to a depth that is likely to intersect with groundwater during the dry season. Individual project-specific work plans will indicate monitoring locations.

The sampling strategy assumes the before stream restoration condition will be assessed for at least one baseflow season. Following implementation of restoration treatments, monitoring locations may be adjusted if needed to accommodate construction activities. Monitoring locations need to reach appropriate depths, and adjustments would be on the order of feet to tens-of-feet and should not impact results. More details regarding the collection frequency of each parameter are below.

7.2.2 Field parameters and laboratory analytes to be measured

<u>Channel bed elevation monitoring</u>
Staff will perform repeat topographic surveys of channel and floodplain cross-sections using an absolute or relative datum, depending on the survey approach. Where possible, RTK GPS will be used to tie into a commonly used vertical datum (e.g., NAVD88). Where adequate satellite connection is unavailable we will establish a relative datum with a semi-permanent monument to

facilitate re-occupation of the same locations and use other survey methods (e.g., total station, laser level, hand level). These surveys will re-occupy cross-section and longitudinal stream profile locations to detect changes in bed surface elevation from year to year. Staff will also take photos from repeat locations, and/or install game cameras programmed to take photos at specific intervals. These images will supplement surveys and provide qualitative evidence of changes to channel bed elevation.

Ground water level monitoring

Groundwater level monitoring will use either groundwater monitoring wells or piezometers (SOP EAP061; Sinclair and Pitz 2018) to measure shallow groundwater levels on a continuous basis using pressure transducers (SOP EAP074; Sinclair and Pitz 2019). During installation, we will record the depth of the well or piezometer, length of screened interval, and water level within screened or slotted section of well or piezometer. The wells are intended to be near the water table elevation since these measurements are intended to characterize the elevation of the water table in the unconfined alluvial aquifer. We will wait for water level to stabilize after installation, in order to allow for adequate depth during driest anticipated conditions. A barometric pressure transducer will collect continuous data at one location in the project area to enable calculation of water pressure via subtraction of atmospheric pressure from total pressure. We will also survey the bolt from which the pressure transducer is suspended, to tie into an absolute or relative datum so we can translate height of the water column to groundwater elevation.

Surface water level monitoring

Surface water level monitoring will use instream stilling wells with pressure transducers to measure stream stage on a continuous basis. We will monitor continuous barometric pressure at one location in the project area to enable calculation of water pressure via subtraction of atmospheric pressure from total pressure. As above, we will survey the elevation of the bolt from which the transducer is suspended to tie into an absolute or relative datum in order to enable translation from height of the water column to surface water elevation.

We will alternatively monitor surface water elevation via deployment and visual reading of staff gages which we will survey in order to tie into an absolute or relative datum that is comparable to other water level measurements. We will read staff gages during field visits occurring at least two times during the field season (April-November) each year or on a regular interval using time lapse cameras to photograph daily or sub-daily images of the staff gages.

Streamflow gaging

Streamflow gaging at each site will utilize a stilling well that monitors the stream stage on a continuous basis and a series of manual discharge measurements to allow development of a rating curve and calculation of discharge on a continuous basis. We will collect discharge measurements across the expected range of flows at each site (SOP EAP056; Shedd 2018b) and develop a stage-discharge relationship following USGS procedures (Kennedy 1984). We will then apply the time series of stream stage data to the stage-discharge curve to calculate streamflow at the gaging station on a continuous basis.

Water temperature monitoring

Water temperature monitoring will utilize the pressure transducers deployed in ground water and in-stream wells to record water temperature on a continuous basis along with the water surface elevation. The spatial distribution of the transducers, coupled with air temperature record with the barometric pressure, will be informative to characterize the spatial and temporal variations in water temperature within the project area.

7.3 Modeling and analysis design

Not applicable

7.4 Assumptions underlying design

We assume that data collection for each project in the Study Area will be sufficient to characterize the variability of the parameters of interest (e.g., flow or water levels); and the measurements will provide sufficient information to be representative of the time and location.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Logistical problems that interfere with measurement collection are likely to occur during field work. These problems include:

1. Access to measurement locations. CCNRD has a process to identify stream reaches where potential alluvial water storage projects may occur. However, this process does not consider the logistical problems associated with accessing a site to install instrumentation and collect measurements. Project site access problems may be due to lack of an access road or trail, dense vegetation, steep hill sides, landslide/debris flow, wash-out of site(s), etc. We prepare for this contingency by planning for multiple potential treatment and control reaches, in case a few are inaccessible.
2. Inability to install monitoring wells or piezometers to the desired depth (e.g., below seasonal water table) due to refusal. Refusal is met after three unsuccessful attempts to install a monitoring well or piezometer to the desired depth within an immediate area. In this case, the installation of the well may be shallower than intended, resulting in data gaps due to groundwater dropping below the depth of the well. Our contingency plan for refusal includes shifting locations to where installation of a new well of piezometer will be feasible.
3. Inability to measure streamflow due to:
    - Deep or high velocity water that pose a risk for personnel safety.
    - Soft bottom substrate from deep mud or silt that can pose a significant safety hazard and prevent collecting a flow measurement by wading.
    - Streamside or aquatic vegetation that can impact stage or velocity measurements; where vegetation is significant, an attempt will be made to find an alternate location.

