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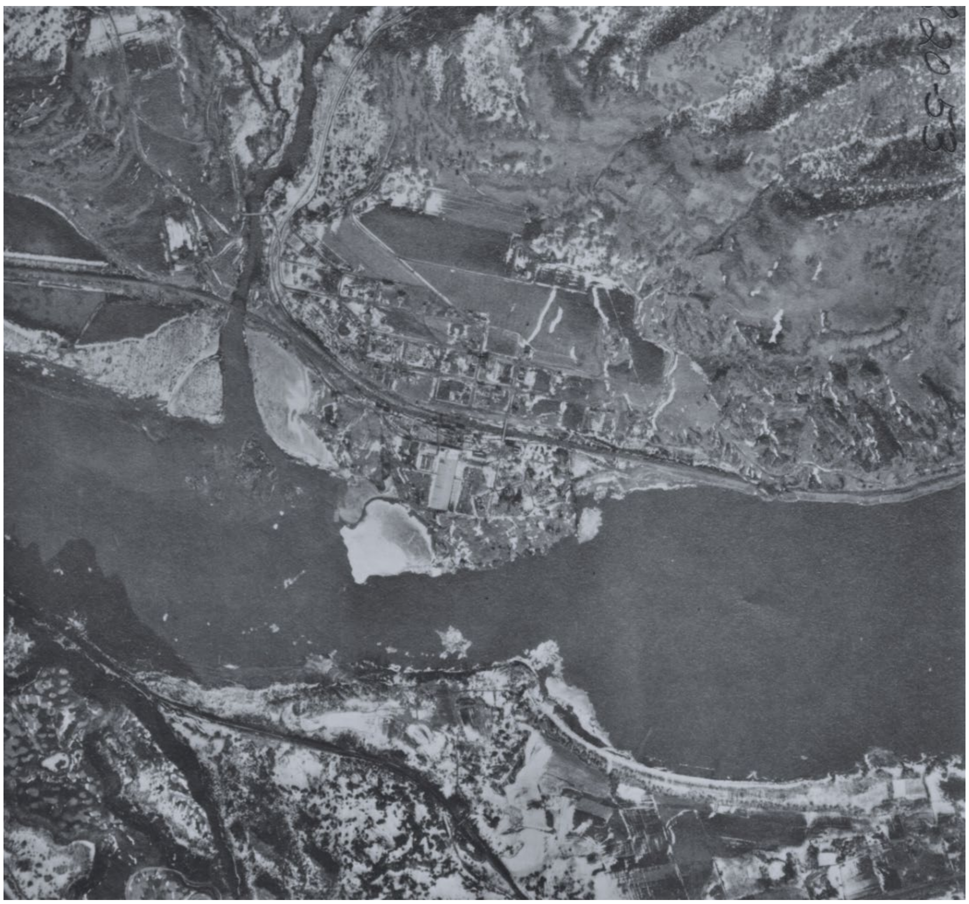
# Sedimentation of Tributary Deltas to the Columbia River in the Zone 6 Fishery and Effects to Cold-Water Refuge Habitat



Aerial Image of Klickitat River delta from 1930

## Planning Assistance to States and Tribes (PAST), Final Report, December 2024

CUI

# EXECUTIVE SUMMARY

The Yakama Nation in coordination with the Columbia River Inter-Tribal Fish Commission (CRITFC) and its member tribes (the Yakama, Nez Perce, Umatilla, and Warm Springs) and the U.S. Army Corps of Engineers (USACE) initiated a Planning Assistance to States and Tribes (PAST) study in 2021. The goal of the PAST study is to examine sedimentation impacts to cold-water refuge habitats at tributary deltas along the Columbia River. In recognition that there would be future restoration and management projects relating to cold-water refuges, the scope of this study evolved to develop knowledge and data sets that can be used as baseline conditions and for model development as described in this report.

Section 1 describes the scope development, outcomes from a planning charrette, and recent executive actions guiding current and future management of cold-water refuge habitat. The planning charrette focused on information gathering from tribes, state and federal resource agencies, and local government to better understand potential issues and objectives for preserving and restoring cold-water refuge habitats.

Section 2 provides a description of the existing conditions of the Zone 6 fishery of the Columbia River from McNary Dam to Bonneville Dam. The original project scope focused on the Wind, White Salmon, and Klickitat Rivers, but the scope of the existing conditions section was done to accommodate upcoming restoration projects that include Hood River and other cold-water refuge tributaries. The existing conditions description is focused on the hydrology, geology, climate, and fish species of the region.

Section 3 provides a geomorphic assessment of the sedimentation impacts that have occurred at the Wind, White Salmon, and Klickitat River deltas based on aerial and satellite imagery along with flow data and limited information on sediment transport in the rivers.

Section 4 summarizes available and collected data as a part of or in connection to this study. The data included information on water temperature, flow, rainfall, snow, sediments, and bathymetry.

Section 5 summarizes the findings of this study with respect to sedimentation of the Wind, White Salmon, and Klickitat Rivers with respect to cold-water refuge habitat. This section also describes the main data and knowledge gaps and proposes how numerical model development could be used to assess restoration scenarios.

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## ACRONYMS

| Acronym | Description |
|---|---|
| BiOp | Biological Opinion |
| BOR | U.S. Bureau of Reclamation |
| BPA | Bonneville Power Administration |
| CAP | Continuing Authorities Program |
| CRBG | Columbia River Flood Basalt Group |
| CRITFC | Columbia River Inter-Tribal Fish Commission |
| CRS | Columbia River System |
| CRSO | Columbia River System Operations |
| CWA | Clean Water Act |
| CWR | Cold-Water Refuge |
| EIS | Environmental Impact Statement |
| ENSO | El Niño-Southern Oscillation |
| EPA | U.S. Environmental Protection Agency |
| ESA | Endangered Species Act |
| FNC | Federal Navigation Channel |
| FNU | Formazin Nephelometric Units |
| FPC | Fish Passage Center |
| FPP | Fish Passage Planning |
| GCAP | Geospatial Center for the Arctic and Pacific |
| GNSS | Global Navigation Satellite System |
| GPA | Global Positioning System |
| HDR | Hood River |
| HUC | Hydrologic Unit Code |
| LiDAR | Light Detection and Ranging |
| MEM | Memaloose Island |
| MOU | Memorandum of Understanding |
| NAVD88 | North American Vertical Datum of 1988 |
| NLCD | National Land Cover Database |
| NMFS | National Marine Fisheries Service |

| Acronym | Description |
|---|---|
| NOAA | National Atmospheric and Oceanic Administration |
| NorWeST | Northwest Stream Temperature database |
| NOS | National Ocean Service |
| NPGO | North Pacific Gyre Oscillation |
| NWIS | National Water Information System |
| NWRFC | Northwest River Forecast Center |
| OSU | Oregon State University |
| PAST | Planning Assistance to States and Tribes |
| PDO | Pacific Decadal Oscillation |
| RMSE | Root Mean Square Error |
| RTK | Real Time Kinetic |
| SNODAS | Snow Data Assimilation |
| SRS | Sediment Retention Structure |
| SWE | Snow Water Equivalent |
| TDG | Total Dissolved Gas |
| TMDL | Total Maximum Daily Load |
| TMT | Technical Management Team |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| WDFW | Washington Department of Fisheries and Wildlife |
| WDOE | Washington Department of Ecology |
| WGS | World Geodetic System of 1984 |
| WML | Wind Mountain Lower |
| WMP | Water Management Planning |
| WRDA | Water Resources Development Act |

# SECTION 1 - INTRODUCTION

## 1.1 STUDY BACKGROUND

The Yakama Nation in coordination with the Columbia River Inter-Tribal Fish Commission (CRITFC) and its member tribes (the Yakama, Nez Perce, Umatilla, and Warm Springs) and the U.S. Army Corps of Engineers (USACE) initiated a Planning Assistance to States and Tribes (PAST) study in 2021. The project is focused on addressing changes in sedimentation and its impact on salmonids, Pacific lamprey, and cold-water refuge habitat at tributary confluences with the Columbia River. The scope of the project was refined over the initial stages of the project that narrowed the study to three tributary deltas that included the Wind, White Salmon, and Klickitat Rivers with their confluences with the Columbia River in the Bonneville Dam pool region at river miles 151, 165, and 177, respectively (Figure 1). The current conditions description (Section 2) was expanded to include the entire Zone 6 fishery region of the Columbia River extending from McNary Dam to Bonneville Dam.

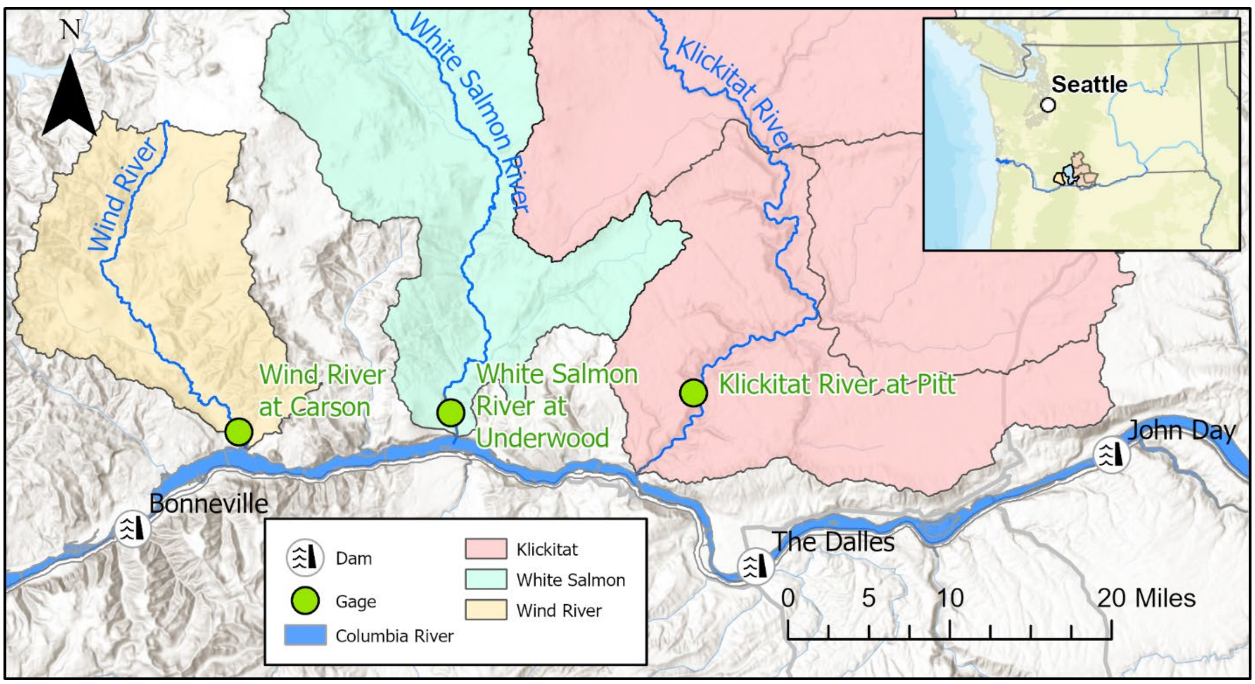



**Figure 1. Map of the study area**

The PAST program is authorized by Section 2.2 of the Water Resources Development Act (WRDA) of 1974 to provide planning and technical assistance to states and Tribes but does not include detailed design or project construction elements. USACE is indirectly involved with cold-water refugia habitat issues through its operations of Columbia River dams and trying to meet applicable water quality standards of the Clean Water Act (CWA) implemented by state agencies. USACE can also engage with cold-water refugia habitat issues as they relate to the ecosystem restoration mission area through its Continuing Authorities Program (CAP), which typically involves a non-federal sponsor in support of the project that can include planning, design, and implementation phases.

The U.S. Environmental Protection Agency (EPA) released a Cold-Water Refuges Plan in 2021 that assessed cold-water refugia habitat along the Columbia River from the Pacific Ocean to the Snake River (EPA 2021a). Cold-water refuges are cooler patches of water that migrating anadromous fish temporarily use to escape warmer temperatures. For the Columbia River, the cold-water refuges tend to occur where cold water from tributaries meets a warmer main channel Columbia River. The resulting cold-water refuge ranges from the cold-water plume into the mainstem Columbia River, to a couple river miles upstream from the tributary delta.

The EPA study classified cold-water refuge habitats based on historical mean flow and water temperature data in August, which represents the warmest months when refuges are most utilized. The criteria for defining cold-water refugia habitat were August flows greater than 10 cubic feet per second and August water temperatures that were 2°C cooler than the mainstem Columbia River. This study adopts the EPA's definition of tributary cold-water refuge habitats (EPA 2021a).

The cold-water refuges along the Bonneville Pool are associated with small- to medium-sized tributaries draining the Cascade Mountains and Columbia Plateau. Information on sedimentation impacts in the tributary deltas in this region is not well known with most stream gages having piecemeal data on past sediment loads that typically have not been active for several decades. In general, the tributaries draining the Cascade Mountains see wetter conditions with steeper elevation slopes and denser forestation. The tributaries draining the Columbia Plateau region to the east are dryer with soils and vegetation characteristic of a high desert landscape. Therefore, the sediment yields from the tributaries draining to the study area tends to increase moving upstream (eastward) along the Columbia River, but episodic hydrologic, glacial, and landslide events can affect the entire region.

Prior to the construction of Bonneville Dam, the Columbia River was a series of cascades, rapids, and pools with tributaries forming broad delta regions that were seasonally affected by the natural hydrograph of the river. It is estimated that prior to the construction of Bonneville Dam that the sediment load was on the order of 16.4 million tons per year (CRITFC 2015). After the construction of Bonneville Dam in the 1930s, the rapids, cascades, and tributary delta regions were submerged by the reservoir pool. Bonneville and a series of upstream dams affects the dynamics of the tributary delta regions by elevating water surface and regulated flows that mute the natural high flows and reduce sediment transport processes.

The quality of the cold-water refuge habitat relates to the mixing of tributary with mainstream water, as well as the sediment transport of tributary and mainstem sediments that dynamically form the delta face. Potential concerns of sedimentation of the tributary deltas are reduced volume of cold water, shallower water depths increasing juvenile salmon exposure to avian and fish predation, shallower depths reducing adult salmon use, and potential disconnection between cold-water refuge habitat and main channel for migrating fish.

## 1.2 PROJECT SCOPE DEVELOPMENT

### 1.2.1 Planning Charrette

A planning charrette was organized with the intent to develop a set of problems cold-water refuges face, as well as key considerations and restoration opportunities that existed specifically for the Wind, White Salmon, and Klickitat Rivers. The charrette focused on information gathering from tribes, state and federal resource agencies, and local government to better understand the area and provide necessary input in the refining of the project's scoped activities. It was held on November 3rd and 4th, 2022 in Bingen, Washington in person and virtually. Participating entities included:

- Confederated Tribes and Bands of the Yakama Nation
- Columbia River Inter-Tribal Fish Commission
- Confederated Tribes of the Umatilla Indian Reservation
- Nez Perce Tribe
- Confederated Tribes of the Warm Springs
- City of Bingen Washington
- City of Stevenson Washington
- City of White Salmon Washington
- Klickitat County
- Washington Department of Fish and Wildlife
- Washington Department of Ecology
- Lower Columbia Estuary Partnership
- Underwood Conservation District
- Lower Columbia Fish Recovery Board
- Sandy River Watershed Council
- Northwest Power and Conservation Council
- Yakima-Klickitat Fisheries Project
- National Oceanic and Atmospheric Administration
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Department of Agriculture
- U.S. Forest Service
- U.S. Geological Survey
- U.S. Army Corps of Engineers

The compiled outputs from the charrette provided a framework to develop the data collection and monitoring strategy. Not all the information provided was within the scope of this study to address. The extent of the planned study is limited to technical assistance with design and implementation of projects not falling within the scope of this authority.

### 1.2.2 Development of Problem Statements and opportunities

**Problems**

Where problems are specific to a delta, they have been identified at the end of the statement (A=All, W=Wind, K=Klickitat, WSR=White Salmon)

- Fluctuation of pool elevations and dam discharges are dictated by external needs and may not be optimal for managing cold-water habitat in the deltas (A)
- Sedimentation is resulting in low velocity, shallow, warm water areas in the deltas that favor fish predators such as northern pikeminnow, smallmouth bass, walleye, and bird predator such as California gulls and double crested Cormorants (A)
- Boaters must cross the shallow areas at the delta to reach the mainstem of the Columbia for fishing and recreation creating a safety issue (A)
- The Little Wind River is an active landslide area with heavy sediment load partially captured by large wood installations (W)
- There is private real estate ownership at the delta of the Wind River (W), unlike federal and tribal ownership at the others.
- Increasing number of permit exempt wells are tapping into the groundwater throughout the watershed potentially impacting flows and temperatures at the deltas (A)
- There is a potential for large, uncontained sediment flows after wildfires that would impact sedimentation in the deltas (A)
- Adult fish passage into the Little Wind is compromised by shallow water due to sediment deposition at its confluence into the Wind (W)
- Sedimentation may have possible impacts to the Spring Creek Hatchery (WSR)
- Commercial and non-commercial recreational needs have negative impacts to the delta areas including bank erosion, safety, and litter due to increased access (WSR)
- The stored sediments build up behind Condit Dam, significantly increased sedimentation in the delta (WSR)
- Stranding has been observed to both juvenile salmon and lamprey during changes in water levels due to pool ramping (A)
- Invasive vegetation in the watersheds could impact bank erosion and sedimentation in the deltas (A)
- Large sedimentation events are unpredictable and have substantial, long-term impacts to habitat in the deltas. (A)
- Recession of the glacier may increase sediment load in the system (K/WSR)
- A specific gauge analysis on historic sediment loads indicates that sediment load on the Klickitat has been increasing from 2007 to 2020 (K)
- Little or no data related to short and long-term discharge, river stage, sediment load, and temperature (W).
- Need for sediment coring for historical sediment pattern analysis (A)

- Extent of water withdrawal and agricultural practices in each delta (A)
- Extent of avian predation due to increase in shallow fish habitats pertaining to sedimentation (A).

**Opportunities**

- Identify restoration activities that restore the river and its tributaries to as near to pre-dam conditions as possible.
- Leverage existing infrastructure to reduce sediment loading or to create restoration opportunities.
- Modify the deltas to expand or enhance the cold-water plume.
- Change or modify take-out and boat ramp locations to minimize impacts to salmon.
- Expand protected areas in the watershed to improve water quality and reduce sedimentation from bank erosion.
- Create education opportunities for commercial and non-commercial recreational users to reduce their impact on resources.
- Modify the deltas to contain or expand cold-water habitat in key areas.
- Modify the deltas to limit warm water predator habitat.
- Modify the deltas to improved adult passage into cold-water refugia and tributaries.
- Modify the deltas to improve juvenile egress from tributaries into mainstem Columbia.
- Modify the deltas to minimize juvenile stranding.
- Modifying each delta such that they mimic natural river conditions and help fish habitats and migration.

**Key Questions**

- How has the river changed from a pre-dam state to present day and how has that affected the characteristics of the deltas being studied?
- What has driven the historical patterns of delta development and have the deltas changed over time?
- What are the key sources of sediment in each of the basins and how are they impacting the delta? How is sediment from the Columbia River impacting the deltas?
- Are the cold-water habitat and access considerations the same for target salmon species and the Pacific Lamprey?
- What impact is highway and railroad infrastructure having to the mouths or upstream within the watersheds being studied?
- How are dam operations affecting the sediment plume? Can operations be modified to improve conditions in the deltas?
- How are deposition patterns between the three deltas different and what causes these differences?

- Are the sandbars maintaining or receding after removal of the Condit Dam, and at what rate? What might a stable delta look like at the White Salmon after remaining sediment has moved through the system?
- How many water withdrawals are in the watersheds and what is their impact to downstream flows and sediment transport?
- Are there different sediment types in each of the deltas, and do they impact rate or type of sedimentation?
- Do backwater effects from the Columbia impact the deltas?

**Future Goals or Objectives**

This section includes a variety of long-term planning goals and objectives for the deltas considered in this study. Inclusion of these items will help inform the data collection aspects of the scope rather than provide a list of tasks to be completed as a part of this effort.

- Identify ways to improve safe egress for juveniles moving out of the delta and improved cold water refugia for adult salmon.
- Identify pre- and post- dam conditions related to fish habitats in the White Salmon River for further implications on potential dam removal opportunities.
- Modify channels and sandbars in the delta areas to fill in warm shallow areas and/or excavate areas to concentrate or direct cold water.
- Headwater meadow restoration (Snyder and Rattlesnake Creeks) to manage sediment and water quality in the tributaries.
- Redevelopment of riparian corridors along the mainstem and tributaries to maintain bank stability and improve water quality.
- Partner with organizations making modifications along the mainstem or at the delta to identify supplemental restoration or mitigation opportunities (BS&F bridge, boat launch, recreation area improvements).
- Coordinate dam releases after large sedimentation events to scour material and reduce development of sandbars or shallows that support predation and restrict access or volume of cold-water habitat.
- Develop a sediment budget for the Columbia River or individual tributaries to understand long term maintenance requirement for modifications to the system.
- Develop sediment transport and water quality models to understand how deltas will develop and change over time and better inform potential and effectiveness of restoration or mitigation measures.
- Identify structural measures that would add stability or improve scour within the deltas or better maintain or extend cold-water refugia.
- Explore other delta restoration projects to better understand effectiveness and long-term impacts to delta modifications.

### 1.2.3 Executive and Judicial Environment

This PAST study was initiated in 2021 with the intent on restoring the cold-water refugia habitats within the tributary delta regions that exist under the current configuration and operations of the Columbia River System. Just prior to this project, the Columbia River

System Operations (CRSO) Environmental Impact Statement (EIS) and Biological Opinion (BiOp) were finalized in 2020 (USACE et al. 2020), which were released in response to ongoing litigation regarding the endangered species act and several previous biological opinions going back to 2001. In October 2021, the Biden administration worked with the plaintiffs to agree to a pause in the litigation challenging the 2020 EIS and BiOp.

Tangential events have also taken place over the span of this project that relate to water temperature in the Columbia River. In May of 2021, the U.S. Environmental Protection Agency (EPA) released its study on the Total Daily Maximum Load for water temperature in the Columbia and Lower Snake Rivers (EPA 2021b), which is a requirement under the Clean Water Act. In 2022, there were two studies released by NOAA Fisheries and Senator Murray and Governor Inslee from Washington that called for the removal of the four Lower Snake River Dams to help restore salmon populations. In 2021, the EPA issued National Pollutant Discharge Elimination System (NPDES) permits to the four Lower Columbia River and four Lower Snake River hydroelectric dams that are now effective. The NPDES permits pertain to the release of contaminants found in cooling water intake structures, floor drains, and maintenance-related discharges of oil, grease, excess heat (temperature), acids and bases affecting pH, polychlorinated biphenyls (PCBs), and silts (EPA 2020a,b), as well as non-point source thermal pollution.

In December 2023, the Biden-Harris administration partnered with Pacific Northwest Tribes to develop a 10-year program to help restore salmon populations, as well as expand clean energy production on tribal lands. The agreement was implemented through a Memorandum of Understanding (MOU) between the United States; the States of Oregon and Washington; the Nez Perce, Umatilla, Warm Springs, and Yakama Tribes and referred to as the Resilient Columbia Basin Agreement (RCBA). Part of this RCBA MOU directed the Bonneville Power Administration (BPA) to invest $300 million over 10 years to restore native fish and their habitats throughout the Columbia River Basin, which included $100 million specifically to be provided to the four Lower Columbia River Treaty Tribes, Washington, and Oregon to use for fish restoration projects. This funding will also be supplemented by investments from other Federal agencies.

## 1.3 STUDY COMPONENTS

The initial planning efforts to define the scope of this project focused on building a baseline knowledge regarding the sedimentation impacts to cold-water refugia habitat along tributary deltas. Between the planning charrette and what culminated in the 2023 RCBA MOU (also referred to as the Columbia River Basin Initiative) it has become clear that there will be considerable investment soon aimed at restoring cold-water refugia habitat in the study area. The scope of this study was refined to focus on synthesis of existing data, establishing real-time monitoring stations, and performing some base line characterizations of the physical environments defining the cold-water refugia habitats.

There are four main components to the project that include a regionally focused literature review on cold-water refugia habitat and sedimentation issues, a geomorphic assessment of the study deltas, data synthesis of existing data and establishing new monitoring data, and the development of conceptual management actions and restoration activities for the tributary delta regions. The overall goal of the project is to develop a baseline of knowledge and data sets of the tributary deltas that can inform future efforts in examining cold-water refugia habitats and issues relevant to the various Columbia River salmon species and Pacific Lamprey.

# SECTION 2 - FISHING ZONE 6 CURRENT CONDITIONS

## 2.1 STUDY AREA

### 2.1.1 Basin Characteristics

The Columbia River Basin has a 258,000 square mile drainage area encompassing portions of British Columbia, Washington, Oregon, Idaho, Montana, Wyoming, Nevada, and Utah. The watershed has an average annual runoff of 198 million acre-feet at the mouth of the Columbia River and an average annual flow of 273,500 cubic feet per second (USACE et al. 2020). The Columbia River flows 1,204 miles from British Columbia through Washington and along the Oregon border to the Pacific Ocean. The 292 miles of Columbia River separating Oregon and Washington were split into six zones for fisheries management. Zones 1 through 5 exist between the Pacific Ocean and Bonneville Dam and are for commercial fisheries. Zone 6 is an exclusive tribal commercial fishery between Bonneville and McNary Dams spanning 145 river miles (CRITFC 2024). This section focuses on cold-water refuge habitats located in Zone 6 of the Columbia River (Figure 2).

The landscape of the Zone 6 fishery spans the high desert region of the Columbia Plateau through the Columbia River Gorge with several tributaries draining off Mount Adams (elevation 12,281 feet) on the Washington side and Mount Hood (elevation 11,245 feet) on the Oregon side. The drier, eastern side of the study area is primarily shrub/scrub and grassland/herbaceous land cover types while the western side is predominately a forested landscape (Figure 2). The major tributaries to the Columbia River in Zone 6 include the Umatilla, John Day, Deschutes, and Hood Rivers from the Oregon side and the Klickitat, White Salmon, Little White Salmon, and Wind Rivers from the Washington side, as well as several smaller streams that drain to the Columbia River.

fourteen federal dams make up the Columbia River System with four being in Zone 6 that include McNary (river mile 291), John Day (river mile 217), The Dalles (river mile 192), and Bonneville (river mile 146) Dams. These dams were constructed with authorized purposes of hydropower and navigation, with flood storage at John Day Dam. Bonneville Dam was the first dam completed in Zone 6 in 1938 with The Dalles, John Day, and McNary Dams being completed in 1957, 1972, and 1957, respectively. All four dams have fish ladders to facilitate salmon spawning migrations, as well as associated navigation locks (USACE 2023a-d). All four dams are considered run-of-river dams where outflows from the dams closely match inflows to each reservoir even for the John Day Dam with 535,000 acre-feet of flood storage. The run-of-river conditions result in a narrow range in normal operating pool elevations for each reservoir that ranges between 340.3 to 343.3 feet at McNary Dam, 265.8 to 271.3 feet at John Day (with seasonal variations), 158.3 to 163.3 feet at The Dalles, and 74.8 to 79.8 feet at Bonneville Dam (USACE et al. 2020). All elevations are relative to the North American Vertical Datum of 1988 (NAVD88).

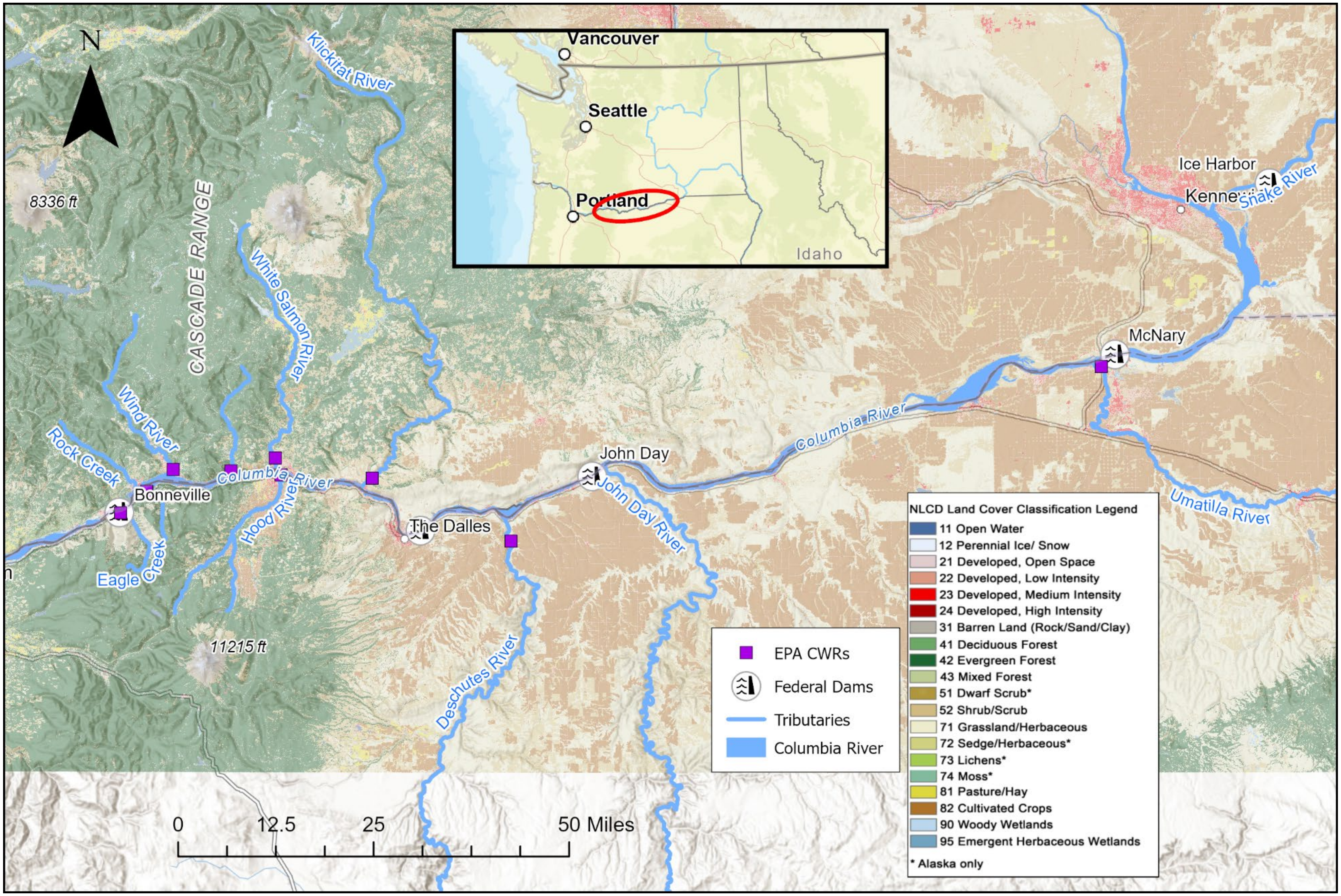



**Figure 2. Map of land cover types, tributary locations, and hydropower dams in the study area.**

### 2.1.2 Columbia River Conditions

Three of the four dams in Zone 6 (Bonneville, The Dalles, and McNary) are considered run-of-river dams. John Day Dam's flood storage is considered minimal relative to the flow in the Columbia River so its acts like a run-of-river dam with respect to its effects on water temperature and sediment transport. Run of river dams back up water to provide the needed head to maintain hydropower and navigation which results in a hydrograph that dampens winter high flow events and increases winter low flows. Figure 3 shows the observed and simulated natural (unregulated) flow hydrographs for water year 2017 along with statistical ranges of the unregulated flow for the period between 1928 and 2017 at The Dalles. The simulated natural flow hydrograph represents what flow conditions would be without the dams in place. In water year 2017, the wintertime natural flows were less than observed flows with similar flows between the natural and observed flows occurring between March and May. The observed freshet flows in April through June were on the order of 400,000 cubic feet per second with the simulated natural flow going as high as 700,000 cubic feet per second.

