Beaver Dam Analog Decision Support
Chehalis Aquatic Species Restoration Plan

December 2021

Pre-implementation report

Reed Ojala-Barbour
Washington State Department of Fish and Wildlife
reed.ojala-barbour@dfw.wa.gov

Jamie Glasgow
Wild Fish Conservancy
jamie@wildfishconservancy.org

Contents

1. INTRODUCTION

The Aquatic Species Restoration Plan (ASRP) is a science-based plan designed to protect aquatic species and restore their habitats throughout the Chehalis River Basin. A priority action identified by the ASRP includes installation of Beaver Dam Analogs (BDAs), human-made structures designed to mimic the form and function of natural beaver dams. Substantial declines in beaver dam building activity in the basin has reduced the occurrence of ponds and other slow water habitats important for coho salmon, amphibians, waterfowl, and other aquatic species (Beechie et al. 2021). Installation of BDAs is intended to increase the occurrence of these important habitats, to the benefit of native fishes and other aquatic species.

Here, we provide an overview of our ongoing BDA project implementation with the intent of informing future BDA projects in the basin and sharing lessons learned with the restoration community.

2. BEAVER DAM ANALOG RESTORATION GOALS

The habitat created by BDAs has the potential to benefit many species, including ASRP target species within and downstream from project sites. Beaver pond habitats have been shown to benefit coho salmon (Pollock et al. 2004, Bouwes et al. 2016), Chinook salmon (Katz et al. 2017), pond-breeding amphibians (Stevens et al. 2007; Romansic et al. 2021) and waterfowl (Cooke and Zack 2008). BDAs generally achieve greater function when they are augmented by beaver dam building. Habitat goals of the BDA implementation include:

- Create and maintain wetland and pond habitat and associated natural processes by impounding water, enhancing aquatic productivity, and improving water storage and groundwater recharge;
- Enhance channel-floodplain interactions;
- Increase the diversity of aquatic habitat (Rosell et al. 2005, Ecke et al. 2017) including thermal heterogeneity and refugia;
- Improve water quality through sediment retention, nutrient retention and transformation, and organic matter storage (Mumma et al. 2018);
- Enhance water storage, groundwater recharge, and thermal variability (Pollock et al. 2003, Westbrook et al. 2006, Dittbrenner 2019).;
- Increase representation of wetland vegetation (Seedang et al. 2008, Silverman et al. 2019). Note, addressing this objective may also include planting appropriate plant species at BDA sites to supplement natural recruitment

Because pond and wetland fauna can utilize the habitat created by BDAs immediately after construction, these structures may help recover functional still-water habitats in the Chehalis Basin over short timelines. Ideally, the abundance, diversity and quality of habitat created by BDAs will improve over time through colonization by beaver and ecological succession as wetland and aquatic plants become established and riparian vegetation develops (Figure 1).

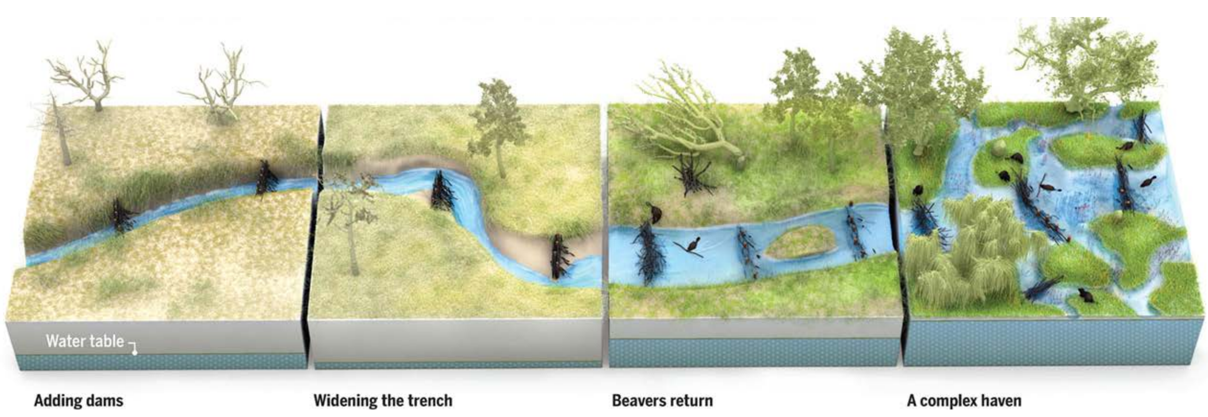


Figure 1. Illustration of a typical restoration sequence from an incised channel to complex wetland meadow facilitated by Beaver Dam Analogs (BDAs). Adapted from Goldfarb, 2018 figure copyrighted Science by V. Altounian, as adapted by Shahverdian et al 2019.

3. BDA SITE SELECTION TOOL

We developed a Chehalis Basin-wide BDA site selection tool as a Web App to help restoration practitioners identify and prioritize stream reaches with characteristics potentially suitable for application of BDA restoration techniques and to guide site selection through initial risk assessment, field assessment, and outreach efforts. The tool is available online: https://geodataservices.wdfw.wa.gov/hp/chehalis-beaver-dam-analog/

3.1. CHEHALIS BEAVER INTRINSIC POTENTIAL MODEL (BIP)

Identifying potential beaver habitat provides a means for assessing and prioritizing sites for the application of beaver-based restoration techniques. The beaver intrinsic potential habitat (BIP) model is a beaver habitat model that uses intrinsic site characteristics to predict potential reach suitability and the capacity of the landscape to support pond or wetland habitats. Specifically, it identifies stream segments with the greatest potential to sustain beaver dams and store surface water. The BIP model is based on three weighted parameters: stream slope, bankfull width, and valley width. The Chehalis BIP model is based largely on the 2020 Washington State BIP model and an approach developed in Skykomish, WA (Dittbrenner et al. 2018). In August of 2020, we conducted a model validation to ensure that the Chehalis BIP model suitably matched local field-verified site parameters (Appendix A).

3.2. AQUATIC RESOURCES, ASRP PRIORTIES AND JURISTICTIONS

Our online tool includes the ASRP Geo-Spatial Units (GSUs) and provides a separate layer for GSUs prioritized for BDA and Beaver Pond restoration actions. We also added Statewide Washington Integrated Fish Distribution (SWIFD) and fish intrinsic potential based on NetMap. Fish distribution layers include presence for coho, chinook, sockeye, chum and steelhead. We also include Ecology's 303d Water Quality List and Chehalis Thermalscape (present year and 2040) to inform thermal profiles under climate change. To help inform permitting we include FEMA flood zones and county boundaries. We also include NWI wetlands and public lands.

3.3. RISK ASSESSMENT

We recognize that beavers can pose a risk to infrastructure. Conversations with landowners suggested that culverts becoming plugged by beaver dam-building and flooding roads were some primary concerns. We added infrastructure layers to the tool including WDFW's Fish Passage Database, WADNR's Road Maintenance and Abandonment Plans (RMAPs) forest landowner culvert database and roads to support identification of culverts and potentially vulnerable road crossings near potential sites.

4. LANDOWNER OUTREACH

We worked with Chehalis Basin habitat restoration practitioners, including the Chehalis Lead Entity Coordinator and the Lewis, Grays Harbor, and Thurston County Conservation Districts to identify landowners potentially interested in allowing and accruing benefit from BDA projects on their property. Additional outreach efforts prioritized larger forest landowners with ownerships in the Chehalis Basin that encompassed suitable stream reaches identified in our site selection tool. We contacted prioritized landowners using a one-page flier (Appendix B) to provide information about the project, and to gauge landowner interest in allowing a BDA project on their property. Where high BIP scores, willing landowners, and low risk to infrastructure converged, the project team performed a site visit to further evaluate the suitability of their property for BDA development. We also developed a beaver coexistence strategies pamphlet to educate about reducing beaver conflict (Appendix C)

5. BDA STRUCTURE PLACEMENT AND DESIGN

We developed a BDA design typical for our project that incorporated elements from other BDA restoration practitioners including Low-Tech Process-based Restoration of Riverscapes Design Manual (Shahverdian et al. 2019) and The Beaver Restoration Guidebook (Pollock et al. 2017). Our intention was to produce a design that could be form-fit to a range of site conditions. Our process involved initial reconnaissance visits with landowners to assess site suitability and risk to infrastructure. We completed site assessment forms (Appendix D) as part of this initial visit. We then prioritized sites and revisited our top candidates with an interdisciplinary team that included fish, geomorphology, ecology, and engineering expertise. We planned to construct multiple BDAs along stream reaches with the recognition that, due to site-specific characteristics, not every structure may be effective at achieving design objectives and some structures might fail (Figure 2).

In addition to a high-BIP score (low gradient, small to medium channel width, and wide valley floor), landowner willingness, low risk to infrastructure and GSUs, we prioritized the following stream reach characteristics:

- Incised channels – our intent is to increase floodplain-channel connectivity, reduce stream power, and aggrade sediment in impaired reaches.

- Plane-bed channels that lacked instream wood and pools – our intent is to increase channel complexity where it is lacking.

- Recent beaver sign including dams, chew, trails, feces, or scent mounds- our intent is to have beavers colonize our BDA reaches by building dams on them where feasible.

- Availability of beaver forage (deciduous vegetation) – our intent is to have beavers colonize the reaches and maintain the structures.

- Coho presence – our intent is to enhance slow-water rearing habitat where it will be utilized by coho, the salmonid that stands the most to benefit from these habitats (Beechie et al. 2021).

Within reaches, we prioritized the following characteristics for BDA structure locations largely based on guidance in Shahverdian and colleagues (2019). These characteristics emulate natural beaver dam placement and help to ensure the maximum benefit and longevity of the structure:

- Natural constrictions in channel width downstream from a wider channel
- Riffle crests
- Stream banks that were not substantially undercut
- Immediately downstream from off-channel habitats, including side channels and relic side channels, that could experience increased connection as a result of backwatering from BDA structures
- Channel substrate that appeared to be suitable for driving wooden posts.

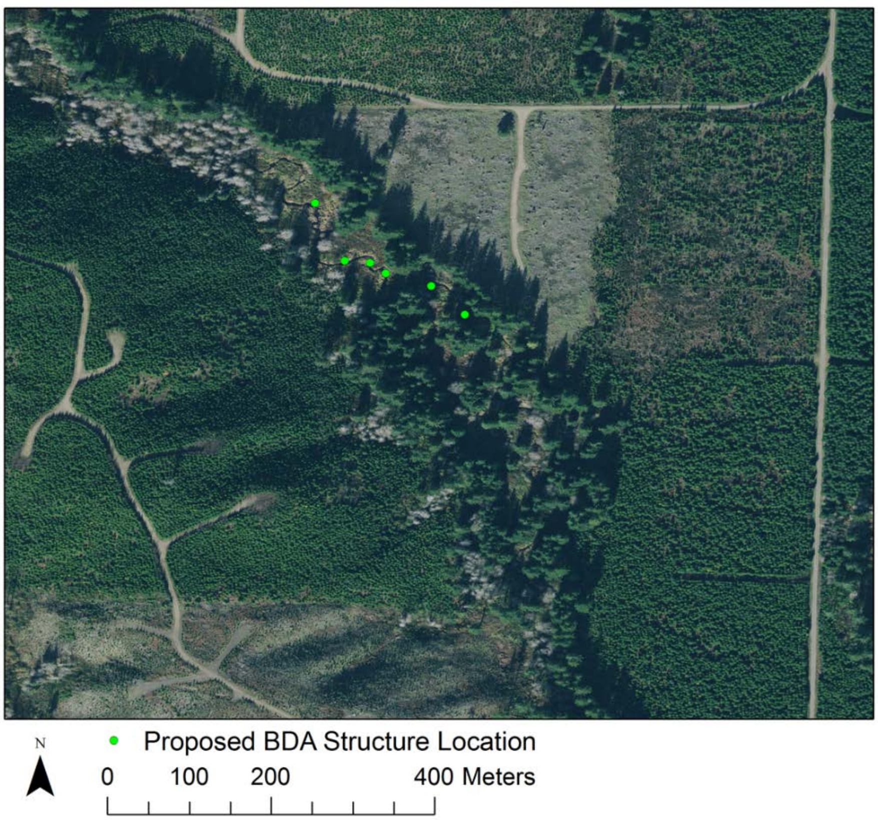
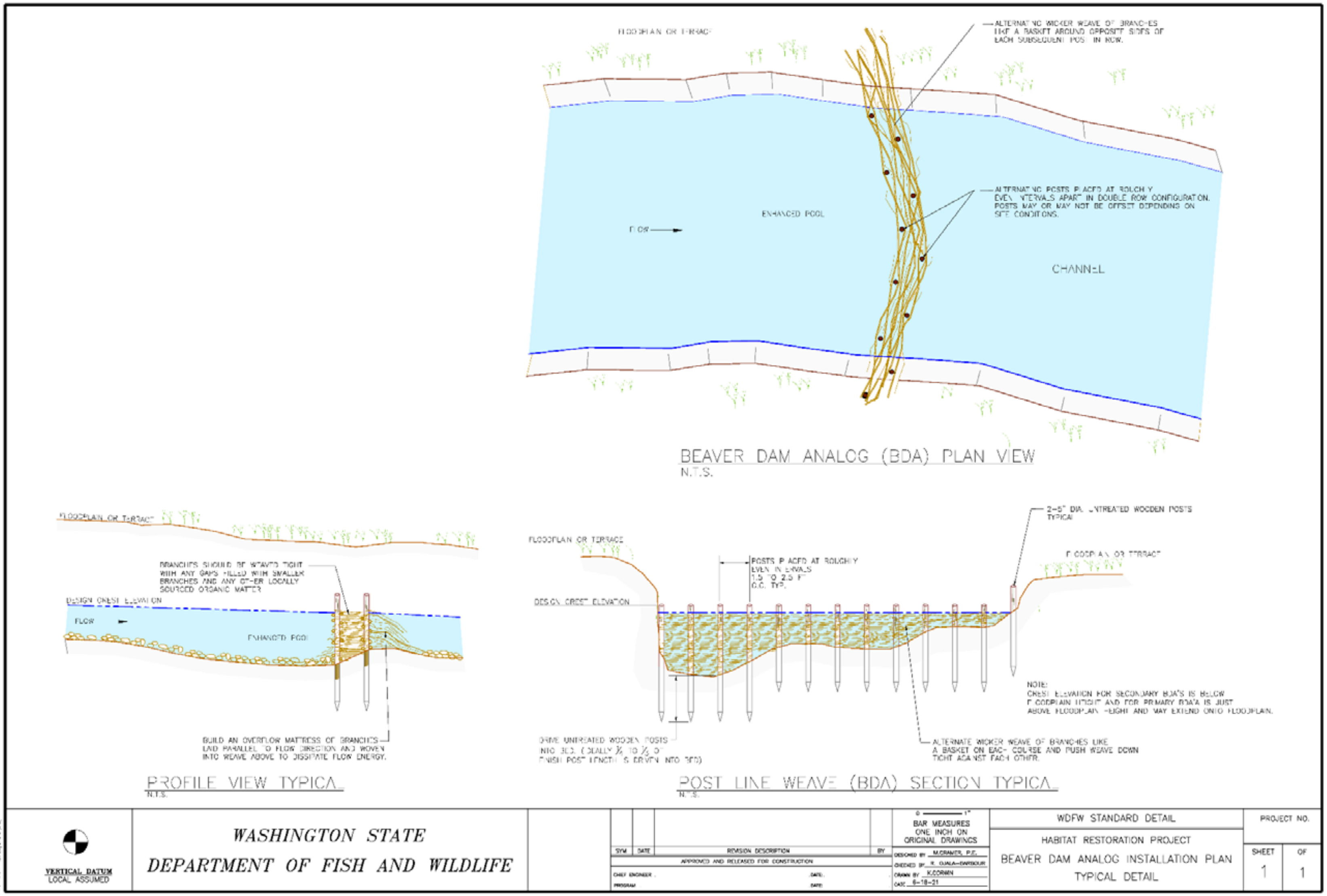


Figure 2. Example site map showing multiple field-fit potential BDA structure locations following a field reconnaissance.

Figure 3. Beaver Dam Analog design typical



6. PERMITING

Permitting is a complex and potentially dynamic process. While interest in BDA implementation appears to be growing rapidly, not all permitters are familiar with novel low-tech process-based restoration approaches. Check with permitting entities early in your project's development. This section reflects our experience and is not intended to be comprehensive of all permitting approaches to BDA construction. Project location, structure design, and construction methods can affect permitting requirements.

6.1. DEPARTMENT OF FISH AND WILDLIFE

Check with the Habitat Biologist for your project area.

Hydraulic Project Approval are needed for all hydraulic projects in or near state waters. This includes BDAs.

We decided to route our project as Fish Habitat Enhancement Projects (FHEP) because they offer a streamlined process for projects designed to enhance fish habitat. Projects supported with ASRP funds qualify for the FHEP process under 1(c) and 2(f) of Guidance: Streamlined Process for Fish Habitat Enhancement Project dated July 2021. The FHEP process bypasses State Environmental Policy Act (SEPA) review and waives local government permits and fees, except that, pursuant to chapter 86.16 RCW, a local government may impose such requirements and/or charge such fees as may be necessary for the local government to administer National Flood Insurance Program (NFIP) regulation requirements.

6.2. DEPARTMENT OF ECOLOGY

Check with the Ecology Wetland staff in your project area.

In Washington, wetlands are protected by several laws overseen by state, local, and federal agencies as well as tribes. Ecology has the authority to regulate wetlands under the state Water Pollution Control Act and the Shoreline Management Act.

If the project impacts wetlands it is possible that a Section 401 federal Clean Water Act permit from Ecology may be needed. Projects constructing hand-built structures may be less likely to require permits from Ecology. Our projects were determined to not impact wetlands. Project locations that intersect Shorelines of the State may also require additional review related to county shoreline master plans.

6.3. DEPARTMENT OF NATURAL RESOURCES

An Aquatic Use Authorization may be required for projects located on state-owned aquatic lands. Contact your District Land Manager to determine if your proposal requires authorization.

6.4. USACE

Check with United States Army Corps of Engineers (USACE) Project Manager in your project area.

