

**Attachment 2:**

**Environmental Impact Reduction Due to Refinement of  
Proposed Reservoir Operations & Debris Management  
During Flood Retention Operations Memorandum**

**Chehalis River Basin Flood Control Zone District**

**February 4, 2026**

# Memorandum

Date: February 4, 2026

Project: Chehalis River Basin Flood Damage Reduction Project

To: Chehalis Basin Flood Control Zone District

From: HDR & Kleinschmidt Associates

Subject: **Environmental Impact Reduction Due to Refinement of Proposed Reservoir Operations & Debris Management During Flood Retention Operations**

## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Cosmopolis during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

Following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), a Chehalis River Basin Flood Damage Reduction draft Preliminary Design Report (PDR) was initiated to document ongoing draft design refinements, as the design process iterates toward a future 30 percent design that will be documented in a completed PDR. The draft PDR records ongoing draft design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements and collects technical details of the main features of the Proposed Project elements as they continue to develop.

A SEPA Revised Draft Environmental Impact Statement (RDEIS) for the Proposed Project was issued on November 20, 2025 with comments due February 4, 2026. To support the submission of comments on the SEPA RDEIS, some draft design elements are being formalized in reports and memoranda to describe the current state of the project design. While still not at a full 30 percent preliminary design level, these elements are at a point at which they can reasonably inform tribal governments, state and federal agencies, partners, stakeholders, and the public about the nature of the project.

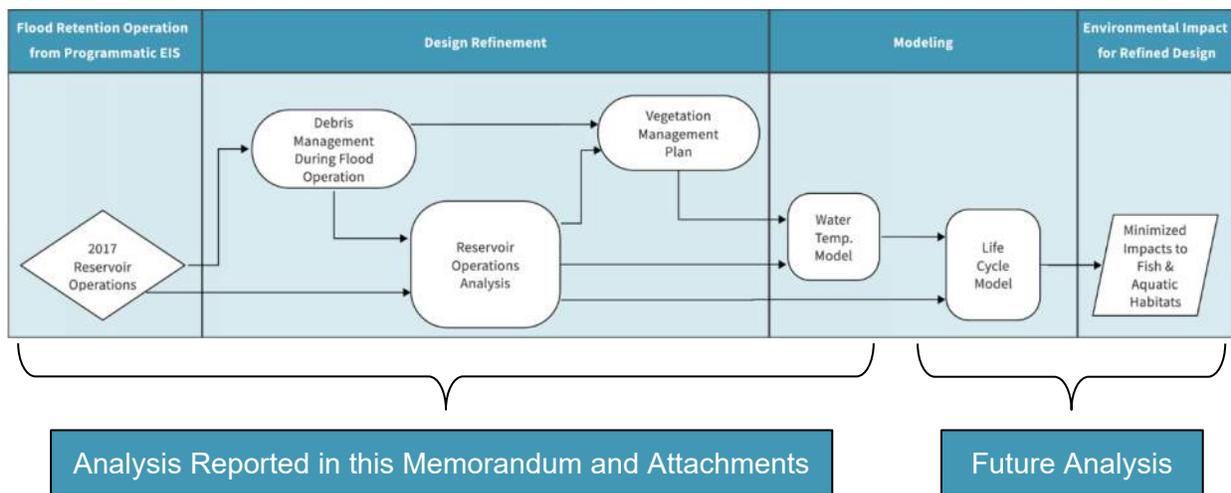
## 2.0 Purpose

This memorandum is provided to inform the reader of one of the efforts undertaken by the Chehalis River Basin Flood Control Zone District (District) since the 2020 SEPA draft EIS and 2024 Revised Project Description, to avoid and minimize potential adverse impacts to salmonid populations in the Chehalis Basin related to the proposed FRE facility.

### 3.0 Introduction

The proposed 2017 operating rules (2017 Operations) for triggering, filling, and draining a temporary inundation pool were developed by Washington state in support of a Programmatic EIS, out of which came the proposed FRE facility. Early evaluation of the environmental impact of the 2017 Operations indicated adverse impacts to salmonid populations in the Upper Chehalis River basin (Washington State Environmental Policy Act [SEPA] draft EIS; Ecology 2020). The FRE facility design was refined over the next several years to avoid and minimize impacts to salmonid populations. A flow chart summarizing the refinement and modeling process is provided in Figure 1.

**Figure 1. Flow Chart of Project Refinement to Reduce Environmental Impact**



Refinement began with flood retention operations, of which an important component is debris management during flood retention operations. Reductions to the time spent collecting debris, smaller areas for debris collection, and locating debris collection areas lower in the temporary inundation area allow greater flexibility in reservoir operation to preserve upstream riparian areas. This information was used in the reservoir operations analysis to refine how the temporary inundation pool is filled and drained, reducing the impact to salmonid populations while continuing to meet flood damage reduction goals. Refined debris management and reservoir operations data allowed examination of how the change in inundation levels would reduce impacts to salmonid redds upstream of the facility, as well as refinement of the Vegetation Management Plan (VMP) analysis regarding vegetation survival (Figure 1). The resulting increased shade and reduced frequency and duration of temporary inundation pools were entered into the water temperature model, showing estimated decreased future river water temperatures. In the future, the updated debris management, reservoir operations, redd inundation, vegetation management, and temperature data will all feed into updated Ecosystem Diagnosis and Treatment model (EDT) and life cycle analyses to demonstrate potential reductions in environmental impacts compared to the 2020 SEPA draft EIS and 2025 SEPA revised draft EIS.

## 4.0 Debris Management During Flood Retention Operation

The 2017 Operations reflected a 14-day debris management period where drawdown of the temporary inundation pool slows to a rate of 2 feet/day from 10 feet/day between the pool elevations of 500 and 528 feet to gather and store woody material that has accumulated in the pool during flood retention operations. From review of debris management operations at a similar flood control reservoir in western Washington, Mud Mountain Dam, further refinement was possible to reduce the debris collection period from 14 days to 5 days for a 100-year storm event. Smaller storms that warrant activation of the FRE facility might not generate significant debris, and thus the period may be truncated or even eliminated. The total storage area required for these operations was also refined, and debris storage areas further downstream, lower in the pool, were selected for debris management. The updated 5-day debris management period exists between the pool elevations of 477 and 487 feet. This allows the pool to more quickly draw down to a lower elevation and return more of the upstream watershed to free-flowing conditions sooner than the 2017 Operations.

The explanation above summarizes an extended analysis of debris management operations for the Proposed Project. For a more rigorous explanation of the analysis, please see the attached Debris Management During Flood Retention Report (Draft; Debris Management Report [Attachment 1]).

## 5.0 Reservoir Operations Analysis

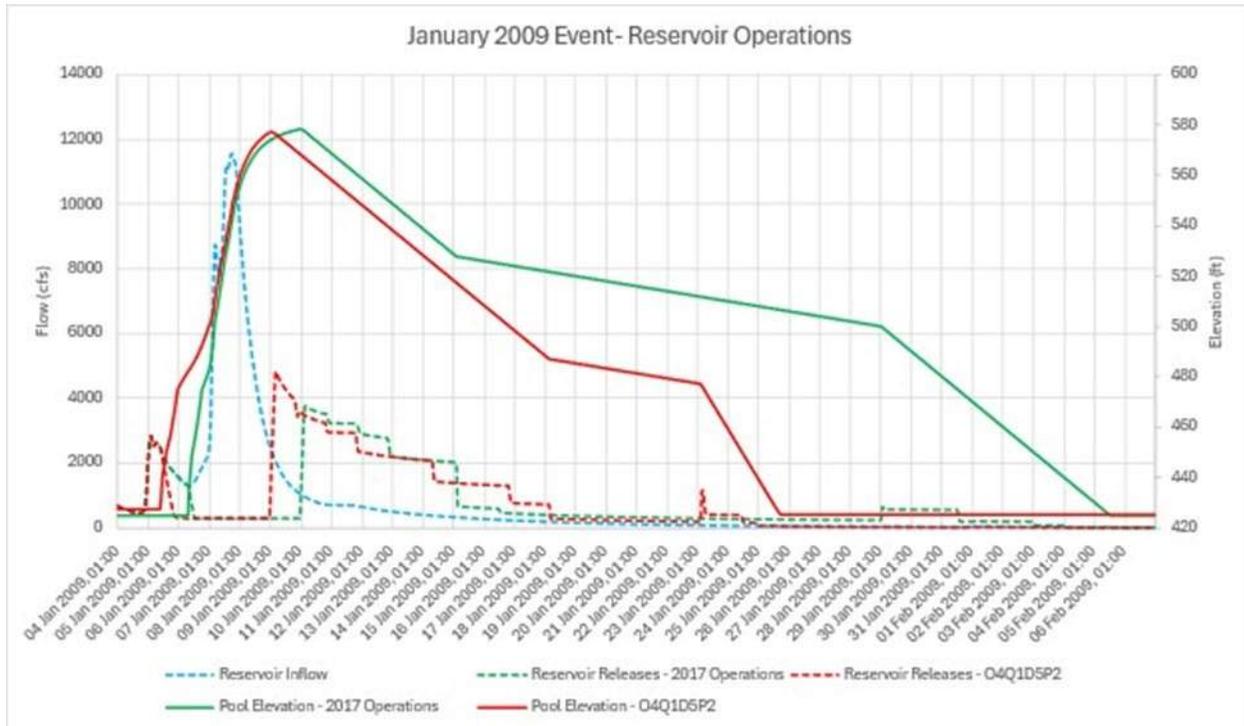
“Reservoir Operations” is a technical engineering term for how the facility fills and then draws down its temporary inundation pool during and after flood events. There is no permanent reservoir for the Proposed Project; it is merely called a “reservoir” in the modeling programs used to simulate the temporary inundation pool.

Starting with the 2017 Operations as a baseline operations set, various operational refinements were proposed and evaluated through modeling with HEC-ResSim and HEC-RAS software. One of the most notable improvements in operations is the O4 operations trigger (refer to Attachment 2 for terminology of operations scenarios), which provides a much more dynamic system than the more rigid 2017 Operations trigger. The 2017 Operations uses a trigger flow of 38,800 cfs at the Grand Mound streamgage; releases are to be reduced to 300 cfs 48 hours before this flow is reached at Grand Mound and pool drawdown is not initiated until flows at Grand Mound drop back below 38,800 cfs. Instead of following this unchangeable schedule for all storms, the O4 operations trigger better replicates the actions of a live reservoir operator who would be actively monitoring streamflow conditions, both upstream and downstream of the FRE facility. The O4 trigger aims for a flow no greater than 38,800 cfs at Grand Mound but allows more freedom in the timing of gate closures and openings. This allows the FRE facility to store less water than the 2017 Operations for the same storm while still providing equivalent levels of protection downstream. The debris management parameter (D5) was also refined based on research discussed above in Section 4 and in more detail within the attached Debris Management Report (Attachment 1). Drawdown rates were also examined, and with

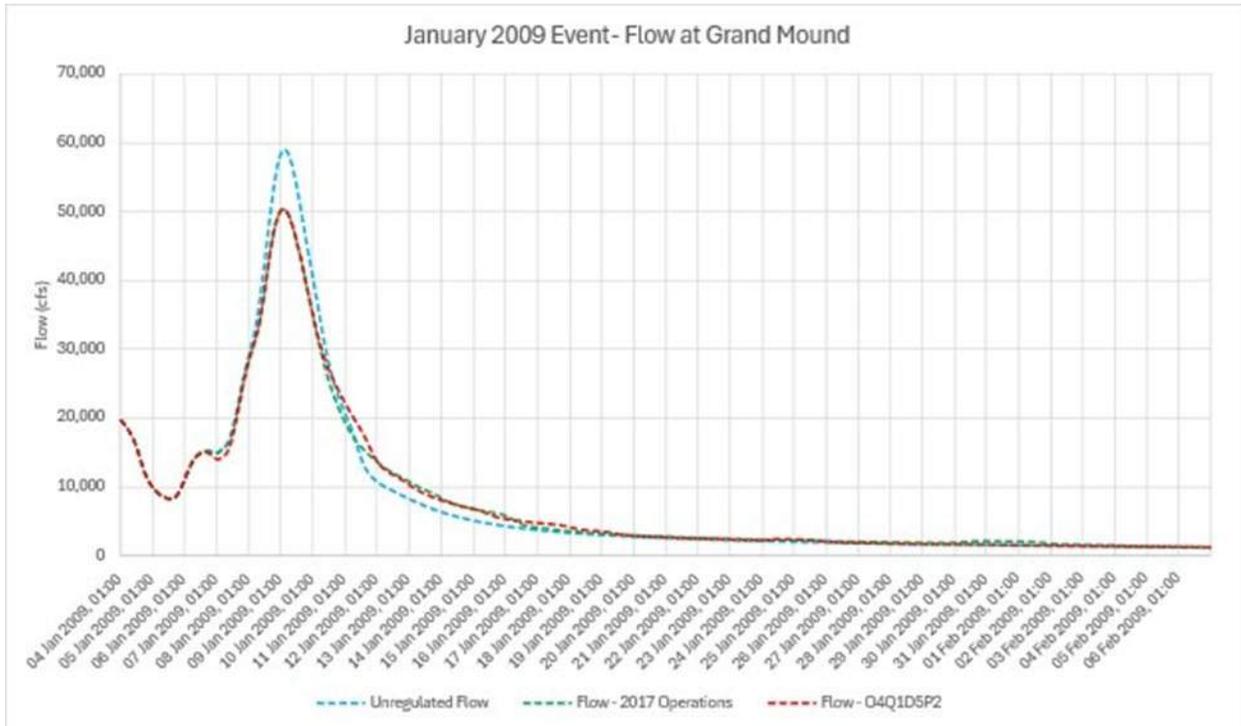
consultation with geotechnical engineers, an increased drawdown rate of 20 feet/day below 480 feet was implemented in the updated operations sets.

The most recent operations sets (O4Q1D5P1 and O4Q1D5P2) now provide similar levels of downstream flood protection while significantly reducing the duration and, in some cases, extent of the temporary inundation pool. Figure 2 and Figure 3 show proposed reservoir operations modeling of the January 2009 flood event between the 2017 Operations and the O4Q1D5P2 operations set. As shown in Figure 2, the O4Q1D5P2 operations set (red line) begins storing water a day earlier than the 2017 Operations (green line) but starts increasing releases and drawing the temporary pool down a day earlier than the 2017 Operations. The refined debris management operations are also apparent with a shorter debris management period at a lower elevation for the O4Q1D5P2 operations set compared to the 2017 Operations. With the increased drawdown rate of 20 feet/day after the debris management period has ended, the O4Q1D5P2 operations set only retains a temporary pool for 20 days, compared to the 2017 Operations which hold a pool for 30 days. Figure 3 shows the flow at Grand Mound based on the proposed reservoir operations, with the 2017 Operations and O4Q1D5P2 peak flows overlapping and both reducing the peak flow from 59,009 to 50,343 cfs – a 17.2 percent decrease.

**Figure 2. Reservoir Elevations, Inflows, and Releases - 2017 Operations and O4Q1D5P2 Operations**



**Figure 3. Flow at Grand Mound – Unregulated, 2017 Operations, and O4Q1D5P2 Operations**



In general, the two new proposed operation sets outperform the 2017 Operations by providing the same or greater level of flood protection while significantly reducing inundation pool durations.

The explanation above summarizes an extended analysis of operations sets that considered the current period of record and potential future storm conditions through the late century, including anticipated climate change effects. For a more rigorous explanation of the modeling, please see the attached Reservoir Operations Analysis Technical Memorandum (Attachment 2).

## 6.0 Redd Inundation and Updated Vegetation Analysis

The above-described reservoir operations refinements produced operations rule sets that would inundate less area than the original 2017 Operations and would drain the temporary inundation pool faster. The District selected one of these rules sets (O4Q1D5P2, called the “2025 Operations” in the analysis below) to examine its impacts on redd and vegetation survival.

When the most comprehensive redd survey data available (2018) was analyzed with respect to the 2025 Operations, it was evident that less than a quarter of each species’ redds were located within the temporary inundation pool. The 2025 Operations improved upon the 2017 Operations in two ways. First, the 2025 Operations would not inundate a portion of the redds that would have been inundated under the 2017 Operations. Second, for those redds that would still be inundated, more would be in the Initial Evacuation Zone which drains faster, making those redds less likely to be inundated at harmful levels.

The 2025 Operations' reduction in inundation area and duration would also reduce vegetation mortality. The area inundated for longer than 7 days was reduced by 0.4 river miles in a catastrophic flood (about 10%) and about 1 river mile in a major flood (about 64%). This corresponds to between 0.4 and 2.1 miles of riparian forest that would remain viable, which under 2017 Operations would not have survived. This increased tree viability will result in a taller canopy and increased shade, the temperature effects of which are described in the next section.

The explanation above summarizes a more extended analysis of redd inundation and vegetative effects. For a more rigorous explanation of the analysis, please see the attached Inundation Analysis with 2024 Project Design and O4P2 Operational Scenario Technical Memorandum (Attachment 3).

## 7.0 Water Temperature Model

The data from the above-described inundation analysis concerning tree viability served as the basis for modeling how the 2025 Operations would affect a canopy cover and height in major and catastrophic floods with and without the Proposed Project's VMP and downstream riparian shade mitigation. These canopy height estimates were then used to inform a CE-QUAL-W2 model to determine water temperatures associated with the same scenarios. The modeling included new topographic data around Crim Creek that more accurately reflected current conditions than the District's previous temperature modeling.

The results showed that 2025 Operations resulted in the unmitigated project having less of a temperature impact on the Chehalis River near the project facility. In contrast, at the mouth of Crim Creek before it reaches the project, the updated topographic data revealed Crim Creek to be cooler without the project than previously modeled, meaning that the project was having a greater warming effect on the lower reaches of Crim Creek than previously expected. Nevertheless, by the time the water reaches the Chehalis River, the overall water temperature impact for the 2025 Operations was less than for the 2017 Operations.

Results including the proposed VMP and downstream riparian planting were similar. Although the impact at the mouth of Crim Creek was more than previously expected, by the time the water reached the Proposed Project site, the temperature impact was reduced. The 2017 Operations were modeled resulting in a maximum 7-day average warming of 1.2°C (C) at the project site, whereas the 2025 Operations resulted in only 0.8°C of such warming, representing a 33 percent impact reduction.

Downstream, the 2025 Operations reduced water temperature impacts as well. Including the proposed VMP and downstream riparian planting, the 2017 Operations' 1.2°C modeled temperature increase at the project site gradually dropped to 0.2°C by Jones Creek; by Elk Creek, the river would be cooler (-0.3°C change), and by Adna the river would be substantially cooler (-1.2°C change). For the 2025 Operations including the VMP and downstream riparian planting, the 0.8°C modeled increase at the project site dropped more rapidly downstream: by

Jones Creek the river would already be cooler (-0.5°C change) and continued substantially cooler at Adna (-1.2°C change).

The explanation above summarizes a more extended analysis of canopy height and cover and temperate effects. For a more rigorous explanation of the analysis, please see the attached Riparian Shade Temperature Model with 2024 Project Design and 2025 (O4P2) Operations Technical Memorandum (Attachment 4).

## 8.0 Conclusion and Future Analysis

The updated debris management and reservoir operations analysis resulted in a flood operation system that would inundate less area and drain the temporary inundation pool faster. These changes would result in fewer redds being inundated and greater tree and shrub viability upstream of the Proposed Project. The ensuing increase in canopy height and cover would reduce the Proposed Project's potential temperature impacts, and in combination with its proposed downstream riparian planting would reduce downstream temperatures faster.

In the future, the debris management, reservoir operations, redd inundation, vegetation management, and temperature data will all feed into updated EDT and life cycle analyses to demonstrate reduced fish impacts in the project vicinity compared to the 2020 SEPA draft EIS and 2025 SEPA revised draft EIS.

## 9.0 References

HDR Engineering, Inc. (HDR)

- 2024 *Revised Project Description Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Control Zone District, Lewis County, Washington. April 2024.
- 2025 *Draft Preliminary Design Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Damage Reduction Project, Lewis County, Washington, June 30, 2025.

## 10.0 Acronyms/Abbreviations

DEIS	SEPA Draft Environmental Impact Statement
District	Chehalis River Basin Flood Control Zone District
EDT	Ecosystem Diagnosis and Treatment model
EIS	Environmental Impact Statement
FRE	Flood Retention Expandable
HDR	HDR Engineering, Inc.
PDR	draft Preliminary Design Report
Proposed Project	Proposed Chehalis River Basin Flood Damage Reduction project
RCC	roller-compacted concrete
SEPA	State Environmental Policy Act
TM	Technical Memorandum
VMP	Vegetation Management Plan

# Attachment 1 – Debris Management During Flood Retention Report (Draft)



# Debris Management During Flood Retention Report (Draft)

Chehalis River Basin Flood Damage Reduction  
Project

*Lewis County, Washington*

**January 9, 2026**



**Chehalis River Basin**  
Flood Control Zone District



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Appendix A. USACE MMD Site Operator Meeting Notes

## Acronyms and Abbreviations

cfs	cubic feet per second
District	Chehalis Basin Flood Control Zone District
Ecology	Washington State Department of Ecology
FRE	Flood Retention Expandable
HDR	HDR Engineering, Inc.
HEC-RAS	Hydrologic Engineering Center River Analysis System
LWM	Large Woody Material
PDR	Preliminary Design Report
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

# 1 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south Pe Ell, Washington.

The Chehalis River Basin Flood Damage Reduction, draft Preliminary Design Report (PDR) documents development of the preliminary design of the FRE facility and related elements. Development of the draft PDR began following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), which was used as the baseline for the draft PDR. This draft PDR reflects design development that has occurred since submittal of the June 30, 2025 draft PDR (HDR 2025a).

The draft PDR documents the design basis for each Proposed Project element, including a record of design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements. The draft PDR also presents the technical details of the main features of the Proposed Project elements.

# 2 Introduction

The proposed FRE structure on the Chehalis River is projected to accumulate woody debris and upstream of the structure during normal flow-through operation and flood retention operation. Smaller woody debris will be captured on trashracks during flow-through design. Larger flow events will transport bedload downstream to the dam, some of which will be small enough to pass through the trashrack; larger diameter bedload will accumulate upstream of the trashrack. Flood retention operations will occur during large storm events and result in a temporary inundation pool above the structure. The pool area and elevation will depend on the size of the storm. Heavy rain in the upper watershed will move large woody material (LWM) to the Chehalis River and cause occasional mass wasting events that will also input LWM to the Chehalis River. LWM will move downstream causing accumulation of LWM in the inundation pool and at the FRE. Accumulated debris at the trashrack and in the inundation pool needs to be managed to avoid debris damage at the structure and excess accumulation of LWM in the Chehalis River that would affect normal flow-through operations. Work boats and log broncs towing log booms will be used to corral LWM from the reservoir and move it to debris storage areas where it will be kept in place with log booms until the temporary pool recedes and the LWM can be removed from the Proposed Project area by land-based equipment and personnel.

In 2021, HDR prepared a *Large Woody Material Downstream Passage and Placement Clarification Technical Memorandum* to inform the impacts analysis for the Final Environmental Impact Statements (EISs; HDR 2021). The 2020 Draft EIS prepared by the Washington Department of Ecology (Ecology) and the USACE identified impacts to aquatic habitats downstream of the proposed FRE facility from the reduction of LWM

inputs from the upstream reach of the Chehalis River. HDR identified temporary storage, staging, and distribution of LWM for downstream habitat enhancement.

This previous study noted the debris would be contained within a single debris storage area during temporary storage. The area would be located between river mile 109.6 and 109.9, approximately 4.5 acres, where processing would occur following flood events. An estimate of the debris that could be generated was not used at this time for the selection. The location was based on a desktop study of the river geomorphology, drawdown elevations, relative flatness, and access of the area.

As described further below, a single debris storage area was determined to be inadequate for the estimated debris volume generated through various flood events during operation and drawdown. Therefore, multiple debris storage areas were examined to determine their ability to provide the area needed for most flood events and allow the operations team to adapt to the unique flood and debris conditions during each event. Additional potential storage areas were also examined to determine their ability to be used for contingency if more LWM is transported to the proposed structure than expected.

This report summarizes the methodology used to develop estimates of the volume of LWM in the inundation pool during flood events. Based on the estimated debris volume calculation results, this report also describes ways in which the expected LWM in the inundation pool may be managed; explains how potential debris storage areas upstream of the proposed structure were identified and evaluates their respective values; identifies two recommended debris storage areas for the Proposed Project, one of which would be needed only for initial flood events; provides a high-level analysis of LWM staging and sequencing which will be used for future operations and sequence planning; and identifies recommended locations and expected function of debris fences upstream of the inundation pool area.

### 3 LWM Volume Estimation Background

Empirical data and theoretical models were used to estimate LWM volume. The Mud Mountain Dam (MMD) project was used as a template for debris management and as a volume generation empirical data point. To understand debris collection, storage, and management, MMD functions similarly to the proposed FRE facility and has more available empirical data compared to other facilities. Except for the MMD project, typical LWM management practices are not consistently documented for other comparable facilities and there is a lack of published literature specific to debris estimates for such flood storage management systems or even natural river systems.

Section 3.1 provides MMD background data that is used to scale LWM volume estimates to the proposed FRE structure. Several approaches calculating LWM estimates for the proposed FRE project rely on the comparative hydrology of the White River watershed above MMD and the Chehalis River basin above the proposed FRE facility. The hydrology for both sites applicable for the calculations is outlined in Section 3.2. For theoretical methods of determining estimated debris volumes, the estimated debris volume is converted to acreage of debris when collected into holding areas (Section 3.3).

## 3.1 Mud Mountain Dam

MMD, located near Buckley, Washington, is a flood control dam protecting the lower White and Puyallup River valleys by storing inflows during flood events and then slowly releasing water back into the river. The project is managed for flood operations by staff in the Reservoir Control Center of the U.S. Army Corps of Engineers' (USACE) Seattle District. The reservoir is not used for water supply, and it is typically kept empty until flood events occur. When full, the reservoir stretches 5.5 miles upstream of the dam and covers 1,200 acres at maximum full pool (at the spillway crest elevation). Though the dam has an uncontrolled emergency spillway situated on the right abutment of the dam, it has never spilled since original construction completion in the late 1940s. All flows are released through three large sluice gates at the base of an outlet tower at the base of the dam.

MMD was primarily selected for developing debris estimates and debris management given its similar operations to that planned for the Chehalis FRE Proposed Project. Similar to how the proposed FRE structure would operate, MMD creates a temporary inundation pool to attenuate downstream flooding, and as a consequence accumulates large volumes of LWM that must be collected, stored, and disposed. Though MMD and the proposed FRE facility are comparable in function, their respective watersheds differ in soil type, geology, hillslopes, channel slope, hydrology, sinuosity, vegetation, and land management aspects, all of which affect the volume of LWM generated during flood events. For instance, MMD watershed has a larger percentage of unmanaged forest land cover than the Chehalis basin above the proposed FRE structure. The basin above the proposed FRE structure is primarily managed for commercial timber production and is in regular rotation of harvest and growth cycle. In addition, the Chehalis River upstream of the proposed FRE structure is highly confined by bedrock compared to the White River which flows through more erodible alluvial deposits. The LWM in the Chehalis River may not be sourced as readily if it is rooted in bedrock. Finally, the White River upstream of MMD is less sinuous than the Chehalis River upstream of the proposed FRE structure. At lower flows, more LWM would be captured in the banks and terraces in the Chehalis River compared to the White River but could have a higher build-up of log jams released at high flows. Hence, if basin sizes were the same the amount and type of LWM generated within each basin would differ based on basin characteristics. The specific differences of soil, geology, vegetation composition, land management, and flow duration were not quantified because models approximating LWM quantities based on characteristics and data comparing each of the basins were not available. The general differences used to scale the LWM values include basin size, stream length and peak flows. Equations were developed to quantify the LWM accumulation based on these general, readily available basin characteristics. The general results were used in planning and management of LWM accumulations herein, but are independent from the specific, non-quantifiable differences listed above.

### 3.1.1 Empirical Data

To develop empirical estimations of LWM areas and rates of removal at MMD, HDR conducted an interview via a video conference with the USACE MMD project operations staff on March 25, 2025. Appendix A contains the interview meeting notes and follow-up

emails, which provide estimates of LWM and operational procedures. During floods, LWM accumulates in the MMD reservoir as a temporary inundation pool forms. The MMD operators work quickly to collect and move the LWM to storage pens contained within floating log booms along the reservoir shoreline near the dam using log bronc boats and floating booms while there is sufficient stored water to accomplish the debris management operation. The LWM volume and debris storage pen areas estimates from operators are imprecise but provide a general estimate of debris storage pen areas typically observed at the Proposed Project. MMD uses three debris storage areas (basins) within the reservoir limits for debris management, mediated by the storage pool elevation achieved during each flood event. The lower basin can contain 5 acres and is used for temporary storage, when needed. The middle and upper basins can contain 13 and 17 acres of debris, respectively. Overflow debris storage areas at the upper basin is used to expand basin capacity by as much as an additional 15 to 20 acres during emergencies. If only the middle and upper basins are used, approximately 30 acres would be available. With additional temporary and emergency storage areas activated, up to 55 acres of storage would be available. Based on an internal debris management plan written by USACE (R. Emry, personal communication, May 5, 2025), debris varies based on frequency and scale of inflow peak flows but between 40 and 60 acres of LWM is expected during larger flood events. Maximum debris loading at MMD is limited to about 60 acres of actively utilized storage area, which has only infrequently been generated at MMD.

Data correlating the amount of LWM stored to flood events or recurrence intervals is limited and based primarily on three flood events observed by USACE (MMD) operators within the past three decades. Previous historical debris estimates for eras prior to the mid-1990s are not available. These three recorded large flood events occurred in 1996, 2006, and 2009, respectively. The USACE operators estimate that in 2009 (the 2009 flood event correlates to a 75-year return interval), between 35 and 40 acres of LWM were generated and stored. For this report, the 2009 flood-generated debris loading was assumed to be approximately 40 acres. The other two floods in 1996 and 2006 used all available storage with debris containment booms expanding into the upper basin emergency storage overflow areas. USACE estimates more than 40 acres of LWM were generated in both the 1996 and 2006 flood events. With emergency storage used and based on the highest gage inflows during these two flood events, the 1996 and 2006 floods were estimated to have generated about 50 and 60 acres of LWM, respectively (refer to Table 4-4 for peak inflow correlations). These LWM acreage estimates at MMD and the White River watershed basin characteristics are used to correlate LWM loadings at the proposed FRE structure.

## 3.2 Hydrologic Comparison of the White and Chehalis Rivers

Basin hydrologic data and flood event return intervals are used in three of the LWM area estimation approaches. The hydrology of the White River above MMD and the proposed FRE structure on the Chehalis River is described in the subsequent sections for comparison. Additionally, inundation pool elevations observed during flood events where estimated LWM loadings were documented at MMD were roughly correlated to

approximate hydrologic flood recurrence intervals. However, it should be acknowledged that maximum reservoir inundation elevation is not necessarily directly correlated with the inflow event recurrence interval given the variable dam regulation operations that might have been conducted during those events.

### 3.2.1 Mud Mountain Dam on the White River

U.S. Geological Survey (USGS) gage number 12098000, located at MMD near Buckley, Washington was used to collect water surface elevation data. The gage is currently active with continuous data dating back to 2007. This data was used to form an approximate return interval - flood stage relationship (Table 3-1; HDR 2024b).

**Table 3-1. Mud Mountain Dam Flood Stage**

Return Interval (year)	Flood Stage (ft)
10	986
20	1,027
50	1,076
100	1,096
500	1,143

Inflow to MMD are recorded at the USGS gage (gage #12097850) located 4.5 miles upstream of USGS gage 12098000. This gage has a continuous period of record from 1974 to 2014. For this analysis, we assumed the inflow at MMD itself is slightly higher than the flow at the upstream USGS gage 12097850, therefore the gage records were scaled up proportionally by the difference in basin size of 6.6 percent. Table 3-2 provides the discharge related to return interval at USGS gage 12097850, which was pulled from StreamStats and multiplied by a factor of 1.066 (USGS 2019).

**Table 3-2. Mud Mountain Dam Peak Flows**

Return Interval (year)	Flow (cfs)
2	13,511
5	19,468
10	23,404
25	28,511
50	32,340
100	36,170
200	40,106
500	45,319

cfs: cubic feet per second

### 3.2.2 Proposed FRE Structure on the Chehalis River

The USGS does not have gages on the Chehalis River above the FRE structure's proposed location, but records from the nearby downstream gage at Doty include significant flood events with approximately 40 years of data. Projected inflows at the FRE were calculated by scaling the Doty gage records 80 percent as described in the HDR report *Chehalis River Above Ground Mound: Unregulated Flood Frequency and Record Extension Analysis (Draft)*. Table 3-3 outlines the flows at the proposed FRE structure from HDR (2024c).

**Table 3-3. Chehalis Proposed FRE Dam Peak Flows**

Return Interval (year)	Flow (cfs)
5	15,500
10	20,200
25	26,800
50	32,200
100	38,000
500	53,500

### 3.2.3 FRE Inundation Pool

Inundation water surface elevations at the proposed FRE structure were developed using a Hydrologic Engineering Center River Analysis System (HEC-RAS) flow files and a reservoir routing analysis. This was developed by Watershed Science & Engineering and Anchor QEA (HDR 2020). Since development of these inundation water surface elevations in 2020, the Proposed Project design has been updated, and new hydrologic data is available. Future iterations of this report will update the proposed inundation stage elevations accordingly. However, this iteration relies on the 2020 proposed surface elevations, which provide a conservative view of potential stage elevations and are therefore appropriate for use at this phase of design.. These previously developed elevations are assumed accurate for this current level of analysis and provided in Table 3-4.

**Table 3-4. Chehalis Proposed FRE Structure Inundation Stage Elevations**

Return Interval (year)	Inundation Pool Elevation (ft)
10	568
20	582
50	590*
100	604
500	620

\*Interpolated

### 3.3 Volume to Area Assumption

USACE provided MMD's recorded observations data to HDR in acres (Appendix A). To maintain consistency across results and estimate wood that will fit in debris storage areas, all LWM quantities are reported in acres. Theoretical volume estimates for the Chehalis basin were converted to acres for comparison, assuming the following:

- The assumed height of the debris when stored is on average 2 feet. This is based on visual inspection from a typical debris storage area such as a reservoir on Ross Lake (Photo 3-1) and the average diameter of LWM in the Chehalis basin.
- Based on the *Chehalis Basin Strategy; Operations Plan for Flood Retention Facilities* document, the average diameter of LWM in the upstream reach is 13.6 inches (Anchor QEA 2017).
- Assumed that debris is stacked two logs high as shown in Photo 3-1, accounting for root wads, the average height is assumed to be 2 feet.
- Based on visual inspection from the example at Ross Lake, the void space is estimated to be 80 percent, calculated by multiplying the area estimates by 0.2 to get only the area formed by stacked in line LWM.

Photo 3-1. Ross Lake LWM Storage Yard



## 4 LWM Area Estimation

Six different approaches were considered to estimate the acreage of LWM that could be transported to the FRE's inundation pool during a flood. The first two approaches outlined in sections 4.1.1 and 4.1.2 are theoretical and assume landslides are the primary source of LWM. Sections 4.1.3 through 4.1.6 outline four approaches that correlate to MMD's empirical data to the proposed FRE facility to estimate LWM acreage.

An additional seventh approach was initially considered but not ultimately adopted. It uses empirical data to predict volumes of debris flows generated by recently burned basins in the western United States. Though this approach is relevant because it uses equations to calculate acreage of LWM based on basin characteristics, the data is sourced more broadly from the western United States. In addition, the burned basins from the study are not relevant to the basin upstream of the proposed FRE facility. These results were so widely varying this method was not used in the analysis (Gartner et al. 2008).

### 4.1 Methodology

The six approaches used to estimate LWM are described in Sections 4.1.1 to 4.1.6.

#### 4.1.1 Debris from Landslides (Previous Geomorphology Study)

This approach considers LWM inputs from landslides as The *Chehalis Basin Strategy; Geomorphology, Sediment Transport, and Large Woody Debris Report* states that most LWM in the Chehalis basin is sourced from landslides (Watershed GeoDynamics and Anchor QEA 2017). As described in the 2017 report, the LWM volumes are based on past inventoried and digitized landslides from aerial photographs from 1955 to 2008 (Figure 4-1; Watershed GeoDynamics and Anchor QEA 2017). These estimates based on historical data are conservative because future volumes will be based on LWM from forests that will have benefited from improved timber harvest practices. Improved timber practices reduce the risk of initiating mass wasting events such as landslides and debris flows, with potentially less LWM transported to the reservoir. From this report, it is assumed the landslide volume of debris captured by aerial photography occurs during the highest flow recurrence interval flood that year. For instance, in 1978 a 21-year recurrence interval flood event occurred, and the aerial photos in 1978 captured 14,000 cubic yards of debris delivered from landslides. Therefore, the 21-year recurrence interval flood is directly associated with 14,000 cubic yards.

Figure 4-1. Estimated Volume of Wood and Debris Based on Past Storms

AERIAL PHOTOGRAPH YEAR	VOLUME OF WOOD AND DEBRIS (CUBIC YARDS)	HIGHEST FLOW RECURRENCE IN AERIAL PHOTOGRAPH PERIOD
1955	5,800	5
1965	10,000	5
1978	14,000	21
1987	2,300	5
1993	25,000	42
1996	36,000	75
2008	3,300,000	500 +/-

Source: Watershed GeoDynamics and Anchor QEA (2017)

The landslide data was then processed for this report to correlate LWM loadings in acreage to return intervals. Unit conversions and the assumptions from Section 3.3 were used to adjust from cubic yards to acres. Table 4-1 provides the data showing a relationship between acres of LWM sourced from landslides and return intervals. The volume of wood and debris assumed is based on all landslides that occur in the basin upstream of the proposed structure, with all the debris conveyed to the structure. This again conservatively estimates the amount of LWM that may be delivered. Based on past observations at MMD on the White River, the material that mobilizes due to landslides would be deposited on lower-gradient slopes and terraces instead of entering the river (Ecology 2020).

A 5-year recurrence interval flood event occurred three times (1955, 1965, and 1987) resulting in three different volumes associated with the 5-year event. In order to arrive at a singular value for the 5-year recurrence interval data from the 2017 report, these three volumes were averaged. In addition, the largest debris flow that occurred in 2008 is beyond 1.5 times the interquartile range, so it was not used as a data point. As a result, only the data before 2008 was used to form a recurrence interval relationship.

Table 4-1. Area of LWM Based on Return Interval

Return Intervals from Data Excluding Outlier (year)	LWM Loading (acres)
5	0.4*
21	1
42	2
75	2

\*Averaged

Plotting the values from Table 4-1 gives a linear regression of  $y = 0.0266x + 0.3046$ , which was used to develop standard return intervals and LWM loadings as discussed in Section 4.2.1.

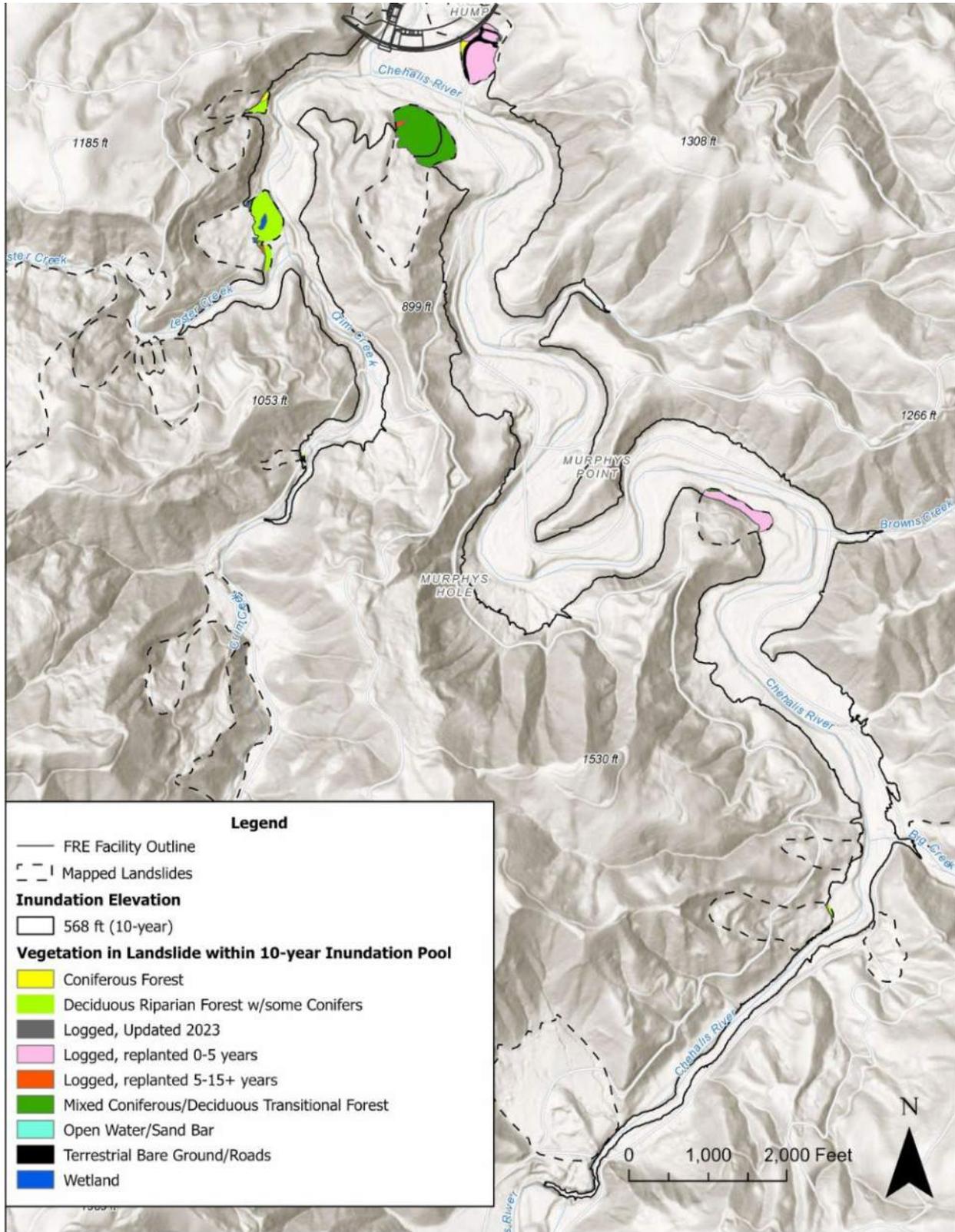
## 4.1.2 Debris from Landslides (Desktop Analysis) and LWM from the Chehalis River

This method also quantifies debris from landslides similarly to that described in Section 4.1.1, but does not use the established volume correlation based on past inventoried and digitized landslide aerial photographs. Instead, it analyzes the intersection of previously developed data on landslides, vegetation, landslide debris and LWM density.

Landslides previously mapped near the FRE site (HDR 2023) and inundation pools were used to locate areas that could contribute LWM to the Chehalis River. Inundation pools correlated to return intervals for 10-, 20-, 100-, and 500-year events are provided in Table 3-4, in Section 3.2.3. The vegetation composition within each landslide area for each inundation pool was used to estimate the amount of debris that could enter the river at the corresponding return interval.

For this analysis, the amount of debris that enters a river is dependent on how much an area slides and vegetation composition in the slide area. It is assumed the entire landslide area that gets inundated during a large flow event slides into the Chehalis River. An example of this is shown in Figure 4-2, which displays where the mapped landslide and 10-year inundation elevation overlap. It is assumed the landslides close to the structure are not removed and will contribute to LWM loading. It is conservatively assumed for this analysis that the entirety of the identified vegetation areas would result in landslides. These areas within the inundated landslide overlap are further grouped by vegetation classes. For instance, the 10-year event inundates classes of vegetation that include coniferous forest, deciduous riparian forest with some conifers, mixed conifers/deciduous transitional forest, logged areas replanted 0-5 years, and logged areas replanted 5-10 years. These vegetation classes are taken directly from the vegetation management plan (Kleinschmidt 2024).

Figure 4-2. Vegetation Contributing to LWM at 10-year Inundation Pool



Each of the vegetation classes have a different density of LWM per acre of land, which dictates how much LWM gets transported to the river. Densities of vegetation are based on the 2017 geomorphology report, but assumptions were used to assign densities to all classes of vegetation from the vegetation management plan.

The highest density described in the 2017 geomorphology report of 10,000 cubic feet of LWM delivered per acre is assumed to describe the coniferous forest class from the vegetation management report. This assumption of 10,000 cubic feet per acre is made from the 2017 geomorphology report. This value corresponds to estimates of the volume of harvestable wood in 40-year-old second growth Douglas fir stands, an average of 237 to 276 trees per acre and a diameter breast height of 12.1 to 12.2 inches (Watershed GeoDynamics and Anchor QEA 2017). The lower density vegetation classes were scaled down based off the starting 10,000 cubic feet as show in Table 4-2. The assumptions used to scale down from the coniferous forest were based on stand age and vegetation composition.

**Table 4-2. Vegetation Class LWM Density Relationship**

Vegetation Class (Kleinschmidt 2024)	LWM (cubic foot per acre*)
Coniferous forest	10,000
Deciduous Riparian Forest with some Conifers	5,000
Mixed Coniferous/Deciduous Transitional Forest	5,000
Logged and Replanted 5-15+ years	2,000
Logged and Replanted 0-5 years/Logged Updated 2023	500
Deciduous Riparian Shrubland	0
Herbaceous/Grass	0
Open Water/Sand Bar	0
Terrestrial Bare Ground/Roads	0
Wetland	0

\*Based on Watershed GeoDynamics and Anchor QEA 2017

Using GIS, the areas where the inundation pool and landslide overlap were calculated. These areas were then grouped into the various vegetation classes and multiplied by their associated density from Table 4-2. This results in a total volume of LWM. This volume of LWM was then converted to acres of LWM based on the assumptions in Section 3.3. This method was applied to all return interval years analyzed. An example calculation is provided below during a 10-year flood event for the Deciduous Riparian Forest with some Conifers vegetation class. Five acres of this class are estimated to slide based on the GIS analysis, and the density is 5,000 cubic feet per acre.

$$5 \text{ acres} * 5,000 \frac{ft^3}{\text{acre}} = 26,700 ft^3$$

This volume is converted to acres of LWM based on the assumptions in Section 3.3.

$$\frac{26,700 \text{ ft}^3}{2 \text{ ft}} * 0.2 \text{ (density factor)} = 2,670 \text{ ft}^2$$

$$\frac{2,670 \text{ ft}^2}{43560 \frac{\text{ft}^2}{\text{acre}}} = 0.1 \text{ acres}$$

Therefore, in this 10-year event scenario approximately 0.1 acres are delivered to the FRE facility for that vegetation class. The summation of all contributing vegetation classes results in total acreage for each recurrence interval.

After computing the LWM contribution from landslides, contributions from LWM in the river were added. Contributions from the river are based on the density of wood in the river based on field surveys detailed in Watershed GeoDynamics and Anchor QEA (2017). Using this data, it is assumed the average volume of LWM per river mile is 2,032 cubic feet. The density per river mile was then multiplied by the river mile reached by the inundation pool at each return interval to find LWM loading volumes. The flood events corresponding to the 10-, 20-, 50-, and 100-year return intervals have inundation pools that extend to river miles 5, 5, 5.5, and 6 respectively as provided in Table 4-3.

**Table 4-3. Vegetation Class LWM Density Relationship**

Return Interval (year)	Chehalis Flood Stage (ft)	River Miles Inundated Upstream of FRE Structure
10	568	5.0
20	582	5.0
100	604	5.5
500	620	6.0

An example calculation for the 10-year event is provided below:

$$5 \text{ miles} * \frac{2,302 \text{ ft}^3}{\text{river mile}} = 10,160 \text{ ft}^3$$

This volume is converted to acres of LWM based on the assumptions in Section 3.3.

$$\frac{10,160 \text{ ft}^3}{2 \text{ ft}} * 0.2 \text{ (density factor)} = 1,016 \text{ ft}^2$$

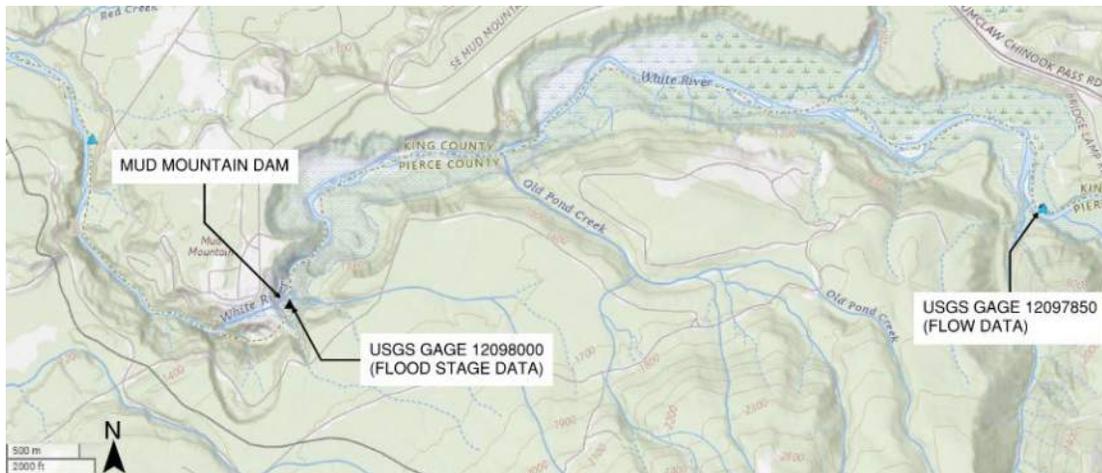
$$\frac{1,016 \text{ ft}^2}{43,560 \frac{\text{ft}^2}{\text{acre}}} = 0.02 \text{ acres}$$

For each recurrence interval, the acreage from the landslides and river mile calculation are added together. Results are shown in section 4.2.2.

### 4.1.3 Peak Flows correlated to LWM Loading

This method uses empirical data from MMD operators, flood stage gage data at USGS gage 12098000, recurrence intervals for flood stage based on gage 12098000, flows at MMD from USGS gage 12097850, and recurrence intervals associated with flow at the proposed Chehalis FRE facility (Table 3-3). See Figure 4-3 for locations of each gage on the White River.

**Figure 4-3. USGS Gage Locations on White River at and Upstream of MMD**



These gages are used for estimating LWM loading based on a return interval at the Chehalis FRE facility. The following is assumed in this methodology:

- The MMD reservoir flood stage recurrence intervals from USGS gage 12098000 are correlated directly to flood flow recurrence intervals from USGS gage 12097850. Therefore, flood stage at a specific recurrence interval are associated with a specific flow event at that recurrence interval.
- Large LWM events that occurred in 1996, 2006 and 2009 are assumed to have delivered that LWM when the highest daily flood stage occurred. This highest daily flood stage is obtained from USGS gage 12098000. Therefore, each LWM loading is associated with one stage elevation (Table 4-4).
- The peak flows-to-LWM scaling factor described in this section is the same for MMD and the proposed FRE facility. Therefore, the same flow is estimated to deliver the same LWM acreage at MMD and the proposed FRE facility independent of basin characteristics.

Based on empirical data from MMD operations, the largest LWM loading events occurred in 1996, 2006, and 2009. The largest daily flow events from 1996, 2006, and 2009 were pulled from USGS gage 12098000. The 2006 flood event was not used as it was evident that the USGS reservoir elevation gage failed to accurately read the actual reservoir level. With daily USGS gage data from 1996 and 2009, the peak flood elevations recorded for those years were 1,196 and 1,160 feet, respectively.



These peak flood stages from 1996 and 2009 at MMD were correlated with a recurrence interval. A power function was fit to flood stage recurrence intervals from Table 3-1 to best model the relationship between flood stage and recurrence interval. Using this power function, a theoretical recurrence interval for the 1996 and 2006 flood stages of 1,196 and 1,160-feet were calculated. The flood stages in 1996 and 2009 are both larger than the known flood stage that occurs at the 500-year event, so the correlated recurrence intervals are larger than a 500-year event. The flood event that occurred in 1996, for instance, was calculated to have a 1,148-year recurrence interval. This recurrence interval is associated with delivering 50 acres of LWM as provided in Table 4-4.

A logarithmic relationship was then fit between peak flow and recurrence intervals from Table 3-2 (from USGS gage 12097850). The logarithmic relationship captures the observed data well and was applied to the theoretical recurrence intervals in Table 4-4 to calculate a flow for two specific return intervals in 1996 and 2009. The full relationships between the flood year, LWM loadings, flood stage, recurrence interval, and flow are provided in Table 4-4.

**Table 4-4. Known LWM Loadings correlated to Peak Flows and Recurrence Intervals at Mud Mountain Dam**

Flood Year	Known LWM Loading During Flood Year (acres)	Highest Flood Stage on Record During Flood Year (ft)	Theoretical Recurrence Interval (year)	Correlated Flow (cfs)
1996	50	1,196	1,148	49,856
2009	40	1,160	521	45,339

The flows based on return interval at the proposed Chehalis FRE dam were then correlated to LWM loadings at MMD based on Table 4-4. The LWM was scaled by relating the LWM loading to the flow at MMD. The relationship between LWM acreage and flow at MMD was calculated to be 0.00094:

$$\frac{\text{LWM Loading in 1996}}{\text{Flow in 1996 during the LWM loading event}} = \frac{50 \text{ acres}}{49,856 \text{ cfs}} = 0.00088$$

$$\frac{\text{LWM Loading in 2009}}{\text{Flow in 2009 during the LWM loading event}} = \frac{40 \text{ acres}}{45,339 \text{ cfs}} = 0.0010$$

$$\text{Average} = 0.00094$$

With this scaling factor of 0.00094, the flows from return intervals for the 10-, 20-, 50-, and 100-year from Table 3-3 were each multiplied by 0.00094 to get the LWM acreage at each return interval. This scaling factor overestimates LWM loading because basin characteristics differences are not fully captured when only scaling LWM estimates off peak flows. Peak flows in the basin upstream of the proposed FRE structure are similar to the peak flows upstream of MMD. Though the basin size above MMD is much larger

than the basin upstream of the proposed FRE structure, peak flows in the Chehalis River are high because it is a flashier system.

#### 4.1.4 Peak Flows Correlated to LWM Loading Scaled by River Mile

Peak flows at the proposed Chehalis FRE structure are larger than peak flows at MMD, yet the basin receiving these flows is six times smaller than the White River basin above MMD. In addition, the river above MMD is three times longer than at the Chehalis River upstream of the proposed FRE facility. The following are assumed for this approach:

- LWM loadings scaled only from peak flow result in an overestimation at the proposed Chehalis FRE structure. The LWM loading is expected to be less at the proposed Chehalis FRE structure than at MMD.
- Basin size and river length are accurate indicators of LWM transport and are used to scale LWM loadings in sequence after scaling LWM from peak flows.

LWM loadings that have been previously scaled by flow (Section 4.1.4) are then scaled again based on river mile. River mile is used instead of basin size because river mile scaling results in a more conservative estimate. The sample calculation below represents the LWM during the 10-year event:

$$\frac{\text{LWM at Chehalis FRE Structure from Peak Flow Correlation (Section 4.1.3)}}{\text{LWM at Chehalis FRE Structure (Section 4.1.4)}} = \frac{\text{River Length Upstream of Mud Mountain Dam}}{\text{River Length Upstream of Chehalis FRE Structure}}$$

$$\frac{19 \text{ acres}}{\text{LWM at Chehalis FRE Structure (Section 4.1.4)}} = \frac{60 \text{ miles}}{19 \text{ miles}}$$

$$\text{LWM at Chehalis FRE Structure (Section 4.1.4)} = 6 \text{ acres}$$

This methodology is applied to all return intervals, and results are provided in Section 4.2.4.

#### 4.1.5 Basin Area versus LWM Loading

This method results in one value for the maximum expected LWM loading based on a correlation of basin areas. The basin area upstream of MMD is compared to the area upstream of the proposed FRE dam to scale LWM loading from the Chehalis River. Though the specific basin characteristics within the two basin areas differ, this scaling compares a general, quantifiable basin characteristic between MMD and the proposed FRE structure. The MMD has a basin area of 400 square miles (USGS 2019) with no anthropogenic structures in the river to obstruct wood conveyance. Similarly, no obstructions are upstream of the proposed FRE structure, which has a basin area of 69 square miles (HDR 2024c). With an assumed maximum LWM loading of 60 acres at MMD, the equation used in this method to solve for LWM at the proposed FRE facility is:

$$\frac{\text{Basin Area Upstream of Chehalis FRO Structure}}{\text{LWM at Chehalis FRO Structure}} = \frac{\text{Basin Area Upstream of Mountain Mountain Dam}}{\text{LWM at Mud Mountain Dam}}$$

This scaling results in a singular LWM acreage that represents the largest acreage that is delivered based on this approach.