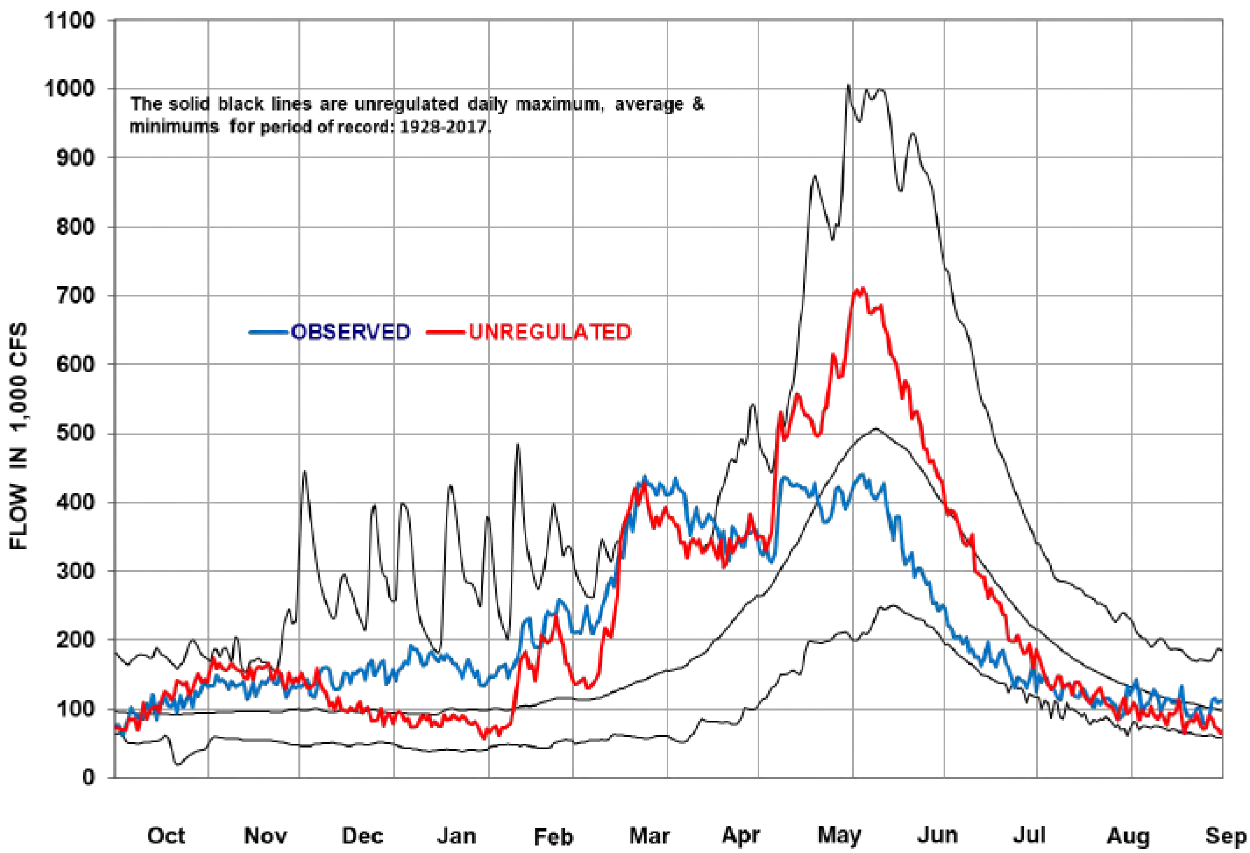



**Figure 3. Columbia River flows at The Dalles, Oregon, water year 2017. (Source: USACE et al. 2020)**

The four dams located in Zone 6 are a part of the overall Columbia River System (CRS) that manages the federal dams in the Columbia River Basin. The operations at each dam are coordinated among the action federal agencies (USACE, BPA, and BOR) along with a Technical Management Team (TMT) with representatives from National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), the states of Oregon, Washington, Idaho, and Montana, and Tribal sovereigns. Reservoir operations at each dam in the CRS is guided by the CRSO EIS of 2020, applicable BioOps, and litigation requirements to meet fish passage standards, flood risk constraints, barge navigation, and hydropower generation. There are annual planning efforts that go into the operations at each dam that include the development of the Water Management Plan (WMP) and Fish Passage Plan (FPP) that describe seasonal operational regimes. The actual operations of each dam that specify the outflow volume and pathway (i.e., spillways, hydropower turbines) are done in “real-time” based on continually updated forecasts and conditions to meet the overall management goals and annual planning targets.

During the spring and summer months, the operations of the four dams in Zone 6 are primarily focused on juvenile fish passage operations as defined in the CRSO EIS, which is a shift away from the historical operations that focused on releases to maximize hydropower production (USACE et al. 2020). The emphasis on spillway releases helps to increase survival and speed of migrating juvenile salmonids. The juvenile fish spill operations vary by project and by month according to the estimates of spillway flows listed in Table 1 and Table 2. In the spring, daily spillway flows are separated out into a 16 hour period where spill (i.e., flow over the spillway) is increased until total dissolved gas (TDG) saturation reaches 125 percent at McNary and Bonneville Dams, and to 120 percent at John Day with the remaining 8 hour period spilling a specified percentage of the total outflow or a set outflow value (Table 1). Note, The Dalles Dam is operated at a constant 40 percent spill throughout the day. In the summer, as flows recede in the Columbia River, the spill targets are set to percentages of the total outflow or a set outflow value (Table 2).The TDG threshold is used as a spill criteria as excess flows over that spillway results in supersaturation of TDG that can lead to gas bubble trauma in fish.

**Table 1. Spring juvenile fish passage spillway flows (10-April to 14-June).**

| Location | Juvenile Fish Spill Cap (16 hours) | Performance Standard Spill (8 hours) |
|---|---|---|
| McNary | 125% TDG | 48% total outflow |
| John Day | 120% TDG | 32% total outflow |
| The Dalles | 40% total outflow | 40% total outflow |
| Bonneville | 125% TDG | 100,000 cubic feet per second |

**Table 2. Summer juvenile fish passage spillway flows (15-June to 31-August).**

| Location | Spillway Flow (15-Jun to 14-Aug) | Spillway Flow (15-Aug to 31-Aug) |
|---|---|---|
| McNary | 57% total outflow | 20,000 cubic feet per second |
| John Day | 35% total outflow | 20,000 cubic feet per second |
| The Dalles | 40% total outflow | 30% total outflow |
| Bonneville | 95,000 cubic feet per second | 55,000 cubic feet per second |

Water temperatures in the regulated Columbia River and the unregulated Fraser River in British Columbia have increased approximately 0.3°C per decade from 1943 through 2018 (Figure 4), with annual maximum temperatures increasing by 2°C at Bonneville Dam since 1943. A historical water temperature reconstruction of the lower Columbia River suggested that water temperatures have increased at a rate of 0.13°C per decade since 1850, with the number of days with water temperatures above 20°C increasing from 5 to 60 days per year (Scott et al. 2023).

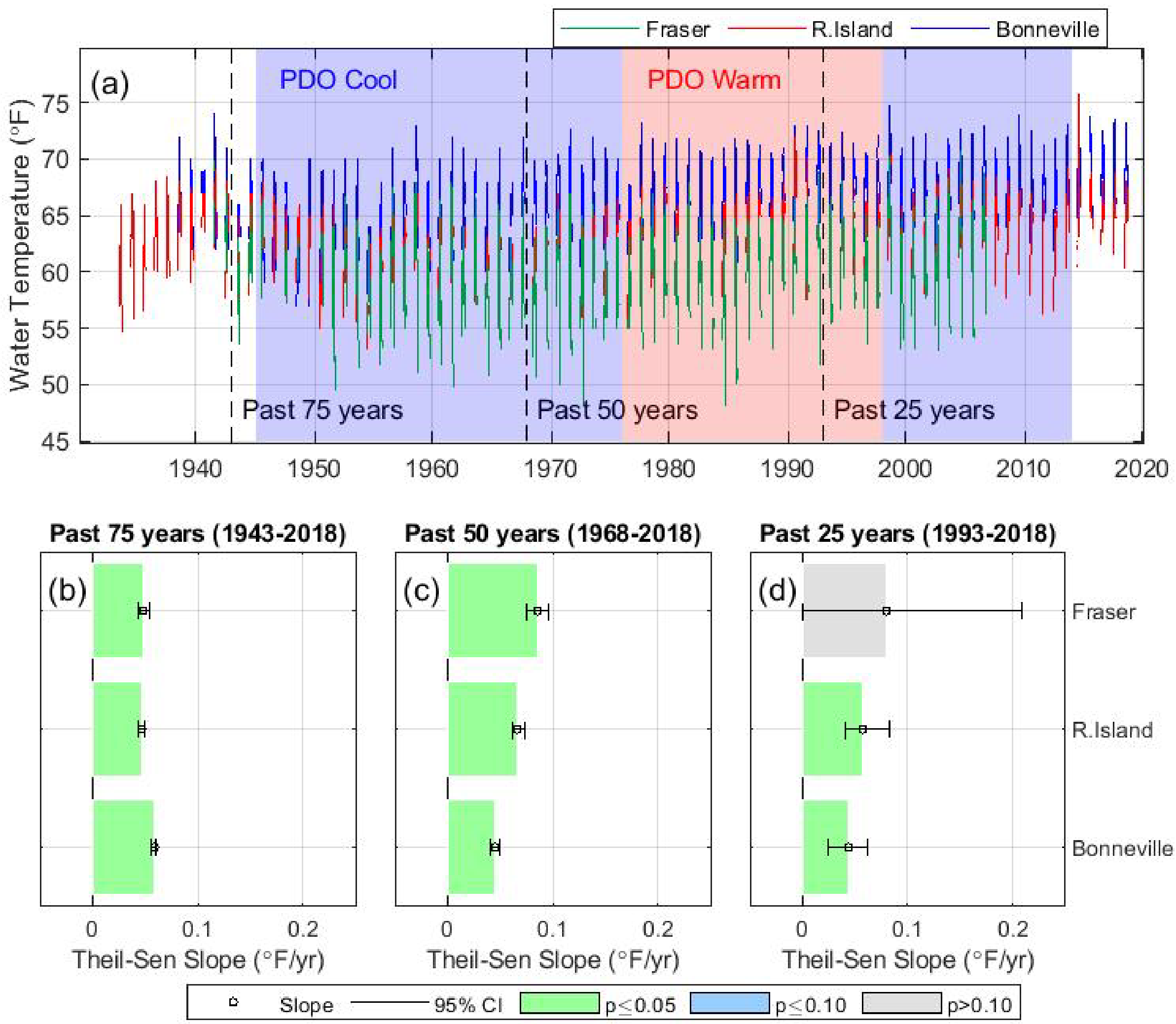



**Figure 4. Long-term water temperatures trends for the Columbia and Fraser Rivers with respect to (a) daily maximum water temperature, and monthly maximum temperatures for analysis periods (b) 1943 to 2018, (c) 1968 to 2018, and (d) 1993 to 2018. (Source: O'Connor 2021).**

Currently, summer water temperatures in the Columbia River often exceed temperature criteria (varies by state) according to the EPA's Columbia and Lower Snake Rivers Temperature Total Maximum Daily Load (TMDL) report (EPA 2021b). The EPA's TMDL study characterized current conditions by averaging water temperature data from 2011 to 2016, with daily mean summer (June through September) water temperatures ranging between 16 and 21.5°C and daily maximum summer temperatures ranging between 21 and 23.4°C. Between McNary and Bonneville Dams, water temperatures exceeding 20°C ranged between 54 and 65 days for the 2011 to 2016 period (EPA 2021b) and spanning the period from 2003 to 2018, the number of days with water temperatures exceeding 18°C has increased by 1 to 1.5 days per year across Zone 6 (O'Connor 2021).

The building of hydropower dams has reduced the capacity of Columbia River to move sediment. Sherwood et al. (1990) used available data and a regression model to estimate the sediment load in the Columbia River near Vancouver, Washington (river mile 53) for periods before and after the construction of the Zone 6 dams, as well as separate out the sediment load between sand and fine material. Prior to dam construction on the Columbia River (1868 – 1934) the total sediment load was 16.4 million tons per year with roughly 50 percent being sand material and 50 percent being finer sands, silts, and clays. The total sediment load for the regulated period (1958 – 1981) was 8.4 million tons per year of which 67 percent of the annual load being finer sands, silts, and clays. The pre-dam sediment load in the Columbia River translates to a sediment yield of 77 tons per square mile, with by comparison is approximately 28 percent of the Mississippi River Basin yield and 7 percent of the Colorado River Basin yield (Holman 1968).

Currently, only silts and clays pass McNary Dam so coarser sands and gravel only come from tributary inputs. Bonneville, The Dalles, and John Day reservoirs have some capacity to trap fine sediments with episodic inputs of larger materials from the tributaries resulting in stratified deposits in the regions of the tributary deltas. The Bonneville pool has a large volume of fine sand that deposited behind the Bridge of the Gods landslide that occurred 550 years ago (USACE et al. 2020).

### 2.1.3 Geologic Setting

The Columbia River Gorge is an 80-mile scenic canyon that cuts through the Cascade Range showcasing a river that has been shaped by lava flows from the Columbia River Flood Basalt Group (CRBG) for about 10.5 million years. The canyon walls are up to 4000-feet deep with the northern wall extent in Washington State and the southern walls in Oregon State. Tectonic activity near the gorge consists of Northeast-directed oblique subduction of the Juan de Fuca plate beneath North America. Earthquakes along the subduction zone accommodate most the tectonic-related deformation. However, regionally this deformation is accommodated with broad clockwise rotation of Oregon and Washington, uplift of the Coast and Cascade Ranges, and subsidence of the intervening Puget-Willamette forarc trough. This regional deformation resulted in folded Paleogene, and Neogene volcanic and volcaniclastic rocks in the gorge. Between Portland and Hood River, Oregon, the stratigraphy has been uplifted and cut by the Columbia River, exposing the gorge's geologic history.

In the gorge, the CRBG is a kilometer thick Miocene aged sequence of basalt flows that inundated Washington, Oregon, Idaho, and Nevada. These flows originated from feeder dikes up to 340 kilometers east of the Cascade volcanic arc, where an estimate of

210,000 cubic kilometers of lava periodically flowed from 16.5 to about 6 million years ago. Approximately 300 individual lava flows have been identified, of which 50 have been found in the gorge. Due to tectonic activity and uplift, not all the flows in the gorge can been seen in a single section of canyon wall. Figure 5 shows the extent of the CRBG flows.

The effects from catastrophic glacial floods have deposited silts and sands within and around the Columbia River area. During the Pleistocene ice age, Glacial Lake Missoula, located in western Montana, was ice-dammed by the Cordilleran Ice Sheet. Through repeated ice-dam failures, Lake Missoula released large amounts of water that flooded surrounding areas to the west, eventually draining into the Pacific Ocean via the Columbia River. During a course of 5,000 years, at least 100 floods have occurred. Figure 5 shows the extent of the Missoula floods overlaying the CRBG.

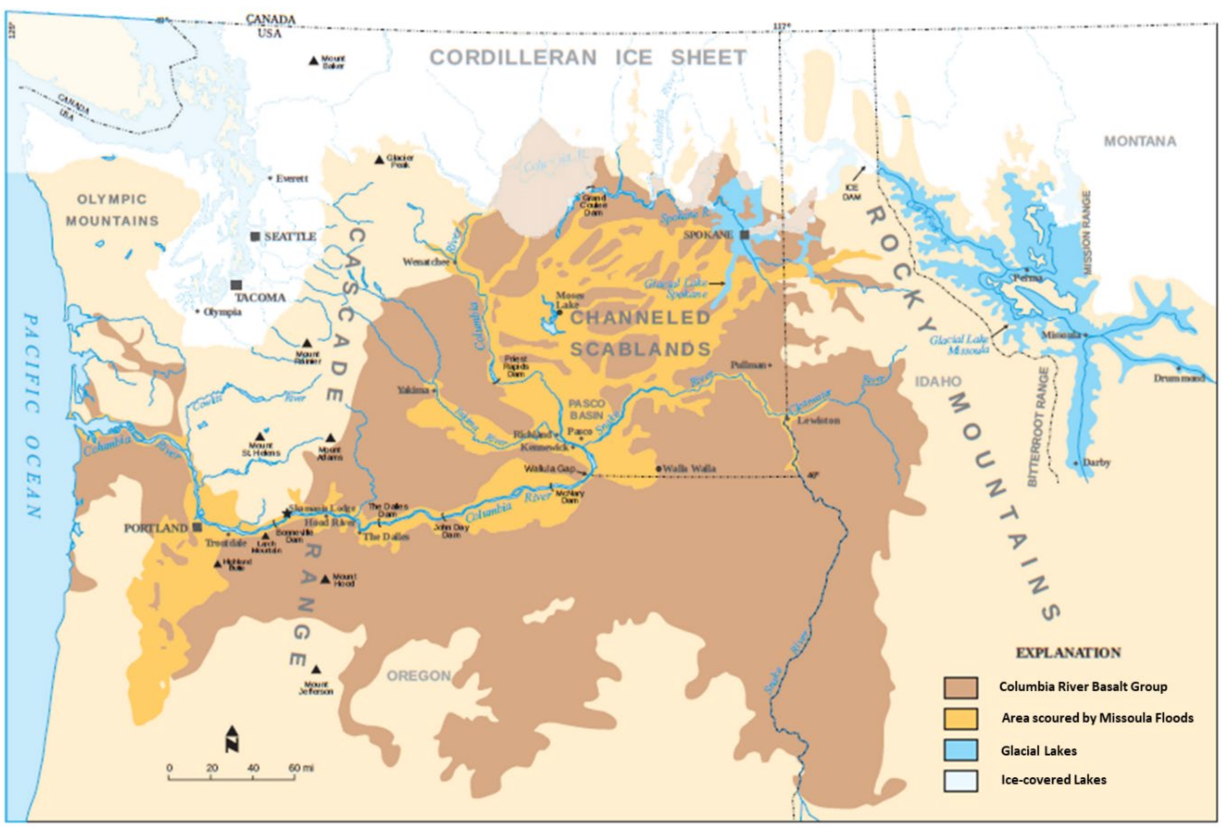


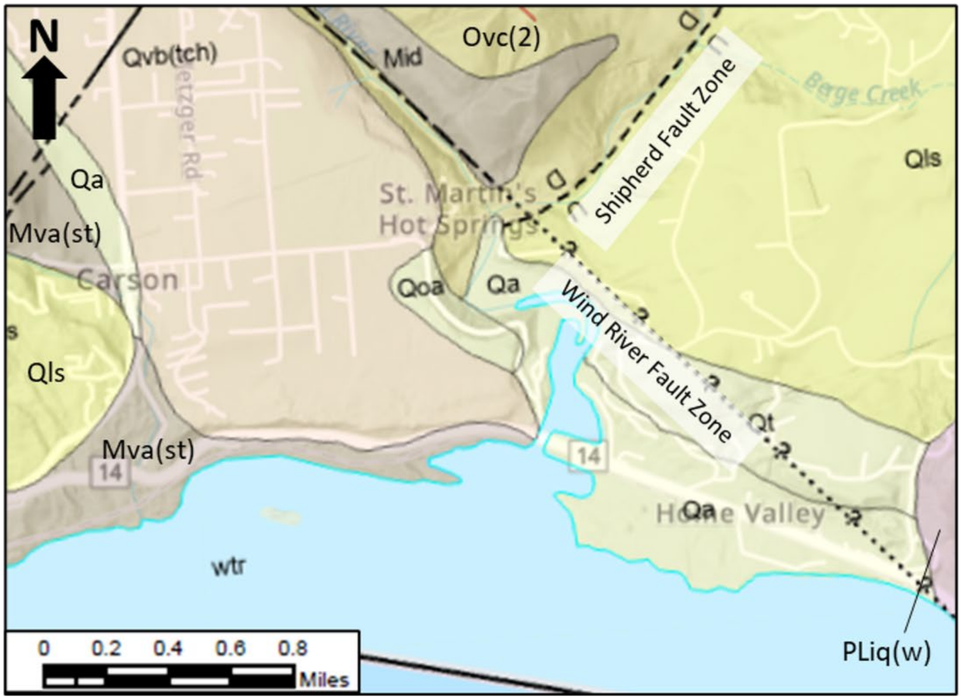

**Figure 5. Map showing the extent of the Columbia River Basalt Group (CRBG) and Missoula flood deposits. (Source: Norman et al. 2004).**

After the CRBG flows, glacial floods, and sea level rise, the Holocene activity consisted of fluvial estuary, debris flows, and landslides. Prior to reservoir inundation and flow regulation, sands from spring snowmelt freshets were carried by wind into active dune complexes that climbed the gorge slopes. Slope processes is prominent in the gorge aided by atmospheric rivers, forest fires, and earthquakes. The north side of the river has been shaped by extensive, deep-seated, southward sliding mass movements.

These slides push the river south, which undercuts the southern slopes causing rockfalls and slumps.

Deltas form when sedimentary deposition exceeds sedimentary removal at the mouth of a river. There is limited research on the geologic history of the deltas within Zone 6 of the Columbia River. The Wind River and White Salmon River deltas appear to not have as much sedimentation compared to the Klickitat delta. Factors that are likely controlling the deposition versus removal of sediments are the current and where the deltas are located along the Columbia River. The current of the Columbia River exceeds the flow coming out of each delta, promoting erosion of sediment. The Wind River and White Salmon River deltas are also located on the outside of a bend in the Columbia River, where more erosion is expected. The Klickitat River delta is located on the inside of a bend, where more deposition is expected. Faulting in the vicinity can affect where a river flows. This seems to be the case for the Wind and White Salmon Rivers where the flow of each river follows an existing fault. This does not appear to be the case for the Klickitat River delta.

The Wind River delta has had the most extensive research as it was a part of a geothermal study that followed Wind River from Carson National Fish Hatchery down to the Columbia River. The region where the Columbia and Wind Rivers meet was mapped as Quaternary unconsolidated or semi-consolidated alluvial deposits that overlay Quaternary landslide deposits, Quaternary volcanics, and Oligocene to Miocene volcanic flows, pyroclastic, and diorite (Washington Geologic Information Portal 2024). The Shipherd Fault Zone and Wind River Fault Zone also run through the area. Figure 6 illustrates the generalized geology at the Wind River delta.

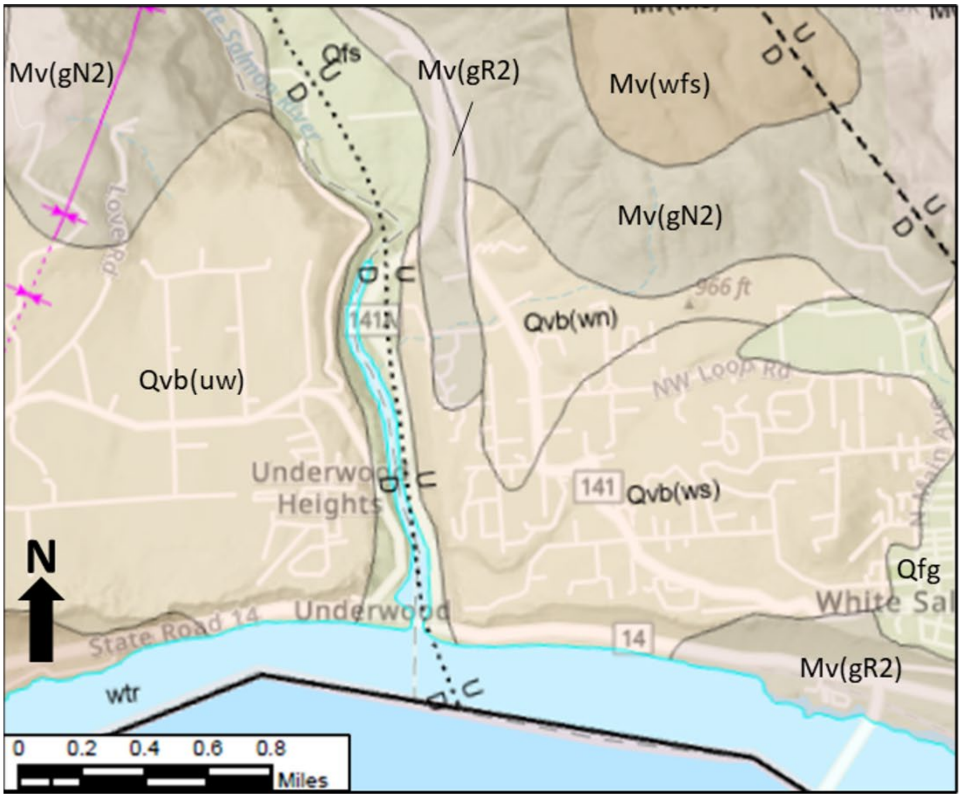



Mid – Miocene diorite
Mvs(st) – Miocene andesite flows (Stevenson Ridge)
Ovc(2) – Oligocene volcaniclastic deposits
PLiq(w) – Pliocene quartz diorite
Qa – Quaternary alluvium
Qls – Quaternary mass-wasting deposits
Qoa, Quaternary alluvium, older
Qt – Quaternary terraced deposits
Qvb(tch) – Quaternary basalt flows (Trout Creek Hill)
wtr – Water

Fault, unknown offset, location certain
Fault, unknown offset, location approximate
Fault, unknown offset, location concealed, questionable
Fault, High-angle dip-slip, Location inferred. Relative motion shown by U (up) and D (down)

**Figure 6. General geologic overview of the Wind River Delta in Carson, Washington. (Modified from the Washington Geologic Information Portal: Surface Geology Information 2024).**

The White Salmon River delta in Underwood, Washington is mapped as Quaternary volcanic rocks overlain by Pleistocene Missoula flood deposits and other Quaternary unconsolidated or semi-consolidated alluvial deposits. A high-angle dip-slip fault runs north to south along the White Salmon River (Washington Geologic Information Portal, 2024). Figure 7 illustrates the generalized geology at White Salmon River delta.

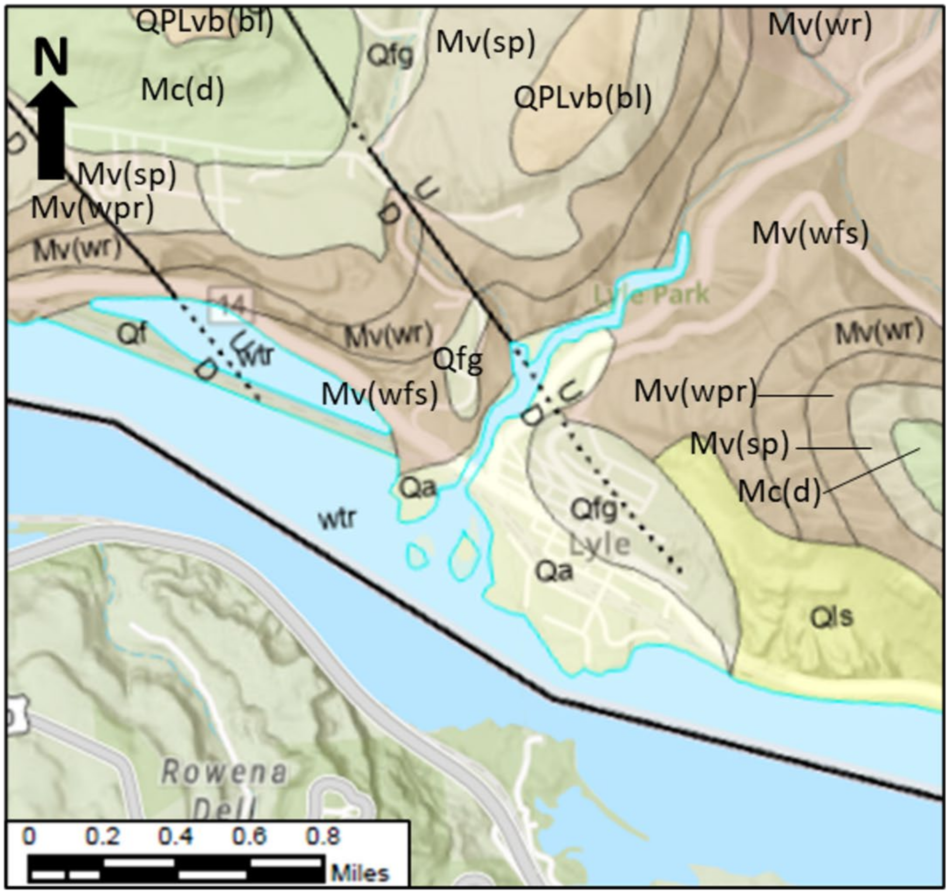



Mv(gN2) – Miocene basalt flows (Grand Ronde Basalt, CRB)
Mv(gR2) – Miocene basalt flows (Grand Ronde Basalt, CRB)
Mv(wfs) – Miocene basalt flows (Frenchman Springs Member, Wanapum Basalt)
Qfg – Pleistocene outburst flood deposits gravel
Qfs – Pleistocene outburst flood deposits sand and silt
Qva(mf) – Quaternary andesite flows (McCoy Flat Unit)
Qvb(wn) – Quaternary basalt flows (North of White Salmon Unit)
Qvb(ws) – Quaternary basalt flows (White Salmon Unit)
wtr – Water

Fault, High-angle dip-slip, Location concealed Relative motion shown by U (up) and D (down)
Fault, High-angle dip-slip, Location inferred. Relative motion shown by U (up) and D (down)
Syncline, Location accurate
Syncline, Location concealed

**Figure 7. General geologic overview of the White Salmon River delta in Underwood, Washington. (Modified from the Washington Geologic Information Portal: Surface Geology Information 2024).**

The geology at Klickitat River delta in Lyle, Washington is Quaternary unconsolidated or semi-consolidated alluvial deposits overlaying Pleistocene Missoula flood deposits, Quaternary landslide deposits and Miocene CRBG. A high-angled dip-slip runs northwest to southeast through the river delta (Washington Geologic Information Portal, 2024). Figure 8 illustrates the generalized geology at Klickitat River delta.