    We will measure streamflow only where/when safe and effective to do so.

7.5.2 Practical constraints

Practical constraints that can interfere with project monitoring may include scheduling problems with personnel or availability of adequate resources, both human and budgetary.

7.5.3 Schedule limitations

CCNRD staff have a variety of projects throughout the county that require monitoring, especially during periods of high flow. Often times, these monitoring tasks can be triaged as different sub-watersheds reach peak flows at different times. However, these scheduling conflicts may lead to the inability to capture peak flow conditions at the site.

8.0 Field Procedures

8.1 Invasive species evaluation

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

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

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

Staff will follow established Ecology procedures if an unexpected contamination incident occurs.

8.2 Measurement and sampling procedures

8.2.1 Channel Bed Elevation

Monitoring channel bed elevation is a primary indicator of the effectiveness of the restoration treatment. In addition, a key hypothesis that is being tested as part of this monitoring effort is that there will be a relationship between increased bed surface elevation, increased surface water storage, and increased floodplain groundwater storage.

Prior to project implementation, staff will establish channel and floodplain cross sections with a pair of semi-permanent monuments, and record cross sections with geotagged photos/azimuths, which will aid in re-occupation of the same cross section locations through time. We will then survey cross-sections to capture existing topographic conditions. We will tie these surveys into an absolute vertical datum (e.g., NAVD88) where possible, or to a relative vertical datum, such as a cross-section end point or a semi-permanent hub in the project area. Staff will record approximate locations of the end points using a hand-held GPS. During subsequent years after restoration implementation, particularly after high flow events, staff will repeat surveys and compare them to previous surveys to assess the extent vertical change in channel bed elevation. Frequency of surveys will be approximately annual.

In addition to cross-sections surveys, staff will install a staff plate or t-post with clearly demarcated intervals a few feet upstream of the crest of a subset of structures immediately prior to structure construction. Staff will record bed surface elevation and surface water elevation (in accordance with SOP EAP 042) during subsequent site visits to quantify the change in channel bed elevation through time upstream of restoration treatments.

The topographic surveys may utilize different methods depending on access, cellular and GPS signal, and equipment available. Methods may include: hand measurements of vertical distance to channel bed from a horizontal string, hand level and stadia rod survey, auto level or total station survey, or RTK GPS. In all cases points along each cross section will be surveyed at a spacing of 3 feet or less. A spacing of 1 feet will be used where bankfull channel width is less than 15 feet and a spacing of 3 feet will be used where bankfull channel width is more than 15 feet.

We will then plot transect and profile data collected during ground surveys and compared over time to estimate rate and magnitude of elevation change.

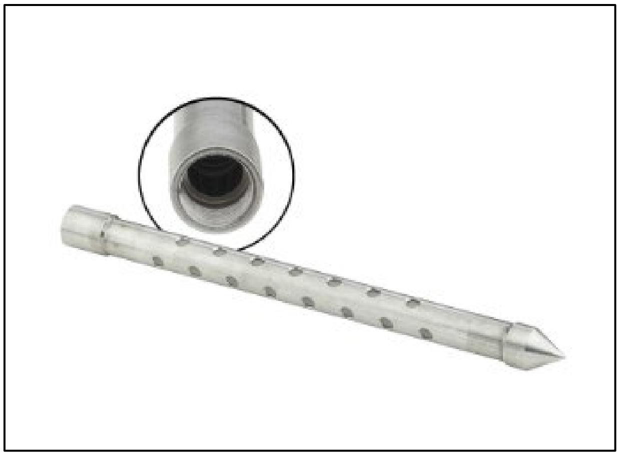
Survey transect location metadata should be recorded following the format of the EIM Location Template, located online at https://apps.ecology.wa.gov/eim/help/HelpDocuments.

8.2.2 Monitoring Well and Piezometer Installation

CCNRD staff will install groundwater monitoring wells and/or piezometers to measure the elevation of the water table within the unconfined, alluvial aquifer that surrounds the streams in these project areas. Installation will generally follow the methods of SOP EAP061 (Sinclair and Pitz 2018) for installation, although the piezometers will be installed in alluvium and used as groundwater monitoring wells rather than in-water piezometers. Deployment of pressure transducers will follow SOP EAP074. Staff will use these water surface elevation measurements to help characterize the amount and timing of groundwater storage, and to compare to surface water elevations to characterize lateral and longitudinal hydraulic gradients in the floodplain. Wells and piezometers will be decommissioned after all monitoring associated with this project is completed, in accordance with SOP EAP061.