Section 404 of the Clean Water Act requires authorization from the USACE for the discharge of dredged or fill material into waters of the U.S. including special aquatic sites such as wetlands. Authorization is generally required for activities which result in the discharge of rock, soil, or other types of fill. Wood alone may not be considered fill by the USACE. Therefore, wood-only structures without associated rock ballast or backfill material may not require USACE authorization. Nationwide Permit 27 for Aquatic Habitat Restoration, Enhancement and Establishment Activities may be appropriate for projects that do discharge fill.
Section 10 of the Rivers and Harbor Act requires a permit for any structures or work in, over or under navigable waters of the United States, or which affects the course, location, condition, or capacity of such waters. A list of navigable waters can be found here. Contact USACE for the most recent and project-specific guidance. Seattle District Regulatory Homepage: https://www.nws.usace.army.mil/Missions/Civil-Works/Regulatory/

6.5. COUNTY

The FHEP process bypasses State Environmental Policy Act (SEPA) review and waives local government permits and fees, except that, pursuant to chapter 86.16 RCW, a local government may impose such requirements and/or charge such fees as may be necessary for the local government to administer National Flood Insurance Program (NFIP) regulation requirements. This is often covered by a flood plain development permit for projects located in FEMA flood hazard areas. A no-rise memo stamped by a licensed engineer may be required.

Projects that are not permitted as FHEP may need to consider shoreline master plans and critical areas. Contact your county land use and permitting office.

6.6. CITY

If your project occurs within a city jurisdiction, city regulations may apply.

7. PROJECT EFFECTIVNESS MONITORING

We coordinated with the ASRP Monitoring and Adaptive Management Team to identify research questions of interest to the ASRP Steering Committee. The Steering Committee directed all project effectiveness monitoring to include only evaluations of physical habitat responses to restoration. Biological responses may be studied in the future under a different monitoring program. The following questions were selected for project effectiveness evaluation:

- Can BDAs be used as a tool to increase fluvial habitat complexity at the reach scale?
- Do BDAs facilitate beaver colonization and maintenance?
- Do BDA structures increase hydrological connectivity with the floodplain?

- Do BDAs increase thermal refugia opportunities?

We developed a Quality Assurance Project Plan that describes a detailed study design and survey techniques (Appendix E).

8. REFERENCES

Barnard, R. J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J. P. Klavas, D. C. Ponder, P. D. Smith, and P. D. Powers. 2013. Water Crossing Design Guidelines. Page (W. D. of F. and Wildlife, Ed.). Olympia, WA, USA.

Beechie, T., and H. Imaki. 2014. Predicting natural channel patterns based on landscape and geomorphic controls in the Columbia River basin, USA. Water Resources Research 50:39–57.

Beechie, T.J., Fogel, C., Nicol, C. and Timpane-Padgham, B., 2021. A process-based assessment of landscape change and salmon habitat losses in the Chehalis River basin, USA. *PloS one*, *16*(11).

Davies, J. R., K. M. Lagueux, B. Sanderson, and T. J. Beechie. 2007. Modeling stream channel characteristics from drainage-enforced DEMs in Puget Sound, Washington, USA. Journal of the American Water Resources Association 43:414–426.

Dittbrenner, B. J., M. M. Pollock, J. W. Schilling, J. D. Olden, J. J. Lawler, and C. E. Torgersen. 2018. Modeling intrinsic potential for beaver (Castor canadensis) habitat to inform restoration and climate change adaptation. PLoS ONE 13.

Goldfarb, B. (2018). Beavers, rebooted. Science 360:1058-1061

Hall, J. E., D. M. Holzer, and T. J. Beechie. 2007. Predicting river floodplain and lateral channel migration for salmon habitat conservation. Journal of the American Water Resources Association 43:786–797.

Nagel, D. E., J. M. Buffington, S. L. Parkes, S. Wenger, J. R. Goode, E. David, M. John, L. Sharon, and R. Jaime. 2014. A Landscape Scale Valley Confinement Algorithm: Delineating Unconfined Valley Bottoms for Geomorphic, Aquatic, and Riparian Applications, Gen. Tech. Rep. RMRS- GTR-321. Fort Collins, CO.

Pollock, M., G. Lewallen, K. Woodruff, C. Jordan and J. Castro, editors, 2017. The Beaver Restoration Guidebook: Working with beaver to restore streams, wetlands, and floodplains. Version 2.0 edition. US Fish and Wildlife Service, Portland, OR.

Romansic, J.M., N.L. Nelson, K.B. Moffett and J. Piovia-Scott. 2021. Beaver dams are associated with enhanced amphibian diversity via lengthened hydroperiods and increased representation of slow-developing species. Freshwater Biology 66(3):481-494.

Shahverdian, S.M., J.M. Wheaton, S.N. Bennett, N. Bouwes, R. Camp, C.E. Jordan, E. Portugal and N. Weber. 2019. Chapter 4 - Mimicking and Promoting Wood Accumulation and Beaver Dam Activity with Post-assisted Log Structures and Beaver Dam Analogues. Page66 66 in J. Wheaten, S. Bennett, N. Bouwes, J. Maestas, and S. Shahverdian (eds.) Low-tech Process-based Restoration of Riverscapes: Design manual. Utah State University Restoration Consortium, Logan, Utah.

Stevens, C.E., C.A. Paszkowski and A.L. Foote. 2007. Beaver (Castor canadensis) as a surrogate species for conserving anuran amphibians on boreal streams in Alberta, Canada. Biological Conservation 134(1):1-13.

USGS. 2014. U.S. Geologic Survey National Elevation Dataset.

USGS. 2019. U.S. Geologic Survey National Hydrography Dataset High Resolution. Retrieved from: https://viewer.nationalmap.gov/basic/?basemap=b1&category=nhd&title=NHD%20View

APPENDIX A – SITE SELECTION BEAVER INTRINISC POTENTIAL MODEL

8.1.1. Model Development

The framework for the BIP model (Figure 3) was developed in the Snohomish River Basin, Snohomish County, WA and published in peer-reviewed literature (Dittbrenner et al. 2018). The methods are presented in detail in this open access article:

Dittbrenner, B.J., Pollock, M.M., Schilling, J.W., Olden, J.D., Lawler, J.J. and Torgersen, C.E., 2018. Modeling intrinsic potential for beaver (Castor canadensis) habitat to inform restoration and climate change adaptation. *PloS one*, *13*(2). https://doi.org/10.1371/journal.pone.0192538

In 2020, Beavers Northwest created a BIP model for Washington Department of Fish and Wildlife that covered the entire state of Washington. The state-wide model was validated by comparing modeled site conditions to actual streams containing 220 vacant reaches and 199 reaches with beaver present. The accuracy assessment of the statewide model west of the Cascade crest showed a combined accuracy of 91%. We used these data as the basis for the Chehalis model, but fine-tuned our model using local data to ensure higher basin-specific accuracy.

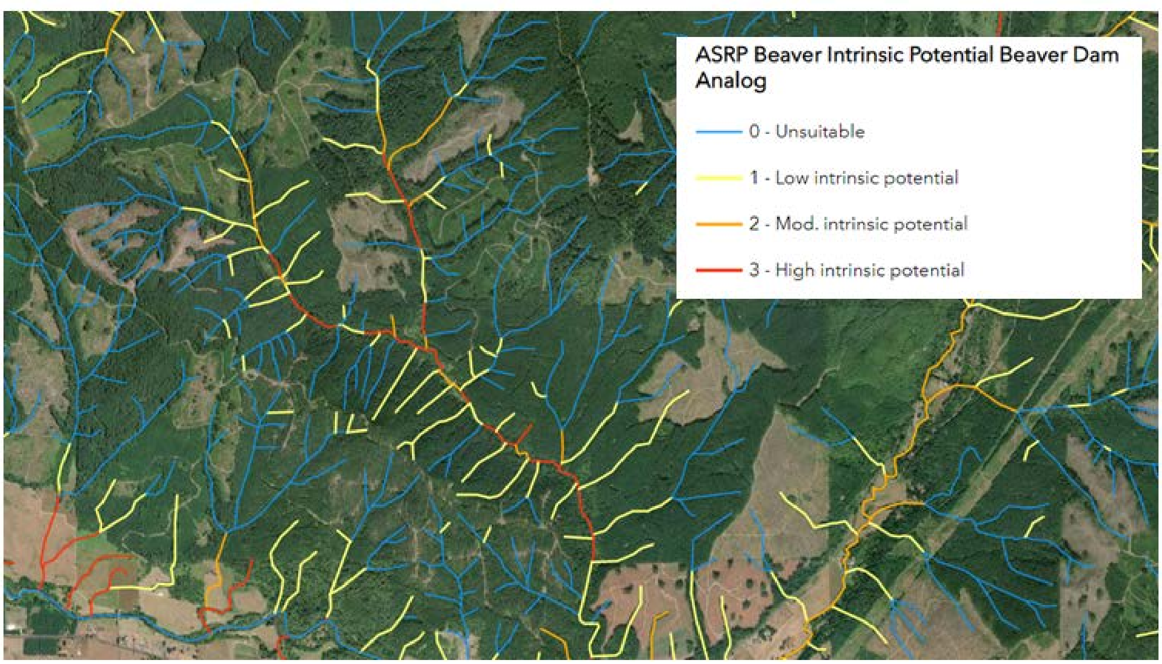


Figure 4. Example of Beaver Intrinsic Potential.

The most important of the three parameters used in the BIP for identifying habitats with the greatest suitability under BIP is stream slope, stream bankfull width (BFW), and valley width. Stream slope is frequently correlated with beaver presence and is an ideal indicator of BIP due to its low likelihood to change over time. Beaver generally prefer reaches with below 3% gradient.

BFW is the second parameter used in the BIP model. BFW is estimated using a regression that includes each segment's drainage area and mean annual precipitation. It has been reported that beavers prefer streams 3-4 m wide for damming with an outside range of 2-10 m in Oregon's Coast Range, USA. Valley width is the third BIP parameter and informs stream confinement.

Based on the range of conditions present at each stream segment, we assigned a ranked value from 0-4 to each of the three variables, commensurate with their level of intrinsic potential according to the criteria in Table 1. The modeled stream lines were broken into approximately 250 m segments consistent with the parent National Hydrography Dataset (NHD) stream lines that the BIP lines are derived from. A final BIP score was assigned to each segment by summing the ranked scores of stream slope, stream width, and valley width (Table 1). We assigned intrinsic potential scores to all stream segments within the Chehalis River Basin to produce the BIP model. The model possesses four predictive categories of beaver intrinsic potential: No BIP, Low, Moderate, and High BIP, numbered 0-3, respectively.

Table 1. Scoring for each of the three parameters used for identifying BIP in the Chehalis. The values of the three parameters are added together to produce a BIP sum score and then condensed to adjusted scores between 0-3 corresponding to BIP category high, medium, low and no BIP.

Stream slope		**Stream bankfull width (m)**		**Valley width (m)**		**Cumulative score**	**Adjusted score**	**BIP category**
< 2 %	4	<7	4	> 30	4	12	3	High
< 4 %	3	<10	3	< 30	2	11, 10	2	Med
< 6 %	2	<13	2	< 20	1	9, 8 , 7	1	Low
< 14 %	1	<17	1	<10	0	<7	0	No BIP
> 14%	0							

8.1.2. Original accuracy assessment

Prior to testing Chehalis basin-specific data, an assessment of modeled BIP in western Washington, a subset of the statewide model, showed the BIP model to have an overall accuracy of 90.7% (Table 2). This accuracy was arrived at following the exclusion of large stream segments (i.e., greater than 1 km in length) from the assessment, as we considered these segments spurious, with a high potential for conflating error in other areas of the model if they were used to subsequently adjust the full model scoring scheme.

Table 2. Contingency table for evaluation of accuracy of modeled BIP in streams of western Washington. Values in the upper left and lower right boxes quantify the number of streams with the correctly predicted BIP score. The values in the upper right and lower left boxes represent error of omission and commission, respectively.

	Field-verified scores

Model scores	Not suitable	Suitable
Not suitable	190	18
Suitable	20	181

8.1.3. Chehalis parameter validation

The BIP model is based on three parameters: slope, BFW, and valley width. We validated each of these parameters with Chehalis Basin-specific data to test whether regional variation was conflating model error in this basin, and if so, to address those errors.

8.1.3.a. Slope

The model's slope parameter is based on a previously generated slope metric in the National Hydrography Dataset (NHD). NHD slope data were evaluated primarily for data omissions in the Chehalis basin. In cases where slope was missing, we calculated slope by finding the difference in elevation at the upstream and downstream extent of that segment and dividing by its total length. We found and fixed a small number of missing slope scores. These omissions were limited to high gradient, first order streams not suitable as beaver habitat.

8.1.3.b. Stream bankfull width

BFW estimates were derived from an empirically derived equation relating field-verified BFW measures to each stream segment's drainage area and mean annual precipitation. We assessed existing BFW equations generated in the past for this region. BFW was initially evaluated in the statewide model using 986 BFW points collected by partners and publicly available surveys. We used these data to evaluate the goodness of fit for the four BFW equations that we tested, which consisted of models from Barnard et al. (2013), Beechie and Imaki (2008, 2014), Davies et al (2007), and Hall et al. (2007). Visual assessments of BFW using orthophotos were conducted at stream segments to ensure that the selected BFW equation was being applied correctly in a general sense.

Following these tests, we found that both the Barnard and Davies BFW models provided good fit, but the Barnard model was slightly better. The Barnard model was used in western Washington in the statewide model.

We retested modeled BFW in the Chehalis basin using 3,477 field collected BFW measurements taken by WDFW and other regional partners. Prior to testing, all points were evaluated to ensure that they clearly corresponded to BIP stream segments. We omitted any point that was greater than 50m away from the corresponding stream line, or existed near a confluences with multiple streams. We found that the Barnard model produced a good fit with a high degree of correlation

(Figure 4; $R^2 = 0.69$, $p << 0.001$). In general, the model slightly underpredicts actual BFW size, but the model holds up well in reaches of core beaver habitat. Furthermore, we do not expect that these levels of discrepancy would change final BIP scores in any appreciable way. The model scoring criteria can correct for these types of minor discrepancies in actual vs modeled BFW if the trend is consistent, which is true in the Chehalis Basin. While the Davies model performed similarly, the Barnard model was ultimately selected for use in the Chehalis as it was more consistent of BFW within the range of stream widths most suitable for beaver dam construction.

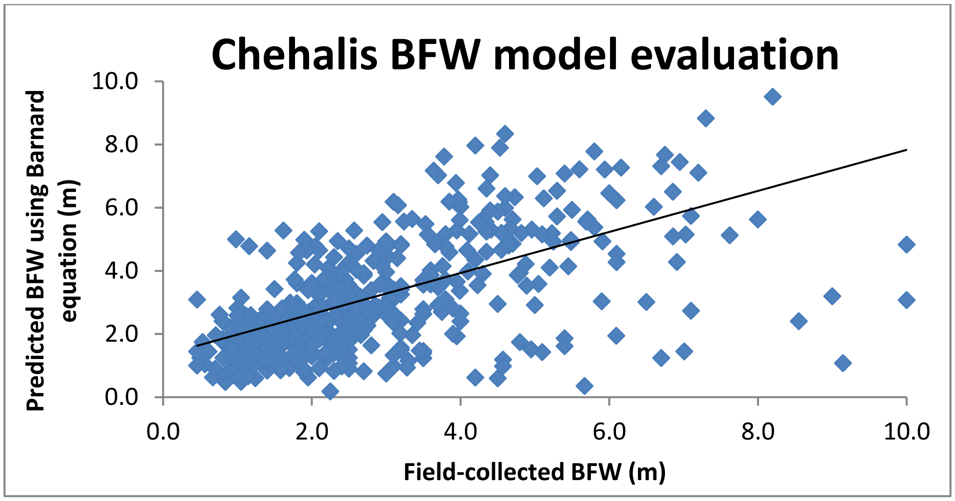


Figure 5. Evaluation of bankfull width (BFW) estimates using Barnard method versus field-collected bankfull width measurements.

8.1.3.c. Valley width

We estimated valley width using a modified version of the Valley Confinement Algorithm tool developed by Nagel et al. (2014), which created valley bottom polygons. To identify the valley width for each stream segment, we calculated the average width of stream cross-sections, spaced every 10 m along each segment, intersecting the extent of the Valley Confinement Algorithm polygon. One hundred randomly selected valley bottom polygons and widths were evaluated for consistency and accuracy using orthophotos, topographic maps, and DEM hillshade layers. All were found to have a good fit within the Chehalis Basin. Any discrepancies identified were due to error associated with variations in the parent DEM data.

8.1.4. Chehalis BIP Accuracy Assessment

Based on the validation tests performed above, we determined that the parameter data used in the 'downscaled' Chehalis BIP provided good predictive fit. Consequently, we used this existing BIP data structure in the full Chehalis model. Our initial assessment of modeled BIP in western Washington showed the BIP model to have an overall accuracy of 90.7% (Figure 4). The Chehalis model largely mirrors the western portion of the Washington statewide model and reflects a similar level of accuracy.

```
          Accuracy : 0.9071
            95% CI : (0.8747, 0.9334)

       Sensitivity : 0.9048
       Specificity : 0.9095
    Pos Pred Value : 0.9135
    Neg Pred Value : 0.9005
        Prevalence : 0.5134
    Detection Rate : 0.4645
Detection Prevalence : 0.5086
 Balanced Accuracy : 0.9072
```

Figure 6. Results of accuracy assessment of western Washington BIP model.

APPENDIX B - LAND OWNER OUTREACH PROJECT DESCRIPTION

Chehalis Basin Beaver Dam Analog Project

The Chehalis Basin Beaver Dam Analog Project is part of the Aquatic Species Restoration Plan (ASRP), a science-based plan designed to protect aquatic species and restore their habitats throughout the Chehalis River Basin. A priority action identified by the ASRP includes installation of Beaver Dam Analogs (BDAs), manmade structures designed to mimic the form and function of natural beaver dams. Substantial declines in beaver activity in the basin has reduced the occurrence of slow water habitats important for coho salmon and waterfowl. Installation of BDAs is intended to increase the occurrence of these important habitats, to the benefit of native fishes and other aquatic species.