#### 4.1.6 River Length versus LWM Loading

This method results in one value based on a correlation of river length. The river length upstream of MMD is compared to the river length upstream of the proposed FRE structure to scale LWM loading from the Chehalis River. Similarly to basin size, though the riverine characteristics within the two basin areas greatly differ, this direct scaling can serve as a preliminary reference point between MMD and the proposed FRE structure. USGS river miles created by Ecology were used to estimate the length of the main forks for the Chehalis and White Rivers. The White River is 46 miles long (Ecology 2023). In addition, the western tributaries to the White River are assumed to convey LWM and added to the length of the main river. This western tributary to the White River was estimated in GIS to be 14 miles long, so the overall length of river contributing to LWM loading upstream of MMD is assumed to be 60 miles. The Chehalis River upstream of the proposed FRE structure is 19 miles (Ecology 2023). With an assumed maximum LWM loading of 60 acres at MMD, the equation to solve for LWM at the proposed FRE facility is:

$$\frac{\text{River Length Upstream of Chehalis FRE Structure}}{\text{LWM at Chehalis FRE Structure}} = \frac{\text{River Length Upstream of Mountain Mountain Dam}}{\text{LWM at Mud Mountain Dam}}$$

## 4.2 Results

Results from the methodologies outlined in Section 4.1 are presented in the following sections.

### 4.2.1 Debris from Landslides (Previous Geomorphology Study)

The linear regression developed from the geomorphology report results in the following LWM loadings based on standard return intervals (Table 4-5):

**Table 4-5. LWM from Debris (Previous Geomorphology Study)**

Return Intervals (year)	LWM Loading (acres)
10	1
20	1
50	2
100	3
500	14

#### 4.2.2 Debris from Landslides (Desktop Analysis) and LWM from River

Adding together the debris acreage from landslides and the river inputs results in the following LWM loadings (Table 4-6):

**Table 4-6. LWM from Landslides and Density in Chehalis River**

Return intervals (year)	LWM Loading (acres)
10	0.2
20	0.3
100	0.4
500	0.4

#### 4.2.3 Peak Flows correlated to LWM Loading

Using linear regression and interpolation, Table 4-7 presents the LWM loading results.

**Table 4-7. LWM correlated from Peak Flows**

Return Intervals (year)	Flow (cfs)	LWM Loading (acres)
10	20,200	19
20	23,200	22
50	32,200	30
75	35,100	33
100	38,000	36
500	53,500	50

#### 4.2.4 Peak Flows Correlated to LWM Loading Scaled by River Mile

Using linear regression and interpolation, Table 4-8 presents the LWM loading results scaled by river mile.

**Table 4-8. LWM Correlated from Peak Flows Scaled by River Mile**

Return Intervals (year)	Flow (cfs)	LWM Loading (acres)
10	20,200	6
20	23,200	7
50	32,200	10
75	35,100	10
100	38,000	11
500	53,500	16

#### 4.2.5 Basin Area versus LWM Loading

Using the equation from 4.2.4, the LWM loading results in 10 acres.

#### 4.2.6 River Length versus LWM Loading

Using the equation from 4.2.6, the LWM loading results in 19 acres.

### 4.3 Summary of Results

The results are summarized into two main categories: theoretical (Sections 4.2.1 and 4.2.2) and empirical data (Sections 4.2.3, 4.2.4, 4.2.5, and 4.2.6). Not distinguishing between categories, four methods (Sections 4.2.1, 4.2.2, 4.2.3, 4.2.4) result in acreages associated with recurrence intervals and two methods (Sections 4.2.5 and 4.2.6) result in singular LWM acreage values. The recurrence intervals inform how the expected LWM acreages align with proposed FRE structure operations. Knowing how much LWM a 10-year flood versus a 100-year flood will deliver will assist in dam planning operations. Singular acreage values do not distinguish how various flows affect LWM loadings but are used as reference data points to understand if the overall results have similar orders of magnitude to increase confidence of the results.

The two theoretical methods use landslide models and result in LWM acreage estimates associated with recurrence intervals (Sections 4.2.1, 4.2.2). The landslide models are specific to the Chehalis basin above the proposed FRE structure and based on several assumptions:

- The landslide volume of debris captured by aerial photography occurs during the highest flow recurrence interval flood that year and does not account for other smaller events (slower processes or lower flow events) that may have occurred and recruited LWM.
- Past amounts of LWM transported will occur in the future, which may not be the case if land management improvements increase soil stability.
- Most or all LWM is sourced from landslides. Though the landslide methods provide a representation of what would be transported during these singular mass wasting

events, it does not account for additional ways LWM could be transported. In addition to landslides, debris loading during floods could come from wind fallen trees, localized hillslope erosion that creates transport pathways for LWM from higher up in the basin, or LWM in or near the river.

This list is not exhaustive and many more methods of LWM recruitment could occur. Aside from the recruitment and transport of LWM from typical river hydraulics, hydrologic impacts, and basin characteristics, how the inundation pool interacts with the surrounding land will affect landslide potential. The surface area of the pool, how high up the pool is on basins' hillslopes, and the reservoir evacuation rate will affect how the LWM interacts with bank stability. These aspects affect LWM buoyancy forces that dictate how LWM will move in an inundation pool but were not modeled. The landslide approaches are based on landslide volume models specific to the basin, but are limited by the lack of empirical data, the assumption that past events are direct indicators of future events, and the uncertainty of how the LWM will be transported.

The four empirical methods (Sections 4.2.3, 4.2.4, 4.2.5 and 4.2.6) use MMD data previously described in Section 3.1. They incorporate documented observations over the last few decades instead of theoretical data based on past landslides and assumptions. The empirical methods does not address the question of how LWM may be recruited and transported within the basin. How LWM is recruited and transported is affected by specific basin differences such as soil composition, vegetation differences, method of LWM transport, hillslope, landslide occurrences and land management. Though these affect transport methods, these specific methods do not have readily available models or equations with adequate basin data to quantify LWM acreage. Instead, these empirical methods are limited to quantifying LWM acreage with more general basin characteristics that may or may not account for the specific differences. To account for basin differences, the methods correlate LWM observed at MMD during large flow events to the proposed FRE structure by scaling off of one or more basin characteristics: peak flows (Section 4.2.3), peak flows and river miles (Section 4.2.4), basin area (Section 4.2.5), and river miles (Section 4.2.6).

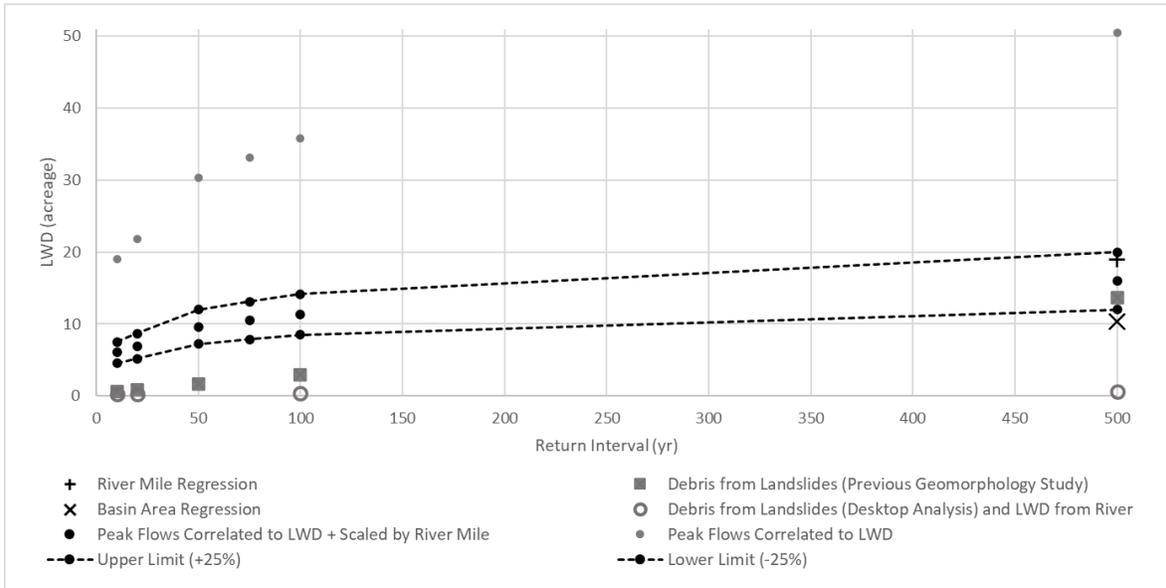
The method from Section 4.2.3 uses peak flows to scale LWM acreage estimates at MMD to the proposed FRE structure. It results in LWM acreage associated with a recurrence interval. The limitation with this result is that the peak flows do not accurately reflect the difference in basin size or river length between MMD and the proposed FRE structure. MMD has a river length three times as long as the river upstream of the proposed FRE structure, and a basin area six times as large as the basin upstream of the proposed FRE structure. Basin hydrology upstream of the proposed FRE structure is much flashier than the basin upstream of MMD, so the peak flows are similar even though the basin sizes and river length vary greatly. The LWM acreage from this method is likely an overestimate because the peak flows at MMD are approximately the same magnitude as flows at the proposed FRE facility.

Scaling off basin area (Section 4.2.5) and river mile (Section 4.2.6) result in lower LWM acreage at the proposed FRE facility than at MMD. This is expected because the basin upstream of MMD is bigger than the basin upstream of the proposed FRE structure, and the White River upstream of MMD is longer than the Chehalis River upstream of the proposed FRE facility. Both methods result in a singular LWM acreage estimate.

The final empirical method (Section 4.2.4) uses the peak flow scaling from Section 4.2.3 and re-scales the LWM acreage estimates by river length capturing specific data for the proposed FRE facility. This method was chosen to approximate acreage at the proposed FRE structure because it is based on empirical evidence from MMD, and accounts for peak flows and river length. This method results in the same order of magnitude of LWM acreage as all other methods, and accounts for uncertainties in transport method by scaling from empirical data and outputs data based on recurrence intervals.

A contingency of 25 percent was applied to the results from Section 4.2.4 to provide an estimate of lower and upper limit bounds of how much storage area is needed based on methodology uncertainties. All results and the upper/lower contingency limits are plotted on Figure 4-4. These uncertainties include how LWM recruitment between MMD and the proposed FRE structure vary and for specific methods of transport that are not modeled. The upper range for the 25 percent contingency is used to size storage areas needed for LWM as provided in Table 4-9.

**Figure 4-4. Return Interval Data Summary**



NOTE: For flood events in which the spillway is activated, a significant portion of the debris would pass over the spillway and not collect in the reservoir.

**Table 4-9. Final LWM Loadings**

Return Intervals (year)	LWM Loading- Upper 25 Percent Limit (acres)
10	8
20	9
50	12
100	14
500	20

## 5 FRE Potential Debris Storage Areas

After a flood occurs and transports LWM to the proposed FRE structure, the LWM must be transported away from the structure to reduce loading on the structure, block the spillway, or cause blockages along the natural river flow. The LWM will be stored in debris storage areas similar to the storage basins at MMD. After the LWM is stored, and the area dries out enough for vehicles to operate in each storage area, the LWM will be removed and managed as described in the Mitigation Plan (Kleinschmidt 2024). Debris storage area locations and sizes were determined with a desktop analysis and refined during a site visit.

From the desktop analysis, storage areas were determined suitable based on characteristics from the existing MMD storage areas. These areas had continuous land accessible by road with slopes less than 5 percent and were accessible by boat after floods.

Debris storage areas need an estimated minimum of 10 feet of water above the ground surface to be navigable by the log broncs. A log bronc is a small, rugged tugboat used to maneuver and corral floating logs. For the Chehalis River, the debris storage areas were initially located based on elevations below 518 feet. This was chosen as the highest elevation possible because the drawdown process was anticipated to begin at a water surface elevation of 528 feet (Anchor QEA 2017). The debris storage areas also were chosen to be located above the bankfull width, so they are not affected by normal run-of-river operations. The bankfull width is based on topographic breaks, vegetation composition and sediment observed in the field as well as LiDAR and aerial imagery. Applying these criteria and evaluating 2-foot topographic LiDAR contours, preliminary debris storage areas were developed remotely. A site visit on May 21, 2025 with HDR and Northwest Hydraulic Consultants was conducted to ground truth the preliminary locations. The locations of six potential yards for LWM storage are depicted in Figure 5-1 and identified as areas 1, 2, A, B, C and D. As described further in Section 7.3.3, areas 1 and 2 are the recommended debris management areas for the Proposed Project. These areas are densely forested and must have trees and shrubs cleared from the area to be used for LWM storage areas. Areas A, B, C, and D are not recommended or necessary for debris management purposes as further described in Section 7.3.3.

The mapped landslide area between debris storage areas 2 and A, noted as LS-4 in Table 7-1 of the draft PDR (HDR 2025a), was not included as a debris storage option at this time. The landslide area will be evaluated for stabilization and further evaluation for its use as a storage yard performed.

The following sections outline details on each storage area's topography, vegetation, accessibility, elevation, and area.



## 5.1 Debris Storage Area 1

Debris storage area 1 is located immediately adjacent to the proposed FRE structure on the right bank of the Chehalis River. The landslide immediately at proposed FRE structure will be removed during construction, so this landslide was ignored when selecting this area as a debris storage area. A road that cuts through the middle of this storage area is accessible from the main logging road (1000 Road). The area mildly slopes towards the river and is densely forested with an understory. Photo 5-1 shows the edge of the forested area where it meets the Chehalis River. The total storage capacity of this yard is 9.2 acres and elevations range from 447 to 495 feet.

**Photo 5-1. Typical Vegetation in Debris Storage Area 1**



Note: Southwestern edge of yard looking at the Chehalis River

## 5.2 Debris Storage Area 2

Debris storage area 2 is located approximately 1,700 feet upstream of the proposed FRE structure location on the left bank of the Chehalis River. It is located immediately south of the Panesko Bridge and can be accessed directly from 1000 Road. Half of this proposed storage area is east of 1000 road and half is west. It occupies 13.2 acres and elevations range from 467 to 495 feet. The area west of 1000 Road is flat with some cleared areas and some densely forested areas as depicted in Photo 5-2. The upper elevations of this

debris storage area are located at the toe of a hillslope that borders this storage area to the west. The eastern portion of this debris storage area slopes slightly to the Chehalis River and is forested with a dense understory of shrubs and ferns. Photo 5-3 depicts the Chehalis River from the perspective of the eastern edge of the storage area.

**Photo 5-2. Western Portion of Debris Storage Area 2**



Photo 5-3. Eastern Edge of Eastern Debris Storage Area 2



Note: Looking at the Chehalis River.

### 5.3 Debris Storage Area A

Debris storage area A is located at the confluence of the Chehalis River and Crim Creek. It runs parallel to Crim Creek's right bank, and a small portion of the Chehalis River left bank. An old road runs through the middle of the potential storage area and splits it into northern and southern areas (Photo 5-4). This road will need to be reconstructed for access to this storage area. While this debris storage area was not scouted during the May 21, 2025 site visit, the road was observed. The area was later determined remotely from the original desktop criteria. It occupies more than 4.7 acres and elevations range from 458 to 503 feet.

**Photo 5-4. Old Road Cutting Through Debris Storage Area A**



Note: At the Most Eastern Edge of the Yard Looking West.

## 5.4 Debris Storage Area B

Debris storage area B is located on the right bank of Crim Creek, approximately 2,500 feet from the proposed structure. The road that cuts through debris storage area 3 is the same road that would need to be reconstructed to access debris storage area B (Photo 5-5). This potential storage area is located on a flat bench approximately 30 feet above Crim Creek's bank toe. This area has a young forest with a low growing understory of ferns and shrubs (Photo 5-6). It occupies 4.1 acres and elevations range from 495 to 518 feet.

**Photo 5-5. Access Road to Yard Storage Area B**



Note: Looking North.

**Photo 5-6. Flat Bench Above Crim Creek in Debris Storage Area B**



Note: With Young Trees and Fern Understory.

## 5.5 Debris Storage Area C

Debris storage area C is located approximately 5,300 feet upstream of the proposed FRE structure on the left bank of the Chehalis River and along 1000 Road. A portion of this proposed storage area is west of 1000 Road, but most is on the east side. It occupies 20.6 acres and elevations range from 485 to 518 feet. The area west of 1000 Road has already been cleared (Photo 5-7), and the flat area to the toe of the hills to the west can be used for LWM storage. Part of the eastern portion of this debris storage area has also already been cleared (Photo 5-8). The rest of the eastern portion slopes slightly toward the Chehalis River and is forested with a dense understory of shrubs and ferns. Photo 5-6 shows the eastern edge of the debris storage area from the Chehalis River where the bank is approximately 10 feet high.

The debris storage area (approximately 4.5 acres) originally identified in Anchor QEA (2017) as the single debris storage area for the Proposed Project and described in additional detail in HDR (2021), is located within debris storage area C.

**Photo 5-7. West Side of Debris Storage Area C**



**Photo 5-8. Cleared Eastern Side of Debris Storage Area C**



Note: Facing Northwest.

## 5.6 Debris Storage Area D

Debris storage area D is located on the right bank of the Chehalis River, approximately 7,100 feet upstream from the proposed FRE structure. It is located on 1000 Road upstream of debris storage area C. Approximately half of this proposed storage area is west of 1000 Road, but the other half is on the east side. It occupies 12.7 acres and elevations range from 494 to 518 feet. The area east of 1000 Road has been partially cleared with a road (Photo 5-9). The area west of 1000 Road is flat with grass and a dense young forest (Photo 5-10). This western portion slopes slightly toward the Chehalis River from 1000 Road.

**Photo 5-9. Eastern Side of Storage Area D**



Note: Partially cleared.

**Photo 5-10. Western Side of Debris Storage Area D**



Note: Young forest with grass ground cover.

## 5.7 Summary of Results

Together these six potential storage areas can provide approximately 64.5 acres of LWM storage area, however estimated LWM volumes provided in Table 4-9 indicate that much less storage area is needed. In addition, during larger storm events in which the spillway crest is overtopped, storage operations will be paused to allow LWM to be transported over the spillway. Current hydraulic and hydrologic analyses indicate the spillway will overtop at less than a 100-year flood event. Therefore, the highest estimated LWM load requiring debris storage will be approximately 14 acres.

Storage areas 1, 2, and A located lower in the reservoir and closer to the FRE structure are preferred compared to B, C, and D. These areas reduce the distance required for transport of LWM following collection, keep equipment closer to the Proposed Project site, and allow more of the inundation area to be drained quickly, reducing potential environmental impact. Areas 1 and 2 provide sufficient storage area for 14 acres of LWM delivered during a 100-year flood event and are located closest to the FRE structure and lower in the temporary inundation area.

Figure 5-2 shows the debris storage areas 1 and 2 which are recommended to be included as part of the Proposed Project. Figure 5-3 shows road features and access to debris storage areas 1 and 2. Areas A, B, C, and D are not planned as part of this Proposed Project but are included herein to document they were studied and found to be unnecessary.

Figure 5-2. Proposed Debris Storage Areas

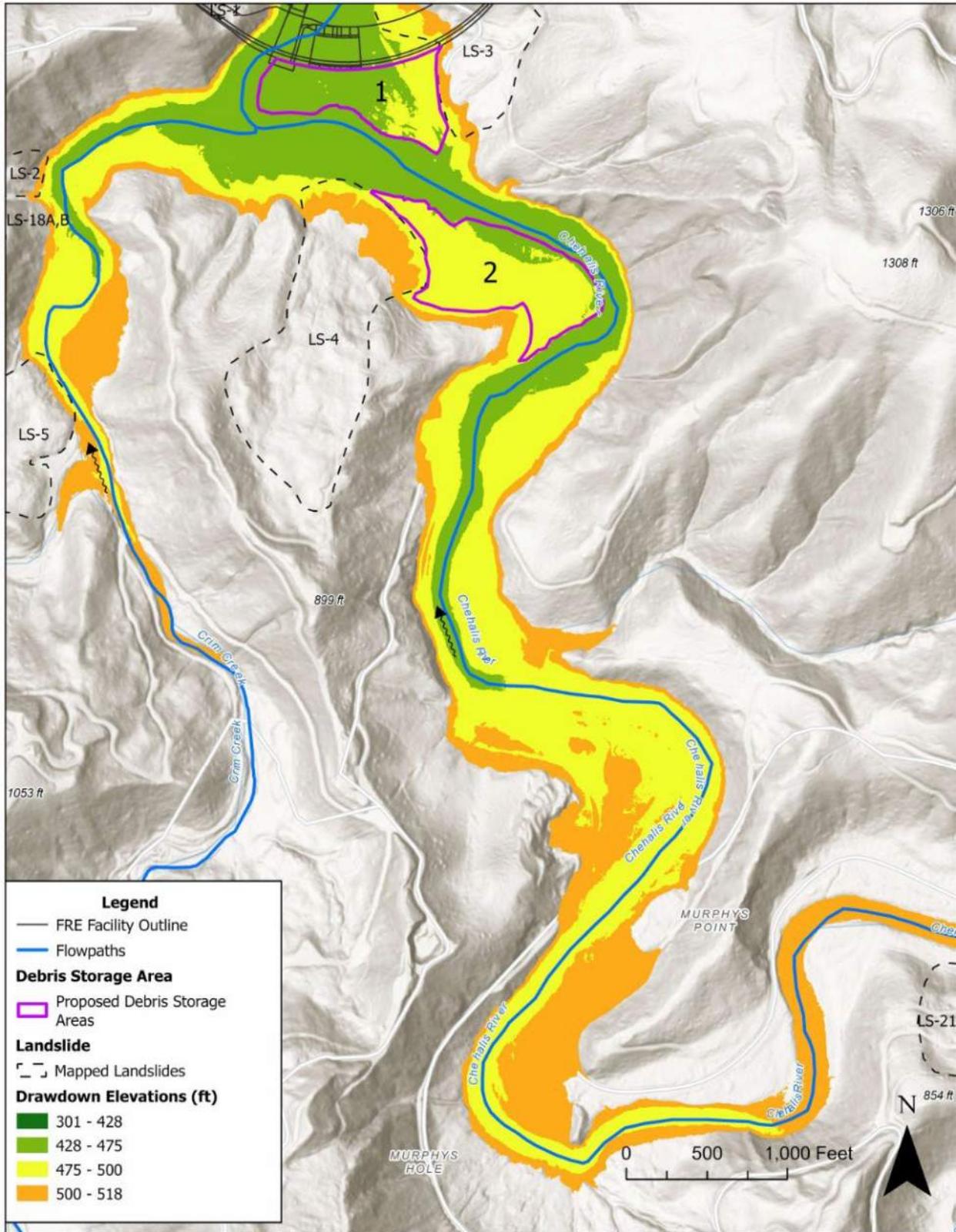
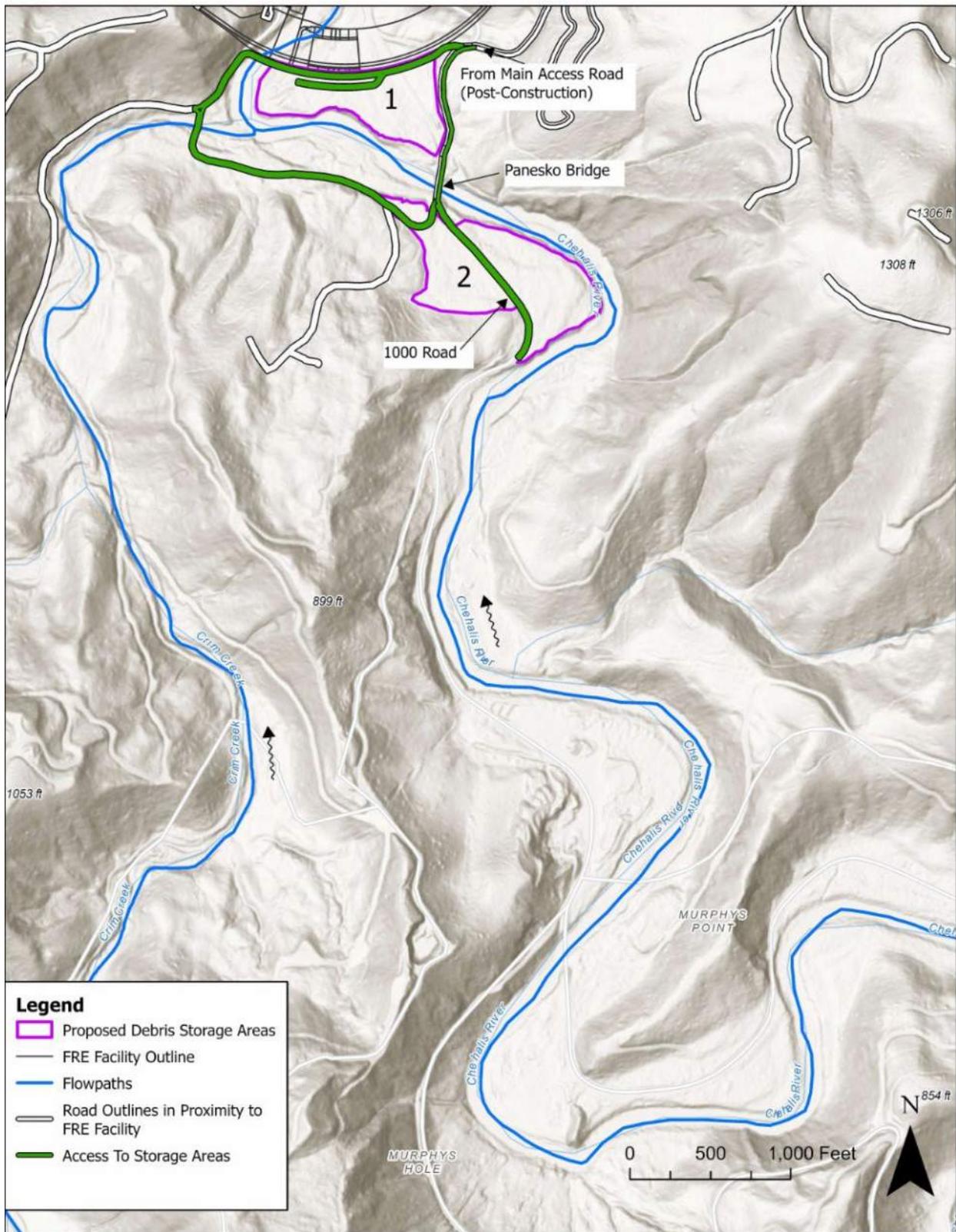


Figure 5-3. Access to Proposed Debris Storage Areas



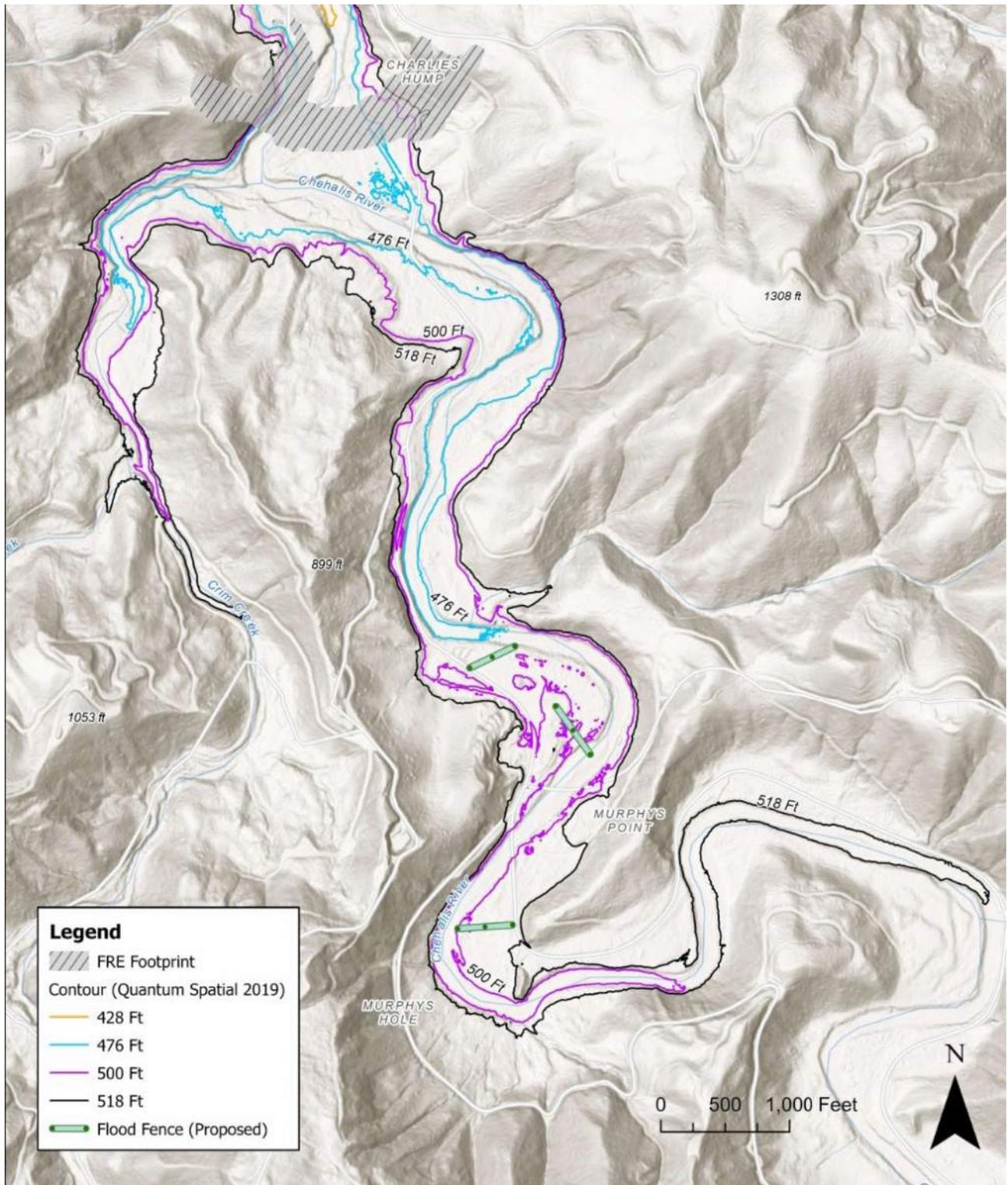
## 6 Debris Fences

During flood operation, debris will also be recovered from the water during drawdown from road accessible debris fences. The debris fences will trap floating debris at different elevations as the temporary reservoir water level recedes. This will also help reduce the time needed for in-water debris removal.

Figure 6-1 presents the proposed layout of debris capture/retention fence locations and alignments that could be implemented to help trap floating debris during flood events when the FRE structure's outlet regulation is triggered. The proposed upstream debris capture fences would not be engaged by the pool inundation except during large flood events. The intent of these fences is to capture woody material upstream to limit LWM at the proposed FRE structure. To avoid boat safety issues, the proposed debris fences are placed beyond the navigable area used by boats to corral LWM.

If the proposed debris fences successfully limit the amount of LWM transported to the proposed FRE structure, more debris fences can be installed during adaptive management. If more debris fences are installed in the navigable areas near the proposed FRE structure, safety and visibility of the fences must be considered. The vertical piles comprising the debris fences in the most upstream locations should extend above the estimated high reservoir water level, given the shallow submergence of the debris storage area during these events, potential for debris boat safety issues during the anticipated inclement weather, and likely ambient conditions during debris clearing operations. Within the adaptive management downstream debris fence capture areas, the height of the fence support piles should not exceed more than about 8 to 10 feet above the ground surface. These piles should be clearly marked and/or delineated to indicate their submergence, to minimize the risk of grounding or collision of the debris management boats with the submerged piles. The debris management boats would require at least 7 to 8 feet of clearance above the vertical piles for safe operation and to prevent debris tows from hanging up on the piles as they are maneuvered into position.

Figure 6-1 Proposed Layout of Debris Fences During Reservoir Drawdown



## 7 Operations

Debris management actions can be broken down into two periods corresponding to the Proposed Project operating periods: Normal, Flow-Through Operation and Flood Retention Operation. The LWM estimates and storage areas described in Sections 4 and 5 are used to determine debris management actions during Flood Retention Operation described in Section 7.1 below. Debris management during normal flow-through operation is described in Appendix J: Operation and Maintenance Considerations TM (HDR 2025a).

### 7.1 Flood Retention Operation

When the FRE facility is operated to hold back flood water, the conduit gates will close—some fully, some partially—to reduce river flows downstream. The temporary inundation area upstream of the FRE structure will fill with the excess flood water, which will then be evacuated after the storm has passed. During evacuation of the inundation pool, discharge from the FRE structure will be reduced to allow floating LWM in the reservoir to be collected and moved to debris storage areas. When debris storage areas are full or no longer needed for storage, discharge will be increased again to speed reservoir evacuation. When the elevation of the inundation pool is below the storage area elevation, collected material will be removed by operations staff. Removal of woody material from debris storage areas and what happens to the material following removal are described in the Mitigation Plan (Kleinschmidt 2024). Estimated sequencing of LWM removal from the reservoir and removal durations for select storm events are described below.

### 7.2 Debris Management During Inundation Pool Evacuation

During flood operation events, the estimated LWM acreage summarized in Section 4.3 is expected to be swept into the temporary inundation pool. Debris management procedures will be used to ensure LWM does not impact FRE facility operations or damage the FRE facility. Drawdown and debris management will start when the inundation pool is at a safe level for crews to begin working in the temporary inundation area. If the inundation pool is flowing over the spillway or immediately below the spillway, all debris management will cease. Once the pool falls below the spillway crest to a level that is deemed safe for crews to operate in the pool, debris management will commence. The inundation levels and spillway operations will be closely monitored and communicated with crew members to ensure safe working conditions.

Once the inundation pool is at a safe working condition below the spillway crest, crews will use boats and log broncs as described in Section 7.3. They will move LWM from the temporary reservoir to the debris storage areas described in Section 5. The steel trashrack columns will protect the gated outlets of the FRE facility from LWM that was not removed by the boats and log broncs and from debris that cannot pass through the trashrack to downstream areas when normal flow-through operation resumes. The slowed drawdown rate will continue until the temporary reservoir reaches elevation

500 feet, at which point debris management actions in the reservoir will conclude. Analysis and refinement of elevation at which debris collection begins, and the duration required to corral and move debris are the subject of this section. Refer to Sections 7.3.3 and 8 for recommended refinements to debris collection water surface elevations and durations.

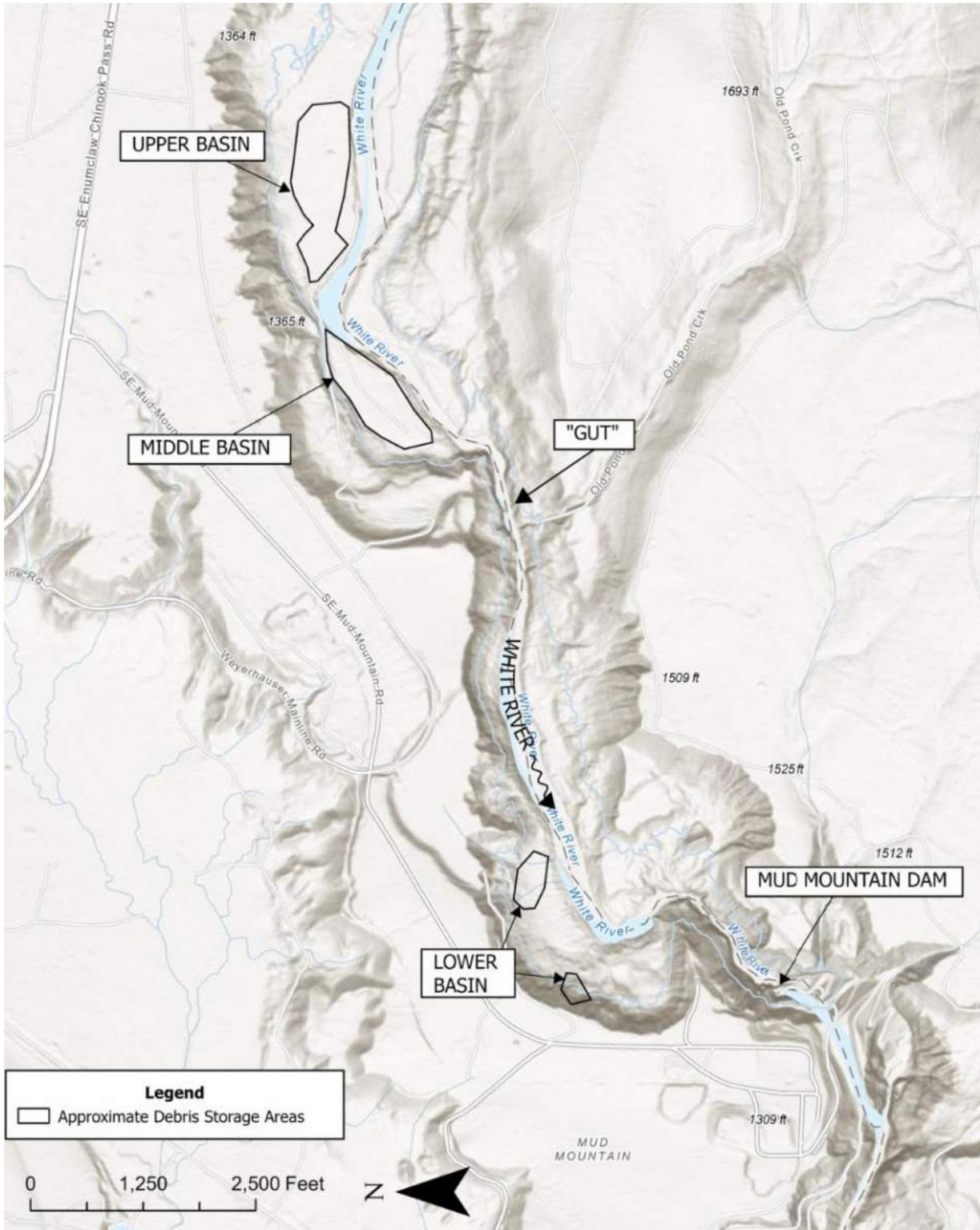
## 7.3 LWM Sequencing and Removal Rate

The LWM sequencing and storage rate on the Chehalis River at the proposed FRE structure were developed directly from MMD current operating procedures. USACE provided detailed information regarding its LWM storage process from email correspondence and an interview via video conference conducted on March 25, 2025 (Appendix A).

### 7.3.1 Mud Mountain Dam Sequencing and Removal Rates

MMD uses several debris storage areas: a lower basin, middle basin, and upper basin (Figure 7-1). During high flow events, the reservoir reaches elevations that can transport LWM up to the middle and upper basins. Because smaller flow events do not create reservoir inundation pool elevations high enough to transport LWM to the middle and upper basins, LWM is stored temporarily at the lower basin near the intake. The lower basin is used for temporary storage during high flows, but because it cannot be accessed from land, the final LWM destination must be the middle or upper storage basin.

Figure 7-1. Existing MMD Debris Storage Areas



Large flood events will create a large inundation pool, with equipment on the water needed to transport LWM. Log booms, work boats and log broncs are the main equipment used to manage and sort LWM. Log booms are set up within the debris storage areas to contain LWM in the lower, middle (Photo 7-1), and upper basins. Upstream of the lower basin, operators sometimes also deploy a boom at a narrow section (the “gut”) of the White River to keep LWM upstream of the lower basin. These booms function as containers to aid in storage of LWM while the reservoir inundation pool is high after a large flood.

**Photo 7-1. MMD Log Booms at Middle Basin**



Note: Inundation elevation 1,030 feet.

Small transportable booms are also used to collect LWM and are mobilized by connecting to log broncs and work boats. The log broncs sort through debris and fill the boom behind them with a teardrop shape of LWM called a “sack.” Once the sack is full, it is transported (pulled) upstream by the work boat and pushed by the log bronc. The sack is transported to either the middle or upper debris storage area and contained by booms. The LWM is towed inside the containment area, released, and then the containment boom is closed behind the boats. This process is repeated until all LWM is transported from the reservoir to storage yards. The log broncs and a work boat at MMD are depicted in Photo 7-2 (after a large flood event ready to be deployed) and Photo 7-3 (when the reservoir does not have an inundation pool).

**Photo 7-2. MMD Log Broncs and Work Boat at Dock Ready for Deployment at High Reservoir Inundation Elevation**



**Photo 7-3. MMD Log Broncs and Work Boat at Dock Stored with No Reservoir Inundation Pool**



The LWM storage rate at MMD is dependent on where the LWM starts. It takes approximately 2 hours to transport one sack of LWM from the lower basin near the intake to the upper and middle basins, which covers approximately 8,000 feet. It takes approximately 3 hours to transport one sack from the intake to the middle and upper basins over approximately 12,500 feet. From USACE anecdotal reports, it takes a full day to store 4 to 5 sacks in the upper and middle basins if the debris starts upstream of the “gut.” Table 7-1 depicts the storage rates based on correspondence with USACE. These storage rates are based on one log bronc operating at a time and assume that four sacks are equal to approximately 1 acre of LWM. Sack size is based on MMD operator estimations.

**Table 7-1. LWM Storage Removal Rates at MMD**

Travel Path	Approximate Distance Traveled (feet)	Transport Time for One Sack (hours)	Sack Storage Rate (sacks/per hour)	Acre Storage Rate (acres/day)**
Intake to middle/upper basins	12,500	3	0.3	0.7
Lower basin to middle/upper basins	8,000	2	0.5	1.0
“Gut” to middle/upper basins	3,000	1.5*	0.7	1.4

\*Assumes 5 sacks are stored in 8 hours of work

\*\*Assumes 1 day of storage is 8 hours

### 7.3.2 Proposed LWM Removal Rate for FRE

For simplicity of calculations at this stage of development, one estimated storage removal rate for the FRE was assumed based on MMD’s LWM storage removal rates (Table 7-1). These calculations assume log broncs and work boats will be operating for 8 hours each day.

The rate of transporting LWM anywhere within the inundation pool upstream of the proposed FRE structure is assumed the same as transporting LWM from MMD’s lower basin to the upper and middle basins. Therefore, using this singular rate, it will take 1 day to store 1 acre of LWM upstream of the proposed FRE structure. This 1 acre of LWM per day rate is estimated with one log bronc and work boat. Assuming operations can occur at three times the rate by deploying two more log broncs and work boats than currently occurs at MMD, the Chehalis storage rate is assumed to be 3 acres per day. This increased rate will only be possible if there is enough width in the inundation pool for the log broncs with their boom sacks to pass each other. With three boats in operation simultaneously, an upstream traveling log bronc will inevitably pass a downstream traveling log bronc during operations. During peak operations three log broncs with three crews of 1 driver and 2 support staff will be deployed.

Table 7-2 provides days to store different LWM loadings based on return intervals, independent from drawdown rate. For the 10-year return interval, from Table 4-9, 8 acres of LWM are anticipated. Based on the storage rate of 3 acres per day, 8 acres will be

stored in 2.7 days. Rounding up to the nearest whole number gives an approximation of 3 days to store the anticipated LWM loading for the 10-year event. The subsequent approximation of days to store in this table are calculated similarly.

**Table 7-2. Final LWM Loadings and Storage Duration**

Return Intervals (year)	LWM Loading (acres)	Days to Store (days)
10	8	3
20	9	3
50	12	4
100	14	5
500	20	7

### 7.3.3 Sequencing and Capacity

The estimated removal rate and debris storage area capacities were used to determine how the LWM storage sequencing would occur. How the storage rate, drawdown rate, navigable elevations, and available storage interact dictates how the debris storage areas will be able to store LWM. As the temporary inundation area drains, the available navigable storage area acreage diminishes, so the highest elevations of the debris storage yards must be prioritized to store the logs first.

Only debris storage areas 1 and 2 will be needed based on the largest debris estimate of 14 acres at the 100-year flood event. Storage areas A, B,C, and D are not needed nor planned as part of this Proposed Project.

The reservoir elevation must follow the depth requirements to navigate areas 1 and 2 during the drawdown period. The reservoir elevation must always be 10 feet above the ground surface where LWM is being stored. Therefore, the highest areas of debris storage areas 1 and 2 should be used first. The highest ground elevation of these storage areas is 495 feet, which needs to be used before the lower elevations of each storage area. The lowest ground elevation of area 1 is 447 feet, and the lowest ground elevation of area 2 is 467 feet. The rate of reservoir drawdown is dependent on how much LWM is left to store in log booms, the debris collection rate, and how much storage area at certain elevations remains. This will be approximated with a desktop analysis, but in addition should be assessed in the field as operations are occurring.

Development of debris storage areas 1 and 2 will include clearing large woody vegetation. Because of the operational considerations for debris storage areas 1 and 2, the vegetation will be cleared and planted with flood tolerant grasses and forbes conducive to use for wood storage. These efforts will aim to minimize potential impacts from tree removal while maintaining the operational requirements of the debris storage areas. HDR’s *Dead Wood Management Technical Memorandum* addressed the potential concern about the volumes of dead wood that might be created within the inundation pool, upslope of the riparian buffer as required by the Forest Practices Act, after initial operation of the FRE (HDR 2025b). This analysis considered recent and future expected

rotational harvests practice future stand age and estimated that approximately 128 acres, or 15 percent of the area within the inundation pool, would contain mature standing dead trees and potentially benefit from harvest pre-operation of the FRE. This analysis included forested habitat within areas 1 and 2.

During operations, debris storage sequencing methods will be adjusted in response to real-time flood and debris conditions including modifying debris management operations based on debris areas. The intent of this approach is to ensure storage areas remain functional under variable conditions while reducing operational risk.

## 8 Conclusion

The temporary inundation pool at the proposed Chehalis FRE facility is anticipated to accumulate LWM during large flooding events. As described herein, it was determined that upstream of the proposed FRE structure, up to 14 acres of LWM during a 100-year flood event will need to be stored and managed. The debris stored near the structure in storage areas 1 and 2, can store up to approximately 22 acres of LWM. The reservoir inundation elevation would range between 457 and 505 feet for debris management in storage areas 1 and 2.

Removal of estimated LWM is expected to take about 3 days for a 10-year storm event and up to 5 days for a 100-year storm event. Some smaller flood events causing activation of the FRE facility might not generate significant debris, and thus the pause or slowing of drawdown rate to manage debris may be truncated or even eliminated. Given the large variability of LWM acreage potential, reservoir operation will need to be flexible, varying the drawdown for each temporary inundation event based on the amount of LWM present in the inundation pool. More specific operating procedures and access to the debris storage areas will be refined with future analyses in coordination with the operations team.

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# Appendix A. USACE MMD Site Operator Meeting Notes



# Meeting Notes

Project:	Chehalis River Basin Flood Damage Reduction Project	
Subject:	USACE Mud Mountain Dam and Howard Hanson Dam Interview for Debris Management	
Date:	Tuesday, March 25, 2025	3:00–4:00 PM
Location:	Virtual	
Attendees:	Lindsey Ackerman, HDR Kristin LaForge, HDR Ed Zapel, NHC	Kevin Heape, Operations Project Manager, USACE (MMD and HHD) Rick Emry, Chief of Maintenance, USACE (MMD)

This interview is intended to discuss empirical data from the Mud Mountain Dam (MMD) and Howard Hansen Dam (HHD), primarily focused on MMD, with the United States Army Corps of Engineers (USACE). The interview will be regarding their estimated large woody debris (LWD) volumes, removal rates, and general site operations for removal. HHD is less applicable to the LWD empirical data because it holds an annual reservoir.

USACE (Rick and Kevin) have conducted site visits for HDR Engineering, Inc. (HDR) and Northwest Hydraulic Consultants (NHC) personnel in the past for debris management—but because of work changes within USACE, they could only hold a virtual meeting. Images provided by USACE are attached to aid in the discussion.

## Introductions and Roles

- HDR and NHC
- USACE
  - Kevin Heap: Operations Project Manager for both MMD and HHD
  - Rick Emery: Chief of Maintenance for MMD

## Agenda Topics

### Question 1: USACE to describe volumes of LWD in past flood events for MMD and HHD

- **HDR:** Do the dams have flood event predictions or have they ever predicted LWD volumes?
  - **USACE:** Use of river forecast (RCC) for flood flows—but LWD predictions are challenging and not predicted or predictable—no way of knowing how much woody debris is coming
    - Challenges are due to durations between events and the level of bank erosion between events

- **USACE:** Every year holding areas are prepared and ready to go year-round; temporary holdings are also prepared for a flood event
  - Logs are pushed ashore for temporary storage in the multiple lower holding areas (not large nor accessible for ground equipment). They are hauled to more accessible areas in the middle and upper holding basins after being temporarily gathered
  - Temporary (lower) basin: high slope angle, trouble with equipment access, use logs tied up on bank with wire rope, can connect two lower storage basins to provide about 5–7 acres
  - Middle + upper (middle) basin: approximately 40 acres total of storage
  - Based on the flood elevation they may use all or just the lower basin (i.e., small pools or bigger pools)
  - Last 5 years they have only had minor flooding
  - They do not have a step by step procedure—they have to think on the fly and adapt to the conditions at hand, taking into consideration of volume of debris, reservoir elevations, flood flows, etc.
    - The 1996, 2006, and 2009 floods were significant—they have debris records, Rick to follow up
- **USACE:** Mowing of vegetation during non-flood events needs to be done (willow)
- **USACE:** HHD has log boom, but a log boom caused more harm than good for MMD—MMD does not have a log boom upstream of the dam
- **USACE:** They do not have records regarding sacks of debris or number of debris piles of the LWD volume
  - 1996 flood had timber sale of debris area, 40 debris piles perhaps
    - Took 2–3 years to clear out the debris
  - Bigger flood events, they need to wait until summer for firmer ground, debris outside of boom grounds can be even longer to get to
- **USACE:** They have a debris to plan for:
  - Floating debris during flood event that can be put into log booms and moved by a log bronc
  - Debris that drops to the bottom and needs to be removed with another piece of equipment when the pool drops
    - Stumps, waterlogged logs that get stuck in sand and as you evacuate the pool it will plug up the trash rack. Use long-reach excavator throughout the summer and use a camera instead of spotters (Hitachi 400, 65-foot reach).

**Question 2: USACE to describe the estimated time of removal for MMD and HHD**

- **HDR:** When do they start the LWD pickup: visually or with a hydrograph?

- **USACE:** When they have a rising hydrograph (rising pool)
- **USACE:** Need to check roads and culverts, with a rising hydrograph they will check basin areas
- **USACE:** They will note what the current debris load is and debris management becomes the main focus
- **USACE:** Elevations are very important for planning laydown
  - Smaller floods they do not get enough pool to the upper/lower basins to store LWD
  - Smaller floods and large floods each carry their different concerns
- **USACE:** They check for debris on roads and decks, and clean up small floods on the way down
- **USACE:** Budget plans for removal and process:
  - They have a budget plan for debris (for chipping)
  - Budget for the middle basin full of debris every year is 10–15 acres
  - Burn if they cannot get it out
  - Excavator with slash buster (stump grinder)
- **USACE:** The debris basin includes:
  - Gate, boom arm tied to chain tied to dead man
  - Boom grounds

### Question 3: USACE to describe the debris management operations for MMD and HHD

- **HDR:** Who are your debris collection contractors?
  - **USACE:** USACE for the on-water debris work because contractors are hard to find
    - USACE debris team
    - USACE log broncs, take a while to build skill set
      - Takes years until proficient, even by people being trained by experienced people
  - **USACE:** For land work they use contractor
    - Tub grinder
    - During a rising hydrograph, they evaluate the basin area upstream to estimate the magnitude of debris that may be coming downstream. At night four workers are available and seven are available during the day. The night shift is short of personnel to accomplish all the tasks of scouting and removing debris.
      - Smaller floods are of equal importance
      - Remember the floods and debris are not predictable and they need to react to the situation as it develops using experience from past events

- For debris removal they supplement with a few USACE people and USACE equipment
  - Hard to contract out because it takes 3 years of experience under trained experts before new employees are proficient
- Some debris can be turned into habitat logs (conifers with root logs, 30 feet or longer)
  - Brought off road dump truck and stockpile above the flood line, give away for free
- Chipped wood stays to add stability of the basin for equipment access
- Chipper not on hand, so they contract every year
- **USACE:** Further clarification on the removal rates and volumes of removal
  - 4 sacks = 1 acre
  - Bigger floods, run up to the “gut” with other log boom so debris stays in the basin
  - 1 sack = 17.5 steel boom logs tied end to end
    - Encircle one sack and then haul back to the work boat
  - Near the upper/middle basin, it is easier and can haul about four to five sacks every 2 hours
  - Elevation 1,100 is about 2/3 of the way up the trash rack
  - Spring pool, allows to move debris (HHD), MMD does not have a spring pool

Mud Mountain Dam – Shared photographs from USACE interview March 25, 2025



Wood chipping operations (2020)



Chipping at the upper basin (2020)

Note: Soft ground, need to wait for summer to start processing LWD



Middle basin (2020)

Lower: Elev. 1035-1040 ft  
Upper (middle) basin: Elev. 1060-1065 ft  
Upper (upper) basin: Elev. 1075 ft



MDD log boom equipment

Note: USACE operates



Picking LWD at the trash rack (pick the rack)

Below the trash rack is 8ft of sediment after a big flood. USACE needs to clean the platforms after a big flood to stage the excavator.