8.2.2.1 Groundwater well construction

Shallow groundwater monitoring wells and piezometers are typically constructed of stainless steel or schedule 40 PVC pipe (Figure 4) that are installed at a target depth in the soil and allow access to the groundwater. Shallow monitoring wells measure total hydraulic head along the entire screened section of the pipe, while piezometers measure total hydraulic head at the limited screened section near the bottom of the pipe only.



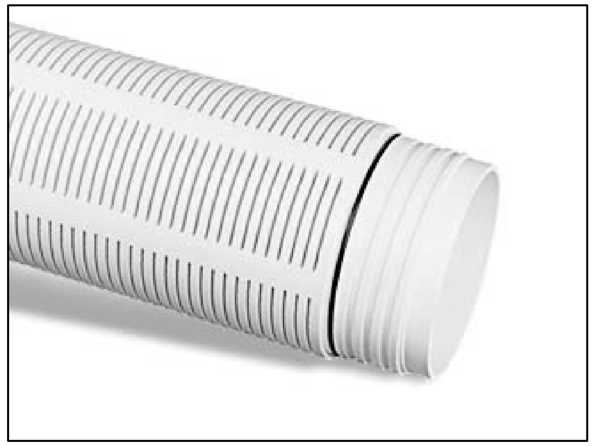


Figure 4. Stainless steel well point piezometer and slotted PVC pipe used for shallow groundwater wells.

Groundwater wells will be installed at a total well depth of less than 10 feet. If the total well depth is less than 10 feet and used only for performing soil and water testing, a licensed driller is not necessary for installation under Revised Code of Washington (RCW) 18.104.020(23)(b)(iii). Wells and piezometers that are installed to depths less than 10 feet are also currently exempt from Washington's well construction and reporting requirements under Chapter 173-160WAC, and Chapter 173-162WAC. In this case, CCNRD staff will install wells or piezometers by pre-drilling a borehole with a hand auger and backfilling the annulus (ASTM, 2106) or by driving a well point directly into the ground with a hammer or powered post pounder. The auger method is best used in unconsolidated soil that is cohesive enough to allow a borehole to remain open during the installation process. For installation in sandy soils, the well point method is advised. Both methods are detailed below.

8.2.2.2 Auger method

Installation of groundwater monitoring well and piezometers via the auger method is detailed below:

1. Select the appropriate auger (hand- or gas-powered) and flight size. The borehole should be as small as possible while allowing space for installation of a filter pack and bentonite seal.
2. Auger a roughly 3- to 4-inch-diameter borehole to a depth of no more than six inches deeper than the planned well depth. Target well depths will be determined by estimating the depth to groundwater based on the surface water elevation. Generally, target well depths are expected to be approximately 5-6 feet, with a screened interval of 5 feet.
3. Thread well screen to a section of blank pipe (riser) long enough to stick up above the ground surface.
    - The material can be made of stainless steel or schedule 40 PVC.
4. Install the well with a few inches of sand pack at the bottom of the hole. Insert either a well with a pre-pack, or insert a well and then backfill the annual space around the well with sand pack.

- We will generally use schedule 40 PVC with a 0.010-inch slot and a 20-40 sand pre-pack or backfill into the annual space. These slot and filter sizes are generally appropriate for alluvium that consists primarily of sand and gravel.
- A smaller slot size and filter pack (e.g., 0.005-inch slot and 100 sand) may be preferred for finer floodplain sediments such as silt and clay. However, given that sourcing these materials can be challenging and that this study is designed primarily to measure water elevations rather than hydraulic properties of the floodplain sediments, in these cases we will use a 0.010-inch slot and a 20-40 sand pack with an additional filter sock on the outside of the pipe or the pre-pack to prevent or delay clogging.

5. Fill the annular space around the well with enough filter pack sand to bury the screen by a few inches. Use a rod if needed to avoid sand "bridging" and leaving void space around the well. If using a pre-pack, the annular space can be filled with additional sand filter material or with native material, with a key aim to avoid leaving void space around the well.
6. Place bentonite chips on top of the sand to within a few inches of the ground surface and hydrate to create a seal. The few remaining inches can be filled with soil or a soil/bentonite mix and mounded around the base of the well to prevent pooling.

8.2.2.3 Driven well-point method

Well-points, or drive-point piezometers, are typically 2½-foot stainless steel well-screens equipped with a sharp point on the end, installed by driving them into the ground using a hammer or powered post pounder and adding extensions of blank (unslotted) pipe, via the method detailed below:

1. Select a well location that will not have surface water pooling around the well.
2. Thread a section of blank, steel pipe to the well screen and attach a drive cap to the top to protect the threads from the hammer. If installing with a post pounder, a threaded steel pipe attached with a coupler may be used instead of drive cap to protect the threads.
3. Drive the well point to the desired depth adding sections of blank pipe as needed to extend above ground.

8.2.2.4 Development and Well Testing

Staff will assess groundwater wells and piezometers for hydraulic connectivity to the surrounding aquifer by observing and recording the response of the water level in the well to a change on water level. After we measure depth to water, we will remove water via pumping or bailing and monitor water levels afterward to assess the rebound of the groundwater and the stability of the water level in the well. Repeated rebound to a similar water level is an indication that the well is hydraulically connected to the surrounding aquifer. Alternatively, for low groundwater levels, we can add water to the well in order to monitor for a response and equalization to similar water level.