Research across the western United States has demonstrated that installation of BDAs can effectively:

- increase aquatic habitat diversity;
- restore stream-floodplain connectivity;
- retain sediment;
- enhance aquatic productivity;
- reduce water temperatures; and
- improve water storage and groundwater recharge.

BDAs are designed to be a simple and cost-effective approach to stream restoration. This project proposes to site, design, and construct BDAs in select Chehalis watersheds. We will also monitor natural resources outcomes to inform the effectiveness of BDAs in achieving the ecological goals identified in the ASRP and to inform future BDA projects.

We seek sites with the greatest potential for sustaining slow water habitats created by BDA installation (low gradient, small to medium stream width, and wider valley floors). **We are seeking interested landowners who would like to learn more about our project. Our goal is to identify landowners willing to consider an evaluation of their stream networks for sites suitable for BDA installation. Sites will be selected to avoid impacts to infrastructure such as culverts and roads.**

Project Activity	Proposed Timeline
Identify interested landowners and assess potential sites	November 2020 – January 2021
Conduct engineering surveys	January – March 2021
Pre-construction monitoring	February 2021 – Summer 2022
Construct BDA structures	July – September 2022
Post-construction monitoring & adaptive management	2022 – 2023

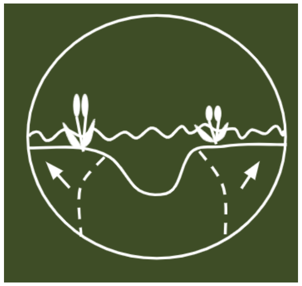
Washington Department of FISH and WILDLIFE   Wild Fish Conservancy   DUCKS UNLIMITED   BEAVERS NORTHWEST

CONTACT:
Reed Ojala-Barbour
Washington State Department of Fish and Wildlife
reed.ojala-barbour@dfw.wa.gov

APPENDIX C – BEAVER COEXISTENCE STRATEGIES

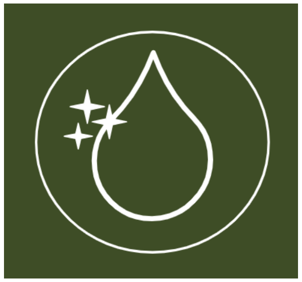
This page intentionally left blank

BEAVER BENEFITS



Increased water storage and groundwater recharge

Improved quantity and quality of fish, amphibian, and waterfowl habitat



Improved water quality

If you have beavers, enjoy the beauty and benefits of the complex ecosystems they engineer!

GOT BEAVERS?

Coexistence strategies

BEAVERS CHEWING DOWN YOUR TREES?

You can protect trees on your property by wrapping them in fencing. To allow the trees room to grow, set the fence several inches away from the trunk.

In the image below, 4ft tall fencing is used to ensure beavers cannot chew above it.

Funding provided by:

This brochure developed in partnership with Beavers Northwest, Wild Fish Conservancy, and WA Dept of Fish and Wildlife. Funding provided by the Chehalis Basin ASRP

BEAVERS BLOCKING YOUR CULVERT?

You can build an exclusion fence around the entrance of a culvert to prevent beavers from building within it. These fences ensure that water can continue to flow.

To build in or near water in Washington you must first obtain an HPA permit from WDFW. More information and technical assistance can be found at https://wdfw.wa.gov/licenses/environmental/hpa

BEAVER PONDS IMPACTING INFRASTRUCTURE?

You can install a flow control device that will allow you to reduce the flooding caused by the beaver pond. Devices include notch exclusion fences (pictured below) and pond levelers. These devices also require an HPA permit.

For technical assistance, including help with permitting and installation, contact Beavers Northwest at info@beaversnw.org beaversnw.org

APPENDIX D - SITE ASSESSMENT FORM

ASRP BDA Site Assessment Form

Site:________________________________ Date/Time:________________________________

Surveyors:____

Stream morphology and site suitability –

Gradient - beavers will most often colonize streams with gradients from 0 to 6%, although those below 3% are preferred:. ____________ **(percent)**

Bankfull width- beavers preferred streams 3-4 m wide for damming with an outside range of 2-10 m in Oregon's Coast Range: ____________ **(m)**

Valley width (m) - defined as the average width of the area adjacent to a stream segment that was within 2 m vertical elevation of the channel elevation: ____________ **(m)**

Notes on valley confinement/loss of lateral connectivity:

Dominant channel substrate – **sand / gravel / cobble / boulders / bedrock / other____________**

Distance to and condition of upstream and downstream culverts?

Describe availability of reference - upstream or independent:

Biological/Physical benefit considerations

Describe Loss of connectivity to adjacent, floodable floodplain present and channel incision:

Average incision in reach ______________________(**m**)

Presence of in channel wood: **Very limited / Moderate / Significant wood jams**

Riparian vegetation: **Conifer / Deciduous / Mixed**

Describe riparian vegetation considering beaver forage:

Evidence of beaver activity in reach? **Yes / No**

<u>Landowner Considerations</u>

Reach length on parcel of willing landowner ____________ **(m)**

Possibility of multiple BDA structures? **Yes / No** Estimate how many: ________________

<u>Logistics and Access Considerations</u>

Distance to nearest access road? ____________ **(m)**

Equipment access to stream? **Hand tools only / Hydraulic post-pounder / Heavy equipment**

Presence of livestock: **Yes / No** Describe how many and relationship to access/site:

Gates: **Yes / No** Gate notes:

<u>Risk Assessment</u>

Consider GIS risk assessment and provide additional notes on infrastructure/land use:

Notes:

APPENDIX E – PROJECT EFFECTIVENESS QAPP

This page intentionally left blank

Quality Assurance Project Plan

Chehalis ASRP Beaver Dam Analog Project Effectiveness Monitoring

July 2021

Washington Department of FISH and WILDLIFE

Contact Information

Reed Ojala-Barbour
Washington Department of Fish and Wildlife
1111 Washington St SE, Olympia WA 98501
Phone: 360-902-2618

COVER PHOTO: North American beaver, *Castor canadensis,* swimming in a pond . PHOTO BY JAMIE GLASGOW

Quality Assurance Project Plan

Building decision support for science-based BDA implementation in the Chehalis

by Tristan Weiss, Reed Ojala-Barbour, Aimee McIntyre, Jamie Glasgow

July 2021

Approved by:

Signature: Tristan Weiss	Date: 7/13/2021
QAPP Author's Name, Title, Organization Tristan Weiss, Research Scientist, Washington Department of Fish and Wildlife Signature: Reed Ojala-Barbour	Date: 7/13/2021
Project Manager's Name (if different from QAPP Author), **Title, Organization** Reed Ojala-Barbour, Fish and Wildlife Biologist, Washington Department of Fish and Wildlife Signature:	Date:
Arati Kaza, Quality Assurance Officer, Department of Ecology	

1.0 Table of Contents

List of Figures

List of Tables

2.0 Abstract

The Chehalis Basin ecosystem has been substantially changed from historic conditions through human activities such as wood removal from rivers, use of splash dams, channel straightening and removal of riparian forests. These actions have contributed to channel incision, reductions in floodplain wetlands, and reduced cover and shading of aquatic habitats, and have had significant consequences for the native aquatic biota that rely on the Chehalis Basin and its ecosystems. Without aggressive protection and restoration actions, climate change and future human population growth will increasingly threaten the viability of aquatic species in the Chehalis Basin. The protection and restoration of habitats for aquatic species is a primary objective of the Aquatic Species Restoration Plan (ASRP; ASRPSC 2019). The ASRP maintains that ecological processes and functions within the Chehalis Basin can be protected and restored to support and sustain productive, diverse populations of native aquatic species.

Beaver Dam Analogues (BDAs) represent a flexible process-based restoration technique to address many of the limiting factors in the Chehalis Basin (Castro et al., 2015; Shahverdian et al., 2019). Over the last 150 years, 90 percent of Chehalis marsh and pond habitats have been lost or degraded (Beechie, 2019). This type of habitat is critical for many of the target species of the ASRP including spring-run Chinook, fall Chinook, Coho, stillwater-breeding amphibians, and waterfowl (Bouwes et al., 2016; Cooke and Zack, 2008; Katz et al., 2017; Pollock et al., 2004; Stevens et al., 2007). Historically, beaver have played a critical role in forming and maintaining these habitats (Naiman 1999). However, beaver trapping and the deliberate destruction of dams has limited the ability for beaver to create and enhance wetland habitat. BDAs effectively mimic natural beaver dams in the way that they create beaver ponds and wetland habitats, restoring a suite of ecological and hydrologic benefits identified in the ASRP (ASRPSC, 2019; Castro et al., 2015).

This project explores how effectively BDA restoration actions in the Chehalis Basin can increase fluvial habitat complexity, hydrological connectivity with the floodplain, and thermal refugia opportunities for native aquatic and semi-aquatic species, and facilitate beaver colonization and dam building. Implementation of BDA structures is one of three restoration actions identified in the ASRP Project Effectiveness Program as a priority in the upcoming biennium. The Project Effectiveness Program will track the response of habitats to restoration actions. This Quality Assurance Project Plan describes a monitoring strategy to evaluate the effectiveness of BDA structures in the Chehalis Basin at three study sites. We will evaluate overall effectiveness of this restoration action by assessing changes in physical and hydrological characteristics, beaver colonization and dam building, water temperature, and fish populations in response to BDA structures. Results of this study will inform the use of this restoration action in the future, including information on project design and siting.

3.0 Background

3.1 Introduction and problem statement

This effort is part of the Aquatic Species Restoration Plan (ASRP), a science-based plan designed to support aquatic species and restore their habitats throughout the Chehalis River Basin. A priority action identified by the ASRP includes installation of Beaver Dam Analogs (BDAs), manmade structures designed to mimic the form and function of natural beaver dams. Substantial declines in beaver activity in the basin has reduced the occurrence of ponds and other slow water habitats important for coho salmon, amphibians, waterfowl and other aquatic and semi-aquatic species. Installation of BDAs is intended to benefit native fishes and other aquatic species by increasing the occurrence of these important habitats.

BDA techniques continue to grow in popularity and can be employed as stand-alone artificial structures, designed to encourage colonization by beaver, or paired with beaver translocation (Pollock et al., 2014). Researchers have reported promising restoration outcomes, but uncertainty remains about effects across variable site conditions and bioclimatic zones. The majority of BDA restoration has occurred on incised steams in arid rangeland and snow dominated systems (Pilliod et al., 2018). The lack of published effectiveness studies in Western Washington's wetter, more temperate climate creates some uncertainty in the effectiveness of the technique in the Chehalis Basin. Our objective is to evaluate the effectiveness of BDA treatments to:

- Increase fluvial habitat complexity
- Increase hydrological connectivity with the floodplain
- Increase thermal refugia opportunities
- Facilitate beaver colonization and dam building

3.2 Study area and surroundings

Geographically, the Chehalis Basin (Water Resource Inventory Areas [WRIAs] 22 and 23; Figure 1) drains an area of approximately 2,700 square miles and contains 1,391 streams with more than 3,400 stream miles. As a part of this project, we selected stream reaches with suitable conditions for Beaver Dam Analog installations. We evaluated suitability considering physical attributes, landowner willingness, and evidence of current or historic beaver use.

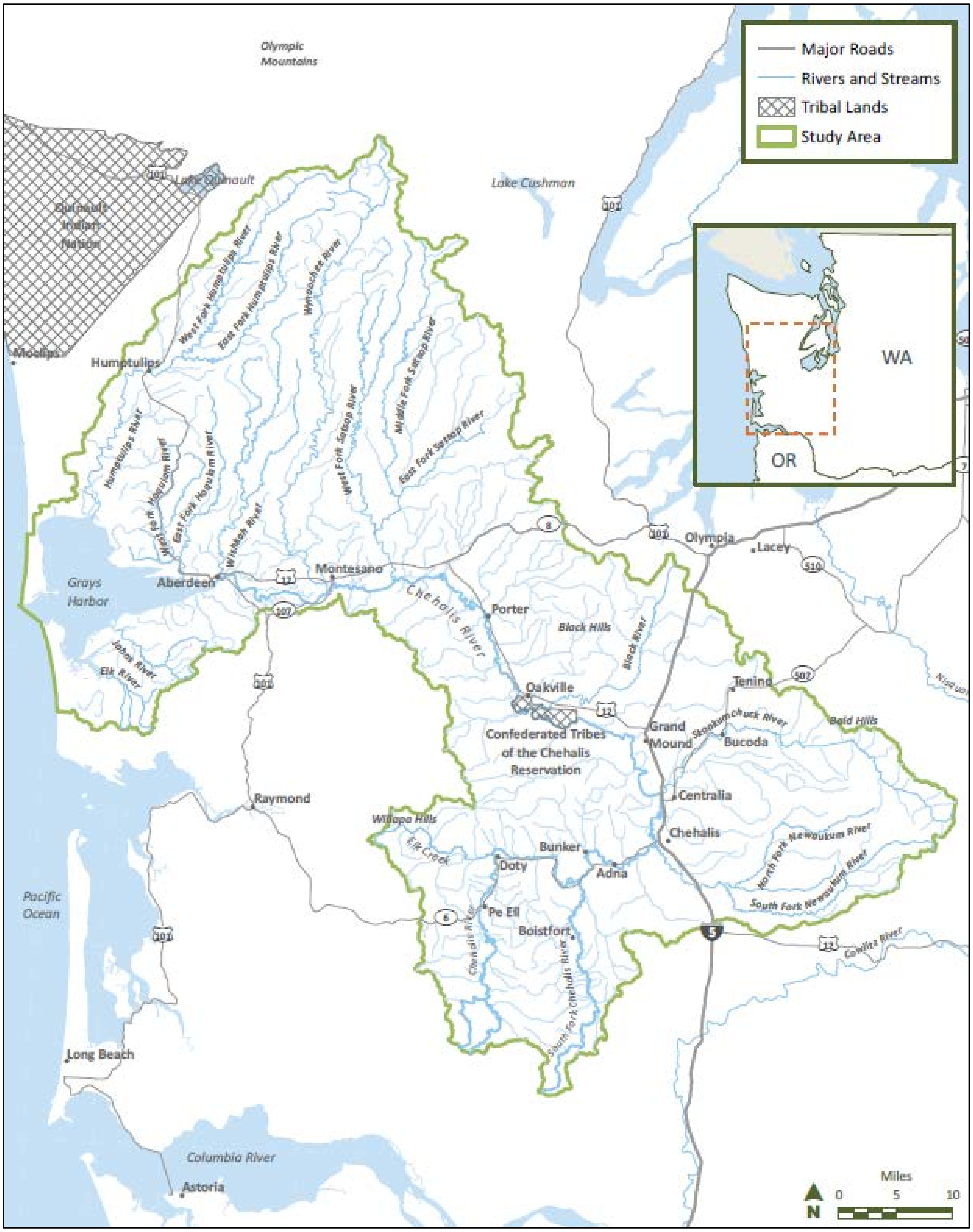


Figure 1. Map of the Chehalis Basin.

3.2.1 History of study area

Much of the Chehalis watershed is important for anadromous fish, including spring and fall run Chinook, Coho, steelhead, and sea-run cutthroat trout, which spawn and rear in the Basin. The Chehalis also provides important habitat for other aquatic and semi-aquatic species such as beaver and amphibians. Land conversion and climate change impact aquatic species and habitats. As a part of this study, we will implement BDA structures in streams located in commercially-managed forests and agricultural areas with the goal of improving aquatic habitat diversity and natural processes.

3.2.2 Summary of previous studies and existing data

BDAs are increasingly employed as a restoration technique (Pollock et al., 2014). Researchers have reported promising restoration outcomes, but uncertainty remains about effects across variable site conditions and bioclimatic zones. The lack of published effectiveness studies in Western Washington's wetter, more temperate climate creates some uncertainty in the effectiveness of the technique in the Chehalis Basin. Table 1 presents publications describing studies that have evaluated the effectiveness of BDAs as a restoration technique across the Western United States.

Table 1. Select peer-reviewed BDA studies, including author, location and responses evaluated.

Author	Location	Responses Evaluated
Bouwes et al., 2016	Central Oregon	Fish density, survival, and production
Weber et al., 2017	Central Oregon	Stream temperature
DeVries *et al.,* 2012* **Choke dam variant*	Western Idaho	Beaver dam persistence, floodplain connectivity
Orr et al., 2020	Central Oregon	Sedimentation, water temperature, groundwater, vegetation
Scamardo and Wohl, 2020	Front Range Colorado	Surface hydrology, shallow groundwater hydrology, geomorphic responses
Norman, 2020 (Thesis)	Montana	Surface flow, shallow groundwater, turbidity, and conductivity

The focus of past BDA research in peer-reviewed literature has varied. In the Bridge Creek intensively monitored watershed (IMW) in Oregon's John Day watershed, BDAs were used to provide supplemental support for existing natural beaver dams (Bouwes et al., 2016). This research helped pioneer BDA restoration techniques. Monitoring revealed increased density, survival and production of juvenile steelhead without impacting migration (Bouwes et al., 2016). The same restoration project showed increased surface water storage and created cool water refugia (Weber 2017). In Colorado, BDAs were shown to store sediment, and sediment accumulation was positively correlated with BDA height and pool surface area; however, the shallow groundwater storage did not change as a result of BDA implementation (Scamardo and Wohl, 2020). In central Oregon rangeland, the amount of sediment retention as a result of BDA implementation varied; however, BDAs increased groundwater levels and floodplain connectivity (Orr et al., 2020). In western Idaho, choke dams were installed without the use of posts. These structures did not create pools, but were colonized by beavers (DeVries et al., 2012).

3.2.3 Parameters of interest and potential sources

This study will not evaluate environmental pollutants.