Mc(d) – Miocene continental sedimentary deposits or rocks (Dalles Formation)
Mv(sp) – Miocene basalt flows (Pomona Member, Saddle Mountain Basalt)
Mv(wfs) – Miocene basalt flows (Frenchman Springs Member, Wanapum Basalt)
Mv(wpr) – Miocene basalt flows (Priest Rapids Member)
Mv(wr) – Miocene basalt flows (Roza member, Wanapum Basalt)
Qa – Quaternary alluvium
Qf – Holocene artificial fill
Qfg – Pleistocene outburst flood deposits gravel
Qls – Quaternary mass-wasting deposits
QPLvb(bl) – Pleistocene-Pliocene basalt flows (Balch Lake Basalt)
wtr - Water

U/D (solid line) Fault, High-angle dip-slip, Location accurate. Relative motion shown by U (up) and D (down)

U/D (dotted line) Fault, High-angle dip-slip, Location inferred. Relative motion shown by U (up) and D (down)

**Figure 8. General geologic overview at Klickitat River delta in Lyle, Washington. (Modified from the Washington Geologic Information Portal: Surface Geology Information 2024).**

### 2.1.4 Climate

The climate in the Columbia River Basin ranges from a moist, mild maritime conditions near the mouth of the river to a relatively cool desert climate in some of the inland valleys of eastern Oregon, Washington, and southern Idaho. Both oceanic and continental weather systems affect the region and are influenced by elevation and proximity to mountain ranges that include the Cascade, Blue, Wallowa, and Rocky Mountains. Most of the annual precipitation occurs between fall and spring with a large portion falling as snow in the mountains, though there can also be wet springs and early summers as heavy rains and occasionally severe thunderstorms affect the region. The annual precipitation and temperature pattern results in two dominant runoff mechanisms that includes wintertime rainfall runoff primarily in the western portion of the basin and a late spring snowmelt runoff throughout the basin with 60 percent of the total runoff occurring between May and July (USACE et al. 2020).

Changes in the basin hydrology resulting from changes to precipitation, snow, and glacier melt will alter water temperatures in contributing tributaries. Air temperatures have increased by 0.8°C since 1970 in the Columbia River Basin, which has impacted the proportion of precipitation falling as snow or rainfall at high elevations in the Pacific Northwest (RMJOC 2018). Warmer air temperatures have increased the melting rate of high elevation glaciers in the Cascade Mountain glaciers near tributary headwaters. Over the last century, glacial areas have decreased by 32 percent on Mount Hood, 24 percent on Mount Rainier, and 49 percent on Mount Adams (Sitts et al. 2010). Model forecasts using projected climate scenarios have suggested that seasonal water temperatures will increase in the Columbia River Basin due to warming air temperatures and changes to the basin hydrology like those observed in the Sierra Nevada region (Ficklin et al. 2013, 2014). Most climate change assessments for the western United States suggest that the projected increases in water temperature correlate with increases in air temperature; however, there is greater uncertainty with respect to the hydrologic response (precipitation amount, type, and timing) that controls the amount and timing of seasonal river flows and advective heat fluxes (e.g., Luce et al. 2014).

Weather patterns in the Pacific Northwest are impacted by climate cycles that operate on timescales on the order of years to decades and are influenced by conditions in the northern Pacific Ocean. Climate cycles have been correlated to changes in oceanic habitat conditions (e.g., nutrient and chlorophyll concentrations and salinity) and riverine flows and water temperatures that affect fish populations in the Columbia River (Hamlet and Lettenmaier 1999, Petersen and Kitchell 2001, Di Lorenzo et al. 2008). The Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) are decadal climate cycles while the El Niño-Southern Oscillation (ENSO) cycle has a periodicity on the order of 5 years. The PDO and ENSO cycles have associated warm and cool phases that describe wintertime weather in the Pacific Northwest having warmer and drier (warm phase), and cooler and wetter (cool phase) weather conditions. The NPGO has phases that correlate to oceanic upwelling conditions (positive phase) and downwelling conditions (negative phase) along the California and Alaskan Coasts.

Indices for the climate cycles have been developed that use a variety of data sources (e.g., sea surface temperatures, air temperatures, and unregulated stream flows) to quantify a relative measure of the strength of the weather pattern. Figure 9 depicts indices quantifying the PDO, NPGO, and ENSO climate cycles based on date collected from the following sources:

- PDO: http://jisao.washington.edu/pdo/PDO.latest.txt
- NPGO: https://www.psl.noaa.gov/gcos_wgsp/Timeseries/NPGO
- ENSO: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

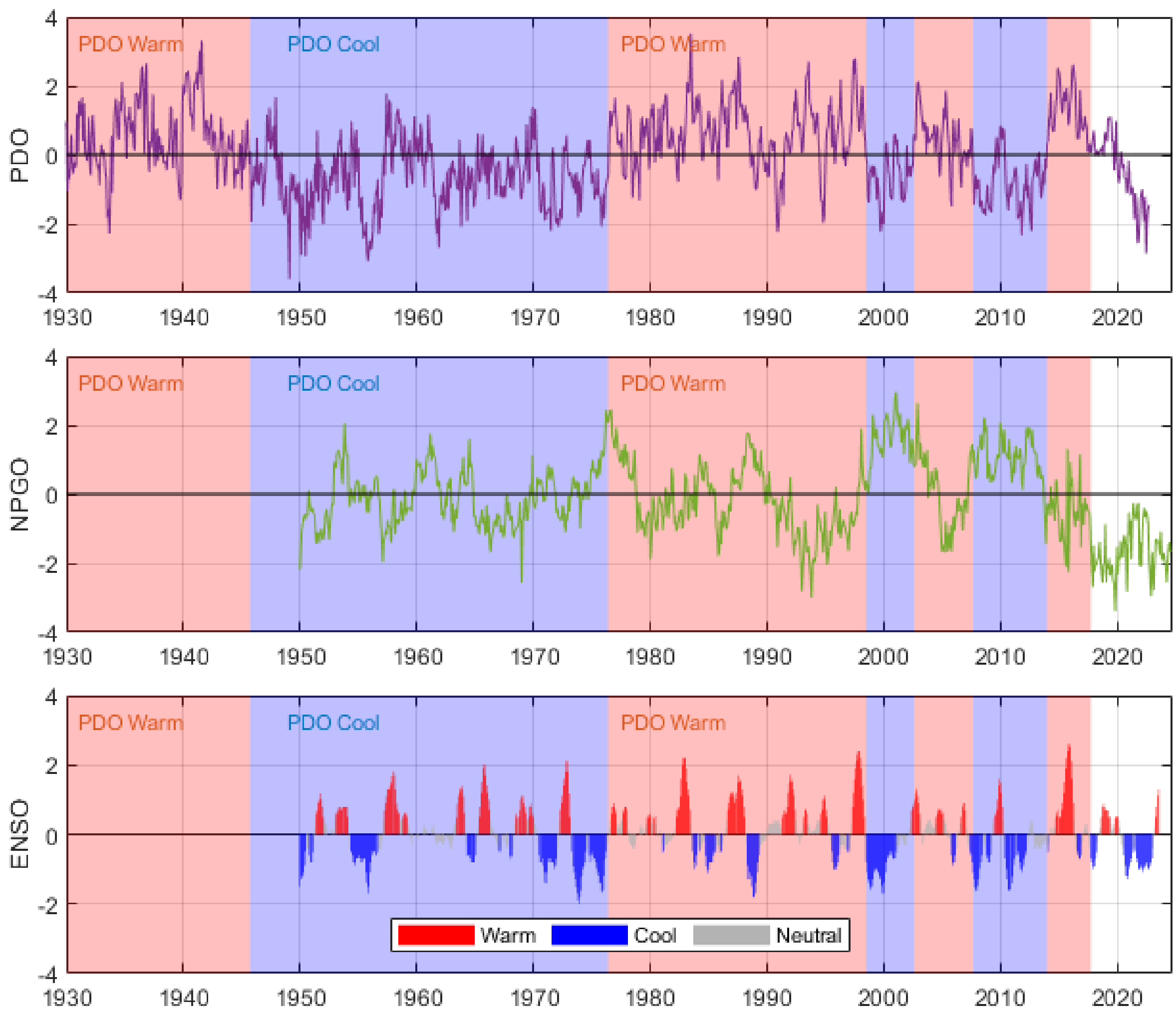



**Figure 9. Climate cycle indices for the Pacific Decadal Oscillation, North Pacific Gyre Oscillation, and El Niño-Southern Oscillation. (red and blue shaded regions represent the identified warm and cool phased of the Pacific Decadal Oscillation, respectively).**

The PDO index is based on sea surface temperatures that correlated with decadal patterns of wetter and cooler winters in the Pacific Northwest between the mid-1940s and mid-1970s over a period that corresponded to increased salmon catches in the Columbia River and deceased catches along the Alaskan Coast (Mantua et al. 1997). The opposite pattern of drier and warmer winters with opposite salmon catches occurred from the mid-1970s through the late-1990s. Since the late 1990s, the decadal patterns of the PDO have broken down. For the Columbia River, predation of salmon species during the PDO warm phase has been identified as one contributing factors to the overall trend in declining salmon (Petersen and Kitchell 2001). The NPGO correlates to oceanic conditions along the western US coast and correlates with cooler ocean temperatures along with higher nutrient and algal concentrations associated with the upwelling positive phase (Di Lorenzo et al. 2008). The shorter duration ENSO cycle correlates with year-to-year variations in salmon populations with concerns to strong El Niño (warm phase) events that lead to seasonal droughts and high temperatures like that experienced in 2015 (Crozier et al. 2015).

## 2.2 COLD-WATER REFUGE TRIBUTARIES

The EPA Cold-Water Refuge report (EPA 2021a) identified 10 tributaries in Zone 6 that met the criteria of having an August mean water temperature of at least 2°C colder than the mainstem Columbia River and an August mean flow of greater than 10 cubic feet per second (Table 3). These tributary delta regions were identified as cold-water refuge habitat because of their size, accessibility to migrating fish, sufficient depth for cover, and are documented or presumed to be used by fish. Note, the Umatilla River was added to the cold-water refuge tributaries list as it has a late-August to late-September mean water temperature difference of 2°C and it is the only potential cold-water refuge tributary feeding the John Day Reservoir. All the tributaries listed in Table 3 except for Rock Creek and the Umatilla River were listed as primary cold-water refuge habitats based on the volume, water temperatures, field observations, and documented use by salmon, with Rock Creek and the Umatilla River being designated as secondary cold-water refuge habitats since they only offer intermittent refuge (EPA 2021a).

**Table 3. Identified cold-water refuge tributaries along Fishery Zone 6 of the Columbia River. (Source: EPA 2021a).**

| Tributary Name (State) | River Mile | August Mean Temperature Difference (°C) | Total Refuge Volume (cubic meters) | Refuge Length (miles) |
|---|---|---|---|---|
| Eagle Creek (Oregon) | 142.7 | -6.1 | 2,988 | 0.2 |
| Rock Creek (Washington) | 146.6 | -3.8 | 1,708 | unknown |
| Herman Creek (Oregon) | 147.5 | -9.2 | 169,698 | 0.3 |
| Wind River (Washington) | 151.1 | -6.7 | 105,220 | 0.8 |
| Little White Salmon River (Washington) | 158.7 | -7.9 | 1,108,661 | 1.3 |
| White Salmon River (Washington) | 164.9 | -5.5 | 153,529 | 1.3 |
| Hood River (Oregon) | 165.7 | -5.9 | 28,000 | 0.2 |
| Klickitat River (WA) | 176.8 | -5.0 | 222,029 | 1.8 |
| Deschutes River (OR) | 200.8 | -2.2 | 880,124 | 3.2 |
| Umatilla River (OR) | 284.7 | -0.1 | 10,473 | 1 |

Eagle Creek (river mile 143) is the closest tributary to the Bonneville pool, located less than half a mile upstream of the dam on the Oregon side. The watershed area is 35 square miles with a maximum elevation of 4,890 feet and is approximately 50 percent evergreen forest, 20 percent shrub/scrub, 29 percent, and 1 percent mixed developed land cover (Dewitz 2023). The 2017 Eagle Creek Fire spread across the watershed and burned over 48,800 acres of the Columbia Gorge, consuming over 80 percent of the Eagle Creek watershed ground cover. This continues to impact vegetation, erosion, and water quality parameters in the system. A diversion dam is located at river mile 2 of Eagle Creek that is associated with the Cascade Hatchery that acts as an organism passage barrier according to the USFS (EPA 2021a).

Rock Creek (river mile 147) is a small and steep stream with a drainage area of 43 square miles with a maximum elevation of 4,220 feet. The tributary confluence is in the city of Stevenson, Washington where it enters Rock Cove, an embayment created by the State Road 14 and Burlington Northern Railroad embankments along the Columbia River. Water temperatures in Rock Creek are warmer than other cold-water refuge tributaries likely the result of mixing of the warm Columbia River water in Rock Cove.

Herman Creek (river mile 148) is 8 miles long, steep stream draining a 19 square mile watershed with a maximum elevation of 4,700 feet. The watershed is 81 percent evergreen forest, 10 percent herbaceous, and 7 percent shrub/scrub landcovers (Dewitz 2023). There are two diversion dams operated by the Oxbow Hatchery in the upper part of the watershed. Levees were constructed to for milling operations at the Columbia River confluence near the city of Cascade Locks, Oregon, that act to retain cold water in Herman Creek Cove, which is where a large portion of the cold-water refuge habitat exists (EPA 2021a).

Wind River (river mile 151) drains a 224 square mile watershed with a maximum elevation of 5,375 feet with 90 percent of that area owned by the U.S. Forest Service in the Gifford Pinchot National Forest. Land cover is comprised of 81 percent forested, 8 percent developed, 6 percent shrub/scrub, and 3 percent herbaceous cover types (Dewitz 2023). Wind River flows include inputs from springs located around river mile 13 near Upper Trout Creek, as well as cold-water flows from Panther Creek. Snowmelt runoff is a contributing factor to water spring water temperatures as the upper watershed averages 108 inches of snow per year (Cooper 2005). In 2009, the Hemlock Dam was removed on Trout Creek with the removal process designed to minimize sedimentation impacts (Claeson and Coffin 2016). The confluence with the Columbia River included a low-lying floodplain that was inundated by the construction of the Bonneville Pool that forms a large embayment on both sides of the State Road 14 and Burlington Northern Railroad bridges on the Washington side of the river. The embayment region is a deposition zone where a large amount of sediment has accumulated creating shallow water depths (EPA 2021a).

Little White Salmon River (river mile 159) is 19 miles long draining an area covering 133 square miles with a maximum elevation of 5,870 feet. Approximately 80 percent of the watershed is in the Gifford Pinchot National Forest. The lower 22 square miles of the watershed consists of 72 percent forested, 14 percent shrub/scrub, 5 percent herbaceous, and 5 percent developed land covers (Dewitz 2023). The upper portion of the river is fed by snowmelt and groundwater contributing to the cold-water conditions, but historical timber harvesting and increased sediment yields to the drainage (EPA 2021a). The Little White Salmon River cold-water refuge is the largest in Zone 6 due to Drano Lake, an inundated portion of the river, separated from the Columbia River mainstem by a man-made embankment for State Road 14 and Burlington Northern Railroad that acts to trap the cold-water from the Little White Salmon River (EPA 2021a).

White Salmon River (river mile 165) is 44.6 miles long with a drainage area covering 392 square miles with a maximum elevation of 12,276 feet as the headwaters drain glaciers off Mount Adams. The basin land cover includes 59 percent forested, 18 percent shrub/scrub, 11 percent developed, 7 percent herbaceous, and 5 percent pasture/cultivated crops (Dewitz 2023). Most of the lower 27 square miles of the watershed are in the Gifford Pinchot National Forest. Groundwater recharge provides at least 200 cubic feet per second to the channel throughout the year (EPA 2021a). The removal of Condit Dam at river mile 3 in 2012 released roughly 2.4 million cubic yards of sediment to the confluence, reducing average depth and likely increasing water temperatures (Wilcox et al. 2014)

Hood River (river mile 166) drains Mount Hood with the East, Middle, and West Forks that merge near river mile 11. The drainage area covers 339 square miles with a maximum elevation of 11,200 feet and consisting of 48 percent pasture/cultivated crops, 19 percent developed, 18 percent forested, 9 percent shrub/scrub, and 3 percent herbaceous land covers (Dewitz 2023). The 2006 atmospheric river event that affected the region resulted in landslides along the Eliot Glacier on Mount Hood resulting in lahar flows and a large deposition of sediments in the Hood River delta (Poole 2016). There were two dams in the watershed that were decommissioned and removed. Powerdale Dam on Hood River (river mile 4.5) was removed in 2010 and a small hydroelectric dam on Odell was removed in 2016. There is currently one dam on Clear Branch, a tributary to the Middle Fork Hood River. The confluence with the Columbia River is affected by the channelization of the lower Hood River and sedimentation that has occurred out into the main channel, which limits the cold-water refuge habitat to the mouth of the Hood River (EPA 2021a).

Klickitat River (river mile 177) flows approximately 96 miles fed by drainages off Mount Adams and Gilbert Peak with a drainage area spanning 1,352 square miles with a maximum elevation of 12,274 feet. The Klickitat River diverges from the trends of other tributaries because it is in the semi-arid region of the Columbia Plateau east of the Cascade Range. The watershed encompassing the lower 48 river miles consists of 43 percent shrub/scrub, 26 percent forested, 21 percent herbaceous, and 5 percent cultivated crop land covers (Dewitz 2023). Lyle Falls is a series of five cascades at river mile 2.2 upstream of the cold-water refuge habitat at the confluence near Lyle, Washington (EPA 2021a).

Deschutes River (river mile 201) is 252 miles long with a drainage area spanning 10,700 square miles with a maximum elevation of 11,200 feet. Much of the watershed is in the high desert regions on the Oregon side of the Columbia Plateau. The lower 42 square miles of the watershed consists of 49 percent cultivated crops, 43 percent herbaceous, 3 percent developed, and 3 percent shrub/scrub land covers (Dewitz 2023). The Deschutes River and its corresponding tributaries annually receive 100 inches of precipitation from the Cascade Mountains (primarily snow), 40 inches from the Ochoco Mountains, and 10 inches from lower central areas. The Pelton Round Butte Hydroelectric Project consists of a series of three dams approximately 100 river miles upstream of the Columbia River. In 2010, a selective withdrawal system was constructed to facilitate downstream juvenile fish passage and downstream water temperature control (EPA 2021a). The cold-water refuge habitat extends upstream three river miles from the confluence with the Columbia River, which makes it the second largest cold-water refuge habitats in Zone 6.

Umatilla River (river mile 285) is 89 miles long with a drainage area covering 2,320 square miles with a maximum elevation of 5,840 feet. The river drains the Blue Mountains and an agricultural valley. The lower 60 square miles of the watershed consists of 38 percent cultivated crops, 25 percent shrub/scrub, 23 percent developed, and 10 percent herbaceous land covers (Dewitz 2023). There is one dam in the watershed on McKay Creek used for irrigation purposes and another dam outside of the watershed that releases water that affects water temperatures in the Umatilla River. The U.S. Bureau of Reclamation operates the Umatilla Project that provides water to four irrigation districts with part of the project suppling Columbia River water in lieu of withdrawals from the Umatilla River to maintain flows for fish purposes (BOR 2012). Water rights in the Umatilla Basin are overallocated that has led to decreased flows in the Umatilla River and declining groundwater levels, that affect the summertime cold-water refuge habitat. In general, water temperatures in the Umatilla River are warmer than the Columbia River in June through early August, but cooler than the Columbia River for the mid-August through September period (EPA 2021a).

## 2.3 FISH MIGRATION AND USAGE OF COLD-WATER REFUGIA

There are several resident fish and stocks of Endangered Species Act (ESA) listed salmon that use the cold-water refuge tributaries in the Zone 6 fishery between Bonneville Dam and McNary Dam (Table 4). Juvenile salmonids must pass these cold-water tributaries on their way to the ocean, and adults pass them to return to spawning grounds and hatcheries. Adult Summer Steelhead and Fall Chinook are most likely to encounter temperatures warm enough to cause them to use the tributary cold-water refuge habitats. Their migration numbers peak in August and September when river temperatures are highest. Telemetry studies found that summer Steelhead began holding in cold-water refuges when Columbia River temperatures reach 19°C, and about 60 to 80 percent of the fish used cold-water refuge habitats when temperatures reach 20°C and higher. Fall Chinook begin using the cold-water refuge tributaries with Columbia River temperatures reach 20°C, and by 21°C or higher that 40 percent of them will rest in the cold-water refuge tributaries (Keefer et al. 2018).

Resident fish are important for river ecosystem function as they provide a food source when salmon are not present. However, they may require cooler water for spawning and egg incubation and cannot escape the warm water like migratory fish do. Table 4 provides a list of resident fish (native and non-native) at Bonneville Dam Smolt Monitoring Facility. In addition, there are more than 20 fish commonly collected at this facility that include (in order of prevalence): sucker species, Mountain Whitefish, Banded Killifish, Large Mouth Bass, Channel Catfish, Crappie species, Sand Roller, Cutthroat Trout (could be migrating to ocean), Redside Shiner, White Sturgeon, Largescale Sucker, and Walleye (FPC 2024). Warmer water also supports several non-native fish including several that feed on out migrating juvenile salmon such as Small Mouth and Large Mouth Bass, Bluegill and Pumpkinseed, Yellow Perch, and Walleye.

Adult migrating salmon become stressed at water temperatures above 18 to 20°C, and juveniles above 15 to 16°C (Marcoe et al. 2018). Water temperatures in the lower Columbia River exceed 20°C between July and September, with August temperatures of 22°C and higher. Since migration timing is linked to water temperatures and river flows, questions have arisen about how warmer summers will impact migration timing (Keefer et al. 2008). Studies hypothesize that spring and summer runs (e.g. Sockeye, summer Chinook) will begin migration earlier, and fall runs (e.g. Fall Chinook) will start later to avoid stressful conditions (EPA 2021a). Table 5 shows the migration timing for individual fish stocks passing the Bonneville Pool that migrate during the spring, summer, and fall periods.

**Table 4. Fish collection counts at the Bonneville Dam smolt monitoring facility from 2010 to 2024.(Source: Fish Passage Center, FPC 2024)**

| Common Name | Percent of Total Catch | 15-year mean | Native (Y/N) |
|---|---|---|---|
| American Shad (juveniles) | n/a | 1.8 million | N |
| American Shad (adults) | n/a | 1010.0 | N |
| Stickleback (3 spine) | 37 | 1510.8 | Y |
| Peamouth | 32 | 1313.7 | Y |
| Sculpin species | 8 | 308.8 | Y |
| Northern Pikeminnow | 5 | 210.3 | Y |
| Siberian Prawn | 5 | 205.2 | N |
| Small Mouth Bass | 5 | 197.6 | N |
| Bluegill and Pumpkinseed | 4 | 167.6 | N |
| Yellow Perch | 1 | 42.0 | N |
| Carp | 1 | 27.3 | N |
| Bullhead | 1 | 22.0 | N |
| Rainbow Trout | 1 | 21.6 | Y |
| Other species (n=20) | 2 | 62.7 | Y & N |
| Notes: Juvenile American are numerically dominate with more than 1.8 million collected each year (mean). They are excluded from the percent calculation so the rank of other fish can be represented. There are 4,089 (mean) other fish and Siberian Prawns collected each year. | | | |

**Table 5. Run timing for adult ESA-listed fish and Pacific Lamprey in the Bonneville pool.**

| **Species of Note Evolutionarily Significant Unit (ESU/DPS) Status*** | **Typical Presence - Adults** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Adult Migration/Presence** | | | | | | | | | | | |
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC |
| Chinook Salmon (*Oncorhynchus tshawytscha*) | | | | | | | | | | | | |
| Snake River spring/summer run (T) | | | | | | | | | | | | |
| Snake River fall run (T) | | | | | | | | | | | | |
| Lower Columbia River (T) | | | | | | | | | | | | |
| Upper Columbia River spring run (E) | | | | | | | | | | | | |
| Coho Salmon (*Oncorhynchus kisutch*) | | | | | | | | | | | | |
| Lower Columbia River ESU (T) | | | | | | | | | | | | |
| Chum Salmon (*Oncorhynchus keta*) | | | | | | | | | | | | |
| Columbia River (T) | | | | | | | | | | | | |
| Sockeye Salmon (*Oncorhynchus nerka*) | | | | | | | | | | | | |
| Snake River (E) | | | | | | | | | | | | |
| Steelhead (*Oncorhynchus mykiss*) | | | | | | | | | | | | |
| Snake River Basin DPS (T) | | | | | | | | | | | | |
| Lower Columbia River DPS (T) | | | | | | | | | | | | |
| Middle Columbia River DPS (T) | | | | | | | | | | | | |
| Upper Columbia River DPS (T) | | | | | | | | | | | | |
| Pacific Eulachon (*Thaleichthys pacificus*) | | | | | | | | | | | | |
| Southern DPS (T) | | | | | | | | | | | | |
| Pacific Lamprey (*Lampetra tridentata*) | | | | | | | | | | | | |

*(T) - Threatened or (E) - Endangered under the Endangered Species Act. Pacific Lamprey are not listed.
Notes: *Dark grey represents middle 80 percent median run timing, light grey represents first and last PIT tags past Bonneville Dam when available.*
Sources include: CRB DART 2019, Myers et al. 2003, Gustafson et al. 2016, USFWS 2024.

Besides modifying their migration timing, which varies greatly between species, anadromous fish also use cold-water refuges to reduce thermal stress. Spring run fish, such as sockeye, summer Chinook, and some earlier steelheads, are less likely to use cold-water refuge habitats because they pass the lower Columbia River prior to warm temperatures in the main channel (EPA 2021a). During the 2015 heatwave, there was almost a complete die-off of adult sockeye (Harrison 2015). Higher than normal mainstem temperatures trapped the sockeye migrating in cold-water refuge tributaries. The use of cold-water refuge tributaries by summer Steelhead and fall Chinook, which frequently encounter warm river temperatures due to their August to September migration timing, has been studied by several USACE funded researchers from the University of Idaho and these are summarized in the recent EPA Columbia River Cold-Water Refuges Plan (EPA 2021a).

Fall Chinook salmon migrate slower as water temperatures increase and only briefly use cold-water refuges when the river is greater than 20 to 21°C. It is uncertain if summer Chinook will behave similarly if water temperatures during their run increase (Keefer et al. 2018). Summer steelhead occupy cold-water refuges above 19 to 20°C and use them much more readily. Overall, 40 percent of fall Chinook and between 60 and 80 percent of summer steelhead use cold-water refuges when water temperatures are above their respective thresholds (EPA 2021a). Chinook also spend less time in cold-water refuges, from 12 to 34 hours, as opposed to the 3 to 25 days for steelhead (Keefer et al. 2009). This means steelhead tend to have longer total migration times due to bioregulatory behavior.

Modeling by Snyder et al. (2020) evaluated if current cold-water refuges were sufficient to mitigate for a warming Columbia River under scenarios of less and more abundant cold-water refuge habitats, as well as a cooler main stem Columbia River. Results indicated that cold-water refuges were more important to summer Steelhead than fall Chinook. While summer Steelhead were able to reduce thermal exposure, modeled results for fall Chinook showed little difference between current conditions and loss of cold-water refuges. In addition, the modeled results suggested a higher sensitivity to the loss of cold-water refuge habitat and minimal sensitivity to the addition of cold-water refuge habitat. The model results also showed that the accumulation of degree days (i.e., a measure of cumulative thermal stress) was lower in both groups when the migration corridor was cooler.

Some juvenile salmonids migrating to the ocean may pass through the Zone 6 deltas. Some deltas are broad and shallow potentially exposing them to predation by birds or other fish. Two recent acoustic telemetry studies of juvenile survival through the Klickitat River delta and the Hood River delta highlight this issue and show each delta has unique characteristics. Evans et al. (2021) noted that natural origin Steelhead and hatchery Coho slowed down as they moved through the Klickitat River delta and reach survival was lowest in this reach. Cumulative survival, from release to hydrophones downstream of the delta were higher for juvenile Steelhead (78 percent in both years) when compared to juvenile Coho (57 and 61 percent in 2018 and 2019). Survival of tagged Coho were particularly low when compared to similar studies and the author's disused piscivorous fish as their main concern. The in-progress study of hatchery Spring Chinook in the Hood River found that from release to hydrophones just upstream of the delta 94 percent of tagged fish were detected and downstream of delta 86 percent of fish were detected indicating a drop in survival through that reach as well (Cramer Fish Sciences in preparation).

More work is needed to determine the mechanism causing a decrease in survival as juvenile fish migrate through these cold-water refuge deltas in the Zone 6 fishery and to determine if juvenile fish leaving the Wind and White Salmon Rivers see a similar drop in survival. After hatchery releases of Coho into the Klickitat River, California gull predation is easily observable in the shallow waters of that delta (Nathan McClain, USACE, personal observation). The influence of delta size and depth has on predation from, birds or other fish, is unknown. Given the low Coho survival reported in Evans et al. (2021), studies providing a finer resolution of predation are warranted.

The work of Harris and Jolley (2017) established that cold-water refuge tributary deltas of the Zone 6 fishery are also important rearing areas for filter feeding juvenile lamprey. They sampled at a range of depths from 0.2 to 23.8 meters, finding larvae from 0.3 to 8.5 meters. Both juvenile Pacific lamprey and other *Lampetra* species (such as Wester River and Brook lamprey) have been found rearing in the deltas of the Wind, White Salmon, and Klickitat Rivers. In particular, the Wind River delta appears to be important for rearing *Lampetra* species as density and abundance was highest there. Also, the Klickitat River delta was home to the highest density and abundance of Pacific Lamprey (Table 6). However, water temperatures above 22°C can cause abnormalities at the larval stage decreasing survival (Meeuwig et al. 2005). Survival of rearing lamprey in these deltas is unknown, thus their contribution to the lamprey population also remains unknown. However, given the high densities rearing there, is it important to use best management practices if dredging or other manipulations of these deltas take place. For example, ensuring the sediment is returned to that water rapidly to prevent these fish from dying.

Of the several resident fish and stocks of ESA-listed salmon that use cold-water refuges in the Zone 6 fishery, the research cited above shows they are likely most important for summer Steelhead and to a lesser degree fall Chinook salmon. The cold-water refuge delta areas could present a challenge for adult fish to access (if too shallow) and could be potential hot spots of predation of salmon by fisherman, birds, and other fish as well. Manipulations to increase the depth of the delta or the size of the CWRs needs to incorporate best management practices to protect juvenile lamprey shown to rear there.