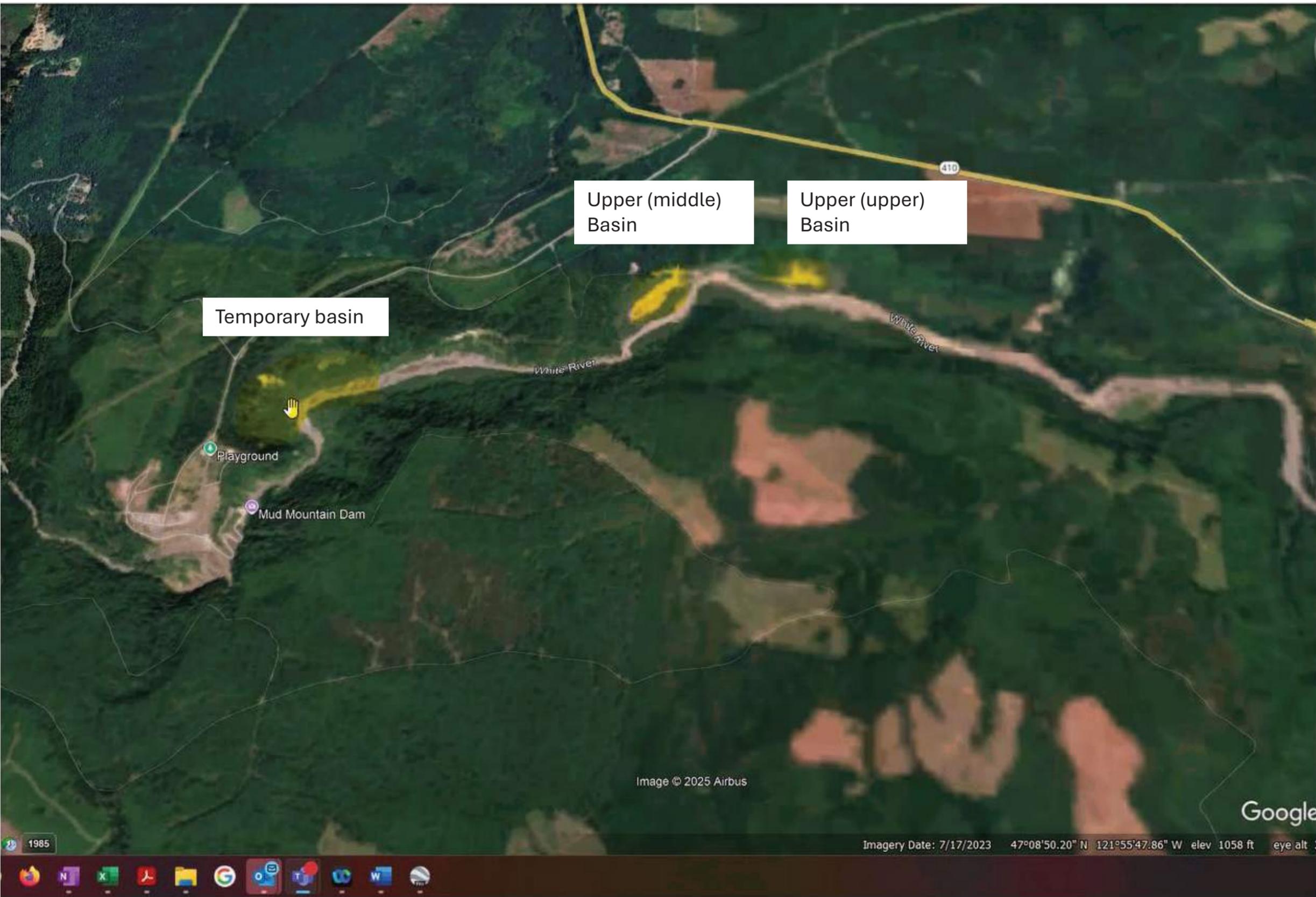
Baldi McDonald



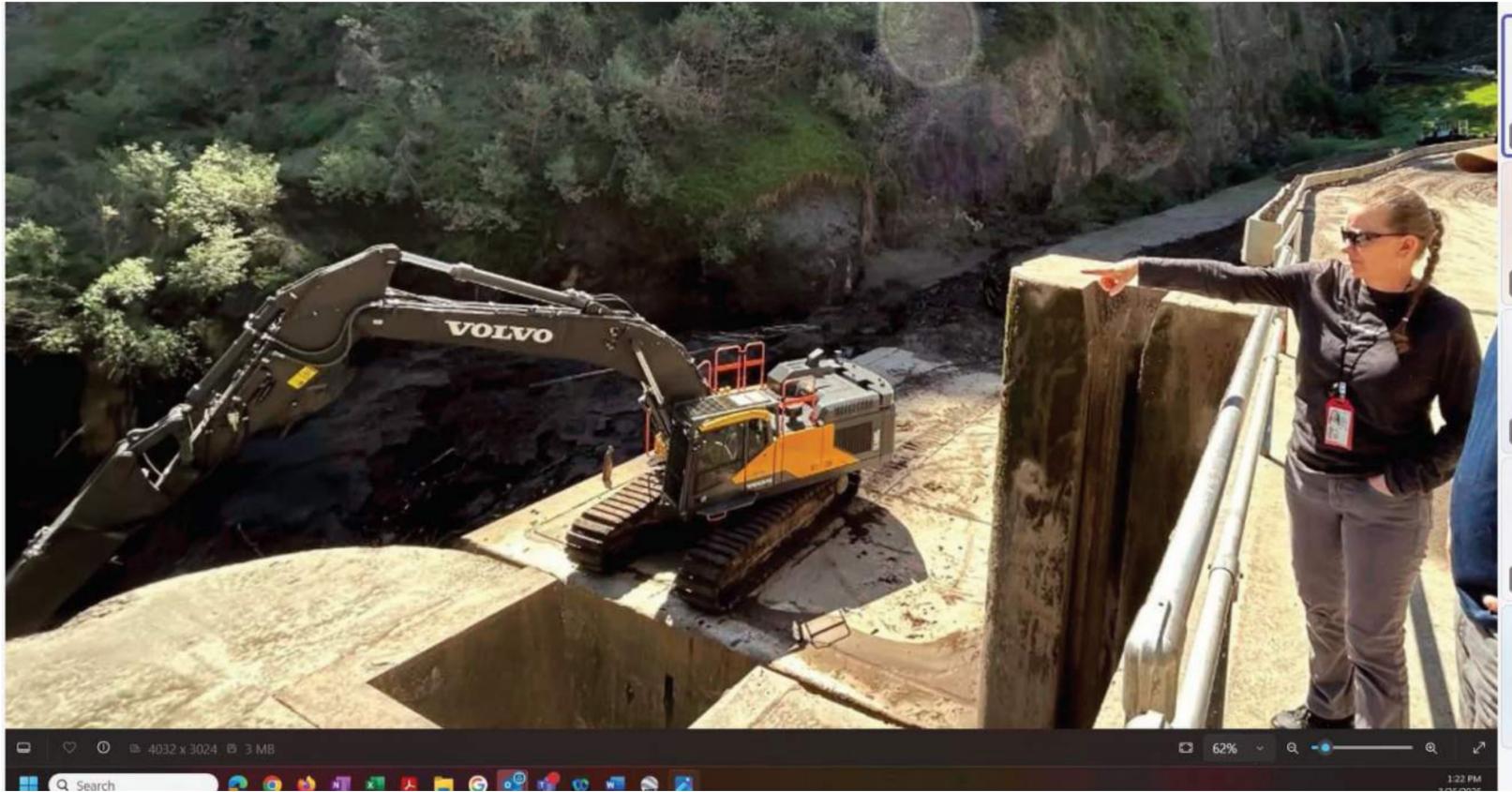
Wood-chipper (2021)



LWD stacking (18 NOV 2021)

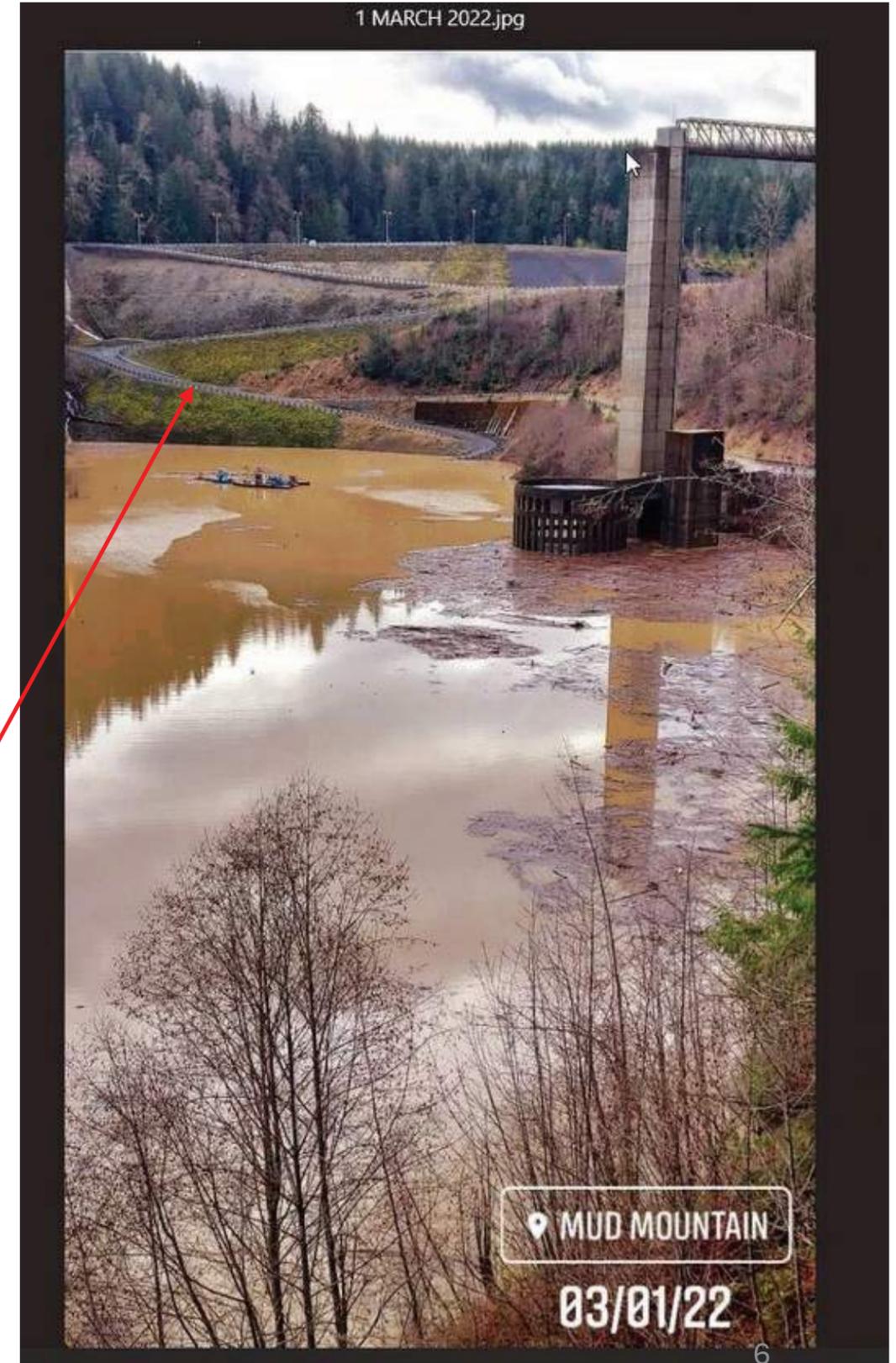


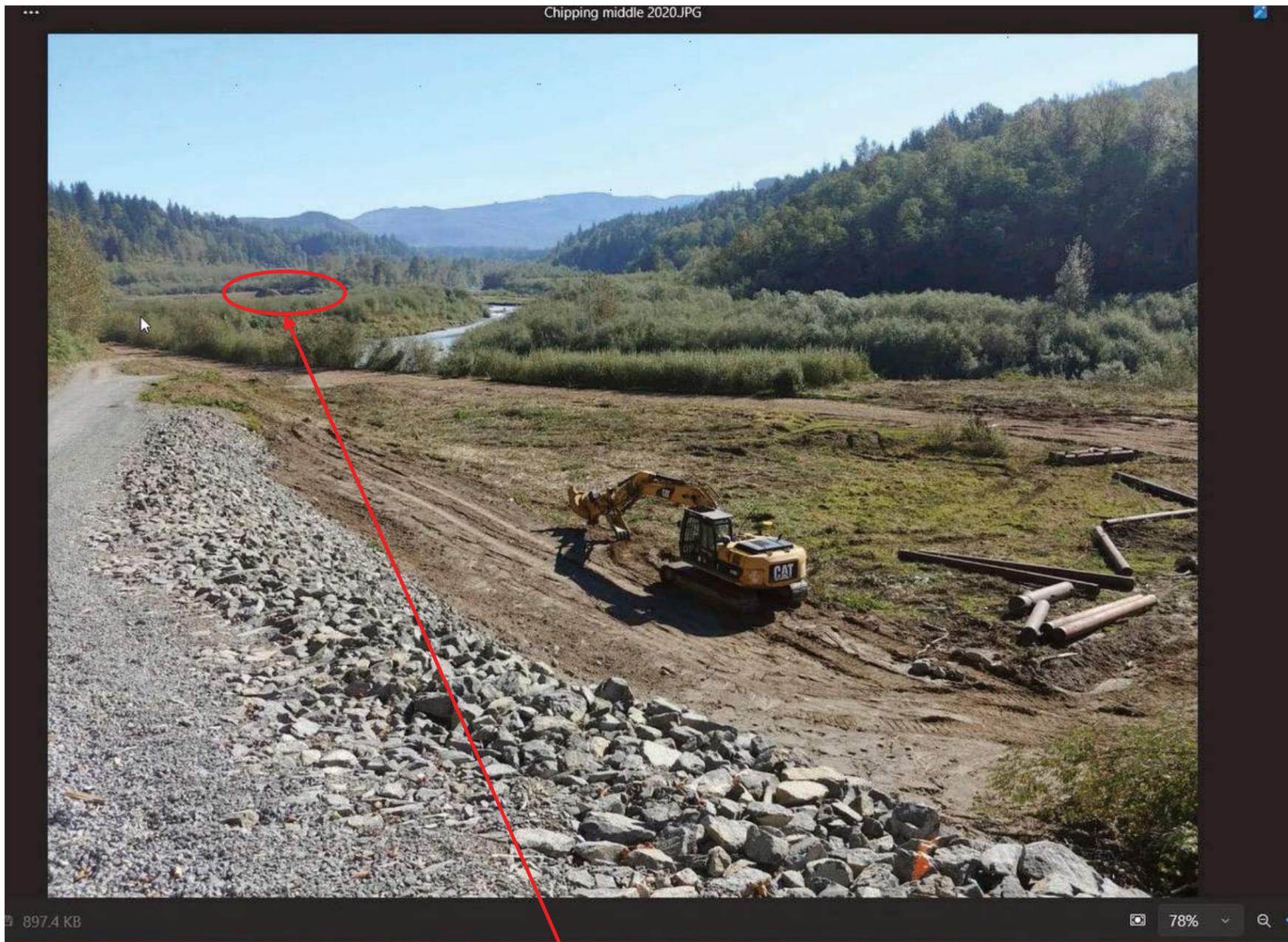
Location of storage basins to estimate distances and sizes



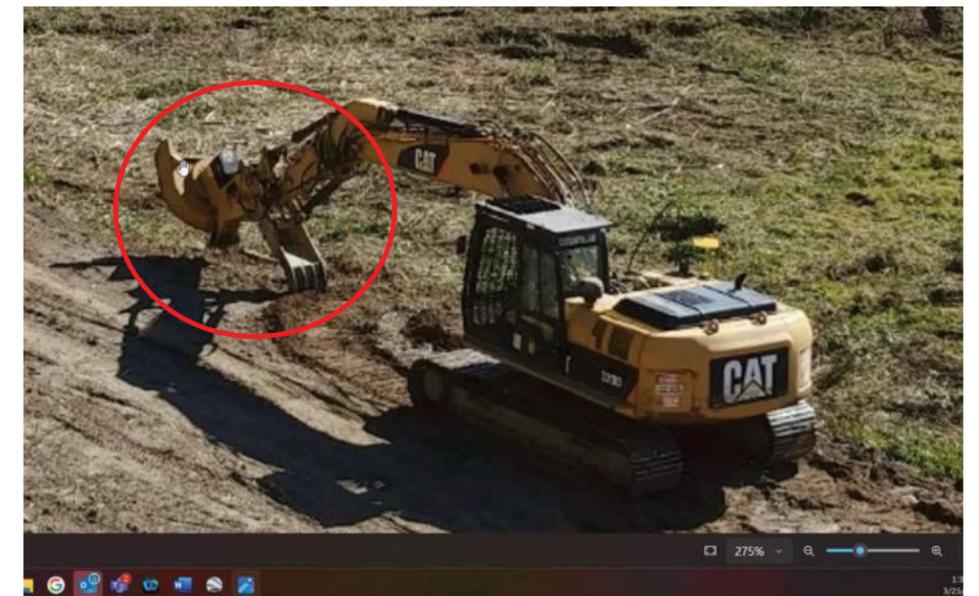
LWD removal at the trash rack w/  
excavator (65ft boom arm)

Access road to access  
the pool at the trash rack





Upper basin and example of debris pile



Rotary cutter at the end of the excavator arm



Image of steel boom logs tied end to end – used to encircle one ‘sack’ and bring to the boat for hauling

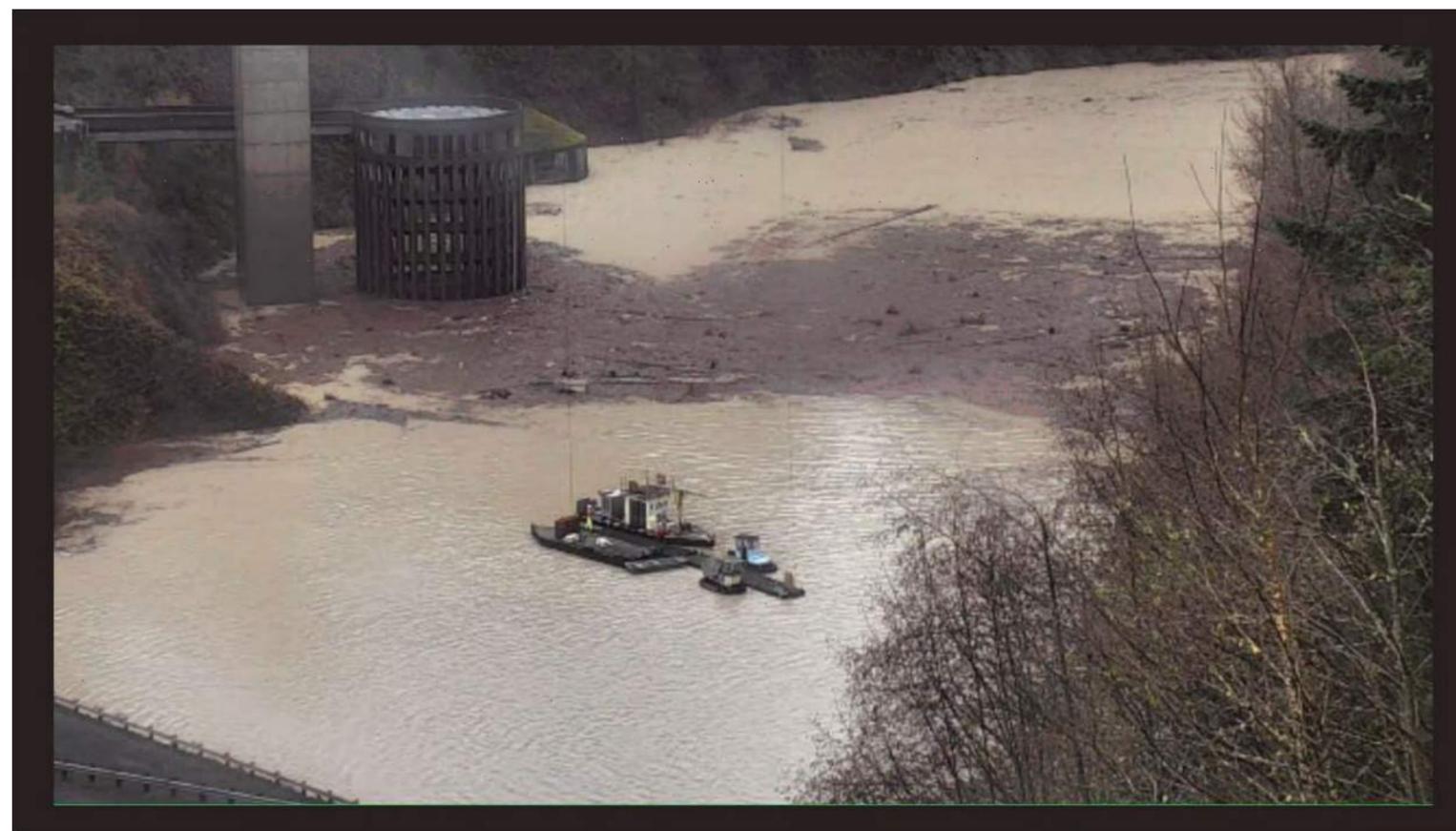


Image of the debris at the trash rack after a flood event

# Attachment 2 – Reservoir Operations Analysis Technical Memorandum

# Technical Memorandum

Date: February 4, 2026

Project: Chehalis River Basin Flood Damage Reduction Project

To: Chehalis Basin Flood Control Zone District

From: HDR

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Subject: **Reservoir Operations Analysis (Draft)**

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## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

The Chehalis River Basin Flood Damage Reduction, draft Preliminary Design Report (PDR) documents development of the preliminary design of the FRE facility and related elements. Development of the draft PDR began following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), which was used as the baseline for the draft PDR, submitted for information-only purposes on June 30, 2025 (HDR 2025). This draft PDR reflects design development that has occurred since submittal of the June 30, 2025 draft PDR.

The draft PDR documents the design basis for each Proposed Project element, including a record of design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements. The draft PDR also presents the technical details of the main features of the Proposed Project elements.

## 2.0 Introduction and Purpose

In 2017, Anchor QEA presented a study of the Chehalis River Basin which included a United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) reservoir operations model (USACE 2021). The analysis was limited in scope and presented a single, simplistic reservoir operations set, which focused solely on reducing peak flood flows at the United States Geological Survey (USGS) Grand Mound gage without consideration for other flood management and environmental impacts within the basin. HDR was tasked to expand this study and develop operational improvements which would reduce peak flood flows downstream, while also minimizing the upstream reservoir pool storage of the Proposed Project to protect critical salmon spawning habitat. Throughout this analysis, the term “reservoir” is used instead of “temporary inundation pool.” The reservoir in question is a

temporary inundation pool, only used during flood detention operations, and not a permanent impoundment.

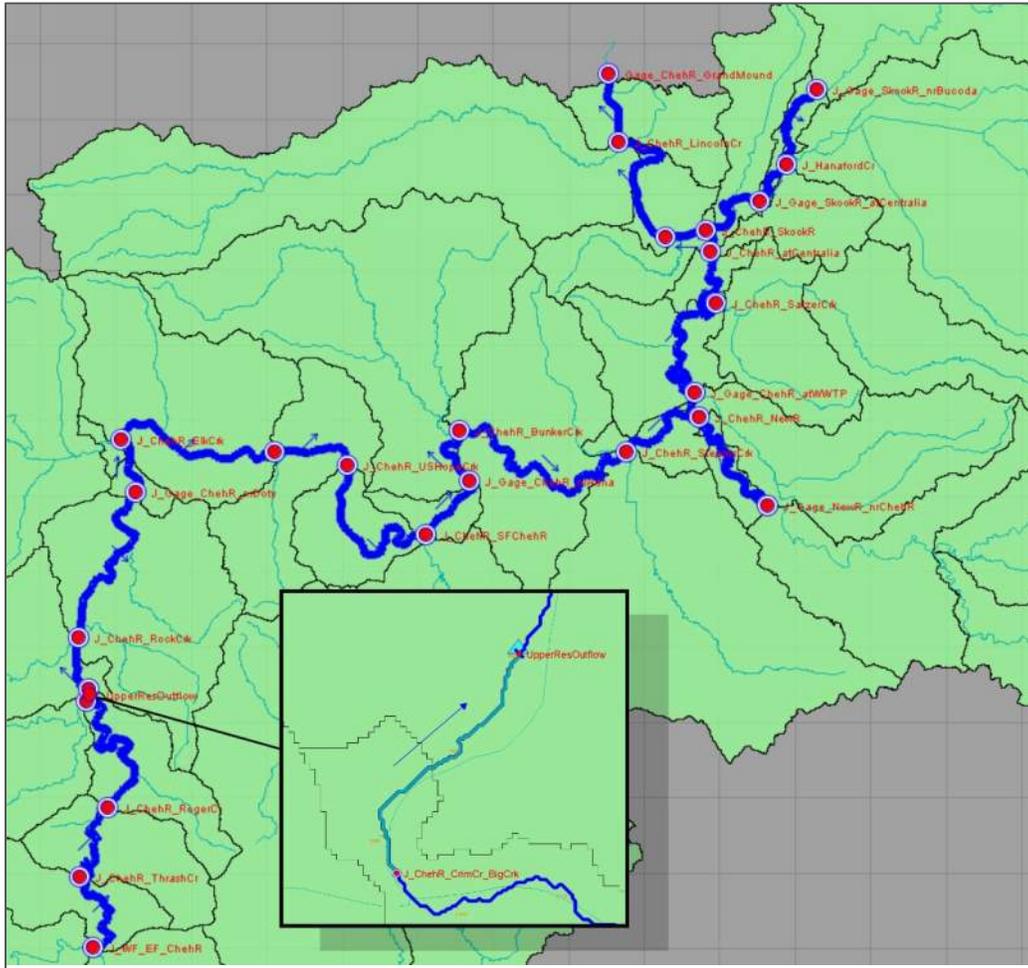
There are six key locations of interest along the Chehalis River, five are USGS gages downstream of the FRE where flood management improvements are desired, and one is the FRE site location. This enhanced HEC-ResSim model expands the extents of the Anchor QEA model using updated hydrology and multiple iterations of alternative sets of flood detention operations. This technical memo summarizes the development, modeling, and resulting discussion of the reservoir operations alternatives.

## 3.0 Model Development

### 3.1 Watershed Setup

The first step in creating the HEC-ResSim model of the Chehalis River Basin was defining the watershed setup. Anchor QEA provided HDR with their HEC-ResSim model from 2017, which consisted only of the reservoir reach and its two inflow and outflow junctions. For this study, the model needed to encompass more of the basin, so enhancements were made to update the configuration to HEC-ResSim Version 3.3 and extend the HEC-ResSim model downstream to Grand Mound consistent with the topology (river junction locations and model naming conventions) of the existing HEC-HMS model. The resulting HDR HEC-ResSim watershed consisted of 27 junctions, 25 reaches, 1 reservoir with an outlet group and spillway, and no other hydraulic structures or diversions in the model configuration. The model spans from the confluence of the West Fork and East Fork Chehalis River and ends downstream at the Chehalis River near Grand Mound USGS gage (12027500; Figure 1).

**Figure 1. Snapshot of the Chehalis River Basin HEC-ResSim Model, Post-Enhancement**



### 3.2 HEC-ResSim Routing Parameters

Once all junctions were defined, the river reaches that connect each junction were added. Routing parameters from the HEC-HMS (Hydrologic Modeling Software) model were imported and assumed to be an appropriate estimation of the system’s hydraulic routing. Of the 25 reaches in the model, 4 used Muskingum-Cunge routing (Table 1), 3 used Muskingum routing, and 17 used Modified Puls routing. The Muskingum-Cunge routing method was applied to reaches without known gage data to better approximate the conditions of the reach using an 8-point cross section sourced from available LiDAR (light detection and ranging). The HEC-ResSim reservoir pool reach does not allow application of routing methods and was automatically set to run with null routing. A storage versus outflow relationship was used to apply the Modified Puls routing to each applicable reach.



**Table 1. Muskingum-Cunge 8-Point Channel Routing Parameters**

Reach ID	Length (ft)	Slope (ft/ft)	Left Manning's n	Channel Manning's n	Right Manning's n
R_ChehR_RM_116_to_118	17,687	0.00791	0.150	0.035	0.150
R_ChehR_RM_113_to_116	18,370	0.00741	0.150	0.035	0.150
R_ChehR_RM_109_to_113	31,000	0.00398	0.150	0.035	0.150
R_SkookR_RM_4_to_6	16,137	0.00100	0.150	0.035	0.100

### 3.3 FRE Physical Characteristics

The FRE structure is modeled with a dam that has a pool, spillway, and outlet group. The outlet group reflects the outlet works configuration as of the June 30, 2025 PDR and consists of one low-level 12-foot-wide by 20-foot-high sluice gate with an invert elevation of 427 feet at the riverbed and two pairs of 10-foot-wide by 16-foot-high sluice gates, with invert elevations of 430 feet. Rating curves for the gates were developed for a 94-percent opening using the orifice equation. Vertical datum was North American Vertical Datum of 1988 (NAVD88). The outlet works described in the Hydraulics and Fish Passage sections of the current PDR reflect the current design. Release capacity and reservoir operations should not be impacted by these changes in the outlet configuration. Based on the current reservoir operation sets, minimum releases are expected to be 300 cubic feet per second (cfs) and maximum releases are expected to be no more than 10,000 cfs using the June 30, 2025 conduit configuration. The maximum reservoir inflows observed in the HEC-ResSim model for the historical period of record (POR) that did not trigger reservoir operations was 13,665 cfs in April 2005; no operations took place and the gates remained fully open, but a small, temporary backwater pool developed due to reservoir inflows exceeding the open-channel inlet capacity of the conduits for a short period.

**Table 2. Reservoir Physical Characteristics**

Variable	Dimension
Elevation at top of dam (ft)	650
Length at top of dam (ft)	1,450
Spillway elevation (ft)	627
Spillway weir coefficient	2.6
Spillway length (ft)	200

### **3.4 Downstream Stage-Discharge Rating Curves**

In addition to the routing parameters from the HEC-HMS model, stage-discharge rating curves were applied to each location of interest on the river where available. Rating curves were developed using 30 design floods modeled in HEC-RAS (River Analysis System) for the 6 key locations on the Chehalis River (Section 5.5.4 of Hydrologic Model Report). These rating curves allowed HDR to calculate water surface elevations (WSEL) and elevation reductions at each location in subsequent analyses.

### **3.5 Local Flow Development**

Local flows used to simulate operations were sourced for the HEC-ResSim model from the updated HEC-HMS model. Operations were simulated with three discrete storms (December 2007, January 2009, and January 2022) and model routings were compared to those in Anchor QEA (2017) to confirm consistency with the original HEC-ResSim model and original 2017 Anchor QEA reservoir operations (2017 Operations). Once this consistency was confirmed, the initial reservoir operations analyses began by using the same three storms with the various operations alternatives to measure their performance against one another and the 2017 Operations. Descriptions of the operations alternatives are in Section 4.0.

### **3.6 Periods of Record – Historical and Future**

After the initial reservoir operations analyses and elimination of most of the operations alternatives, historic POR runs were completed to test operations performance over longer periods. The POR flows simulated in the HEC-ResSim model spanned 42 years, from October 1980 through September 2022. To estimate operational performance under future climate conditions, the HEC-HMS routings of 12 Global Climate Models (GCMs) were then routed through the HEC-RAS model. The future climate GCM POR spans from 1970 through 2100.

## **4.0 Reservoir Operations Alternatives**

### **4.1 Introduction**

A series of brainstorming sessions were held to analyze the 2017 Operations and propose potential areas of improvement for the operations. Performance for any operations alternatives would be measured both at how well the operations reduce the unregulated peak flood flow at Grand Mound and the duration of upstream inundation caused by flood detention operations. A Hydrologic Engineering Management Plan was prepared as a roadmap for the overall operations analysis and a related workshop held to discuss potential alternatives, constraints, and metrics (HDR 2024b). The various operational parameters would be combined, modeled using the three discrete storm events (2007, 2009, and 2022), and compared against one another and the 2017 Operations. Those combinations that performed worst would be eliminated over subsequent modeling rounds until a final set of one to two operational parameters remained. These final combinations would be proposed to the District to be carried forward for future climate analysis and further refinement. The two current recommended operations sets are discussed in Section 6.0.

## 4.2 Operational Parameters

Four major parameters were studied to test their ability to improve the performance of the original 2017 Operations:

- **Operation Triggers** – The suite of conditions that would cause the reservoir to begin storing water to reduce downstream flows in a flood event.
- **Maximum Releases** – How much water may be released downstream of the reservoir during peak storm flows, while maintaining a minimum flow release of 300 cfs to avoid dewatering the river reach just downstream of the Proposed Project.
- **Pool Drawdown/Debris Removal** – After the storm has passed and downstream flows have begun to recede, the drawdown rate for stored water in the reservoir is constrained by the need to remove any accumulated logs and other floating debris while also maintaining slope stability in the upper reaches of the reservoir.
- **Drawdown Releases** – Releases during the post-storm drawdown period may be temporarily limited to avoid secondary flooding resulting from a second storm closely following the initial storm.

### 4.2.1 Operation Triggers (O1-O4)

One of the most critical elements of reservoir operations is deciding when to actually go into flood detention operations. The 2017 Operations set a single trigger of 48 hours before the USGS Grand Mound gage is forecasted to exceed 38,800 cfs (corresponding to the National Weather Service major flood stage of 144 feet) to start restricting flows at the reservoir, and this is reflected in the O1 parameter. It was hoped that adding additional trigger requirements, first at Doty and then in the eastern Chehalis basin, would allow reservoir operations to operate only when they would be most effective at reducing flows at Grand Mound. The O2 parameter required that both the original 2017 Operations 38,800 cfs trigger at Grand Mound and a Doty trigger of 24,400 cfs (Moderate Flood at the Doty gage) be fulfilled before flood detention operations would begin. The O3 parameter adds a third trigger requirement that looks at the expected percentage of contribution to the total flow at Grand Mound from two eastern basin USGS gages: Skookumchuck near Bucoda and Newaukum near Chehalis. If 50 percent or more of the forecast flow at Grand Mound is expected to come from those two gages, reservoir operations would not be triggered. By adding these additional flow conditions to the operation trigger, the Proposed Project is not triggered as frequently as the O1 alternative, leading to fewer days of inundation upstream of the project. The O4 parameter was designed to act as many flood management reservoirs are operated, with a downstream maximum flow target (38,800 cfs) set at Grand Mound and a more flexible operation trigger that would factor in the current basin flow conditions and updated travel times between the reservoir and Grand Mound. Operations would not be automatically triggered 48 hours before a certain flow is forecast at Grand Mound, but it could be triggered earlier or later than the 48-hour mark depending on baseflows within the basin just prior to the storm. It was expected that this improved flexibility could allow the reservoir to store less water in small to midsized storms while achieving the same downstream peak flow reduction at Grand Mound by closing slightly later than the 2017 Operations O1 operation trigger. During larger storms, the O4 operation trigger could close at the same time as, or possibly even earlier than, the O1 trigger, but it was expected that the



extra flexibility in operations would be a net positive in reducing the duration of stored water in the reservoir.

**Table 3. Operation Trigger Parameters**

Parameter	Name	Description
O1	2017 Operations	Flood detention operations are triggered 48 hours before the flow at the USGS Grand Mound gage is forecast to rise above 38,800 cfs.
O2	2017 Operations + Doty Trigger	Adds additional requirement of a required forecast of 24,400 cfs at the USGS Doty gage to trigger operations.
O3	2017 Operations + Doty Trigger + Eastern Basin Trigger	Adds third requirement of a required forecast trigger in the eastern Chehalis basin.
O4	Downstream Flow Control Rule	Attempts to limit flow at Grand Mound to no more than 38,800 cfs by factoring in current basin flow conditions and travel times between the reservoir and USGS Grand Mound gage.

#### 4.2.2 Maximum Releases (Q1-Q4)

The Q1-Q4 parameters dictate how much water may be released during flood detention operations, particularly during the peak of downstream flow. A minimum flow release of 300 cfs will be maintained at all times during operations to provide water for fish in the river reach just downstream of the reservoir. The 3,000- to 7,000-cfs range was developed to avoid significant bed scour downstream and allow adequate sediment to pass through the structure for salmon redds downstream of the reservoir.

**Table 4. Maximum Release Parameters**

Parameter	Name	Description
Q1	2017 Operations: 300 cfs	The set release of 300 cfs during activation, according to the 2017 Operations.
Q2	Maximum releases during storm event: 3,000 cfs	This increases the maximum release allowed during the storm event to 3,000 cfs while maintaining the 300 cfs minimum.
Q3	Maximum releases during storm event: 5,000 cfs	This increases the maximum release allowed during the storm event to 5,000 cfs while maintaining the 300 cfs minimum.
Q4	Maximum releases during storm event: 7,000 cfs	This increases the maximum release allowed during the storm event to 7,000 cfs while maintaining the 300 cfs minimum.



### 4.2.3 Pool Drawdown/Debris Removal (D1-D5)

During and after a storm, varying amounts of logs and other floating debris are expected to accumulate in the reservoir pool which will need to be collected to avoid clogging or damaging the conduits of the Proposed Project. This debris removal will involve using boats to drag large pieces of floating debris and logs to onshore collection sites for later removal. The typical drawdown rate of the reservoir pool is 10 feet/day and was chosen to provide soil stability in the upper elevations of the reservoir conservatively; future geotechnical analyses will investigate the possibility of increasing the drawdown rate in the upper reaches of the reservoir to a maximum of 20 feet/day to further reduce the inundation time of upstream salmon redds.

The 2017 Operations (D1) involve a 2-week debris removal period where the drawdown of the stored water behind the dam will be slowed temporarily to a pool elevation drawdown limit of 2 feet/day to allow debris to be removed from the pool before the drawdown continues at its typical, faster pace of 10 feet/day. The D2 parameter includes no pause for debris removal, so the 10 feet/day pool drawdown limit continues until the reservoir is empty, thus reducing the inundation duration upstream of the reservoir. The D3 parameter reduced the 2-week debris removal period to 5 days based on early estimates of the minimum debris removal period needed, and the D4 parameter removed both the debris removal period and the 10 feet/day pool elevation drawdown limit to demonstrate the fastest possible pool drawdown that would not increase downstream flooding. A subsequent refinement known as D5, in consultation with HDR’s geotechnical and debris management teams, allows a slightly increased drawdown rate of 20 feet/day below 477 feet as the risk of landslides is reduced due to slope stability measures planned for the lower reaches of the reservoir. This refinement also reduced the duration of the debris management period to 5 days and moved debris management activities lower in the pool to 487-477 feet NAVD88 to support as much of the upper basin returning to free-flowing conditions as quickly as possible. The D5 parameter is reflected in the operations results shown in Section 5.0 herein.

**Table 5. Pool Drawdown/Debris Removal Parameters**

Parameter	Name	Description
D1	2017 Operations	This is the 2017 Operations pool elevation decrease limit of 10 feet/day with a limit of 2 feet/day from elevation 500 to 528 feet.
D2	Maximum pool elevation decrease of 10 ft/day – no debris removal period	This parameter removes the 2 ft/day slowdown during log/debris removal to demonstrate the drawdown period in cases where captured debris is minimal.
D3	Maximum pool elevation decrease of 10 ft/day – 5-day debris removal period	This parameter reduces the 2017 Operations log/debris removal slowdown from 14 days to only 5 days as debris removal may not be longer than that while in operation.

Parameter	Name	Description
D4	No pool elevation decrease limit	To demonstrate the fastest possible pool drawdown, this parameter removes any pool drawdown rate limit. Downstream flow and physical release limits are still included and modeled.
D5	Updated drawdown rates – 5-day debris removal period lower in the basin	This parameter reduces the debris management period to 5 days and shifts it lower in the pool (487-477 feet). Below 477 feet, the drawdown rate limit is increased from 10 feet/day to 20 feet/day.

#### 4.2.4 Drawdown Releases (P1-P2)

In addition to the Pool Drawdown/Debris Removal parameters (D1-D5), a set of Drawdown Release parameters (P1-P2) also control how quickly flow releases can change when the reservoir is emptying the pool. The P1 parameter is the basic 2017 Operations limit that restricts releases from increasing more than 1,000 cfs/hour once flow has peaked at Grand Mound. During most drawdown periods, maximum releases are dictated by the maximum pool elevation drawdown limits (D1-D5) so the P1 parameter only acts as a limit to prevent releases from increasing too rapidly. The P2 parameter includes this 1,000 cfs/hour limit while also maintaining releases to avoid flow at Grand Mound from rising above the Minor Flood stage (141 feet NAVD88). This allows post-storm recovery downstream of the reservoir to be carried out safely even in the event of a secondary storm occurring soon after the initial major storm. If a secondary storm event occurs, the P2 parameter may limit pool drawdown temporarily or even store additional water in an attempt to keep flow at Grand Mound below the Minor Flood stage.

**Table 6. Drawdown Release Parameters**

Parameter	Name	Description
P1	2017 Operations	This is the 2017 Baseline operation, which allows post-storm release increases of 1,000 cfs/hour once flow has peaked at Grand Mound. Typically, maximum releases are then dictated by the maximum pool elevation decrease rate.
P2	2017 Operations + Minor Flood stage (141 ft NAVD88) limit at Grand Mound	This operational parameter continues the 1,000 cfs/hour release rate maximum and adds a limit that attempts to maintain downstream flows at Grand Mound at less than the Minor Flood stage (141 ft NAVD88).

#### 4.3 2017 Operations: Baseline Operations Set for Study

The original 2017 Operations for the Proposed Project have not been modified and remain as Anchor QEA configured them in the HEC-ResSim model. Along with its 2017 HEC-ResSim model, Anchor QEA provided HDR its 2017 final operations plan report. The current proposed 2017 Operations use the following five phases which are triggered by hydraulic thresholds established by Anchor QEA (2017).

To demonstrate how 2017 Operations would occur, a walk-through of a typical flood detention operation using 2017 Operations' ruleset is below, including which parameters are guiding the operation at any specific phase:

### **1. Operations Prior to the Storm Event (O1)**

The Proposed Project will be triggered to begin closing its gate(s) when the discharge at the USGS Grand Mound gage is forecast to reach or exceed 38,800 cfs within the next 48 hours. This analysis assumes a perfect forecast at Grand Mound. USGS forms stage-discharge rating curves for their gages, which Anchor QEA was able to obtain for their analysis. Using the National Oceanic and Atmospheric Administration's definition of a major flood, along with the USGS rating curve for the Grand Mound gage, it was determined that when the Chehalis River reached a stage of 17.0 feet (gage datum was 123.65 feet above National Geodetic Vertical Datum of 1929 [the major flooding threshold according to the National Oceanic and Atmospheric Administration]), the discharge was predicted to reach 38,800 cfs. Once a Major Flood is forecast at Grand Mound in the next 48 hours, the sluice gates will begin to close, commencing flood control operations.

### **2. Operations During Floods (Q1)**

When the sluice gates are triggered and begin to close, retaining the flood, releases will decrease at a maximum rate of 200 cfs/hour, until reaching the maximum flood event release of 300 cfs. This maximum discharge is the low flow that typically occurs in winter months when these operations were developed in 2016. The reservoir will continue to release water at a rate of 300 cfs until the flood peak at Grand Mound has passed.

### **3. Initial Drawdown (D1)**

The initial drawdown begins after the flood peak at Grand Mound has passed by increasing reservoir releases by a maximum rate of 1,000 cfs/hour, until a maximum drawdown of 10 feet/day is achieved. After a flood, the drawdown rate is controlled to avoid rapid drawdown, which could potentially cause a landslide or other erosion-related issues to occur. This drawdown rate would allow soils to properly drain, once exposed by the dropping water level, and help to avoid slope failures.

### **4. Debris Removal (D1)**

During flood events, it is expected that large logs and other floating debris will accumulate in the pool and may disrupt reservoir operations. To avoid clogging and the potential for damage, the 2017 Operations incorporate a debris removal period into the drawdown process. When the reservoir pool has been drawn down to an elevation of 528 feet, large debris can be collected from the pool and trashrack. While the debris is being removed from the reservoir, the drawdown rate will be reduced to a maximum of 2 feet/day to provide easier access during debris collection. This debris recovery stage will be in operation for 2 weeks until the reservoir reaches an elevation of 500 feet.

## 5. Finish Drawdown (P1)

With debris removed from the pool, the reservoir is then able to finish drawing down the remaining accumulated flood storage. Once again, the 2017 Operations limit the drawdown rate to 10 feet/day and increasing outflow to no more than 1,000 cfs/hour. Once the pool has been completely emptied, the project will resume its normal flow-through operations, allowing all water to freely pass through open gates.

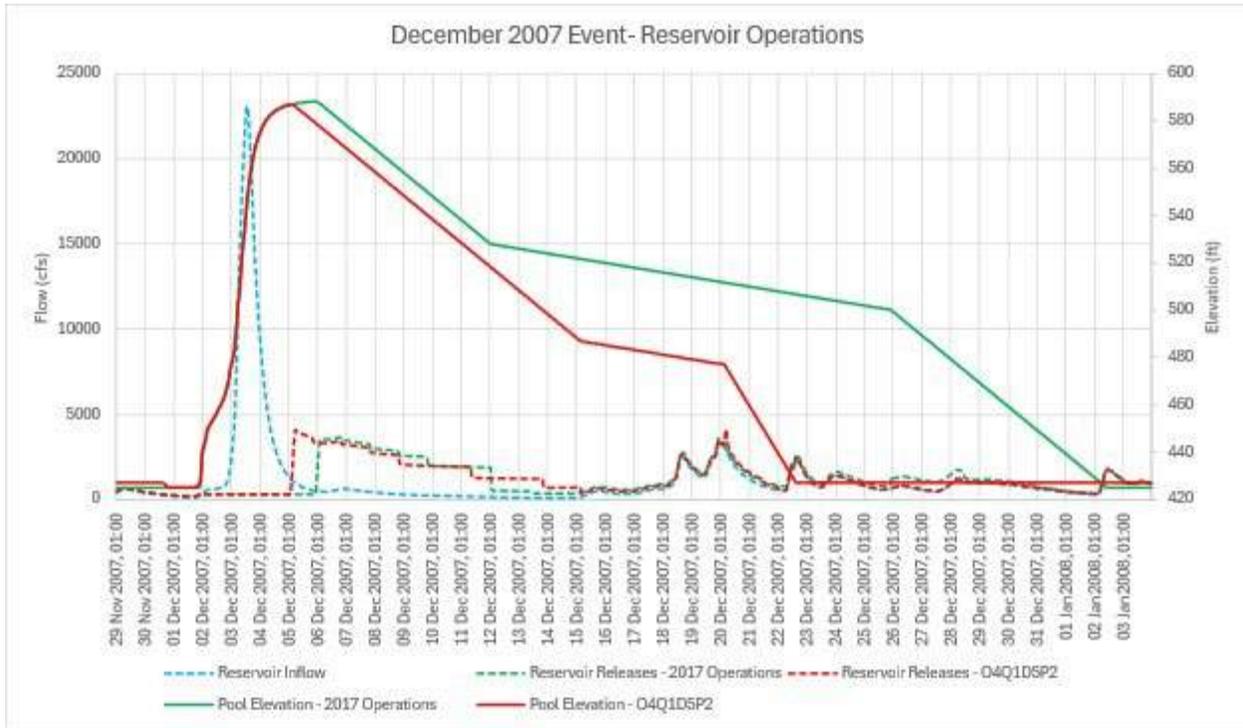
## 5.0 Results

This analysis updated an existing 2017 HEC-ResSim model from Anchor QEA with previously defined reservoir operations to simulate operations alternatives to reduce environmental impacts during flood detention operations. Results from the HEC-ResSim model included inflow/outflow to the reservoir, elevation and flow at each of the five USGS gages of interest, and reservoir pool elevation and storage. The proposed alternatives' performances were evaluated based on how well the operations could decrease flows and WSEL at the USGS Grand Mound gage, while also minimizing environmental impacts by reducing the reservoir pool duration (when the WSEL in the reservoir is above 447 feet).

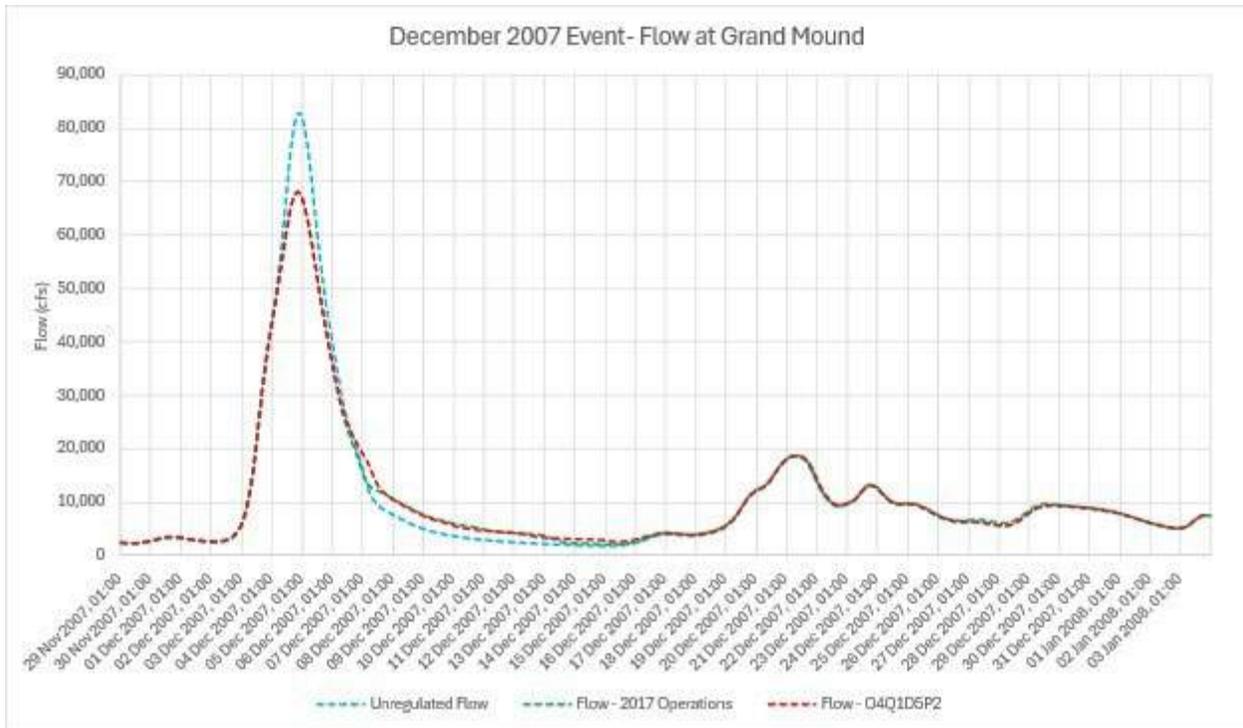
### 5.1 Discrete Storms Modeling

To timely assess the initial collection of 128 operations alternatives (the total combinations of the operational parameters described in Section 4.0: O1-4, Q1-4, D1-5, P1-2), initial modeling rounds were restricted to three discrete historical storm events (2007, 2009, 2022). Operations sets are labelled by the operational parameters they employ. The 2017 Operation uses the first parameter in each category and is therefore labelled O1Q1D1P1. One of the two best-performing operations sets used the fourth operations trigger parameter O4, the first maximum release parameter Q1, the fifth initial drawdown/debris management parameter D5, and the second finish drawdown parameter P2, leading to the label O4Q1D5P2. Figure 2 through Figure 7 show modeled reservoir operations during these three storm events with 2017 Operations and alternative operations set O4Q1D5P2. Further discussion of how the collection of operational parameters was evaluated and reduced follows in Section 5.4.

**Figure 2. Modeled Reservoir Operations for the December 2007 Flood Event**

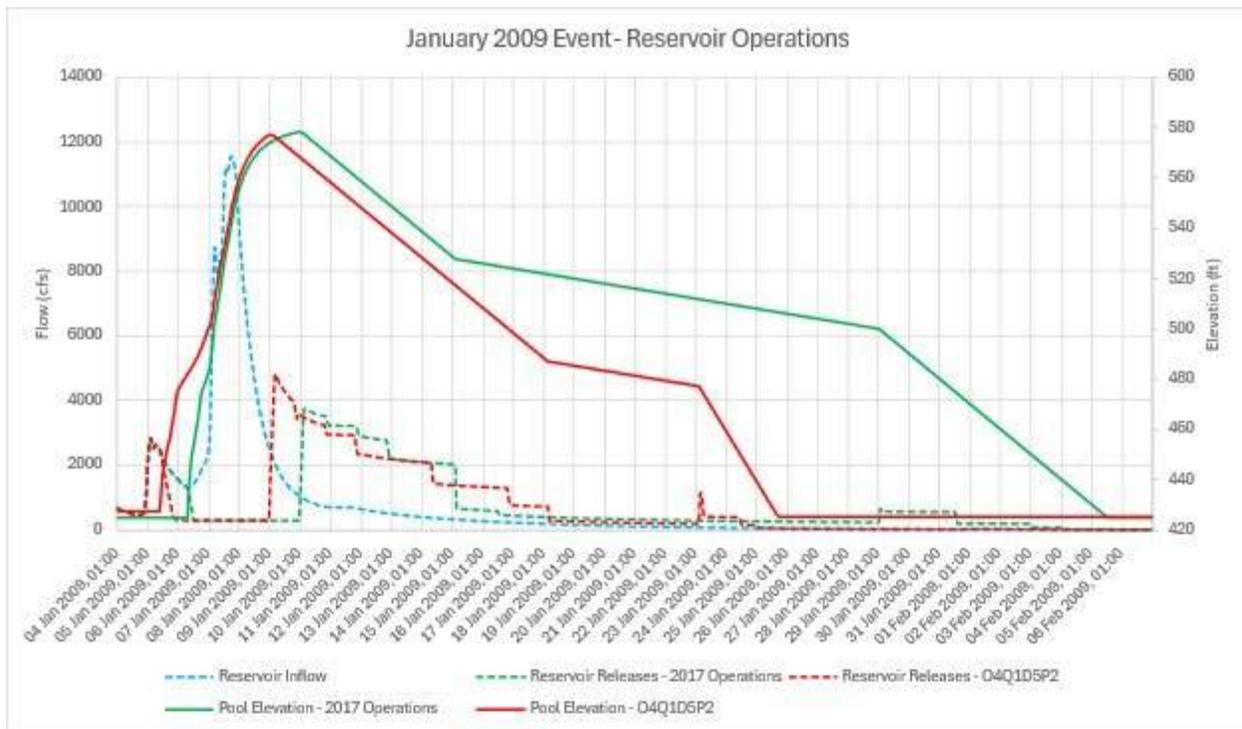


**Figure 3. Modeled Flow at Grand Mound for the December 2007 Flood Event**

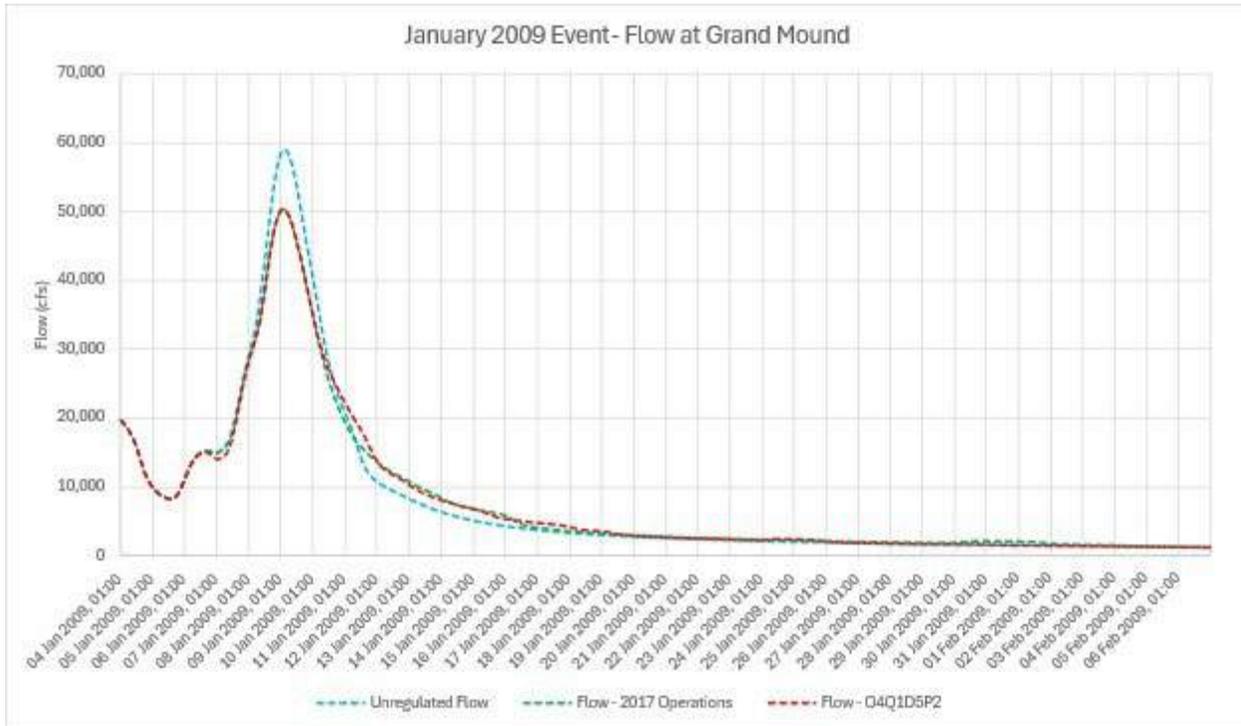


Given the magnitude of the December 2007 storm, both operations sets behaved nearly identically with operations initialization in the first part of the storm event. Both reduced the peak flow at Grand Mound from 82,887 cfs to 68,174 cfs, more than 20 percent lower than the unregulated (without-project) flow. The O4Q1D5P2 operations react quicker to decreasing flow at Grand Mound and begin drawing the reservoir down earlier than the 2017 Operations, and the maximum drawdown rate below 477 feet increases to 20 feet/day as discussed in Section 4.2.3. The O4Q1D5P2 operations set reaches an empty pool on December 22, 2007, with the 2017 Operations trailing by just under 11 days. Stated another way, the O4Q1D5P2 operations set reduces the duration of inundation from 32 days to 21 days, about a 34 percent reduction.