Staff will attempt to develop the wells and flush the fines via surging and pumping. We will observe the turbidity of the water removed and ideally continue pumping until the water becomes visually clearer; however, given the small amount of water expected in the wells and the high content of fine sediments and organic soils in the floodplains of some of the project areas, the water may not clear up through pumping and overly aggressive pumping can result in sediment intrusion through the bottom of the casing. In this case, as long as the water levels in the well demonstrate hydraulic connectivity to the shallow alluvial aquifer (see above), groundwater level monitoring will proceed. We will also assess the representativeness of a given groundwater monitoring location via analyzing the data to assess for a relationship with other groundwater and surface elevations. For example, if the groundwater level in a single well does not rise and fall in sync with other nearby groundwater wells, the location will be flagged as potentially not hydraulically connected with the shallow aquifer.

8.2.3 Groundwater Level Monitoring

Once groundwater wells and/or piezometers are installed, staff will survey the bolt from which the transducer is suspended, and tie it into an absolute or relative datum so that we can translate water level observations to water elevations and compare to other measurement points. Survey that is tied into a relative datum will use a semi-permanent hub so that the datum can be re-occupied, and survey re-checked if locations are suspected to have shifted.

Staff will install pressure transducers in each well and/or piezometer to record continuous values of water level (SOP EAP074; Sinclair and Pitz 2019). During installation of the pressure transducers and each subsequent visit to download data, staff will measure and record the distance from the TOC down to the water surface in the well (SOP EAP052) and the time and date that the measurement was collected. Measurements will be completed following the procedure detailed below:

1. Establish TOC height in reference to the land surface datum (LSD). TOC is surveyed at the elevation of the bolt from which the transducer is suspended.

- The LSD is generally chosen to be approximately equivalent to the average altitude of the ground surface around the well.
- Measure the height of the TOC (highest point) in feet relative to the LSD using a pocket tape. Record the distance to the nearest 0.01 foot and the date the TOC was established.
- TOCs and LSDs may change over time, so staff will check the distance between the two whenever there have been activities such as land development that could have affected either the TOC or LSD at the site. Such changes must be measured as accurately as possible, documented and dated in field-data sheets and in any database(s) into which the water-level data are entered.

All subsequent water-level measurements will be referenced to the TOC, which is the established measuring point. The TOC value will be used to convert measurements into values that are relative to land surface.

2. Measure distance from TOC to water surface in each above ground monitoring well or piezometer:

- Open the top of the well and note any popping sounds that would indicate pressure buildup, any odors, and the condition of the well head. If the well was air-tight, wait a few minutes for the water level to return to equilibrium with atmospheric pressure and make note of this. Consider additional venting for measurements moving forward.

- If there is a pressure transducer attached to the well cap, carefully note the initial position of the cap (mark cap position on casing with permanent marker).
- Turn the water level meter on and slowly lower the probe into the well until it makes a tone indicating contact with the water level. To confirm contact with the distinct water boundary, slowly raise and lower the electric-tape probe in and out of the water column. If necessary, adjust the sensitivity setting of the meter to provide a "crisp" indication of the water surface. Measure the depth to water against the highest elevation on the TOC and mark down the date and time the reading was made.
- At the precise location the indicator shows contact with the water surface, pinch the tape between your fingernails at the point exactly opposite the TOC. Read the depth-to-water.
- Repeat measurement to ensure that the water level is stable (not rising or falling over time).
- Turn the water level meter off and lower the probe to the bottom of the well and collect a total depth measurement. Make note of whether the bottom contact feels hard or soft to determine if sediment is accumulating at the bottom of the well. When the probe is pulled back up, make a note of any mud, staining, or anything else on the tip. Rinse the probe before moving on to the next well.

8.2.4 Surface Water Level Monitoring

Each surface water level monitoring station will consist of a surveyed (local datum or true elevation) staff plate, a water-level sensor deployed within a stilling well, and a Stage of Zero Flow (SZF). The actual installation at each site will vary based on site conditions but the following is a general guidance for each component, following SOP EAP042.

Staff plate. Each site will have a staff plate installed as a point of reference for all manual and recorded measurements of stage. Each staff plate should be installed adjacent to the stage measurement sensor and should be low enough in the channel to cover the expected lowest stage and extend high enough to cover the expected highest stage. The staff plate will be surveyed relative to a local or absolute datum so that water levels can be translated to water surface elevations to compare to other surface and groundwater elevations across the project area. The survey will also be used to track the stability of the staff plate over time and to reposition the staff plate accurately if it is damaged or lost.