**Table 6. Density and abundance of rearing lamprey larvae collected from the deltas of the Wind, White Salmon, and Klickitat Rivers. (Source: Harris and Jolley 2017).**

| Species | Tributary | Larvae collected (count) | Larvae Density (count/square meter) | Abundance |
|---|---|---|---|---|
| Pacific lamprey | Wind | 40 | 0.79<br>(0.67–0.96) | 252,100<br>(211,600–306,200) |
| Pacific lamprey | White Salmon | 3* | 0.18<br>(0.11–0.35) | 66,650<br>(39,990–133,300) |
| Pacific lamprey | Klickitat | 89 | 1.72<br>(1.51–2.02) | 556,600<br>(488,700–651,600) |
| Lampetra spp. | Wind | 89 | 1.72<br>(1.50–2.00) | 544,800<br>(477,300–634,900) |
| Lampetra spp. | White Salmon | 5 | 0.28<br>(0.18–0.46) | 106,600<br>(66,650–173,300) |
| Lampetra spp. | Klickitat | 13 | 0.29<br>(0.21–0.41) | 95,030<br>(67,880–131,200) |

Notes: Due to their small size and similar look, some larvae of the genus Lampetra could not be identified to species. Density and abundance values in parentheses represent the 95 percent confidence interval.
*Survey was prior to the removal of Condit Dam so there would have been less delta sediment and likely greater water depth.

## 2.4 SEDIMENTATION IMPACTS & RESTORATION ACTIVITIES

The dams in the Zone 6 region reduce peak flows in the Columbia River, as well as elevate water surface elevations in the reservoirs, which has reduced the sediment transport capacity with only finer sands, silts, and clays capable of being transported downstream. Sediment load from the tributaries is driven by episodic hydrologic events such as storms, glacial dam breaches, and snowmelt, as well as anthropogenic events such as dam removals. The sediment yield potential in tributary watersheds is related to land cover and uses, development (i.e., roads and impervious areas), logging, and channelization of stream networks leading to increased sediment yields. These factors result in the tributary deltas often being comprised of an alternating stratigraphy of course and fine sediment layers repressing the episodic tributary inputs layered by the fine sediment settling throughout the reservoir (USACE et al. 2020). The EPA Cold-Water Refuge report (EPA 2021a) identified several tributaries where sedimentation at the delta is causing shallower depths and degraded habitat conditions that include Herman Creek, Wind River, White Salmon River, and Klickitat River within the Zone 6 region.

The tributary confluences for many of the cold-water refuge tributaries include a levee or embankment structure that effectively work to contain the cold-water from the tributaries, but also result in creating low velocity regions that enhance sedimentation. At Herman Creek, the levees that create Herman Creek Cove were installed in the mid-1900s to create a harbor for milling operations, whereas the embankments affecting the Wind, White Salmon, and Klickitat Rivers were initially developed for the railroad and were present prior to the Bonneville Dam construction. Herman Creek has a small, step, and largely forested watershed with minimal disturbances. The sedimentation in Herman Creek Cove is attributed to the development and agriculture located near the delta, as well as deposition of fine sediments from the Columbia River. The Wind River watershed has been impacted by historical logging practices such as clear cutting that have led to increased sedimentation (EPA 2021a). The embankment of the Burlington Northern Railroad and State Road 14 generates bays on both sides of the embankment where low-lying floodplain regions were inundated by the Bonneville Reservoir. For the White Salmon and Klickitat Rivers, the delta regions were predominately located on the Columbia River side of the railroad and highway embankment prior to the Bonneville Dam, which were inundated once the reservoir filled. Current sedimentation of the delta regions on the Columbia River side of the embankment is more evident on the Klickitat River.

Dam removals have occurred over the past couple decades in Zone 6 that include the Powerdale (2010) and Odell (2016) Dams in the Hood River watershed, Hemlock Dam (2009) in the Wind River watershed, and the Condit Dam on the White Salmon River (2012). The techniques used in the removal of the Hemlock and Condit Dams represent contrasting methods for managing the release of stored sediments. The Hemlock Dam was located on Trout Creek approximately 10 river miles upstream of the Columbia River confluence. Concerns of sedimentation impacts to downstream fish habitat were mitigated by excavating most of the impounded sediments prior to removal. The process started with a flow diversion to lower the pool, excavation of 55,000 cubic yards of fine sediment by truck, followed by the restoration of a natural channel through the reservoir that included the addition of 2,600 cubic yards of cobble and gravel sediments and large woody debris in the restored floodplain. Post-removal, water quality impacts to water temperature and turbidity were minimal with macroinvertebrate communities recovering over a period of two years (Claeson and Coffin 2016). Condit Dam was located on the White Salmon River three river miles upstream of the Columbia River confluence. The removal strategy for Condit Dam was a rapid removal by explosion to sluice the stored sediments out to the Columbia River, which resulted in and estimated 1.3 million cubic yards of sediment passing the U.S. Geological Survey (USGS) gage at Underwood (USGS 141235600), as well as bed aggregation followed by channel incision near the delta region (Wilcox et al. 2014). The sedimentation in the White Salmon River delta filled in portions of the Underwood In-lieu fishing site that limited fishing access for Columbia River Treaty Tribes (EPA 2021a).

The EPA Cold-Water Refuge Report (EPA 2021a) discusses ongoing management and restoration planning for each of the primary cold-water refuge tributaries in the lower Columbia River that vary based on existing watershed disturbances, local management plans, and land ownership. Common among the restoration activities presented were plans to protect and restore riparian vegetation to provide shade, land management activities that reduce sediment yield (e.g., logging practices, road removals, and restoring floodplain connectivity), and a reduction of water withdrawals especially in summer. In addition, the report recommended conducting feasibility studies of sediment removal from the delta regions of Herman Creek, Wind River, White Salmon River, and Klickitat River to provide greater volume to the cold-water refuge habitat and to improve fish access.

# SECTION 3 - GEOMORPHIC ASSESSMENT

This section contains a synthesis of historical aerial imagery, recent satellite imagery, river flow data, limited sediment load data, and information on past floods and reservoir operations of the Bonneville pool to assess the geomorphic changes that have occurred along the Wind, White Salmon, and Klickitat River deltas. The primary concern is sedimentation of the cold-water refuge habitats that coincide with the delta regions. The information on sediment loads in the Columbia River and the individual tributaries is insufficient to quantify a sediment budget. In addition, there is limited bathymetric data of these regions that could be used to quantify volumetric changes to the cold-water refuge habitats. USACE does periodic hydro-surveys and annual to semi-annual dredging of the federal navigation channel of the lower Columbia River mostly downstream of Bonneville Dam. The last hydro-survey of the Bonneville pool was in 2020 and limited to the federal navigation channel that does not include the study tributary delta regions. Section 4.1.6 discusses recent efforts conducted by National Oceanic and Atmospheric Administration (NOAA), CRITFC, and Oregon State University to obtain bathymetric data of the study area included the cold-water refuge deltas.

In absence of a quantitative sediment budget or changes in bathymetry of the delta regions, the geomorphic assessment is limited to qualitative interpretation of imagery and changes to visible features with respect to the data available on tributary flows and sediment transport, Bonneville pool elevations, and ancillary data on flood events and changes to the tributary watersheds.

## 3.1 HYDROLOGY AND SEDIMENT TRANSPORT

Flow data on the Wind, White Salmon, and Klickitat River have period of records that date back to pre-Bonneville Dam times with respect to daily mean flows and annual peak flows. The USGS gages are the Wind River near Carson, Washington (USGS 14128500), White Salmon River near Underwood, Washington (USGS 14123500), and Klickitat River near Pitt, Washington (USGS 14113000). The Wind River gage became inactive around 1980 and the White Salmon and Klickitat gages are currently active (Figure 10). Flood flows typically exceeded 10,000 cubic feet per second on the Wind and Klickitat Rivers, whereas annual peak flows on the White Salmon River only exceeded 10,000 cubic feet per second during the 1974 and 1996 flood events. Peak flood flows on the White Salmon River were regulated by Condit Dam until 2012 and there have not been any significant flood events since its removal (Figure 10).

Daily mean flows on the three rivers suggest that flows are largest on the Wind and Klickitat Rivers followed by the White Salmon River, which is driven by precipitation totals and drainage area. Precipitation decreases moving east through the Columbia Gorge caused by the rain shadowing effect of the Cascade Mountains. The drainage areas and river lengths of the three rivers varies from the 31-mile-long Wind River with a drainage area of 224 square miles, the 45-mile-long White Salmon River with a drainage area of 392 square miles, and the 95-mile-long Klickitat River with a drainage area of 1,352 square miles. The elevation profile for the three rivers depicts steep headwater regions with slopes between 0.04 and 0.06 with relative shallow confluence regions with slopes between 0.006 to 0.012 (Figure 11).

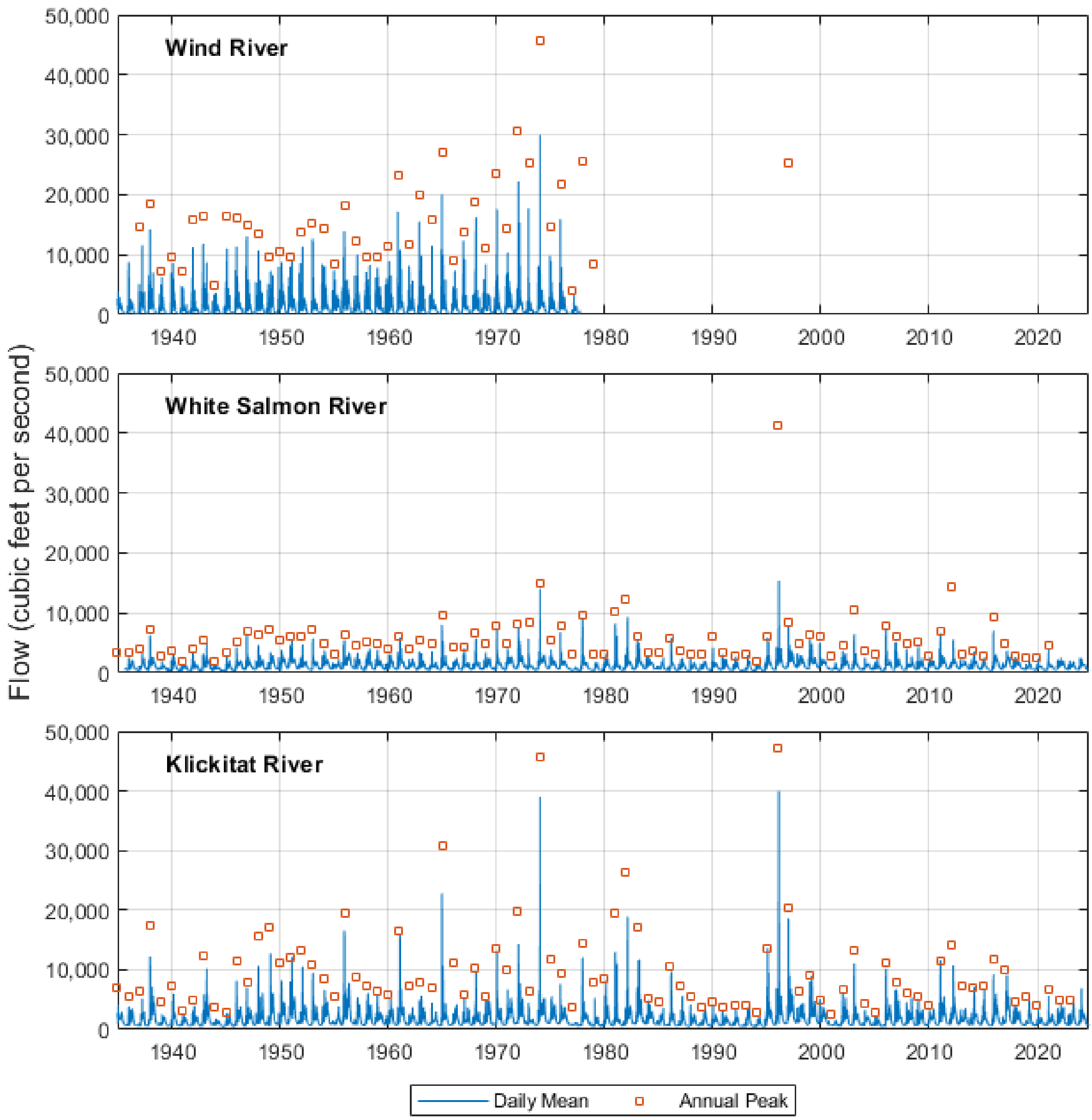



**Figure 10. Daily mean and annual peak flows in the Wind, White Salmon, and Klickitat Rivers.**

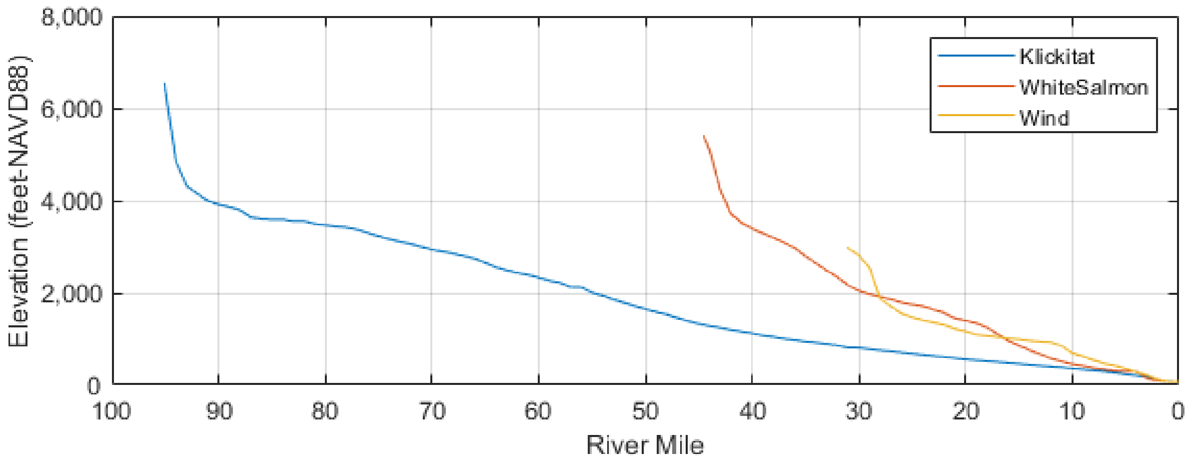



**Figure 11. Elevation profiles of the Wind, White Salmon, and Klickitat Rivers.**

River flows are typically greater during winter months with a shift towards high flows in the spring for the Klickitat River compared to the White Salmon and Wind Rivers. A threshold flood of 7,000 cubic feet per second was used for the Wind and Klickitat Rivers and a threshold flood of 5,000 cubic feet per second was used for the White Salmon River. Based on daily mean flows above the threshold flood for each river, the relative frequency of flood flows was estimated showing that the most floods occur in December on the Wind River, December and February for the White Salmon River, and in February for the Klickitat River (Figure 12).

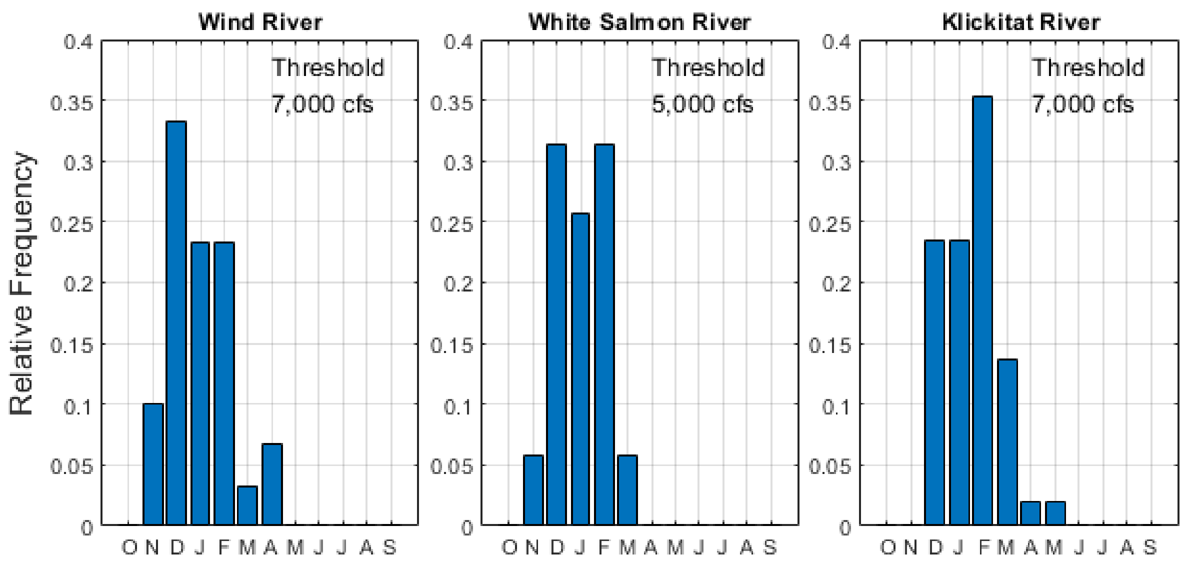



**Figure 12. Seasonal frequency of floods on the Wind, White Salmon, and Klickitat Rivers.**

Sediment transport data is sparse for all the tributaries that enter the Columbia River. Flow and suspended sediment concentration data can be used to calculate the sediment load (load equals the flow multiplied by the sediment concentration) with observed data available for the Klickitat River gage near Pitt, Washington (USGS 14113000) from 1975 to 1986, and on the John Day River at McDonald Ferry, Oregon (USGS 14048000) from 1962 to 1970 (Figure 13). Note, the suspended sediment load data is a field measurement, so the frequency of the sediment load is approximately monthly, but there is a tendency to sample during runoff events. The December 1964 flood on the John Day River had a maximum daily mean flow of 39,400 cubic feet per second with a daily peak sediment load of 3.8 million tons per day, an order of magnitude larger than the other daily peak sediment loads that range between 0.01 and 0.3 million tons per day at this site. Sediment load data was not available on the Klickitat River for the December 1964 event, but the peak flow reached 30,675 cubic feet per second, representing the third largest peak flow value over the period of record at the Klickitat gage. The measured daily peak sediment loads on the Klickitat River ranged between 0.004 to 0.02 million tons per day from 1974 to 1986. The largest single sediment load event on the Klickitat River was associated with the December 1977 event that had a peak flow of 14,496 cubic feet per second.

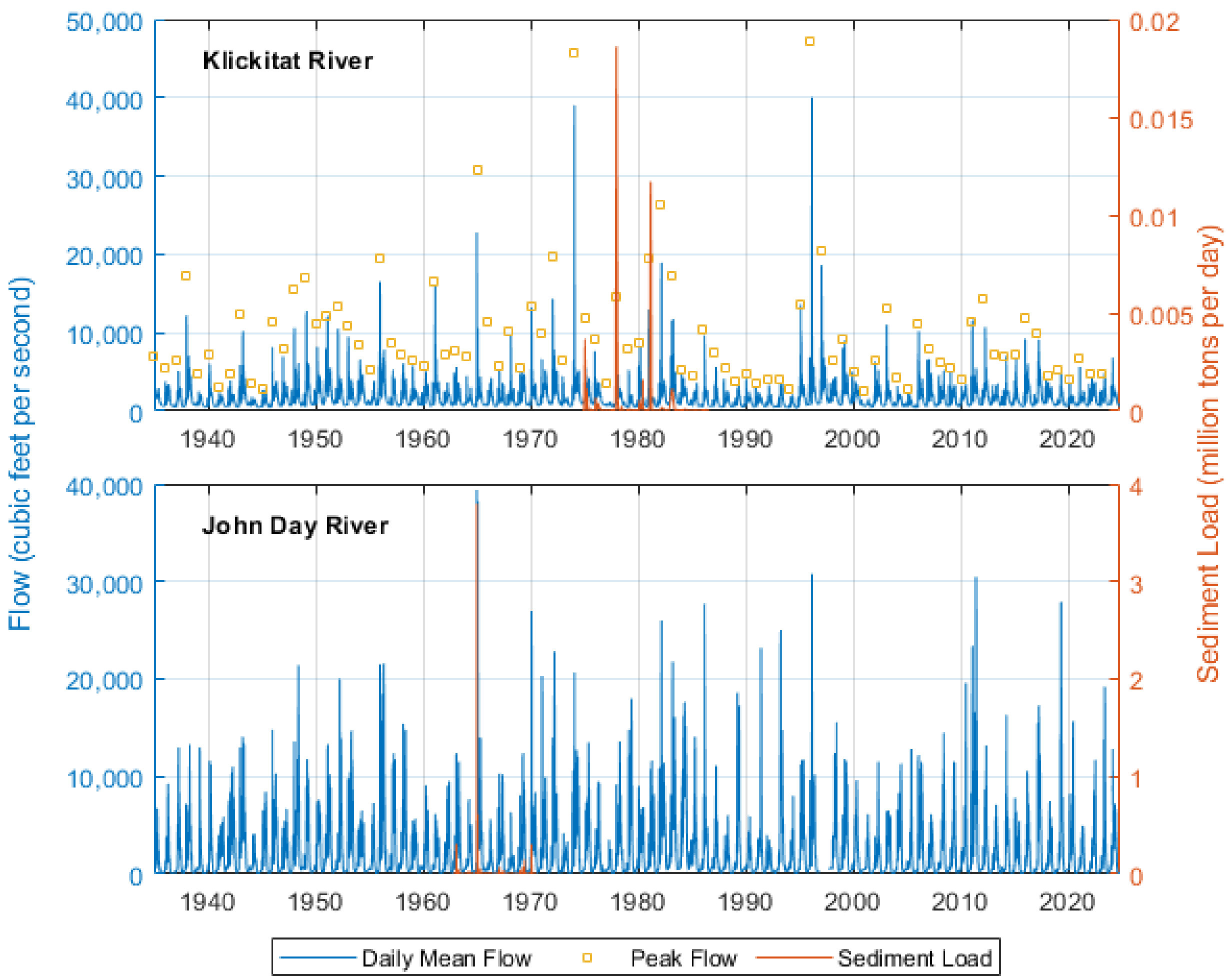



**Figure 13. Flow and sediment load data for the Klickitat and John Day Rivers.**

The limited period of record of suspended sediment load in the Klickitat River can be used to develop a rating curve between flow and sediment load to estimate past and current sediment loads (Figure 14). It should be noted that rating curves between flow and suspended sediment load have large uncertainties with respect to the hysteresis of sediment transport along the leading and trailing portions of a flood hydrograph, as well as being highly sensitive to the watershed conditions affecting sediment yield. The rating curve was developed using the available flow and suspended sediment load data available for water years 1975 to 1986. The log-transformed data was fitted using a linear equation according to

$$\log_{10} Q_s = 2.0858 \log_{10} Q - 3.5824 \quad (1)$$

where $Q_s$ is the measured suspended sediment load in tons per day and $Q$ is the daily mean flow in cubic feet per second. The regression had a coefficient of determination ($R^2$) value of 0.6543 with a root-mean-square-error (RMSE) of 0.3949. The 95 percent confidence intervals on the log-linear regression equation coefficients were 1.8039 to 2.3677 and -5.6874 to -3.9279, respectively. Equation 1 was used to estimate the suspended sediment load using the daily mean flow values and the annual sediment load (by water year) for comparison to the measured annual sediment loads for the 1975 to 1986 period. The estimation of the Klickitat sediment loads did not capture large sediment events resulting in an underestimation of the annual sediment load. For water years without a significant sediment load event, the estimated annual sediment load matched well with the measured values. The estimated annual sediment loads ranged between 0.006 and 0.2 million tons.

Suspended sediment load on the White Salmon River was measured during the months after the dam removal with the initial dynamited breach in the fall of 2011 and the full removal of structures in 2012. The peak sediment load reached 1.4 million tons per day and the total sediment load passing in the first month was 1.8 million tons, which is similar to the value of 1.7 million tons estimated by Wilcox et al. (2014).

Part of this study established flow, water temperature, and turbidity measurements at the Wind River (USGS 14128500), White Salmon River (14123500), and Klickitat River (USGS 14113000) gages (see Section 4.4 for further details). Turbidity and flow measurements at the gages can be used with field measurements of suspended sediment concentrations to develop a more robust regression for estimating sediment loads in future studies. In lieu of sediment load measurements, the limited historical sediment load data, estimates based on flows, historical flow records, and measurements during an abrupted sediment release during the Condit Dam removal allows for some general inferences to be made regarding sediment loads in the study rivers. Annual sediment load is driven by episodic events that is partially related to flood flow magnitudes. Large sediment transport events such as a dam breach-scale event (e.g., glacial dam breaches) can carry approximately 1 million tons of sediment to the tributary deltas, whereas the large hydrologic events often have sediment loads on the order of 0.1 million tons or less.

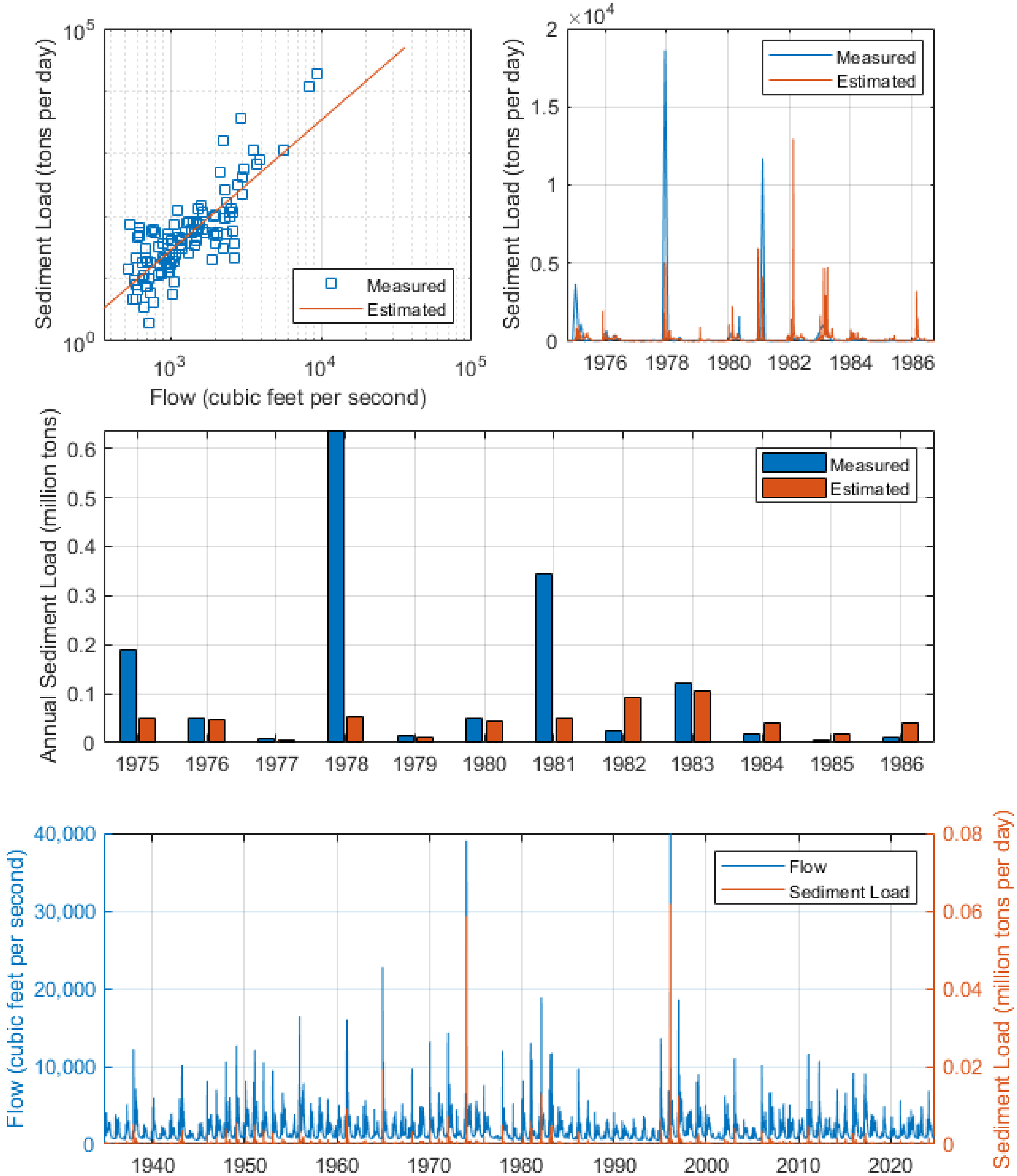



**Figure 14. Estimation of sediment load for the Klickitat River.**

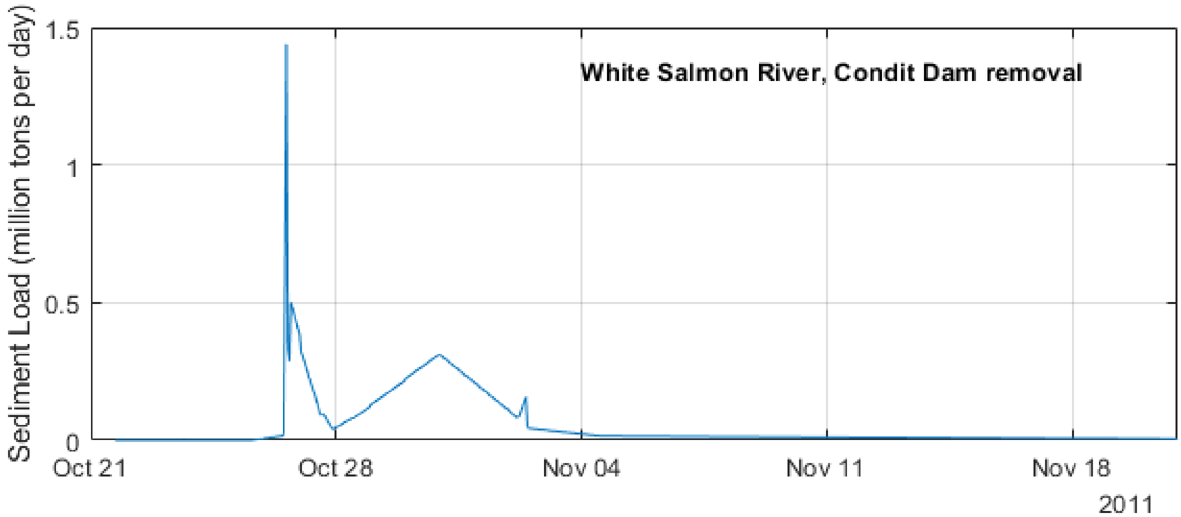



**Figure 15. Sediment load in the White Salmon River during the Condit Dam removal.**

Sediment loads from the study rivers were measured and estimated at USGS gage locations that vary from 1.5 river miles (Wind River), 2 river miles (White Salmon River), and 8 river miles (Klickitat River) upstream from the tributary delta area at the confluence with the Columbia River. Sediment load reaching the Columbia River meets the elevated water surface elevation of the Columbia River created by the Bonneville Dam, which raised water surface elevations on the order of 50 to 60 feet relative to pre-dam conditions. The deep and slow-moving Columbia River generates a deposition zone at the tributary deltas that can be affected by the stage fluctuations occurring due to reservoir operations at Bonneville. The Bonneville pool fluctuates at a sub-daily timescale based on reservoir operations but with a maximum overall change within 5 feet (Figure 16). During the summer months, as shown in Figure 16, there is year-to-year variability in the pool elevation with more daily to weekly changes occurring in June followed by more consistent elevations in July and August (see Section 2.1.2 for details regarding Bonneville reservoir operations).