**Figure 4. Modeled Reservoir Operations for the January 2009 Flood Event**



**Figure 5. Modeled Flow at Grand Mound for the January 2009 Flood Event**

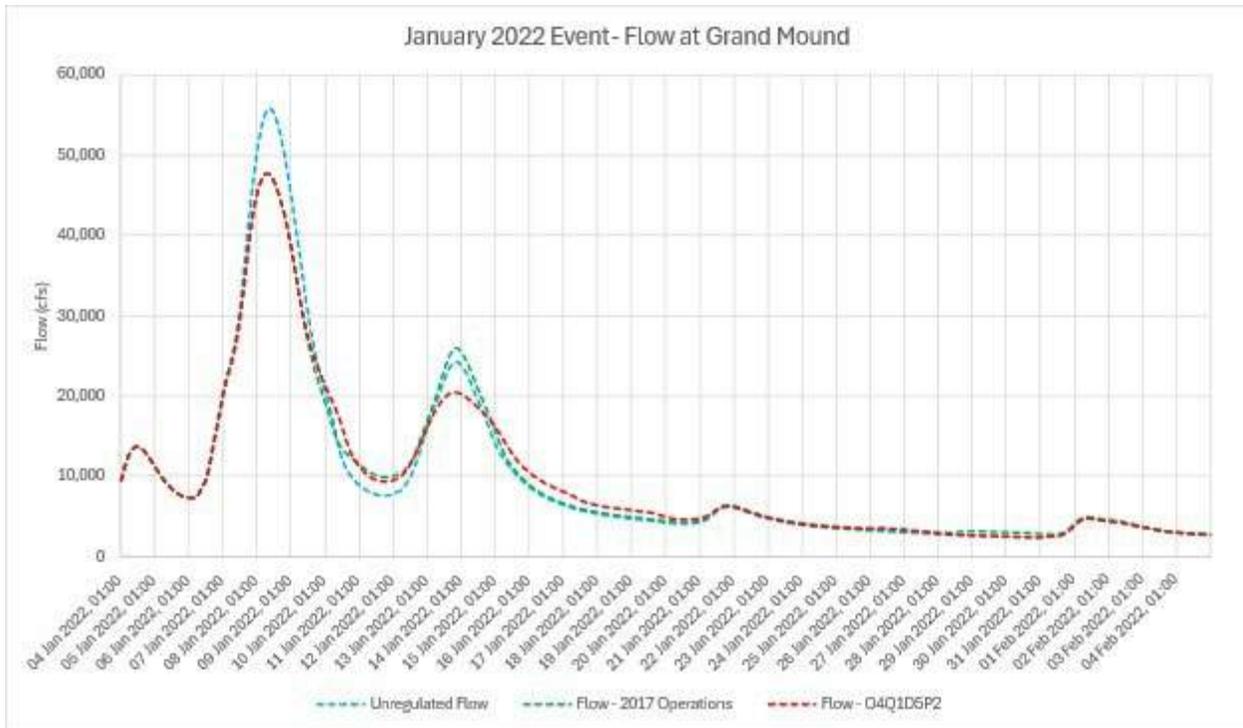


For the 2009 event, though the O4Q1D5P2 operations set begins storing water almost a day earlier than the 2017 Operations set, the overall pool duration of O4Q1D5P2 ends up almost 11 days shorter than the 2017 Operations (about at 33 percent decrease in inundation time). Both hold Grand Mound to a peak flow of 50,348 cfs (peak Grand Mound flow for O4Q1D5P2 was 50,343 cfs) compared to an unregulated peak flow of 59,010 cfs, a 17 percent decrease. The difference in pool durations is due to O4Q1D5P2 starting drawdown 1 day earlier, having the shorter debris management period, and drawing down at the faster rate of 20 feet/day once the pool is below elevation 477 feet.

**Figure 6. Modeled Reservoir Operations for the January 2022 Flood Event**



**Figure 7. Modeled Flow at Grand Mound for the January 2022 Flood Event**





The 2022 event demonstrates the P2 parameter driving the O4Q1D5P2 operations during pool drawdown, after the primary storm has passed. When a large secondary storm struck the basin on January 11 and 12, 2022, the O4Q1D5P2 held back releases to keep flows at Grand Mound below the Minor Flood stage. This resulted in a reduction of the secondary peak at Grand Mound of 5,536 cfs compared to 2017 Operations, which slightly increased the secondary peak flow relative to unregulated flows by continuing to empty the reservoir during the secondary storm. Despite this additional flood protection, the O4Q1D5P2 operations set reduced the inundation period by 7 days compared to the 2017 Operations (about a 24 percent decrease in inundation time). During the main, larger storm, both operations reduced flow at Grand Mound from an unregulated peak of 55,788 cfs to 47,765 cfs, a 16 percent decrease.

Table 7 and Table 8 summarize the performance of two key operations sets, 2017 Operations and O4Q1D5P2, for these three discrete historical storm events.

**Table 7. Summary of Historical Event Routing Performance – 2017 Operations**

Event	Maximum Reservoir Inflow (cfs)	Maximum Flow at Grand Mound (cfs)	Reduction in Peak Flow at Grand Mound		Duration of Reservoir Pool (days)
			(cfs)	(%)	
Dec 2007	23,100	68,174	14,713	21.6%	32
Jan 2009	11,571	50,348	8,661	17.2%	30
Jan 2022	11,487	47,765	8,023	16.8%	29

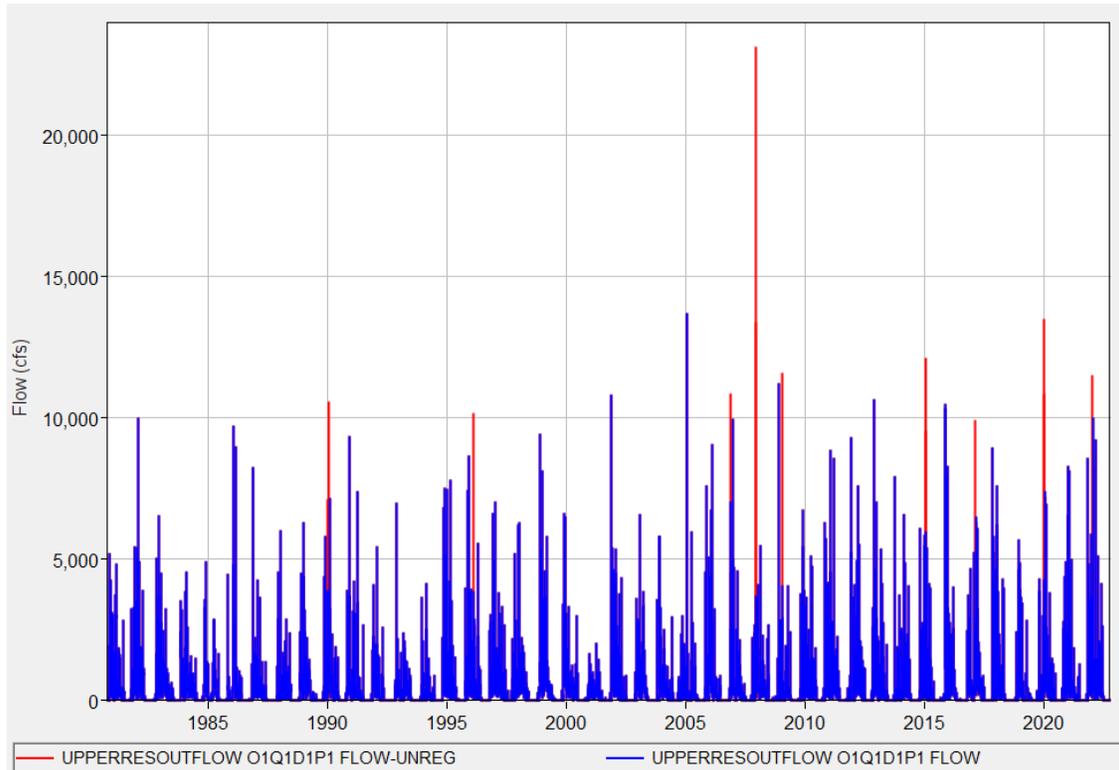
**Table 8. Summary of Historical Event Routing Performance – O4Q1D5P2**

Event	Maximum Reservoir Inflow (cfs)	Maximum Flow at Grand Mound (cfs)	Reduction in Peak Flow at Grand Mound		Duration of Reservoir Pool (days)
			(cfs)	(%)	
Dec 2007	23,100	68,174	14,713	21.6%	21
Jan 2009	11,571	50,343	8,666	17.2%	20
Jan 2022	11,487	47,765	8,023	16.8%	22

## 5.2 Current Climate Period of Record Modeling

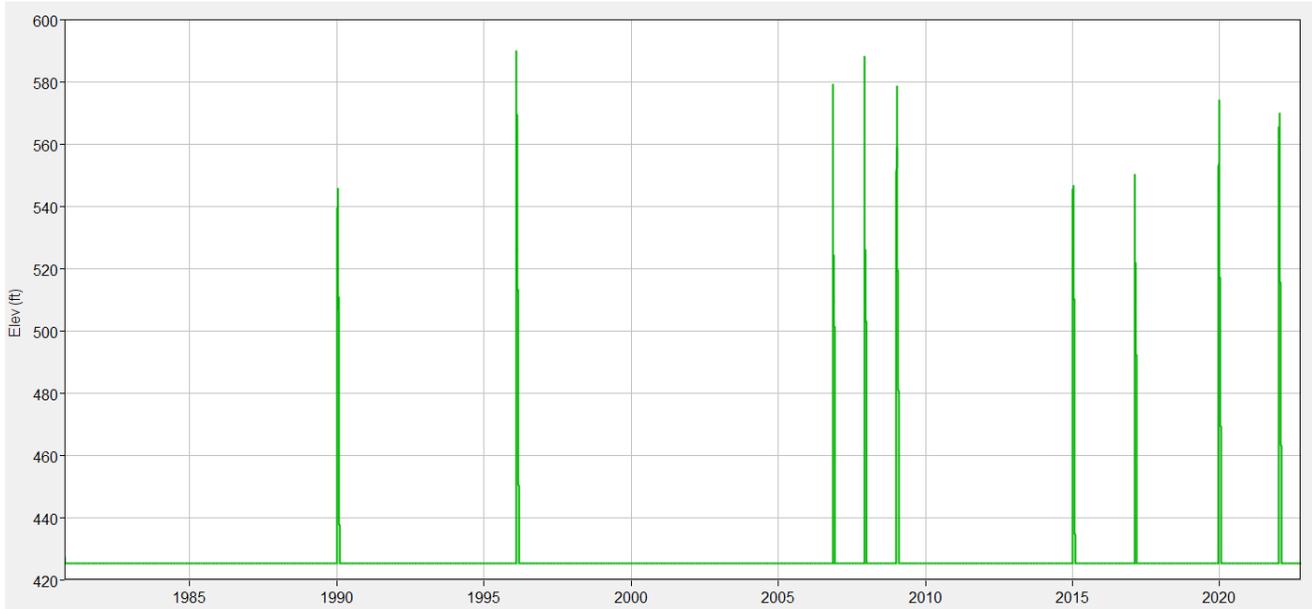
The HEC-ResSim model was run with a 42-year POR local flow time series developed in the HEC-HMS model. Figure 8 shows the results of the unregulated inflows to the reservoir and releases using the 2017 Operations.

**Figure 8. Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



In Figure 8, the HEC-ResSim model and its associated regulated flows display a reduction in some flood event peaks modeled at the FRE site. Red and blue peaks in the plot represent unregulated flood flows and regulated flows (using 2017 Operations) respectively. Figure 9 shows a plot of the reservoir pool elevation results from the 2017 Operations POR run.

**Figure 9. Plot of Regulated (2017 Operations) Reservoir Pool Elevations at the FRE Site**



During the 42 historic years of record run in the simulation, the reservoir was triggered to commence flood control operations nine times using the 2017 Operations due to the 38,800 cfs forecast trigger at Grand Mound.<sup>1</sup> Additional flood events that did not trigger flood control events but exceeded outlet flow capacity caused some minor pooling. The dam’s spillway, which has a crest at elevation 627 feet, was not used during any events that occurred over the 42-year POR modeling run. The maximum reservoir pool elevation over the POR is 589 feet, which occurred during the February 1996 flood event. This was 1 foot higher than the modeled operations for the 2007 storm due to the longer overall duration of the 1996 storm compared to the 2007 storm, despite the 2007 storm having a higher peak inflow into the reservoir.

### 5.3 Evaluation of Operational Parameters

Through multiple series of reservoir operations modeling runs, the operational parameters under consideration were evaluated and most were eliminated from the analysis. Some parameters were removed because they did not improve operations. Others would not make sense in real-world operations and were used to set operational boundaries (i.e., how quickly the reservoir pool could be emptied given no drawdown or debris removal restrictions). In summary, these parameters were eventually removed: O2-O3, Q2-Q4, and D1-D4.

#### 5.3.1 Operation Triggers (O1-O4)

The O1 trigger, which starts storing water 48 hours before a forecast flow of 38,800 cfs at Grand Mound, is considered the most conservative operation trigger parameter because it is rigid in its

<sup>1</sup> The actual period of record during this time, according to USGS data, resulted in only 7 years in which peak flows exceeded 38,800 cfs at Grand Mound. Peak flows during some years were close to but under that level. Therefore, the nine triggered operations in this model represent a slight overprediction compared to historical flows, in which some modeled flows are slightly higher than the observed flows, resulting in two additional triggered operations.

operations initiation logic and tends to store more water than other alternatives for similar downstream peak flow reductions based on the siting of the reservoir. This overstorage of water is most apparent during smaller storms that are forecast to just cross the 38,800 cfs trigger at Grand Mound, which results in the O1 operations typically having longer pool durations than the other options.

The O2 and O3 operation triggers were designed to operate the reservoir only when it was expected to be most effective, when the storm is focused on the western side of the basin upstream of the reservoir. These two parameters considered trigger flows at additional gages besides Grand Mound. While such secondary triggers achieved slightly fewer operations, they made the overall operations too insensitive, so flow reduction benefits at Grand Mound suffered and were not achieved often enough for these parameters to be carried forward. Increasing the operation triggers' sensitivities by lowering their respective trigger thresholds only resulted in operations similar enough to the O1 trigger that their value was not apparent. In other words, limiting operations to times when gages other than Grand Mound were high either failed to trigger when flood protection was needed at Grand Mound or (if the other gages' trigger flows were lowered enough to fix that problem) made these secondary triggers irrelevant.

The O4 trigger, which replicates a real-world operation with a live reservoir operator monitoring downstream flows and basin conditions, performed especially well after some extra troubleshooting and programming within the HEC-ResSim model. The O4 operation sets matched the O1 peak flow reduction in major storms and were able to store less water than O1 operations sets in small to moderate storms while not exceeding 38,800 cfs at Grand Mound.

### **5.3.2 Maximum Releases (Q1-Q4)**

The maximum release triggers were designed to understand potential impacts of releasing slightly more water during flood operations to decrease the duration of the reservoir pool. It was evident early on in modeling that any additional water released would only increase downstream flooding by that amount while decreasing the reservoir pool duration by only a few hours. This tradeoff was unacceptable for the proposed flood control structure.

### **5.3.3 Pool Drawdown/Debris Removal (D1-D5)**

Varying the duration of the debris removal period was found to be unrealistic as it made comparing operations sets with different drawdown parameters a difficult prospect; whichever operations set had the shorter debris removal period would inevitably have a shorter reservoir pool duration, regardless of the actual debris conditions after a storm. Given this potential for variation, it was initially decided that using any parameter other than the 2017 Operations D1 parameter would be an unfair and unrealistic comparison. Additionally, the D4 parameter, with no pool drawdown restrictions, is unrealistic in real-world operations where slope stability in the upper reaches of the reservoir would be a concern.

After consulting with the geotechnical team, however, it was decided to allow an increased drawdown rate of up to 20 feet/day below 477 feet in the reservoir. Below 500 feet, all identified landslide areas within the reservoir would be stabilized so the increased drawdown rate was considered acceptable. The debris management team also increased the clarity of expected



debris management operations, reducing the expected duration from 14 days to 5 days. The elevation band for debris management operations was lowered to 487-477 feet to allow important spawning habitat in the upper basin to return to free-flowing conditions sooner than other alternatives. These updated debris management operations became part of scenario D5 and are reflected in the O4Q1D5P1 and O4Q1D5P2 results provided herein.

**5.3.4 Drawdown Releases (P1-P2)**

Both P1 and P2 parameters performed as expected, with P1 limiting release increases to 1,000 cfs/hour and P2 adding logic to also avoid downstream flows rising above the Minor Flood stage at Grand Mound during pool drawdown. This additional logic was shown to be helpful in cases where a second or third storm followed the primary storm while the reservoir was still being emptied. The P2 parameter could reactivate storage operations, reducing releases and storing water again to reduce downstream flows, while the 2017 Operations P1 parameter would continue drawing the reservoir down until it was empty without considering downstream local flows.

**5.4 Future Climate Period of Record Modeling**

The variation of frequency of reaching the Grand Mound trigger flow of 38,800 cfs ranged from 11 times to 57 times over the future climate period modeled from 2026-2100, depending on the GCM. The variation in operational frequency between GCMs and operations sets is depicted below in Table 9. In some GCMs, the O4Q1D5P1 and O4Q1D5P2 operations sets show 1 to 2 more operation events (defined as when operations are initiated until the reservoir pool is considered empty, below WSEL 447) than the 2017 Operations, but this is a result of the 2017 Operations having a much longer pool duration compared to the O4 operations, which store less water and empty the reservoir pool sooner. When two large storms occur within 1 month of one another, the 2017 Operations are sometimes still in the midst of emptying the reservoir pool when storage is reinitiated, so this would only count as a single operation event, whereas the O4 operations, which have already emptied the reservoir pool due to storing less water initially, count another operation event when they store water for the second storm in the series. Attachment 1 contains plots of each GCM under 2017 Operations to provide visual context for the frequency of operations of each GCM.

**Table 9. Operational Frequency Using 2017 Operations in Future Climate POR**

Global Climate Model	2017 Operations	O4Q1D5P1	O4Q1D5P2
Access 1.0	27	28	28
Access 1.3	24	24	24
bcc-csm 1.1	27	27	27
canesm2	13	14	14
ccsm4	22	22	22



Global Climate Model	2017 Operations	O4Q1D5P1	O4Q1D5P2
csiro-mk3.6	40	41	41
fgoals-g2	15	15	15
gfdl-cm3	40	42	42
giss-e2-h	11	11	11
MIROC5	41	43	43
mri-cgcm3	17	17	17
noresm1-m	57	57	57

## 5.5 Statistical Results

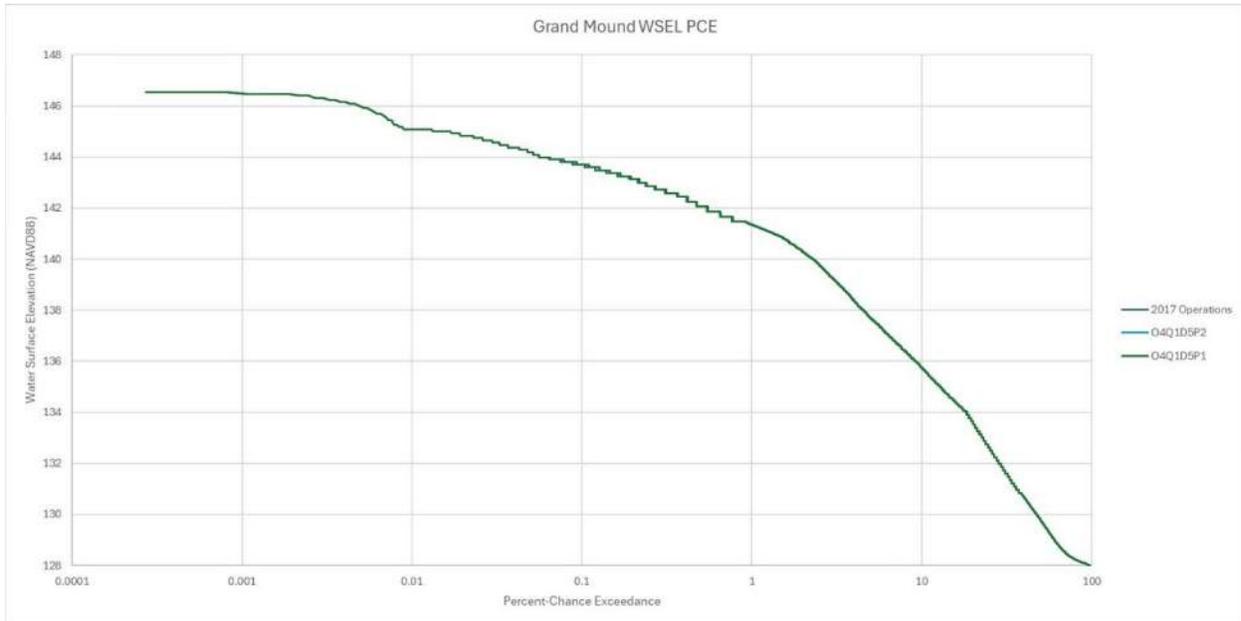
After comparing the performances of the original 128 operations sets and reducing the number of viable parameters, two final candidate operations sets (O4Q1D5P1 and O4Q1D5P2) remained the likely best-performing options. To confirm these results, a series of statistical analyses were performed to compare these operations to the original 2017 Operations under current climate and potential future climate conditions.

### 5.5.1 Current Climate (Historic) Statistical Results

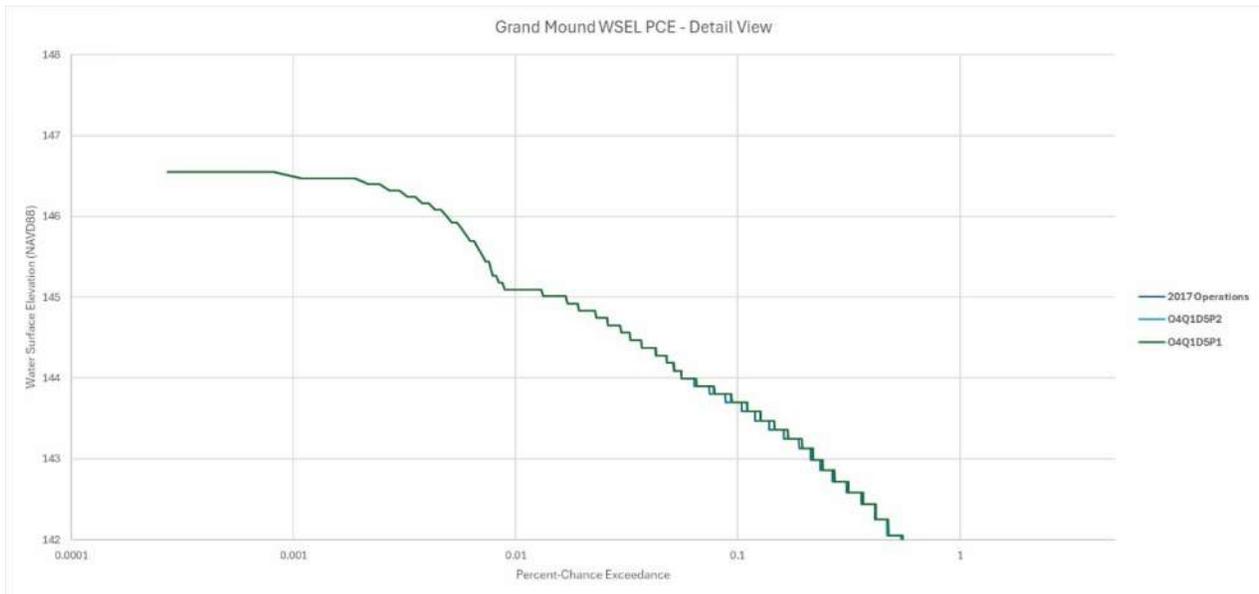
#### 5.5.1.1 Grand Mound Water Surface Elevation Percent-Chance Exceedance

Comparing the downstream performance of the O4Q1D5P1 and O4Q1D5P2 operations with the 2017 Operations, the percent-chance exceedance indicates the operations sets all show similar WSELs at Grand Mound in the upper WSELs associated with larger storms (Figure 10 and Figure 11). The O4Q1D5P1 and O4Q1D5P2 operations were associated with a slightly higher probability of occurrence in the 143- to 144-foot WSEL range. This is because WSEL 144 feet is equivalent to a flow of 38,000 cfs, which is the target flow that the O4 parameter is not to exceed at Grand Mound. This allows the O4 operations sets (O4Q1D5P1 and O4Q1D5P2) to keep flows at Grand Mound below the 38,800 cfs major flood flow during small to moderate storms while storing much less water than the 2017 Operations and emptying their reservoir pools days or weeks earlier than the 2017 Operations. Despite the higher probability of the O4 operations being triggered as compared to 2017 Operations, the difference is so subtle that it is difficult to see when represented visually (Figure 10), even in the detail view in Figure 11.

**Figure 10. Grand Mound Water Surface Elevation Percent-Chance Exceedance**



**Figure 11. Grand Mound Water Surface Elevation Percent-Chance Exceedance – Detailed View**



### 5.5.1.2 Fisk Falls Spawning Reach Inundation Duration

The majority of salmon spawning habitat in the temporary inundation reach exists in the two river miles below Fisk Falls in the upper areas of the proposed reservoir; the bottom elevation of this habitat is at WSEL 530 feet. For this analysis, inundations of this habitat at less than 2 feet of depth were deemed less impactful. Therefore, determining how long the area above WSEL 532 feet remains inundated is important to understand potential impacts on salmon rearing in the watershed and minimize environmental impacts from reservoir operations. Comparing the 2017 Operations with the O4 operations sets over the current climate POR gives an average of



1.22 days of inundation per year for 2017 Operations compared to 0.85 average days of inundation per year for the O4Q1D5P1 operations set and 1.08 days of inundation per year for the O4Q1D5P2 operations set. These averages are low because the facility does not operate in most years of the POR. The analysis below also considers the specific years in which the facility would have operated.

Over the modeled POR (1980-2022), Fisk Falls was inundated to some extent nine times with 2017 Operations, seven times with O4Q1D5P1 operations, and eight times with O4Q1D5P2 operations. The time of inundation above WSEL 532 for each operations set varied considerably depending on the character and magnitude of the storm, with the durations shown below in Table 10 for each historic storm event and operations set. For two of these nine flood events (1990 and 2022) the 2017 Operations inundate the area downstream of Fisk Falls for a shorter duration than one or both of the O4 operations sets. In 1990, both O4 operations sets started storing water to provide downstream protection a few hours earlier than the 2017 Operations, and in 2022, the O4Q1D5P2 operations set stores additional water to provide additional downstream protection, as shown previously in Figure 6 and discussed in Section 5.1.

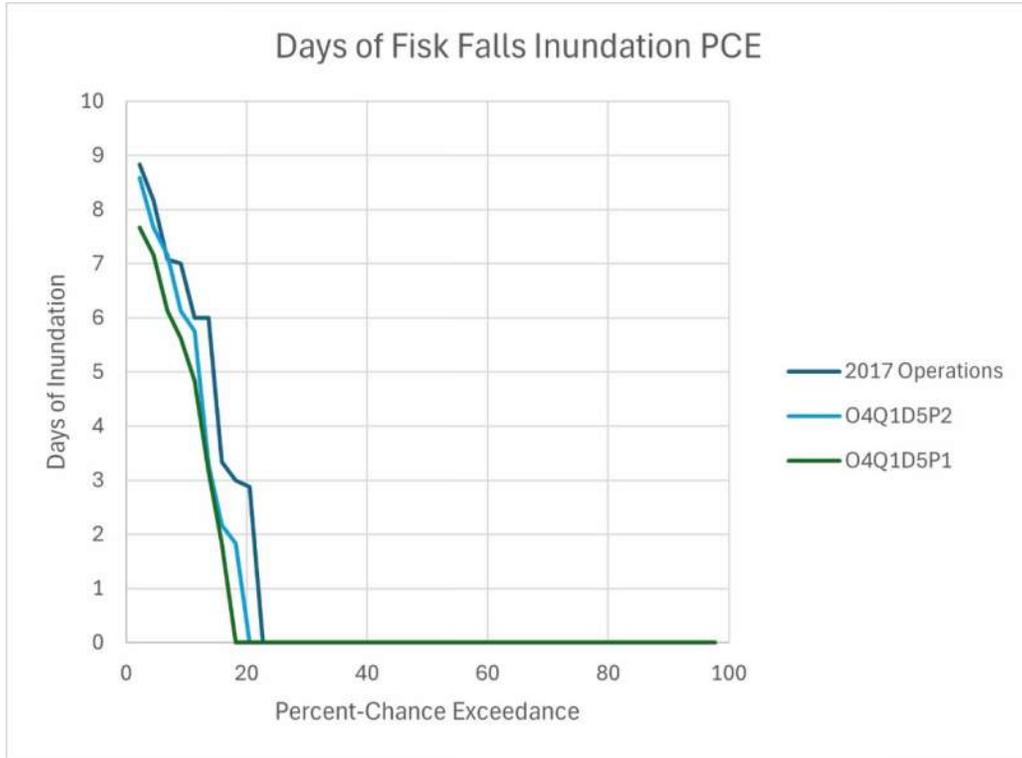
**Table 10. Fisk Falls Inundation Duration (above WSEL 532) – Current Climate POR**

Year	Total Days per Year above WSEL 532		
	2017 Operations	O4Q1D5P1	O4Q1D5P2
1990	2.88	3.17	3.29
1996	8.83	7.67	7.67
2006	7.00	5.63	5.75
2007	8.17	7.17	7.17
2009	7.08	6.13	6.13
2015	3.00	1.83	1.83
2017	3.33	0	2.38
2019	6.00	0	3.46
2022	6.00	4.83	8.58
Average (for Years w/ Facility Operation)	5.81	4.05	5.14

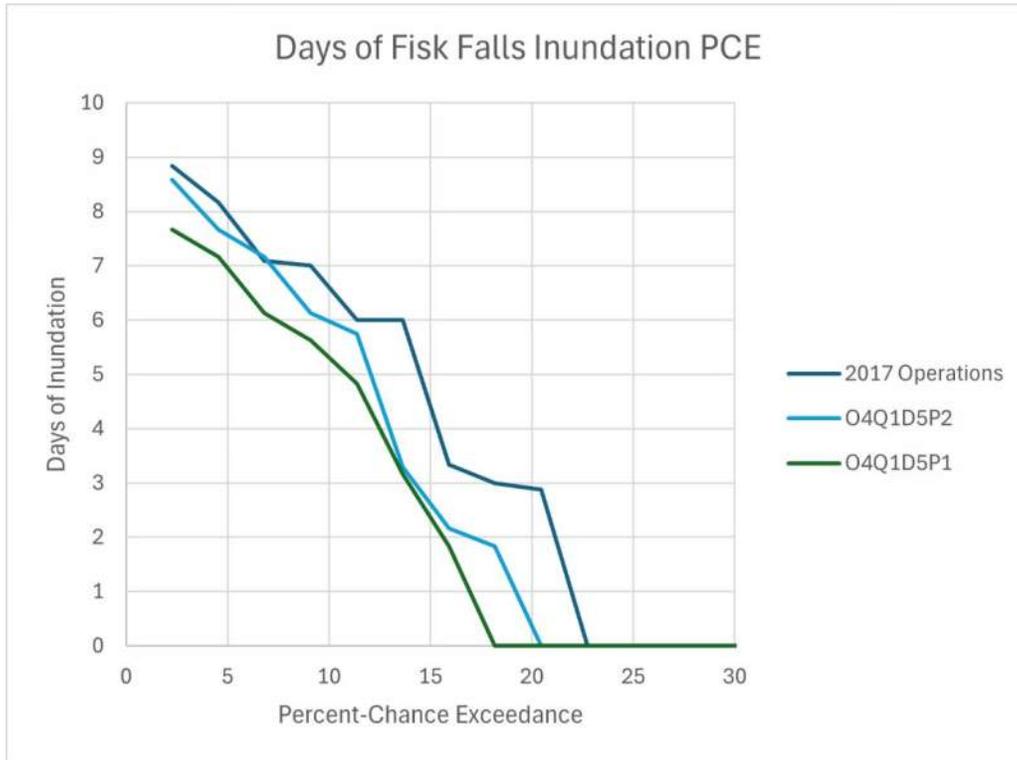
Figure 12 and Figure 13 show the percent-chance exceedance of Fisk Falls inundation between 2017 Operations, O4Q1D5P1, and O4Q1D5P2. The operations sets track closely together, with the O4Q1D5P2 operations set occasionally requiring additional water storage to keep Grand Mound below Minor Flood stage during secondary storms following the primary storm. In all

storm events for the current climate POR, the O4Q1D5P1 operations set has the least inundation of Fisk Falls of the three operations sets. Figure 14 presents the duration of Fisk Falls inundation by calendar year for each operations set. In these modeled results, there was no calendar year in which there were two inundation events; therefore, Figure 14 also shows the duration of inundation per event.

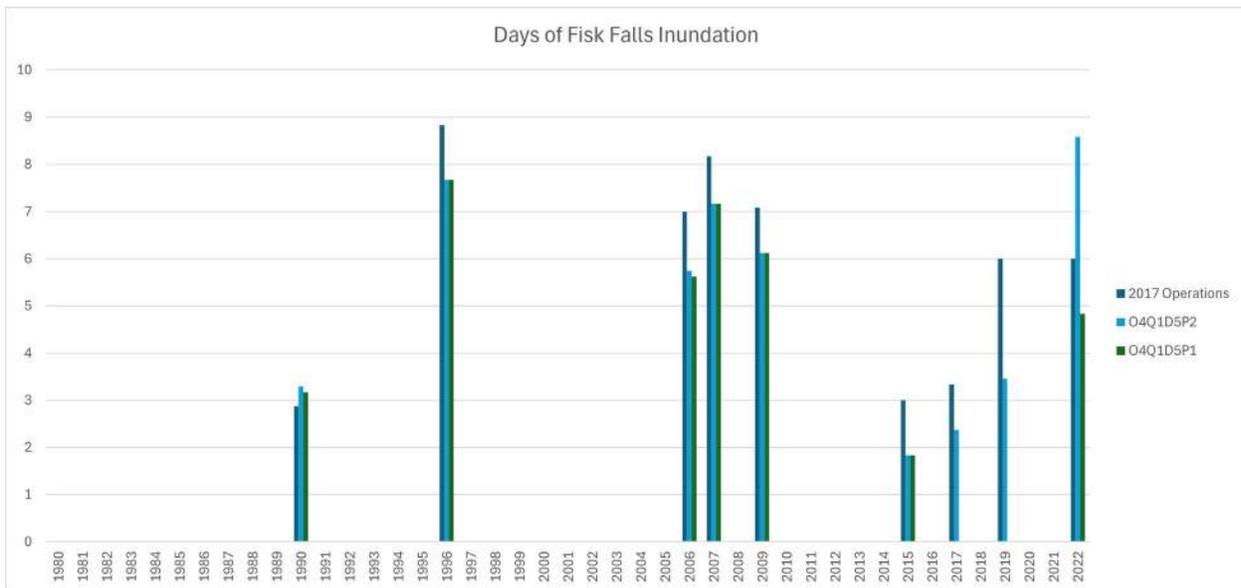
**Figure 12. Fisk Falls Inundation (above WSEL 532) Annual Percent-Chance Exceedance for Historic POR (1980–2022)**



**Figure 13. Fisk Falls Inundation (above WSEL 532) Annual Percent-Chance Exceedance for Historic POR (1980–2022) - Detailed View**



**Figure 14. Days of Inundation at Fisk Falls (above WSEL 532) by Calendar Year**

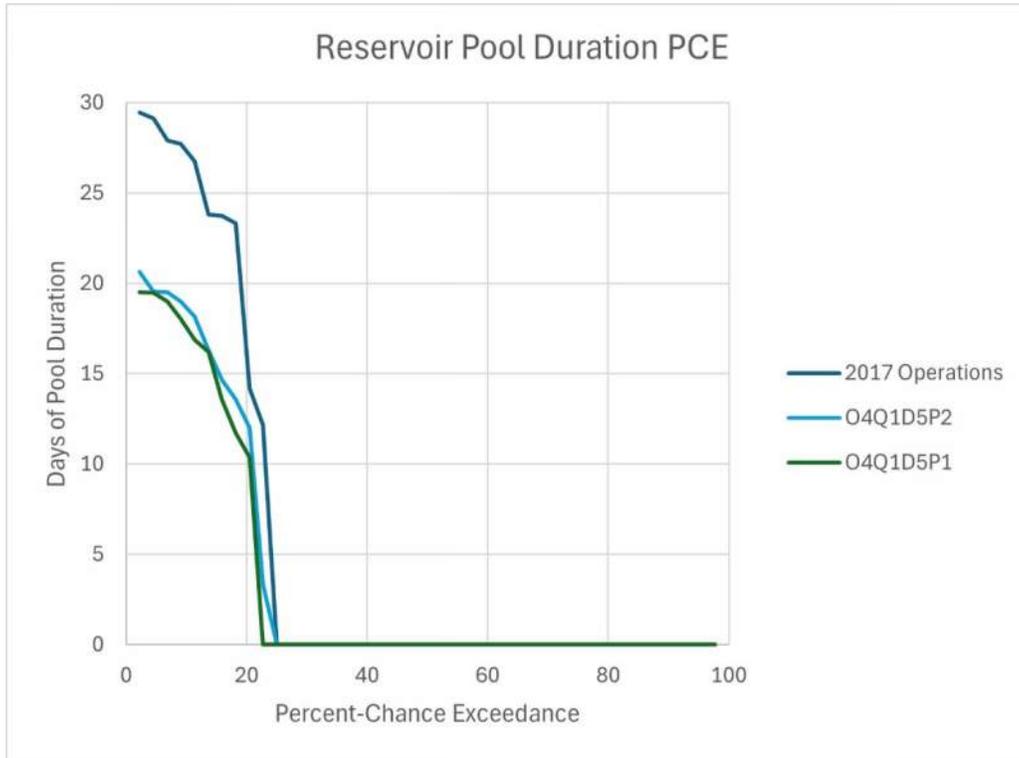


### 5.5.1.3 Reservoir Pool Duration

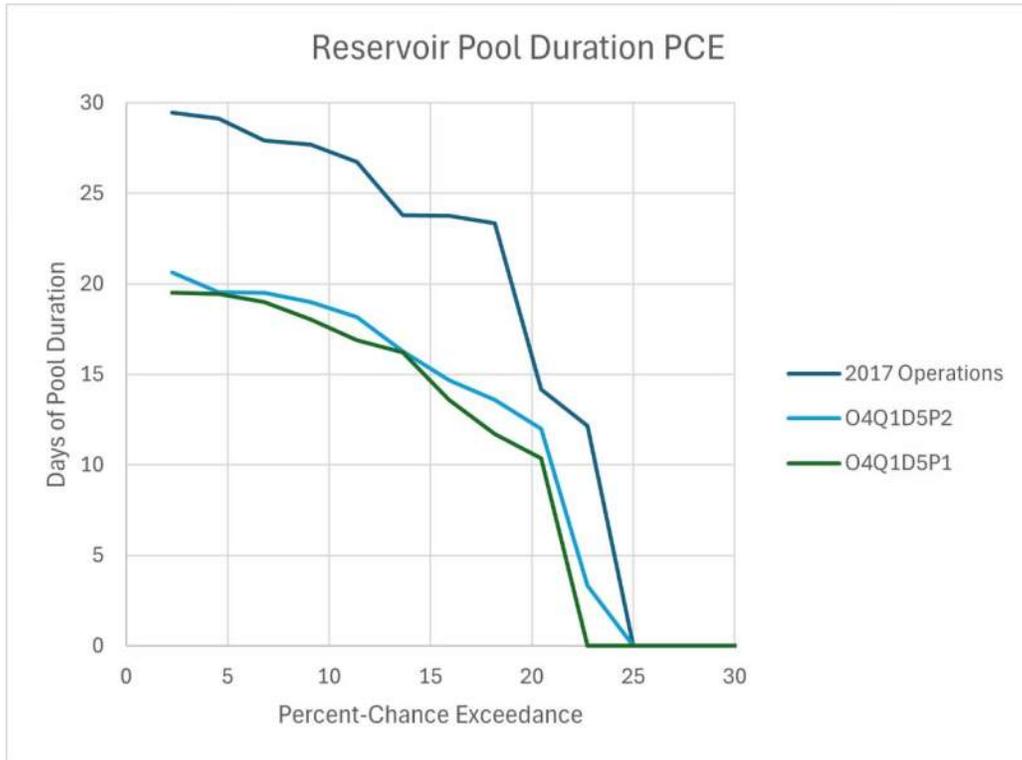
The O4 operations sets show an improvement in overall reservoir pool duration (when the WSEL in the reservoir is above 447 feet) in comparison with the 2017 Operations, as shown in

Figure 15 through Figure 17. Over the historic POR HEC-ResSim modeling run, O4Q1D5P1 operations held a reservoir pool for 0.9 percent, O4Q1D5P2 operations held a pool for 1.0 percent, and 2017 Operations held a reservoir pool for 1.6 percent of the overall time period. The performance of the O4Q1D5P2 operations set was slightly lower than O4Q1D5P1 due to storing extra water during subsequent storms to prevent secondary flooding.

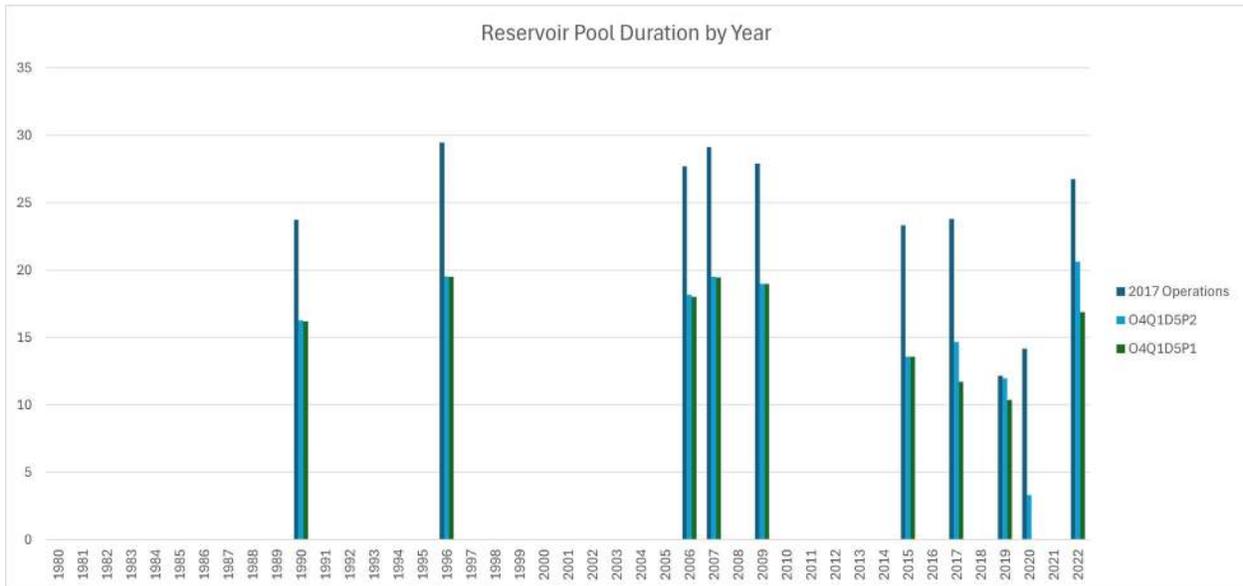
**Figure 15. Reservoir Pool Duration (above WSEL 447) Percent-Chance Exceedance**



**Figure 16. Reservoir Pool Duration (above WSEL 447) Percent-Chance Exceedance – Detailed View**



**Figure 17. Reservoir Pool Duration (above WSEL 447) by Calendar Year**



#### 5.5.1.4 Location-specific Regulated Annual WSEL Maxima

Regulated annual WSEL maxima were developed at the FRE and downstream sites of interest (Doty, Adna, Wastewater Treatment Plant [WWTP], and Grand Mound) using the following procedures:

1. Estimate 1 percent annual exceedance probability (AEP) without-project, unregulated WSELs using the candidate flow-frequency curves and rating curves established.
2. Route historical and scaled reservoir inflows and downstream local flows for the POR using HEC-ResSim.
3. Create post-processed routings to develop an event maximum dataset.
4. Identify the critical duration associated with each location.
5. Develop an unregulated flow to regulated peak flow transform at each location using the event maximum dataset and critical duration information.
6. Combine the unregulated flow-frequency information with the flow transforms to develop candidate regulated peak flow-frequency curves at each location.
7. Estimate 1 percent AEP with-project, regulated WSELs using the candidate regulated peak flow-frequency curves and rating curves established.

#### With-Project Conditions

With-project, regulated flood frequency curves were calculated using the Information Processing and Synthesis Tool (IPAST) software application following procedures consistent with the Central Valley Hydrology Study (USACE and California Department of Water Resources 2015). The general steps for computing the regulated curves for each location of interest in IPAST are:

1. Input unregulated frequency information.
2. Develop a dataset of maximum unregulated and regulated peak flow and n-day volumes for simulated flood events.
3. Assess critical duration.
4. Develop an unregulated-to-regulated flow transform.
5. Compute regulated frequency curves by combining unregulated flow-frequency information and unregulated-to-regulated flow transform.

#### Unregulated Flow Frequency

Unregulated flow-frequency information—Log Pearson Type III (LP3) statistics—are configured in IPAST for each analysis point. Table 11 lists the LP3 statistics developed by HDR and input into IPAST.

**Table 11. LP3 Statistics Configured into IPAST**

Location	Mean	Standard Deviation	Adopted Skew
Doty	4.078	0.251	0.081
Adna	4.318	0.181	0.094

Location	Mean	Standard Deviation	Adopted Skew
WWTP	4.334	0.23	-0.035
Grand Mound	4.437	0.22	0.043

## Event Maximum Dataset Development

### Scale Historical and Synthetic Flows

To capture the full range of desired flow quantiles in the regulated curves, the historical and synthetic local flow time series with a simulation period of 42 years were scaled by multipliers that ranged from 0.2 to 3.0, in increments of 0.2, consistent with Engineering Manual (EM) 1110-2-1415 (USACE 1993). This yielded 15 scaled sets of local flows to be routed through the HEC-ResSim model that represented 20 to 300 percent of the POR flows. Scaled versions of historical events were used to represent the coincidence and timing of flows for different events that have been observed in the basin. While the unscaled, unregulated events in the historical period of record cover a wide range of event recurrence, unscaled regulated flows are typically not large enough to define the upper end of the regulated frequency curve, requiring the need for scaling. It is important to note that the scaled flow data was not used in the previous unregulated flow frequency curve computations.

### HEC-ResSim Routing and Simulating of Scaled Flows

After the flows had been assembled in the Hydrologic Engineering Center Data Storage System (HEC-DSS) collections ranging from 20 to 300 percent of the POR dataset, the flows were routed through the HEC-ResSim model using an ensemble simulation alternative. At each of the USGS gages of interest, stage-discharge rating curves were applied to the regulated flows to calculate regulated stage frequency information.

### Identify Floods-of-Record

To select the flood events that would be used in generating the regulated frequency curves, HDR identified a set of four large floods observed in the Chehalis River Basin from the POR dataset (Table 12). These choices were based on peak flows observed at the Chehalis River near Grand Mound and Doty locations.

**Table 12. Event Extraction Time Window Groups**

Event Name	Start Date	End Date
1996	02/02/1996	03/20/1996
2008	11/29/2007	1/31/2008
2009	12/30/2008	02/19/2009
2022	12/25/2021	02/14/2022



### Critical Duration Analysis

Critical duration is the unregulated volume (average flow over a duration) that drives the peak regulated flow, as defined in Central Valley Hydrology Study documentation (California Department of Water Resources 2015). It is also the volume used to assign a probability to a peak regulated flow or storage value. The critical duration for each flood event and scale group was selected based on the duration with a volume ratio between 0.9 and 2.0, and closest to 1.0. If these criteria were not met, the software was set to default to an assumed critical duration of 1 day. At the FRE and Doty locations, the critical duration was locked to 3 days. At all other locations downstream of Doty, the critical duration was determined to be 1 day by using the volume ratio approach described above.

### Regulated Curve Development

To verify that all regulated frequency curves are monotonic and increasing, the IPAST software prompts the user to choose an envelope method for smoothing the event-specific curves (USACE and California Department of Water Resources 2015). After visually inspecting the differences between the envelope methods, HDR decided to use a forward-looking trend.

### Flow Transform Fitting and Curve Combinations

The last step in generating regulated frequency curves is to fit the flow transforms and combine the unregulated curves with the regulated curves. Fitting the flow transforms was performed using the local weighted scatterplot smoothing (LOWESS) regression method in which a local polynomial is fitted through each point in a scatterplot using weighted least squares. The number of iterations used to fit the curve was set to 100, and a smoothing coefficient of 0.3 was chosen, from a scale of 0 to 1. These parameters were used for each site on the river.

### Results

Regulated flow and stage annual maxima applicability is limited to operational alternative comparative analysis only and is not intended for design of risk analysis. Additional refinements are required in future phases for such applications to be appropriate. Results of the 1 percent AEP peak flows are presented below in Table 13. All operations sets successfully achieve a reduction in 1 percent AEP flows. At the FRE and Doty, O4Q1D5P2 results in significantly lower peak regulated flows compared to O4Q1D5P1 and 2017 Operations. At Grand Mound, O4Q1D5P2 reduced the peak flow slightly more than O4Q1D5P1 and 2017 Operations.

**Table 13. Estimated 1% AEP Peak Flows**

Operation Set Result	FRE	Doty	Adna	WWTP	Grand Mound
Unregulated Flow (cfs)	38,010	47,520	56,500	73,040	90,160
2017 Operations Flow (cfs)	15,780	16,350	33,810	38,950	62,010
O4Q1D5P1 Flow (cfs)	16,220	16,260	33,810	38,950	62,010
O4Q1D5P2 Flow (cfs)	9,720	10,680	33,810	38,950	62,000

Results of the 1 percent AEP peak WSEL are presented in Table 14. Like the peak flows, all operations sets are able to achieve a decrease in 1 percent AEP peak WSEL at all locations downstream of the FRE. At the FRE, 2017 Operations result in the lowest 1 percent AEP regulated WSEL, and O4Q1D5P2 operations result in the highest regulated FRE WSEL. At Grand Mound, the reduction in peak 1 percent AEP WSEL is equal across operation sets.

**Table 14. Estimated 1% AEP Peak WSEL**

Operation Set Result	FRE (Reservoir Pool Elevation)	Doty	Adna	WWTP	Grand Mound
Unregulated WSEL (ft)	455.3	330.1	215.1	184.5	148.2
2017 Operations WSEL (ft)	629.4	319.9	211.9	181.4	146.1
O4Q1D5P1 WSEL (ft)	629.8	320.2	211.9	181.5	146.1
O4Q1D5P2 WSEL (ft)	631.1	317.8	211.9	181.5	146.1

#### 5.5.1.5 Flow Frequency Analysis

Annual flood frequency quantiles (Table 15) at the FRE location were calculated for the 2017 Operations and the O4 operations sets. Specific time windows used for the Unregulated Flow Frequency Analysis (USACE: July–August, HDR Recommended: July–September, Washington Department of Fish and Wildlife: August) are not shown in Table 15 as no flood events that trigger operations were observed during the specified time windows. Table 16 through Table 18 provide a monthly breakdown of flow exceedance values at the FRE location.



**Table 15. Annual Flood Frequency Quantiles for Flow at the FRE Location**

AEP	Unregulated Flow (HDR 2025)	2017 Operations		O4Q1D5P1		O4Q1D5P2	
		Regulated Flow	Decrease from Existing	Regulated Flow	Decrease from Existing	Regulated Flow	Decrease from Existing
(cfs)							
50%	9,496	3,458	6,038	4,482	5,104	4,474	5,022
20%	15,531	4,848	10,683	5,127	10,404	4,791	10,740
10%	20,175	8,346	11,829	8,416	11,759	5,273	14,902
6.7%	23,011	9,718	13,293	9,920	13,091	5,725	17,286
5.0%	25,098	10,755	14,343	10,535	14,563	5,836	19,262
4.0%	26,756	11,683	15,073	11,379	15,377	6,157	20,599
2.0%	32,169	14,310	17,859	14,277	17,892	7,470	24,699
1.0%	38,014	15,777	22,237	16,224	21,790	9,723	28,291
0.4%	46,478	15,980	30,498	17,150	29,328	14,383	32,095
0.2%	53,491	16,818	36,673	17,409	36,082	17,857	35,634



**Table 16. Monthly Exceedance Flow Values (cfs) Downstream of the FRE Location – 2017 Operations**

Exceedance (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99	12.9	9.0	13.9	23.4	3.4	0.8	0.1	0.0	0.0	-	0.1	6.0
95	30.3	39.6	57.4	45.9	9.1	1.5	0.2	0.1	0.0	-	6.0	35.8
90	67.7	70.0	90.7	65.7	15.9	2.5	0.4	0.1	0.0	-	16.9	65.4
80	142.6	125.6	150.6	99.9	31.5	5.7	0.7	0.1	0.1	0.3	70.8	140.9
75	180.6	154.4	179.6	122.5	40.9	7.7	0.8	0.2	0.1	0.6	115.9	175.6
50	421.8	349.8	358.6	269.3	109.7	29.2	1.9	0.3	0.3	9.4	384.9	392.3
25	917.7	728.2	674.1	507.1	264.7	100.8	5.2	0.7	2.0	99.6	885.1	886.1
10	1,734.7	1,403.1	1,143.9	853.4	492.3	268.9	15.2	1.6	11.3	487.6	1,765.3	1,725.4
5	2,573.5	2,117.9	1,575.2	1,177.3	696.3	454.4	31.3	3.0	37.3	1,007.9	2,667.6	2,479.8
1	4,810.7	3,950.6	3,044.5	2,488.6	1,234.8	1,039.9	138.5	29.2	265.5	2,675.2	5,307.1	4,537.2



**Table 17. Monthly Exceedance Flow Values (cfs) Downstream of the FRE Location – O4Q1D5P1**

Exceedance (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99	13.0	9.0	13.9	23.4	3.4	0.8	0.1	0.0	0.0	0.0	0.0	6.0
95	30.0	37.9	57.4	45.9	9.1	1.5	0.2	0.1	0.0	0.0	6.0	35.8
90	64.0	68.1	90.7	65.7	15.9	2.5	0.4	0.1	0.0	0.0	17.0	65.4
80	138.0	124.6	149.7	99.9	31.5	5.7	0.7	0.1	0.1	0.0	71.0	140.3
75	173.0	153.4	178.4	122.5	40.9	7.7	0.8	0.2	0.1	1.0	116.0	174.6
50	411.0	344.5	354.5	269.5	109.7	29.2	1.9	0.4	0.3	9.0	383.0	393.9
25	922.0	726.8	670.1	507.1	264.8	100.8	5.2	0.7	2.0	100.0	882.0	881.4
10	1,731.0	1,427.9	1,142.3	853.4	492.3	269.5	15.2	1.6	11.3	487.0	1,781.0	1,708.9
5	2,560.0	2,098.8	1,571.9	1,177.3	696.3	454.3	31.3	3.0	37.3	1,008.0	2,683.0	2,478.4
1	4,796.0	4,048.9	3,044.5	2,488.6	1,234.8	1,039.9	138.5	29.2	281.1	2,675.0	5,289.0	4,700.1



**Table 18. Monthly Exceedance Flow Values (cfs) Downstream of the FRE Location – O4Q1D5P2**

Exceedance (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99	13.0	9.0	13.9	23.4	3.4	0.8	0.1	0.0	0.0	0.0	0.0	6.0
95	30.0	37.9	57.4	45.9	9.1	1.5	0.2	0.1	0.0	0.0	6.0	35.8
90	64.0	68.1	90.7	65.7	15.9	2.5	0.4	0.1	0.0	0.0	17.0	65.4
80	138.0	124.6	149.7	99.9	31.5	5.7	0.7	0.1	0.1	0.0	71.0	140.6
75	173.0	153.4	178.4	122.5	40.9	7.7	0.8	0.2	0.1	1.0	116.0	174.9
50	413.0	343.6	354.5	269.5	109.7	29.2	1.9	0.4	0.3	9.0	383.0	394.6
25	934.0	729.3	670.1	507.1	264.8	100.8	5.2	0.7	2.0	100.0	883.0	886.5
10	1,739.0	1,438.3	1,142.3	853.4	492.3	269.5	15.2	1.6	11.3	487.0	1,783.0	1,718.1
5	2,560.0	2,122.9	1,571.9	1,177.3	696.3	454.3	31.3	3.0	37.3	1,008.0	2,683.0	2,470.2
1	4,673.0	4,010.8	3,044.5	2,488.6	1,234.8	1,039.9	138.5	29.2	281.1	2,675.0	5,243.0	4,573.3



## 5.5.2 Future Climate Statistical Results

The performance of each operation set was evaluated under potential future climate conditions for 12 GCMs, as well as mid-century (2060) and late-century (2090) climate conditions.