Parameters of interest include water temperature, hydrological and physical characteristics, and biological response:

Water Temperature:

- Net change
- Thermal diversity (i.e., identification of cold-water patches)
- Structure-based thermal diversity (i.e., post-treatment spatial diversity and diel patterns of stream temperatures across BDA impounded and free-flowing stream sections)

Hydrological:

- Riparian groundwater
- Inundated area
- Seasonal stage
- BDA pond water level

Physical:

- Site topography
- Stream geomorphic units
- Stream longitudinal profile
- Stream cross sections
- Reach-scale large wood load
- BDA structure volume

Biological:

- Beaver structure use

- Fish

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

Beaver dam analogs (BDA) are artificial structures that emulate the form and function of natural beaver dams. In recent decades, BDAs have been extensively employed across the arid intermountain west of the United States to lower stream power, reverse channel incision, improve river-floodplain connectivity, and improve overall stream ecosystem functioning (Pollock et al., 2014). While the physical and hydrologic, and to a lesser extent, chemical and biological responses to BDA restoration have been investigated in snowmelt-dominated arid regions of the Western U.S. for over a decade, implementation and monitoring of BDAs in rain-dominated temperate coastal areas such as the Chehalis Basin have been minimal. Despite the limited application of BDAs in coastal Washington basins to restore stream processes, evidence suggests that restoring river-connected wetlands may improve summer and winter habitat for aquatic species including juvenile coho salmon (*Oncorhynchus kisutch*; Pollock et al., 2004).

This study seeks to conduct pre- and post-treatment monitoring at BDA structures across three study locations within the Chehalis basin to evaluate the physical and hydrological changes to habitat under previously unevaluated climactic and hydrologic conditions. Specifically, this work will evaluate whether BDA structures increase fluvial habitat complexity, increase hydrological connectivity with the floodplain, increase thermal refugia opportunities, and facilitate beaver colonization and dam building to inform how BDAs can maximize habitat improvements for salmonids and other native aquatic and semi-aquatic species.

4.1 Project goals

Monitoring goals associated with the implementation of BDA structures include evaluating the following responses relative to pre-treatment conditions:

- Evaluate whether BDA structures are a useful restoration tool for increasing fluvial habitat complexity.
- Evaluate whether BDA structures are a useful restoration tool for increasing hydrological connectivity with the floodplain.
- Evaluate whether BDA structures are a useful restoration tool for increasing thermal refugia opportunities to the benefit of native aquatic and semi-aquatic species.
- Evaluate whether BDA structures facilitate beaver colonization and dam building.

4.2 Project objectives

Specific monitoring objectives and associated activities include:

Water Temperature

- *Net change:* Assess before-after changes in water temperatures above, across, and below treatment reaches.
- *Thermal diversity:* Map cold-water patches across control and treatment reaches before and after treatment.

- *Structure-based thermal diversity:* Evaluate post-treatment spatial diversity and diel patterns of stream temperatures across BDA impounded and free-flowing stream sections.

Hydrological

- *Riparian groundwater:* Evaluate changes in riparian water table elevations.
- *Inundated area:* Evaluate changes in floodplain connectivity and inundation.
- *Seasonal stage:* Describe the timing and range of hydrologic conditions.
- *BDA pond water level:* Evaluate changes in water level in ponded areas associated with each BDA structure.

Physical

- *Site topography:* Map study site topography before and after treatment.
- *Stream geomorphic units:* Characterize post-treatment changes in the amount and distribution of aquatic habitat.
- *Stream longitudinal profile:* Characterize before-after changes in channel bedload aggradation and erosion.
- *Stream cross sections:* Assess before-after changes in the magnitude, extent, and timing of floodplain connection.
- *Reach-scale large wood load*: Characterize the distribution of naturally recruited wood across the study reach and evaluate before-after changes in wood loading.
- *BDA structure volume:* Evaluate changes in BDA structure volume through time.

Biological

- *Beaver structure use:* Evaluate the presence and activity of beaver relative to BDA structures.
- *Fish:* Evaluate before-after changes in fish species diversity, relative abundance, density, and condition.

4.3 Information needed and sources

The information required to achieve the project goals and objectives will be collected during the pre-treatment period beginning summer 2021 until treatment implementation in summer 2022 and continuing until late summer/early fall 2025. During this time, we will collect in-situ stream temperature data and surface water level using continuous temperature and pressure transducer dataloggers. Manual measurements of in-channel surface water elevations will be collected using staff gauge readings and riparian groundwater elevations will be collected from groundwater observation wells. Additionally, we will collect annual data on stream longitudinal profile elevations; cross-section elevations; develop digital terrain elevation models (i.e., topographic maps); stream geomorphic units; reach-scale large wood abundance and volume; fish diversity, relative abundance, density, and conditions; beaver structure use (see Section

7.2.1 Sampling locations and frequency, and Section 8.2 Measurement and sampling procedure). We will supplement newly collected data with existing lidar and GIS layers.

4.4 Tasks required

Water Temperature

- *Net change:* Continuously monitor stream temperature above, across, and below treatment reaches before and after treatment.
- *Thermal diversity:* Conduct synoptic temperature surveys during summer low flow across control and treatment reaches before and after treatment.
- *Structure-based thermal diversity:* Install and monitor arrays of automated temperature loggers across BDA impounded and free-flowing stream sections post-treatment.

Hydrological

- *Riparian groundwater:* Install and monitor riparian monitoring wells across control and treatment reaches before and after treatment.
- *Inundated area:* Conduct assessments of wetted areal extent across control and treatment reaches before and after treatment.
- *Seasonal stage:* Monitor stream stage to characterize the timing and range of hydrologic conditions at each study site.
- *BDA pond water level:* Measure water level in ponded areas associated with each BDA structure.

Physical

- *Site topography:* Generate digital terrain model maps of study sites using drone-based aerial imagery before and after treatment.
- *Stream geomorphic units:* Perform ground-based surveys of stream geomorphic unit types across control and treatment reaches before and after treatment.
- *Stream longitudinal profile:* Measure thalweg channel bed elevations across control and treatment reaches before and after treatment.
- *Stream cross sections:* Characterize before-after changes in channel bed elevations and water surface elevations perpendicular to the stream reach across control and treatment reaches before and after treatment.
- *Reach-scale large wood load*: Conduct surveys of large wood within the extent of the channel bankfull across control and treatment reaches before and after treatment.
- *BDA structure volume:* Conduct surveys of BDA structure dimensions during the post-treatment period to evaluate changes in the spatial extent of BDA structures through time.

Biological

- *Beaver structure use:* Conduct beaver activity surveys to evaluate beaver use of BDA structures during the post-treatment period. Record incidental observations of beaver use.
- *Fish:* Monitor fish species diversity, relative abundance, density, and condition in control and treatment reaches before and after treatment.

4.5 Systematic planning process

This QAPP details the systematic planning process for this project. The ASRP Adaptive Management and Monitoring sub-committee also contributed to defining the objectives of this project.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2 shows the responsibilities of those who will be involved in this project.

Table 2. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Nat Kale **Department of Ecology** **Phone: 360-706-4277**	**Client**	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP.
Reed Ojala-Barbour **WDFW** **Phone: 360-902-2618**	**Project Manager and Principal Investigator**	Writes the QAPP. Oversees field sampling and transportation of samples to the laboratory. Conducts QA review of data, analyzes and interprets data. Writes the draft report and final report. Assists with data collection and analysis, and writing the draft and final report.
Aimee McIntyre **WDFW** **Phone: 360-902-2560**	**Principal Investigator**	Assists with data collection and analysis, and writing the draft and final report.
Tristan Weiss **WDFW** **Phone: 360-480-4381-**	**Principal Investigator**	Assists with data collection and analysis, and writing the draft and final report.
Jamie Glasgow **Wild Fish Conservancy** **Phone: 206-310-9302**	**Principal Investigator**	Assists with data collection and analysis, and writing the draft and final report.
Name **Washington Department of Fish and Wildlife – Field Staff** **Phone: NA**	**Field Assistant**	Helps collect samples and records field information.
Name **Wild Fish Conservancy – Field Staff** **Phone: NA**	**Field Assistant**	Helps collect samples and records field information.
Aimee McIntyre **WDFW** **Phone: 360-902-2560**	**Supervisor for the Project Manager**	Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Arati Kaza **Department of Ecology** **Phone: 360-407-6964**	**Quality Assurance Officer**	Reviews and approves the draft QAPP and the final QAPP.

QAPP: Quality Assurance Project Plan

5.2 Special training and certifications

Project staff are trained in preforming field sampling and will be trained and calibrated to minimize variability. All project staff will review and follow the procedures outlined in this QAPP and the referenced Standard Operating Procedures (SOPs).

5.3 Organization chart

Not applicable – see Table 1.

5.4 Proposed project schedule

Tables 3 and 4 list key activities, due dates, and lead staff for this project.

Table 3. Schedule for completing field and laboratory work

Task	Due date	Lead staff
Field work	October 2025	Reed Ojala-Barbour
Laboratory analyses	NA	NA
Contract lab data validation	NA	NA

Table 4. Schedule for final report

Task	Due date	Lead staff
Draft to supervisor	March 2026	Reed Ojala-Barbour
Draft to client/ peer reviewer	April 2026	Reed Ojala-Barbour
Draft to external reviewers	NA	NA
Final draft to Strategic Initiative	NA	NA
Final report due on web	June 2026	Reed Ojala-Barbour

5.5 Budget and funding

Funding for this project is provided through the Project Effectiveness Program of the Aquatic Species Restoration Plan, which includes monitoring to evaluate the effects of restoration actions and adaptively manage the ASRP through time. The purpose of the Project Effectiveness Program is to track the physical response of habitats to restoration. Three project types were identified for evaluation under the Project Effectiveness Program starting in FY22, one of which was BDA implementation. See Table 5 for the project budget proposed under the Project Effectiveness Program for funding for FY22-26.

Table 5. Project budget and funding

	21-23 BN		23-25 BN		25-27 BN
Cost Category	**FY22 Cost**	**FY23 Cost**	**FY24 Cost**	**FY25 Cost**	**FY26 Cost**
Salary and benefits	$73,000	$79,000	$79,000	$79,000	$82,000
Equipment	$12,015	$4,015	$4,015	$4,015	$2,995
Travel and other	$10,000	$12,000	$12,000	$12,000	$6,000
WDFW Indirect (36.28%)	$34,985	$34,985	$34,985	$34,985	$33,505
Subrecipient (WFC)	$70,000	$70,000	$70,000	$70,000	$75,500
Laboratory	$0	$0	$0	$0	$0
Fiscal Year Total	$200,000	$200,000	$200,000	$200,000	$200,000

6.0 Quality Objectives

6.1 Data quality objectives [1]

The data quality objectives (DQO) for this project are to collect a suite of thermal, hydrological, physical, and biological parameters to evaluate the effects of BDA treatments across three treatment reaches. Data collection parameters directly evaluate whether the project goals of increasing fluvial habitat complexity, increasing hydrological connectivity with the floodplain, increasing thermal refugia opportunities, and facilitating beaver colonization and dam building have been achieved.

The objective of physical monitoring data collection is to characterize geomorphic conditions of each site before treatment (i.e., BDA installation) and create a baseline to evaluate geomorphic change following BDA installation. Physical monitoring data will be used to contextualize and interpret hydrologic, thermal, and biological parameters collected throughout the experiment. Physical monitoring surveys will follow established methods using engineering grade surveying equipment to characterize changes in channel bedform across each study site before and after treatment for a minimum of one year pre- and three years post-treatment.

Thermal and hydrological data will be collected to evaluate changes in stream hydrology including channel and groundwater level elevation, inundated extent of surface waters, net changes in stream temperature, and thermal diversity (i.e., identification of cold-water patches) before and after BDA installations. We will have a period if intensive data collection focused on measuring the recession and low flow periods approximately monthly April through October of each study year, with less intensive data (2-3 samples total) collected during winter periods.

We will evaluate the biological responses as beaver activity (chew, tracks, scent mounds, dam-building) twice-annually with on-the-ground quantification supplemented by camera traps. Though not a primary objective of the current study due to funding constraints and priorities related to the ASRP Monitoring and Adaptive Management Program, we will also characterize changes in fish use (species composition, relative abundance, and density) and salmonid condition in response to treatment. This evaluation is made possible through the participation of Wild Fish Conservancy.

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

6.2 Measurement quality objectives

The measurement quality objective (MQO) is to collect data that accurately describes the conditions occurring on the site. The development of this study was informed by protocols that have been established by reputable institutions to collect data that are accurate, repeatable and representative.

6.2.1 Targets for precision, bias, and sensitivity

We will collect stream temperature data continuously at designated monitoring stations. Downloads of stream temperature sensors will occur approximately monthly during the intensive monitoring period (April-October) and every two to three months during the remainder of the year (November-March). See section 11 for information about data storage. In addition to continuous temperature monitoring to evaluate net change, we will evaluate patterns of spatial and diel fluctuations in surface water temperatures upstream and downstream of BDA structures (i.e., structure-based thermal diversity). We will conduct synoptic sampling of thermal diversity annually during the warmest period of each year (mid-July to mid-August) during a single afternoon at each site.

Hydrologic monitoring includes continuous stage monitoring year round. We will download water level loggers approximately monthly during the intensive monitoring period (April-October) and every two to three months during the remainder of the year (November-March). We will collect manual measurements of in-channel and groundwater levels approximately monthly during the recession and low flow periods (April - October) each year to evaluate changes in and riparian water table elevations. The first year of pre-treatment monitoring will begin no later than July 15 to ensure that the lowest flows are monitored.

Physical monitoring will include annual surveys of longitudinal profile and channel cross sections beginning the first year of pre-treatment monitoring and continuing until the conclusion of the study. Additional physical MQOs will include developing annual terrain maps using an unmanned aerial system (UAS) to collect aerial photographs. Aerial photographs will require at least 20 ground control points during acquisition. Annual on-the-ground stream geomorphic unit and in-channel wood surveys will be conducted during low flow period to map dominant habitats and measure changes in the distribution of large wood within treatment reaches.

Biological surveys will include fish and beaver surveys. We will conduct fish sampling one time annually during the summer low flow period. We will evaluate beaver activity on-site formally two times a year, once in summer and again in winter. We will supplement these surveys with the targeted use of camera traps, and will also record incidental observations of beaver colonization and dam building activities to maximize opportunities for beaver observations.

6.2.1.1 Precision

We will collect field measurements of temperature and water level continuously at multiple stations located throughout each study site. We will ensure some redundancy in the number and placement of sensors such that if a sensor is lost due to natural or human causes, backup data will still be available. We will download loggers regularly (at least every 2 months depending on the time of year) to ensure that if a sensor becomes displaced or is lost, that the equipment is either repositioned or replaced in a timely manner with as little opportunity for lost data as possible.

6.2.1.2 Bias

Failure to follow the procedures outlined in this document and the referenced SOPs and protocols, including the timing and duration of data collection, could result in bias. We will reduce the potential for bias in data collection by calibrating all data recording instrumentation per manufacturer instruction prior to launching, recalibrate instruments annually, and by strict adherence to sampling protocols.

6.2.1.3 Sensitivity

Sensitivity for this project will be the lowest degree to which a parameter can be measured. The expected range of the parameter is much greater than what the utilized instruments are capable of differentiating. All monitoring loggers have a factory-documented range, accuracy, and resolution for which data is collected (Table 6).

Table 6. Parameters measured with measurement instruments and their respective range, accuracy and resolution of data collection.

Sensor	Parameter	Range	Accuracy	Resolution
Onset HOBO TidbiT v2 Data Logger*	Temperature	-40° to 70°C (-40° to 158°F) in air; maximum sustained temperature of 50°C (122°F) in water	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)	0.02°C at 25°C (0.04°F at 77°F)
Onset HOBO Water Pro v2 Data Logger*	Temperature	-40° to 70°C (-40° to 158°F) in air; maximum sustained temperature of 50°C (122°F) in water	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)	0.02°C at 25°C (0.04°F at 77°F)

Sensor	Parameter	Range	Accuracy	Resolution
Onset HOBO Water Level (13ft) Data Logger	Pressure (Water Level) and Temperature	69 to 145 kPa (10 to 21 psia), 0° to 40°C (32° to 104°F)	Typical error: ±0.1% FS, 0.4 cm (0.013 ft) water Maximum error: ±0.2% FS, 0.8 cm (0.026 ft) water	<0.014 kPa (0.002 psi), 0.14 cm (0.005 ft) water
Staff Gauge	Water Level	3ft	1/10th foot	1/100th foot
Solinst 101 P7 Water Level Meter	Water Level	100m	1mm	1mm
DJI Zenmuse X5S RBG camera	Topography	1 to 4828m visibility in air	< 0.3 m	Photo Resolutions: 4:3, 5280×3956 16:9, 5280×2970 (CMOS, 4/3", Effective Pixels: 20.8MP)
Trimble Geo 7x	Inundated area	0.05 to 120 m	< 0.3 m	±0.05 m
Leica TS16 Total Station	Topographic and Water Level Elevation	0.9 m to 3,500 m (Single Prism)	1 mm + 1.5 ppm / typically 2.4 s (Single Prism)	8 mm x 20 mm (target at 50m)
iBalance i1200 Compact Scale	Fish weight	0.1g to 1200g	0.1g	0.1g
Cooper-Atkins Corp. handheld digital thermometer (Model 35200K)	Temperature	-73°C to 537°C	+/-0.5 Degrees F	0.1°C

* Onset HOBO TidbiT v2 Data Logger and Onset HOBO Water Pro v2 Data Logger have the same range and accuracy. We treat them as interchangeable. TidbiT v2 loggers are slightly smaller and will be deployed in locations that have a greater potential of not maintain adequate surface water depth.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

Data collected will be used to assess changes in fluvial habitat complexity, hydrological connectivity with the floodplain, thermal refugia, beaver colonization and dam building, and salmonid habitat use and condition in response to BDA installations at study sites. Data will be comparable across various timeframes based on data collection timing (see chapter 7.0 Sampling Process Design). Comparability will be enhanced by adhering to scientifically defensible protocols and continuously collecting standardized data.

6.2.2.2 Representativeness

Temperature and stage data will be collected continuously and at multiple stations to ensure that data are representative of site conditions. Manual measurements of temperature will be taken in the field to corroborate measurements collected by loggers. Manual measurements of temperature will be taken by a NIST calibrated Cooper-Atkins Corp. handheld digital thermometer (Model 35200K). Manual stage measurements will taken by reading a staff gauge. Other data will be collected at regular intervals with measurements replicated throughout the site to ensure that site and seasonal variability are represented in the data set. Geomorphologic/topographic data will be collected following the CHaMP protocol (Bouwes et al., 2011), using georeferenced control points and a topographically stratified sampling method to collect representative data (Kiem et al., 1999). Biological data will be collected annually during optimal survey periods (see Section 8 – Field Procedures) and will be supplemented with incidental observations made during the many site visits scheduled for thermal, hydrological and physical monitoring.