The deposition of sediments along the tributary delta regions follows a typical delta front for reservoirs where the coarser gravel and sands deposit upstream with finer material depositing further downstream or carried out into the Columbia River either in the main flow or as a turbidity current. Because the water surface elevation is artificially high from the Bonneville pool, there is minimal flood plain deposition near the cold-water refuge regions. As an analogy, the USACE monitors sedimentation in the Toutle and Cowlitz Rivers as a part of the Mount Saint Helens monitoring program. The Toutle River receives elevated sediment load from the 1980 eruption of Mount Saint Helens, which deposited an estimated 3.8 billion cubic yards of material in the upper watershed. The Sediment Retention Structure (SRS) was built in 1989 and is actively managed and raised to limit downstream sedimentation. The sediment load that is transported past the SRS makes its way downstream in the steep Toutle River to the low gradient and regulated Cowlitz River where sedimentation issues affect flood hazards along several levee systems. The Mount Saint Helens monitoring program quantifies the annual sediment load from the Toutle River to the Cowlitz River, as well as the net deposition that occurs in the lower 20 river miles of the Cowlitz River. There is a lot of year-to-year variability in the sediment loads and deposition volumes, but in general the deposition in the Cowlitz River is less than 10 percent of the incoming Toutle River load, with the remainder assumed to be mostly transported to the Columbia River (USACE 2024).

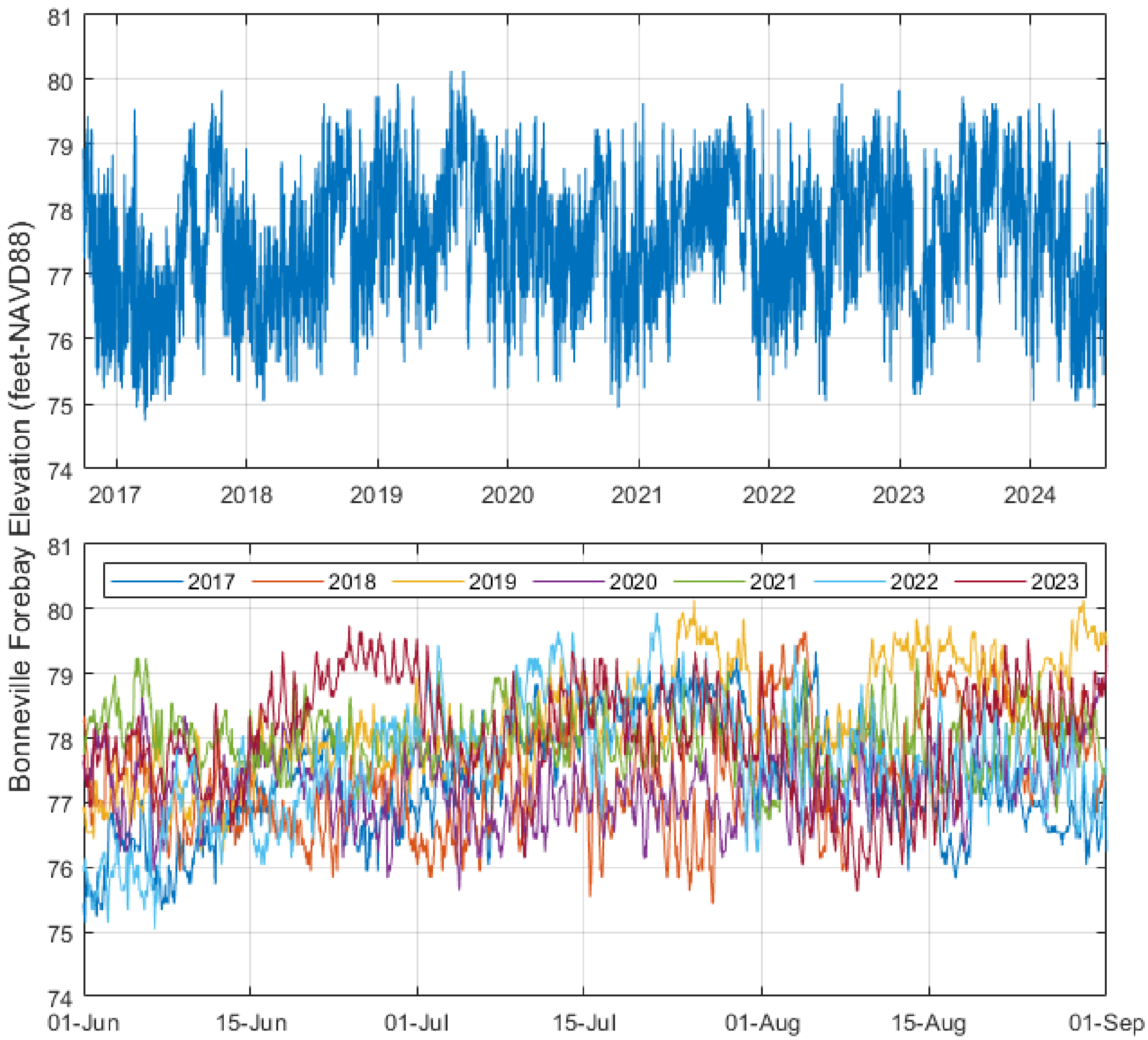



**Figure 16. Bonneville forebay water surface elevations.**

Based on this qualitative look at the existing hydrologic and sediment data, sedimentation impacts are likely limited to the tributary delta regions given that there is minimal deposition in the Columbia River itself and minimal dredging needed to maintain the federal navigation channel. The sediment loads in the tributaries feeding the Bonneville reservoir as not well quantified, but based on the limited data, they are low with respect to the sediment load transported by the Columbia River. Based on the landcover and connection between sediment load and episodic events, the sediment loads are likely largest for the tributaries east of the Columbia Gorge with annual sediment loads on the order of 0.01 to 0.1 million tons that are mostly delivered during large hydrologic runoff events with up to 1 million tons for events such as dam breaches (i.e., dam removal or large-scale glacial dam breaches). Of concern to the cold-water refuge habitats is the fine sands to coarse materials that can deposit higher upstream in the delta leading to reduced cold-water volumes, shallower depths with warming and predation, as well as the potential to cut off fish access to the refuge areas.

## 3.2 HISTORICAL AERIAL & RECENT SATELLITE IMAGERY

The tributary delta regions of the Wind, White Salmon, and Klickitat Rivers do not have any historical quantification of their sedimentation patterns except for the limited data on sediment loads collected for this study. Currently the best method to assess historical changes in the geomorphology of the tributary deltas is by examining changes from aerial and satellite imagery.

USACE has a collection of aerial mosaics at each tributary that were taken roughly twice a decade spanning the 1930s to the 1990s. Aerial images of the Wind, White Salmon, and Klickitat River deltas with good resolution and minimal cloud cover were collected. Since photos are taken at different times of year, more of the deltas are visible in certain images than others depending on Bonneville pool elevations. Unfortunately, most USACE aerial images do not note the month or day that the image was taken. The aerial images were scanned and geo-rectified to known, identifiable, features in the images (e.g., the alignments of the Burlington Northern Railroad and State Road 14). The geo-rectified aerial images typically aligned with most features but with images from certain years having some distortion when compared to other years.

More recent satellite imagery was acquired from the Copernicus Date Space Ecosystem (Copernicus 2024). The Sentinel-2 project consists of two polar-orbiting satellites placed in synchronous orbit phased at 180° from one another allowing for a frequent view of the Earth’s surface on the order of every five days. Imagery from the Sentinel-2 project was acquired for summer periods between 2016 and 2024. Cloud cover is an issue with using the satellite imagery, so the images selected have minimal cloud interference. The downloaded images from the Level-1C collection come in the World Geodetic System of 1984 (WGS84) projection with a resolution on the order of 12 meters. The downloaded images were clipped to a user-defined area of interest polygon that is limited to the cold-water refuge region of each of the study tributaries.

The geo-rectified aerial and satellite images are provided as ancillary data to this report as described in Appendix A. Table 7 lists the dates that aerial and satellite imagery were collected from. In addition, Table 7 lists available historical imagery in Google Earth, which was not used for this geomorphic assessment.

**Table 7. Summary of aerial and satellite imagery.**

| Delta | USACE Historic Aerial Imagery | Copernicus Sentinal-2 Satellite Imagery | Google Earth Historical Imagery |
|---|---|---|---|
| Wind River | 1930, 1935, 1969, 1971, 1978 (distortion), 1991 | 26-Aug-2017, 21-Aug-2018, 26-Aug-2019, 25-Aug-2020, 25-Aug-2021, 25-Aug-2022, 15-Aug-2023, 20-Jul-2024, 29-Aug-2024 | 1993, 2000, 2003, 2005, 2006, 2009, 2010, 2011, 2016-2018, 2021, 2022 |
| White Salmon River | 1935, 1948 (distortion), 1957, 1969 (distortion), 1975, 1991, 1992, 1995 | 26-Aug-2017, 21-Aug-2018, 26-Aug-2019, 25-Aug-2020, 25-Aug-2021, 25-Aug-2022, 25-Aug-2023, 25-Jul-2024, 24-Aug-2024 | 1993, 2000, 2003-2006, 2009-2011, 2016-2018, 2021 |
| Klickitat River | 1930, 1935, 1944, 1969, 1973 | 26-Aug-2017, 21-Aug-2018, 26-Aug-2019, 10-Sep-2019, 25-Aug-2020, 25-Aug-2021, 25-Aug-2022, 18-Nov-2022, 25-Aug-2023, 20-Jul-2024, 25-Jul-2024, 29-Aug-2024 | 1996, 2000, 2003, 2005, 2006, 2009-2011, 2014, 2016-2018, 2020, 2021 |

### 3.2.1 Wind River

The pre-dam Wind River delta formed an alluvial fan deposit with distributary channels connecting to the Columbia River (Figure 17, 1935 image). The main distributary channel turned to the west likely the result of the downstream flow of the Columbia River along with large bar features on the eastern side of the Wind River confluence deposited during flood flows on the Columbia River that were then dry as flood water receded. Upstream along the Wind River showed a meandering river channel with alternating bar features. The region downstream of the bridges were two low-lying floodplain regions that appear to have had some agricultural activity.

The riverbanks, bars, channels, and alluvial fan outline were digitized from the 1935, pre-dam, image and overlayed on the post-dam images from 1969, 1991, and 2021 in Figure 17. The Bonneville pool inundates most of the pre-dam delta region south of the road and railroad alignment, as well as low-lying floodplain regions on the northern side. The post-dam Wind River delta moved upstream with embayment areas created on both sides of the bridge.

The 1969 image shows the intensive logging activities in the watershed with log-bundles being stored in the delta area. The large s-turn in the upstream portion of the river visible in the images was turned into a small harbor and the eastern side of the delta region was turned from agricultural land into a milling facility. The alluvial fan and its distributary channels are completely inundated in the 1969 image, but there is a visible island bar in the downstream embayment in the 1991 and 2021 images, as well as a small point bar forming at the upstream end of the northern embayment at the location of a pre-dam channel bar.

The satellite imagery from the month of August in 2017, 2019, 2021, and 2023 of the Wind River delta region is shown in Figure 18. The satellite imagery among the years depicts no major changes to the delta region. The island bar in the south embayment has remained since the 1991 image with the color imagery showing a fan-shaped deposit with a more elevated bar feature on its upstream end. Relative differences in this feature among the satellite imagery is likely due to the stage fluctuations of the Bonneville pool that span a couple of feet (Figure 16). The point bar feature in the northern embayment appears to be experiencing vegetation growth when comparing the images from 2017 and 2023 suggesting the feature is becoming more stable with respect to sediment transport.

The island bar feature in the south embayment appears to have been formed sometime between 1969 and 1991 and grew between 1991 and 2021 based on the aerial imagery (Figure 17) with little changes since 2017 based on satellite imagery (Figure 18). The Wind River watershed has been most affected by historical logging and the Hemlock Dam removal in 2009. The Hemlock Dam breach was not a significant sediment release event as it was performed in stages with most of the stored sediments being manually removed (Claeson and Coffin 2016). The largest peak flow observed on the Wind River occurred in 1974, with the period of record ending in 1980, and the 1974 and 1996 floods are the largest floods observed in the White Salmon and Klickitat Rivers since the 1930s (Figure 10). The 1974 likely resulted in the initial deposit forming the island bar and was enlarged during the 1996 flood.

### 3.2.2 White Salmon River

The pre-dam White Salmon River delta formed a narrow delta fan at the Columbia River confluence with a large island bar feature on the north side of the bridge (Figure 19, 1935 image). The White Salmon River flows appear to head straight out into the Columbia guided by the exposed deposits on either side with a submerged depositional fan extending outward approximately 0.25 miles from the bridge. There is also a large, fan shaped region along the western side of the confluence along the Columbia River bank that looks like relic deposition that stabilized and vegetated. The Condit Dam was constructed in 1913 on river mile 3 of the White Salmon River, which reduced the sediment load being carried to the White Salmon River delta. This provides further evidence that the delta region was likely larger than what appears in the 1935 image and was connected to the vegetation bar feature seen to the west of the confluence. The White Salmon River channel upstream of the bridge appears to have alternating bars that are largely submerged in the 1935 image.

All fan deposits, including the vegetated region to the west of the confluence, are inundated by the Bonneville Dam. The floodplain region on the west bank of the White Salmon River upstream of the bridge is also inundated by the Bonneville pool (Figure 19). The 1957 image depicts logging activity in the watershed with log-bundles stored on the north side of the bridge and no visible bar features in the river channel. There are no bar features visible in the 1991 image, suggesting that the reduction in sediment supply caused by Condit Dam and the elevated water surface elevations of the Bonneville pool likely eroded the bar features in the delta region of the White Salmon River. The Condit dam removal in 2012 released over 1 million tons of sediment with a large deposition occurring along the western bank to the north of the bridge, which was partially dredged and revegetation as a part of a restoration project in 2018 (Yakama Nation Fisheries 2021).

The satellite imagery from 2017 to 2023 depicts the post-Condit Dam removal conditions with the 2017 image showing the pre-restoration conditions of the riverbank along the western side (Figure 20). The White Salmon River channel contains several point and island bars suggesting a reconnection to the sediment load transported by the river in the post-Condit Dam conditions. The submerged delta of the White Salmon River appears to extend outwards approximately 800 feet from the confluence with the fan deposit predominately on the western, downstream side, of the Columbia River confluence.

The historical dynamics of the White Salmon River have largely been the result of the Bonneville Dam construction and reservoir pool inundation and the Condit Dam removal. The sedimentation effects of the 1974 and 1996 floods were largely controlled by Condit Dam with subsequent release during the initial dam breach in 2011 (Figure 15). The riverine portion of the delta to the north of the bridge was largely devoid of sediments prior to the Condit Dam removal and has since established bar dynamics with island and point bars scattered throughout, suggesting that sediment supply is currently larger that its sediment load capacity.

### 3.2.3 Klickitat River

The pre-Dam Klickitat River delta formed a narrow alluvial fan in between vegetated floodplain areas located south of the railroad and road bridges, with the main flow headed to the west steered by a large bar in the middle of the delta and a fan deposit with several distributary channels that came together to form a secondary channel that flowed eastward (Figure 21, 1935 image). The western floodplain region of the delta on the south side of the railroad contained agricultural fields. The Klickitat River starting approximately 800 feet upstream of the railroad and road bridges had alternating bar formations in the canyon reach with the reach flowing under the bridges being a narrow canyon devoid of bar features.

The shoreline and bar features were digitized from the 1935, pre-dam, image and overlaid on the post-dam images from 1969, 1973, and 2020 in Figure 21. The 1969 image shows how the Bonneville pool inundated most of the delta region on the south side of the railroad bridge including all the agricultural fields and there was a loss of trees that lined the channel banks. Portions of pre-dam channel banks remain in the post-dam images with less vegetation and movement of bar features. The transition between the 1969, 1973, and 2020 images depict the eastern bank of the delta region filling with sediment and vegetation starting to establish in the 2020 image, whereas the western bank has slowly aggraded and expanded westward along the Columbia River flow.

The satellite imagery from 2017 to 2023 depicts a large amount of temporal variation in the river flow between the main channel and distributary channels along the alluvial fan deposits (Figure 22). The Bonneville pool fluctuations on the order of two feet likely result in the observed altered flow paths suggesting that summer water depths at the entrance to the cold-water refuge habitat are low and susceptible to the reservoir operations.

The Klickitat River delta receives the largest sediment load of the study rivers due to its large drainage area and more arid landscapes that are susceptible to erosion during runoff events. The Klickitat River delta size did not change its location significantly since the construction of Bonneville Dam. The channel bank features changed from vegetated and agricultural landscapes to more sediment bar features that have slowly grown since the 1969 image (Figure 21). The largest flood events were in 1974 and 1996, which likely accounts for the sedimentation that has taken place along the western bank of the Klickitat River delta.


**Figure 17. Historical aerial imagery of the Wind River delta. (1935 represents pre-dam with features digitized in post-dam images from 1969, 1991, and 2021)**


**Figure 18. Recent satellite imagery of the Wind River delta.**

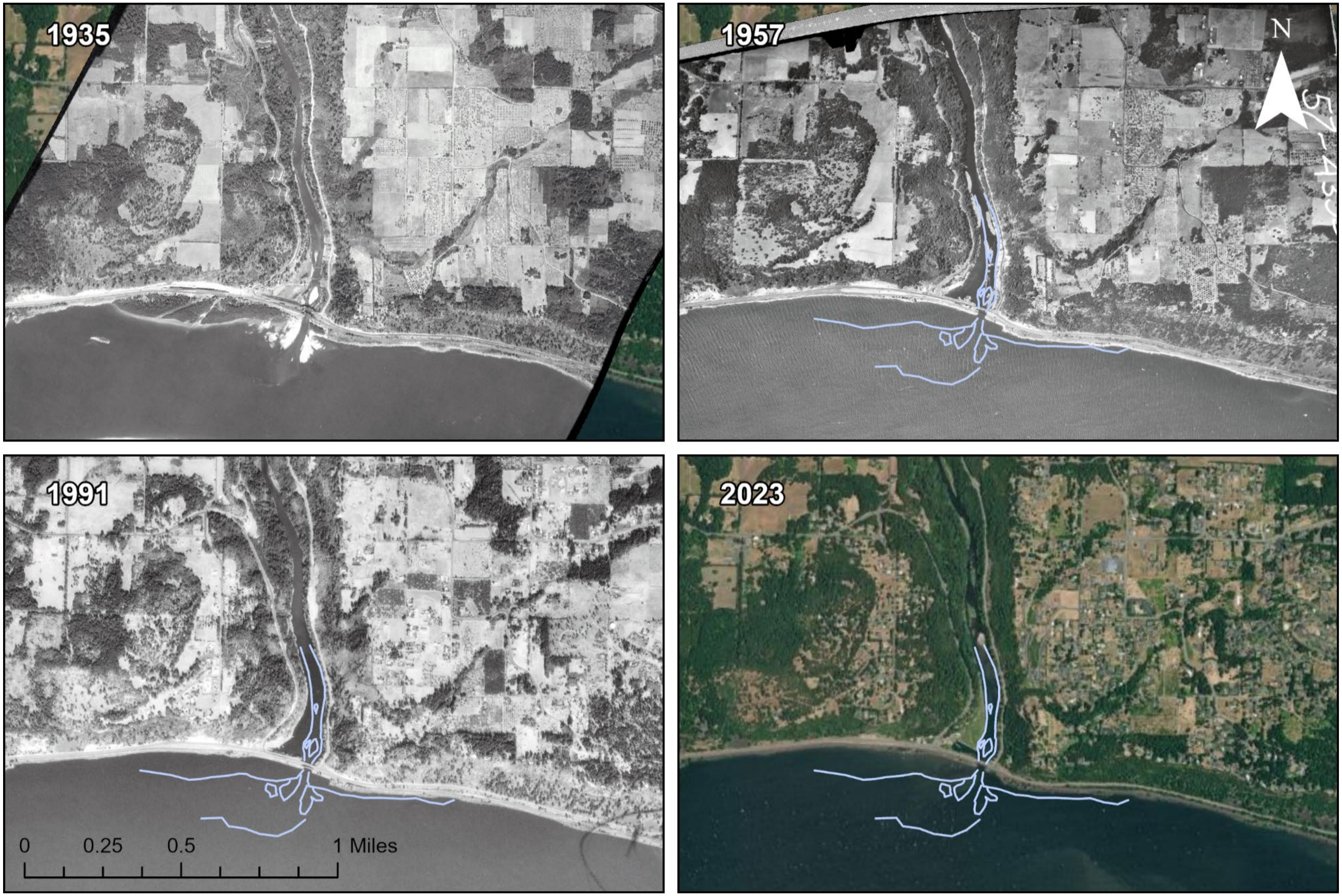



**Figure 19. Historical aerial imagery of the White Salmon River delta. (1935 represents pre-dam with features digitized in post-dam images from 1957, 1991, and 2023)**


**Figure 20. Recent satellite imagery of the White Salmon River delta.**

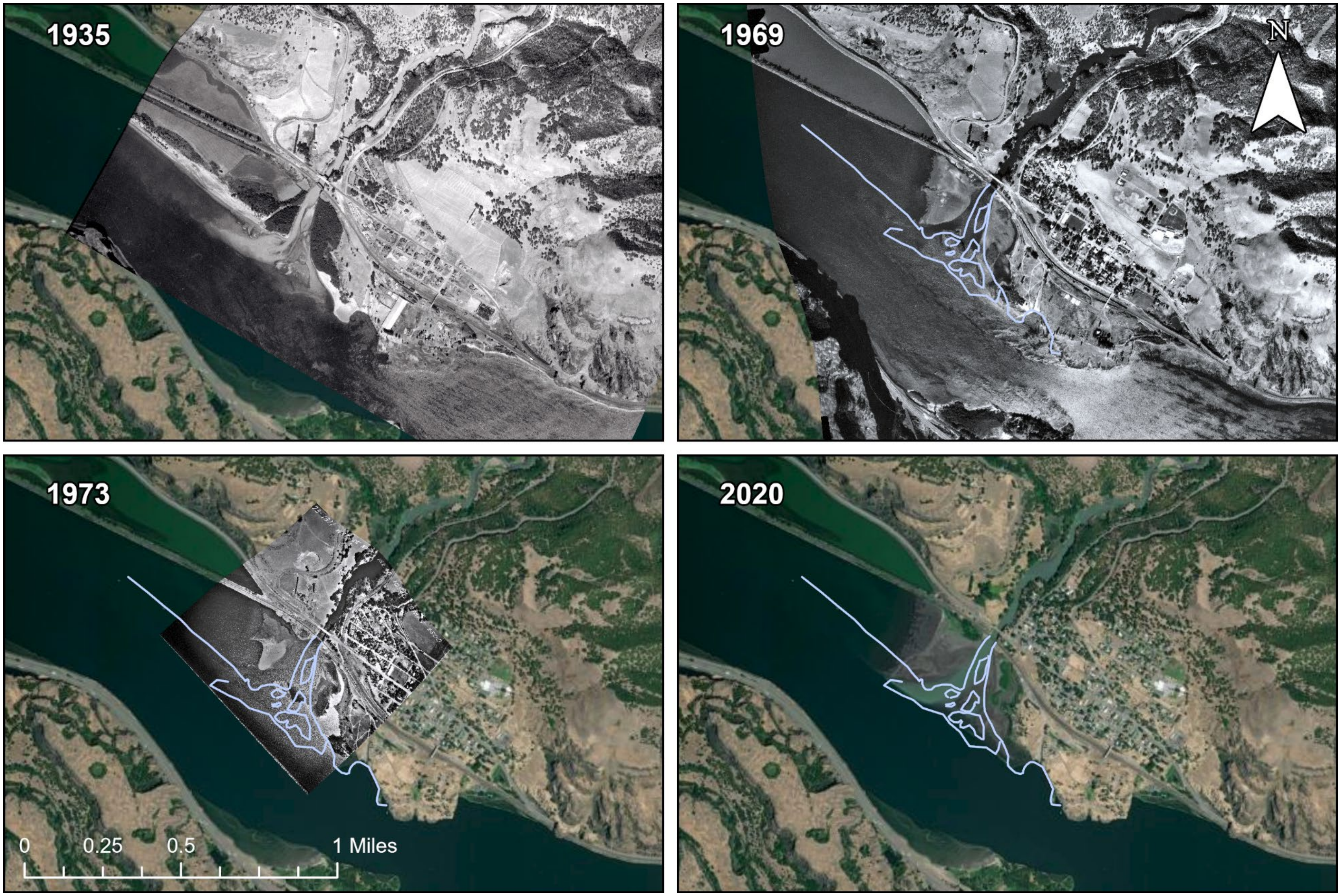



**Figure 21. Historical aerial imagery of the Klickitat River delta. (1935 represents pre-dam with features digitized in post-dam images from 1969, 1973, and 2020)**


**Figure 22. Recent satellite imagery of the Klickitat River delta.**

# SECTION 4 - DATA SYNTHESIS AND COLLECTION

## 4.1 EXISTING DATASETS

### 4.1.1 U.S. Geological Survey Data

Data on river flow, stage, water temperature, sediment, and other water quality parameters are available on the National Water Information System (NWIS, USGS 2024). There are 21 active and inactive USGS gages within the study area that are on the Columbia, Wind, White Salmon, and Klickitat Rivers (Table 8). Available data included instantaneous, hourly, daily, and peak annual flow and stage across all four rivers, as well as hourly and daily water temperature on the Columbia River. Ten of these gages are currently active with five on the Columbia River, one on the White Salmon River, and three on the Klickitat River. USGS Gage 14128500 (Wind River near Carson, WA), was active from 1934 to 1980, and recently began collecting gage height and water temperature data in April 2024. Consistent water temperature records are only from the Columbia River upstream of the three tributaries.

The gages closest to the study area cold water refuge sites are the Wind River near Carson, Washington (USGS 14128500), White Salmon River near Underwood, Washington (USGS 14123500), and Klickitat River near Pitt, Washington (USGS 14113000). Historically, these gages collected flow and stage data and additional information is needed to assess sedimentation effects on the dynamics of cold water refugia along the Columbia River. USACE and the USGS collaborated to begin recording turbidity and temperature for this project at these three gages in Spring 2024 (Table 9). In addition to flow, stage, water temperature, and turbidity at the three gage sites, there has been historical water quality data collected that includes physical, inorganic (metal and non-metal), nutrient, microbiological, biological, organic, and radiochemical data. A total of 111, 253, and 291 samples were collected on the Wind, White Salmon, and Klickitat Rivers, respectively (Table 10). Physical parameters include variables such as temperature, discharge, turbidity, suspended solids, and dissolved solids.

**Table 8. Summary of data availability at U.S. Geological Survey gages.**

| Gage Name | Gage Number | Water Temperature | Flow | Stage |
|---|---|---|---|---|
| Columbia River at McNary Dam near Umatilla, Oregon | 14019220 | **h,d** | | |
| Columbia River below McNary Dam near Umatilla, Oregon | 14019240 | **h,d** | | |
| Columbia River at The Dalles, Oregon | 14105700 | **d** | s,**d**,a | a |
| Columbia River at Hood River, Oregon | 14113290 | | | **s**,h,**d** |
| Columbia River at Stevenson, Washington | 14128600 | | | **s**,h,**d** |
| Wind River above Trout Creek near Carson, Washington | 14127000 | | d | |
| Wind River near Carson, Washington | 14128500 | | d,a | a |
| White Salmon River below Cascades Creek near Trout Lake, Washington | 14121300 | | d,a | a |
| White Salmon River above Trout Lake Creek near Trout Lake, Washington | 14121400 | | d,a | a |
| White Salmon River near Trout Lake, Washington | 14122000 | | d,a | a |
| White Salmon River at Splash Dam near Trout Lake, Washington | 14122500 | | d,a | a |
| White Salmon River at B-Z Corner, Washington | 14122900 | | d,a | a |
| White Salmon River at Husum, Washington | 14123000 | | d,a | a |
| White Salmon River near Underwood, Washington | 14123500 | | **s,d,a** | **s,d,a** |
| Klickitat River near Glenwood, Washington | 14107000 | | **s,d,a** | **d,a** |
| West Fork Klickitat River near Glenwood, Washington | 14108000 | | d | |
| Klickitat River near Glenwood, Washington | 14110000 | | d,a | a |
| Klickitat River below Summit Creek near Glenwood, Washington | 14111400 | | **s,d,a** | **d,a** |
| Little Klickitat River near Goldendale, Washington | 14112000 | | d,a | a |
| Little Klickitat River near Wahkiacus, Washington | 14112500 | | d,a | a |
| Klickitat River near Pitt, Washington | 14113000 | | **s,d,a** | **s,d,a** |
| Notes: s = instantaneous, h = hourly, d = daily, a = peak annual, and bold font indicates that the gage is currently active. | | | | |

**Table 9. Period of records at U.S. Geological Survey gages.**

| Parameter Frequency | Wind River at Carson (14128500) | White Salmon River near Underwood (14123500) | Klickitat River near Pitt (14113000) |
|---|---|---|---|
| Instantaneous Flow | | 12/31/1995- current | 12/31/1995-current |
| Daily Flow | 10/01/1934-10/14/1980 | 11/01/1912- current | 07/01/1909-current |
| Annual Peak Flow | 12/21/1934-01/01/1997 | 03/21/1916-11/13/2021 | 11/24/1909-current |
| Instantaneous Stage | 04/18/2024- current | 12/31/1995- current | 12/31/1995-current |
| Daily Stage | | 12/21/1991- current | 10/30/1997-current |
| Annual Peak Stage | 12/21/1934-01/01/1997 | 03/21/1916-11/13/2021 | 11/24/1909-current |
| Instantaneous Temperature | 04/19/2024- current | 05/02/2024- current | 04/22/2024- current |
| Instantaneous Turbidity | 04/19/2024- current | 05/02/2024- current | 04/22/2024- current |

**Table 10. Period of record of water quality and sediment data at U.S. Geological Survey gages.**

| Gage Name | Physical Properties | | Suspended sediment | |
|---|---|---|---|---|
| | Period | Number of Samples | Period | Number of Samples |
| Wind River (14128500) | 10/04/1972 - 11/20/1980 | 111 | 03/28/1980 - 09/16/1980 | 12 |
| White Salmon River (14123500) | 08/01/1960 - 10/26/2011 | 126 | 03/28/1980 - 02/04/2012 | 135 |
| Klickitat River (14113000) | 09/22/1947 - 07/28/1986 | 127 | 10/08/1974 - 07/28/1986 | 126 |

### 4.1.2 Washington State Agencies

The Washington State Department of Ecology (WDOE) maintains both real-time and grab sample data on flow, sediments, and water quality that are available through their Freshwater DataStream (WDOE 2024a) and Freshwater Information Network (WDOE 2024b).