### 5.5.2.1 Frequency of Operations

The variation of frequency of reaching the Grand Mound trigger flow of 38,800 cfs ranged from 11 to 57 times over the future climate period modeled from 2026 to 2100, depending on the GCM. The variation in operational frequency between GCMs and operations sets is depicted below in Table 19. In some GCMs, the O4Q1D5P1 and O4Q1D5P2 operations sets show one to two more operation events (defined as when operations are initiated until the reservoir pool is considered empty, below WSEL 447 feet) than the 2017 Operations, but this is a result of the 2017 Operations having a much longer pool duration compared to the O4 operations, which store less water and empty the reservoir pool sooner. When two large storms occur within a month of one another, the 2017 Operations are sometimes still in the midst of emptying the reservoir pool when storage is reinitiated, so this would only count as a single operation event whereas the O4 operations, which have already emptied the reservoir pool due to storing less water initially, count another operation event when they store water for the second storm in the series. Attachment 1 contains plots of each GCM under 2017 Operations to provide visual context for the frequency of operations of each GCM.

**Table 19. Operational Frequency in Future Climate POR**

Global Climate Model	2017 Operations	O4Q1D5P1	O4Q1D5P2
Access 1.0	27	28	28
Access 1.3	24	24	24
bcc-csm 1.1	27	27	27
canesm2	13	14	14
ccsm4	22	22	22
csiro-mk3.6	40	41	41
fgoals-g2	15	15	15
gfdl-cm3	40	42	42
giss-e2-h	11	11	11
MIROC5	41	43	43
mri-cgcm3	17	17	17
noresm1-m	57	57	57



### 5.5.2.2 Grand Mound Water Surface Elevation Percent-Time Exceedance

Comparing the downstream performance of the O4 operations sets with the 2017 Operations, the PTE of all 12 GCMs show slight variations in the WSEL 143- to 144-foot range, though in general, the O4Q1D5P1 and O4Q1D5P2 operations have a slightly higher PTE in that elevation range. Similar to the current climate results in Section 5.5.1.1, the O4 operation sets allow flows at Grand Mound to approach, but not exceed, 38,800 cfs in order to store less water in the reservoir to reduce Fisk Falls inundation and the overall pool duration. Within the slight variation of PTE at the WSEL 143- to 144-foot range, the O4Q1D5P1 operation set tends to have slightly higher WSELs than the O4Q1D5P2 operation set. This is due to the P2 parameter avoiding exceedance of the Minor Flood stage of WSEL 141 feet at Grand Mound during drawdown, minimizing impacts of secondary flood peaks. Attachment 2 provides a detailed view of the Grand Mound WSEL PTE of each GCM between WSEL 140 and 148 feet.

### 5.5.2.3 Fisk Falls Spawning Reach Inundation Duration

As described in section 5.5.1.2, it is important to evaluate the inundation around Fisk Falls (above WSEL 532 feet in the reservoir) to understand potential impacts to salmon rearing in the watershed. Comparing the 2017 Operations with the O4 operations sets over the future climate POR (1970–2100) gives an average of 2.4 days of inundation per year for the 2017 Operations, compared to 1.4 days for O4Q1D5P1 and 2.5 days for O4Q1D5P2 when averaged across the 12 GCMs. Of the 12 GCMs, the highest number of days inundated within a single year for the 2017 Operations was 47 days under the conditions of the MIROC5 GCM. The highest number of days inundated within a single year for O4Q1D5P1 was 35.8 days under MIROC5 GCM conditions. The highest number of days inundated within a single year for O4Q1D5P2 was 51.9 days under noresm-1 GCM conditions. Attachment 3 provides percent-chance exceedance plots of annual days of expected inundation at Fisk Falls. Comparing the percent of days inundated over the entire future climate POR between the operations sets shows that under every GCM condition, O4Q1D5P1 results in the lowest percent of days inundating Fisk Falls. The 2017 Operations and O4Q1D5P2 operations closely align for this metric, with O4Q1D5P2 inundating Fisk Falls for more days than 2017 Operations under the conditions of 7 of 12 GCMs. Averaging the percent days inundated at Fisk Falls across the GCMs shows that O4Q1D5P1 inundates Fisk Falls for 0.4 percent, O4Q1D5P2 for 0.69 percent, and 2017 Operations for 0.65 percent of the time.

**Table 20. Percent of Days Inundating Fisk Falls Reach – Future Climate (1970–2100) POR**

GCM ID	2017 Operations	O4Q1D5P1	O4Q1D5P2
	(%)		
Access 1-0	0.55	0.33	0.58
Access 1-3	0.42	0.22	0.46
Bcc-csm1-1	0.53	0.26	0.47
canESM2	0.19	0.08	0.19



GCM ID	2017 Operations	O4Q1D5P1	O4Q1D5P2
	(%)		
CCSM4	0.57	0.42	0.63
CSIRO-Mk3-6-0	0.98	0.63	1.01
FGOALS-g2	0.27	0.12	0.36
GFDL-CM3	0.87	0.53	0.82
GISS-E2-H	0.22	0.09	0.22
MIROC5	1.26	0.81	1.38
MRI-CGCM3	0.37	0.14	0.32
norESM1-M	1.53	1.12	1.85
<b>AVERAGE:</b>	0.65	0.40	0.69

#### 5.5.2.4 Reservoir Pool Duration

The reservoir pool inundation duration was evaluated for each GCM. Across the 12 GCMs, the 2017 Operations are, on average, inundated 2.5 percent of the time. The 2017 Operations held a pool the longest when compared to O4Q1D5P1 and O4Q1D5P2, which were inundated 1.5 and 1.9 percent of the time, respectively (Table 21). The norESM1-M GCM returned the highest pool inundation percentages of each alternative, with the 2017 Operations set holding pool for 5.3 percent, O4Q1D5P1 holding pool 3.4 percent, and O4Q1D5P2 holding pool 4.3 percent of the time. O4Q1D5P2 shows a slight improvement over the 2017 Operations, and O4Q1D5P1 shows an even greater improvement across all GCMs.

**Table 21. Percent of Days with FRE Pool – Future Climate (1970–2100) POR**

GCM ID	2017 Operations	O4Q1D5P1	O4Q1D5P2
	(%)		
Access 1-0	2.4	1.4	1.8
Access 1-3	1.8	1.0	1.4
Bcc-csm1-1	2.3	1.3	1.6
canESM2	1.0	0.5	0.7
CCSM4	2.2	1.3	1.7
CSIRO-Mk3-6-0	3.7	2.2	2.8
FGOALS-g2	1.1	0.6	0.9



GCM ID	2017 Operations	O4Q1D5P1	O4Q1D5P2
	(%)		
GFDL-CM3	3.5	2.1	2.6
GISS-E2-H	1.1	0.6	0.7
MIROC5	4.4	2.8	3.6
MRI-CGCM3	1.6	0.8	1.1
norESM1-M	5.3	3.4	4.3
<b>AVERAGE:</b>	2.5	1.5	1.9

Percent of days spent inundating the FRE pool, on average, is increased for all operation sets, when compared to the current climate analysis in 5.5.1.3. When comparing the current climate POR to the 12 GCMs, 3 GCM routings result in a lower percent of days inundated for the 2017 Operations, 4 result in a lower percent of days inundated for the O4Q1D5P1, and 3 result in a lower percent of days inundated for the O4Q1D5P2 operations sets.

#### 5.5.2.5 Location-specific Regulated Annual Maxima

Regulated flow and stage annual maxima applicability is limited to operational alternative comparative analysis only and is not intended for design of risk analysis. Additional refinements are required in future phases for such applications to be appropriate. Location-specific regulated annual maxima were computed by applying climate change scale factors under mid-century (2060) and late-century (2080) climate conditions to the current climate regulated frequency information. Climate change scale factors were developed for the following USGS stream gage locations: Doty, Adna, WWTP, and Grand Mound. Scale factors were developed for individual recurrence intervals for each of these sites using methods described in the Hydrologic Modeling Report. Table 22 and Table 23 highlight the applied scale factors for the 1 percent AEP mid-century (2060) and late-century (2080) climates. To scale the regulated flows at the FRE location, the Doty scale factors were applied to the unregulated frequency quantiles of the critical duration and the corresponding regulated peak flow as identified using a flow transform.

**Table 22. Mid-Century Future Climate 1% AEP Scale Factors**

Location	Peak	1-day	3-day	7-day	15-day	30-day
Doty	1.041	1.040	1.039	1.037	1.048	1.077
Adna	1.070	1.103	1.206	1.265	1.176	1.107
WWTP	1.122	1.147	1.223	1.297	1.174	1.094
Grand Mound	1.183	1.180	1.231	1.305	1.167	1.082



**Table 23. Late-Century Future Climate 1% AEP Scale Factors**

Location	Peak	1-day	3-day	7-day	15-day	30-day
Doty	1.036	1.122	1.124	1.138	1.157	1.136
Adna	1.080	1.146	1.158	1.184	1.188	1.199
WWTP	1.126	1.152	1.171	1.207	1.210	1.201
Grand Mound	1.171	1.200	1.165	1.219	1.208	1.199

Table 24 provides the mid-century estimated 1 percent AEP flow results. Under mid-century climate conditions, all operation sets are capable of providing downstream peak flow reduction when compared to unregulated, without-project, conditions. At the FRE, O4Q1D5P1 and O4Q1D5P2 both result in higher peak regulated flows when compared to 2017 Operations, but at Grand Mound, the two O4 operations sets result in a slightly lower (10 cfs) peak flow at Grand Mound.

**Table 24. Mid-Century Estimated 1% AEP Peak Flows**

Operation Set Result	FRE	Doty	Adna	WWTP	Grand Mound
Unregulated Flow (cfs)	39,570	49,470	60,450	81,950	106,660
2017 Operations Flow (cfs)	16,090	19,170	37,760	43,810	69,980
O4Q1D5P1 Flow (cfs)	17,240	20,100	37,760	43,810	69,970
O4Q1D5P2 Flow (cfs)	17,170	14,220	37,760	43,810	69,970

Table 25 provides the late-century estimated 1 percent AEP flow results. Under late-century climate conditions, all three operations sets perform similarly at Adna in terms of 1 percent AEP regulated flows. At the FRE and Doty, O4Q1D5P1 performs worse than the other two operations sets but achieves a higher peak flow reduction at Grand Mound when compared to 2017 Operations. The O4Q1D5P2 operations reduces peak flows at the FRE, Doty, and Grand Mound more than 2017 Operations. The O4Q1D5P1 and O4Q1D5P2 operations achieve the same level of peak flow reduction at Grand Mound.



**Table 25. Late-Century Estimated 1% AEP Peak Flows**

Operation Set Result	FRE	Doty	Adna	WWTP	Grand Mound
Unregulated Flow (cfs)	39,380	49,230	61,020	82,240	105,580
2017 Operations Flow (cfs)	16,310	18,770	38,680	45,480	71,250
O4Q1D5P1 Flow (cfs)	17,030	19,240	38,680	45,480	71,240
O4Q1D5P2 Flow (cfs)	13,520	12,650	38,680	45,480	71,240

Unregulated flow-regulated WSEL transforms were applied to determine the mid-century regulated stages. Table 26 contains the resulting mid-century regulated WSELs at the FRE and downstream locations. As the FRE spillway elevation is 627 feet, all three operation sets are estimated to utilize the spillway in the 1 percent AEP mid-century flood. At Grand Mound, all operations result in the same 1 percent AEP peak WSEL reduction. The O4 sets perform equally well at Adna and WWTP.

**Table 26. Mid-Century Estimated 1% AEP Peak WSEL**

Operation Set Result	FRE (Reservoir Pool Elevation)	Doty	Adna	WWTP	Grand Mound
Unregulated WSEL (ft)	455.8	330.8	215.6	185.3	149.3
2017 Operations WSEL (ft)	635.5	320.8	212.6	181.9	146.7
O4Q1D5P1 WSEL (ft)	636.7	321.4	212.7	182.0	146.7
O4Q1D5P2 WSEL (ft)	636.3	319.4	212.7	182.0	146.7

Unregulated flow-regulated WSEL transforms were applied to determine the late-century regulated stages. Table 27 contains the resulting late-century regulated WSELs at the FRE and downstream locations. Under late-century climate conditions, the operations sets result in the greatest peak WSEL reductions at Grand Mound, Adna, and WWTP and perform equally well. At the FRE, the O4Q1D5P2 operation results in the highest regulated WSEL. At Doty the O4Q1D5P1 operation results in the smallest peak WSEL reduction. The 2017 Operations have a larger peak reduction at the FRE when compared to the O4 operations sets.

**Table 27. Late-Century Estimated 1% AEP Peak Regulated WSEL**

Operation Set Result	FRE (Reservoir Pool Elevation)	Doty	Adna	WWTP	Grand Mound
Unregulated WSEL (ft)	455.8	330.8	215.7	185.3	149.2
2017 Operations WSEL (ft)	633.3	321.0	212.8	182.1	146.8
O4Q1D5P1 WSEL (ft)	634.0	321.2	212.8	182.1	146.8
O4Q1D5P2 WSEL (ft)	634.5	318.8	212.8	182.1	146.8

### 5.6 Current Climate Sensitivity Analysis

The HEC-ResSim model was set up using the reservoir operations developed by Anchor QEA (2017) where reservoir operation effects were not evaluated downstream of the reservoir. Because there are downstream stage reduction requirements for this design, a sensitivity analysis of the reservoir operation set was completed. HDR found that, with flood events exceeding the 38,800 cfs trigger flow at Grand Mound, the reservoir had varying degrees of success in providing downstream flood control benefits based on storm distribution. Of the three discrete storm events (2007, 2009, and 2022) used in testing, the event that returned the largest downstream flood control benefit was December 2007 and the event with the smallest benefit was January 2022.

The 2022 event’s peak flow at Grand Mound was decreased from 55,788 to 47,765 cfs, a 16.8 percent decrease using 2017 Operations. The 2022 flood event triggered the reservoir to commence flood control operations with the O1 trigger, but the benefit of closing the sluice gates was only slightly observed at Grand Mound.

In contrast, the December 2007 flood event was identified as having large flood control benefits at Grand Mound when regulated by the reservoir. During this flood, the peak flow at Grand Mound was reduced by 21.6 percent from 82,887 (USGS recorded peak was 68,700 cfs) to 68,174 cfs.

Events that are forecast to meet or exceed the 38,800 cfs trigger flow at Grand Mound are not guaranteed to result in a large flood reduction. Because the December 2007 event precipitation was heavily centered in the reservoir area, the flood control operation results in a large downstream benefit. Floods that are more evenly distributed across the basin or centered further downstream with higher contributions from the Skookumchuck and Newaukum Rivers are more likely to result in less satisfactory flood control reductions.

## 6.0 Discussion

Based on the HEC-ResSim modeling results provided herein, the O4Q1D5P1 and O4Q1D5P2 operations sets appear to match the 2017 Operations for peak flow reduction at Grand Mound while also reducing the reservoir pool duration, the time of inundation around Fisk Falls, and with the P2 parameter, life safety hazards due to secondary flooding from subsequent storms during downstream flood recovery efforts. The additional flexibility allowed in the O4 parameter better replicates a human reservoir operator following water control guidelines to operate the reservoir and is modeled on how many flood control reservoirs are operated throughout the United States.

The O4Q1D5P1 operation set performs best when considering inundation duration at Fisk Falls and above WSEL 532 feet in the reservoir. However, unlike O4Q1D5P2, it provides no additional flood protection from secondary storms. The O4Q1D5P2 operations set performs similarly to the 2017 Operations set due to the O4Q1D5P2 operations' requirement to provide additional downstream flood protection from more frequent, large secondary storms in future climate scenarios.

With the possibility of more frequent and larger storms, as shown in the modeled future climate results, flexibility in reservoir operations (via both O4 operations sets) show the most benefit during the increasingly frequent storms that are forecast to just exceed the 38,800 cfs target flow (Major Flood) at Grand Mound. In these storms, increased operations flexibility allows the O4 operations sets to store less water than the 2017 Operations while achieving the objective of keeping flows below the downstream Major Flood level, which results in days to weeks of fewer operations and upstream inundation per storm event.

Some additional HEC-ResSim modeling work remains. After deciding on a final proposed reservoir operations set, further modeling may be needed to refine topics such as faster drawdown rates on the upper reaches of the reservoir, and resiliency/sensitivity studies should be completed to test the robustness of the HEC-ResSim model and operations. Finally, known deficiencies in the HEC-ResSim modeling software require additional programming to eliminate minor statistical noise in the bottom 5 feet of the reservoir pool during some low baseflow conditions in long-term modeling runs. This noise does not affect reservoir operations during flood detention operations and is not statistically important to the overall POR runs.

## 7.0 References

### Anchor QEA

- 2017 Chehalis Basin Strategy Operations Plan for Flood Retention Facilities, June 2017.

### California Department of Water Resources

- 2015 Central Valley Hydrology Study. Prepared by the U.S. Army Corps of Engineers, Sacramento District, and David Ford Consulting Engineers, Inc. Sacramento, California. November.

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- 2024a *Revised Project Description Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Control Zone District, Lewis County, Washington. April 2024.
- 2024b Hydrologic Engineering Management Plan.
- 2025 *Draft Preliminary Design Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Damage Reduction Project, Lewis County, Washington, June 30, 2025.

### U.S. Army Corps of Engineers (USACE)

- 1993 Engineering Manual [EM]-1110-2-1415, Engineering and Design Hydrologic Frequency Analysis. March 5, 1993.
- 2021 HEC-ResSim Reservoir System Simulation User's Manual. Version 3.3. U.S. Army Corps of Engineers Hydrologic Engineering Center.

### U.S. Army Corps of Engineers (USACE) and California Department of Water Resources

- 2015 Information processing and synthesis tool (IPAST), part of Central Valley Hydrology Study.

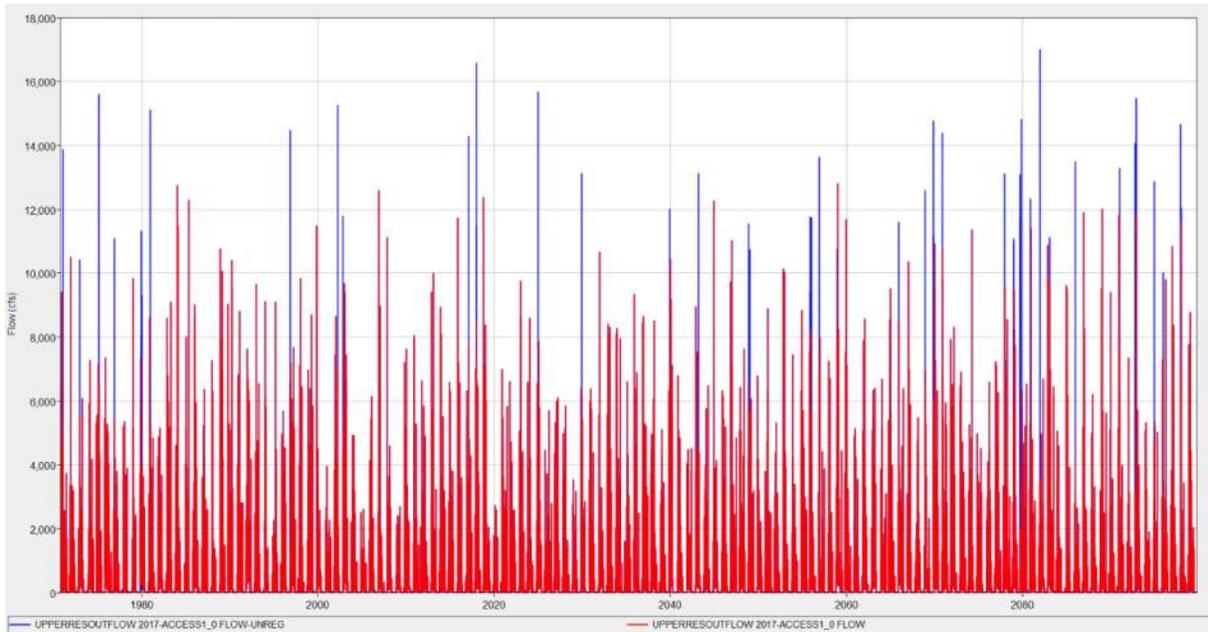
## 8.0 Acronyms/Abbreviations

HDR	HDR Engineering, Inc.
FRE	Flood Retention Expandable
PDR	Preliminary Design Report
AEP	annual exceedance probability
cfs	cubic feet per second
GCM	Global Climate Model
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HEC-ResSim	Hydrologic Engineering Center Reservoir System Simulation
IPAST	Information Processing and Synthesis Tool
LiDAR	light detection and ranging
LOWESS	local weighted scatterplot smoothing regression method
NAVD88	North American Vertical Datum of 1988
POR	Period of Record
PTE	percent-time exceedance
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSEL	water surface elevation
WWTP	Wastewater Treatment Plant

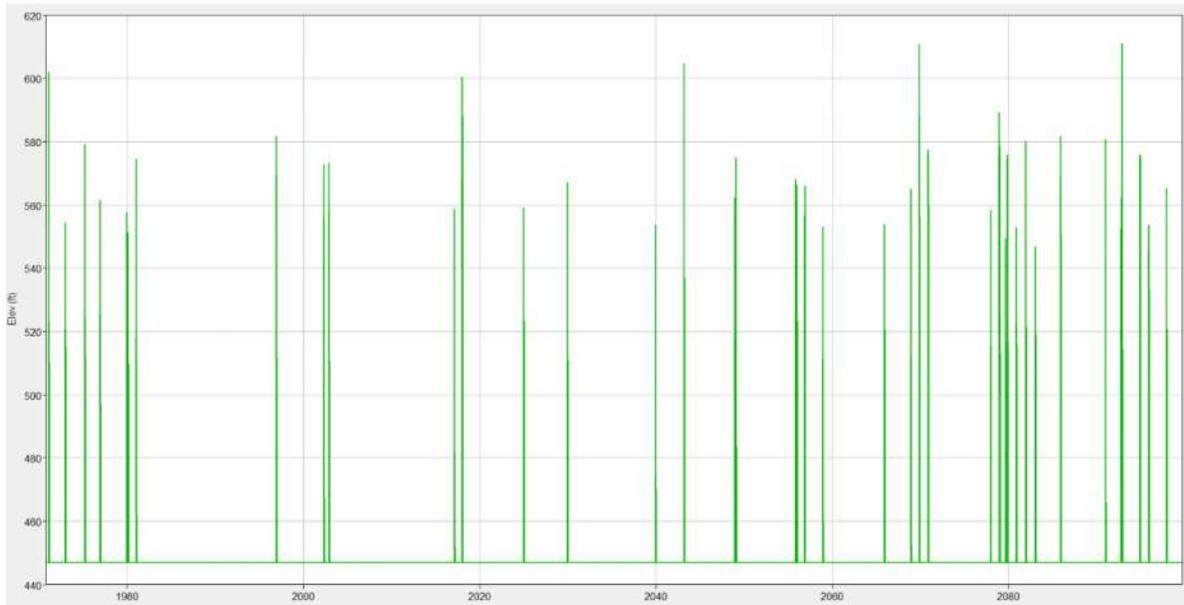


# Attachment 1. Future Climate Operation Plots

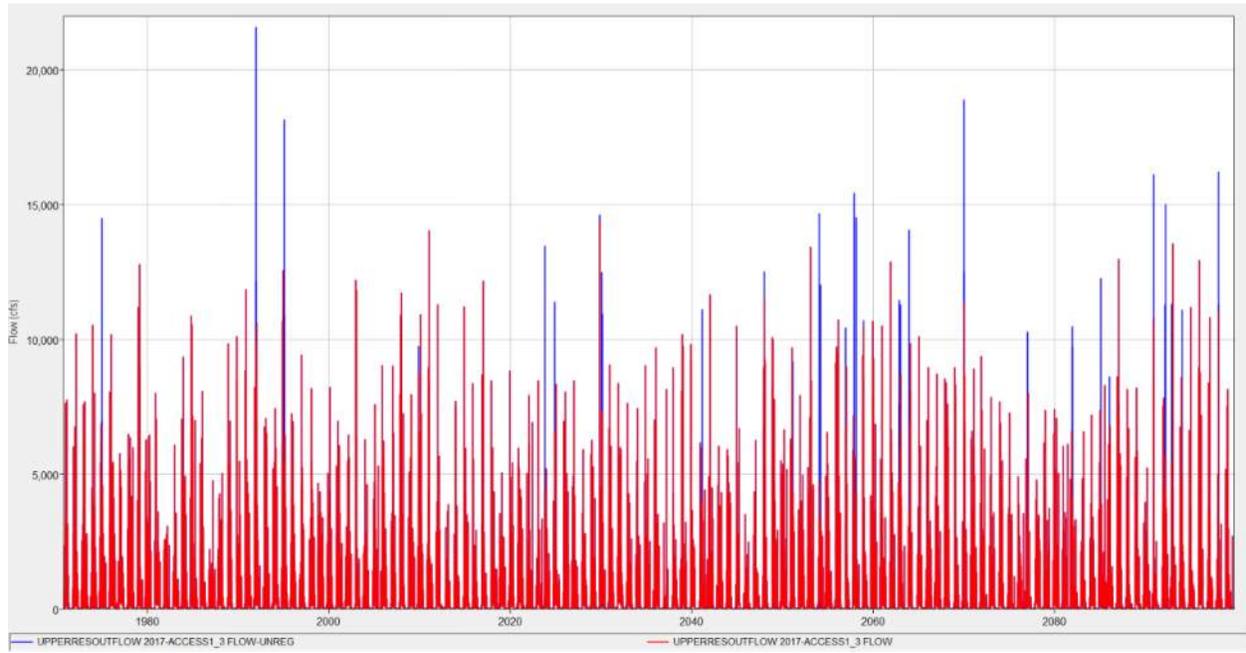
**Figure 1-1. Access 1.0 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



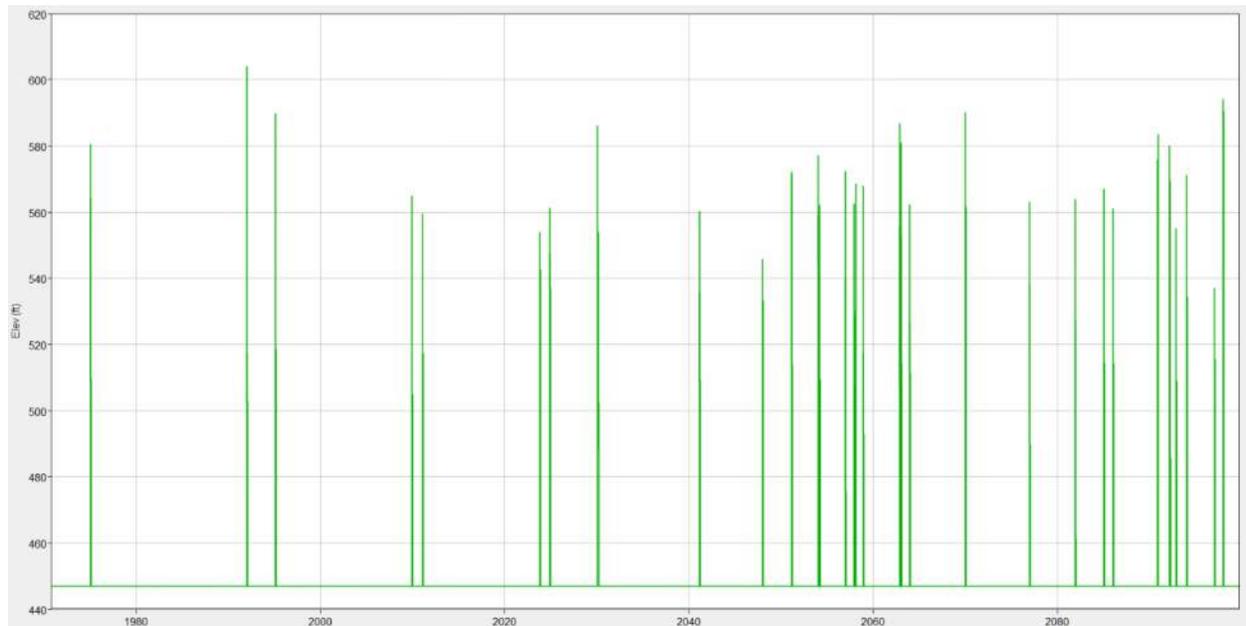
**Figure 1-2. Access 1.0 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



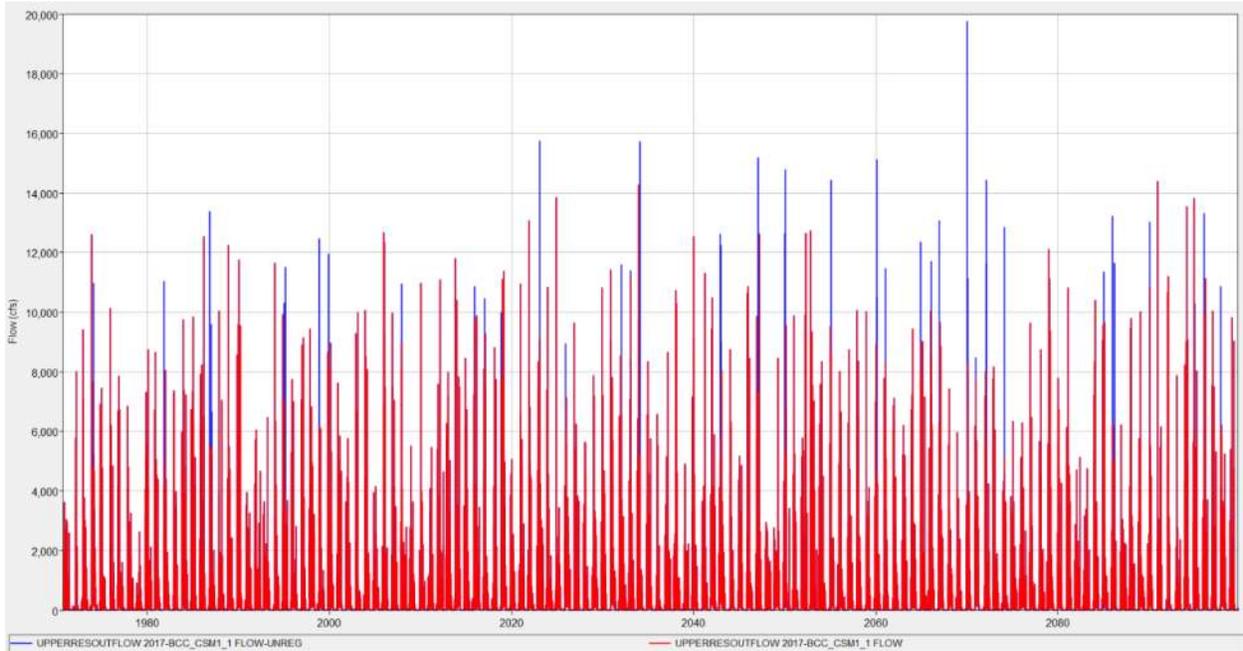
**Figure 1-3. Access 1.3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



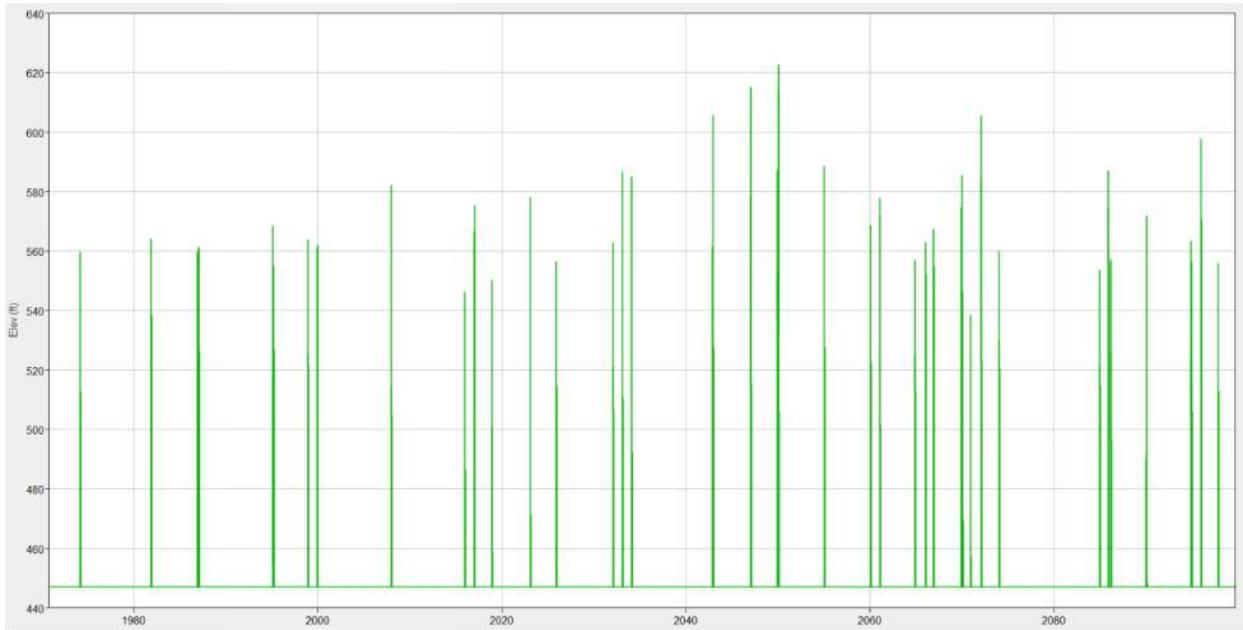
**Figure 1-4. Access 1.3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



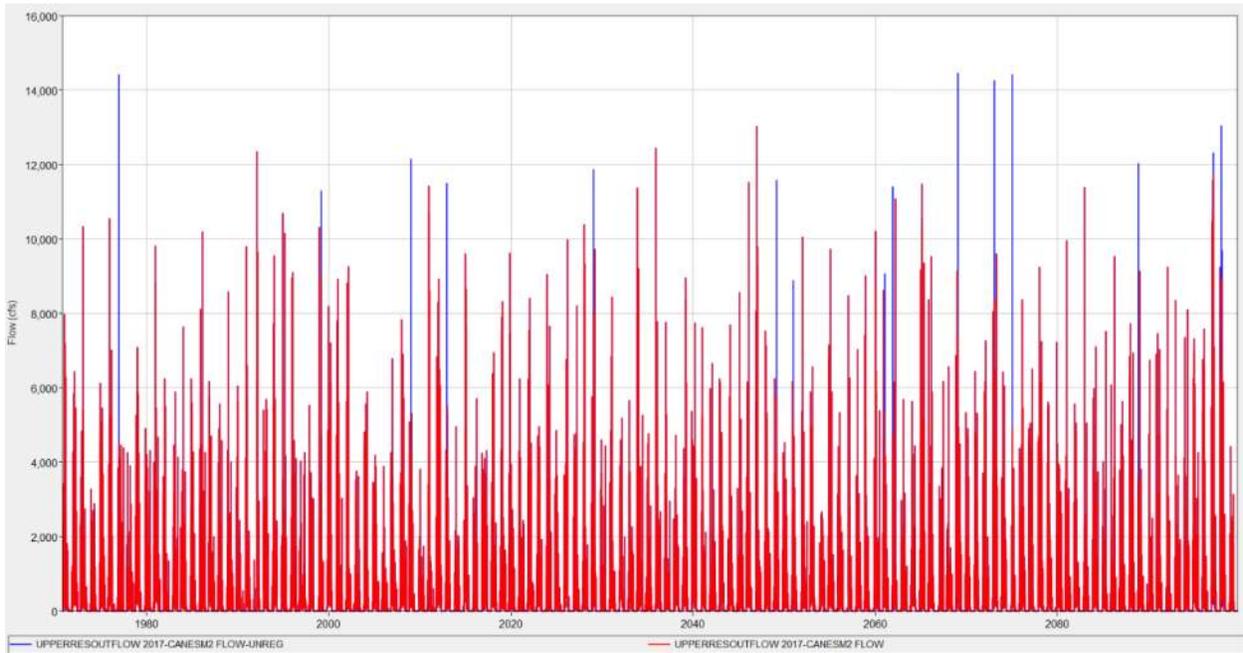
**Figure 1-5. BCC-CSM 1.1 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



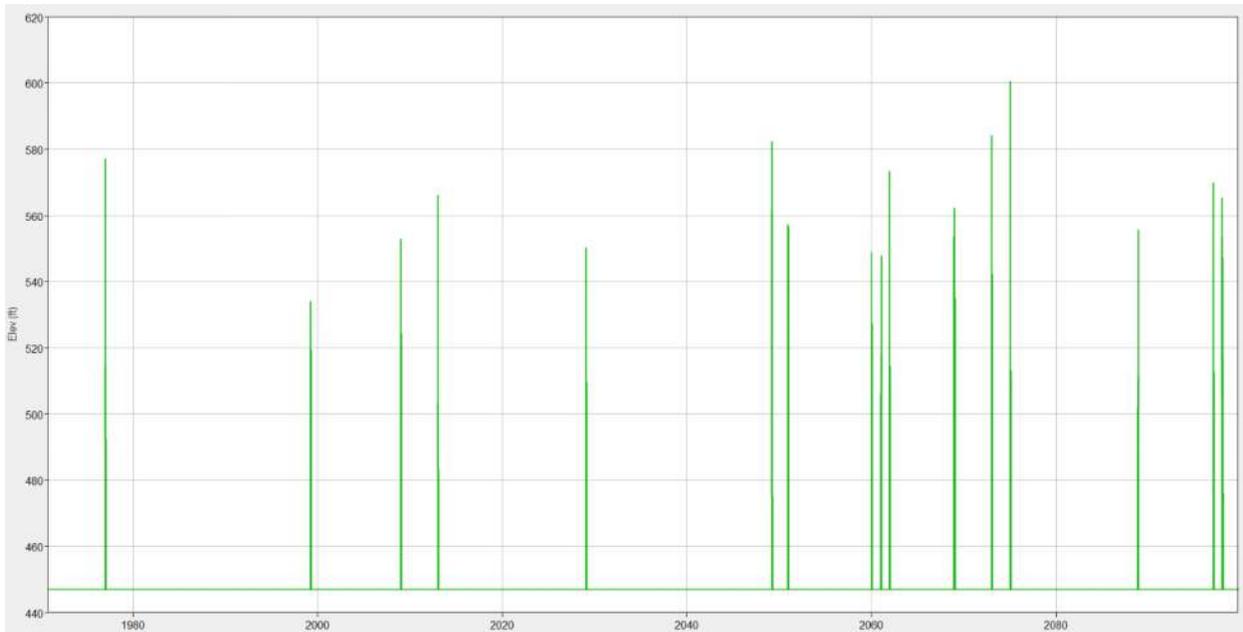
**Figure 1-6. BCC-CSM 1.1 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



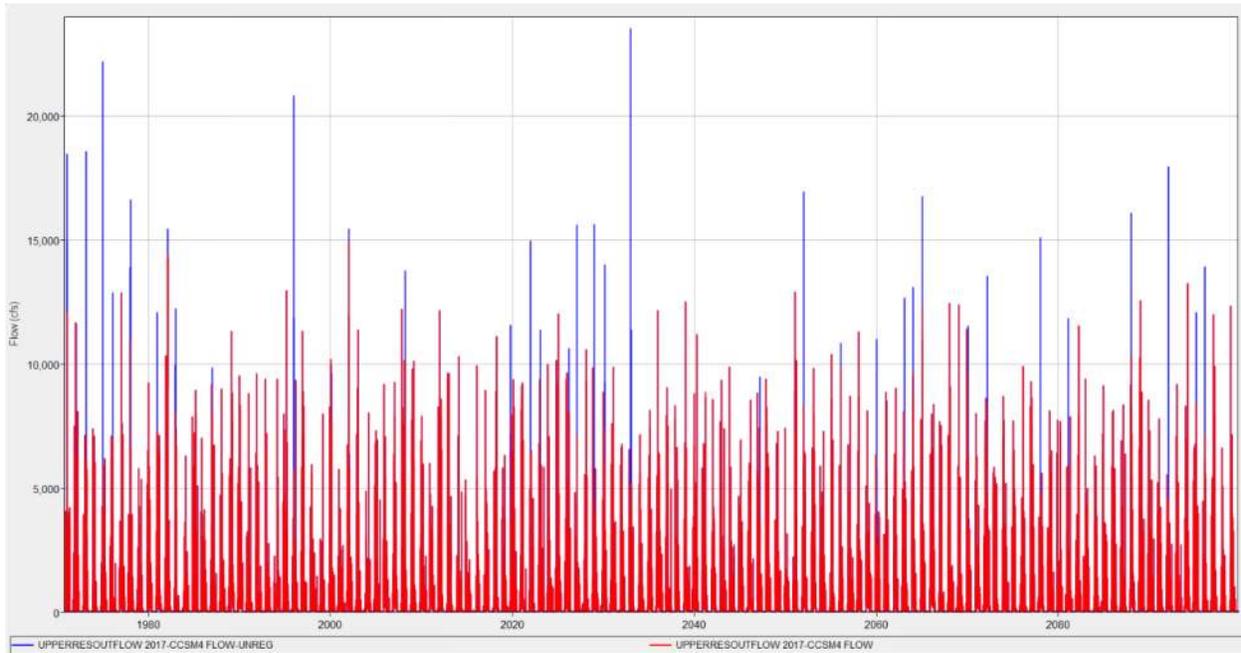
**Figure 1-7. CanESM2 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



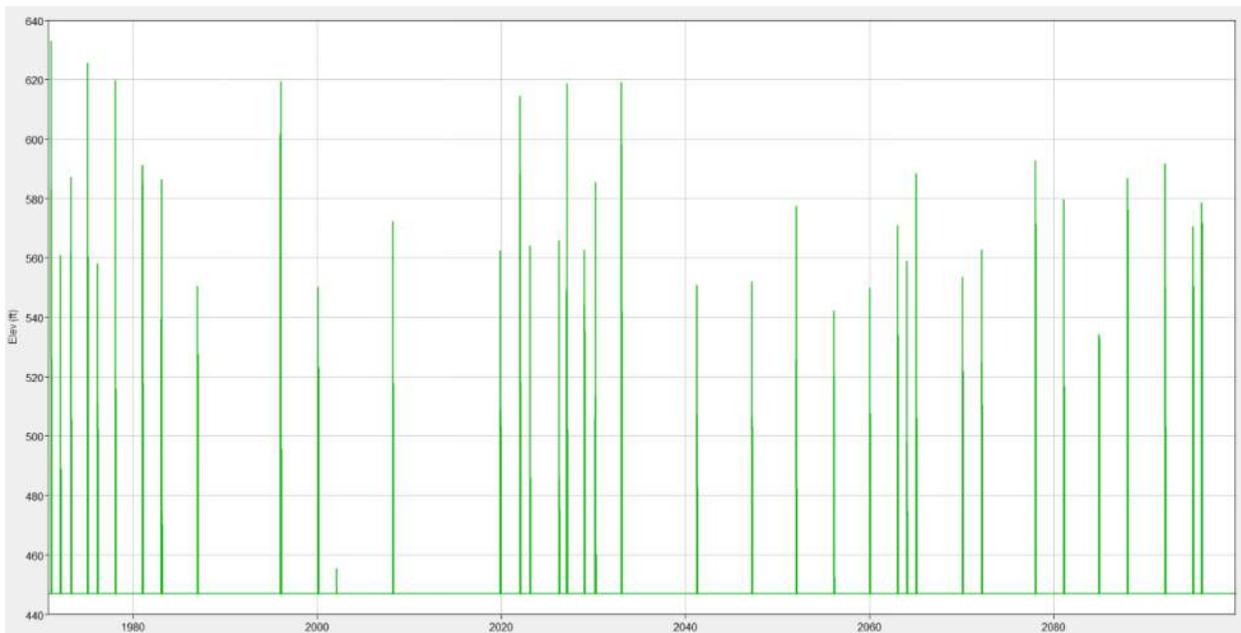
**Figure 1-8. CanESM2 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



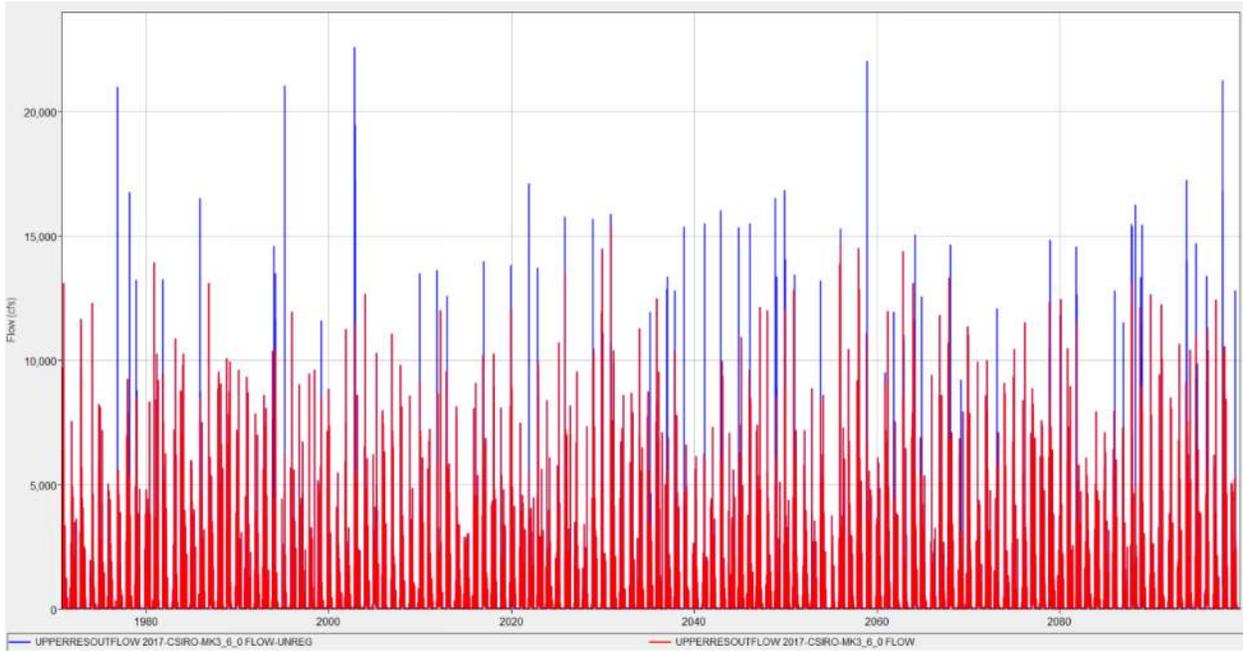
**Figure 1-9. CCSM4 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



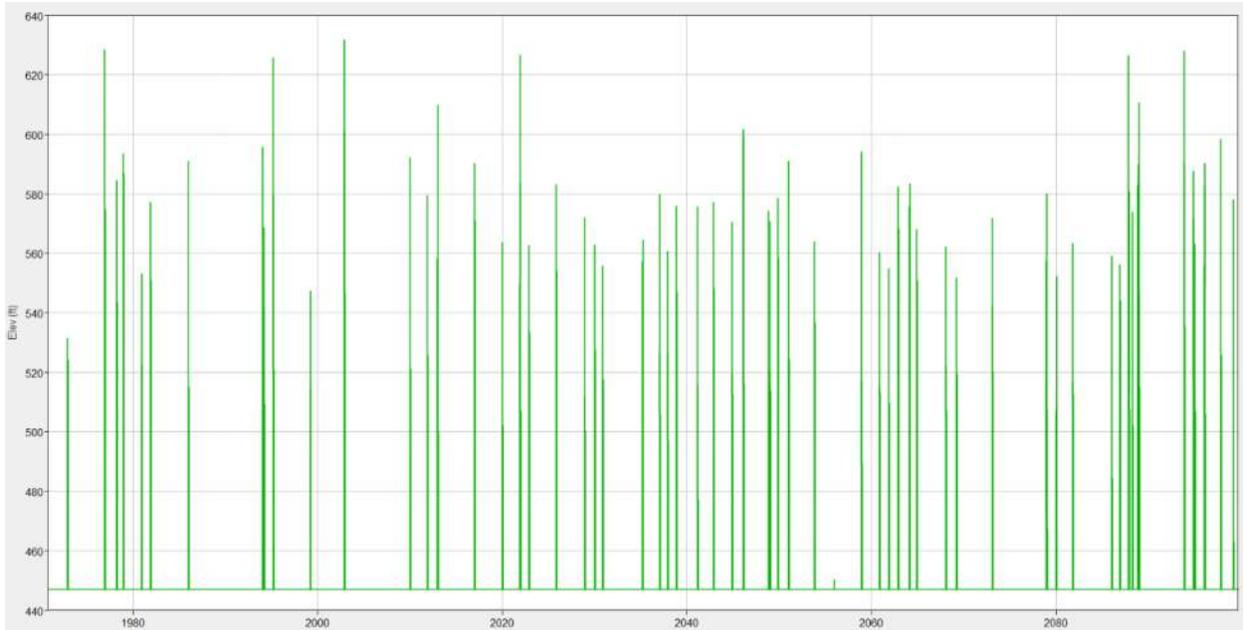
**Figure 1-10. CCSM4 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



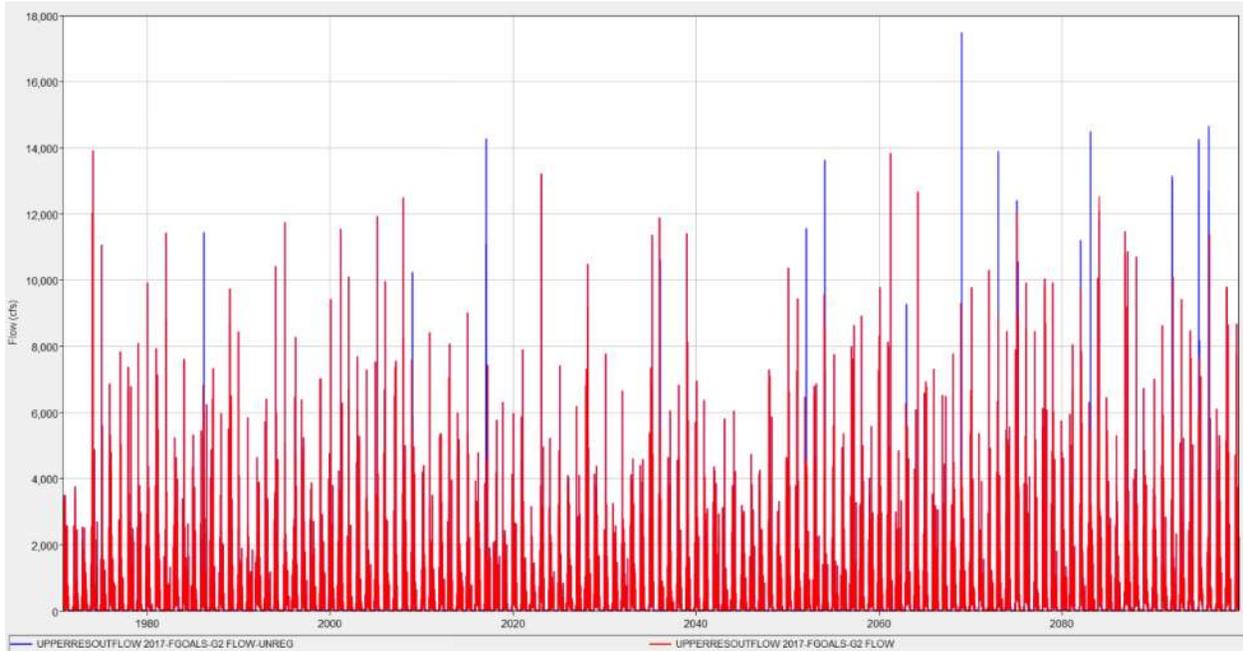
**Figure 1-11. Csiro-mk3\_6\_0 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



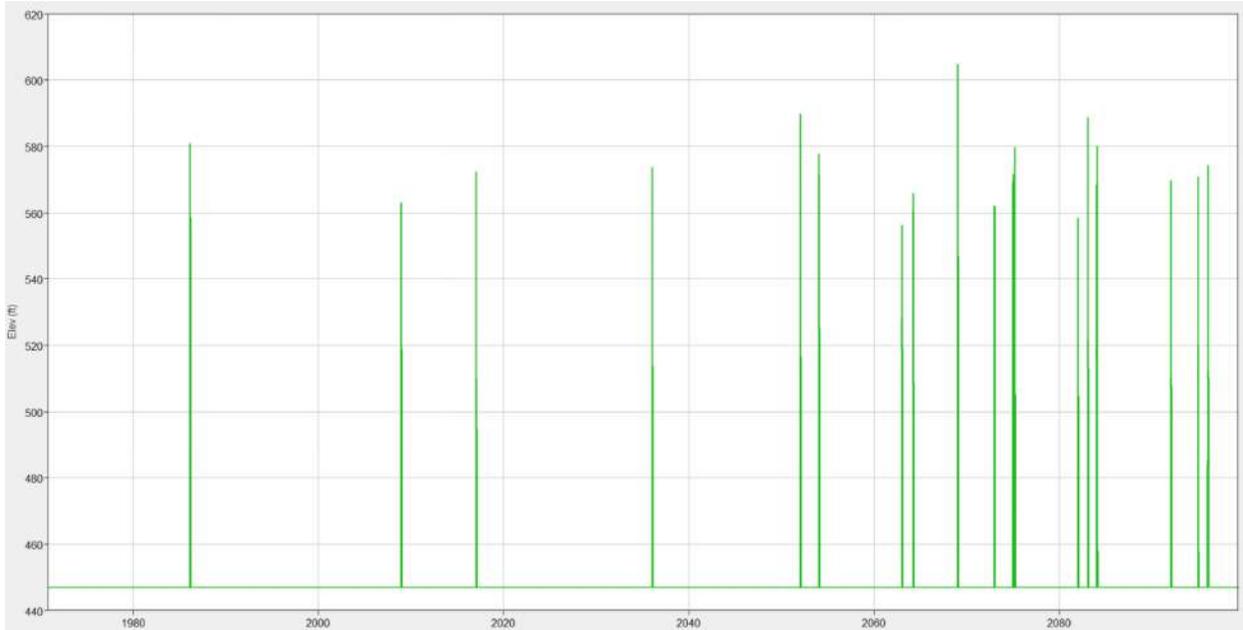
**Figure 1-12. Csiro-mk3\_6\_0 CCSM4 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



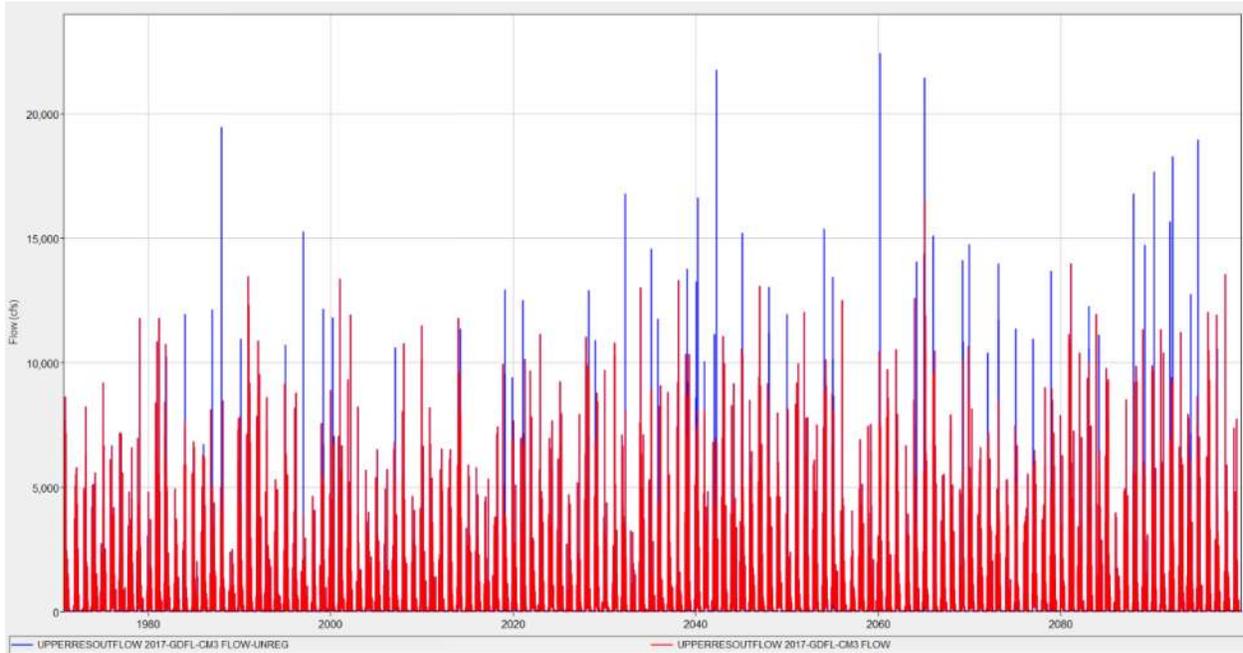
**Figure 1-13. FGOALS-g2 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