6.2.2.3 Completeness

We will determine completeness by dividing the number of measurements collected by the number of measurements scheduled to be collected; if the resulting value is at least 80% for each parameter and monitoring station, then the project will be considered successfully completed. We will consider temperature and stage data 100% complete when data loggers have collected data for the period and at the intervals described in this document. Survey data will be considered complete if enough survey points were taken annually to create a topographic map as described in this document. Physical and biological surveys will be considered complete if they are conducted consistent with the timeline and frequency outlined in Table 10.

6.3 Acceptance criteria for quality of existing data

Not applicable.

6.4 Model quality objectives

Not applicable.

7.0 Study Design

7.1 Study boundaries

This project is conducted within WRIA 22 and 23 at three study sites. Six sites are currently in consideration for inclusion in this monitoring program (Table 7; Figure 2), with final site selection dependent on landowner and other constraints.

Table 7. Prospective site locations where monitoring will occur. Three of these six sites will be selected for final instrumentation.

Name	**County**	**Site Location Latitudes and Longitudes**
Pig Farm	Grays Harbor	47.080644, -123.305742
Smith	Grays Harbor	47.15558, -123.54462
Sedge	Grays Harbor	47.124472, -123.552716
East Branch Newman	Grays Harbor	47.048231, -123.431593
Halsea	Grays Harbor	47.194319, -123.526115
Quad	Mason	47.163812; -123.489012

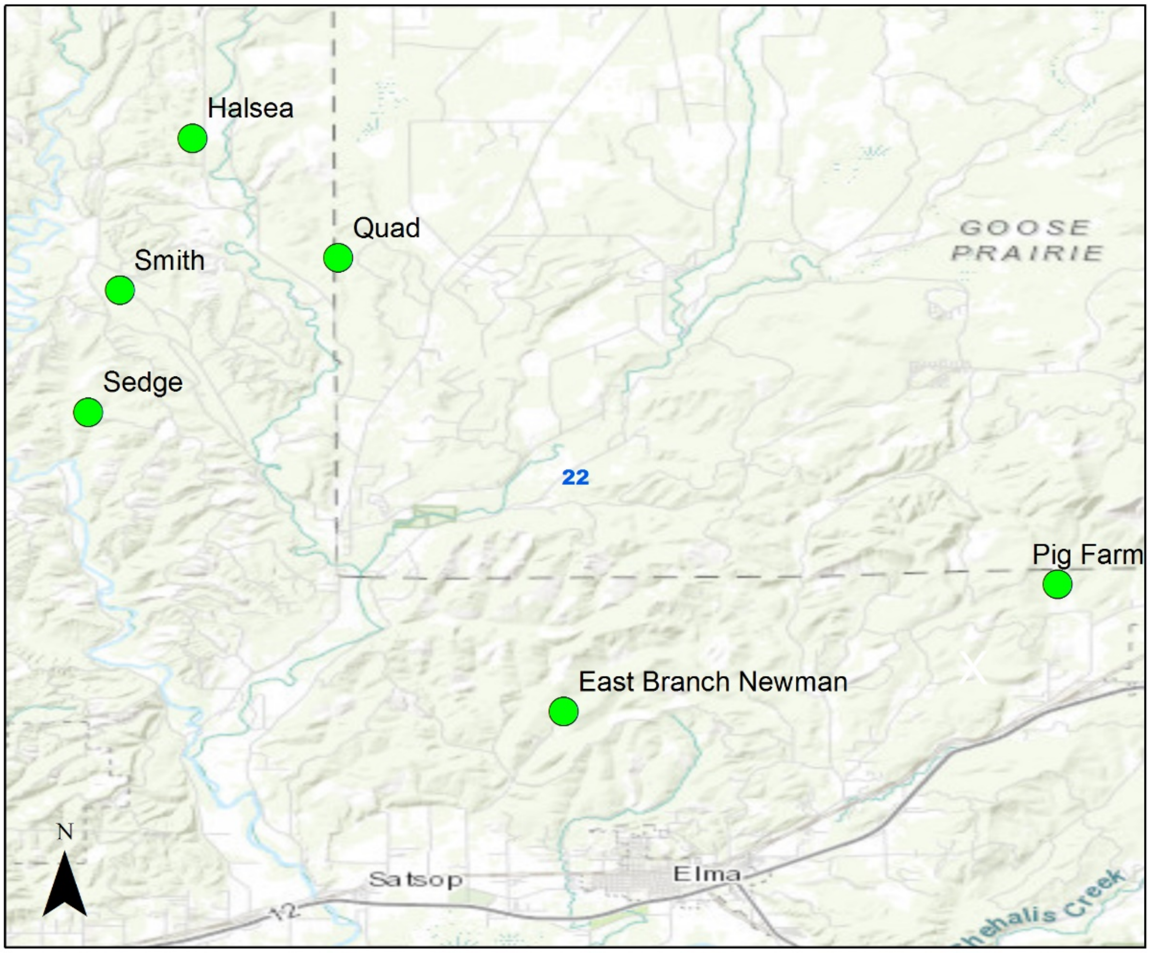


Figure 2. Map of boundary of project study area and localities of six potential study sites, three of which will ultimately be selected for inclusion in this study.

7.2 Field data collection

Field measurements will be taken using a combination of monitoring approaches including *in situ* continuous data loggers at designated monitoring stations, periodic repeated manual measurements, and biannual and annual surveys. Figure 3 illustrates relative locations of measurement stations across the control, treatment, and downstream reaches of each study site.

Automated *in situ* stream temperature sensors (Onset UTBI-001 and U22-001) will be placed within the thalweg of the stream at each transect. Automated measurements of stream stage will be collected using an unvented pressure transducer (Onset U20L-001) at the upper most transect of each study reach.

Repeat measurements of in-channel water level within the treatment reach will be manually collected using staff gauges at designated monitoring stations coinciding with cross sections 1-6 during the pre-treatment period. Immediately prior to BDA installation, staff gauges will be added (if necessary) to a location within each anticipated BDA pond to capture the water level crest elevation induced by each structure. Groundwater levels will be measured along monitoring well transects within the control and treatment reaches, with additional monitoring wells placed in an alternating fashion on each side of the stream between each set of transects without a full monitoring transect. Staff gauge measurements will be recorded at least seasonally.

Cross-sectional topographic surveys and water level elevation surveys will be conducted along designated transects. All geomorphic and topographic surveys, including surveys of wood will be performed across the entire study site (control, treatment, and downstream reaches). Electrofishing to evaluate fish use and condition, and surveys for beaver use will occur across the entire study site.

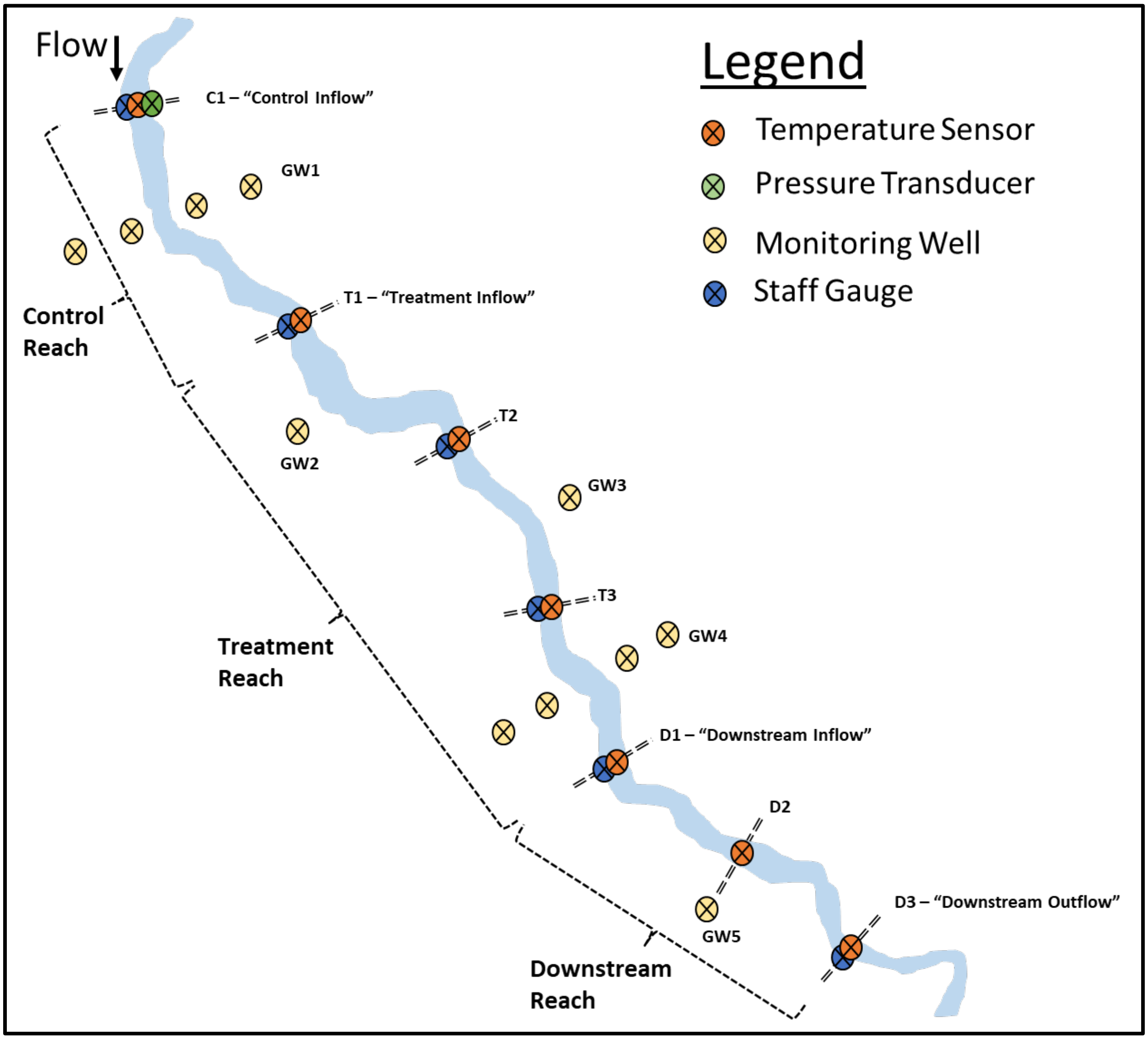


Figure 3.Conceptual site map illustrating the sampling location naming convention and general study site layout. Sensor placement and sampling locations during the pre-treatment period are described relative to control, treatment, and response reaches which comprise the study area. Key measurement stations are numbered sequentially from upstream to downstream using abbreviated "C", "T", or "D" corresponding to "control", "treatment", and "downstream" reaches, respectively. Groundwater monitoring wells are similarly numbered sequentially in an upstream to downstream direction and labeled as "GW".

7.2.1 Sampling locations and frequency

General Study Design

This study will be performed on three geographically independent stream reaches within the Chehalis Basin (Figure 2) to evaluate the effects of a sequence of BDAs on river-floodplain connectivity, fluvial habitat complexity, stream temperature, fish, and beaver activity. The data collected in this study will follow one of two sampling approaches (Table 8):

(1) Before-After Control-Impact (BACI)

(3) Post-Treatment (PT)

This monitoring design allows for multiple project effectiveness parameters to be evaluated at varying spatial and temporal scales during the pre- and post-treatment periods. Pre-treatment monitoring will begin in summer 2021 and continue until summer 2022 up until BDA installations. To accommodate the BACI sampling design, each study site will be comprised of an upstream control reach, treatment reach, and downstream reach positioned longitudinally adjacent to one another. Figure 4 illustrates the relative position of monitoring transects and measurement stations that will be used for each study reach.

BDA installation will occur during the summer low flow 2022 consistent with permit conditions. The structures use untreated wood posts driven into the streambed spanning the channel. Vegetation is woven between the posts to slow the flow of water. BDAs designs will be based on Shahverdian et al. (2019) and Castro et al. (2015; Figure 4). Between 4-12 BDAs will be installed over a length of 300-500m within the treatment reach of study site during late summer 2022. Control and downstream reaches will range in length from 100-300m depending on treatment lengths and site conditions. We will evaluate two BDA structure response parameters post-treatment: thermal diversity and structure volume.

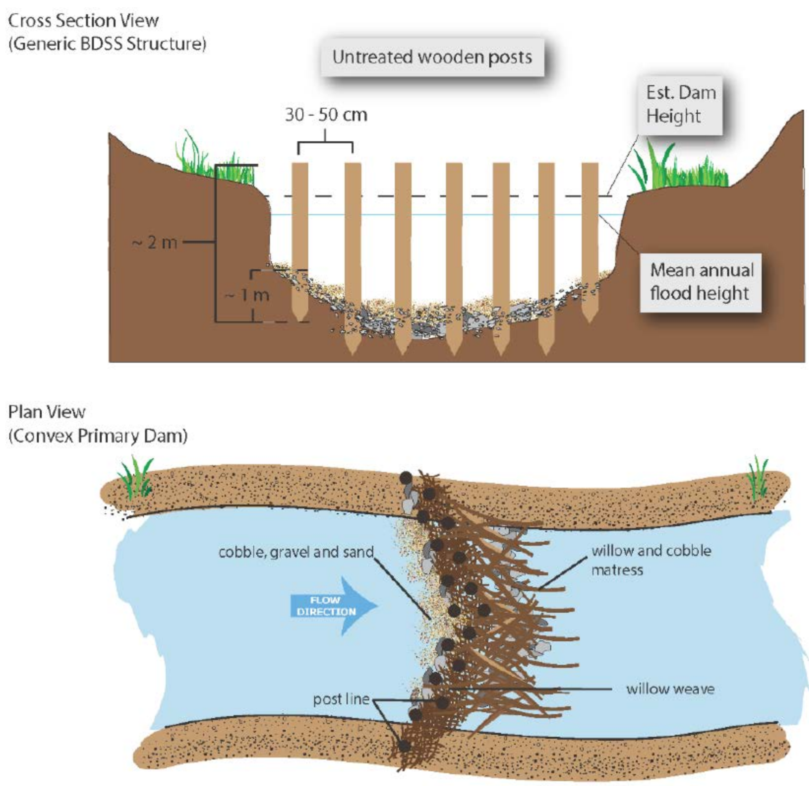


Figure 4. Conceptual design of BDA structure (Portugal 2015)

Data collected under the BACI sampling approach will include all quantitative measurements occurring during the pre-treatment (before) and post-treatment (after) periods within both the control and treatment (impact) reaches during the duration of the study. Post-treatment (PT) sampling includes surveys of BDA structure volume, structure-based thermal diversity, and beaver structure use following treatment.

Table 8. Monitoring designs by response categories and sub-categories. BACI = before-after, control-impact. PT = post-treatment.

Response Category	Response Sub-Category	Monitoring Design
Water Temperature	Water temperature net change	BACI
	Thermal diversity	BACI
	Structure-based thermal diversity	PT
Hydrological	BDA pond water level	BACI
	Riparian groundwater	BACI
	Inundated area	BACI
	Seasonal stage	BACI
Physical	Reach-scale large wood load	BACI
	BDA structure volume	PT
	Stream geomorphic units survey	BACI
	Stream longitudinal profile	BACI
	Stream cross sections	BACI
	Site topography	BACI
Biological	Fish diversity, relative abundance, density, condition	BACI
	Beaver structure use	PT

Sampling Locations and Frequency

Sampling frequency and timing are summarized in Table 10.

Water temperature net change: Temperature sensors deployed as part of BACI monitoring will be placed within or near the relatively well-mixed area of the stream thalweg at monitoring stations beginning at the inflow of the control reach and concluding at the outflow of the downstream response reach. Automated stream temperature sensors will be inspected and downloaded at intervals no longer than two months across the hydrologic year (October 1-September 30). Temperature will be recorded at 30-minute intervals.

Thermal diversity: Surveys of thermal diversity will be conducted annually across the entire study site during the low flow period. Surveys will be performed during a single afternoon per study site during the hours of 13:00-18:00.

Structure-based thermal diversity: To assess the effects of BDAs on diel thermal patterns during the warmest part of the year, we will install temperature sensors for approximately three days per site during the low flow period (~July 15 through August 30). Sensors will be positioned in the ponded area associated with the downstream-most BDA structure, as well as in a section of the free flowing reach above that structure. We will place approximately 15 sensors arrayed in a coarse grid laterally across the channel and vertically within the water column in the ponded and free flowing sections (Figure 5). Temperature will be recorded at 30-minute intervals. To ensure capture of variability in temperature associated with variable channel bed configurations, longitudinal placement of sensors within free flowing sections and ponds will occur along a minimum of two transects along the channel thalweg or deepest pool areas, and along the channel margins. Lateral placement of sensors along transects will follow natural breaks along the channel bed, with sensors placed laterally at approximately every halving of channel depth along a given transect. Where pond depths are less than 0.5m, single sensors will be placed 5cm above the channel bed. Where pond depths are greater than 0.5m, two vertically arrayed sensors will be placed at 5cm above the channel bed and approximately 80% of the water column depths to evaluate thermal stratification.