There are two real-time gages in the study area that include the Wind River at Stabler, Washington (29C100) and the Little Klickitat River near Wahkiacus, Washington (30C070). The Wind River gage is located approximately 12 river miles upstream of the Wind River delta with a period of record from June 2008 to present. The Little Klickitat River gage is located approximately 18 river miles upstream of the Klickitat River delta with a period of record from June 2000 to present. Both gages record data on flow, stage, water temperature, and air temperature in mean daily and 15-minute intervals (WDOE 2024a).

Water quality data is grouped by study locations within watershed units, such that the Wind and White Salmon River sites are lumped into a single watershed unit (WRIA 29) and the Klickitat sites in a single watershed unit (WRIA 30). There are a total of 22 sites in the study area with water quality data records with 10 sites still being active (Table 11).

**Table 11. List of Washington Department of Ecology water quality data site locations.**

| Site | Site Code | Status | Watershed Unit |
|---|---|---|---|
| Buck Creek at Big Buck Creek Road | 29F060 | Active | Wind-White Salmon |
| Trapper Creek At North Fork | 29M050 | Active | Wind-White Salmon |
| White Salmon River at Sunnyside Road | 29M120 | Active | Wind-White Salmon |
| Trout Lake Ck at Old Creamery Road | 29N060 | Active | Wind-White Salmon |
| Major Creek at Old Hwy 8 | 29O050 | Active | Wind-White Salmon |
| Jewett Creek at SR-14 | 29P010 | Active | Wind-White Salmon |
| Klickitat River at Lyle Park | 30B050 | Active | Klickitat |
| Snyder Creek at Mouth | 30D050 | Active | Klickitat |
| E. Pr. Little Klickitat below Brooks Mem | 30F070 | Active | Klickitat |
| Butler Creek 1 (river mile 0.99) | 30G070 | Active | Klickitat |
| Gilmer Creek near Mouth | 29E070 | Inactive | Wind-White Salmon |
| Columbia River at The Dalles | 30A070 | Inactive | Klickitat |
| Columbia River at The Dalles Dam | 30A090 | Inactive | Klickitat |
| Klickitat River near Lyle | 30B060 | Inactive | Klickitat |
| Klickitat River near Pitt (USGS) | 30B070 | Inactive | Klickitat |
| Little Klickitat near Wahkiacus | 30C070 | Inactive | Klickitat |
| White Salmon River near Underwood | 29B070 | Inactive | Wind-White Salmon |
| Wind River near Carson | 29C070 | Inactive | Wind-White Salmon |
| Rattlesnake Creek near Mouth | 29D070 | Inactive | Wind-White Salmon |
| Little Klickitat River at Olson Road | 30C090 | Inactive | Klickitat |
| White Salmon River at Husum Street | 29B090 | Inactive | Wind-White Salmon |
| Little Klickitat River at Hwy 97 | 30C150 | Inactive | Klickitat |

There is one active water quality monitoring station on the Klickitat River at Lyle Park (30B050) that last reported in 2022. Inactive stations include the Wind River near Carson (29C070), which recorded from 1973 to 1995, the White Salmon River at Sunnyside Road (29M120) in 2020, at Husum Street (29B090) from 2008-2009, and near Underwood (29B070) from 1960-1995, and the Klickitat River near Pitt (30B070) from 1967 to 1980 and near Lyle (30B060) from 1994-1995. The stations report a variety of water quality parameters such as dissolved oxygen, flow, water temperature, total suspended solids, and turbidity.

The Washington Department of Fisheries and Wildlife (WDFW) has the SalmonScape data portal with information pertaining to fish. The portal provides data in a GIS framework with layers showing which species have a documented presence, rearing, or spawning in each river, as well as information on barriers to fish passage and Endangered Species Act (ESA) units and ranges (WDFW 2024).

### 4.1.3 National Oceanic and Atmospheric Administration Data

The National Oceanic and Atmospheric Administration (NOAA) has one inactive gage on each of the three tributaries. The gages recorded climatological data such as air temperature, precipitation (including snowfall), and weather type. The White Salmon 4 NNE, Washington gage is located near the White Salmon River and collected from January 1911 through November 1952. The Stevenson, Washington gage near the Wind River recorded from January 1948 through mid-April 1952. The Lyle, Washington gage near the Klickitat River recorded from July 1892 through March 1910 (NOAA 2023a).

NOAA manages the Northwest River Forecast Center (NWRFC), which provides river forecasting as one of thirteen National Weather Service hydrologic centers in the United States. There are two stations in the study area that include the Klickitat River near Pitt (PITW1) and White Salmon near Underwood stations. Both stations provide forecasts on river stage but only the Klickitat River station reports action, flood, moderate flood, and major flood stages (NOAA 2023b).

### 4.1.4 Northwest Division USACE Hydrology Portal Data

The Northwest Division of USACE has a web portal that collects and assimilates gridded hydrologic data from various sources (USACE 2022). The gridded data can be downloaded directly or as a timeseries that is spatially averaged to subbasins of the Columbia River that are similar in size to the Hydrologic Unit Code (HUC) 12 watersheds. The data includes snow water equivalent (SWE) and snow depth data from 2004 to present made available through the Snow Data Assimilation System (SNODAS) operated by NOAA. Daily precipitation and air temperature (daily mean, minimum, and maximum) from 1981 to present is made available through the PRISM Climate Group.

### 4.1.5 Northwest Stream Temperature Database

The Rocky Mountain Research Station, U.S. Forest Service (USFS), developed the Northwest Stream Temperature (NorWeST) database of observed and simulated water temperatures for streams in the Pacific Northwest (USDA 2024). The NorWeST database has two main products that consists of a regional aggregation of observed water temperatures and spatially simulated water temperatures that accompanies the geospatial network National Hydrography Dataset (NHD). The observed water temperature records were aggregated from various local, state, and federal agencies and other organizations at locations totaling more than 20,000 sites. The spatially simulated water temperatures use the NHD representation of stream networks and applies spatial-stream-network modeling to develop regressions of water temperature to covariates such as air temperature, stream flow, and watershed characteristics. The simulated water temperatures pertain to the month of August with values simulated for individual NHD stream reaches for various scenarios (36 in total) that include two baseline average periods of 1993 to 2011 and 2002 to 2011, along with 10 future scenarios with varying assumptions of future climate change (Isaak et al. 2017). The baseline August water temperatures for the 1993 to 2011 period are shown in Figure 23 that depicts the cold-water streams in the headwater regions of each watershed. The simulated August water temperatures at each of the tributary deltas was 14.5°C for the Wind River, 15.7°C for the White Salmon River, and 16.9°C for the Klickitat River.

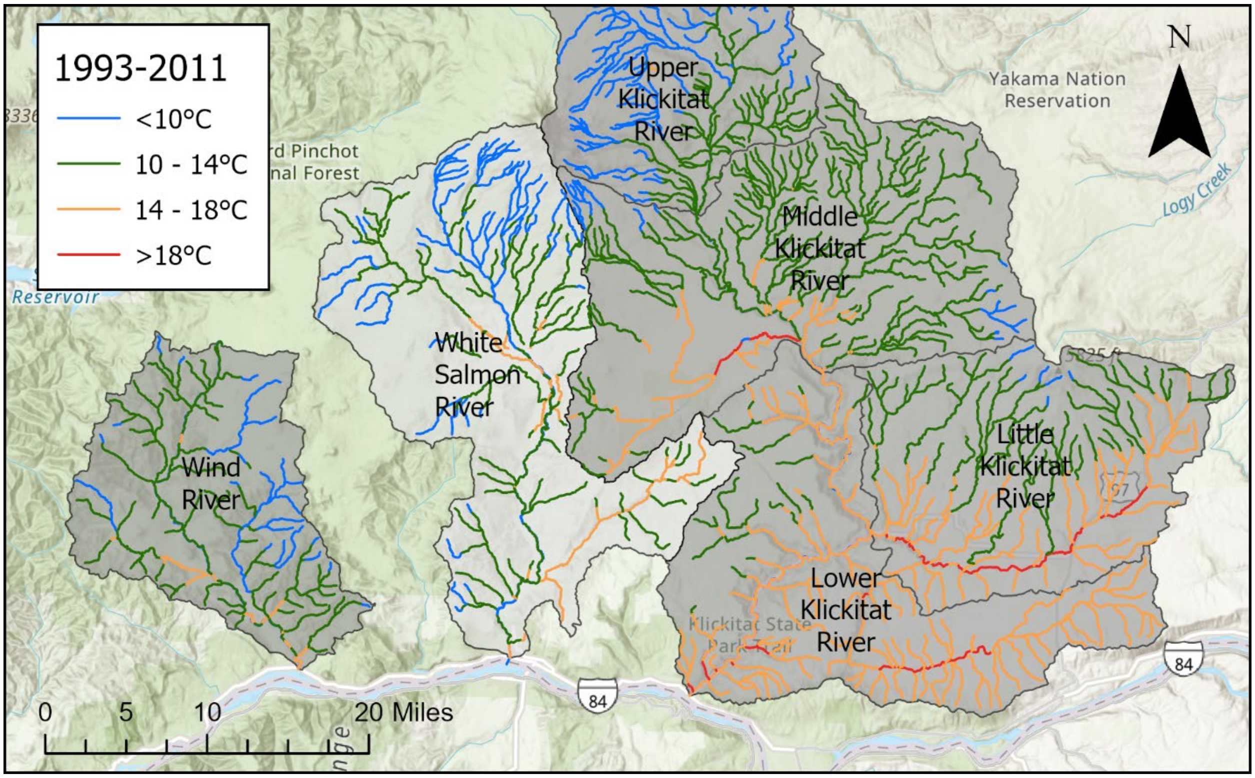



**Figure 23. Map of simulated August water temperatures from 1993 to 2011 from NorWeST simulated water temperature database.**

### 4.1.6 Fish Information

There are various sources of data relating to fish location, catch, release, survival, growth, and recovery in the Columbia River Basin that are collected by several local, state, federal, and tribal agencies in the Pacific Northwest. Common methods of monitoring fish populations involve the attachment of passive integrated transponder (PIT tags) and coded wire tags (CWTs) to individual fish, as well as visual counts past fish passage structures at dams, commercial fish landing reports, and site-specific studies.

The Regional Mark Processing Center (RMPC) provides coordination regarding fin marking and the use of CWTs among various agencies collecting fish data and maintains the Regional Mark Information System (RMIS) database that serves as a repository for all CWT numbers in salmonoids in the Pacific Ocean region of North America spanning from California through Canada. The RMIS database can access fish data collected by individual agencies, locations, and fish facilities and the RMPC provides various summary reports and tables that can be customized to specific needs. (RPMC 2024).

The Columbia Basin Research (CBR) is an interdisciplinary research center at the University of Washington that synthesizes several fish-related data sets into the Data in Real Time (DART) database and develops models to forecast the in-season fish passage numbers and water quality variables. The DART database has data on juvenile and adult salmon passage counts and other movement and growth metrics, as well as data on climate variables and physical conditions of the river (e.g., flows, water temperature, and total dissolved gas) and ocean (e.g., buoy measured air and water temperature, indices of upwelling and along-shore transport) environments (CBR 2024).

The Fish Passage Center (FPC) aggregates data sets from various sources and provides technical support focused on the passage of salmon, steelhead, and Pacific lamprey through the federally owned hydropower dams along the Columbia and Lower Snake Rivers. The FPC provides links to the various data sources, as well as analyses relating to the gas bubble trauma (GBT) program, comparative survival study (CSS), adult migration, dam operations, hatchery releases, and environmental conditions (FPC 2024).

The Yakama Nation Fisheries collects data, conducts studies, and implements restoration actions to improve culturally important fish populations relevant to the Yakama Nation. The fish data program provides links to data and visualization tools regarding information on juvenile and adult fish counts, tag detections, and passage (Yakama Nation Fisheries 2024).

## 4.2 TOPOGRAPHIC AND BATHYMETRIC DATA

Topographic and bathymetric data refer to elevation data of above and below water regions of the cold water refugia habitats, respectively. This study did not directly collect any topographic or bathymetric data, but this section summarizes recent efforts by CRITFIC, Yakama Nation, and USACE in collaboration with Oregon State University (OSU) and NOAA to develop a complete bathymetric map of the delta regions of the Wind, White Salmon, and Klickitat Rivers capturing the cold water refugia regions both in the tributaries and the main channel of the Columbia River.

USACE periodically surveys the Federal Navigation Channel (FNC) in the Bonneville Pool with the last survey performed in 2020 (Figure 24) with the previous survey done in 2012. The authorized FNC through the Bonneville Pool is a 300-foot-wide channel with a depth of 27 feet. The 2020 survey shows some shoaling occurring near the White Salmon River confluence (Figure 24, middle figure). The 2020 survey data of the FNC is included in Appendix A.

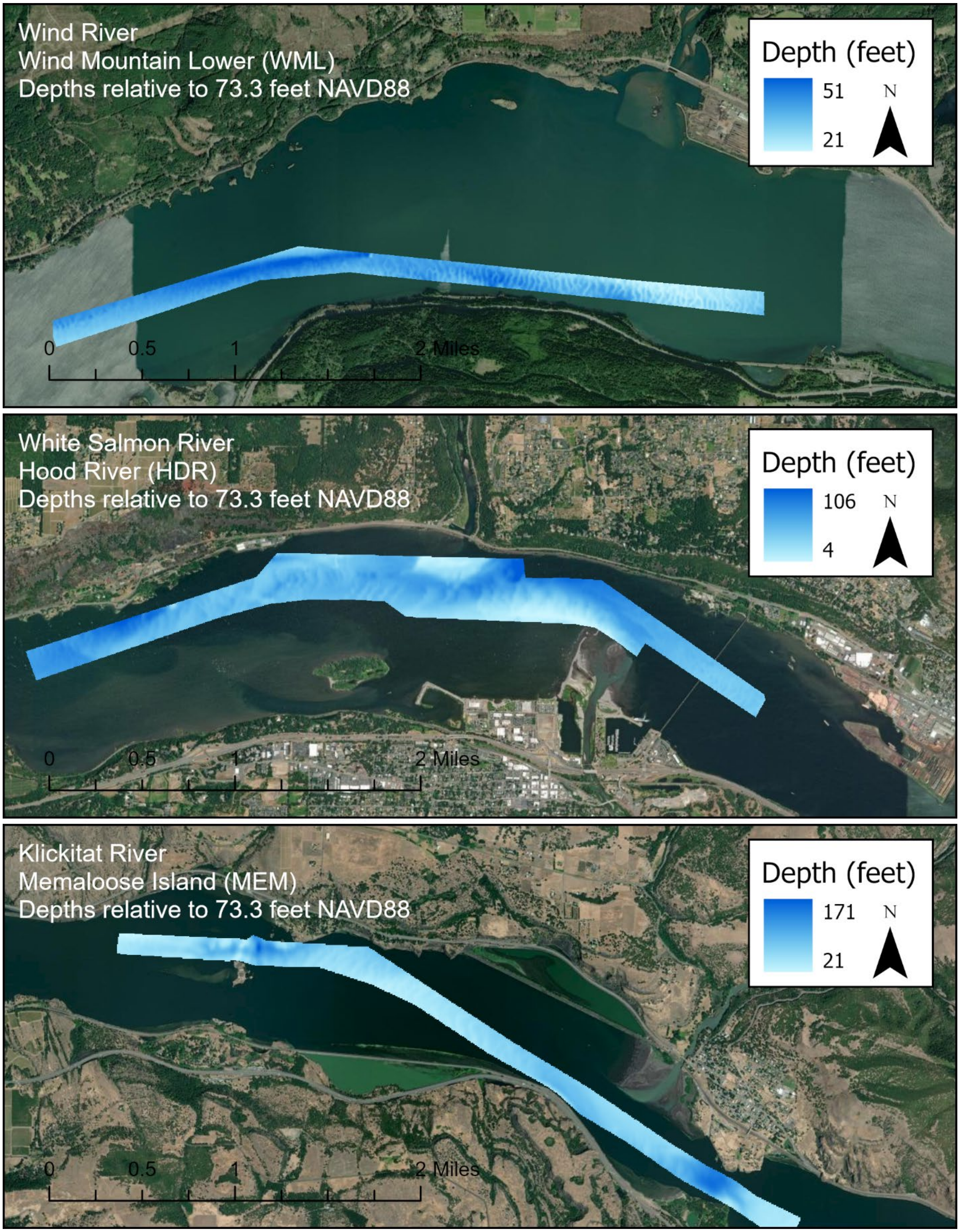



**Figure 24. Bathymetric survey of the Federal Navigation Channel in 2020.**

NOAA's National Ocean Service (NOS) performed a multibeam sonar survey of the Columbia River through a portion of Zone 6 in 2022 and 2023 that was sponsored by CRITFC and Yakama Nation to investigate areas of sediment build-up in the Columbia River and tributary waters. The 2022 survey spanned from the Little White Salmon River to upstream of the Klickitat River with a draft bathymetric map shown in Figure 25 (NOAA 2024a). The 2023 survey extended from Eagle Creek to the Little White Salmon River (NOAA 2024b). The Columbia River survey captured the main channel and bank areas with an approximate water depth of greater than 13 feet.

CRITFC and OSU conducted a bathymetric survey of the Klickitat River delta south of the railroad bridge in September 2022. In August and September 2024, CRITFC, as part of the OSU led Geospatial Center for the Arctic and Pacific (GCAP), conducted four days of bathymetric surveys of the Klickitat River. The areas surveyed included the reach upstream past the railroad bridge to the county park (head of slack water), the interior of the delta, and the shallow area to the west of the delta out in the Columbia River. Surveys were conducted with single-beam echo sounder linked to real-time kinetic (RTK) corrected global navigation satellite system (GNSS) using the Oregon Department of Transportation RTK service, providing bathymetric data where water depths were greater than 1 foot.

In addition to the bathymetric surveys, CRITFC collaborated with Cayuse Native Solutions and DelMar Aerospace to collect light detection and ranging (LiDAR) data of the Klickitat delta and canyon in November 2023 under low flow conditions. The survey did not include the southern extent of the delta.

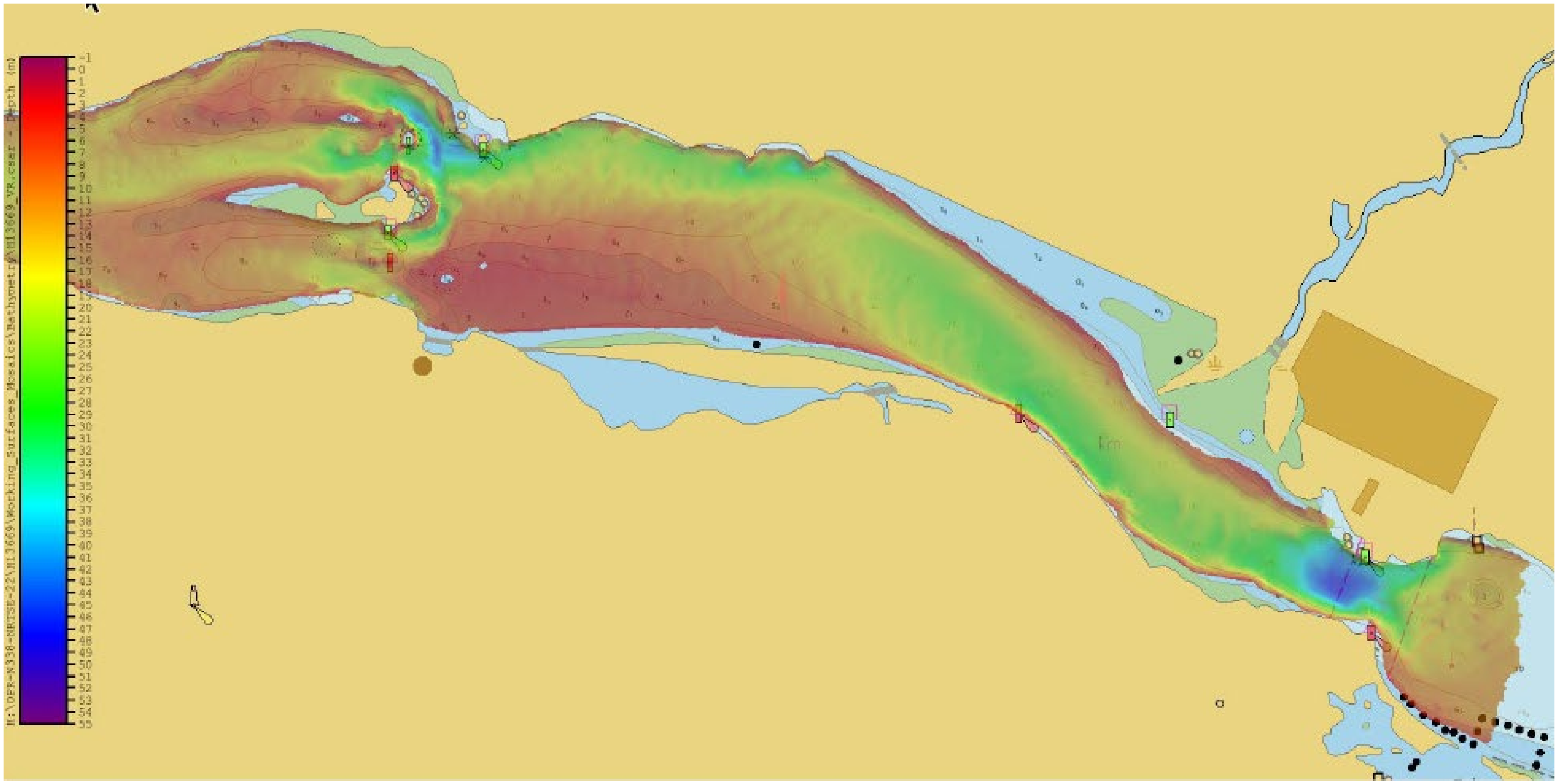


**Figure 25. Bathymetric data of the Columbia River near the Klickitat River confluence. (Source NOAA 2024a)**

## 4.3 COLD-WATER REFUGE CHARACTERIZATION 2024

Water quality and sediment data was collected along the Wind, White Salmon, and Klickitat River deltas during a site visit from July 22-25, 2024. Wind River and Klickitat River Deltas were sampled on July 23 and July 24, respectively. The White Salmon was sampled on both July 22$^{nd}$ and 25$^{th}$ due to unsafe wind and wave conditions on the first day. To avoid wind and waves, sampling started at roughly 5:30 AM for the remaining sites.

The cold-water refuge areas were accessed using a 20-foot-long powerboat with dual motors to aid in navigation with swift currents and unpredictable waves. Water temperature and depth was collected with a YSI EXO data sonde with individual sensors that collect data on pH, conductivity, dissolved oxygen, chlorophyl, and phycocyanin. Pairs of Onset Hobo water temperature thermistors were attached to concrete anchors with rope and buoys and deployed at selected locations where a range of water temperatures were observed with the EXO probe.

There are inherent limitations to sonde and thermistor location resolutions due to boat movements and location accuracy. Due to the thermistor setup, it is also possible that the top thermistor drifted away from the bottom thermistor such that they weren't in the same vertical water profile. For these reasons, spatial accuracy of temperature data is likely within 15 meters. Limited delta access due to shallow water depths and wind conditions made it difficult to get regular sediment samples and logger placements at some locations. In these cases, samples were collected off the overbanks, and loggers were placed as close to the delta as possible.

Water temperatures during the field study were on the order of 10°C on the White Salmon River and 16°C on the Klickitat River based on the USGS gages on the White Salmon near Underwood (USGS 14123500) and the Klickitat River at Pitt (USGS 14113000), respectively. The Wind River near Carson gage (USGS 14128500) was malfunctioning at the time of the field effort.

Access across the Klickitat River delta was difficult due to windy conditions and shallow water depths. The powerboat was unable to proceed into the delta and thermistors were placed at the edge of the confluence with the Columbia River. There appeared to be no obvious channel at the time of the field study with depths typically less than 0.5 meters, which was later confirmed by satellite imagery (Figure 26). Kayaks were used to access the delta for collecting sonde data points and sediment samples.


**Figure 26. Satellite image of Klickitat River delta on July 20, 2024. (Source: Copernicus 2024).**

### 4.3.1 Temperature Sonde Data

Temperature data was collected using the YSI ECO multi-parameter sonde at five second intervals. It was held just under the surface for most of the survey and was occasionally released to the channel bed to capture temperature along a vertical water profile. Profiles were taken approximately every 30 meters, when there was a change in surface temperature, or at a feature relevant to cold water refugia, such as still alcoves along the bank or near sand bars.

While the EXO probe collects location information using global positioning system (GPS) data, location data quality was poor, so the EXO location data was merged with GPS data that was collected using the Gaia GPS application on an iPhone SE Version 17.6.1. A gridded raster dataset of water temperature minimum, maximum, mean, range, and water depth for each of the three deltas was processed at a 15.24-meter cell size using R software (Figure 27). The White Salmon River delta displayed the greatest range in water depth and water temperature of the three deltas. The White Salmon River delta also represented the coolest water of the three sites during July 22-25, 2024, field study. While distinct channels where cool water traversed through the deltas was apparent at the White Salmon River (Figure 28) and Wind River (Figure 29) deltas, there was no obvious tributary channel at the Klickitat River delta (Figure 30).