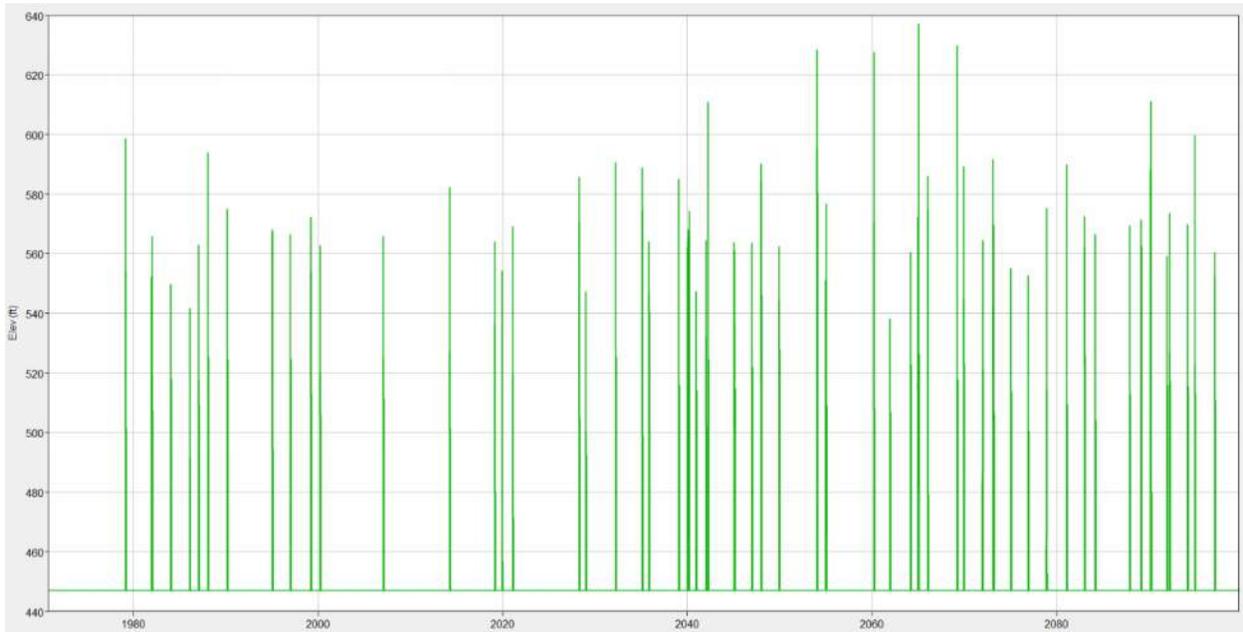
**Figure 1-14. FGOALS-g2 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



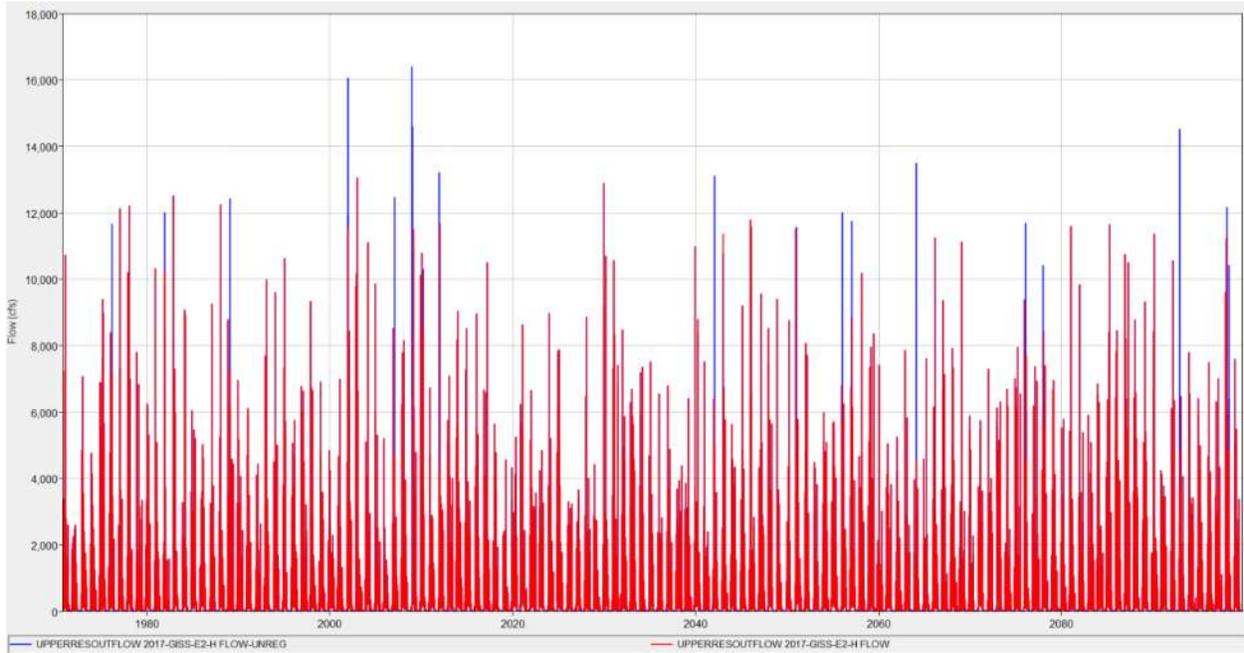
**Figure 1-15. GFDL-CM3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



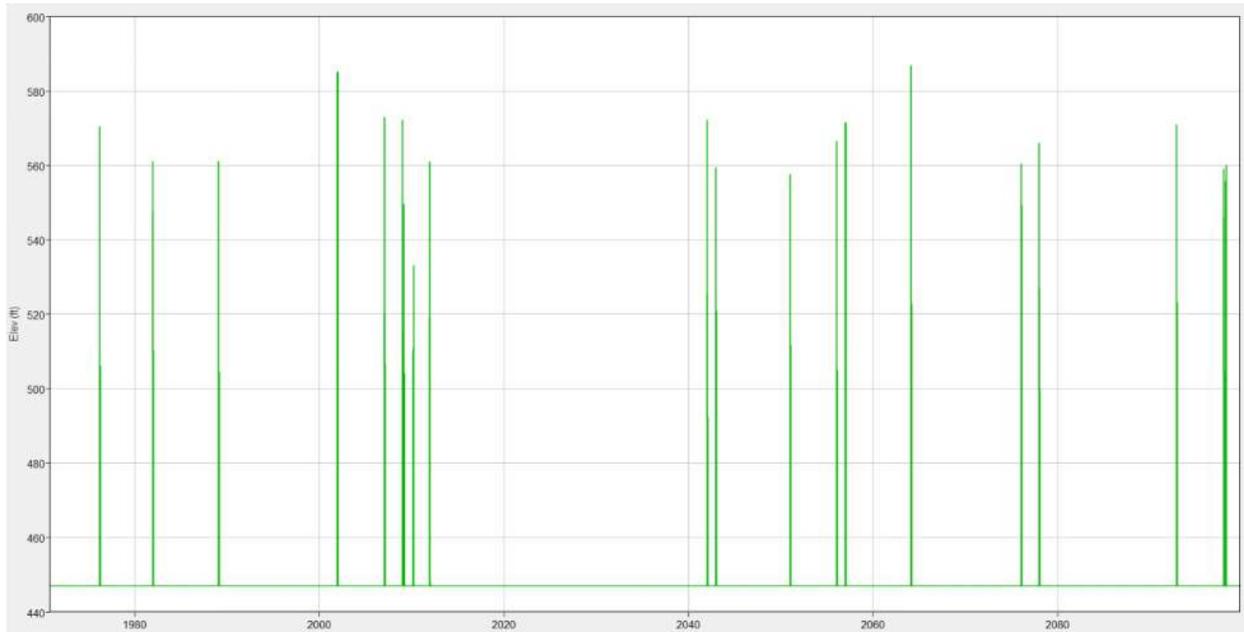
**Figure 1-16. GFDL-CM3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



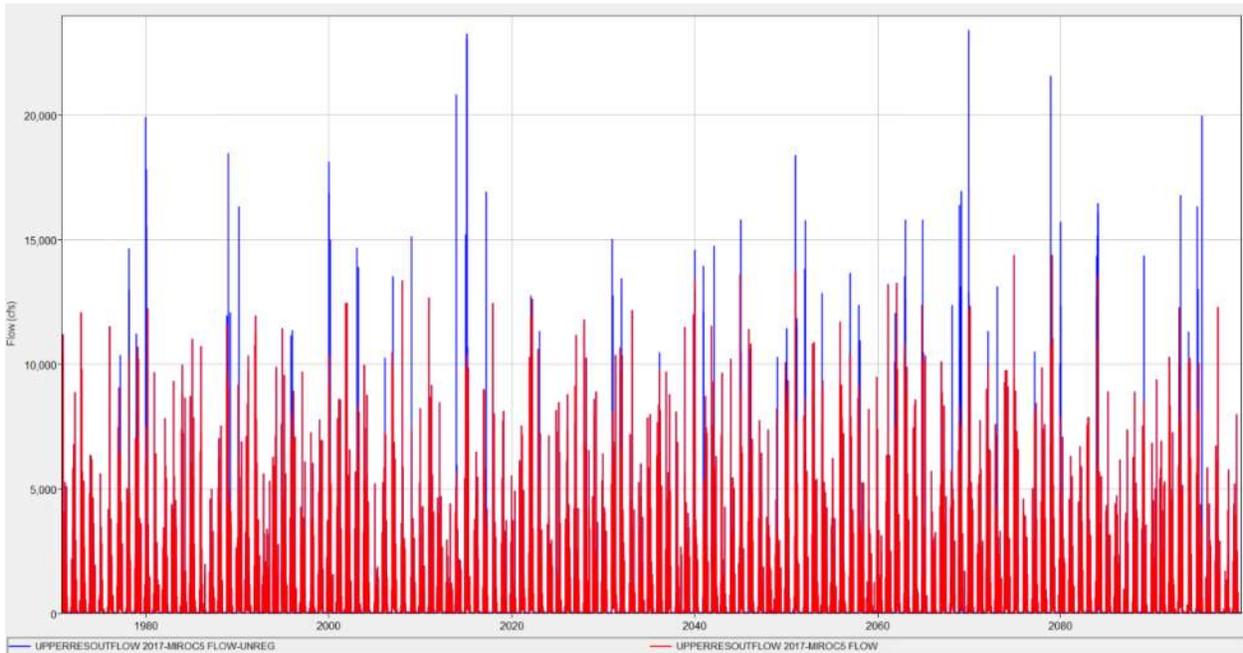
**Figure 1-17. GISS-E2-H Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



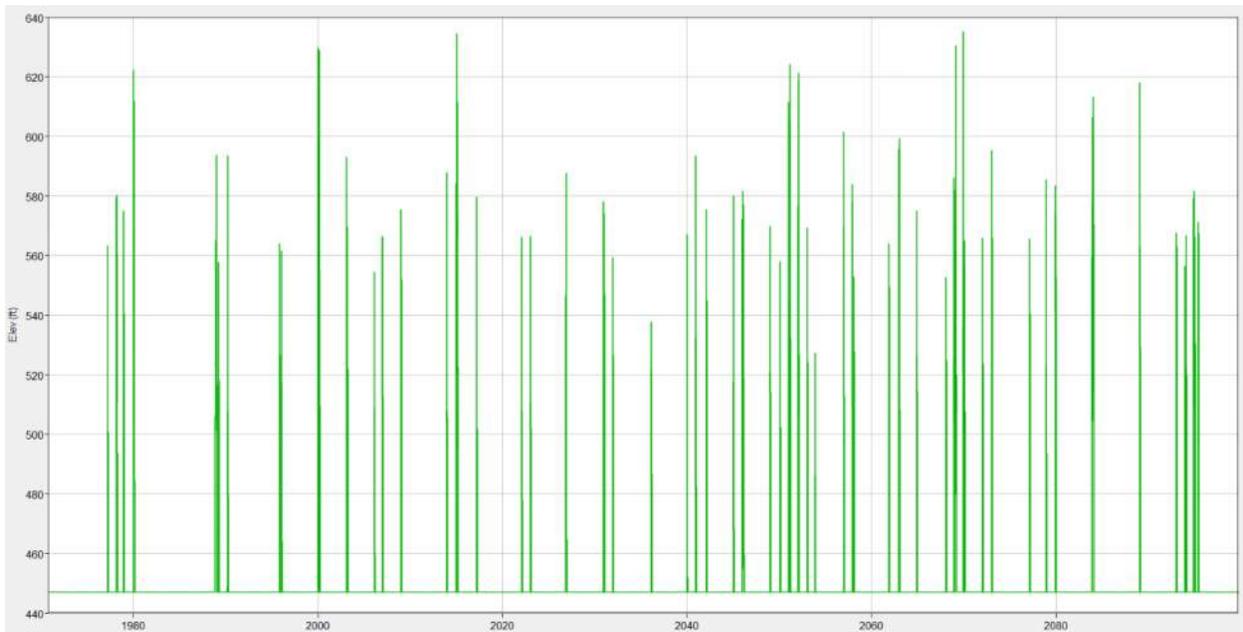
**Figure 1-18. GISS-E2-H Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



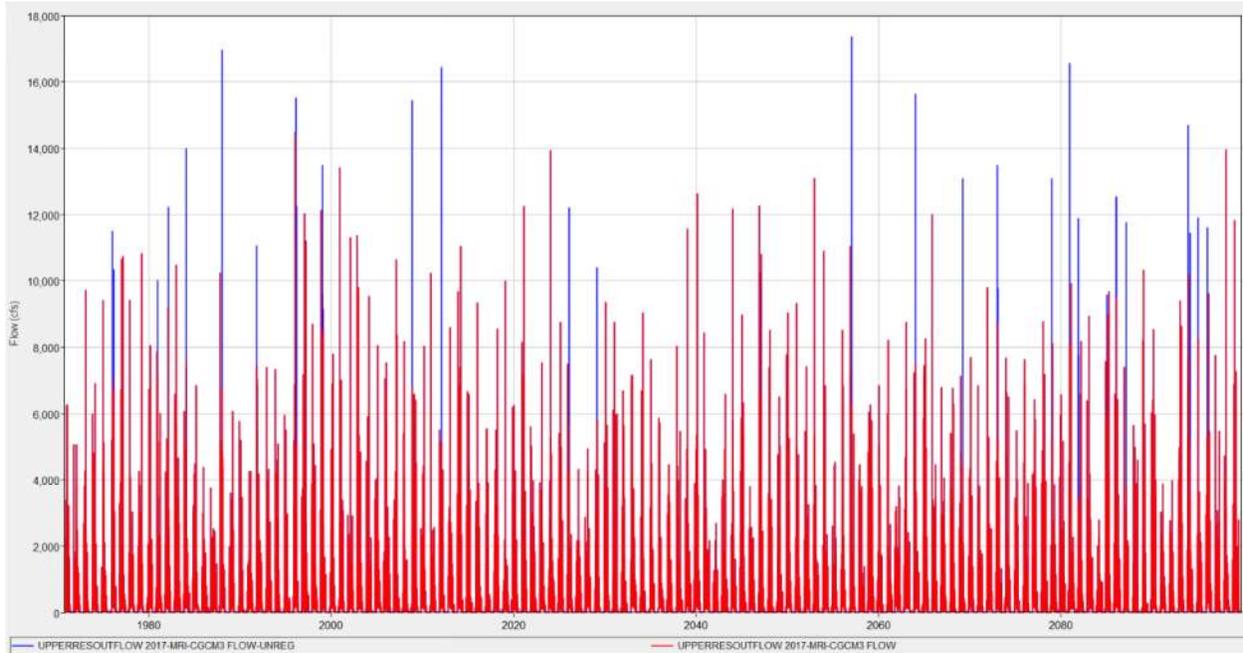
**Figure 1-19. MIROC5 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



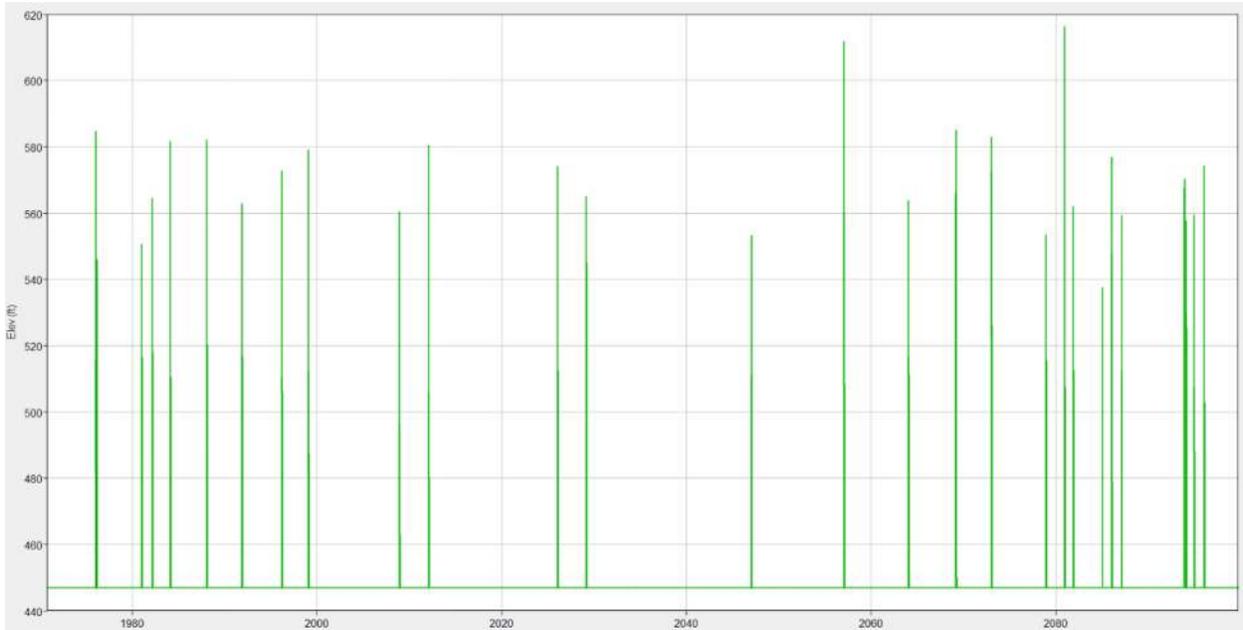
**Figure 1-20. MIROC5 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



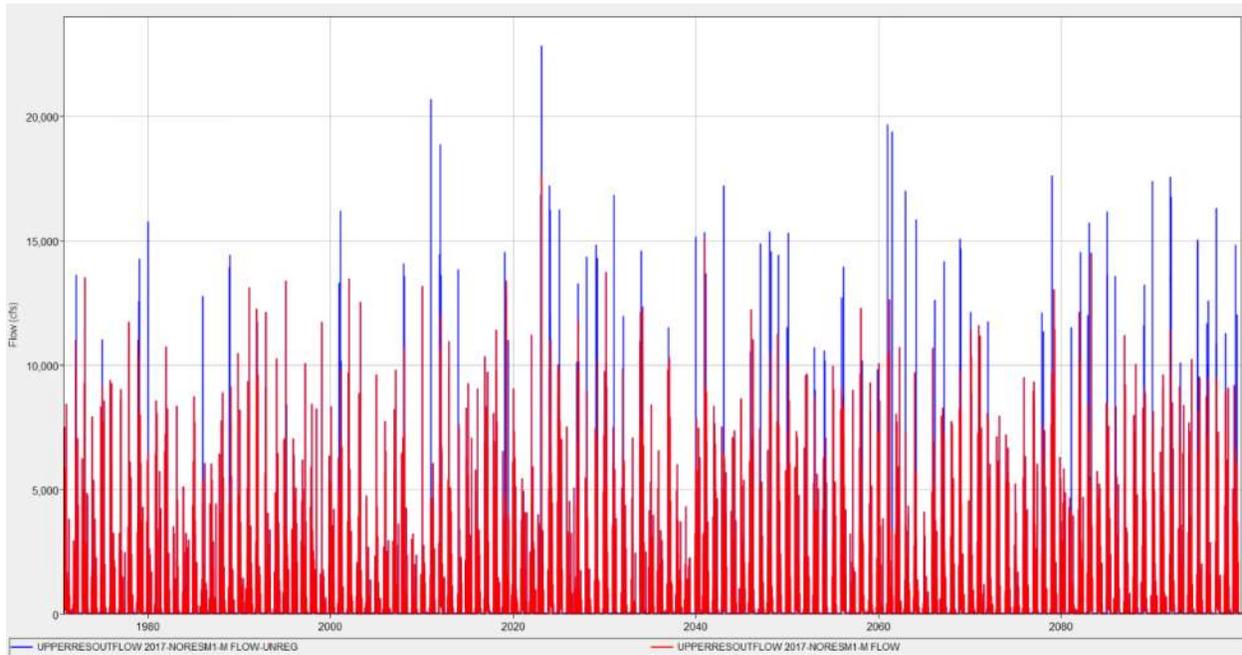
**Figure 1-21. MRI-CGCM3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**



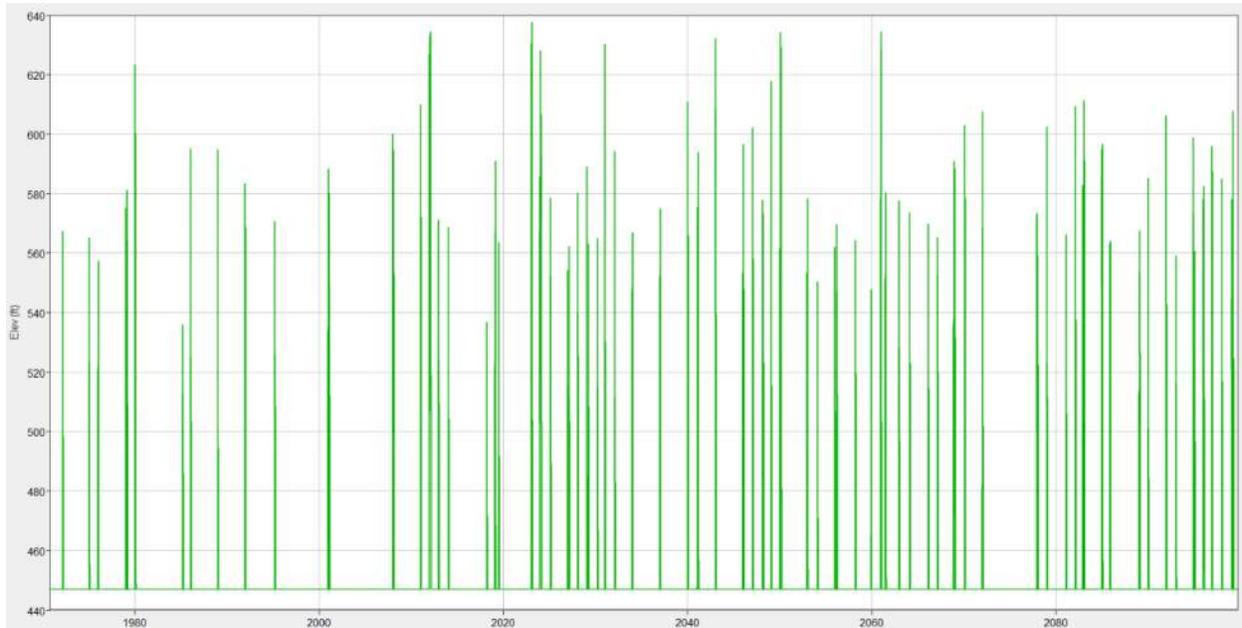
**Figure 1-22. MRI-CGCM3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**



**Figure 1-23. NorESM1-M Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site**

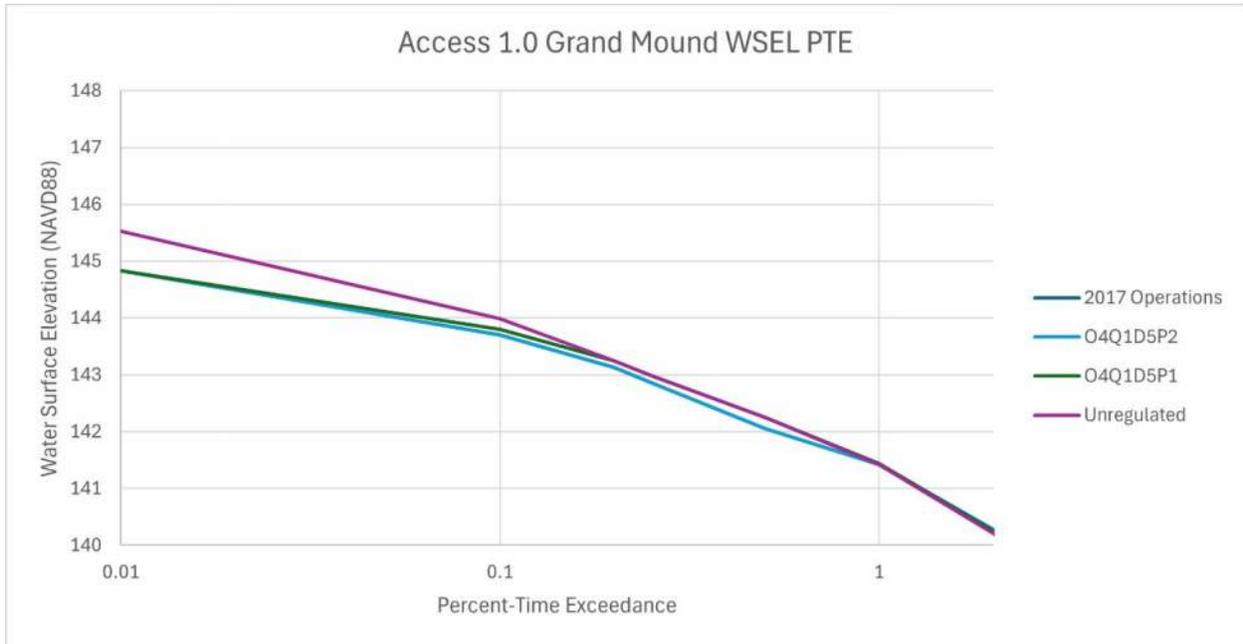


**Figure 1-24. NorESM1-M Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site**

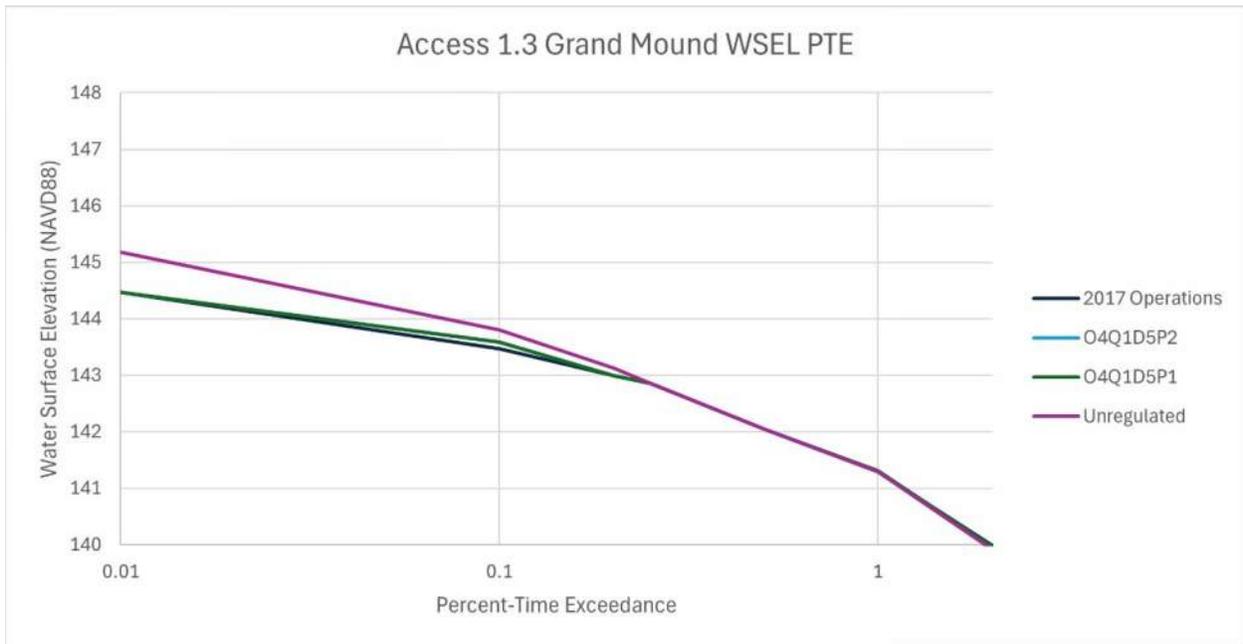


## Attachment 2. Grand Mound WSEL PTE – Detailed View (140–148 feet)

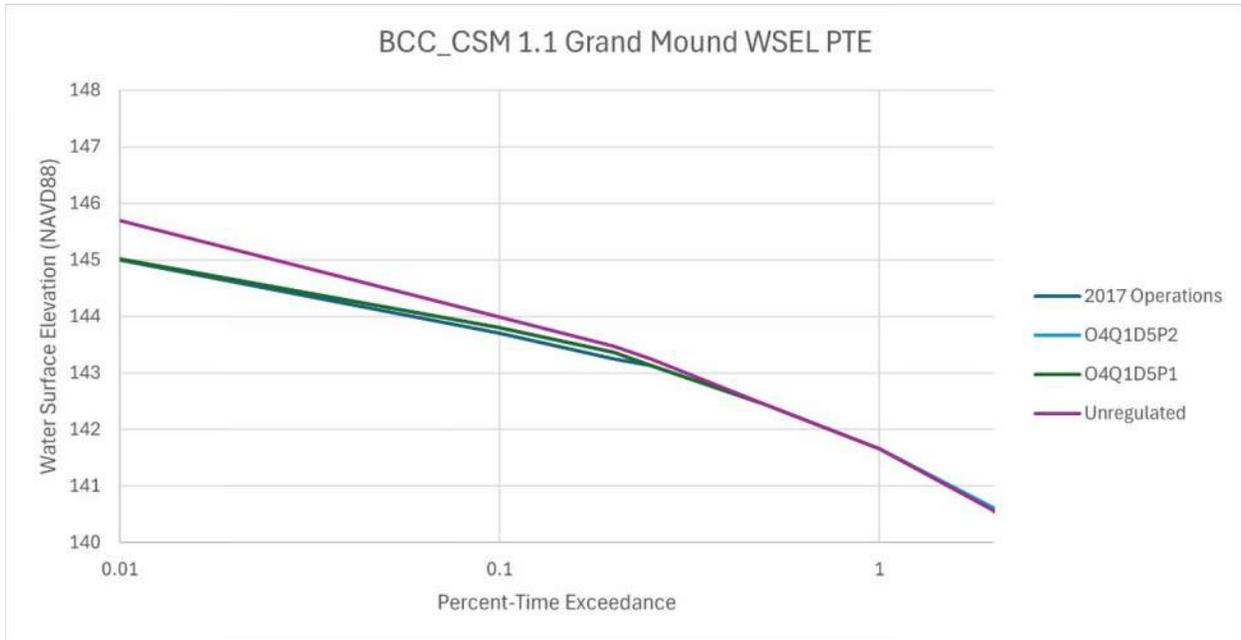
**Figure 2-1. Access 1.0 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



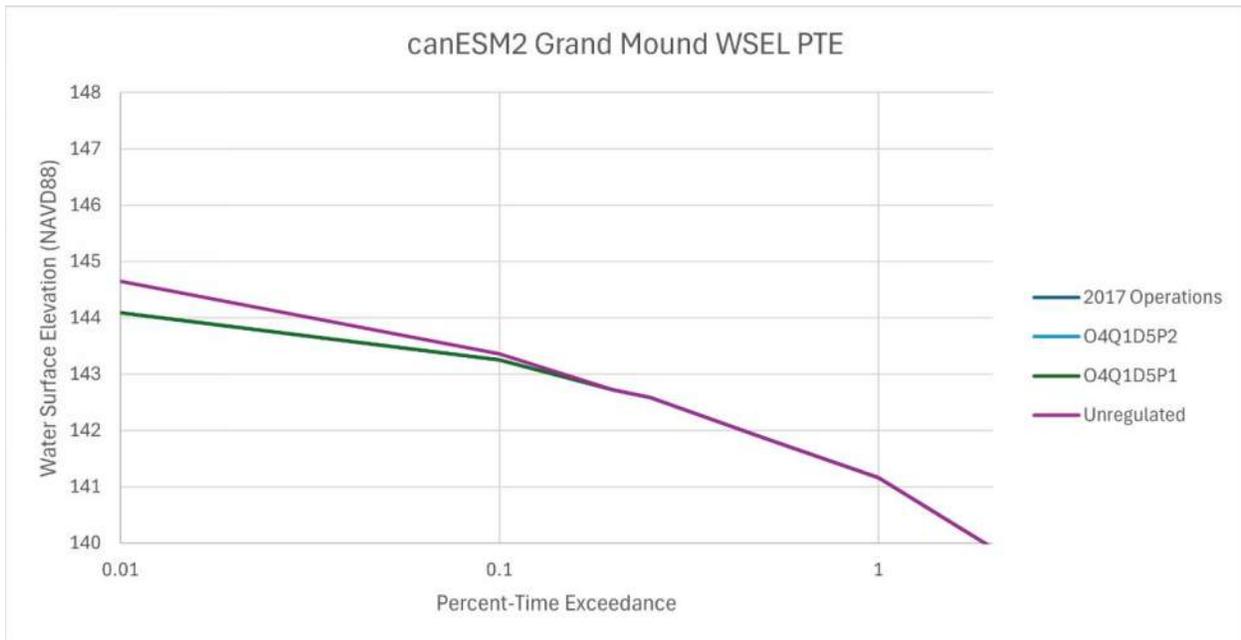
**Figure 2-2. Access 1.3 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



**Figure 2-3. BCC\_CSM 1.1 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



**Figure 2-4. canESM2 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



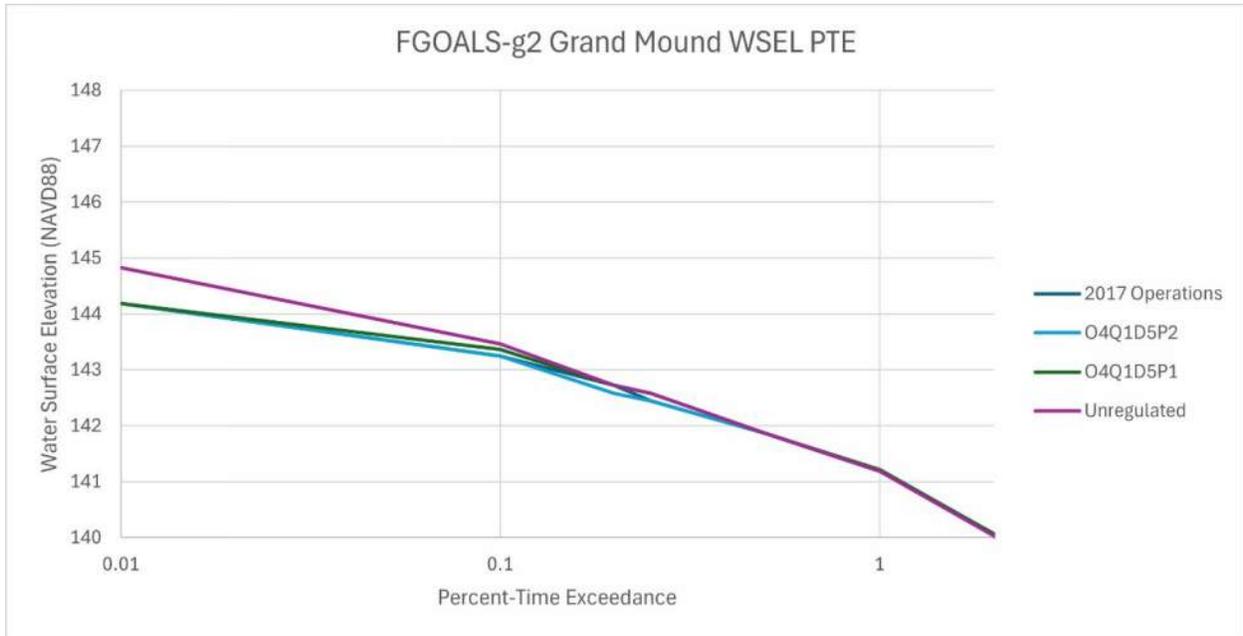
**Figure 2-5. CCSM4 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



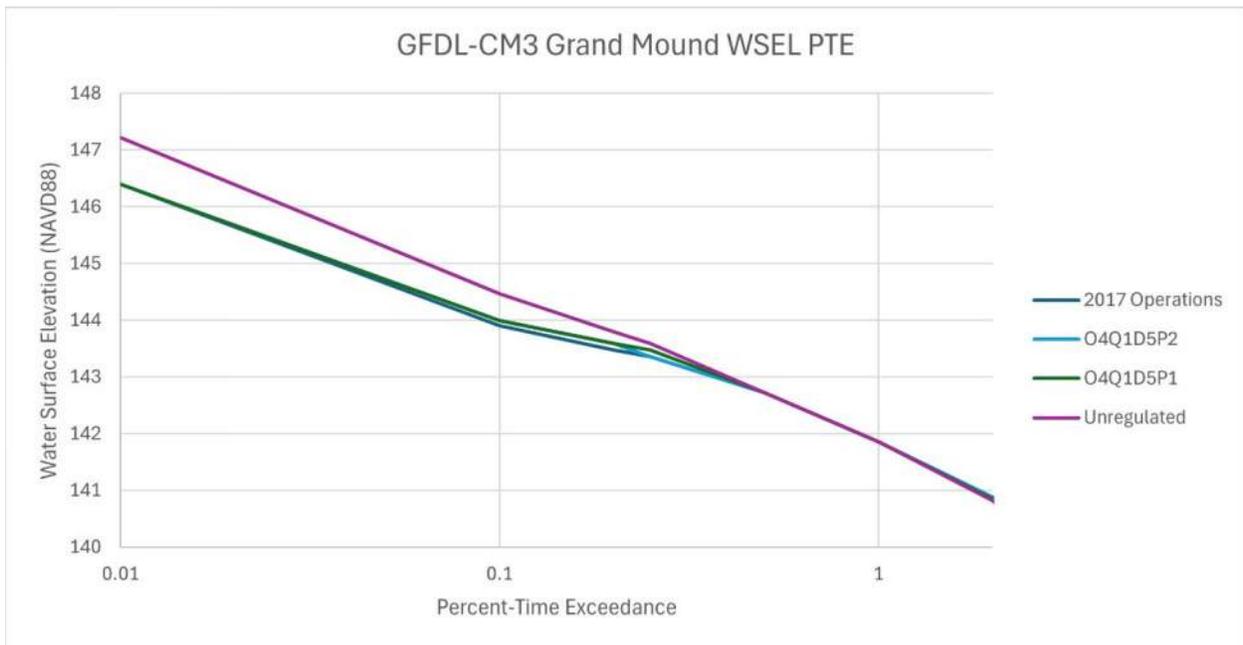
**Figure 2-6. Csiro-mk3 6.0 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



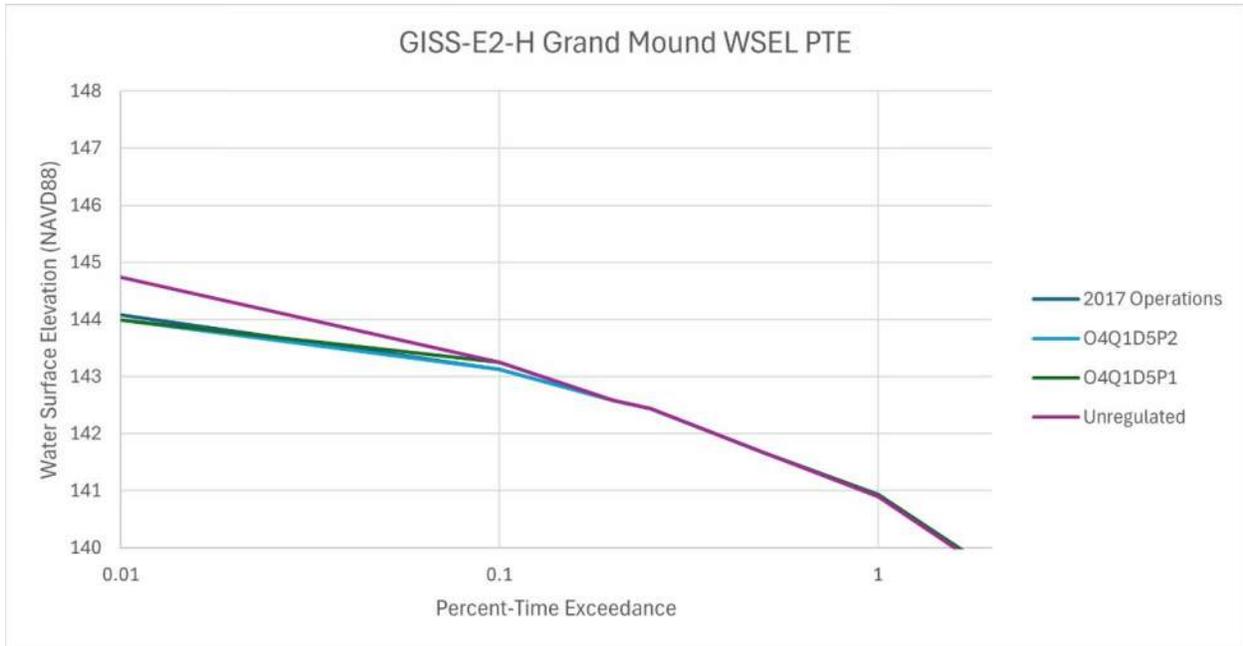
**Figure 2-7. FGOALS-g2 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



**Figure 2-8. GFDL-CM3 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



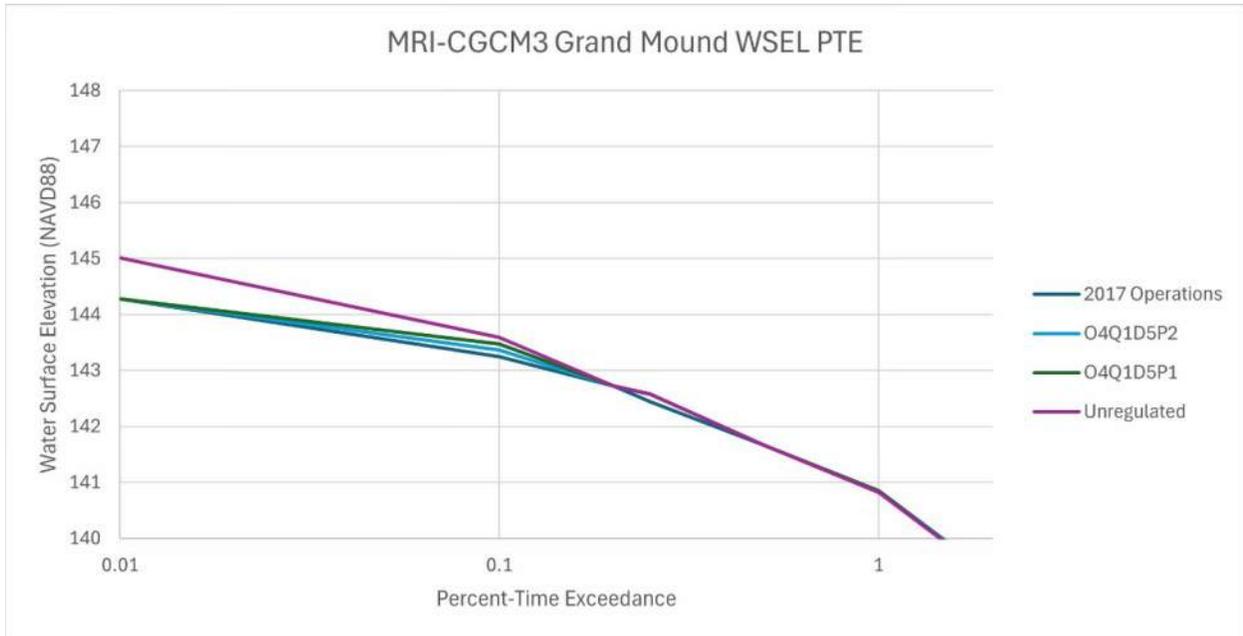
**Figure 2-9. GISS-E2-H Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



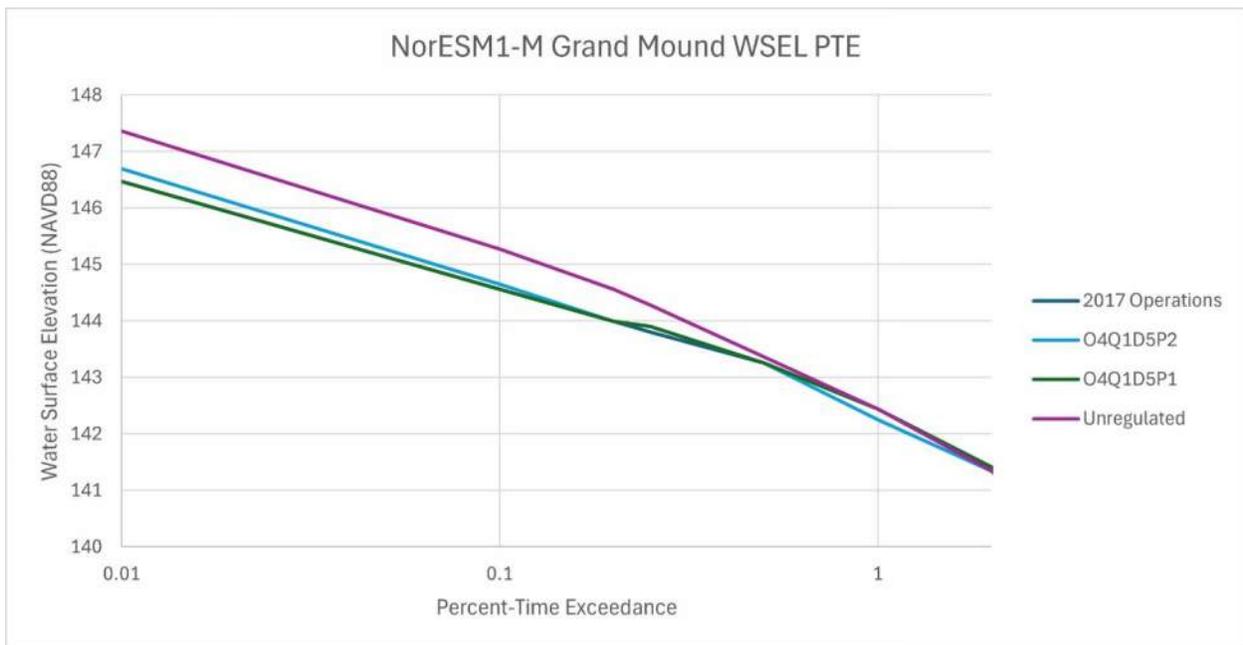
**Figure 2-10. MIROC5 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



**Figure 2-11. MRI-CGCM3 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**



**Figure 2-12. NorESM1-M Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet**





## Attachment 3. Future Climate Fisk Falls Spawning Reach Inundation Days and PTE

**Table 3-1. Days of Inundation at Fisk Falls Spawning Reach – 2017 Operations**

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2026	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	8.9	6.0	3.8
2027	0.0	0.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	0.0	5.2
2028	0.0	0.0	0.0	0.0	0.0	6.0	0.0	10.9	0.0	0.0	0.0	6.9
2029	5.4	0.0	0.0	3.0	4.6	0.0	0.0	0.0	0.0	0.0	5.1	13.3
2030	0.0	11.8	0.0	0.0	7.7	8.4	0.0	0.0	0.0	6.9	0.0	5.7
2031	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.0	13.6
2032	0.0	0.0	4.8	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	9.2
2033	0.0	0.0	11.6	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
2034	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
2035	0.0	0.0	0.0	0.0	0.0	5.1	0.0	13.0	0.0	0.0	0.0	0.0
2036	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	1.0	0.0	0.0
2037	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0	0.0	0.0	0.0	6.5
2038	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0
2039	3.8	0.0	0.0	0.0	0.0	0.0	0.0	7.8	0.0	5.5	0.0	0.0
2040	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.3	0.0	8.9	0.0	11.1
2041	0.0	4.5	0.0	0.0	3.0	6.5	0.0	2.5	5.0	0.0	0.0	8.8
2042	0.0	0.0	15.5	0.0	0.0	6.3	0.0	13.8	5.6	6.5	0.0	0.0
2043	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.3
2044	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.8	0.0	0.0
2045	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	0.0	7.2	0.0	3.6
2046	0.0	0.0	0.0	0.0	0.0	9.8	0.0	4.9	0.0	13.4	0.0	10.2
2047	0.0	0.0	11.9	0.0	3.3	0.0	0.0	8.0	0.0	0.0	3.3	10.0
2048	5.0	2.5	0.0	0.0	0.0	11.6	0.0	7.8	0.0	5.1	0.0	13.4
2049	6.4	0.0	8.4	7.6	0.0	7.4	0.0	5.0	0.0	0.8	0.0	17.3
2050	0.0	0.0	14.0	4.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	17.3
2051	0.0	6.0	0.0	0.0	6.0	8.9	0.0	0.0	4.2	24.8	0.0	0.0

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2052	0.0	0.0	0.0	0.0	0.7	0.0	8.8	0.0	0.0	20.4	0.0	8.9
2053	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5.5	0.0	0.0
2054	0.0	11.6	0.0	0.0	0.0	0.0	6.8	20.5	0.0	0.0	0.0	3.3
2055	11.1	0.0	7.9	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	4.6
2056	5.4	6.0	0.0	0.0	2.0	0.0	0.0	0.0	5.4	9.9	0.0	5.8
2057	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	11.7	11.0	0.0
2058	3.5	10.9	0.0	0.0	0.0	8.8	0.0	0.0	0.0	3.8	0.0	5.0
2059	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
2060	0.0	0.0	5.6	3.0	1.0	4.5	0.0	13.0	0.0	0.0	0.0	13.3
2061	0.0	0.0	6.8	9.1	0.0	4.0	0.0	1.3	0.0	7.8	0.0	8.0
2062	0.0	8.8	0.0	0.0	0.0	7.5	0.0	0.0	0.0	17.1	0.0	6.7
2063	0.0	12.0	0.0	0.0	6.0	0.0	4.0	0.0	0.0	7.7	0.0	0.0
2064	0.0	0.0	4.1	0.0	4.3	12.8	5.5	10.4	8.5	6.5	5.0	6.3
2065	3.6	0.0	0.0	0.0	8.2	0.0	0.0	15.0	0.0	0.0	0.0	0.0
2066	0.0	0.0	10.3	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	5.8
2067	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
2068	5.0	0.0	0.0	3.5	0.0	5.0	0.0	0.0	0.0	11.3	0.0	8.8
2069	15.6	4.5	7.7	4.8	0.0	3.5	10.6	23.1	0.0	47.0	7.8	8.3
2070	7.1	11.8	4.0	0.0	3.6	0.0	0.0	0.0	0.0	5.4	0.0	10.2
2071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	8.6
2072	0.0	0.0	10.5	0.0	4.7	0.0	0.0	0.0	0.0	5.3	0.0	3.5
2073	0.0	0.0	0.0	8.1	0.0	6.0	4.8	14.3	0.0	9.4	13.8	0.0
2074	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2075	0.0	0.0	0.0	10.0	0.0	0.0	13.3	3.7	0.0	0.0	0.0	0.0
2076	0.0	5.0	0.0	0.0	0.0	0.0	0.0	3.5	4.4	0.0	0.0	0.0
2077	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	5.3	0.0	8.1
2078	15.2	0.0	0.0	0.0	9.0	11.1	0.0	6.5	0.0	7.8	3.3	13.1

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2079	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	0.0
2080	3.7	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	12.3	0.0
2081	7.0	5.0	0.0	0.0	7.6	4.8	1.0	8.5	0.0	0.0	4.7	5.0
2082	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	20.0
2083	2.6	0.0	0.0	0.0	0.0	0.0	8.3	10.8	0.0	17.1	0.0	11.4
2084	0.0	0.0	3.8	0.0	0.5	0.0	12.8	5.4	0.0	18.5	0.0	10.4
2085	7.7	5.5	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	10.5
2086	0.0	4.4	4.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0	6.9	0.0
2087	0.0	0.0	0.0	0.0	0.0	21.3	0.0	5.7	0.0	0.0	4.2	0.0
2088	0.0	0.0	0.0	3.9	8.0	27.5	0.0	0.0	0.0	0.0	0.0	0.0
2089	0.0	0.0	0.0	0.0	0.0	1.8	0.0	6.0	0.0	12.5	0.0	18.7
2090	7.2	7.3	6.1	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0
2091	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	10.5
2092	19.4	16.8	0.0	0.0	8.5	0.0	5.5	6.3	5.8	0.0	0.0	4.4
2093	0.0	0.0	0.0	0.0	0.0	18.5	0.0	0.0	0.0	9.6	11.0	0.0
2094	6.5	6.0	8.6	0.0	0.0	8.2	5.8	15.7	0.0	19.7	8.5	9.8
2095	3.6	0.0	4.4	0.0	5.9	4.9	0.0	0.0	0.0	11.0	0.0	11.3
2096	0.0	0.0	5.5	0.0	6.9	15.1	12.0	0.0	0.0	0.0	6.3	17.0
2097	5.5	1.3	4.2	11.5	0.0	9.2	0.0	4.4	4.2	0.0	0.0	7.8
2098	0.0	9.1	0.0	2.7	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.3
2099	0.0	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	0.0	18.3

**Table 3-2. Days of Inundation at Fisk Falls Spawning Reach – O4Q1D5P1 Operations**

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2026	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	5.1	0.0	0.0
2027	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	0.0	0.0	0.0	0.0	0.0	4.3	0.0	10.6	0.0	0.0	0.0	5.0
2029	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	9.8
2030	0.0	7.5	0.0	0.0	7.8	0.0	0.0	0.0	0.0	6.8	0.0	1.1
2031	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8
2032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0	0.0	8.1
2033	0.0	0.0	9.7	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	4.4
2034	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2035	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0	0.0	0.0	0.0
2036	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0
2037	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2
2038	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
2039	0.2	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.0	1.8	0.0	0.0
2040	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	0.0	7.6	0.0	9.5
2041	0.0	0.0	0.0	0.0	0.0	6.5	0.0	2.7	4.9	0.0	0.0	7.5
2042	0.0	0.0	14.3	0.0	0.0	0.0	0.0	13.0	0.3	3.1	0.0	0.0
2043	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.6
2044	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.8	0.0	0.0
2045	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	6.3	0.0	0.0
2046	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.6	0.0	7.6	0.0	1.5
2047	0.0	0.0	11.7	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	8.2
2048	7.0	0.0	0.0	0.0	0.0	8.8	0.0	4.7	0.0	4.3	0.0	14.2
2049	0.5	0.0	7.1	3.7	0.0	3.0	0.0	3.6	0.0	0.0	0.0	11.1
2050	0.0	0.0	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.4
2051	0.0	0.3	0.0	0.0	6.5	8.7	0.0	0.0	0.0	23.2	0.0	0.0
2052	0.0	0.0	0.0	0.0	0.8	0.0	4.9	0.0	0.0	15.3	0.0	0.0