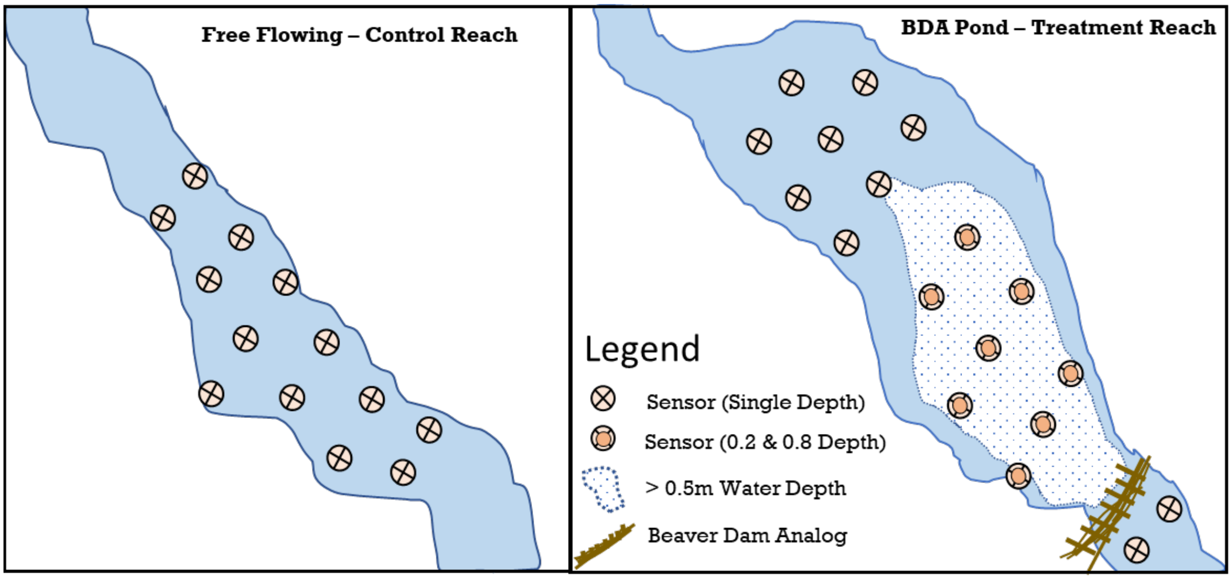


Figure 5. Conceptual illustration of sensor placements during post-treatment structure-based thermal diversity monitoring.

Seasonal stage and BDA pond water levels: Year-round stream stage will be collected at 30-minute intervals at the control reach inflow beginning the first year of pre-treatment monitoring to characterize seasonal flow conditions and provide a surface water control for surface water level measurements within the treatment reach. Stage monitoring will be conducted using staff gauge readings located along designated monitoring stations (Figure 3). Additional staff gauges will be installed immediately prior to BDA installations within the anticipated pond area of each BDA structure within the treatment reach during the pre-treatment period that correspond with anticipated BDA pond areas. Staff gauges will be measured on a monthly frequency from April to October of each study year. Measurements will continue to be made but at a slower frequency of every month or two months from November to March of each study year, with a target to collect measurements within 5 days of seasonal peak flow events.

Riparian groundwater: Monthly manual measurements of groundwater level will be taken at well locations (Figure 3) from April to October (Table 9). Manual measurements will continue to be made but at a slower frequency of every month or two months from November to March of each study year, with a target to collect measurements within 5 days of seasonal peak flow events. Riparian groundwater monitoring transects will be positioned perpendicular to flow approximately mid-way between the inflows of the control and treatment reaches and within the lower 30% of the treatment reach. Additional monitoring wells will be placed in an alternating fashion on each side of the stream between each set of transects without a full monitoring transect. Each well will be installed to a depth assumed to be below the lowest mean annual water table elevation. The estimated lowest annual stream surface water elevations will be used as the assumed riparian water table elevation. Each transect will consist of four monitoring wells spanning the valley floor, bisected by the stream. Wells closest to the stream will be located no more than 5m from bankfull. Distal wells will be located approximately halfway between the valley bottom inflection point and the wells proximal to the stream.

Physical surveys: Cross-sectional topographic and water elevation surveys will be conducted annually during the seasonal low flow period (July 15- Aug 30) at transects (Figure 3). All geomorphic, topographic and wood surveys will be conducted for the entire study site (control, treatment, and downstream response reaches) once per year during the low flow period (for in-stream surveys) or during winter months (during leaf off).

Biological surveys: Single-pass electrofishing surveys will be conducted annually to evaluate fish species diversity, relative abundance, density, and condition during the summer low flow period. Four block nets will be installed to isolate the downstream, treatment, and control reaches to prevent fish movement between reaches during surveys (Figure 3).

Table 9. Timing and frequency of sampling for all responses included in the Chehalis BDA Project.

Response Category	Response Sub-Category	Frequency	Timing
Water Temperature	Water temperature net change	Continuously	Sep 30 – Oct 1 (Download every 2-3 months)
	Thermal diversity	1/yr	Jul 15 – Aug 30 (low flow)
	Structure-based thermal diversity	1/yr	Jul 15 – Aug 30 (low flow), 1 day per site
Hydrological	BDA pond water level	Monthly (2-3 times per winter)	Apr 1 – Sep 30 (monthly); Oct 1 – Mar 31 (Every 2-3 months)
	Riparian groundwater	Monthly (2-3 times per winter)	Apr 1 – Sep 30 (monthly); Oct 1 – Mar 31 (Every 2-3 months)
	Inundated area	Monthly (2-3 times per winter)	Apr 1 – Sep 30 (monthly); Oct 1 – Mar 31 (Every 2-3 months)
	Seasonal stage	Continuously	Sep 30 – Oct 1 (Download every 2-3 months)

Physical	Reach-scale large wood load	1/yr	Jul 15 – Aug 30 (low flow)
	BDA structure volume	2/yr	Jul 15 – Aug 30 (low flow) and Dec 15 – Mar 1 (high flow)
	Stream geomorphic units survey	1/yr	Jul 15 – Aug 30 (low flow)
	Stream longitudinal profile	1/yr	Jul 15 – Aug 30 (low flow)
	Stream cross sections	1/yr	Jul 15 – Aug 30 (low flow)
	Site topography	1/yr	Dec 1 – Mar 1 (leaf off)
Biological	Fish (diversity, relative abundance, density, condition)	1/yr	Jul 15 – Aug 30 (low flow)
	Beaver structure use	2/yr; + incidental	Jun 15 – Aug 15 and Dec 15 – Feb 15

7.2.2 Field parameters and laboratory analytes to be measured

See Table 9.

7.3 Modeling and analysis design

Not applicable.

7.3.1 Analytical framework

BACI Analysis:

We will use a Before-After Control-Impact (BACI) study design to compare treated reaches to their pre-treatment condition and untreated control reaches. BACI designs control for the effect of temporal variation (e.g., interannual variation) by establishing relationships between the control (untreated) and impact (BDA treatment) sites in the pre- versus post-periods. This allows us to determine whether observed differences in treated sites are associated with environmental variation or a response to the BDA treatment. As shown by Chevalier et al. (2019), the assessment of BACI contrast can be shown as:

$$BACI = (U_{IA} - U_{IB}) - (U_{CA} - U_{CB})$$

Where U_C and U_I represents the average response in each reach (U_C = Control; U_I = Impact) and period (U_B = Before; U_A= After). In general, analyses following the BACI design evaluate the generalized null hypothesis that the mean difference of response variables contrasted before and after the treatment is equal to zero, or:

$$\Delta U_{Control}\ (U_{CA} - U_{CB}) = \Delta U_{Impact}\ (U_{IA} - U_{IB})$$

Where $\Delta U_{Control}$ is the change in mean responses before and after along the treatment reach, and ΔU_{Impact} is the change in mean responses before and after at the impact reach.

For example, with respect to water elevations and longitudinal changes in temperature and water, we anticipate a divergence between control and treatment reaches in thermal conditions between pre-treatment temperatures and post-treatment periods, such that:

$$\text{Control-Impact Divergence} = |U_{IA} - U_{CA}| - |U_{IB} - U_{CB}| > 0$$

Parameters that will undergo BACI analysis and associated hypothesized pre- and post-treatment changes in between reaches are described in Table 10.

Table 10. Description of hypothesized pre- and post-treatment change between the control and impact reach by response. The measurement parameter is the parameter that will be used in each hypothesis test.

Response Category	Measurement Parameter	Hypothesis
Water Temperature Net Change	Water Temperature	Control > Impact
Thermal Diversity	Spatial Diversity of Water Temperature	Control < Impact
Riparian Groundwater	Water Elevation	Control < Impact
Inundated Area	Surface Water Area	Control < Impact
BDA Pond Water Level	Water Elevation	Control < Impact
Longitudinal Profile and Cross Sections	Channel Elevation	Control < Impact
Reach-scale Large Wood Load	Large Wood Abundance and Volume	Control < Impact
Fish	Species Abundance, Diversity, and Condition	Control < Impact

Non-BACI Analysis:

Pre- and post-treatment water temperature data will be processed for maximum and mean temperatures across temporal resolutions (daily, weekly, monthly, annually) to examine patterns of temperature change across the treatment reaches over the study period. To initially explore longitudinal temperature dynamics across each site, net changes (outflow of reach minus inflow of reach) across the control reach and treatment reach will be plotted as a time series across the study period (pre- and post-treatment). Scatterplots of absolute and percent change in temperature and water level by reach will be plotted to visualize temperature relationships across sites, pre- and post-treatment periods, and seasons. Timeseries and boxplots of measured values will be created for all parameters (temperature, surface water level and area, groundwater level, channel elevations, beaver structure use and fish parameters) by day, month, or season to examine treatment effects.

7.3.2 Model setup and data needs

Not applicable.

7.4 Assumptions of study design

We assume that the temporal and spatial scales of data collection are made at resolutions adequate to detect treatment effects of interest. Additionally, we assume that streamflow within each study site is perennial and that streamflow levels are sufficient to maintain continuous submersion of sensors across the monitoring reaches.

7.5 Possible challenges and contingencies

Possible challenges to data collection include tampering of instrumentation or BDA structures. BDA structure implementation is contingent on numerous logistical considerations and final structure placement, integrity, and longevity will remain unknown until after installation.

7.5.1 Logistical problems

Several logistical problems or constraints may be:

Adverse Conditions: Adverse conditions may limit site access or limit staff ability to conduct specific activities. High flows may make winter data downloads or surveying difficult or infeasible. Adverse conditions, including weather and flow, will be monitored prior to field visits. Appropriate safety precautions and logistical decisions will be made accordingly.

Theft or Tampering: Field instrumentation and infrastructure risks theft, vandalization or tampering. We anticipate these risks to be low, however some sites may carry more risk than others. Equipment will be hidden from plain view, camouflaged, and secured to the extent possible to minimize risk.

Site Character and Conditions: Canopy obstructions may limit data collection during ground and UAS flights and subsequent analysis. We plan on scheduling floodplain surveys and flights in the fall/winter after the leaves have fallen to avoid this in areas of concern.

7.5.2 Practical constraints

There are three potential constraints to project implementation timing:

- **Funding:** The Chehalis Basin Board has yet to approve budgets for BN21-23 spending, which includes the Monitoring and Adaptive Management Program and Implementation budgets. The Board is scheduled to discuss and hopefully approve the budget at their next regular meeting on July 1st, 2021.

- **Landowner Access**: While we have landowner agreements to access study sites, we do not yet have signed implementation agreements with participating landowners.
- **QAPP Approval:** Implementation of pre-treatment monitoring cannot begin until we have an approved QAPP.

7.5.3 Schedule limitations

The constraints in the previous section may impact the proposed study schedule in the following ways:

- **Funding:** Project monitoring activities cannot begin until the budget has been approved by the Board. Fortunately, the funding for site selection, sampling plan development, and pre-treatment monitoring set up and installation was covered by a prior grant. Rollover funds from this grant can be used to cover pre-treatment monitoring until new contracts are put in place. However, if the delay is more than several months, this will hamper our ability to maintain the level of pre-implementation monitoring under our current study plan.
- **Landowner Access**: If a landowner decides not to allow permission for implementation that would have implications for study execution. Luckily, we have six sites at which we intend to implement BDA installations and only three that will be used for restoration effectiveness monitoring, so if a landowner decides against implementation, we can use another site. We cannot formalize landowner implementation agreements until BDA designs are complete, but once they are, we will work to get agreements finalized and signed, thus minimizing concerns in this area.
- **QAPP Approval:** If QAPP approval is not obtained by July 9th, 2021, then we will have to delay start of pre-treatment monitoring and implementation of BDA installations by one year.

8.0 Field Procedures

8.1 Invasive species evaluation

Study sites are not located within areas of extreme concern. The precautions and procedures outlined in SOP EAP070 (v.2.2) will be followed prior to and after all field activities.

8.2 Measurement and sampling procedures

See Table 12 for a summary of responses and primary methods or SOPs on which the following field procedures are based.

Stream Temperature Net Change

Water temperature sensors will be installed at all study sites at the inflow and outflow of each reach (Figure 3). Precise sensor locations will be surveyed by total station relative to a local benchmark. To safeguard against sensor failure or confounding environmental conditions (e.g. unintended beaver dam influences), a second backup sensor will be placed within 10 meters of the control and treatment outflow gauges.

At all sites water temperature sensors will be placed along transects throughout the treatment reach as illustrated in Figure 3. Precise sensor locations will be surveyed by total station relative to a local benchmark. These sub-reach transects will be placed downstream of BDA structures at a distance that will allow for thermal mixing of outflowing water impounded by BDAs (~5-10m). Additionally, to evaluate the longitudinal temperature response downstream of the treatment reach, 3-5 temperature sensors will be placed at intervals no greater than 100m downstream of the outflow gauge. The number and spacing of sensors in this downstream reach will depend on stream morphology and site-specific conditions (e.g., downstream beaver influence, landowner constraints).

Study sites will be intensively monitored in the post-treatment period only to assess diel patterns in the lateral and vertical thermal impacts of BDAs. Water temperature sensors will be placed within a subset of waters impounded by BDAs (~1 or 2 per site). Installation will occur during the low flow period (~mid-July through August) and sensors will be arrayed in an approximate grid to assess diel patterns in the lateral and vertical thermal impacts of BDAs. Depending on the number of sensors available, sensors will be arrayed longitudinally in transects along the length of the impounded area upstream of the BDA and immediately downstream of the BDA to capture patterns in spatial and diel fluctuations in surface water temperatures. To ensure adequate spatial resolutions of data collection, longitudinal transects will be placed at intervals no less than 25% of the length of the pond. Lateral placement of sensors will occur at intervals no less than 15% of the wetted low flow width of a pond. Where pond depths are less than 0.5m, single sensors will be placed 5cm above the channel bed. Where pond depths are greater than 0.5m, paired sensors will be placed at 20% and 80% depths to evaluate thermal stratification. A similarly arrayed grid of sensors will be placed within an upstream free flowing reach representative of channel characteristics prior to BDA influence.

Stream Thermal Diversity

To evaluate the presence of discrete cold-water patches more than 2°C cooler than the adjacent ambient water temperature, we will survey each treatment reach using a handheld digital thermometer (Model 35200K ±0.1 °C, response rate < 1 s; Cooper-Atkins Corp.) with a 1m probe. We will survey the length of each study site's treatment reach to locate cold-water patches following the methods of Ebersole et al., 2001 with minor modifications. Thermal diversity surveys will consist of walking the treatment reach longitudinally while sweeping the thermometer probe laterally across the stream bed approximately 5cm from the stream channel bottom. Sweeps will occur every longitudinal meter until the entirety of the treatment reach has been surveyed. Where temperatures cooler than 2°C of adjacent ambient water temperature are detected, the spatial boundaries of the cold-water patches will be delineated by intensive probing. If cold-water patches cannot be clearly delineated using a 2°C threshold, the threshold will be incrementally increased by 1°C until cold-water patch boundaries are discernable from the ambient water temperature. The extent and location (GPS) of the patch will be noted and sketched relative to a surveyed control point corresponding to the nearest upstream sub-reach transect. The lateral position of the cold-water patch will be recorded relative to the thalweg or pool centerline. Longitudinal temperature changes within each cold-water patch will be assessed by recording the highest and lowest temperatures measured along the length of the patch. Because cold-water patches reflect upwelling and ambient surface water mixing, surveys will be timed during rainless periods in the late summer when streamflows are lowest and seasonal air temperature is presumed to be highest. Surveys will be conducted during the afternoon to include the thermal maxima of daily air temperature to ensure the greatest difference between ambient stream water and cold-water patch temperatures. Thus, the size of cold-water patches during the survey are expected to conservatively estimate their smallest spatial extent of the season.

Structure-based Thermal Diversity

Water temperature sensors will be deployed in a grid array for approximately 3 days per site during the low flow period (~July 15 through August 30). Temperature will be recorded will be collected at 30-minute intervals. Approximately 15 sensors will be arrayed per free flowing or ponded section in a coarse grid (Figure 5). Lateral placement of sensors along transects will follow natural breaks along the channel bed, with sensors placed laterally at approximately every halving of channel depth along a given transect. Where pond depths are less than 0.5m, single sensors will be placed 5cm above the channel bed. Where pond depths are greater than 0.5m, two vertically arrayed sensors will be placed at 5cm above the channel bed and approximately 80% of the water column depths. Longitudinal placement of sensors within free flowing sections and ponds will occur along a minimum of two transects along the channel thalweg or deepest pool areas, and along the channel margins.

BDA Pond Water Level

Staff gauges will be installed during the pre-treatment period at each transect, with additional staff gauges installed at the time of BDA construction within the anticipated pond area of each structure. Each staff gauge will be constructed of a 3' length of a ceramic coated staff plate labeled in 1/10th feet and mounted to a 6-foot T-post driven into the channel substrate. Where possible, gauges will be located near the permanently wetted channel margin, devoid of persistent hydraulics or debris accumulations. Staff gauge locations and heights will be geospatially referenced to a stable benchmark outside of active channel influence. Gauges will be measured monthly from before and after treatment from April 1st – September 30th. Gauge readings will be measured every 2-3 months from October 1st – Mar 31st.

Riparian Groundwater

Shallow groundwater monitoring adjacent to the treatment reach will be conducted using floodplain transects of groundwater observation wells. Observation wells will be constructed of 1.5" stainless steel pipe perforated along most of its below ground length. Wells will be installed in three transects roughly dividing the reach into three segments and will be arrayed approximately perpendicular to the flow of water (Figure 3). Emanating from the stream margins outwards, monitoring wells will be placed following floodplain topography beginning just beyond the bankfull margin, any terrace margins, and then spaced approximately equidistant across the floodplain to the valley wall. Observation wells will be installed following the same procedure as piezometers and communication with groundwater adjacent to each well will be flushed by either pumping the wells dry or rapidly filling the wells. The geospatial coordinates and heights of all observation wells will be surveyed relative to a local benchmark by Leica Total Station. Groundwater levels will be measured monthly or monthly before and after treatment across all flow periods using a Solinst 101 P7 water level meter.