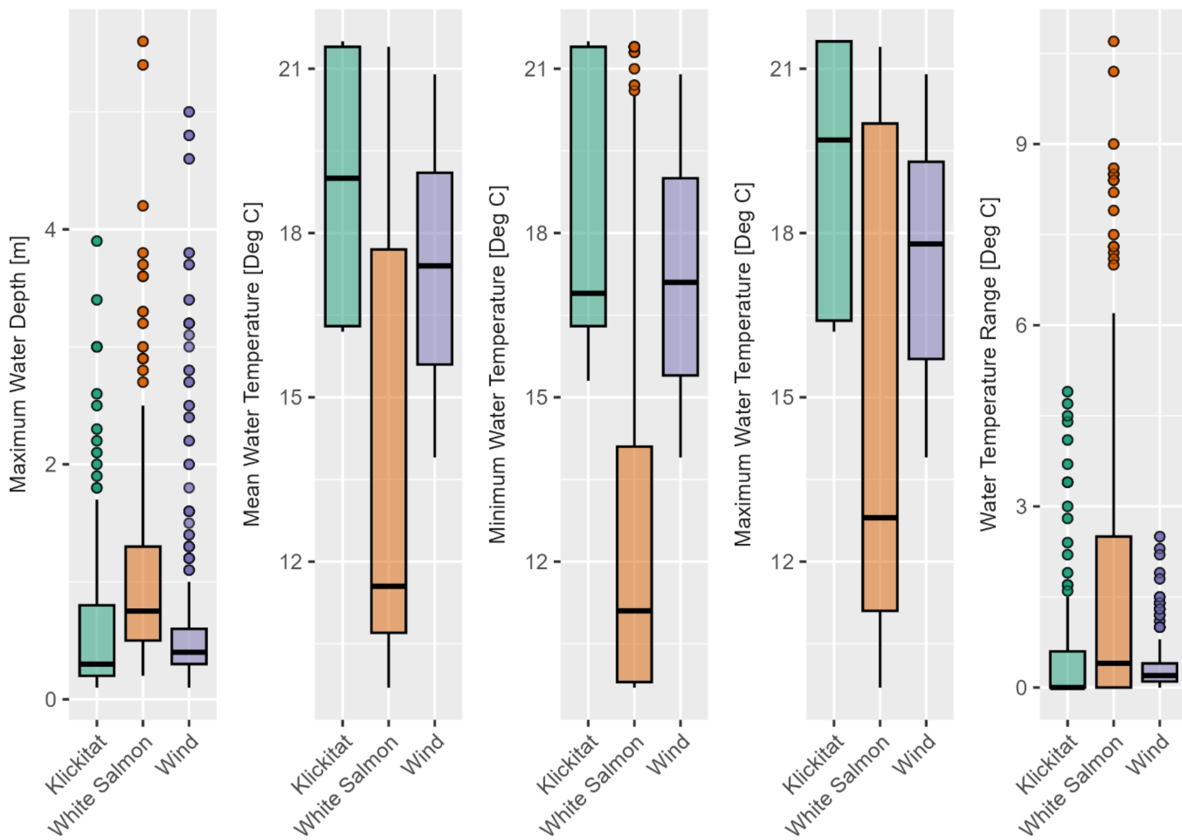



**Figure 27. Boxplots of gridded EXO water depth and temperature data.**

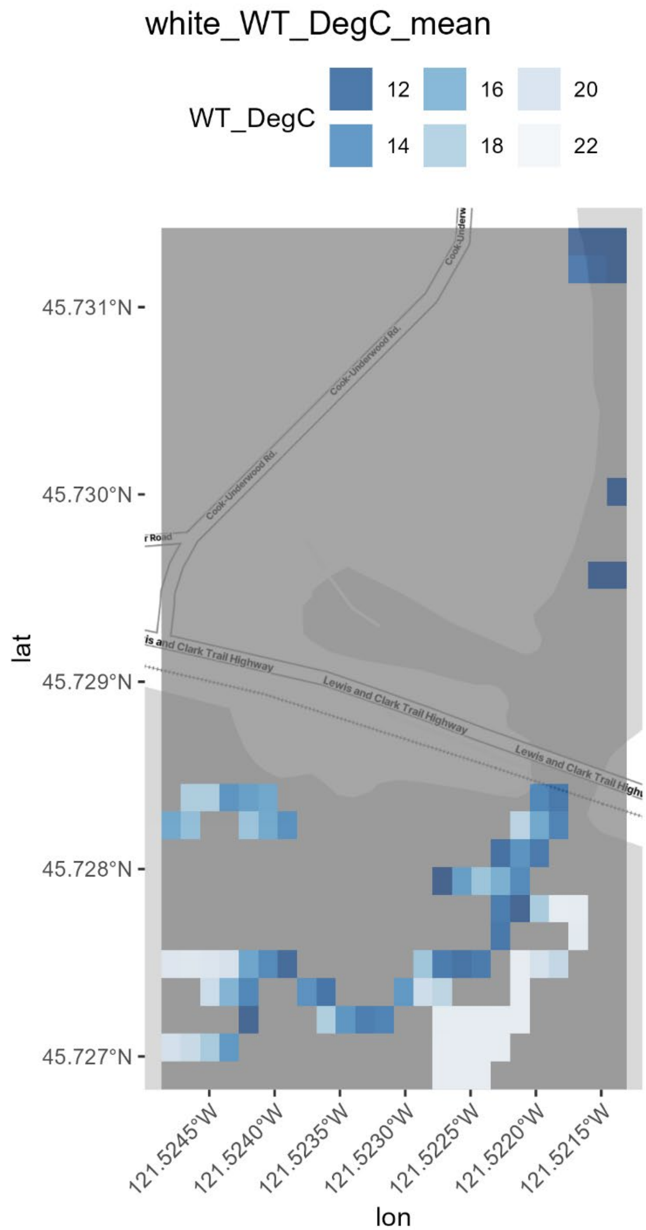



**Figure 28. Map of mean water temperature in the White Salmon River delta recorded on July 22 and July 25, 2024.**

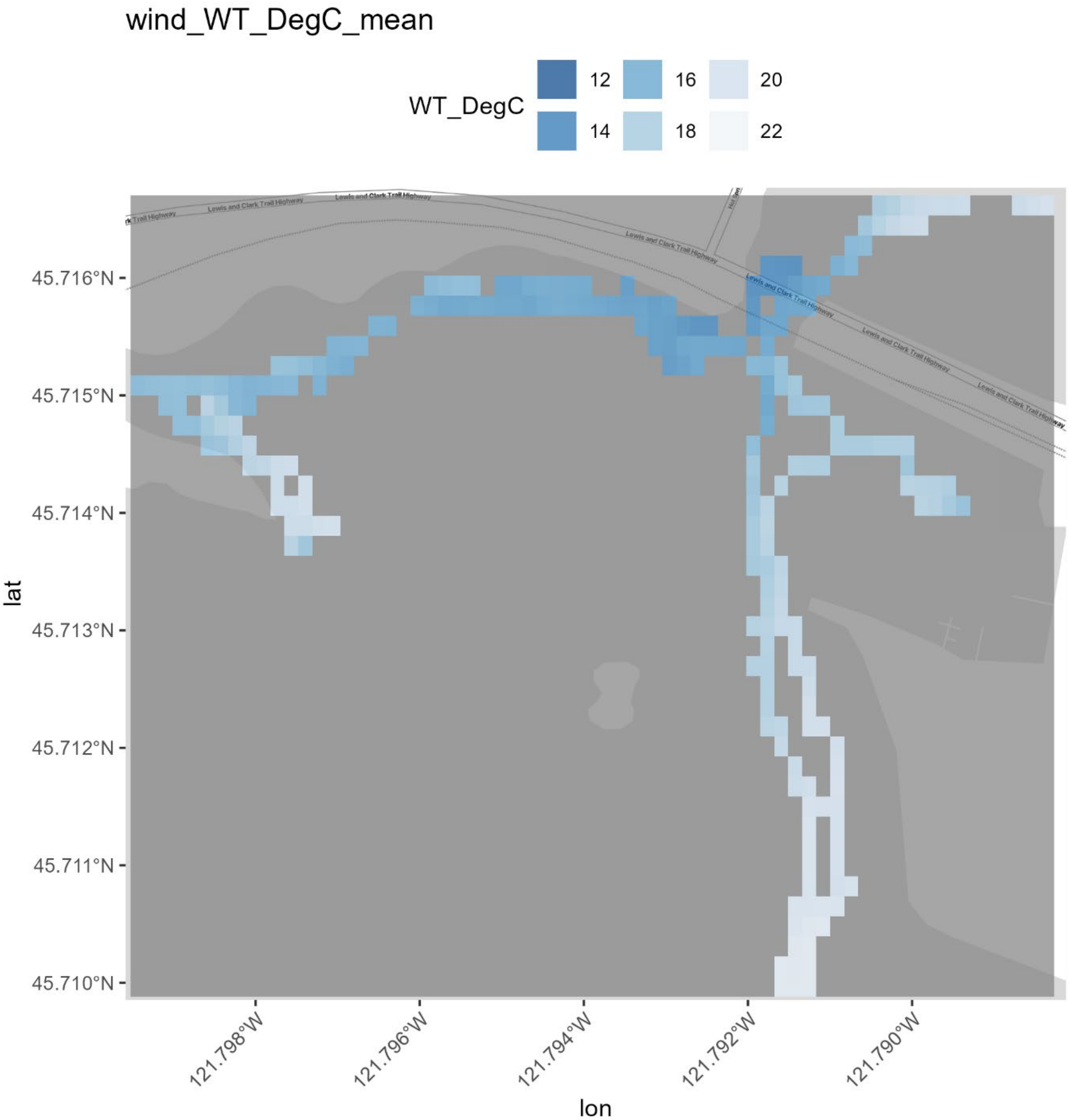



**Figure 29. Map of mean water temperature recorded in the Wind River delta on July 23, 2024.**

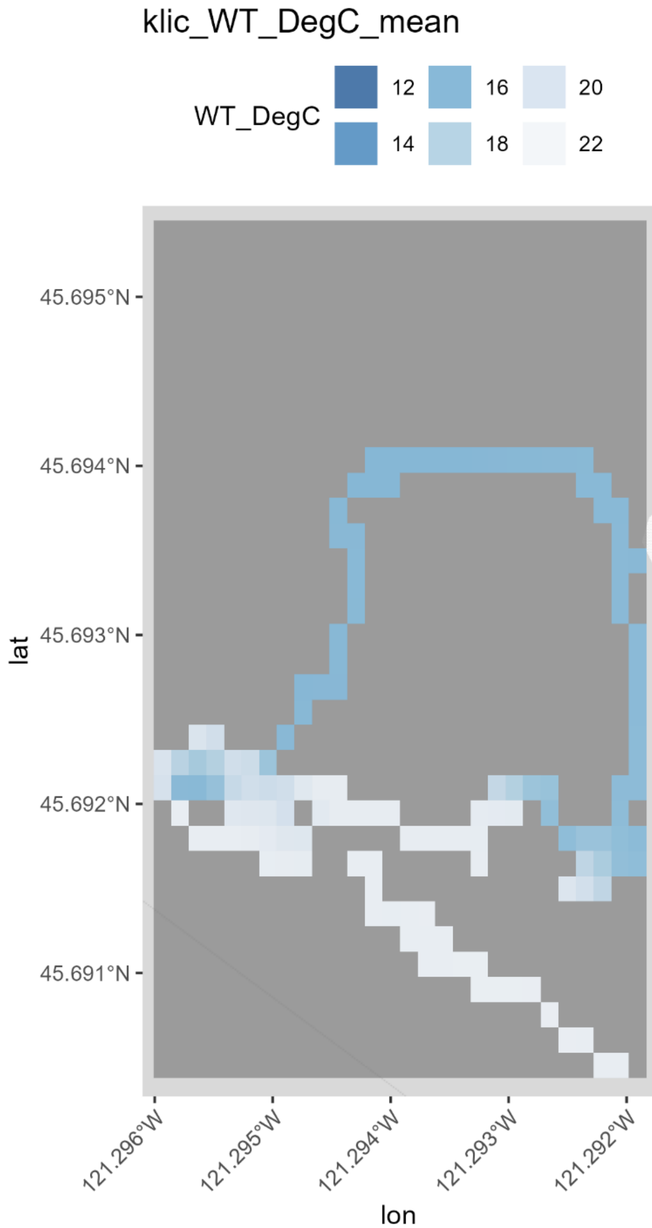



**Figure 30. Map of mean water temperature in the Klickitat River delta recorded on July 24, 2024.**

### 4.3.2 Temperature Thermistor Data

Sixteen HOBO temperature loggers were deployed at eight sites as shown in Figure 31. Two temperature loggers were used per site to capture hourly differences between surface and near-bed temperatures to observe potential thermal stratification in the delta regions. The temperature loggers collected data for 68 hours on the White Salmon River (Figure 32), 22 hours on the Wind River (Figure 33), and 48 hours on the Klickitat River (Figure 34). Thermal stratification was observed at site A on the White Salmon

River and site D on the Wind River. The water temperature data is attached in Appendix A.


**Figure 31. Map of water temperature profile locations from July 2024 field study.**

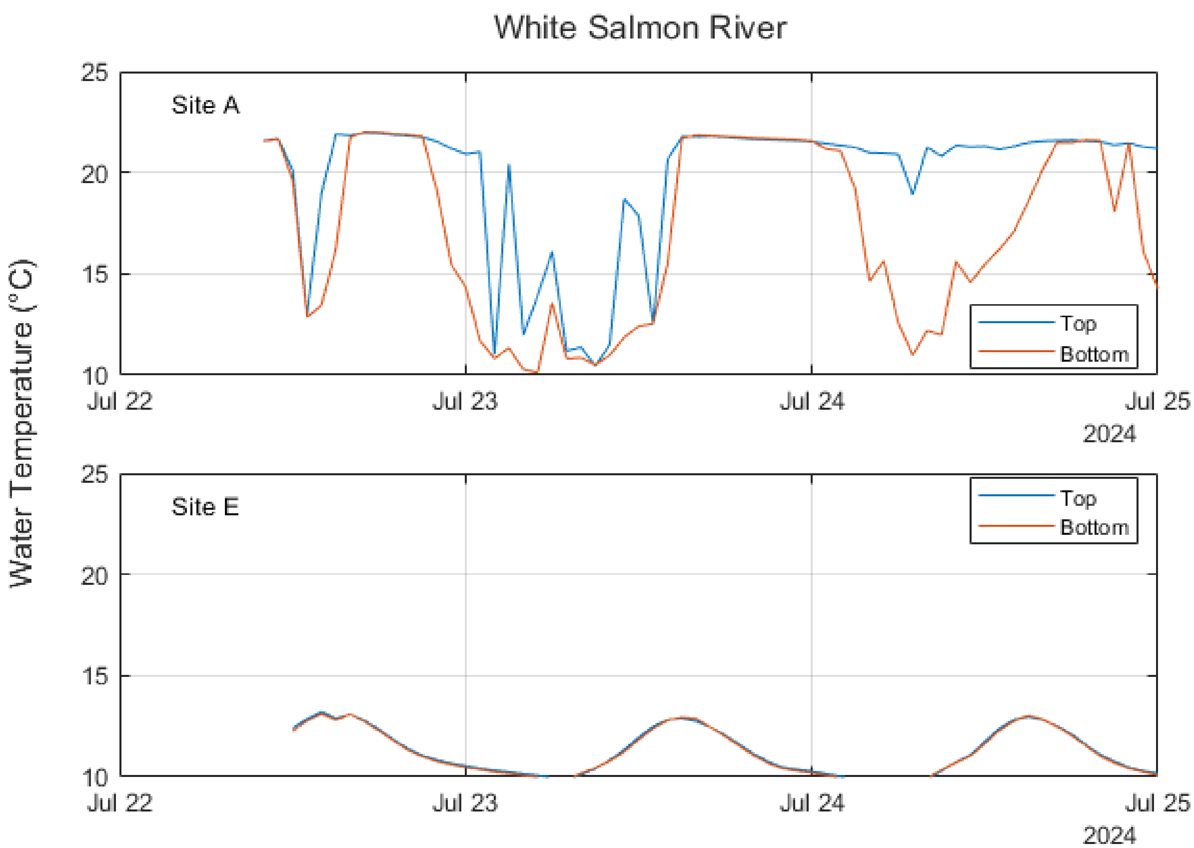



**Figure 32. Water temperature profile data collected at the White Salmon River.**

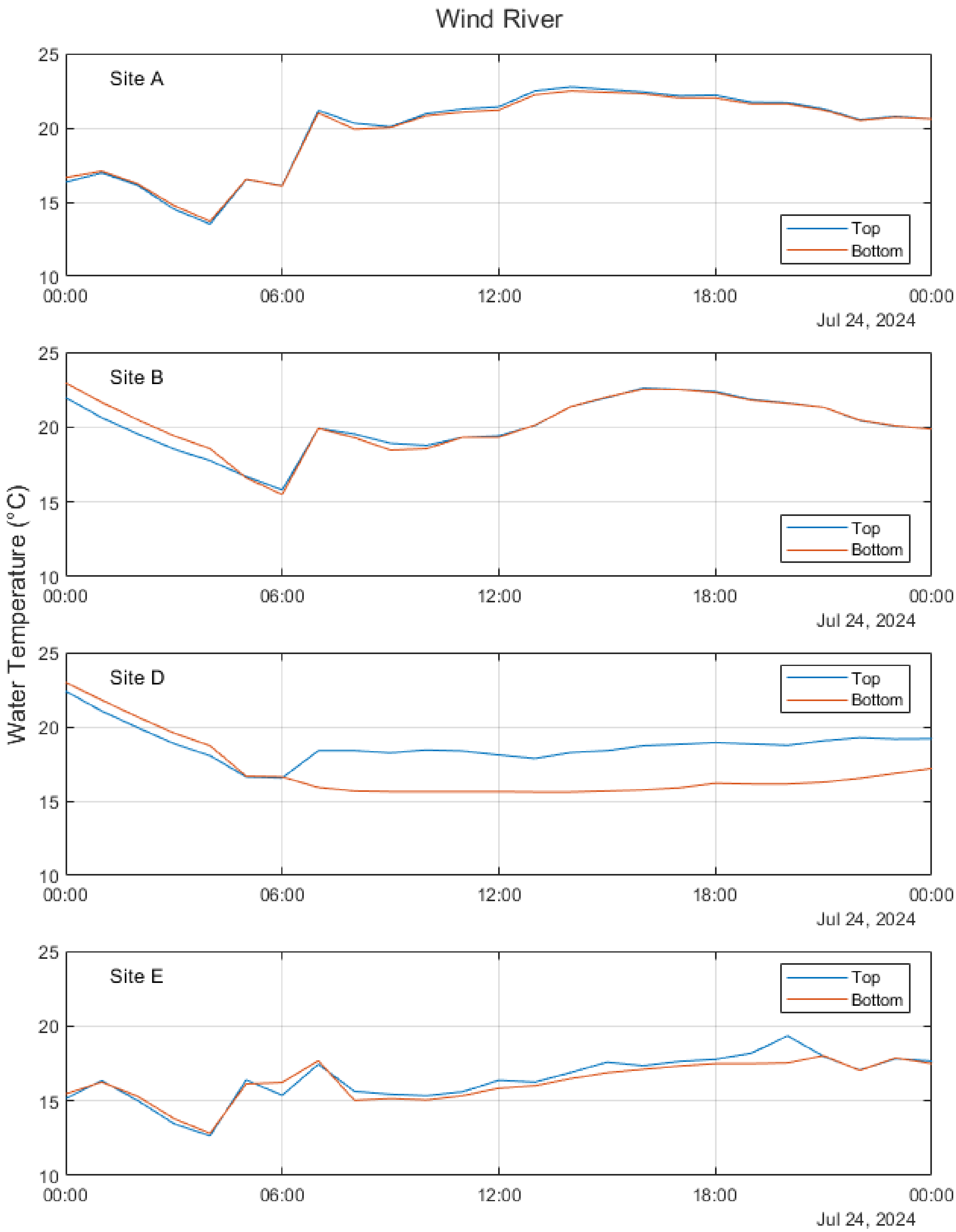



**Figure 33. Water temperature profile data collected at the Wind River.**

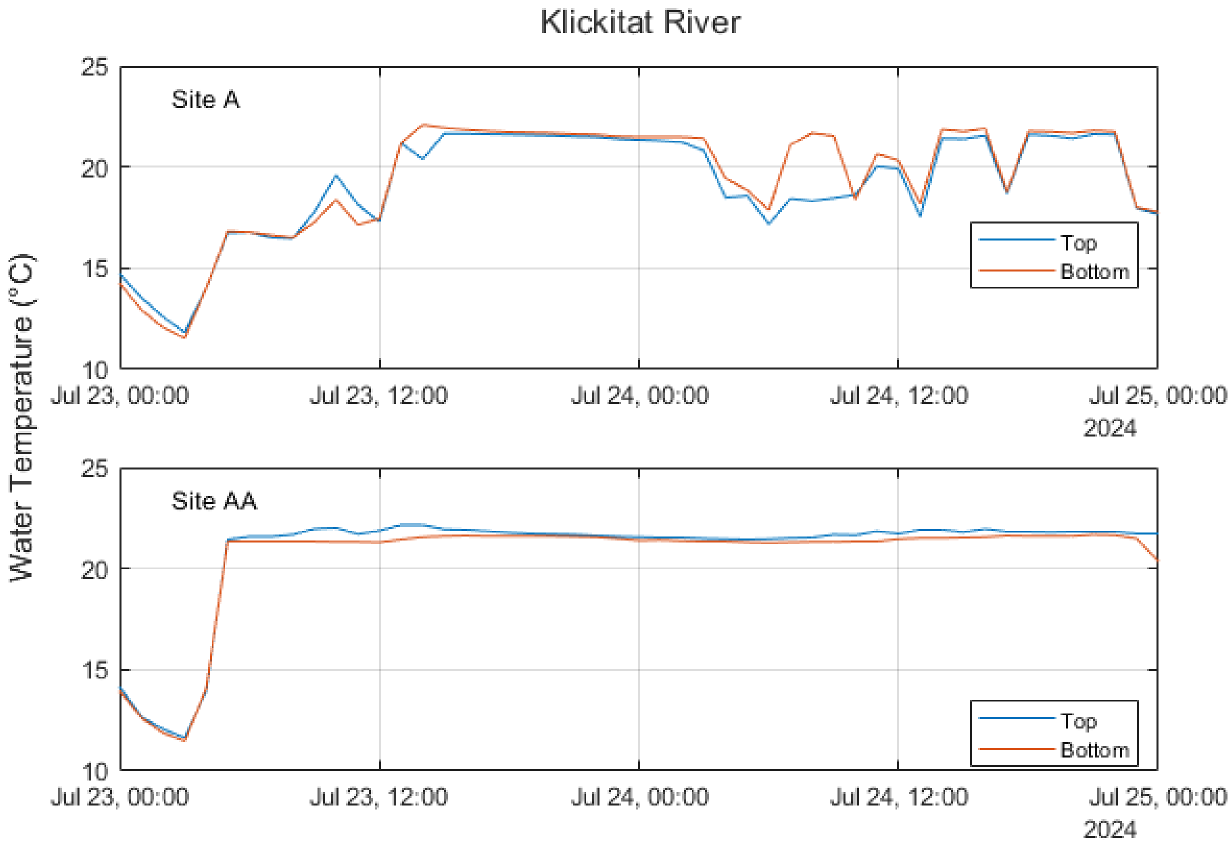



**Figure 34. Water temperature profile data collected at the Klickitat River.**

The temporal patterns of water temperature measured at the thermistor sites suggests the potential for stratification between bottom and near surface waters, as well as temporal patterns of plume mixing between the tributary and Columbia River mainstem waters. Site A at the White Salmon River delta is located out in the Columbia River and shows temperatures ranging between 10 and 22°C in a span of 24 hours for both the surface and bottom thermistor (Figure 32). Water temperatures measured at the USGS gage on the White Salmon River in July of 2024 never exceeded 15°C (Figure 40) suggesting that site A water temperatures greater than 15°C are indicative of a plume of Columbia River water in the location during that time. Bonneville pool elevations fluctuate on the order of two feet during the summer months (Figure 16), which likely alters the cold-water refuge plume dynamics. The connectivity between daily fluctuation in Bonneville pool elevations to changes in water surface elevations at the tributary deltas and plume mixing of water temperature was not examined as a part of this study. The preliminary data collected in July 2024 suggests there is significant cold-water refuge plume mixing occurring at the daily time scale and should be considered for future restoration or management actions of cold-water refugia habitat.

### 4.3.3 Sediment Data

Twenty-seven sediment samples were collected at locations that were feasible, best capture longitudinal changes in delta bed material, and in key areas such as alcoves and sand bars (Figure 35). Four samples on the White Salmon River yielded cobbles that prevented the ponar dredge sampler from grabbing a complete sample and were excluded from lab analyses with the remaining samples sent to a laboratory and were analyzed for particle size distribution using methods D7928 and D6913. The particle size distribution data of the collected sediment samples is attached in Appendix A.

The sediment size distributions of the collected sediment samples are depicted in Figure 36, Figure 37, and Figure 38 for the Wind, White Salmon, and Klickitat River deltas, respectively. The Wind and White Salmon River delta sediments show a broad range in sediment sizes ranging from silts to gravels with the Klickitat River delta being comprised mostly of sands and silts.

In the Wind River delta, the finest sediments were at location 405 in the eastern embayment to the south of the railroad and road bridges while the coarsest sediments were at location 406 directly under the bridges. Sample locations 407 and 404 had similar size distributions, as well as locations 401, 402, and 403 that align with flow paths to either side of the large delta deposition (Figure 36).

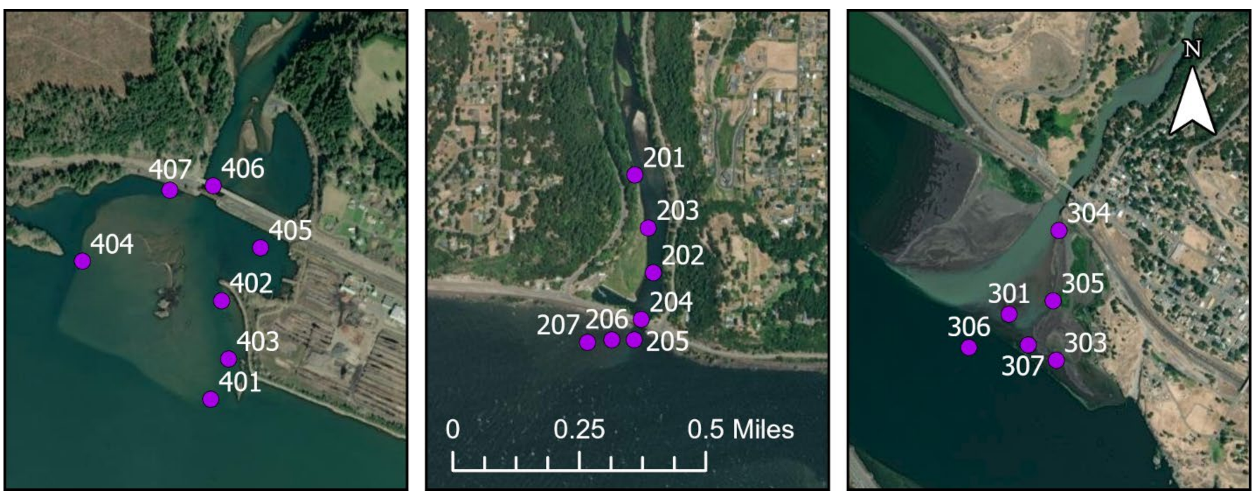



**Figure 35. Map showing sediment sample locations from July 2024 field study.**

In the White Salmon River delta, the most upstream sample location, 201, had the coarsest sediments and the finest sediments were at location 206 out in the mainstem Columbia River. Locations 203 and 207 had similar sediment size distributions to one another, as well as sample locations 202, 204, and 205 (Figure 37).

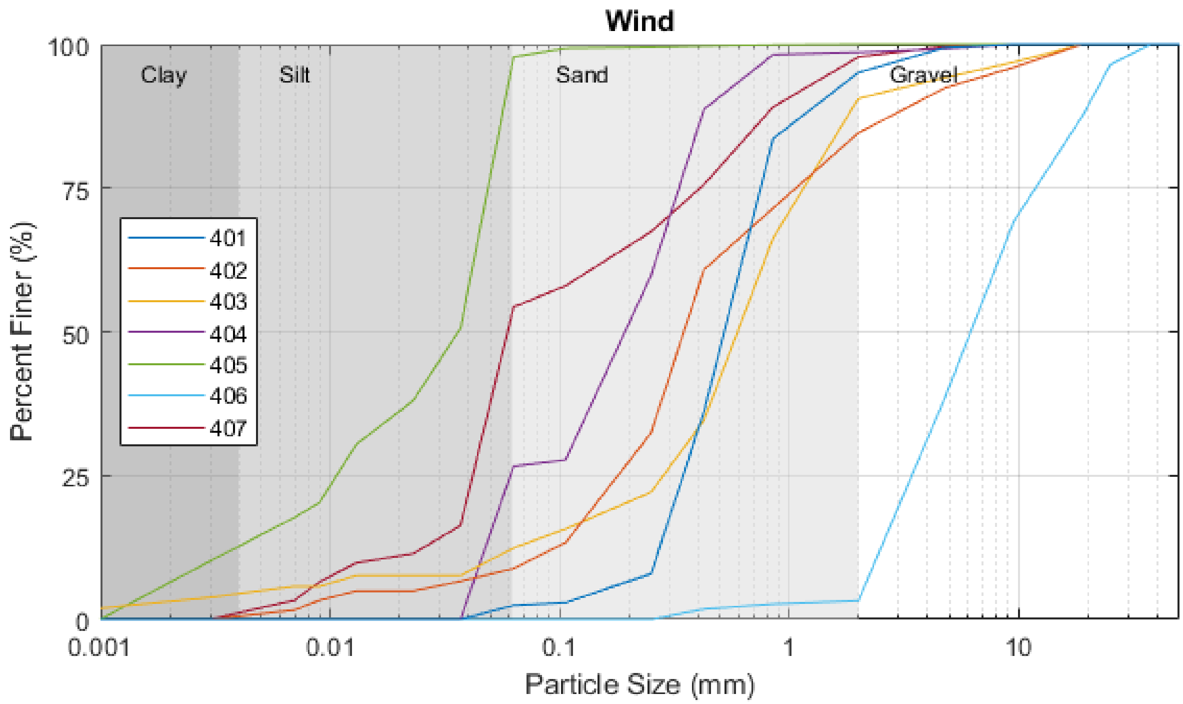



**Figure 36. Sediment size distribution for Wind River delta samples. (Sample numbers correspond to locations in Figure 35).**

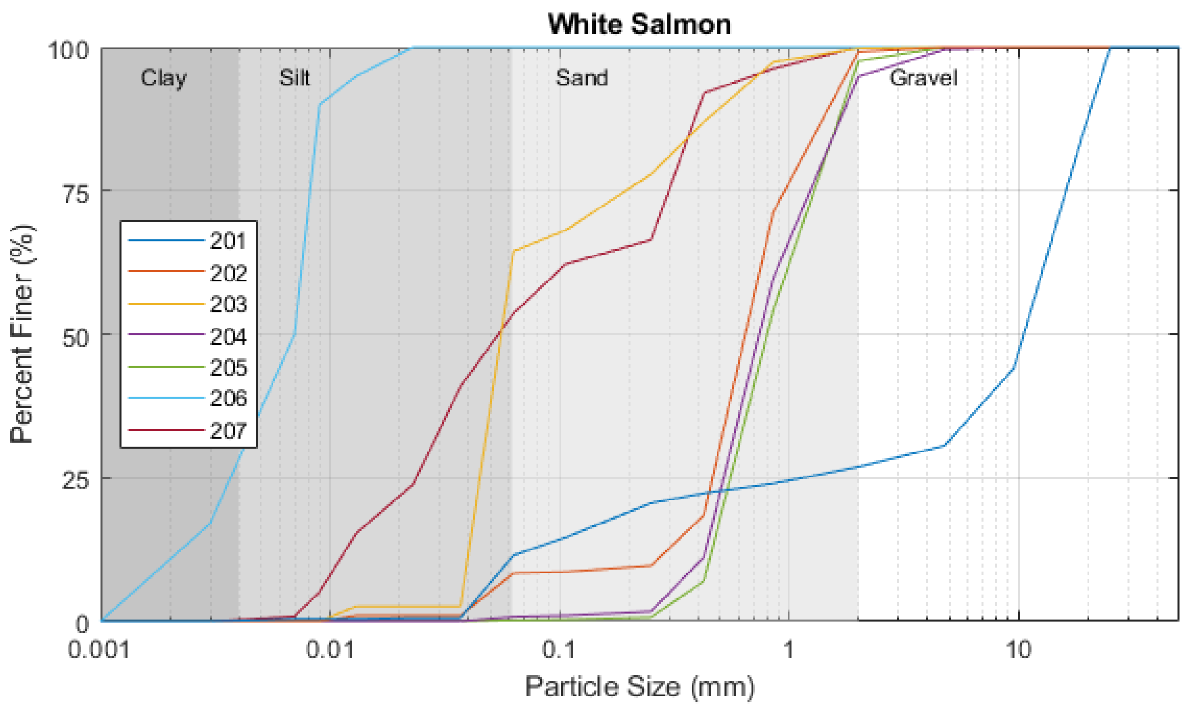



**Figure 37. Sediment size distribution for White Salmon River delta samples. (Sample numbers correspond to locations in Figure 35).**

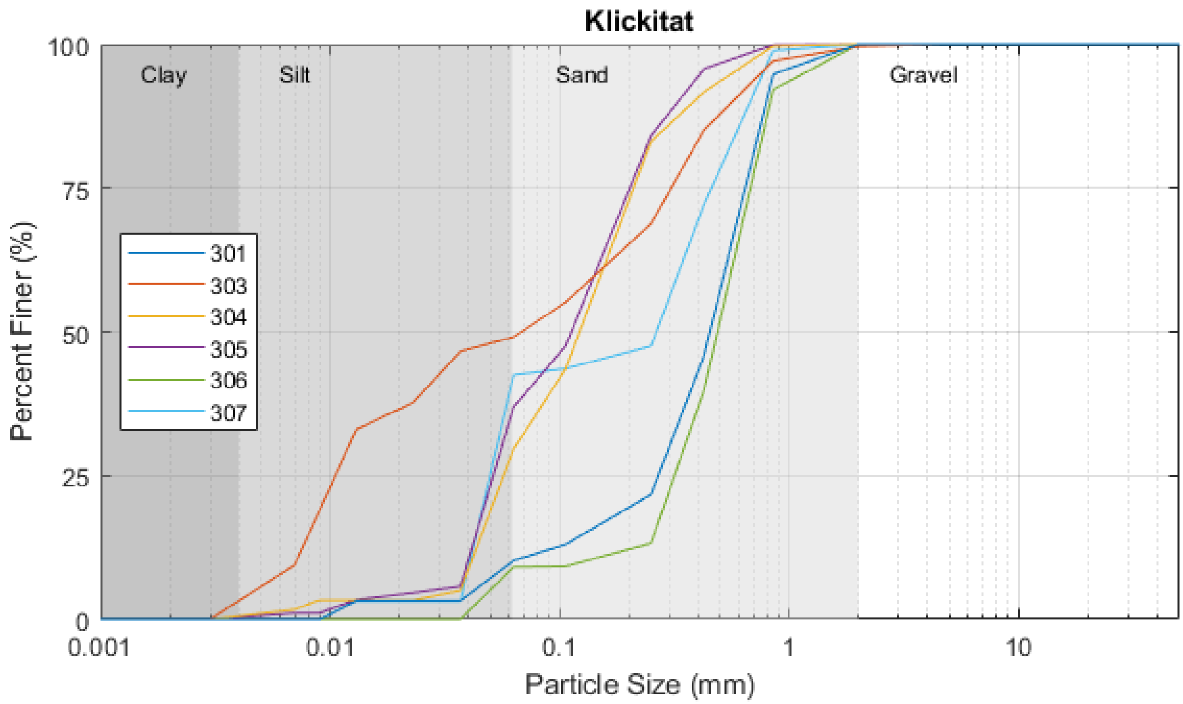



**Figure 38. Sediment size distribution for Klickitat River delta samples. (Sample numbers correspond to locations in Figure 35).**

While the Klickitat River delta sediment size distributions were similar, the sample location 303, the furthest sample to the east had the most silts of all the samples and sample locations 301 and 306 being coarser than the rest (Figure 38).