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2053	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
2054	0.0	6.7	0.0	0.0	0.0	0.0	2.2	17.1	0.0	0.0	0.0	0.7
2055	8.7	0.0	8.5	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0
2056	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	8.3	0.0	4.5
2057	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	5.9	3.8	7.3	0.0
2058	0.0	4.4	0.0	0.0	0.0	10.6	0.0	0.0	0.0	2.8	0.0	0.4
2059	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2060	0.0	0.0	3.8	0.0	0.0	0.0	0.0	12.1	0.0	0.0	0.0	13.6
2061	0.0	0.0	6.3	5.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	6.1
2062	0.0	5.6	0.0	0.0	0.0	6.0	0.0	0.0	0.0	16.4	0.0	5.3
2063	0.0	6.4	0.0	0.0	0.3	0.0	0.0	0.0	0.0	7.2	0.0	0.0
2064	0.0	0.0	3.2	0.0	0.0	1.7	4.3	4.7	7.5	5.4	0.0	5.0
2065	0.0	0.0	0.0	0.0	10.9	0.0	0.0	14.1	0.0	0.0	0.0	0.0
2066	0.0	0.0	10.0	0.0	0.0	0.0	0.0	6.5	0.0	0.0	0.0	1.8
2067	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7
2068	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	6.6	0.0	7.6
2069	14.7	4.5	0.5	0.0	0.0	0.0	9.4	18.9	0.0	35.9	6.0	7.0
2070	6.0	12.6	4.4	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	8.5
2071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9
2072	0.0	0.0	9.5	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	3.2
2073	0.0	0.0	0.0	6.1	0.0	5.8	0.0	14.8	0.0	8.4	5.9	0.0
2074	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2075	0.0	0.0	0.0	8.7	0.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0
2076	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2077	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	5.3	0.0	7.4
2078	11.5	0.0	0.0	0.0	8.2	6.3	0.0	5.1	0.0	6.3	0.0	12.4
2079	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.0	0.0

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2080	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0
2081	3.3	3.5	0.0	0.0	6.3	0.0	0.0	5.0	0.0	0.0	0.0	0.0
2082	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.1
2083	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.8	0.0	10.5	0.0	10.8
2084	0.0	0.0	0.0	0.0	0.0	0.0	9.1	6.3	0.0	14.0	0.0	10.5
2085	6.3	4.1	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
2086	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0
2087	0.0	0.0	0.0	0.0	0.0	13.5	0.0	4.0	0.0	0.0	0.0	0.0
2088	0.0	0.0	0.0	0.5	6.6	20.9	0.0	0.0	0.0	0.0	0.0	0.0
2089	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	10.9	0.0	10.4
2090	6.0	3.3	6.7	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0
2091	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5
2092	7.2	6.5	0.0	0.0	7.0	0.0	0.0	5.2	3.2	0.0	0.0	0.0
2093	0.0	0.0	0.0	0.0	0.0	17.4	0.0	0.0	0.0	4.7	4.2	0.0
2094	4.9	4.7	21.9	0.0	0.0	7.3	2.4	9.9	0.0	15.3	0.0	9.0
2095	0.0	0.0	4.5	0.0	3.8	0.7	0.0	0.0	0.0	4.2	0.0	6.3
2096	0.0	0.0	4.5	0.0	3.5	12.1	6.4	0.0	0.0	0.0	2.4	15.5
2097	4.8	0.5	3.0	4.8	0.0	7.9	0.0	0.0	0.0	0.0	0.0	8.4
2098	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.6
2099	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	18.2

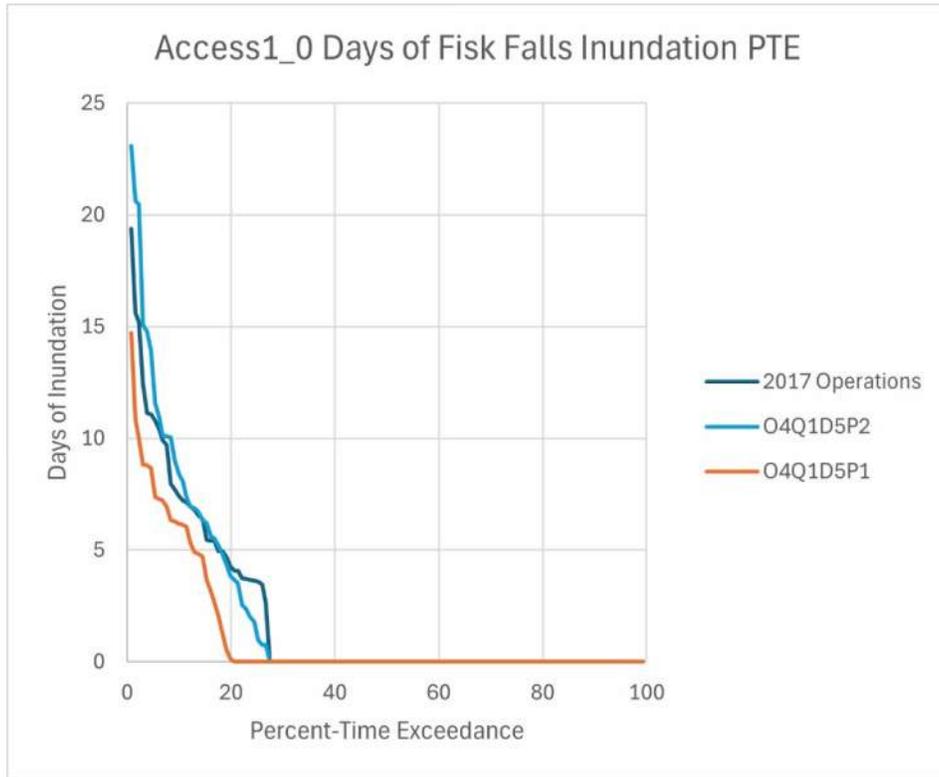
**Table 3-3. Days of Inundation at Fisk Falls Spawning Reach – O4Q1D5P2 Operations**

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2026	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	10.1	0.0	0.0
2027	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	0.0	0.0	0.0	0.0	0.0	9.4	0.0	10.9	0.0	0.0	0.0	5.4
2029	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	11.7
2030	0.0	12.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	7.1	0.0	1.1
2031	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	0.0	12.9
2032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3	0.0	0.0	0.0	8.1
2033	0.0	0.0	0.7	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	4.4
2034	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
2035	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	0.0	0.0	0.0	0.0
2036	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0
2037	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.2
2038	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0
2039	2.6	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.0	11.2	0.0	0.0
2040	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.1	0.0	15.1	0.0	11.3
2041	0.0	2.3	0.0	0.0	0.0	6.5	0.0	2.7	3.0	0.0	0.0	10.8
2042	0.0	0.0	10.6	0.0	0.0	0.0	0.0	13.0	0.0	5.6	0.0	0.0
2043	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.8
2044	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.8	0.0	0.0
2045	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	13.9	0.0	0.0
2046	0.0	0.0	0.0	0.0	0.0	11.8	0.0	4.0	0.0	9.9	0.0	9.1
2047	0.0	0.0	10.1	0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	8.3
2048	7.0	0.0	0.0	0.0	0.0	9.1	0.0	5.7	0.0	4.3	0.0	32.3
2049	4.0	0.0	7.0	4.4	0.0	21.8	0.0	3.6	0.0	0.0	0.0	11.9
2050	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7
2051	0.0	0.0	0.0	0.0	6.5	12.1	0.0	0.0	0.0	23.3	0.0	0.0
2052	0.0	0.0	0.0	0.0	0.8	0.0	8.0	0.0	0.0	19.5	0.0	0.0

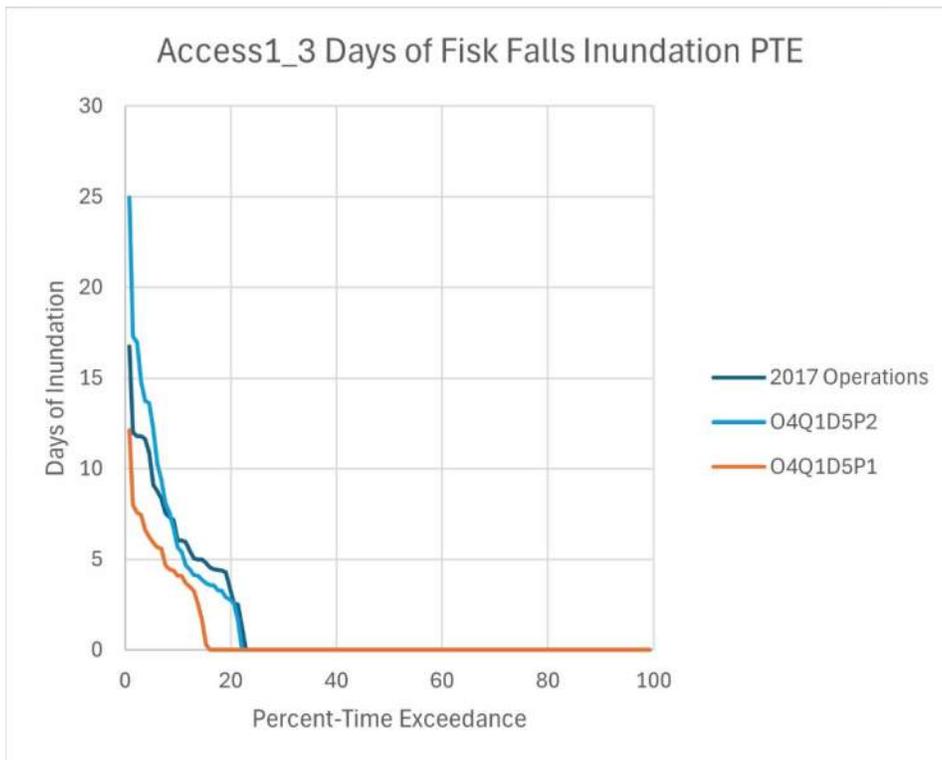
Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2053	0.0	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	9.1	0.0	0.0
2054	0.0	9.3	0.0	0.0	0.0	0.0	10.8	17.2	0.0	0.0	0.0	2.4
2055	11.7	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0
2056	7.4	0.0	0.0	0.0	6.8	0.0	0.0	0.0	3.0	13.6	0.0	4.5
2057	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	2.4	8.0	8.8	0.0
2058	0.0	4.4	0.0	0.0	0.0	18.3	0.0	0.0	0.0	2.8	0.0	3.4
2059	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2060	0.0	0.0	3.8	0.0	0.0	0.0	0.0	16.3	0.0	0.0	0.0	13.6
2061	0.0	0.0	5.3	5.1	0.0	2.4	0.0	0.0	0.0	0.0	0.0	6.3
2062	0.0	11.9	0.0	0.0	0.0	6.6	0.0	0.0	0.0	18.3	0.0	10.7
2063	0.0	6.5	0.0	0.0	4.0	0.0	0.0	0.0	0.0	18.8	0.0	0.0
2064	0.0	0.0	0.8	0.0	0.0	8.5	5.0	4.7	7.5	5.4	0.0	5.1
2065	0.0	0.0	0.0	0.0	16.7	0.0	0.0	24.9	0.0	0.0	0.0	0.0
2066	0.0	0.0	5.8	0.0	0.0	0.0	0.0	18.3	0.0	0.0	0.0	4.7
2067	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7
2068	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	12.2	0.0	7.8
2069	14.8	4.5	0.5	0.0	0.0	2.7	9.4	26.1	0.0	40.5	6.3	7.3
2070	15.6	17.3	4.1	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	11.5
2071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9
2072	0.0	0.0	9.2	0.0	4.3	0.0	0.0	0.0	0.0	5.6	0.0	3.2
2073	0.0	0.0	0.0	17.3	0.0	5.8	1.2	19.3	0.0	8.4	13.2	0.0
2074	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2075	0.0	0.0	0.0	8.8	0.0	0.0	15.8	0.0	0.0	0.0	0.0	0.0
2076	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2077	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	5.3	0.0	22.3
2078	14.0	0.0	0.0	0.0	8.2	6.3	0.0	5.7	0.0	9.6	0.0	13.3
2079	11.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.7	0.0	14.1

Calendar Year	Access 1.0	Access 1.3	bcc-csm 1.1	canesm2	ccsm4	csiro-mk3.6	fgoals-g2	gfdl-cm3	giss-e2-h	MIROC5	mri-cgcm3	noresm1-m
2080	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.7	0.0
2081	5.3	3.6	0.0	0.0	7.1	0.0	0.0	15.5	0.0	0.0	0.0	0.0
2082	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.7
2083	0.0	0.0	0.0	0.0	0.0	0.0	7.2	6.4	0.0	10.7	0.0	10.9
2084	0.0	0.0	0.0	0.0	0.0	0.0	26.5	6.8	0.0	28.0	0.0	10.5
2085	6.3	4.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
2086	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0
2087	0.0	0.0	0.0	0.0	0.0	32.9	0.0	4.0	0.0	0.0	0.0	0.0
2088	0.0	0.0	0.0	3.0	8.5	31.7	0.0	0.0	0.0	0.0	0.0	0.0
2089	0.0	0.0	0.0	0.0	0.0	4.0	0.0	5.5	0.0	13.6	0.0	34.7
2090	8.4	3.3	5.0	0.0	0.0	0.0	0.0	10.1	0.0	0.0	0.0	1.5
2091	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	9.5
2092	22.6	12.0	0.0	0.0	7.3	0.0	0.0	5.3	0.4	0.0	0.0	0.0
2093	0.0	0.0	0.0	0.0	0.0	17.4	0.0	0.0	0.0	8.0	11.5	0.0
2094	5.5	4.7	0.9	0.0	0.0	17.8	11.7	13.6	0.0	22.3	0.0	9.0
2095	0.0	0.0	4.5	0.0	4.1	1.4	6.1	0.0	0.0	12.5	0.0	11.0
2096	0.0	0.0	4.5	0.0	11.8	16.3	13.3	0.0	0.0	0.0	5.5	36.8
2097	12.8	3.3	3.0	10.5	0.0	24.5	0.0	0.0	0.0	0.0	0.0	8.4
2098	0.0	26.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
2099	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	19.1

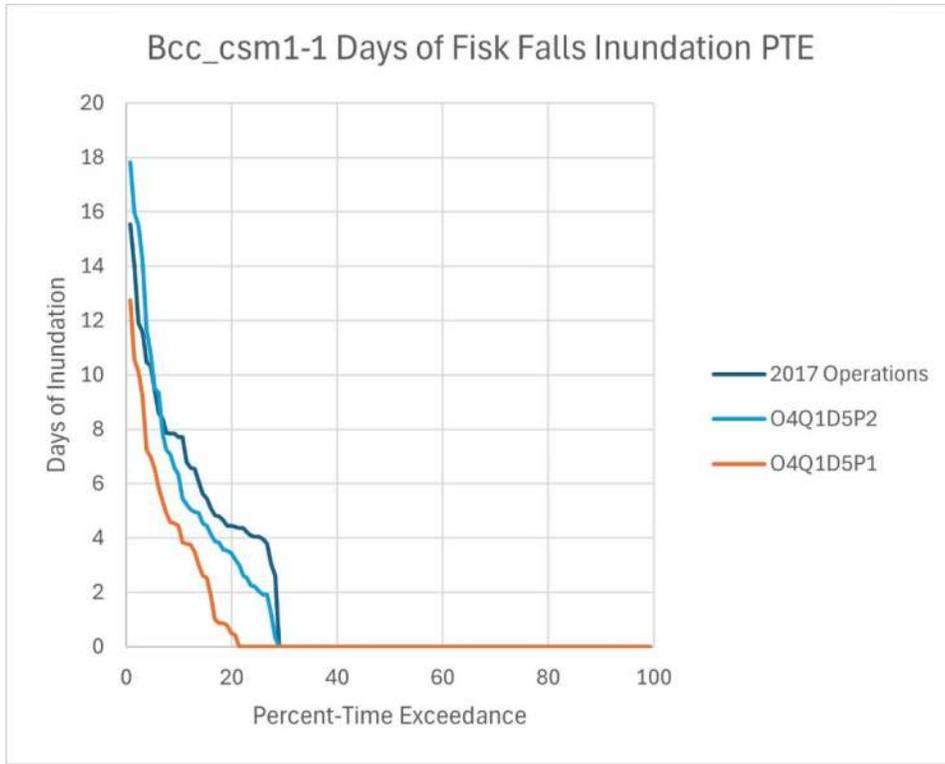
**Figure 3-1. Access1\_0 Days of Fisk Falls Inundation PTE**



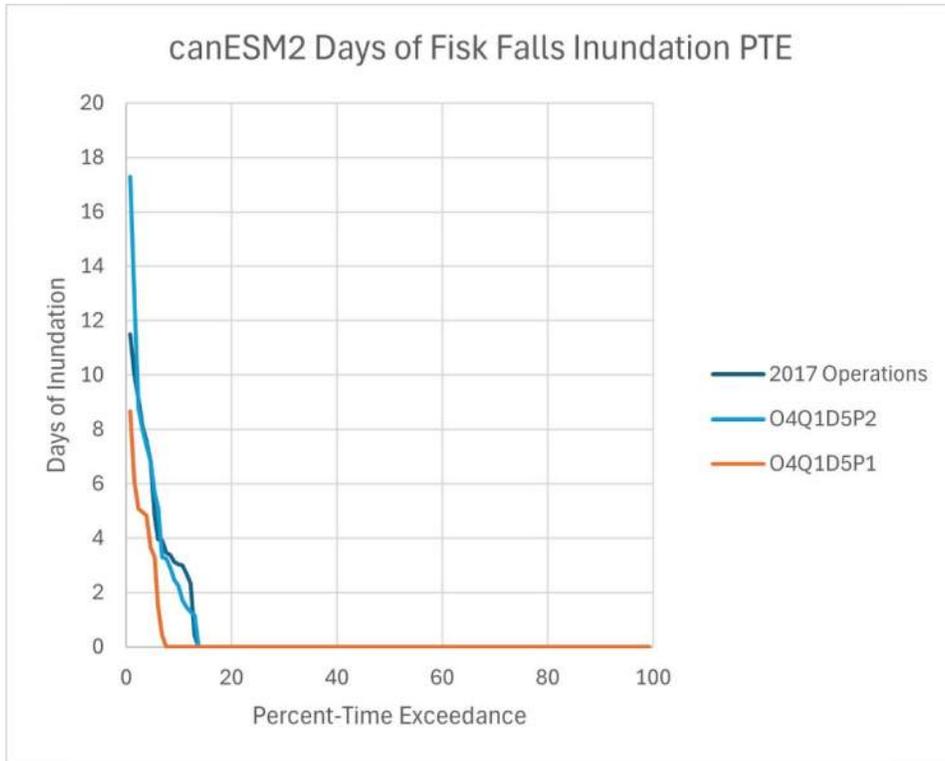
**Figure 3-2. Access1\_3 Days of Fisk Falls Inundation PTE**



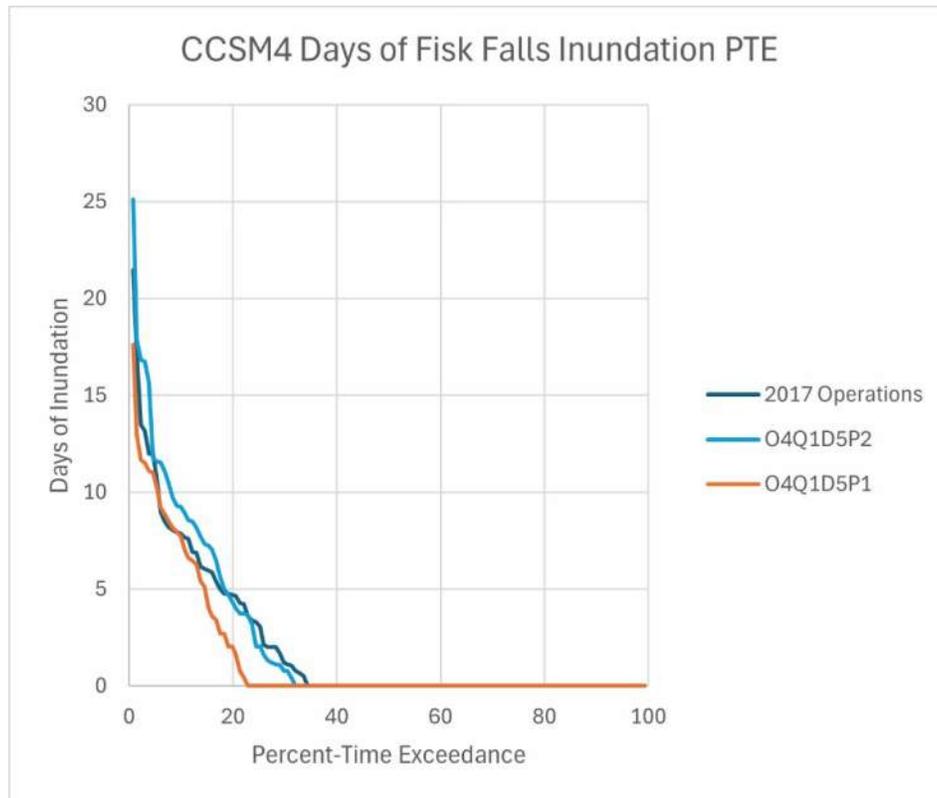
**Figure 3-3. Bcc\_csm1-1 Days of Fisk Falls Inundation PTE**



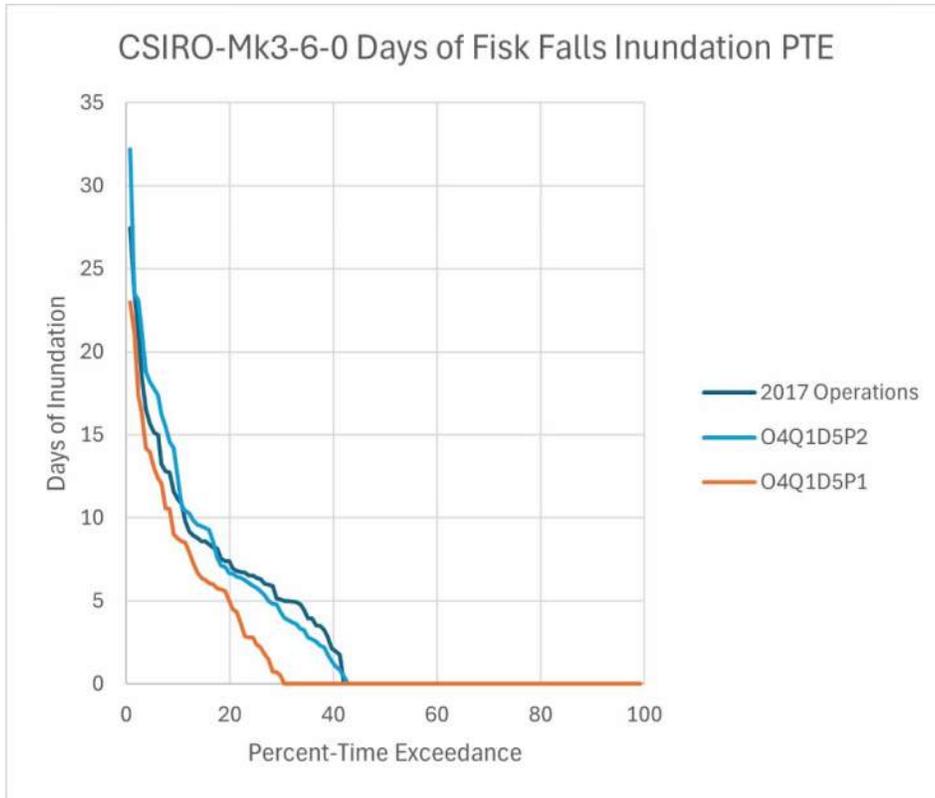
**Figure 3-4. canESM2 Days of Fisk Falls Inundation PTE**



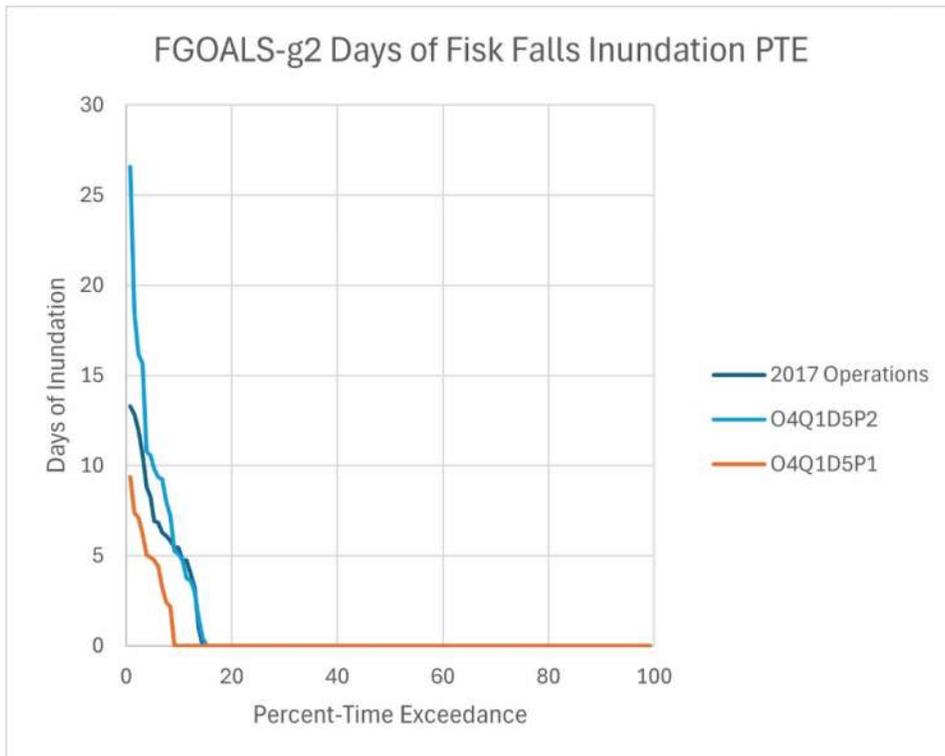
**Figure 3-5. CCSM4 Days of Fisk Falls Inundation PTE**



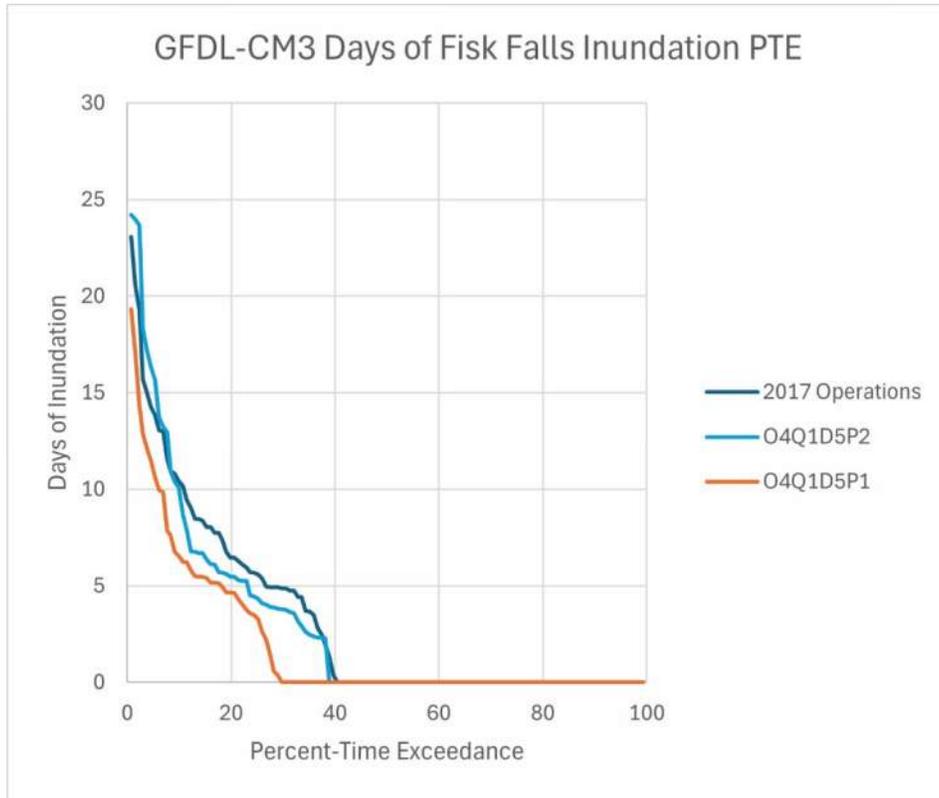
**Figure 3-6. CSIRO-Mk3-6-0 Days of Fisk Falls Inundation PTE**



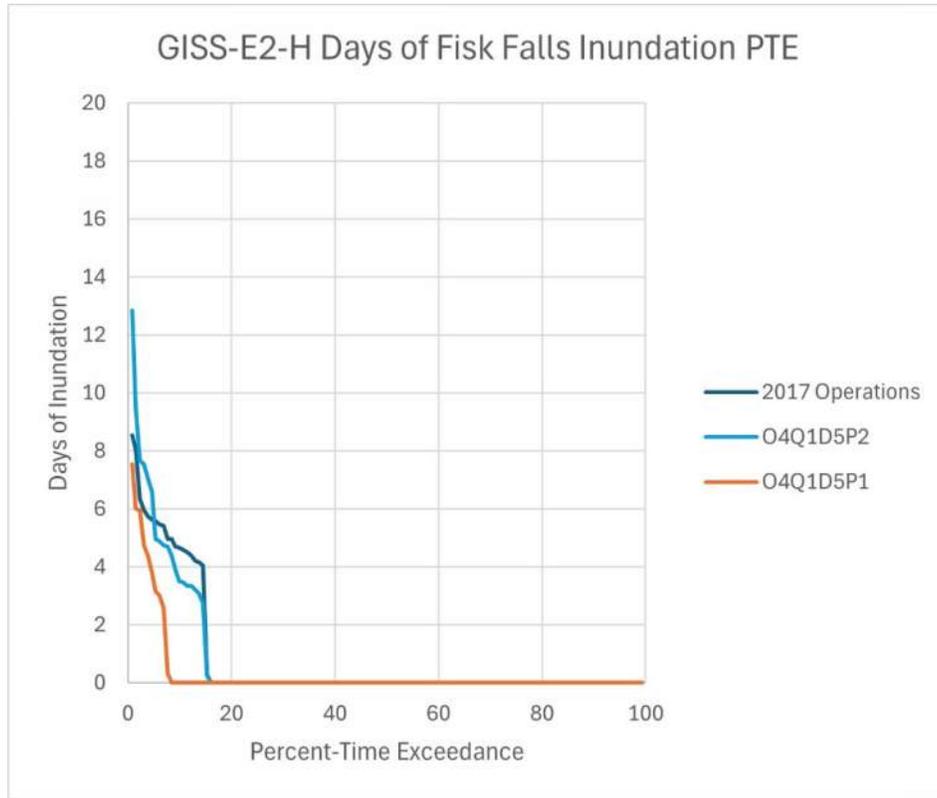
**Figure 3-7. FGOALS-g2 Days of Fisk Falls Inundation PTE**



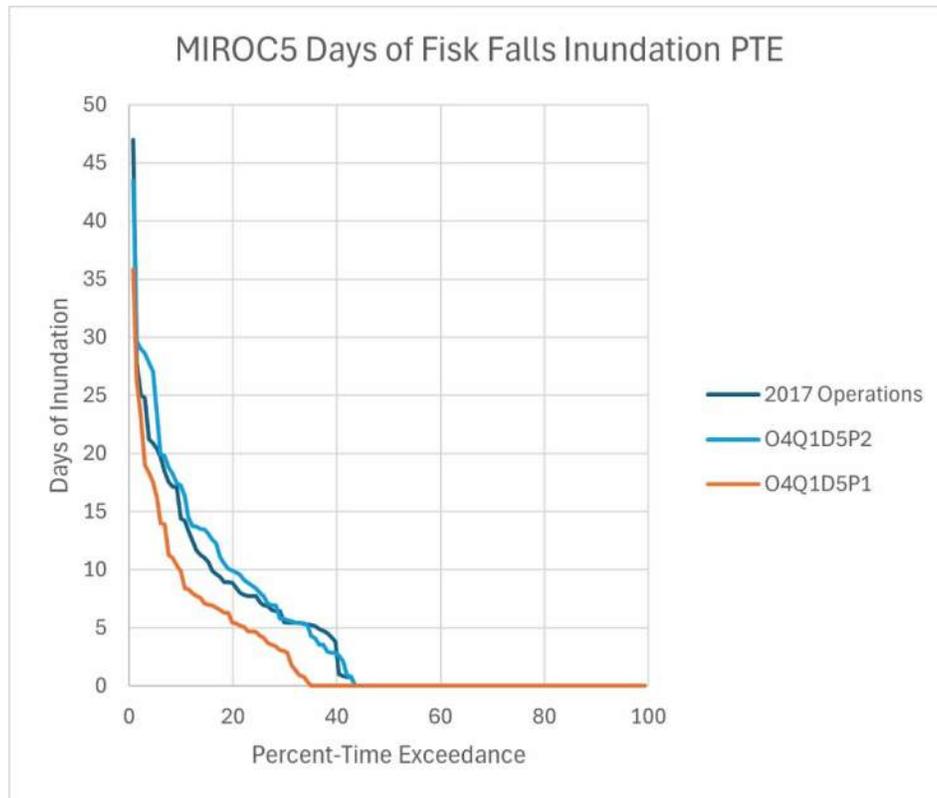
**Figure 3-8. GFDL-CM3 Days of Fisk Falls Inundation PTE**



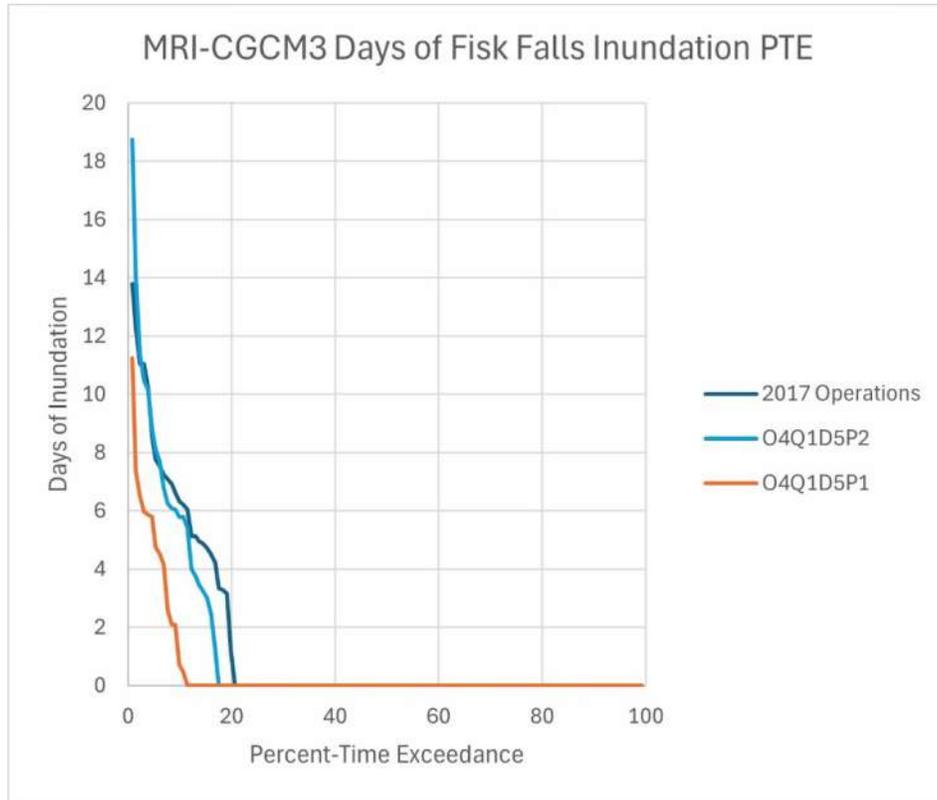
**Figure 3-9. GISS-E2-H Days of Fisk Falls Inundation PTE**



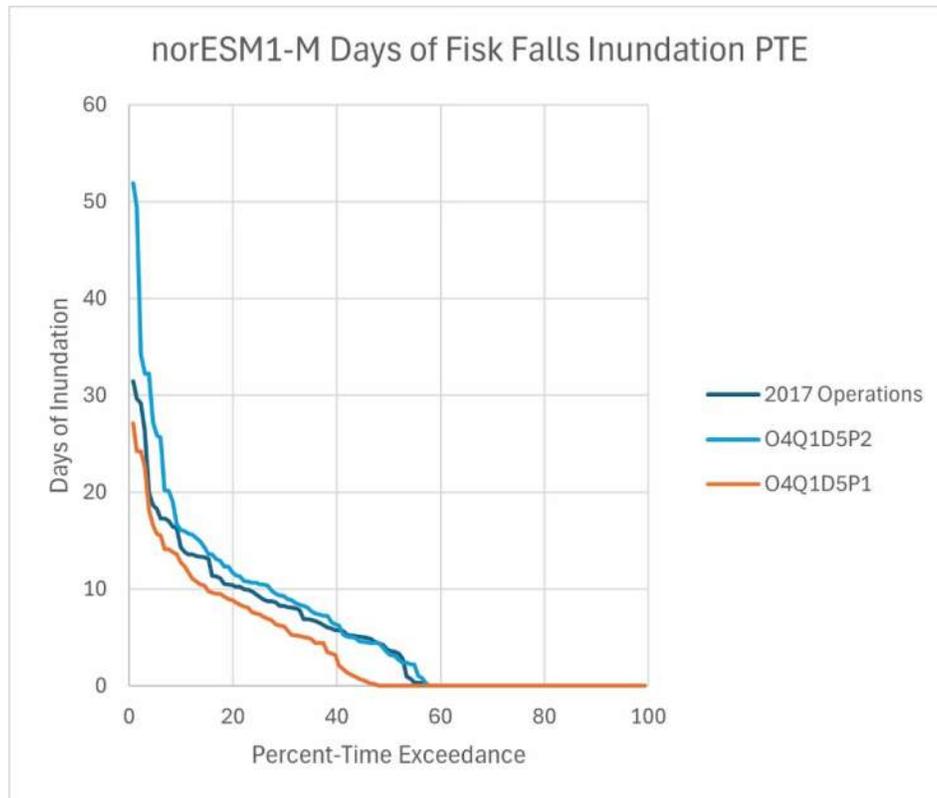
**Figure 3-10. MIROC5 Days of Fisk Falls Inundation PTE**



**Figure 3-11. MRI-CGCM3 Days of Fisk Falls Inundation PTE**



**Figure 3-12. norESM1-M Days of Fisk Falls Inundation PTE**



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## Attachment 3 – Inundation Technical Memorandum

# TECHNICAL MEMORANDUM

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**Date:** February 2, 2026  
**To:** Kathy Burnaham, Chehalis River Basin Flood Control Zone District  
**From:** MaryLouise Keefe, PhD, Jason Romine Ph.D., and Kai Steimle Kleinschmidt Associates  
**Cc:** Jason Kent, PE, PMP, Kleinschmidt Associates  
**Re:** Inundation Analysis with 2024 Project Design and 2025 (O4P2) Operational Scenario

## Introduction

The Chehalis River Basin Flood Control Zone District (District) is proposing to construct a Flood Retention Expandable (FRE) facility to reduce the risk of flood damage along the mainstem Chehalis River. The primary purpose of the FRE facility is to reduce flooding coming from the Willapa Hills by storing floodwaters in the temporary pool during major or greater floods. Thus, the FRE facility will include a temporary pool that is only inundated during infrequent flood operations.

State and Federal environmental reviews of the FRE facility (Ecology 2020, 2025; Corps 2020) have determined that by temporarily storing peak flows during major flood events, operating the FRE facility would inundate fish redds and riparian vegetation, resulting in the mortality of both. For redds, the 2025 Draft Environmental Impact Statements (DEISs) assumed that 100 percent redd mortality would occur within the temporary pool. The DEISs also assumed a loss of trees that would result in a loss of riparian shade and, in turn, was hypothesized to negatively impact water temperatures. The water temperature impact was predicted based on results from a water quality model that was updated in 2025 (PSU 2025) based on the 2024 Chehalis River Basin Flood Damage Reduction Project (Project) design. The DEIS predicted water temperature impacts of up to 1.5 °C immediately downstream of the FRE facility and 0.3 °C or greater downstream to approximately river mile (RM) 94.9 (downstream of Dryad, Washington).

In 2024, the FRE facility was relocated to avoid cultural impacts, which resulted in design revisions. A refined 2024 Project design incorporated two changes relevant to inundation. First, the FRE was moved upstream to approximately RM 108.7, thereby eliminating inundation impacts in the approximate 0.25-mile reach between the 2017 and 2024 FRE locations. Second, under a 2025 Project operations model (O4P2), operations would result in both inundation of a slightly smaller temporary pool and a reduced duration of inundation. This technical memorandum describes the analyses done by Kleinschmidt Associates (Kleinschmidt) to evaluate how changes in the FRE location and operation will affect redd and tree mortality within the temporary pool as summarized in the main body of this document.

## Methods

### Inundation

As described in the main body of this technical memorandum, the 2025 (O4P2) operations modeled nine different flood events that would trigger operation of the FRE facility based on historic flows (Table 1). Data on depth and duration of the temporary pool that formed during several of these events were used in this inundation analysis. In evaluating the potential effects of temporary inundation on redds, data from flood events representing a catastrophic flood (1996) and major floods (2019 and 2022) were used. For vegetation, to be consistent with a previous vegetation analysis completed for the District’s Revised Mitigation Plan (Kleinschmidt 2024), the representative catastrophic flood event used was based on hydrology from 2007 and the major flood was based on 2015. Both analyses used hourly depth data modeled by HDR under the O4P2 operations model. Hourly data were then filtered for FRE operational events listed above and identified by year (Table 1).<sup>1</sup>

**Table 1**

**FRE operations by flood event and year with start and stop times for the O4P2 operational scenario.**

OPERATIONAL EVENT	START TIME	END TIME	YEAR
1	1990-01-07 11:00	1990-01-23 17:00	1990
2	1996-02-06 10:00	1996-02-25 22:00	1996
3	2006-11-05 11:00	2006-11-23 14:00	2006
4	2007-12-02 04:00	2007-12-21 15:00	2007
5	2009-01-05 15:00	2009-01-24 14:00	2009
6	2015-01-05 00:00	2015-01-18 13:00	2015
7	2017-02-09 02:00	2017-02-23 17:00	2017
8	2019-12-20 01:00	2020-01-04 08:00	2019
9	2022-01-05 20:00	2022-01-26 10:00	2022

The hourly depth data from HDR demonstrated how the 2025 and 2017 operations, respectively, would fill and drain the temporary inundation pool in a flood event comparable to the catastrophic 1996 flood. In general, both operations sets begin filling the temporary inundation pool when major or catastrophic flooding is forecasted; eventually, each fills the pool to a maximum extent and then begins to drain. The portion of the pool that drains first is labeled the “Initial Evacuation Zone.” Each operation set then slows drainage of the pool while debris is collected; the area inundated during this time is called the “Debris Management Zone.” Drainage resumes until the pool is completely evacuated. The extent of the

<sup>1</sup> Historically, the Grand Mound gage did not reach 38,800 cubic feet per second (cfs) in either 2015 or 2019, and so flood operations would not have been triggered. The HDR hydrology overestimates flows somewhat, however, making these modeled floods exceed that threshold. The overestimate in 2015 was slight; Grand Mound reached 37,700 cfs that year. The 2019 overestimate was more pronounced, but the redd analysis using that flood also considers 1996 and 2022, both of which exceeded the 38,800 cfs trigger at Grand Mound historically. In the context of this analysis, the 2015 and 2019 modeled floods are suitable candidates for the types of major floods in which flood operations may occur in the future, and so can inform the analysis.

pool during this time is called the “Final Evacuation Zone.” For both operations sets, the Initial Evacuation Zone is inundated for the least time and the Final Evacuation Zone is inundated for the most time. For a flood comparable to 1996, the 2025 operations set does not inundate quite as much area as the 2017 operations set, so there is a portion of the 2017 Initial Evacuation Zone that the 2025 operations set does not inundate. Moreover, the 2025 operations set drains faster than the 2017 operations set, and so the sizes of the Initial Evacuation, Debris Management, and Final Evacuation zones are not the same.

## Redds

Data from annual redd surveys conducted by Washington Department of Fish and Wildlife (WDFW) in the middle and upper Chehalis Basin was obtained from WDFW. Data reviewed for this analysis included data from surveys conducted for spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*) upstream of the proposed FRE site from 2013 through 2020. In the 2017 and 2018 survey seasons, redd surveys were also conducted downstream of the FRE facility (Ronne et al. 2020). Given the new upstream location of the FRE facility, a small number of redds that were classified as being upstream of the FRE during those survey years are now downstream of the FRE under the refined alignment.

WDFW redd data consisted of species and locations (latitude and longitude) for individual redds from 2014 through 2020. Data were imported to R (R Core Team 2025) and spatially filtered to remove redds with incorrect location information (n=3). A digital elevation model was developed in ArcPro (ESRI) from available light detection and ranging data. The digital elevation model was brought into R and was used to interpolate redd elevation using the extract function in the terra package. All analyses were conducted in the North American Vertical Datum of 1988 (NAVD 88).

For the purposes of this analysis, the Chehalis River from the confluence with the Newaukum River upstream to the forks was divided into seven different river zones (Table 2). Based on their elevation, each redd was classified into one of the river zones. The extent of these zones differed between the 2025 and 2017 operations. The change in FRE facility location (upstream and at a higher elevation) combined with operational changes in debris management resulted in shifts to the upper extent of the Rainbow Falls to FRE zone and changes to the size and extent of the evacuation zones within the inundation pool (Table 2). Two of the more notable changes were a decrease in the extent of the Debris Management Zone, an increase in the Initial Evacuation Zone, and a lower extent of the maximum inundation pool for the modeled 1996 flood event.

**Table 2**

**Analyses zones for redd inundation and elevation range of each zone for 1996 modeled flood under 2017 and 2025 (O4P2) operations.**

RIVER ZONE	ELEVATION BAND IN FEET (NAVD 88)		
	2025 (O4P2) OPERATIONS	2017 OPERATIONS	RELATIVE LOCATION
Newaukum River to Rainbow Falls	<265	<265	Downstream of FRE
Rainbow Falls to FRE	265 – 447	265 – 425	Downstream of FRE
Final Evacuation <sup>1</sup>	447 – 477	425 – 500	Within Max Inundation Pool
Debris Management <sup>1</sup>	477 – 487	500 – 528	Within Max Inundation Pool
Initial Evacuation – 2025 Operations <sup>1</sup>	487 – 587	528 – 587	Within Max Inundation Pool
Initial Evacuation – 2017 Operations	587 – 627	587 – 627	Upstream of Max Pool
Mainstem and Tributaries Upstream	>627	>627	Upstream of Max Pool

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

After redds were assigned elevations, the FRE operational data were analyzed to calculate the depth and duration of redd inundation for three flood scenarios (1996, 2019, 2022; catastrophic flood, minor flood, median flood, respectively). Based on known depths of fall-run Chinook salmon redds in the Columbia River and the presumed presence of water flow over the substrate associates with infilling and outflow, Kleinschmidt assumed that redds that experienced a depth of 30 feet or more for three consecutive days would suffer complete mortality. This level of mortality is likely overestimated, as the nature of flows at depth within the temporary pool are unknown at this time, but it provides a basis to understand how variability in floods and refined Project operations could impact redds in the temporary inundation area. Given these criteria, Kleinschmidt assigned a nonviable or viable condition to each redd for each FRE scenario for all species. For consistency and comparison purposes Kleinschmidt used 2017 and 2018 redd survey data to examine the “population” level impact of the FRE to compare impacts to salmon redds upstream of Newaukum.

Run year classification for Chinook salmon (spring- and fall-run) and coho salmon differed from the run year classification for steelhead in WDFW data. Chinook salmon arriving and spawning in fall of 2018 were classified as run year 2018, whereas steelhead spawning in December 2018 were classified as run year 2019. To maintain consistency across species for impacts, run year for steelhead was aligned with Chinook arriving in the same season (September – April). For example, steelhead spawning in the spring of 2019, were re-classified as run year 2018 for analysis purposes.

To identify any potential changes to FRE-related impacts, Kleinschmidt also examined the conditions created by the first proposed 2017 alignment and operations as compared to the refined 2024 alignment and 2025 (O4P2) operations. Redds observed in 2018 were used in these comparisons.

## **Vegetation**

Analysis of riparian vegetation mortality due to temporary inundation was based on survival estimates included in the Vegetation Management Plan (Appendix D of the 2024 Revised Mitigation Plan, Kleinschmidt 2024). Vegetation inundated for more than a week was not expected to survive, based on observations at Mud Mountain Dam. Vegetation survival was predicted to be selective when inundation duration was less than 7 days. Because the tree species that are tolerant of inundation mature at shorter heights than evergreens, for example, that canopy height was reduced to 50 feet. Vegetation survival was assessed for both representative catastrophic flood (2007) and major flood (2015) events.

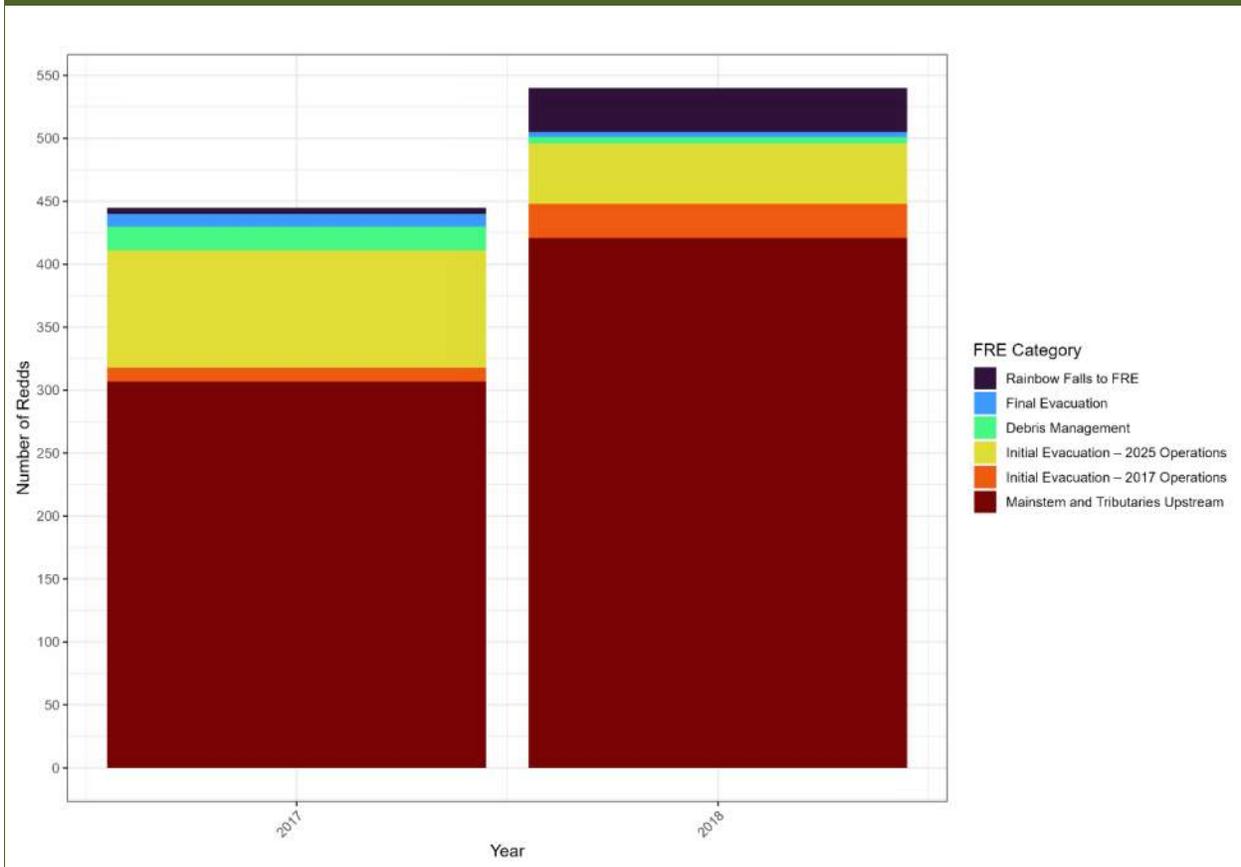
## **Results and Discussion**

### **Redd Distribution under 2025 (O4P2) Operations**

The numbers of observed redds within river zone classifications under 2025 operations are presented by species in Figures 1 through 4, Table 3 for coho salmon and steelhead, and Table 4 for spring- and fall-run Chinook salmon. Tables 3 and 4 also show the number of observed redds within river zone classifications under 2017 operations, as well as the differences between the 2025 and 2017 operations. During both survey years, the majority of coho salmon and steelhead redds were located upstream of the inundation zone. In contrast, the majority of spring-run Chinook and fall-run Chinook salmon redds were observed downstream of the FRE facility to the Newaukum. For all species, the proportion of the redds observed in FRE inundation zones, including the portion of the Initial Evacuation Zone that would not be inundated based on the 2025 operations set, was less than one-fourth of the total redd count. For spring-run Chinook salmon, the redd count within all FRE inundation zones was less than 3%.

Figure 1

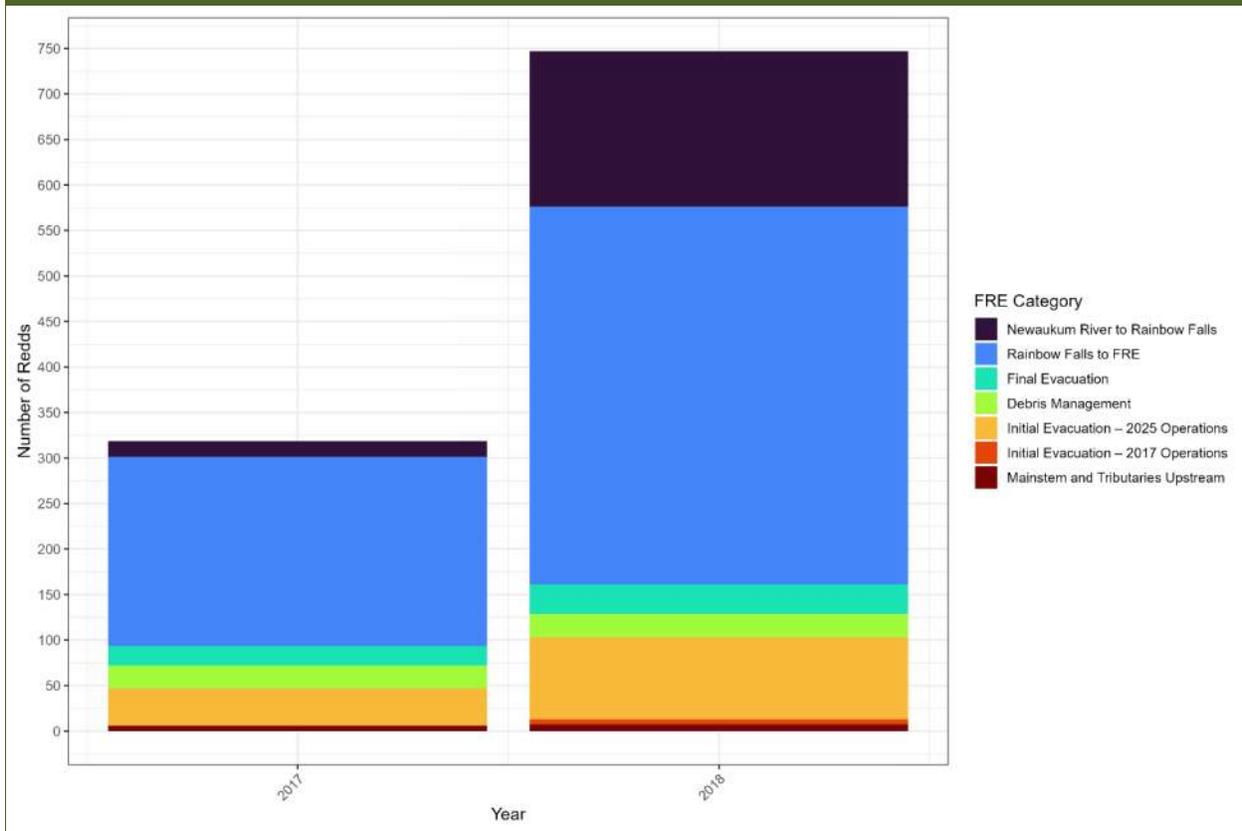
2017 and 2018 redd distribution for coho salmon in the mainstem Chehalis River upstream of the Newaukum<sup>1</sup> to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.