Inundated Area

Estimates of inundated area will be delineated by manually walking the inundated extent of the treatment reach using a Trimble Geo 7x twice a year, once during the summer low flow period and again during the winter high flow period. Beginning at the treatment outflow, surveyors will walk the left and right wetted edge of each stream bank and collect geo-referenced coordinates approximately every meter. Surveyed points of wetted areas must be in hydrologic connectivity with the stream channel for measurements to be collected.

Seasonal Stage

Continuous stream stage monitoring gauges will be installed at the inflow of each sites' control reach. Each gauge will be constructed of a 1.5-inch (inside-diameter) stainless steel stilling well mounted onto a 6-foot T-post driven into the channel bed. A staff gauge will either be affixed to the stilling well or anchored to a stable location adjacent to the stilling well for visual readings of stage. A vented cap will be placed on top of each well to prevent accumulation of debris and to minimize tampering of sensors. Stilling well casing height and horizontal position will be geospatially referenced to a stable benchmark outside of active channel influence. The heights and horizontal positions of each stilling well will be surveyed to a local datum reference point using a Leica Total Station. Each stilling well will be fitted with an Onset U20L pressure transducer and temperature sensor, hung from well caps.

Instream pressure transducers will be launched to record stream stage at 30-minute intervals and will be downloaded every 2-3 months. A single barometric pressure transducer will be deployed with a solar shield near the middle of the study reach to measure air pressure and temperature. These data will be used to correct water level pressure values at the inflow of the control reach. Stilling wells will be visually inspected for tampering, damages, or accumulations of debris during staff gauge readings and after any major storm events. Accumulated sediment around the base of the stilling wells will be removed to minimize sensor entrenchment and sensors will be removed and gently cleared to minimize excess biological growth. Following high flow periods, relative positions of stilling well and staff plates will be checked against survey references to ensure gauge stability and apply corrections if necessary.

Reach-scale Large Wood Load

To evaluate annual large wood load at the reach scale (control treatment, and downstream reaches), we will conduct reach-scale large wood surveys annually during summer low flow. Each piece of large wood (≥10 cm diameter and ≥1 m in length) that intrudes into the plane of the bankfull channel (i.e., instream and suspended) will be tallied following a modified Timber, Fish and Wildlife (TFW) protocol (Roorbach and Schuett-Hames 2003). For each piece, the length and midpoint diameter of the portion within the bankfull channel will be recorded. The channel functions associated with each piece (pool formation, step formation, sediment retention) will be noted.

BDA Structure Volume

We will conduct BDA structure-focused surveys to evaluate changes in accumulations associated with the BDA structures themselves and measure the dimensions of the structure including wood and sediment that accumulates on the BDA. We will measure the maximum structure length along the longest axis, the width at a point representative of the mean, and height of the structure using a field tape and two surveyors. We will also note any beaver additions and enhancements.

Stream Geomorphic Units

We will conduct a complete census of stream geomorphic units in control and treatment reaches once annually during summer low flow. We will follow a modified approach based on the sampling methodology outlined in Pleus et al. (1999). All habitats within the bankfull channel will be identified as riffle, pool and pool type, glide, sub-surface flow, or obscured. For each discrete habitat identified (hereafter, unit) we will measure and record the total length and average width using a field tape and two surveyors. Average width is the mean of multiple measurements taken perpendicular to the unit length, where the number of unit width measures is relative to the overall unit length (i.e., more measures for longer units). We will measure residual depth of pool units with a meter tape or stadia rod.

Stream Longitudinal Profile

Longitudinal profiles will be surveyed by Leica Total Station along the thalweg (300-600m depending on treatment reach length) before and after treatment following the procedures described in EAP119 (v1.3) sections 6.2-6.2.4. Only main channel thalweg profiles will be measured. During the low flow period, thalweg geospatial coordinates and elevations will be surveyed approximately every two meters (longitudinally) or at rapid channel-bed inflections walking in an upstream direction from the lowest transect to the upper most monitoring station along the study site (Figure 3). Where the thalweg location is indeterminate due to a pool, the approximate centerline of the deepest area will be surveyed. Where abrupt channel controls are met (such as BDA structures), additional measurements will be made immediately downstream and upstream of the channel control and the control feature will be noted.

Stream Cross Sections

Cross sectional surveys will be conducted annually at each field site during the low flow period before and after treatment. Cross sectional surveys will take place along cross section transects as shown in Figure 3. Channel bed and water surface elevations and the spatial coordinates of point measurements will be collected by Leica Total Station, referenced to local benchmarks. Intervals between measurements will be made approximately every 25cm to capture trends in the channel bedform. Where inflection points in channel bedform occur (bankfull, slump-blocks, terrace, etc.), additional measurements will be collected to describe the feature.

Site Topography

Where site conditions allow, we will conduct unmanned aerial systems (UAS) flights using a DJI Matrice 210 RTK-enabled drone mounted with a Zenmuse X5S RBG camera pre- and post-treatment to take repeat aerial photographs of the study sites. In addition, we will place up to twenty 2’x2’ targets throughout the study site and collect ground control coordinates using a Total Station and/or RTK GPS. The aerial photos combined with these points will enable us to develop a high-resolution geo-referenced point cloud of the site using the structure-from-motion software Agisoft Metashape. From these point clouds we will then create 3-dimentional model surfaces, orthophotos, and digital elevation models for analysis. Analyses may include geomorphic change detection through surface differencing and floodplain feature delineation.

Fish

We will characterize fish species diversity, relative abundance via catch per unit effort (CPUE), density, and condition within control and treatment reaches at each site annually during summer low flow. We will follow field methods outlined in the Western Environmental Monitoring and Assessment Program (Stoddard et al., 2005) for sampling aquatic vertebrate assemblages, including Peck et al. (2005a,b) manuals. We will install four primary block nets at each site to isolate the downstream reach, treatment reach, and control reach (Figure 3). We will measure the length and average wetted width of each reach. We will measure the length and average wetted width of each reach. Fish surveys will be completed with a Smith-Root Model LR-24 electrofisher. The electrofisher will be autocalibrated to best suit stream conditions to minimize harm to fish and maximize capture efficiency. We will record water temperature and conductivity at each survey. Electrofishing will not be completed when water temperature is greater than 18°C. Prior starting any survey, staff will perform a safety check, and all staff will acknowledge that they know where the safety switch is located and that they are ready to begin. The surveyor handling the electrofisher will alert all other field staff that they are ready to begin. Pre-sampling electrofisher setting tests will be situated well outside of each sampling reach to ensure that the audio and light signals are emitting at a standard pace. The surveyor will check to see that fish are attracted to the anode with the least possible application of electrical intensity. If captured fish show signs of harm we will lower the settings, first voltage, followed by frequency if necessary.

Each survey will be conducted by two or three surveyors: one with the backpack electrofisher and one or two netters depending on the channel size and complexity. Surveyors will begin at the downstream-most block net in the treatment reach and work upstream. We will place all captured fish in an aerated bucket (live-well) filled with fresh stream water. If staff are working in open sunlight, they will wear polarized sunglasses and a brimmed cap to maximize visibility. Netters will record any fish seen but not captured (noting species and estimated length if possible). To minimize harm to fish, netters will ensure nets are empty prior to fishing, net fish away from the electrodes, minimize fish exposure to air, sunlight and handling, process the live-well contents quickly (at least once per reach), monitor fish behavior for signs of distress (gaping, lethargy), keep fresh, well aerated water in the live-well and ensure it does not become crowded. If the live-well becomes crowded or fish show signs of stress, surveyors will immediately process and release fish. Large predatory fish will be processed first.

At the upstream end of each reach, when more than 15 fish are in the aerated bucket, or when fish are showing signs of stress, we will enumerate fish by species. If necessary, the fish will be anesthetized using MS-222 (WSU 2020). For all salmonids we will record total length (mm) (Anderson and Gutreuter, 1983) using a measuring board, and weight (g) using a portable electronic scale. If stopping before a reach break (i.e., treatment-control break), surveyors will do so at a habitat unit break to minimize the chance of movement into or out of habitat units. If there are more than 20 salmonids of a given species within a reach, then we will measure and weigh only the first (randomly selected) 20. Surveyors will photograph representative fish, and any of uncertain identity, in a photarium and release all fish within the reach in which they were captured. We will record the on-button time (seconds) from the display of the electrofisher control panel for each reach, and then zero out the timber prior to sampling in the next reach.

Surveyors will tally any unintentional mortalities or injuries resulting from fishing activities. When harm to fish is detected surveyors will reduce power, decrease handling time, and/or cease fishing. We will follow strict adherence to the guidelines developed by the American Fisheries Society (Jenkins et al., 2014) for the use of fishes in research.

Beaver Structure Use

Reconnaissance surveys will be conducted quarterly by walking the length of the site along each bank and visually searching for beaver sign including chews and foraging, scent mounds, lodge building, burrow excavation and dam building. Each BDA structure will be inspected for the presence of wood, mud, and other materials added by beavers.

Table 11. Standard methodology or SOP used for sampling protocol development for each response.

Response Category	Response Sub-Category	Method/SOP
Water Temperature	Water temperature net change	EAP080 v2.1, Continuous Temperature Monitoring of Freshwater Rivers and Streams
	Stream thermal diversity	Ebersole et al., 2011
	Structure-based thermal diversity	Weber et al., 2017
Hydrological	Riparian groundwater	Baxter and Hauer, 2003; EAP074 v1.2, Use of Submersible Pressure Transducers During Groundwater Studies
	Seasonal stage	EAP042 v1.2, Measuring Gage Height of Streams
	BDA pond water level	EAP042 v1.2, Measuring Gage Height of Streams (Staff gage only)
Physical	Site topography	EAP113 v1.7, Channel Dimensions
	Stream geomorphic units	Pleus et al., 1999
	Stream longitudinal profile	EAP119 v1.3, Thalweg Profile
	Stream cross sections	EAP113, v1.7, Channel Dimensions
	Reach-scale large wood load	Roorbach and Schuett-Hames, 2003
Biological	Fish	EAP124 v1.4, Watershed Health Monitoring: Standard Operating Procedures for Vertebrate Assemblage Sampling; Jenkins et al., 2014

8.3 Containers, preservation methods, holding times

Salmonids which have been measured and weighed will be held in a perforated (flow-through) recovery bucket until signs of distress, if any, are no longer apparent. Immediately thereafter they will be gently released near their point of capture.

8.4 Equipment decontamination

Not applicable.

8.5 Sample ID

Not applicable.

8.6 Chain of custody

Not applicable.

8.7 Field log requirements

Data will be primarily recorded electronically, either with dataloggers that are deployed and downloaded in the field, or as data forms in Survey 123 and iForms. Dataloggers will be downloaded regularly and data transferred to a database housed on a server at WDFW Forms will be developed with dropdown lists to minimize mistypes and ensure consistent terminology for site names, personnel and other categorical data. Necessary fields will be designated as required such that staff cannot move onto the next field without first filling in the previous required field. This helps to ensure data are complete before moving on from a sample or site. Constraints will be put on select data fields to reject impossible data values. The date and time are automatically populated every time a record is created. Survey 123 has the added benefit of being GPS enabled so all data will be spatially georeferenced. Staff will be directed to note any changes from QAPP or SOPs directly into a notes field in the data form. Fields to denote weather and other environmental conditions (e.g., air temperature) will be included. Forms will be run on iPads and data will be automatically uploaded to cloud storage when in cell service or at the office using Wi-Fi. Data from the cloud will be regularly downloaded (monthly) into a database housed on a server at WDFW.

8.8 Other activities

Prior to any planned field work staff will be briefed on responsibilities for data collection and safety measures while in the field. All field equipment will be inspected for proper function and calibrated as needed prior to conducting field measurements.

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

Sensor downloads will occur in the field every 2 or 3 months using Onset Optic Shuttles (*Onset Computer Corporation, Bourne, Massachusetts*), with data visually inspected in the field using HOBOware Pro software. Air temperature data will be used for ambient site characterization, data quality assurance, and troubleshooting. If a sensor appears inoperable or damaged, it will be immediately replaced with a reserve sensor and the exchange will be recorded. At the time of download, each sensor's serial number, condition (battery percentage, physical condition), and status (e.g. submerged, sedimented, exposed to air) will be recorded. Raw field data will be permanently stored on WDFW servers, which are automatically backed up on a nightly basis. We will identify and flag poor quality data based on the presence of outliers. Field observations will be used to identify periods when sensors are buried in sediment or exposed to air. Air temperature data will be compared to water temperature data to discern periods when sensors may have been exposed to the air. Poor quality data may result from sensor exposure to air, burial in silt or mud, freezing, or sensor damage. Anomalous outliers or large segments of missing or erroneous data will be flagged. All raw field data will be permanently retained as downloaded and any edited data files will be saved as new files.

Field crews will undergo a sampling method review each year under the supervision of the Principal Investigator or the Field Lead. The stream monuments will ensure that samples are collected at the proper locations within the stream. Datasheets will be checked for accuracy and completeness before leaving the study basin and the field lead will keep a record of all sampling activities in the study basins.

Data calculations will be reviewed by a Principal Investigator. All analyses will be done by or under the guidance of one Principal Investigator.

10.1 Table of field and laboratory quality control

Table 12. Quality control field references and frequency by sensor type.

Parameter	Instrument	Manual Calibration Checks	Manual Reference Measurement Device	Frequency of Field References
Water Level	HOBO U20L-04 Water Level Data Logger	Pressure calibration test will be conducted in dry air prior to deployment (following EAP074, v1.2)	Staff Gauge ±0.1ft	At least 8 manual references measurements per sensor per year.
Continuous Water Temperature	HOBO TidBiT v2 Water Temperature Logger and HOBO Pro v2 Water Temperature Logger	Pre-and-post deployment calibration in ice bath and room temperature bath to NIST referenced thermometer (following EAP080, v2.1)	Cooper-Atkins Handheld Digital Thermometer Model 35200K NIST-Calibrated Thermometer ±0.3°C	At least 6 manual reference measurements per sensor per year.

10.2 Corrective action processes

If quality control checks identify issues, the following corrective actions may be taken as appropriate:

- Review pre- and post-calibration checks.
- If logger is unable to connect or data file is corrupted, we will attempt to retrieve missing information.
- If data errors are found, data will be rejected
- Post-deployment, if a second calibration check result confirms a consistent bias above the stated accuracy, then the raw data should be adjusted by the mean difference of the

pre- and post-calibration check results to correct for the logger bias (Schuett-Hames et al., 1999).

- Pressure transducer stage data will be corrected for linear drift following EAP074 v1.2 Appendix C.

• 11.0 Data Management Procedures

11.1 Data recording and reporting requirements

Field data will be recorded using digital data forms or a waterproof notebook than transferred into EXCEL® spreadsheet or a database for storage. Data downloaded from data loggers will be transferred to HOBOware® Pro software. Analyses will be conducted in R, SAS or another statistical program.

11.2 Laboratory data package requirements

Not applicable.

11.3 Electronic transfer requirements

Not applicable.

11.4 Data upload procedures

Water temperature and level data will be uploaded into o Ecology's Environmental Information Management (EIM) system following the procedures outlined in Ecology's EIM User's Manual (Ecology 2015). All other data will be stored on WDFW servers that are routinely backed up. The data kept in spreadsheets and databases will be available for Ecology review upon request.

11.5 Model information management

Not applicable.

12.0 Audits and Reports

12.1 Audits

Not applicable.

12.2 Responsible personnel

Not applicable.

12.3 Frequency and distribution of reports

Biennial reports that outline study implementation and data collection progress are due at the end of each biennium (21-23BN and 23-25 BN). A final report outlining complete study results along with implications for future implementation and siting will be submitted at the end of Fiscal Year 26 (FY26).

12.4 Responsibility for reports

The following individuals have joint responsibility for the project reports.

- Reed Ojala-Barbour, WDFW
- Tristan Weiss, WDFW
- Aimee Mcintyre, WDFW
- Jamie Glasgow, Wild Fish Conservancy

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

Proper deployment of instruments, data downloads, and instrument accuracy checks will used to minimize data error. Field notes will verify that proper field procedures were carried out by field staff. Data will be scanned for outliers and outlier data will be flagged and then removed from the analysis if found to be an error.

13.2 Laboratory data verification

Not applicable.

13.3 Validation requirements, if necessary

Not applicable.

13.4 Model quality assessment

Not applicable.

13.4.1 Calibration and validation

Not applicable.

13.4.1.1 Precision

Not applicable.

13.4.1.2 Bias

Not applicable.

13.4.1.3 Representativeness

Not applicable.

13.4.1.4 Qualitative assessment

Not applicable.

13.4.2 Analysis of sensitivity and uncertainty

Not applicable.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

The objectives for this project will be met if data were collected using the scientifically defensible protocols described above and presented to Ecology in the final document.

14.2 Treatment of non-detects

Not applicable.

14.3 Data analysis and presentation methods

To statistically analyze water temperature net change, regression relationships will be developed by pairing each study site's treatment outflow gauge with their corresponding treatment inflow gauge. This approach is similar to Watson et al. (2001) and modified by Gomi et al. (2006). Regression relationships between temperatures measured at the treatment gauge and paired upstream control gauge will be used to predict expected 1-day (daily) maximum temperatures during pre- and post-treatment periods for all sites. Predicted daily maximum temperatures will be subtracted from observed daily maximum temperature to calculate daily temperature response. Any significant positive autocorrelation detected during the post-treatment period will be adjusted by applying coefficients derived from an iterative auto-regression generalized least squares procedure. This same autocorrelation analysis will be applied to pre-treatment (calibration) data across study sites to ensure that the relationship between control gauges does not change between the pre-treatment period compared to the post-treatment period. This procedure will allow the evaluation of our assumption of stationarity between control gauges so that trends between study sites can be compared.