Stilling Well with Water Level Sensor. Each site will have a water level sensor installed in a stilling well (see section 8.2.6.1 for proper siting) within the wetted channel. The elevation of the top of casing (TOC) will be surveyed relative to a local or absolute datum so that water levels recorded by the pressure transducer can be translated to water surface elevations to compare to other surface and groundwater elevations across the project area. The survey will also be used to track the stability of the stilling well over time and to reposition if it is damaged or lost. Data from this sensor will be recorded at specified intervals (1 hour) on a continuous basis. A barometric pressure transducer will also be deployed at each project site in order to compensate measured total pressure data for the atmospheric pressure.

The Stage of Zero Flow is the water level at which flow in the channel will cease. The SZF is directly related to the hydraulic control within the reach. The hydraulic control is the channel feature or features that controls the water level at the gaging station. In a long riffle reach the control is a function of channel geometry, slope, and roughness. In this case the SZF is likely just the elevation of the deepest part of the transect that the stilling well is installed in. In a pool reach the control is the shallow tailout of the pool and the SZF is the lowest elevation within the tailout. The SZF will be surveyed into the same benchmark as the staff plate and checked periodically as it can change with scour or deposition.

8.2.5 Pressure transducer installation

Water-level in groundwater and stilling wells will be recorded by pressure transducers with onboard data loggers (SOP EAP074; Sinclair and Pitz 2019). Guidance for the installation and use of pressure transducers is presented below.

1. Measure water level and total depth in the well.
2. Suspend the transducer in the water column using thin, stainless steel cable or non-elastic cord made of inert material (such as Kevlar) secured to the well head.
3. Install the pressure transducer as low as possible in the well to ensure the pressure transducer captures as much water level change possible. Do not rest on the bottom. The wells are intended to be less than 10 feet deep, and combined atmospheric and water pressure should not exceed the transducer pressure ratings.
4. If a PVC slip cap is used to close the top of the piezometer, a hole can be drilled into the cap to secure the wire/cord. Otherwise, the transducer should be attached by securing it to some immobile piece of the well casing or well cap.
5. Mark caps to ensure they are replaced at the exact same elevation whenever they're removed. Ensure the well cap is vented and exposes the water column to atmospheric pressure to ensure accurate readings.
6. Program the pressure transducers to collect a reading on simultaneous 1-hour intervals.
7. Measure the depth-to-water prior to pressure transducer removal whenever data is downloaded from the pressure transducers to monitor potential movement of the transducer.
8. Install one dedicated pressure transducer as a barometer either in a well above the water level or in a protected, drained casing in the project area (e.g., attached to a tree). The sensor will collect barometric readings of atmospheric pressure, which allows water pressure to be isolated from total pressure recorded by the submerged transducers. The barometer should be the first transducer installed and the last to be downloaded during subsequent site visits to avoid creating data gaps in the data record.

8.2.6 Streamflow gaging

Streamflow gaging is dependent upon proper site selection, accurate discharge measurements across the expected range of flows, accurate stream stage measurements, and the development and regular maintenance of the stage-discharge curve (SOP EAP042; Shedd 2018a).

Each streamflow gaging station will consist of a surveyed (local datum or true elevation) staff plate, a water-level sensor, and a Stage of Zero Flow (SZF).

8.2.6.1 Gaging site selection

We will select gaging sites in order to characterize the hydrology at the upstream and downstream ends of the project area. We will select the sites for representativeness of project area inflows, and for characteristics that improve the ability to accurately measure discharge, which include (Ecology 2018a, Turnipseed and Sauer 2010):

- Relatively straight channel with parallel edges upstream and downstream of cross section.
- Defined channel edges on both banks.
- Channel with relatively uniform shape.
- Channel free of vegetation, large cobbles, and boulders.
- Cross section free of eddies, slack water, and turbulence.
- Cross section with depths greater than 0.5 feet.
- Velocities greater than 0.5 feet per second (fps) and evenly distributed across the cross section.
- Stable channel geometry with little or no evidence of active scour or deposition.

It is often difficult to find a cross section that will meet all of these criteria in a natural channel and the personnel selecting the site will choose the best available site based on the above characteristics. Within the selected reach the ideal gaging location will be near the discharge measurement cross section and have the following additional characteristics (Sauer and Turnipseed 2010):

- The stilling well or stage measurement point should be located in a pool where stream velocity is low and not subject to turbulence.
- The stilling well should be low enough to record lowest expected stage.
- The stilling well should be out of main flow path to help avoid damage from floating debris carried by stream.

Site access must also be considered, both to equipment on the bank and from the bank down into the channel.

8.2.6.2 Discharge measurements

The streams included in this study are tributaries that are wadeable during high and low flow, so we will use hand-held velocity meters to measure discharge. Discharge measurements should be collected across the expected range of flows at each site to the extent possible; snow may prevent access to sites during a portion of the spring freshet flows.

Staff will follow the Midsection Method (Turnipseed and Sauer 2010) to collect discharge measurements. Each cross-section is divided across its width into sections, with each section ideally containing no more than 5 percent of the total discharge for the cross section. At each section the field staff will record the distance from the bank, the depth of water, the average velocity (at six-tenths depth for locations under 2 feet deep and at both two-tenths and eight-tenths depth at locations deeper than 2 feet). Full details of the methods are described by the USGS (Turnipseed and Sauer 2010) and SOP EAP056.