The sediment particle size distribution data came from a limited number of samples so interpreting the results should be done with caution. The Wind and White Salmon River delta sediment size distributions had the coarsest deposits located the most upstream into each tributary with finer sediments found moving along the delta towards the main stem Columbia River following a typical pattern for a delta sedimentation front. The Wind River delta has a large deposition in the embayment to the south of the railroad and roadway bridges where the flow is forced to go to either side of the deposition with the bed sediments suggesting there is more capacity to move coarser sediments in the pathway that goes to the west of the deposition. The White Salmon River delta had a large portion of gravel sediments at its most upstream location near the part of the river where island bars have formed with coarse and fine sand distributions further downstream and the silt deposits along the delta deposition to the southwest of the confluence region. The Klickitat had sand deposition throughout the delta, but with its coarsest sediment distributions further out into the Columbia River portion of the delta. This confirms with field observations made during the July 2024 sampling where it was difficult to access the delta by boat caused by the lack of a clear channel through the delta. This suggests that the sedimentation along the Klickitat River delta is potentially trapping coarser sediments at its outlet rather than following the typical delta front dynamics of downstream fining.

## 4.4 GAGE IMPLEMENTATION

The USACE-NWP contracted through the USGS to purchase, install, and maintain water temperature and turbidity sensors at the existing gages on the White Salmon River near Underwood, WA (USGS 14123500) and the Klickitat River near Pitt, WA (USGS 14113000). In addition, the inactive gage on the Wind River near Carson, WA (14128500) had flow gage improvements and the installation of water temperature and turbidity sensors with bringing the gage into active service. These three gages are the most downstream gages on each of the study rivers and will be used to characterize future flood events and seasonal thermal inputs to the cold-water refuge delta habitats (Figure 39). The Wind and White Salmon River gages are located approximately 2 river miles upstream of the Columbia River and the Klickitat River gage is located approximately 9 river miles upstream. The water temperature and turbidity gages became active on the Klickitat and White Salmon Rivers on 22-Apr-2024 and 05-May-2024, respectively, while the Wind River gage became active on 19-Apr-2024.

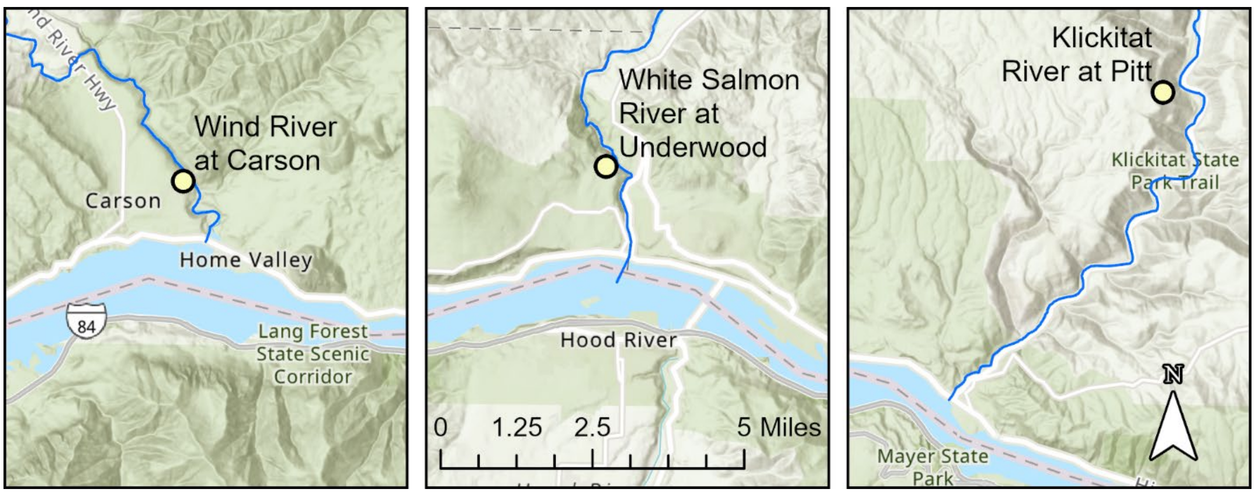



**Figure 39. Map showing locations of U.S. Geological Survey gages on study tributaries.**

Water temperature data recorded from 01-April to 01-October-2024 for the Wind, White Salmon, and Klickitat Rivers, as well as for the Columbia River at The Dalles is depicted in Figure 40. The Wind River temperature gage was not operations from 15-July through 24-July-2024. The Columbia River water temperature increased form 10°C in April to 22°C in August and did not get below 20°C until the end of September 2024. Of the three cold-water tributaries, water temperatures were the lowest in the White Salmon River that never exceed 13°C. Water temperatures in the Klickitat River were the highest of the tributaries with daily maximum temperatures above 20°C in July with diurnal oscillations between 14 and 20°C. The tributaries reach their maximum summer water temperatures in July whereas the Columbia River peaks in August.

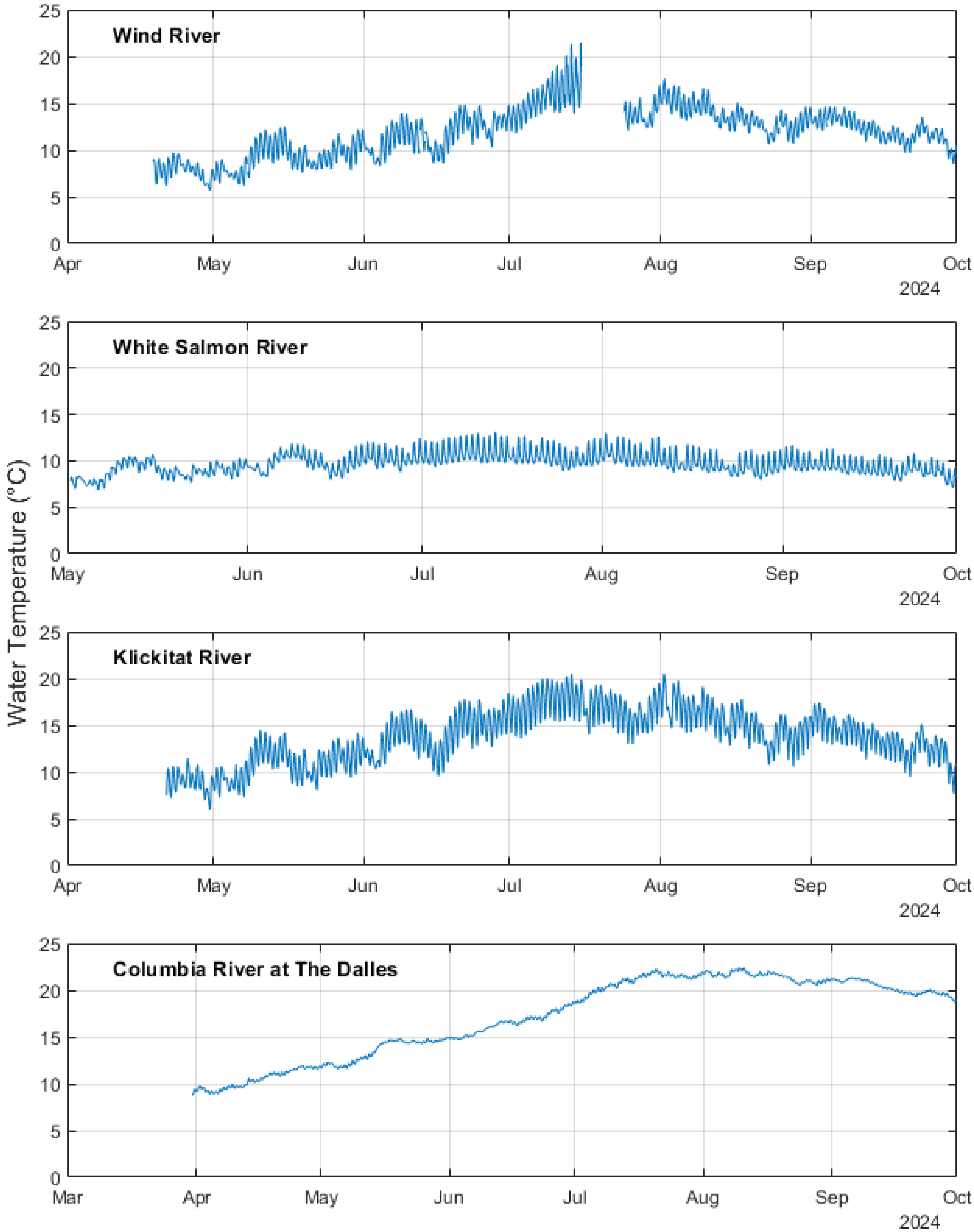



**Figure 40. Water temperature at Wind, White Salmon, and Klickitat Rivers for April through September 2024, along with Columbia River at The Dalles.**

The flow and turbidity data collected at the three USGS gages for April through September 2024 is shown in Figure 41. The Wind River gage shows the measured gage as a rating curve to flow has not been established yet. Flows and stages were declining in all rivers through September with an early June event detected at all sites. Turbidity values are reported in Formazin Nephelometric Units (FNU), which is a relative unit pertaining to how clear the water is. The Wind and White Salmon Rivers had turbidity values between 0 and 15 FNUs, while the Klickitat River had values between 0 and 250 FNUs. The baseline turbidity is higher in the Klickitat River which is visible by the brown coloration of the water in aerial and satellite imagery (see Section 3.2). The goal of these gages is to develop a baseline record of the thermal and sediment inputs from the tributaries that will require several years of continuous data collection.

The turbidity records at White Salmon and Klickitat gages have some peaks not associated with flood events (Figure 41). There have been observations of glacial sediment sources from Mount Adams resulting in sediment delivery during non-hydrologic events in these rivers that could account for the turbidity peaks, but there are several factors including algal blooms, wind, and sediment bed resuspension that can also affect turbidity values. Plans to fund the USGS to collect suspended sediment samples and develop a rating curve of sediment concentration from turbidity have been considered and would allow for direct observations to better understand the causes of non-event turbidity fluctuations.

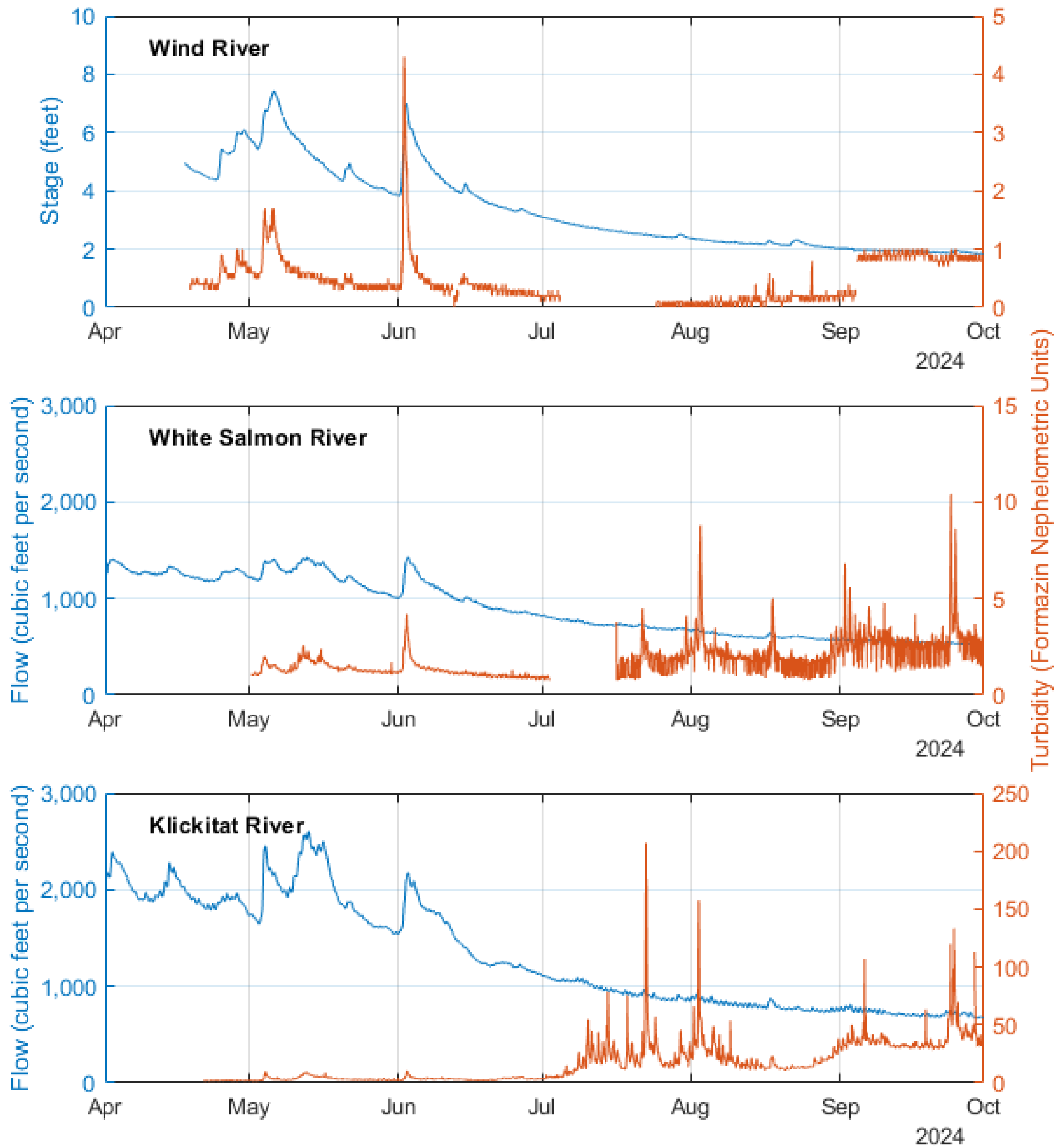



**Figure 41. Flow, stage, and turbidity data recorded at the Wind, White Salmon, and Klickitat Rivers for April through September 2024.**

# SECTION 5 - SUMMARY AND FUTURE ACTIONS

## 5.1 SEDIMENTATION AND COLD-WATER REFUGE

The EPA characterizes the tributary delta regions of the Wind, White Salmon, and Klickitat Rivers as primary cold-water refuge habitat because of their ability to create and maintain cold-water temperatures in summer months (EPA 2021a). The designation as primary habitats are largely due to information on water temperature obtained from the NorWeST database (Section 4.1.5) and an estimation of habitat volume based on aerial imagery, field observations, and simple models of mixing plumes at the tributary confluences. Sedimentation is characterize as having a negative effect on cold-water refuge habitats assumed to be caused by reducing the habitat volume and filling in gravel sediments with finer materials, which can both affect the heat budget processes leading to warmer water temperatures. The EPA assessment of cold-water refuge habitats points to land management actions to reduce erosion in the watershed to minimize the impacts of sedimentation but did not provide details regarding potential restoration actions for addressing the effects of sedimentation in the tributary delta regions.

The sediment load carried by the Wind, White Salmon, and Klickitat Rivers is largely derived by bank erosion and sediment yield from the river channel, floodplain, and the overall watershed and transported downstream by episodic flow events, as well as by non-event glacial sources from Mount Adams. It is assumed that the bedload and wash sediment loads occurring during base flow periods is small relative to the amount of sediment transported during high flow events. The rivers follow a meandering path as they near their confluences with the Columbia River with flow regimes that generate alternating point bar features where sediments settle out where velocities are low and accelerate the flow around the bar features. The alternating bars also form island bars (most notable in the White Salmon River after the Condit Dam removal) where deposition is occurring due to a lack of stream power to maintain sediments in suspension. As sediment-laden flows move downstream to the confluence with the Columbia River, the water surface elevation at the confluence is artificially elevated by the reservoir created by Bonneville Dam. The sediments start to deposit along the delta as the flows meet the pooled confluence regions and velocities are drastically reduced by the large depth of water. Coarser sediments deposit first, followed by finer sediments resulting in a downstream fining effect along the tributary delta as well as a flux of sediments out into the Columbia River.

The net effect of these processes was assessed in this study (Section 3) using limited information consisting of aerial and satellite imagery, along with flow data and limited sediment load data available for the study area. Significant sedimentation events can be thought of as ones that visibly change the structure of the tributary delta with respect to erosion and deposition and can be categorized as hydrologic or breaches. The processes of sediment generation to transport to the delta region described above are further influenced by local geomorphic factors of each delta such as the embankments of the railroad and roadway bridges and pre-dam floodplain elevations and connectivity. The Wind River delta is characterized by the low-lying floodplain regions that filled in after the construction of Bonneville Dam that created an embayment on either side of the railroad and roadway bridges. The White Salmon River delta was abruptly changed after the removal and sediment release from the Condit Dam removal in 2011 through 2012. The Klickitat River delta runs through a small canyon reach where the railroad and roadway bridges cross the river with depositional floodplain regions that reach out into the Columbia River that are nearing pre-dam extents, but with significant deposition in the channel directly at the confluence.

Deposition in the Wind and Klickitat River deltas appears to have largely been the result of the floods that occurred in 1974 and 1996, while changes to the White Salmon River delta was most affected by the Condit Dam removal from 2011 to 2012. The embayment on the Columbia River side of the Wind River delta formed a large deposit observed in 1991 image and appeared to have grown in the 2017 image and remain similar in size in the 2023 image (Figure 17 and Figure 18). The Klickitat River confluence is located downstream of a narrow constriction in the Columbia River known as the Ortley Narrows (Hodge 1938). The floodplain region at the Klickitat River confluence was inundated by the Bonneville pool, but images starting in 1969 (Figure 21) show significant deposits along the pre-dam channel that have largely filled in during summer conditions as observed in more recent satellite Imagery (Figure 22). Prior to the removal of Condit Dam, peak flows were reduced on the White Salmon River with the delta regions largely devoid of sediment bar features as most sediments were trapped upstream of Condit Dam. The breach of Condit Dam sent 1.8 million tons of sediment towards the Columbia over a few months (Figure 15) and resulted in a large deposition along the western bank upstream of the railroad bridge that was later dredged, reshaped, and vegetated as a part of a mitigation effort to restore navigation to the Underwood In-Lieu Site. The recent satellite and aerial imagery since 2017 depict the formation of channel point bars and island bars forming within the White Salmon River delta as this portion of the river is adjusting to the post-Condit Dam sediment load dynamics. While not a part of the study area, the Hood River delta saw a large change in its deposition in 2006 after a glacial dam breached on Mount Hood from a significant atmospheric river event (Poole 2016).

The field characterization of the cold-water refuge habitats conducted in July 2024 (Section 4.3) suggests that cooler water was present in areas not associated with the sedimentation features described previously. Sedimentation at the Klickitat River confluence was such that the channel was limited in flow depths of a couple feet suggesting that fish access could be limited. The map of water temperatures shown in Figure 30 for the Klickitat River only extends to approximately 600 feet to the south of the railroad and roadway bridge as most of the delta was inaccessible by boat from the Columbia River. The White Salmon River delta had greater water depths and cooler water temperatures relative to the other sites (Figure 27). The cooler water along the White Salmon River delta was in areas away from the bar features north of the bridge and a cold-water plume extending out into the Columbia River was observed (Figure 28). Water temperatures in the Wind River delta were coldest along the channels to either side of the sediment bar feature to the south of the bridge (Figure 29) where water depths were large such that thermal stratification was observed (Figure 33).

Data gaps will be addressed in the next section, but it was identified early on that the three study tributaries did not have water temperature recordings at the USGS gages nor flow for the Wind River. As described in Section 4.4, the three gages are now recording real-time values of flow (currently only stage at Wind River until a rating curve is developed), water temperature, and turbidity since April 2024. Of the three tributaries, water temperatures are coldest on the White Salmon River with temperatures below 15°C with July temperatures reaching 20°C on the Wind and Klickitat Rivers (Figure 40). The Wind and Klickitat River also depict larger daily changes in water temperature relative to the White Salmon River. For reference the water temperature data from the Columbia River at The Dalles was included that showed that the Columbia River exceeded 20°C in early July but reached its maximum temperature in August, whereas all three tributary sites showed decreasing water temperatures in August after their peak in July.

This study's characterization of sedimentation effects to cold-water refuge habitats is largely qualitative based on changes observed in aerial and satellite imagery, along with limited observed data on water temperature, flow, and sediment loads. The bathymetry data of the tributary delta regions currently being collected (Section 4.1.6) will be informative and set a baseline for examining future sedimentation for each delta. The EPA characterization of the cold-water refuge habitats is currently the baseline with respect to what is known about water temperatures and fish utilization (EPA 2021a). The flow and water quality gaging on the tributaries will provide the needed temporal and event information on thermal and sediment loadings to the deltas. All of these baseline datasets will inform the development of numerical models capable of quantifying sedimentation impacts to cold-water refuge habitat, as well as assess scenarios to help future preservation and restoration efforts.

## 5.2 DATA AND KNOWLEDGE GAPS

The primary data gaps for assessing the sedimentation impacts on cold-water refuge habitats is the lack of repeat bathymetry data of the deltas and gage data on sediment loads. These two data streams would allow for the quantification of the sediment load entering and the net deposition along the delta. These data types are needed at varying temporal resolution as the sediment load is needed in real-time to capture the large events that drive the geomorphic changes in the delta with the repeat bathymetric surveys needing to be performed periodically (approximately 5-year periods) and can be conducted after significant flood events occur.

The repeat bathymetric surveys should focus on the tributary delta regions up to depths of approximately 15 feet or less. The survey would likely require the use of a single beam sonar attached to a small remote operated craft, or manual kayak in order to navigate the shallow regions and move upstream into each tributary, as described in Section 4.1.6 regarding the effort CRITFC and OSU are currently conducting. Challenges to the survey effort will be winds and surface wave conditions affecting the sonar detection of the channel bottom, as well as the extensive area that needs to be covered. A potential option that could be considered is the use of green-laser LiDAR data collection, which can get elevations below water. The ability of green-laser LiDAR to penetrate water surfaces is often affected by the color and clarity of the water, which means its use for the Klickitat River might not be as effective due to its higher baseline turbidity (Figure 41).

The gage implementation described in Section 4.4 established real-time flow and turbidity measurement at the USGS gages on the study rivers. Field sample collection of suspended sediment concentrations can be used to develop a rating curve between turbidity and suspended sediment load using the methods described in Rasmussen et al. (2009). The USGS Washington Science Center were contracted to perform the gage implementation tasks and provided a scope of work for developing the suspended sediment load data, which consisted of approximately 15 field visits that spanned several years to cover a range in flood events. The effort to add in the suspended sediment load data at the Klickitat River gage (USGS 14128500) was estimated to cost $62,000 over a 3-year period for field work, $7,000 in lab fees, and $35,000 in technical labor to process the data and develop the regression equations needed to convert flow and turbidity values into suspended sediment concentration and load estimates. This totals to $104,000 to add suspended sediment load to the Klickitat River over a three-year period. Most of the costs associated with this task are related to the mobilization of the field data collection and data processing such that there would be substantial efficiencies if all three sites were done at the same time. The USGS estimated that each additional site beyond the Klickitat River gage would add another $9,000 to the total cost. This PAST study was not able to fund the suspended sediment data collection because of funding limitations, but it is anticipated that future studies and restoration efforts relating to cold-water habitats in this region of the Columbia River will be able to add in this data stream in the future.

## 5.3 NUMERICAL MODEL DEVELOPMENT

Numerical models of water temperature, sediment transport, and the dynamics of the tributary deltas are needed to better understand effects to cold-water refuge habitat and to assess alternatives for management and restoration strategies. A goal of this study was to establish the needed data for developing such models as described in Section 4. It is likely that multiple models would need to be developed to fully assess the cold-water habitat as sediment transport, water temperature, and fish utilization span a range of scales and resolution needs.

The EPA used a combination of models for the cold-water refuge assessment that included the simulated stream temperatures from the NorWeST database (Section 4.1.5) in combination with a plume mixing model (CORMIX) and a fish tracking model (HEXSIM) (EPA 2021a). A one-dimensional water temperature model (RBM10) was used to develop the water temperature TMDL for the lower Columbia and Snake Rivers (EPA 2021b). The Lower Columbia River Thermal Refuge study (Marcoe et al. 2018) developed three-dimensional hydraulic and water temperature models using Tuflow FV software to examine the feasibility of increasing cold-water refuge habitats at Bridal Veil Creek, Horsetail/Oneonta Creek, and Multnomah/Wahkeena Creek that are all located downstream of Bonneville Dam. All these models vary with respect to the processes they model, dimensionality (one- to three-dimensional), scale (temporal and spatial), and accuracy.

Model development for the Wind, White Salmon, and Klickitat River deltas should focus on the hydrodynamics and sediment transport elements relating the sedimentation effects to complement the existing CORMIX and HEXSIM models. A water temperature model could also be developed, but it may prove more cost-effective to measure water temperature directly given that the goal of the modeling would be to assess management and restoration actions focused on habitat. Quantifying the sediment budget for each delta through sediment load into each delta and repeat surveys to quantify the bathymetric changes would be used to calibrate a numerical model. The processes governing the dynamics of the tributary deltas are three-dimensional but given the relatively shallow water depths (on the order of 15 feet or less) a two-dimensional (vertically averaged) modeling approach would be appropriate. Establishing boundary conditions would include using the three USGS gages as inputs to the model as well as the USACE-Portland District's existing one-dimensional model of the Columbia River to establish the Bonneville pool elevations. Once the model is developed, it could be used to assess the tributary delta conditions for actions such as structure placement and removal of sediments like the scenarios proposed by Lower Columbia River Thermal Refuge study (Marcoe et al. 2018).

## 5.4 RESTORATION STRATEGIES

The primary impacts of sedimentation on the cold-water refuge habitats relate to reduction in habitat volume, limiting fish access to habitat, and filling in the sand/gravel deposits with fine materials. Therefore, management actions to limit sedimentation impacts focus on reduction of sediment yield from the watershed with numerous management plans given as examples in the EPA's cold-water refuge plan (EPA 2021a). Restoration strategies focus on creating more habitat volume, as well as actions to reduce sedimentation in the delta regions by allowing for more sediments to pass to the Columbia River.

The Lower Columbia River Thermal Refuge study (Marcoe et al. 2018) proposed several restoration implementations to enhance cold-water refuge habitat at tributary confluences downstream of Bonneville Dam that included modifying nearshore topography and diversion structure placement to force warmer Columbia River water away from the tributary confluence. Proposed structures were developed conceptually and typically consisted of a combination of small knolls with planted cottonwoods and continuous wood structure peninsulas held in place by large wood piles driven deep into the sediment bed. The study also looked at using a combination of dredging with proposed structures both in the tributary channels and out in the cold-water plume of the Columbia River. None of the proposed restoration strategies have been implemented yet so there is no information regarding viability of such structures in the Columbia River yet.

The Wind, White Salmon, and Klickitat Rivers have varying features such that restoration strategies need to be custom designed for each. For the Wind and Klickitat

Rivers, there are obvious depositional features in each delta that could be removed by dredging that would increase the cold-water refuge volume. The large embayment on the south side of the railroad and roadway bridges at the Wind River delta is problematic in that deposition will likely continue in the same location because of the low velocities in the embayment. Currently the flow is directed to either side of the shoal and numerical modeling would inform the best way to maintain flow channels by removing portions of the shoal and possibility elevating other portions to better direct the flow. The conditions for the Klickitat River are clearer as sedimentation has filled in most of the main confluence channel such that dredging the channel and elevating the floodplains to either side would likely force sediments out into the Columbia River. Elevating the floodplain regions to either side of the Klickitat River delta has additional merit based on aerial imagery of the pre-Bonneville Dam delta with its current state (Figure 21) that shows the floodplain regions are filling in to their pre-dam extents right at the river confluence. There is no obvious recommendation for increasing cold-water refuge volume in the White Salmon River delta. Of the three rivers examined, the White Salmon currently has the coldest water temperatures and greatest water depths. The sediment bar dynamics occurring to the north of the railroad and roadway bridges appears to be geomorphic adjustments of the river since the removal of Condit Dam.

Dredging activities in any of the deltas would fall outside of USACE’s authorized propose on the Columbia River FNC and dredging activities for the purpose of environmental restoration would require execution by another entity or a legislative modification. In October 2024, the Bureau of Indian Affairs announced a $9.9 million investment in improving conditions at in-lieu and treaty fishing access sites along the Columbia River, which could involve dredging regions of tributary deltas. Prior to dredging, the responsible party would need to identify suitable upland placement sites for material disposal and additional sediment testing to ensure that any contaminated sediment is properly disposed of. USACE would become involved with the dredging activities through the Section 404 permitting phase.

Any future restoration or management activities aimed at improving cold-water refuge habitat along the Columbia River would likely need to be assessed relative to other uses and constraints identified during the planning charette (Section 1.2.1). Dredging or constructing river training structures might have unintended consequences for fisherman and recreational uses (e.g., windsurfers and kayakers) that would have to be considered on a case-by-case scenario.

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# APPENDIX

Appendix A – Attached datasets.

| File | Description |
|---|---|
| AerialImagery_Klickitat_River.zip | Folders containing the original scanned historical imagery and the geo-rectified images. All final geo-rectified images are in the .aprx ArcPro file, associated geodatabase, and in the \RECTIFIED folder as geo-tiff files. |
| AerialImagery_White_Salmon.zip | Folders containing the original scanned historical imagery and the geo-rectified images. All final geo-rectified images are in the .aprx ArcPro file, associated geodatabase, and in the \RECTIFIED folder as geo-tiff files. |
| AerialImagery_Wind_River.zip | Folders containing the original scanned historical imagery and the geo-rectified images. All final geo-rectified images are in the .aprx ArcPro file, associated geodatabase, and in the \RECTIFIED folder as geo-tiff files. |
| Columbia_FNC_bathymetry.zip | Folders containing the bathymetric data collected for the Federal Navigation Channel survey of 2020. \CL_42_WML… = Wind River; \CL_46_HDR… = White Salmon River; \CL_49_MEM… = Klickitat River. Each subfolder has GIS shapefiles for contours and sounding points. |
| FieldData_July2024_SedimentParticleSize.zip | Collection of text files describing the sediment sampling locations, field and lab identification codes, and individual particle size distribution tables for each sample. There is also two .pdf files that are the final reports provided by the analytical laboratory the performed the sediment particle size distribution analyses. |
| FieldData_July2024_SondeEXO_data.zip | Contains comma separated value files of the water quality sonde data. The data columns include time, location, and depth for each row of sonde data. There is a folder \processed that contains the generated images of the data presented in the report. |
| FieldData_July2024_TermisterTimeseries.zip | Collection of files with the HOBO thermistor timeseries data and a GIS shape file with all the data in it. |
| SatelliteImagery_All.zip | Folders for each river that contain the geo-rectified tiff files downloaded from the Copernicus Date Space Ecosystem |