Structure-based thermal diversity monitoring data will be graphically analyzed by visualizing diel curves of water temperatures in both free flowing and impounded sub-reaches. Timeseries of diel temperature curves will be symbolized to illustrate pond/channel position (longitudinal/lateral) and depth to reveal emergent temporal patterns related to sensor placement. We expect variability between sensor locations through time to become apparent based on patterns of phase shifting (timing of thermal maxima/minima) and differences in magnitudes of temperature at both impounded and free flowing sub-reaches. Spatial variability between sensor locations will be illustrated by depicting absolute sensor temperatures overlayed on an aerial image during the warmest and coldest periods of the low flow periods for both free flowing and impounded sites, similar to the approach used by Weber et al. (2017).

Thermal diversity data will be used to calculate reach-scale (control, treatment, downstream) estimates of cold-water patch abundance (discrete number of patches), mean frequency of cold-water patches per 100m of stream length, total cold-water patch area, proportion of cold-water patch area to total wetted area, deviation of the lowest cold-water patch temperature from ambient water temperature, and mean depth of each cold-water patch. These data will be used to compare before-after changes in cold-water patches for between control, treatment, and downstream reaches of each site.

We will calculate reach-scale means and variance by month and season for ground and surface water elevations to compare pre-post treatment differences, normalized to an arbitrary datum. Continuous measurements of stream stage will be thinned to coincide with staff gauge observations to compare differences in control and treatment water elevations over time. Survey observations will be graphically analyzed by scatterplot and boxplot, displayed by longitudinal distance, treatment reach, and year to examine differences in control and treatment reaches. Stream geomorphic unit surveys will be summarized to evaluate pool prevalence and characteristics. Measures of topographic change, BDA structure volume, and beaver use will be mapped by year to qualitatively examine and illustrate changes within treatment and control reaches. We will employ 3D analysis tools to difference surface elevation models of the sites to identify areas of geomorphic change in terrain. Additionally, we will analyze the longitudinal profiles and elevation cross-sections to assess elevation and surface water changes within inundated and in-stream sections of the floodplain. To calculate and analyze change in inundated area and timing, we will digitize mosaiced aerial images in GIS for each time interval captured.

Fish data will be summarized to describe fish species composition, and to calculate the relative abundance via catch per unit effort (CPUE) for each species by dividing the number of individuals of each species captured within each reach by the number of seconds each reach was electrofished. Density of each species will be calculated within each reach by dividing the number of individuals of each species captured within each reach by the area of each reach (length x avg. width). Fulton's Condition Factor will be calculated (F_k = weight/length^3) for each species of salmonid within each reach.

14.4 Sampling design evaluation

This project is a case study intended to inform project effectiveness for ASRP Adaptive Management. Many parameters of interest are set up in a Before-After Control-Impact monitoring framework to control for environmental variability and isolate BDA treatment effects. Our sample size of three sites is constrained by funding and objectives defined by the ASRP Monitoring and Adaptive Management Committee.

14.5 Documentation of assessment

The final report will document the usability and fitness of the data collected during this study. The project will be considered successful if the BDAs are installed as planned, and if the parameters described in this QAPP are characterized using the data collected.

15.0 References

Anderson, R.O., S.J. Gutreuter, 1983. Length weight and associated structural indices. In: Nielsen, L.A., Johnson, D.L. (Eds.), Fisheries Techniques. American Fisheries Society, Bethesda, Maryland, pp. 283–300.

ASRPSC (Aquatic Species Restoration Plan Steering Committee), 2019. Chehalis Basin Strategy Aquatic Species Restoraiton Plan – Phase 1 document. Publication 19-06-009.

Baxter, C., F. R. Hauer, and W. W. Woessner, 2003. Measuring groundwater–stream water exchange: New techniques for installing minipiezometers and estimating hydraulic conductivity. *Transactions of the American Fisheries Society*, *132*(3), 493-502. https://doi.org/10.1577/1548-8659(2003)132%3C0493:MGWENT%3E2.0.CO;2

Beechie, T. J., C. Nicol, C. Fogel, J. Jorgensen, J. Thompson, G. Seixas, J. Chamberlin, J. Hall, B. Timpane-Padgham, P. Kiffney, S. Kubo, and J. Keaton, 2019. *Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmon Life Cycle Model.* Seattle, WA.

Bouwes, N., N. Weber, C. E. Jordan, W. C. Saunders, I. A. Tattam, C. Volk, J. M. Wheaton, and M. M. Pollock, 2016. Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (Oncorhynchus mykiss). *Scientific reports, 6*, 28581.

Bouwes, N., J. Moberg, N. Weber, B. Bouwes, S. Bennett, C. Beasley, C. E. Jordan, P. Nelle, S. Polino, S. Rentmeester, B. Semmens, C. Volk, M. B. Ward, and J. White, 2011. *Scientific Protocol for Salmonid Habitat Survyes within the Columbia Habiat Monitoring Program*, Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA, 118 pp.

Castro, J., M. Pollock, C. Jordan, G. Lewallen, and K. Woodruff, 2015. The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains, Version 2.0. *US Fish and Wildlife Service, Portland, OR*.

Chevalier, M., J. C. Russell, and J. Knape, 2019. New measures for evaluation of environmental perturbations using Before-After-Control-Impact analyses. *Ecological Applications*, *29*(2), e01838.

Cooke, H. A., and S. Zack, 2008. Influence of beaver dam density on riparian areas and riparian birds in shrubsteppe of Wyoming. *Western North American Naturalist, 68*(3), 365-373.

DeVries, P., K. L. Fetherston, A. Vitale, and S. Madsen, 2012. Emulating riverine landscape controls of beaver in stream restoration. *Fisheries, 37*(6), 246-255.

Ebersole, J. L., P. J. Wigington, Jr, S. G. Leibowitz, R. L. Comeleo, and J. V. Sickle, 2015. Predicting the occurrence of cold-water patches at intermittent and ephemeral tributary confluences with warm rivers. *Freshwater Science*, *34*(1), 111-124.

Ecology (Washington State Department of Ecology). 2015. myEIM user manual: environmental information management, Olympia, Washington. https://apps.ecology.wa.gov/eim/help/Training/OpenDocument/65.

Gomi, T., R. D. Moore, and A. S. Dhakal, 2006. Headwater stream temperature response to clear-cut harvesting with different riparian treatments, coastal British Columbia, Canada. *Water Resources Research*, 42, W08437, doi:10.1029/2005WR004162.

Jenkins, J. A., H. L. Bart, Jr, J. D. Bowker, P. R. Bowser, J. R. MacMillan, J. G. Nickum, J. W. Rachlin, J. D. Rose, P. W. Sorensen, B. E. Warkentine, and G. W. Whitledge, 2014. Guidelines for Use of Fishes in Research—Revised and Expanded. *Fisheries* 39(9), 415-416.

Katz, J. V., C. Jeffres, J. L. Conrad, T. R. Sommer, J. Martinez, S. Brumbaugh, S., N. Corline, and P. B. Moyle, 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. *PLOS ONE, 12*(6), e0177409.

Keim, R. F., A. E. Skaugset, and D. S. Bateman. 1999. Digital terrain modeling of small stream channels with a totalstation theodolite. Advances in Water Resources 23:97–104.Naiman, R. J., S. R. Elliott, J. M. Helfield, and T. C. O'Keefe, 1999. Biophysical interactions and the structure and dynamics of riverine ecosystems: The importance of biotic feedbacks. *Hydrobiologia* 410, 79-86.

Lemmon, J. 2018. Standard Operating Procedure EAP113, Version 1.7: Watershed Health Monitoring: Measuring Channel Dimensions. 18-03-219. https://apps.ecology.wa.gov/publications/SummaryPages/1803219.html

Merritt, G. 2018. Standard Operating Procedures for Vertebrate Assemblage Sampling Version 1.4. 18-03-228. https://apps.ecology.wa.gov/publications/documents/1803228.pdf

Merritt, G. 2018. Standard Operating Procedure EAP119, Version 1.3: Standard Operating Procedure for Thalweg Profiling. 18-03-223. https://apps.ecology.wa.gov/publications/SummaryPages/1803223.html

Norman, E. G, 2020. *Hydrologic Response of Headwater Streams Restored with Beaver Dam Analogue Structures*. M.S. Thesis, Montana Technological University. 79 pp.

Orr, M. R., N. P. Weber, W. N. Noone, M. G. Mooney, T. M. Oakes, and H. M. Broughton, 2020. Short-term stream and riparian responses to beaver dam analogs on a low-gradient channel lacking woody riparian vegetation. *Northwest Science, 93*(3-4), 171-184.

Parsons, J. et al. 2018. Standard Operating Procedure EAP070, Version 2.2: Minimize the Spread of Invasive Species. 18-03-201. https://apps.ecology.wa.gov/publications/SummaryPages/1803201.html

Peck, D. V., D. K. Averill, A. T. Herlihy,R. M. Hughes, P. R. Kaufmann, D. J. Klemm, J. M. Lazorchak, F. H. McCormick, S. A. Peterson, M. R. Cappaert, T. Magee, and P. A. Monaco, 2005a. Environmental Monitoring and Assessment Program - Surface Waters Western Pilot Study: Field Operations Manual for Non-Wadeable Rivers and Streams. EPA Report EPA 600/R-05, US Environmental Protection Agency, Washington, DC.

Peck, D. V., A. T. Herlihy, B. H. Hill, R. M. Hughes, P. R. Kaufmann, D. J. Klemm, J. M. Lazorchak, F. H. McCormick, S. A. Peterson, P. L. Ringold, T. Magee, and M. R. Cappaert, 2005b. Environmental Monitoring and Assessment Program - Surface Waters Western Pilot Study: Field Operations Manual for Wadeable Streams. EPA Report EPA 600/R-05/003, US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Pilliod, D. S., A. T. Rohde, S. Charnley, R. R. Davee, J. B. Dunham, H. Gosnell, H., G. E. Grant, M. B. Hausner, J. L. Huntington, and C. Nash, 2018. Survey of beaver-related restoration practices in rangeland streams of the western USA. *Environmental Management, 61*, 58-68.

Pleus, A.E., D. Schuett-Hames, and L. Bullchild, 1999. TFW Monitoring Program method maunal for the habitat unit survey. Prepared for the Washington State Department of Natural Resources under the Timber, Fiwh, and Wilflie Agreement. TFW-AM9-99-003. DNR #105. June.

Pollock, M. M., T. J. Beechie, J. M. Wheaton, C. E. Jordan, N. Bouwes, N. Weber, and C. Volk, 2014. Using beaver dams to restore incised stream ecosystems. *BioScience, 64*(4), 279-290.

Pollock, M. M., G. R. Pess, T. J. Beechie, and D. R. Montgomery, 2004. The importance of beaver ponds to coho salmon production in the Stillaguamish River basin, Washington, USA. *North American Journal of Fisheries Management, 24*(3), 749-760.

Roorbach, A. and D. Schuett-Hames. 2003. Field Methods: *CMER Type N Riparian Buffer Integrity, Function and Characteristics Project.* Northwest Indians Fisheries Commission Report.

Scamardo, J., and E. Wohl, 2020. Sediment storage and shallow groundwater response to beaver dam analogues in the Colorado Front Range, USA. *River Research and Applications, 36*(3), 398-409.

Schuett-Hames, D. TFW Monitoring Program Method Manual for Stream Temperature Survey. TFW-AM9-99-005. https://apps.ecology.wa.gov/publications/documents/99e01.pdf

Shahverdian, S. M., J. M. Wheaton, S. N. Bennett, N. Bouwes, R. Camp, C. E. Jordan, and N. Weber, 2019. Chapter 4 - Mimicking and Promoting Wood Accumulation and Beaver Dam Activity with Post-assisted Log Structures and Beaver Dam Analogues. In J. Wheaten, S. Bennett, N. Bouwes, J. Maestas, & S. Shahverdian (Eds.), *Low-tech Process-based Restoration of Riverscapes: Design manual* (pp. 66). Logan, Utah: Utah State University Restoration Consortium.

Shedd, J. 2018. Standard Operating Procedure EAP042, Version 1.2: Measuring Gage Height of Streams. 18-03-232. https://apps.ecology.wa.gov/publications/SummaryPages/1803232.html

Sinclair, K.; Pitz, C. Standard Operating Procedure EAP074, Version 1.2: Use of Submersible Pressure Transducers During Groundwater Studies. 19-03-205. https://apps.ecology.wa.gov/publications/SummaryPages/1903205.html

Stevens, C. E., C. A. Paszkowski, and A. L. Foote, 2007. Beaver (*Castor canadensis*) as a surrogate species for conserving anuran amphibians on boreal streams in Alberta, Canada. *Biological Conservation, 134*(1), 1-13.

Stoddard, J., D. Peck, A. Olsen, D. Larsen, J. Van Sickle, C. Hawkins, R. Hughes, T. Whittier, G. Lomnicky, and A. Herlihy, 2005. Environmental monitoring and assessment program (EMAP): Western streams and rivers statistical summary. US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Ward, W. 2018. Standard Operating Procedures EAP080, Version 2.1: Continuous Temperature Monitoring of Freshwater Rivers and Streams. 18-03-205. https://apps.ecology.wa.gov/publications/SummaryPages/1803205.html

Watson, F., R. Vertessy, T. McMahon, B. Rhodes, and I. Watson, 2001. Improved methods to assess water yield changes from paired-catchment studies: Application to the Maroondah catchments. *Forest Ecology and Management, 143*, 189-204.

Weber, N., N. Bouwes, M.M. Pollock, C. Volk, J.M. Wheaton, G. Wathen, J. Wirtz and C.E. Jordan. 2017. Alteration of stream temperature by natural and artificial beaver dams. *PLOS ONE* 12(5):e0176313.

WSU (Washington State University). 2020. Tricaine Methanesulfonate (MS-222) Preparation Storage and Use. Institutional Animal Care and Use Committee. Policy #13. https://iacuc.wsu.edu/documents/2018/11/policy-13.pdf/

16.0 Appendices

Appendix A. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

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

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

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

Reach: A specific portion or segment of a stream.

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

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

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

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

Thalweg: The deepest and fastest moving portion of a stream.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less.

Acronyms and Abbreviations

e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others

GIS	Geographic Information System software
GPS	Global Positioning System
i.e.	In other words
MQO	Measurement quality objective
QA	Quality assurance
QC	Quality control
SOP	Standard operating procedures
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
ft	feet
g	gram, a unit of mass
m	meter
mm	millimeter

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 (Kammin, 2010). For Ecology, it is defined according to WAC 173-50-040: "Formal recognition by [Ecology] that an environmental laboratory is capable of producing accurate and defensible analytical data."

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* (USEPA, 2014).

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: Discrepancy between the expected value of an estimator and the population parameter being estimated (Gilbert, 1987; USEPA, 2014).

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, 2014; USEPA, 2020).

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, 2014; USEPA 2020).

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: The process of determining that the data satisfy the requirements as defined by the data user (USEPA, 2020). There are various levels of data validation (USEPA, 2009).

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, 2014).

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)/LCS duplicate: 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. Monitors a lab's performance for bias and precision (USEPA, 2014).

Matrix spike/Matrix spike duplicate: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias and precision errors 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 (USEPA, 2001).

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): The minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results (USEPA, 2016). MDL is a measure of the capability of an analytical method of distinguished samples that do not contain a specific analyte from a sample that contains a low concentration of the analyte (USEPA, 2020).

Minimum level: Either the sample concentration equivalent to the lowest calibration point in a method or a multiple of the method detection limit (MDL), whichever is higher. For the purposes of NPDES compliance monitoring, EPA considers the following terms to be synonymous: “quantitation limit,” “reporting limit,” and “minimum level” (40 CFR 136).

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:

$$RPD = [Abs(a-b)/((a + b)/2)] * 100\%$$

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).

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).

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).

Reporting level: Unless specified otherwise by a regulatory authority or in a discharge permit, results for analytes that meet the identification criteria (i.e., rules for determining qualitative presence/absence of an analyte) are reported down to the concentration of the minimum level established by the laboratory through calibration of the instrument. EPA considers the terms "reporting limit," "quantitation limit," and "minimum level" to be synonymous (40 CFR 136).

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, 1992).

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, 2014).

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, 2014).

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

40 CFR 136. Title 40 Code of Federal Regulations, Part 136: Guidelines Establishing Test Procedures for the Analysis of Pollutants. Available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=3cf9acace214b7af340ea8f6919a7c39&mc=true&node=pt40.25.136&rgn=div5 (accessed 26 Feb. 2020).

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Available at: https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html (accessed 6 Mar. 2020).

Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York, NY.

Kammin, W., 2010. Definition developed or extensively edited by William Kammin, 2010. Washington State Department of Ecology, Olympia, WA.

USEPA, 1992. Guidelines for exposure assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C. EPA/600/Z-92/001. Available at: https://www.epa.gov/sites/production/files/2014-11/documents/guidelines_exp_assessment.pdf (accessed 26 Feb. 2020).

USEPA, 2001. EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5. U.S. Environmental Protection Agency, Washington, DC. EPA/240/B-01/003. Available at: https://www.epa.gov/quality/epa-qar-5-epa-requirements-quality-assurance-project-plans (accessed 26 Feb. 2020).

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/sites/production/files/2015-06/documents/g4-final.pdf (accessed 26 Feb. 2020).

USEPA, 2009. Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use, OSWER No. 9200.1-85, EPA 540-R-08-005. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/nscep.

USEPA, 2014. Compendium: Project Quality Assurance and Quality Control: Chapter 1. U.S. Environmental Protection Agency, Washington, DC. SW-846 Update V. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/chap1_1.pdf (accessed 26 Feb. 2020).

USEPA, 2016. Definition and Procedure for the Determination of the Method Detection Limit, Revision 2. EPA 821-R-16-006. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/sites/production/files/2016-12/documents/mdl-procedure_rev2_12-13-2016.pdf (accessed 6 Mar. 2020).

USEPA, 2020. Glossary: Environmental Sampling and Analytical Methods (ESAM) Program. U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/esam/glossary (accessed 26 Feb. 2020).

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. U.S. Geological Survey, Reston, VA. Available at: https://pubs.usgs.gov/of/1998/ofr98-636/ (accessed 26 Feb. 2020).

WAC 173-50-040. Title 173 Washington Administrative Code. Accreditation of Environmental Laboratories: Definitions. Available at: https://apps.leg.wa.gov/WAC/default.aspx?cite=173-50-040 (accessed 26 Feb. 2020).