Safe wading practices (see below) should be reviewed and followed at all times when collecting discharge measurements.

8.2.6.3 Safe wading guidelines

Any instream activities must observe safe wading procedures. Staff will adhere to the following guidelines to assure safety while wading the stream included in this project:

- Do not attempt to wade a stream for which values of depth multiplied by velocity equal or exceed 10 ft^2/s. For example, do not wade into a stream that is 2 feet deep with velocities of 5 ft/s or more.
- Wear hip boots or chest waders for wading depths of 0.5 ft or more. For shallower depths staff can choose waterproof knee-high boots.
- Be aware of surrounding conditions including, but not limited to:
    - Soft or unstable channel bottom
    - Floating debris such as logs
    - Rapidly rising stream stage
- Stay within your ability and comfort level. If you are questioning safety, stop wading and return to collect data when flows have lowered.

8.2.6.4 Stage discharge curves

Staff will develop and maintain stage-discharge curves at all streamflow gaging sites. Each stage-discharge curve will require a minimum of three measurements to develop, with more measurements preferred. Channels with more complex geometry will require additional flow measurements at stages around bank slope break points during development. Extrapolating stage-discharge curves above or below actual measurements can be very inaccurate, and it is important that discharge measurements bracket the expected range of flows. We will follow USGS methods (Kennedy 1984 and Rantz, et al. 1982) to develop each curve and will use the following equation to calculate flows.

$$Q = p(G - e)^N$$

where,

Q = discharge, in cfs

p = constant that is numerically equal to Q when (G-e) = 1; fitted parameter

G = gage height or stream stage in feet

e = SZF

N = fitted parameter that describes the shape of the curve

Once a stage-discharge curve is developed it will require maintenance. We will collect discharge measurements at regular intervals and compare them to the existing curve. These ongoing measurements will indicate whether the stage-discharge curve is stable or if it is shifting due to changes in channel geometry (scour, deposition, etc.). If the discharge measurements indicate that the curve is no longer accurate, we will make additional measurements and update the curve.

8.2.7 Temperature monitoring

All pressure transducers are also equipped with temperature sensors that will record continuous temperature data at the sites that are already collecting atmospheric or water pressure data.

8.3 Containers, preservation methods, holding times

Not applicable.

8.4 Equipment decontamination

Not applicable.

8.5 Sample ID

Not applicable.

8.6 Chain of custody

Not applicable.

8.7 Field log requirements

We will record and retain information included in field sheets (Appendix B) in a field log designated for the project. This information will include:

- Name and location of project.
- Field personnel.
- Sequence of events.
- Any changes or deviations from the QAPP.
- Environmental conditions.
- Date, time, location, site ID.
- Field measurement, with units.
- Identity of QC measurements (e.g., field replicates) collected.
- Unusual circumstances that might affect interpretation of results.
- Any changes to deployment equipment (cable length, well stick-up height)

We will use field logs that are bound, waterproof notebooks with pre-numbered. We will make corrections with single line strikethroughs; initial and date corrections. Electronic field logs (e.g., iPad) may also be used.

8.8 Other activities

No other activities not included under previous sections are anticipated at this time.

9.0 Laboratory Procedures

9.1 Lab procedures table

Not applicable.

9.2 Sample preparation method(s)

Not applicable.

9.3 Special method requirements

Not applicable.

9.4 Laboratories accredited for methods

Not applicable.

10.0 Quality Control Procedures

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

10.1 Field quality control procedures

Staff will perform the following QC procedures on instrumentation to be used in the field: Pre and post calibration on field instrumentations and field duplicates (see Table 5). To minimize bias, the following instruments will undergo a calibration check for the following parameters prior to and following deployment in the field.

Temperature: The procedures for pre- and post-calibration described in SOP EAP080 (Ecology 2015) and Ward (2003).
Pressure: The procedures for pre- and post-calibration described in SOP EAP074 (Sinclair and Pitz 2019).
Velocity: The procedures for pre- and post-calibration described in SOP EAP056 and Turnipseed and Sauer (2010). In addition, refer to velocity meter manufacturer recommendations for field QC checks.

10.2 Corrective action processes

QC results may indicate problems with data during the course of the project. Corrective action processes (e.g., recalibration) will be used if any of the following occur:

- Activities are inconsistent with the QAPP.
- Field instruments yield unusual results.
- Results do not meet MQOs or performance expectations.

11.0 Data Management Procedures

Field technicians will record all field data in a water-resistant field notebook or an equivalent electronic collection platform. Before leaving each site, staff will check field notebooks or electronic data forms for missing or improbable measurements. Field technicians will enter field-generated data into spreadsheets or a project database as soon as practical after they return from the field. For data collected electronically, data will be backed up on servers when staff return from the field. Raw data files will be stored separate from processed data files.

The field lead will check data entry against the field notebook data for errors and omissions. The field lead will notify the project manager of missing or unusual data.

Staff will keep all final spreadsheet files, paper field notes, and final products created as part of the data collection and data QA process with the project data files.

Staff will store all continuous data in a project database that includes station location information and data QA information. This database will facilitate summarization and graphical analysis of the data for uploading to EIM.

11.1 Data recording and reporting requirements

Data collected under this QAPP will be transferred annually to Ecology's EIM database via coordination with Ecology staff. Data will be reviewed for accuracy prior to submission to EIM by graphing the data to assess outliers; querying the data to detect ranges, averages, and other statistical quantification to assess the accuracy of the data against itself and other data loggers.

11.2 Laboratory data package requirements

Not applicable.

11.3 Electronic transfer requirements

Not applicable.

11.4 EIM/STORET data upload procedures

Staff will formulate and submit all data funded by Ecology into Ecology's EIM data system. Staff will use EIM templates found in the EIM help center (https://apps.ecology.wa.gov/eim/help/HelpDocuments) to submit data including, location of cross-sections and wells, water level and temperature time-series data, and well water-level data.

11.5 Model information management

Not applicable.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

All projects will follow the audit and report procedures outlined in this QAPP. Any other planned audit will be documented within a specific project work plan.

12.2 Responsible personnel

Personnel responsible for the audits are:

- Field audit: project managers.
- Field consistency review: experienced (at least 3 years) staff.
- Data analysis: project manager or other personnel familiar with analysis procedure.

12.3 Frequency and distribution of reports

Results of the field data collection, data quality assessment, and any data analysis will be documented in annual and final (end of grant) reports and submitted to the project grant page in Ecology's Administration of Grants and Loans (EAGL) system. Staff will also distribute all final reports to all other stakeholders involved or interested in the study as determined by CCNRD and Ecology.

12.4 Responsibility for reports

The Field Lead (Table 2) will be responsible for analyzing data and preparing the draft final report. The Field Lead will also be responsible for verifying data completeness and usability before the data are used in the technical report and entered into EIM. The Project Manager will review the draft and coordinate internal review. The Project Manager will be responsible for assigning a peer reviewer with the appropriate expertise for the technical report. The final report will go through an internal (CCNRD) and external (Ecology) review process. The peer reviewer is responsible for working with the report author to resolve or clarify any issues with the report.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

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

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

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

Review Discrete Field QC Checks

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

Review/Adjust Time Series (Continuous) Data

1. Plot raw time series with field checks. Reject data based on deployment/retrieval times, site visit disruption, blatant fouling events, and sensor/equipment failure.
2. Review sensor offsets for both pre-calibration and post-deployment buffer/standard checks. Flag any potential chronic drift or bias issues specific to the instrument.
3. If applicable, review fouling check and make drift adjustment if necessary. In some situations, an event fouling adjustment may be warranted based on abrupt changes in flow, stage, sediment loading, etc.
4. Review residuals from both field checks and post-checks, together referred to as QC checks. Adjust data as appropriate, using a weight-of-evidence approach. Give the most weight to post-checks with NIST standards, then field checks rated excellent, then good, and then fair. Do not use field checks rated poor. Potential data adjustments include:
5. Bias – Data are adjusted by the average difference between the QC checks and deployed instrument. Majority of QC checks must show bias to use this method.

6. Regression – Data adjusted using regression, typically linear, between QC checks and deployed instrument. This accounts for both a slope and bias adjustment. The regression must have at least 5 data points and an R2 value of >0.95 to use for adjustment. Do not extrapolate regressions beyond the range of the QC checks.

7. Calibration/Sensor Drift – Data adjusted using linear regression with time from calibration or deployment to post-check or retrieval. Majority of QC checks, particularly post checks, must confirm pattern of drift. Typically, choose the adjustment that results in the smallest residuals and bias between the adjusted values and QC checks. Best professional judgement and visual review are necessary to confirm adjustment.

8. If the evidence is weak, or inconclusive, do not adjust the data.

9. It will be noted in the final report if any data is adjusted. Data adjustment must be performed or reviewed by a project manager, or personnel, with the appropriate training and experience in processing raw sensor data.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

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

14.2 Data analysis and presentation methods

Data found to be of acceptable quality for project objectives will be analyzed before being summarized. Any relevant and interesting data analysis will be presented in the final report using a combination of tables and plots of various kinds, such as time series plots, histograms, and box plots.

Data analysis will leverage the BACI design to detect change between the treatment and control reaches. In particular, the relationship between groundwater and surface water level values in the treatment and control reaches will be established for the period before and after restoration treatment. In addition, discharge data and temperature data will be summarized to characterize the hydrologic conditions in the project areas.

Data analyses will include:

- Water level values at groundwater and surface water monitoring locations will be converted to elevations using a common vertical datum. These values will be plotted for the control reach and the treatment reach as elevations as a function of time, and as elevations as a function of upstream discharge to assess for relationships before and after restoration treatment.

- Water level elevation values will be used along with estimated hydraulic properties of the sediments to approximate groundwater storage volumes.
- The elevations and positions of each monitoring location will be used to estimate lateral and longitudinal hydraulic gradient and groundwater flow direction as a function of time in both the treatment and control reaches.
- The time series and frequency of discharge and water temperature values will be plotted and summarized to characterize existing hydrologic conditions.

14.3 Sampling design evaluation

The project manager will assess whether (1) the data package meets the MQOs, and criteria for completeness, representativeness, and comparability and (2) meaningful conclusions can be drawn from data visualizations and summary statistics.

Given that the monitoring effort is designed to test and provide “proof of concept” for the effectiveness of restoration treatments, the sampling design will be considered effective if the data are collected and are analyzed as intended. Whether the data indicate effectiveness will depend on whether the projects are effective in increasing channel bed elevation and increasing the magnitude and duration of groundwater storage. This effort is not expected or intended to have statistical power without multiple samples; however, a preliminary conclusion of effectiveness can be drawn if changes in channel bed elevation or water level elevations that (1) are greater than the accuracy of the measurement method, and (2) are greater than the values measured in the control reach.

The sampling design presented here also considers the data needs of analytical tools that will be used to complete the analysis, including potential numerical modeling. If numerical modeling is performed, a separate, model-specific QAPP will be developed to guide that effort and to fill any data gaps. Compliance with this QAPP helps ensure that data collected during this project, will be satisfactory support use of future modeling tools and will meet project goals and objectives.

14.5 Documentation of assessment

CCNRD staff will document the data usability assessment in the final report for the project.

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16.0 Appendices

Appendix A. Acronyms

Aspect	Aspect Consulting, LLC
AWS	alluvial water storage
BACI	Before-After Control-Impact
Bgs	below ground surface
CCNRD	Chelan County Natural Resources Department
DQO	decision quality objective
Ecology	Washington State Department of Ecology (Ecology)
EIM	Environmental Information Management
IRPP	Instream Resources Protection Program
LSD	land surface datum
MP	measuring point
MQO	measurement quality objective
NSD	Natural Systems Designs, LLC
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
SOP	standard operating procedure
SZF	Stage of Zero Flow
SWL	static water level
TMDL	total maximum daily loads
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WQS	Water Quality Standards
WRIA	Water Resources Inventory Area
WWPU	Wenatchee Watershed Planning Unit

Appendix B. Field Forms

Qualitative Field Assessment of Flow	
Cross Section Condition	
Velocity Conditions	
Equipment Operation	
Distribution of flow across sections	
Change in Stage	
Wind	
Ice	
Overall Assessment Excellent (2%) Good (5%) Fair (8%) Poor (>8%)	

Qualitative Conditions	Ideal	Non-Ideal
Cross-section condition	-smooth, stable channel -uniform depths across channel -deep enough for propeller -no upstream obstruction altering flow paths	-loose or unstable channel -too shallow for propeller -large rocks or debris affecting flow paths
Velocity	-uniform across channel -perpendicular to cross-section	-large back-eddies -too fast or too slow for propeller -too fast for accurate depth -turbulent
Equipment	-smooth propeller -recent propeller calibration -propeller and shaft in good condition	-damaged propeller -floating debris or grit affecting propeller during measurement -outdated propeller calibration
Distribution of flow	-no single section with more than 5% of the flow	-5-10% in any section=fair ->10%=poor
Change in stage	-stable or small change in stage during measurement	-change of more than 0.1 ft. during measurement
Wind	-calm or no effect	-wind altering current direction -wind affecting depth measurements
Ice	-no ice present	-ice covering some or all of channel

Figure B-1 - Field form for assessing discharge measurement quality.

Discharge Measurement

Date:	Site ID:		Weather:
Observer:	D.L.? Y/N D.L. Time:		
Start Time			Enviromental Notes:
Stage Begin (ft)		Error:	
(R/L) Edge of Water (ft)			
(R/L) Edge of Water (ft)			
Stage End (ft)		Error:	
End Time			
Qm (cfs)			
Comments			

Date:	Site ID:		Weather:
Observer:	D.L.? Y/N D.L. Time:		
Start Time			Enviromental Notes:
Stage Begin (ft)		Error:	
(R/L) Edge of Water (ft)			
(R/L) Edge of Water (ft)			
Stage End (ft)		Error:	
End Time			
Qm (cfs)			
Comments			

Figure B-2 - Field form for recording discharge measurement data/details.

Groundwater Monitoring

Date:	Project ID:	Weather:
Observer:	Last Data run:	

Well ID	Time	D/L?	Tapedown (ft)	Bottom (ft)	Cable Length (ft)	Shifts (ft)	Notes:
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					
		Y/N					

Figure B-3 - Field form for recording groundwater level data/details.

Quality Assurance Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examples of data types commonly validated would be:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

%RSD = (100 * s)/x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

References for QA Glossary

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