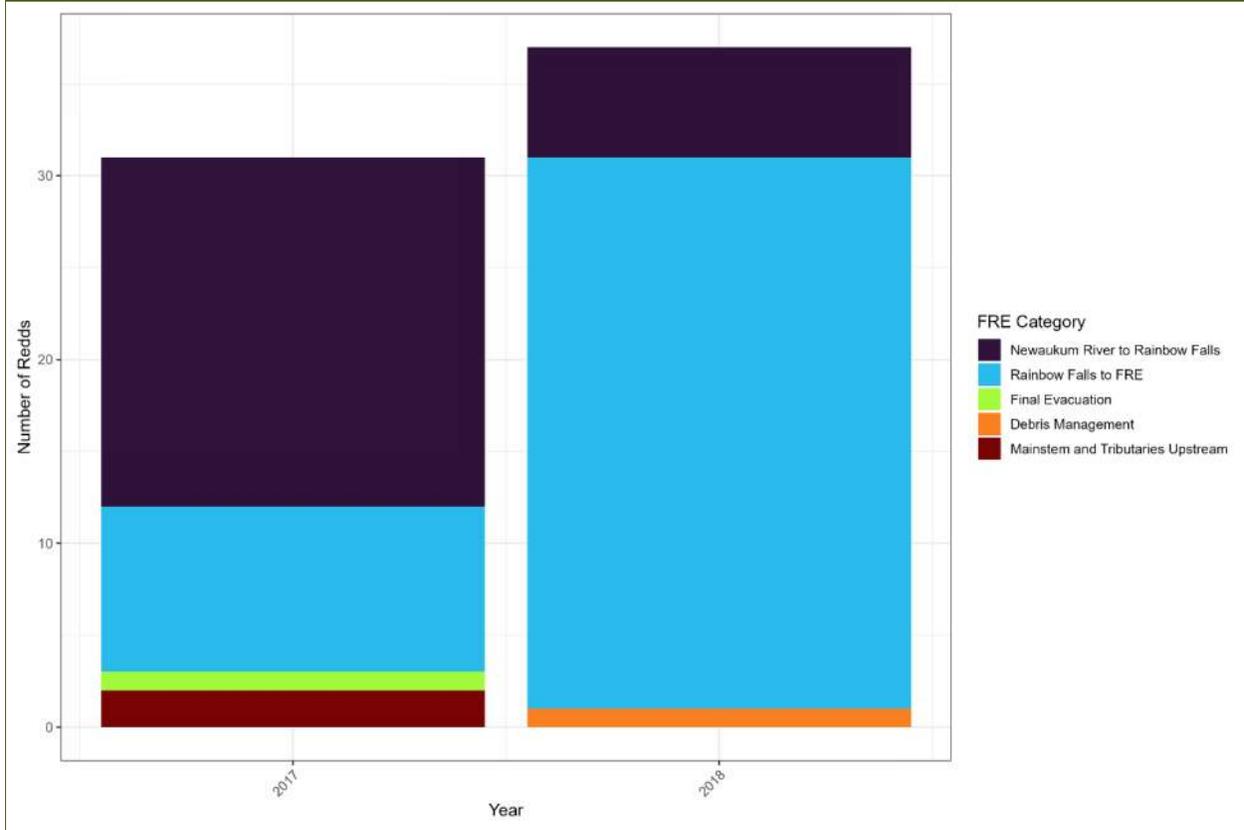
<sup>1</sup> Zero redds observed between the confluence of the Newaukum and Rainbow Falls.

Figure 2

2017 and 2018 redd distribution for fall-run Chinook salmon in the mainstem Chehalis River upstream of the Newaukum to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.

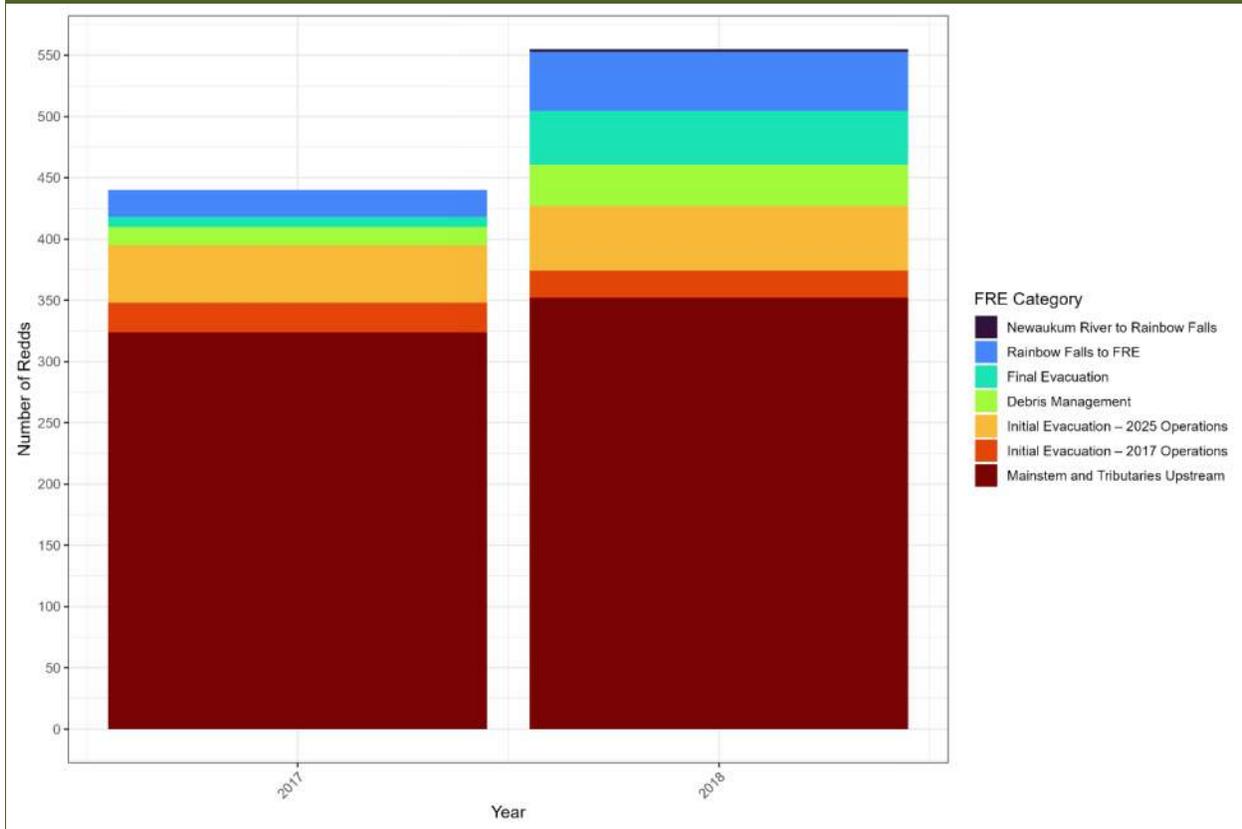


**Figure 3**  
2017 and 2018 redd distribution for spring-run Chinook salmon in the mainstem Chehalis River upstream of the Newaukum to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.



**Figure 4**

2017 and 2018 redd distribution for steelhead in the mainstem Chehalis River upstream of the Newaukum to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.



**Table 3**

Changes to coho salmon and steelhead redd distribution by species under 2017 operations and 2024 FRE design and 2025 (O4P2) operations.

RIVER ZONE	NUMBER OF REDDS OBSERVED IN 2018					
	COHO SALMON			STEELHEAD		
	O4P2	2017	DIFFERENCE	O4P2	2017	DIFFERENCE
Newaukum River to Rainbow Falls	0	0	0	2	2	0
Rainbow Falls to FRE	37	35	2	49	48	1
Final Evacuation <sup>1</sup>	1	4	-3	20	44	-24
Debris Management <sup>1</sup>	1	5	-4	16	34	-18
Initial Evacuation – 2025 Operations <sup>1</sup>	53	48	5	94	53	41
Initial Evacuation – 2017 Operations	27	27	0	22	22	0
Mainstem and Tributaries Upstream	421	421	0	352	352	0

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

**Table 4**

**Changes to spring- and fall-run Chinook salmon redd distribution under 2017 operations and 2024 FRE design and 2025 (O4P2) operations.**

RIVER ZONE	NUMBER OF REDDS OBSERVED IN 201					
	SPRING-RUN CHINOOK SALMON			FALL-RUN CHINOOK SALMON		
	O4P2	2017	DIFFERENCE	O4P2	2017	DIFFERENCE
Newaukum River to Rainbow Falls	6	6	0	171	171	0
Rainbow Falls to FRE	30	30	0	428	415	13
Final Evacuation <sup>1</sup>	0	0	0	12	32	-24
Debris Management <sup>1</sup>	0	1	-1	5	26	-21
Initial Evacuation – 2025 Operations <sup>1</sup>	1	0	1	118	90	28
Initial Evacuation – 2017 Operations	0	0	0	6	6	0
Mainstem and Tributaries Upstream	0	0	0	7	7	0

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

Because the FRE was moved upstream from the originally proposed location, the assignment of the redds to the river zones shifted between 2017 and 2025 operations, resulting in differences in numbers within each zone (Tables 3 and 4). While these numbers are small for some categories, there are notable differences. First, the increase in numbers in the Rainbow Falls to FRE zone shows that 16 redds (across three species) that previously would have been inundated under the 2017 operations would not be inundated under 2025 operations. In addition, even with a catastrophic flood event under 2025 operations, the upper extent of the temporary pool is predicted to be downstream of the 2017 operations Initial Evacuation Zone. Thus, it is highly unlikely that any of the redds within this zone would experience inundation under 2025 operations. Finally, the 2025 operations with faster drainage of the temporary inundation pool results in a reduction in the number of redds in the Debris Management and Final Evacuation zones; these redds are instead in the Initial Evacuation Zone, where the upper extent of the temporary inundation pool varies with flood level. This zone is where understanding the variability in the extent of the inundation pool will help to understand potential impacts.

Under 2017 operations, 78.5% of fall-run Chinook salmon redds were located downstream of the FRE facility and 21.5% were located upstream of the FRE facility (Table 6). Under 2025 (O4P2) operations, 80.2% of fall-run Chinook redds were located downstream of the FRE facility and 19.8% were located upstream of the FRE facility (Table 5). Distribution of coho salmon and steelhead redds between the two alignments did not vary much given that these species generally do not spawn in the mainstem, but in tributaries upstream of the inundation zone (Tables 5 and 6). For all species/runs the proportion of redds within the FRE zones that would be inundated by a catastrophic flood represents less than one fourth of the total redd count; for spring-run Chinook salmon, it is less than 3%.

**Table 5**

Percentage of total 2018 redds by FRE zone and species under the 2025 (O4P2) operations.

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	0.0%	22.9%	16.2%	0.4%
Rainbow Falls to FRE	6.9%	57.3%	81.1%	8.8%
Final Evacuation <sup>1</sup>	0.2%	1.6%	0.0%	3.6%
Debris Management <sup>1</sup>	0.2%	0.7%	0.0%	2.9%
Initial Evacuation – 2025 Operations <sup>1</sup>	9.8%	15.8%	2.7%	16.9%
Initial Evacuation – 2017 Operations	5.0%	0.8%	0.0%	4.0%
Mainstem and Tributaries Upstream	78.0%	0.9%	0.0%	63.4%

**Table 6**

Percentage of total 2018 redds by FRE zone and species under the 2017 (O4P2) operations.

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	0.0%	22.9%	16.2%	0.4%
Rainbow Falls to FRE	6.5%	55.6%	81.1%	8.6%
Final Evacuation <sup>1</sup>	0.7%	4.3%	0.0%	7.9%
Debris Management <sup>1</sup>	0.9%	3.5%	2.7%	6.1%
Initial Evacuation – 2025 Operations <sup>1</sup>	8.9%	12.0%	0.0%	9.5%
Initial Evacuation – 2017 Operations	5.0%	0.8%	0.0%	4.0%
Mainstem and Tributaries Upstream	78.0%	0.9%	0.0%	63.4%

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

### **Redd Viability Across All Modeled Flood Events**

Under both alignments, the percentage of redds predicted to be nonviable (inundated at a depth greater than 30 feet and for longer than 3 days) within the maximum pool varied across operational scenarios and across river zones within the pool. By zone, both the broadest range and the largest estimated percent of redds that may suffer inundation mortality occurred in the Initial Evacuation 2017 Operations Zone (Tables 7 and 8). In general, there was no variation in inundation impact to redds across operational years for the Final Evacuation Zone and the Debris Management Zone.

**Table 7**

**Estimated impacts to 2018 redds by species from 2025 (O4P2) operations across all operational years. Percentages represent percent of total observed redds. Number in parentheses represent the total number of redds observed in 2018 for that run or species.**

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	No Risk	No Risk	No Risk	No Risk
Rainbow Falls to FRE	No Risk	No Risk	No Risk	No Risk
Final Evacuation <sup>1</sup>	0.2-0.2%	1.6-1.6%	0.0-0.0%	0.9-0.9%
Debris Management <sup>1</sup>	0.2-0.2%	0.7-0.7%	0.0-0.0%	0.5-0.5%
Initial Evacuation – 2025 Operations <sup>1</sup>	0.0-1.5%	0.0-5.5%	0.0-2.7%	0.0-6.6%
Initial Evacuation – 2017 Operations	0.0-0.0%	0.0-0.0%	0.0-0.0%	0.0-0.0%
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

**Table 8**

**Range of estimated impacts to 2018 redds by species from 2017 operations across all operational years. Percentages represent minimum and maximum percent of total observed redds. Number in parentheses represent the total number of redds observed in 2018 for that run or species.**

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	No Risk	No Risk	No Risk	No Risk
Rainbow Falls to FRE	No Risk	No Risk	No Risk	No Risk
Final Evacuation <sup>1</sup>	0.4-0.4%	2.5-2.5%	0.0-0.0%	1.6-1.6%
Debris Management <sup>1</sup>	0.0-0.9%	0.1-3.5%	0.0-2.7%	0.2-3.4%
Initial Evacuation – 2025 Operations <sup>1</sup>	0.0-1.3%	0.0-5.6%	0.0-0.0%	0.0-4.3%
Initial Evacuation – 2017 Operations	0.0-0.0%	0.0-0.0%	0.0-0.0%	0.0-0.0%
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

### ***Redd Viability with a Catastrophic Flood Event***

During a catastrophic flood event (e.g., 1996) under 2017 operations, Kleinschmidt estimated that 11.6% of 2018 fall-run Chinook salmon redds would not be viable if the inundation event occurred prior to emergence. This percentage was reduced under 2025 operations to 7.8% (Table 9). The percentage of nonviable redds would also be reduced from 2.9% to 1.9% for coho salmon and from 9.3% to 7.8% for steelhead (Table 9). However, HDR’s modeling of future floods across a 56-year period of record predicted that FRE facility operation would occur, on average, less than 1 day in March and less than 4 hours in April. Thus, it would be expected that the vast majority of Project operations would occur prior

to steelhead spawning in the upper basin and inundation of steelhead redds would likely be closer to 0%.

**Table 9**  
**Catastrophic flood event (e.g., 1996) impacts to 2018 redds under 2025 (O4P2) operations. Percentages represent percent of total observed redds.**

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	No Risk	No Risk	No Risk	No Risk
Rainbow Falls to FRE	No Risk	No Risk	No Risk	No Risk
Final Evacuation <sup>1</sup>	0.2%	1.6%	0.0%	0.9%
Debris Management <sup>1</sup>	0.2%	0.7%	0.0%	0.5%
Initial Evacuation – 2025 Operations <sup>1</sup>	1.5%	5.5%	2.7%	6.4%
Initial Evacuation – 2017 Operations	0.0-0.0%	0.0-0.0%	0.0-0.0%	0.0-0.0%
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

### **Redd Viability with a Major Flood Event<sup>2</sup>**

Under 2025 (O4P2) operations the redd viability impact from the two major floods analyzed was much less than estimated for the catastrophic flood. The percentage of nonviable redds from a flood operation similar to 2019 was estimated at 3.2% of fall-run Chinook salmon, 0.4% of coho salmon, and 1.9% of steelhead (Table 10). Zero spring-run Chinook salmon redds were estimated to be nonviable. Operation during a flood similar to 2022 was estimated to result in 6% of fall-run Chinook salmon redds, 1.3% of coho salmon redds, 2.7% of spring-run Chinook salmon redds, and 5% of steelhead redds becoming nonviable (Table 11). Once again, the steelhead estimate is likely further reduced by the very small likelihood of FRE operation after the onset of steelhead spawning.

The differences in redd inundation presented are a function of differences in the maximum extent and depths of the temporary pool between the 1996 catastrophic and major floods (2019 or 2022) events. Figures 6 through 21 provided at the end of this technical memorandum depict how changes in area of the maximum temporary pool and the nonviable redd area would change under the Maximum, Median, and Minimum modeled flood levels, and provide a visualization of variation in redd inundation given the viability criteria developed for this analysis. For coho salmon, fall-run Chinook salmon, and steelhead, these map figures are presented in the same sequence beginning with the 2018 redd distribution followed by redds under the Maximum, Median, and Minimum modeled flood events. Only a 2018 redd

<sup>2</sup> This section discusses results only under 2025 (O4P2) operations, rather than comparing 2025 operations to 2017 operations, because the 2017 operations do not address specific flood years; they instead address floods at different recurrence intervals. A direct comparison of the two sets is possible only for the catastrophic flood, since the 1996 flood was almost exactly equal to a 100-year recurrence flood under current conditions.

distribution map was included for spring-run Chinook salmon as only one redd was observed upstream of Crim Creek in 2018.

**Table 10**

**Impacts to redds with major, 2019-type, flood under 2025 (O4P2) operations. Percentages represent percent of total observed redds.**

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	No Risk	No Risk	No Risk	No Risk
Rainbow Falls to FRE	No Risk	No Risk	No Risk	No Risk
Final Evacuation <sup>1</sup>	0.2%	1.6%	0.0%	0.9%
Debris Management <sup>1</sup>	0.2%	0.7%	0.0%	0.5%
Initial Evacuation – 2025 Operations <sup>1</sup>	0.0%	0.9%	0.0%	0.5%
Initial Evacuation – 2017 Operations	0.0-0.0%	0.0-0.0%	0.0-0.0%	0.0-0.0%
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

**Table 11**

**Impacts to redds with a major, 2022 type, flood, under 2025 (O4P2) operations. Percentages represent percent of total observed redds.**

RIVER ZONE	COHO SALMON (N = 540)	FALL-RUN CHINOOK SALMON (N = 747)	SPRING-RUN CHINOOK SALMON (N = 37)	STEELHEAD (N = 440)
Newaukum River to Rainbow Falls	No Risk	No Risk	No Risk	No Risk
Rainbow Falls to FRE	No Risk	No Risk	No Risk	No Risk
Final Evacuation <sup>1</sup>	0.2%	1.6%	0.0%	0.9%
Debris Management <sup>1</sup>	0.2%	0.7%	0.0%	0.5%
Initial Evacuation – 2025 Operations <sup>1</sup>	0.9%	3.7%	2.7%	3.6%
Initial Evacuation – 2017 Operations	0.0-0.0%	0.0-0.0%	0.0-0.0%	0.0-0.0%
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

<sup>1</sup> The 2025 and 2017 operations sets have different elevation bands for these three rows because the pool evacuates at different speeds under the two operations sets. The 2025 operations evacuate to a lower elevation faster.

## Vegetation

Under the 2017 operational scenario, vegetation impacts were modeled for a catastrophic flood condition similar to the 2007 flood event. This flood event would have inundated 3.9 RMs for longer than 7 days, causing riparian vegetation mortality (Table 12). During a major flood event similar to 2015, inundation longer than 7 days would have occurred over 2.8 RMs. The 2024 Project design and 2025 (O4P2) operations model have reduced the extent of this inundation. Under the 2025 operations, a catastrophic flood (2007) would inundate 3.5 RMs for longer than 7 days, a reduction of 0.4 RMs. During

a major flood (2015), inundation longer than 7 days would be limited to 1.8 miles (Table 12, Figure 5), a reduction of 1.0 RM. These results indicate an additional 0.4 to 2.1 miles of riparian forest that will remain viable, producing shade and exhibiting additional growth as compared to the 2017 design and operations. The riparian forest range exceeds the RM range because the trees grow on both sides of the pool (Figure 5).

**Table 12**  
**Extent of the vegetation mortality under 2007- and 2015-type flood event under 2025 (O4P2) and 2017 operations.**

OPERATIONS MODEL	YEAR	CHANCE OF BEING FLOODED IN A YEAR (%)	MIN DURATION OF INUNDATION AT UPSTREAM EXTENT (DAYS)	WATER SURFACE ELEVATION (FEET)	AREA (ACRES)	RIVER LENGTH (MILES)
2017	NA <sup>1</sup>	10	7 days	521	218.1	2.8
	2007	<1	7 days	543	336.5	3.9
O4P2	2015	10	7 days	487	85.3	1.8
	2007	<1	7 days	532	275.7	3.5

<sup>1</sup>The 2017 operations modeled the 10-year flood, based on recurrence interval, not a flood event associated with a specific year; however, the 2007 was identified as a catastrophic flood.

This increased tree viability and the associated reduction of potential loss of shade have important implications for evaluating the shade-related temperature impacts of the refined Project design and operations. The result of this analysis were used to estimate changes to canopy height along the affected reaches of the inundation pool. These data were input into a water temperature model of the refined project that is presented as a separate attachment to the main body of this document. Beyond these temperature effects, the additional acreage that remains viable under 2025 (O4P2) operations will reduce wildlife habitat impacts due to vegetation mortality and reduce erosion and landslide potential.

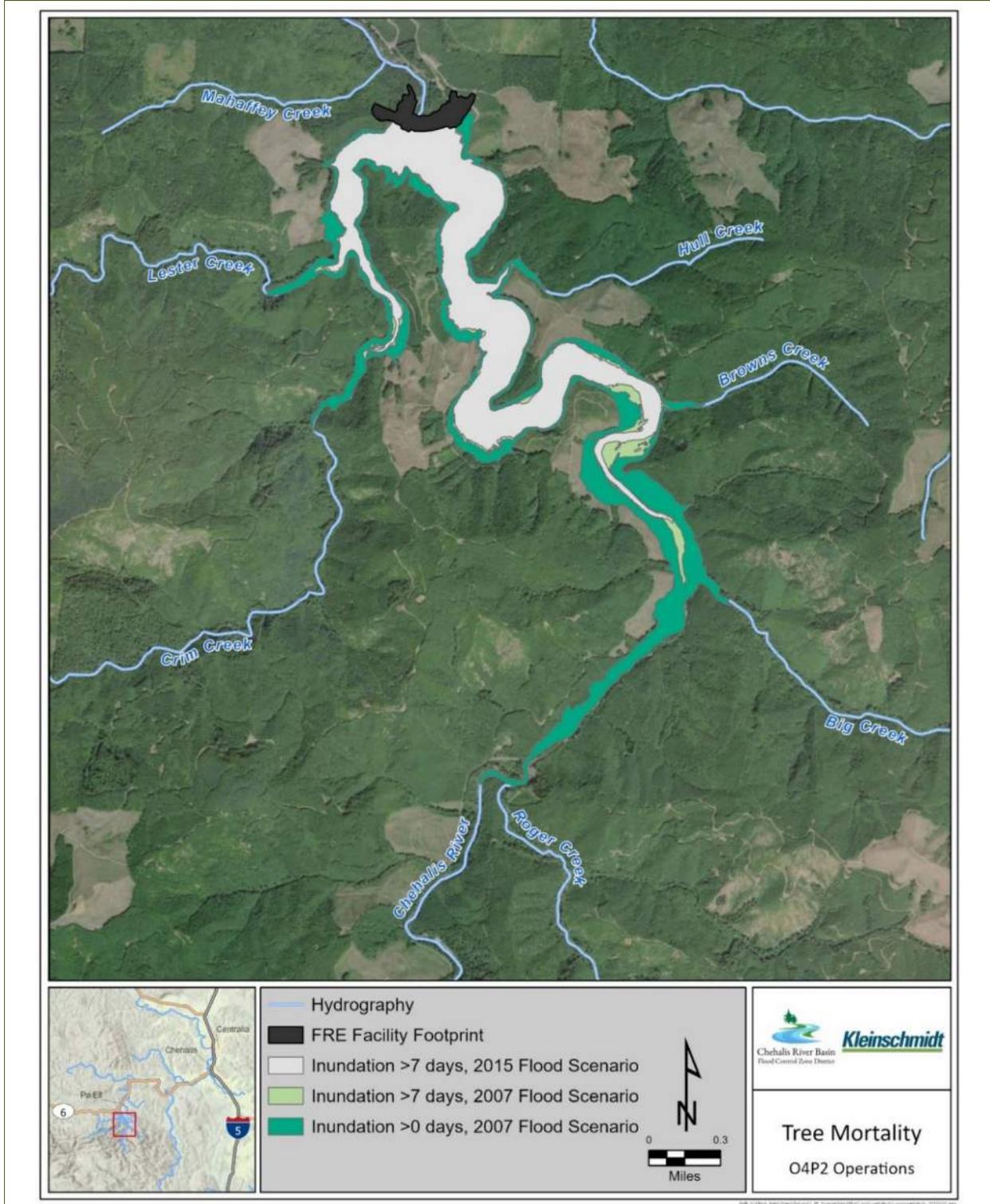
## Conclusion

HDR produced a 2025 (O4P2) operations rule set that would inundate less area than the original 2017 operations and would drain the temporary inundation pool faster. This operational refinement reduces impacts to redds and minimizes vegetation mortality, thus reducing shade impacts.

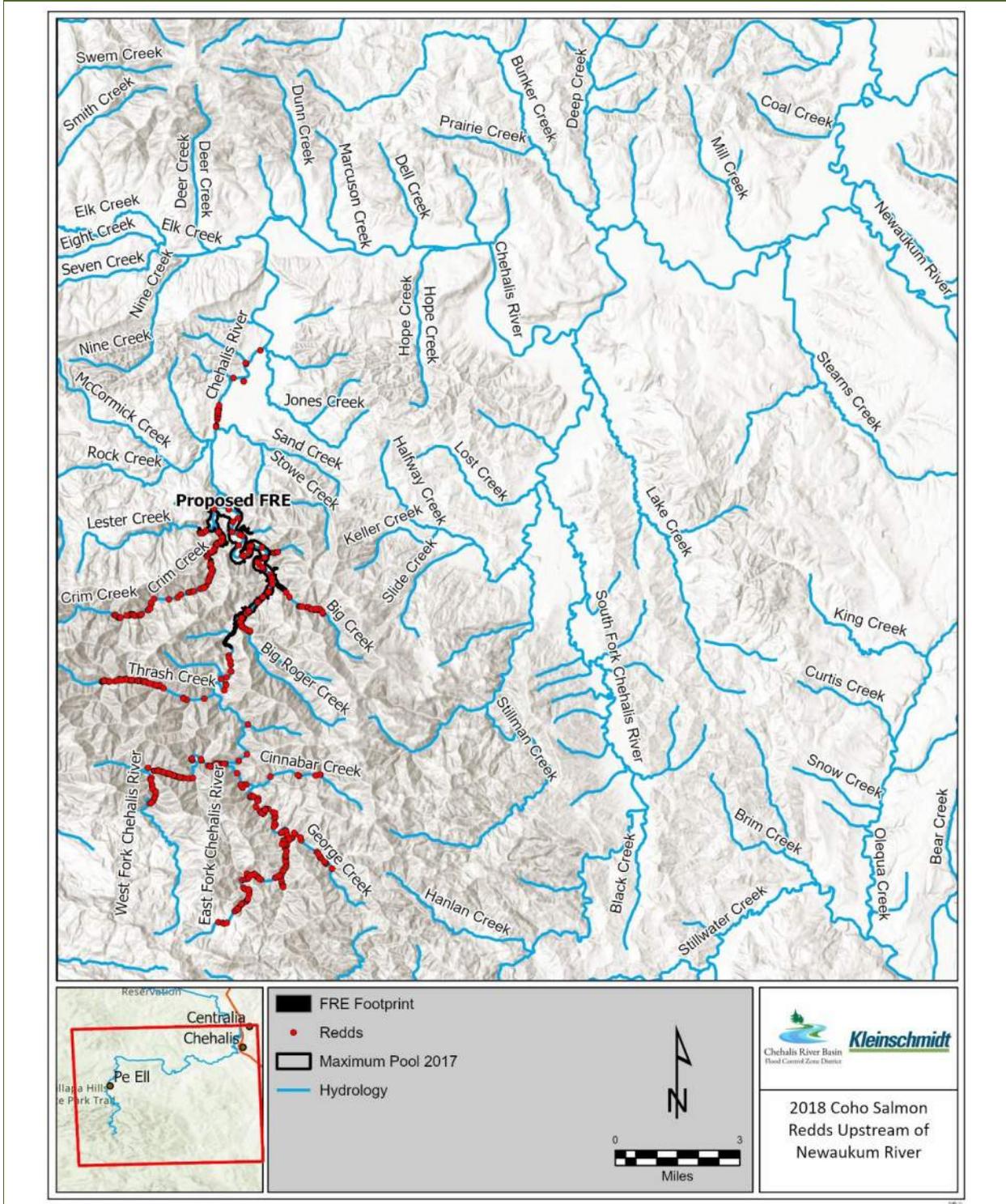
When the most comprehensive redd survey data available (2018) was analyzed with respect to 2025 operations, it was evident that less than a quarter of each species' redds was located within the temporary inundation pool. The 2025 operations improved upon the 2017 operations in two ways. First, the 2025 operations would not inundate a portion of the redds that would have been inundated under 2017 operations. Second, for those redds that would still be inundated, more would be in the Initial Evacuation Zone that drains faster, making those redds less likely to be inundated at harmful levels.

The reduction in inundation area and duration would also reduce vegetation mortality. The area inundated for longer than 7 days was reduced by 0.4 RMs in a catastrophic flood (about 10%) and about 1.0 RM in a major flood (about 64%). This corresponds to between 0.4 and 2.1 miles of riparian forest that will remain viable, which under 2017 operations would not have survived. This increased tree viability will result in a taller canopy and increased shade, the temperature effects of which are modeled in a separate accompanying technical memorandum, and will reduce wildlife habitat impacts and erosion and landslide risk.

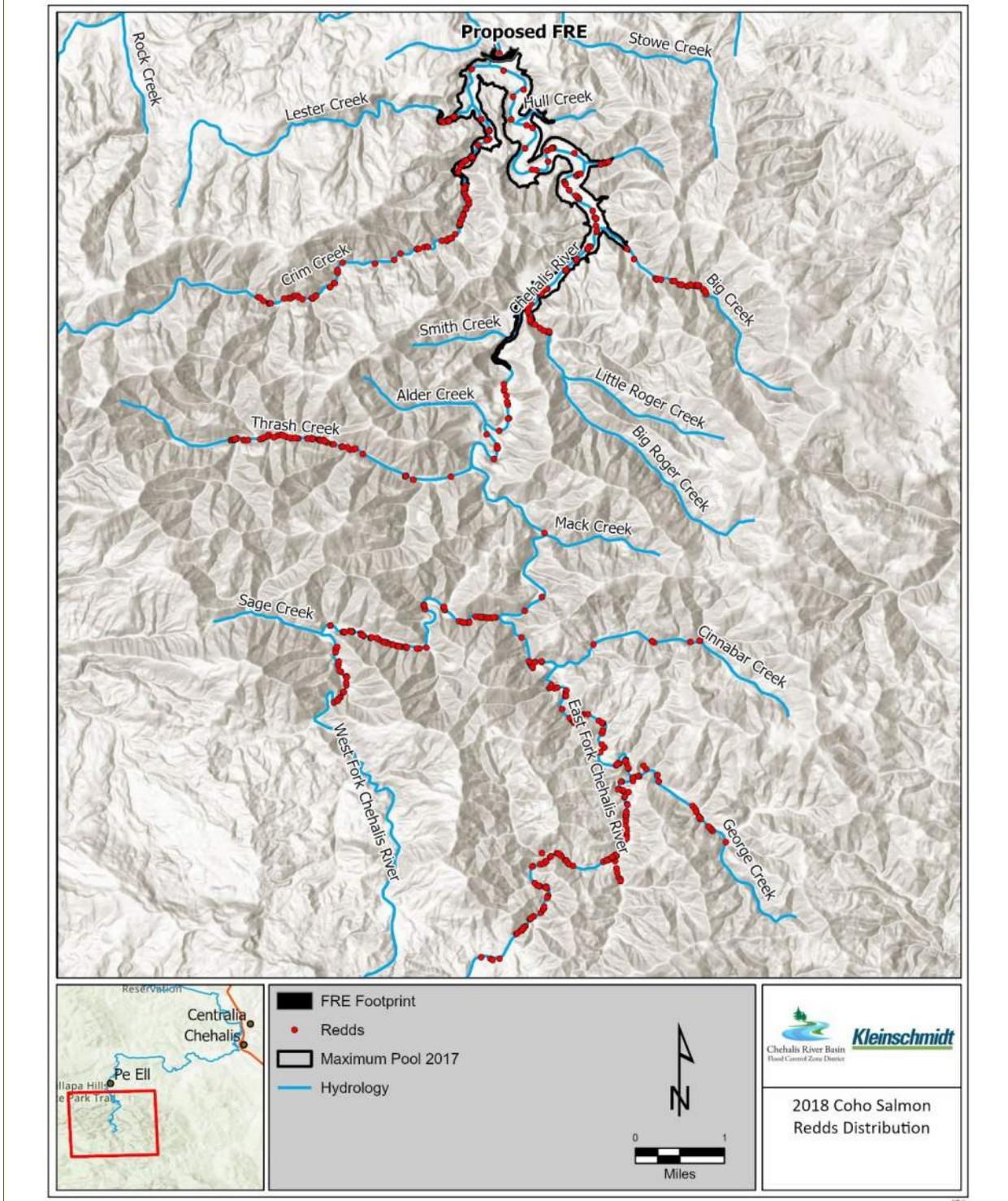
Figure 5  
Extent of inundation upstream of the FRE under 2025 (O4P2) operations.



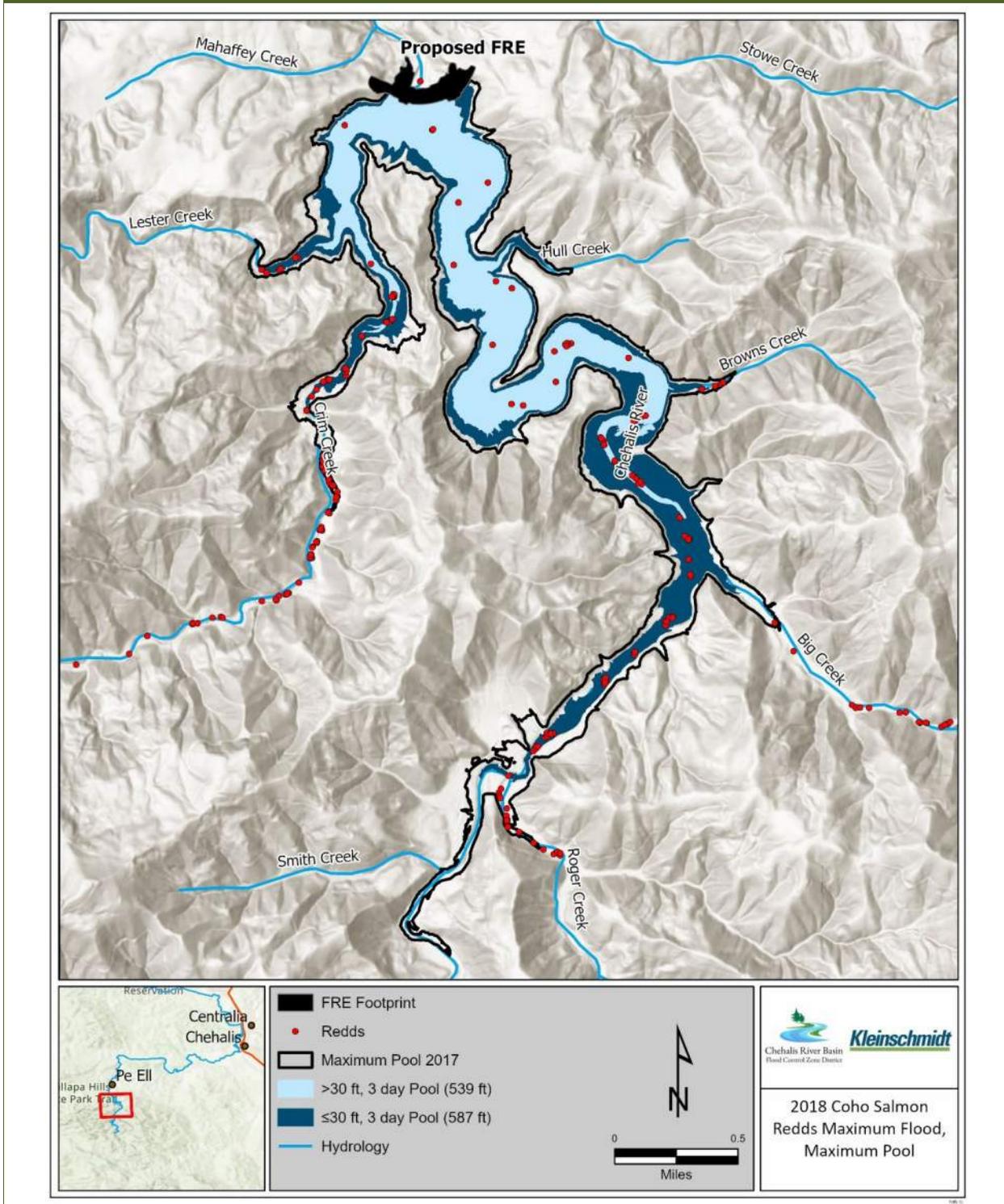
**Figure 6**  
Distribution of 2018 coho salmon redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.



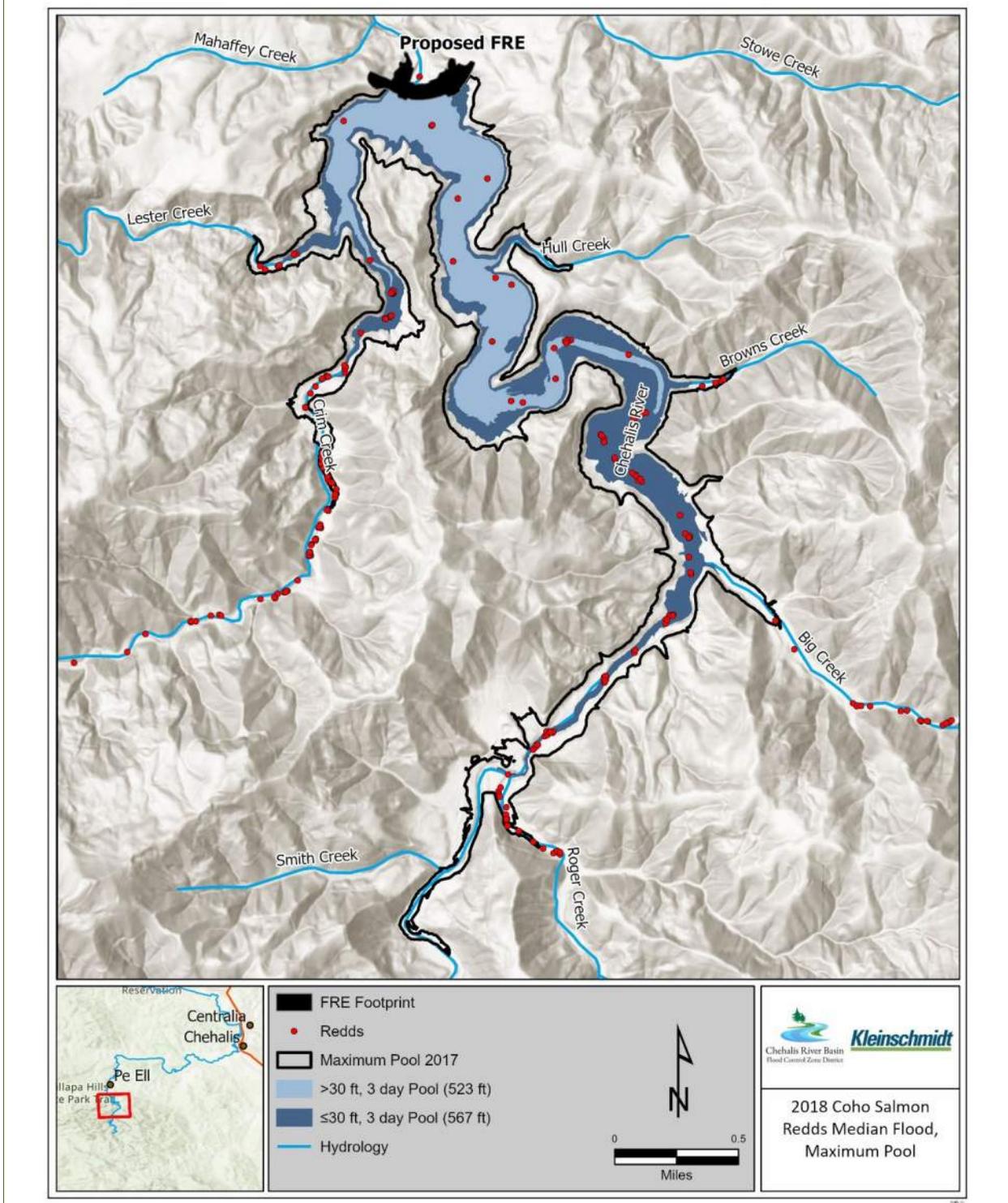
**Figure 7**  
2018 coho salmon redd distribution upstream and immediately downstream of the FRE facility location.



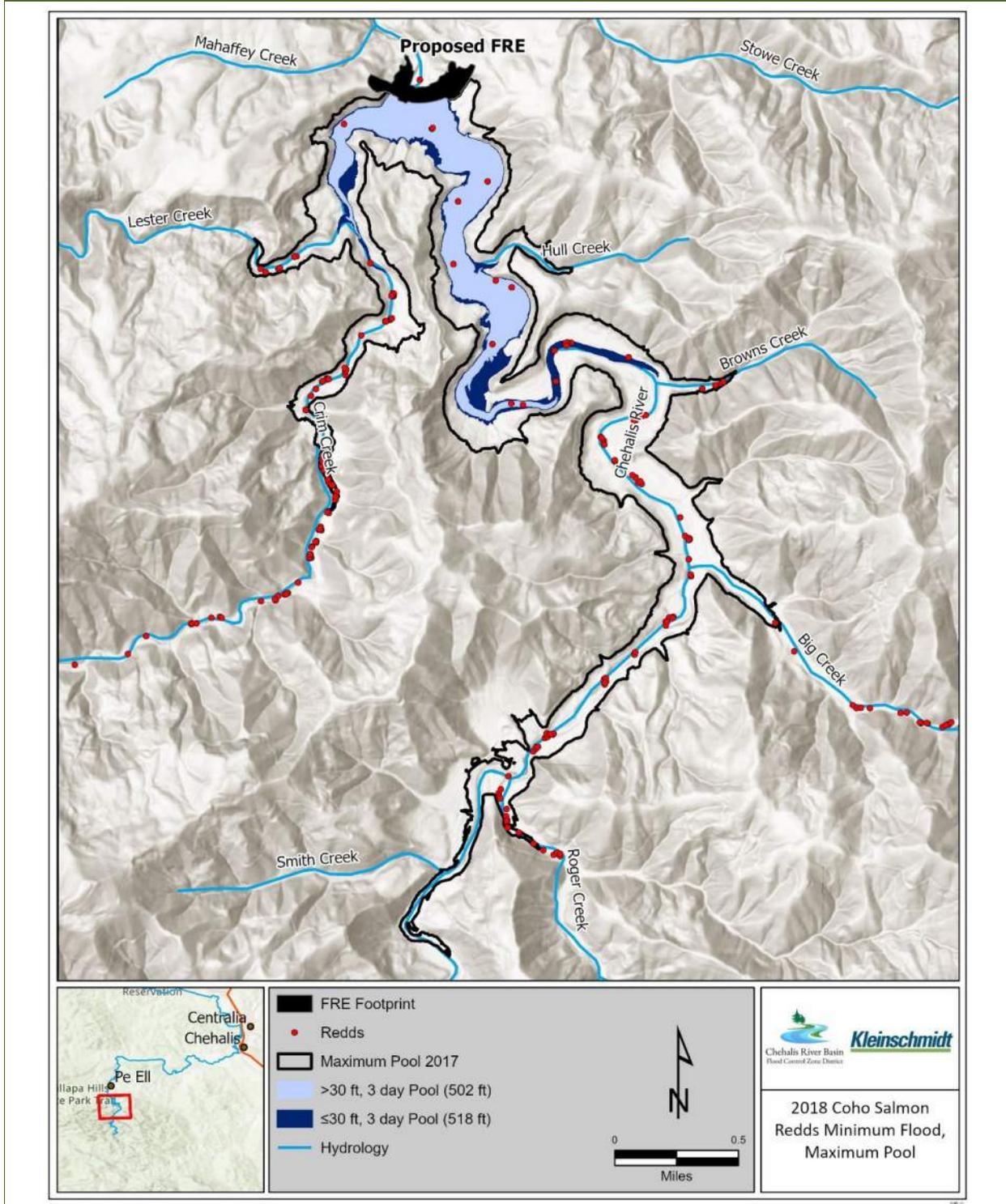
**Figure 8**  
2018 coho salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.



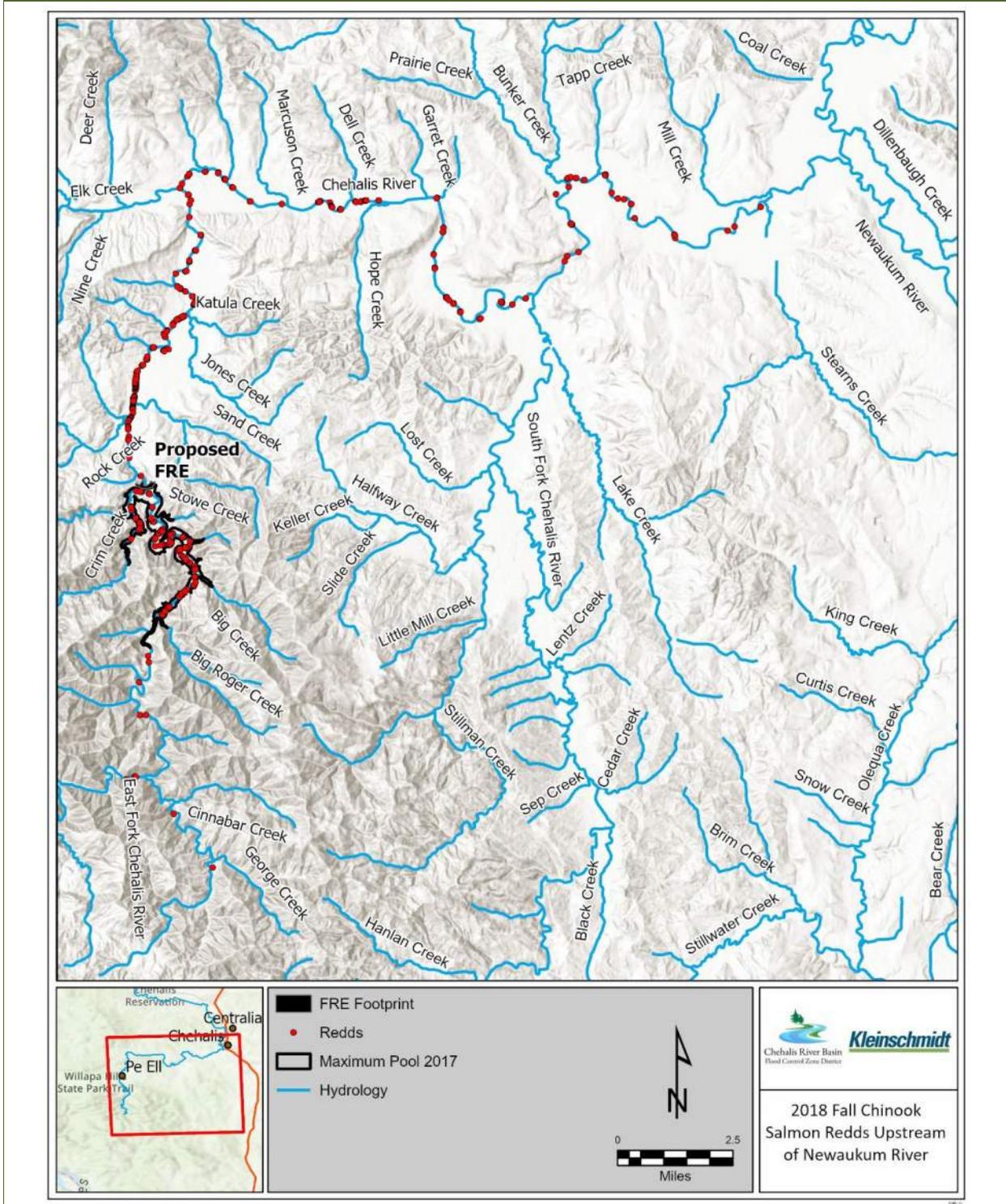
**Figure 9**  
2018 coho salmon redds across portions of the temporary less than or greater than 30 feet deep for 3 days with a median flood event.



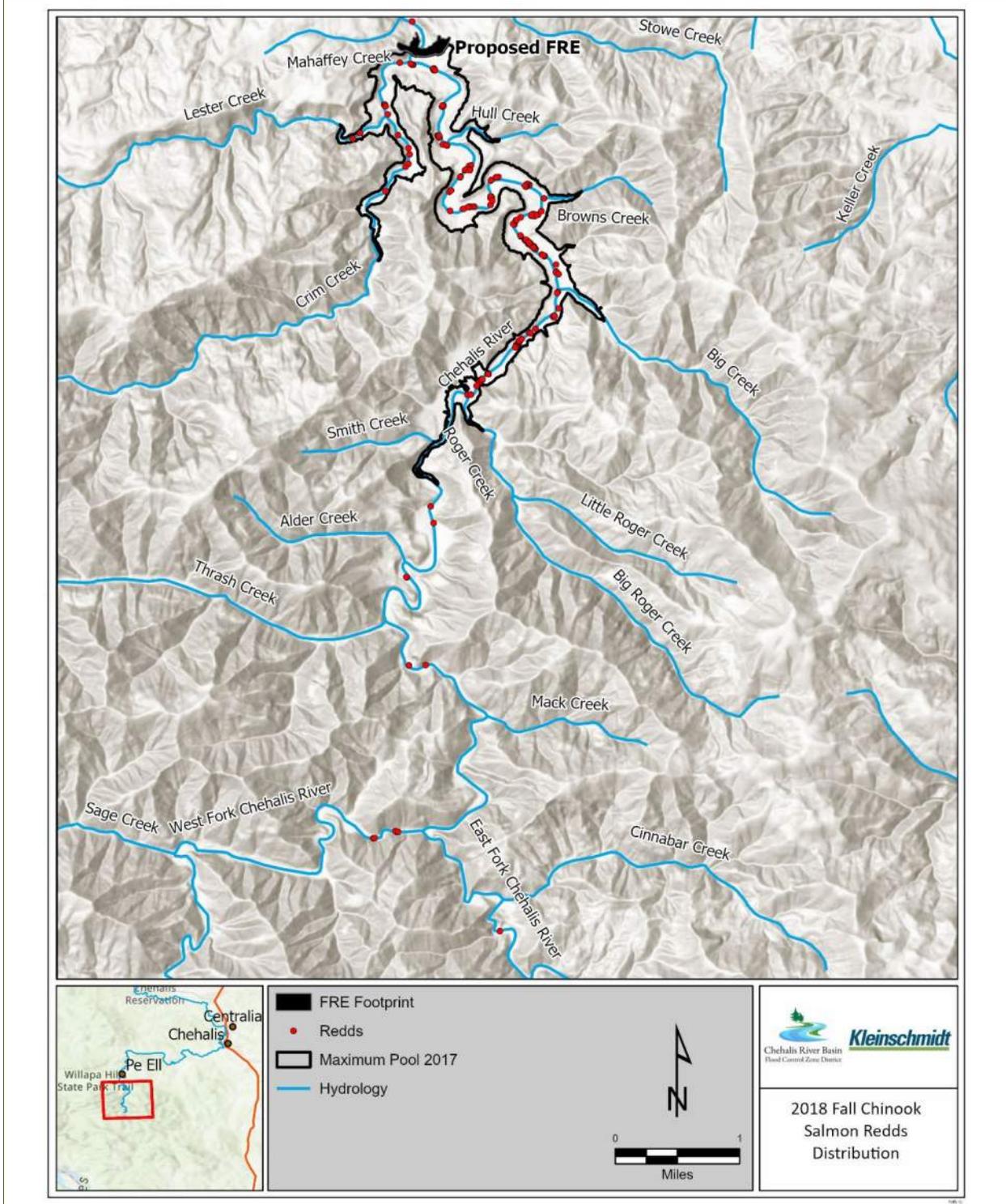
**Figure 10**  
2018 coho salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.



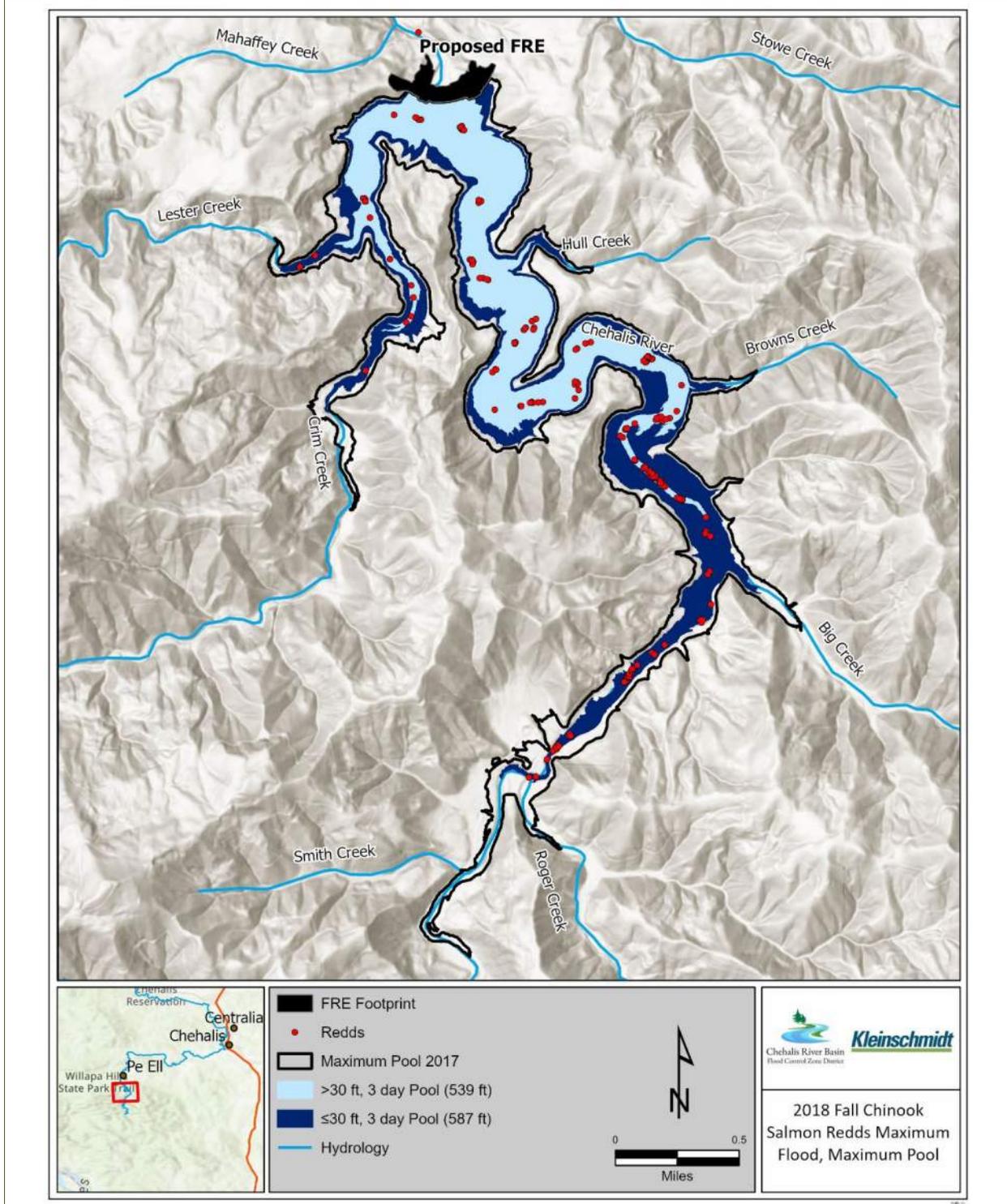
**Figure 11**  
Distribution of 2018 fall-run Chinook salmon redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.



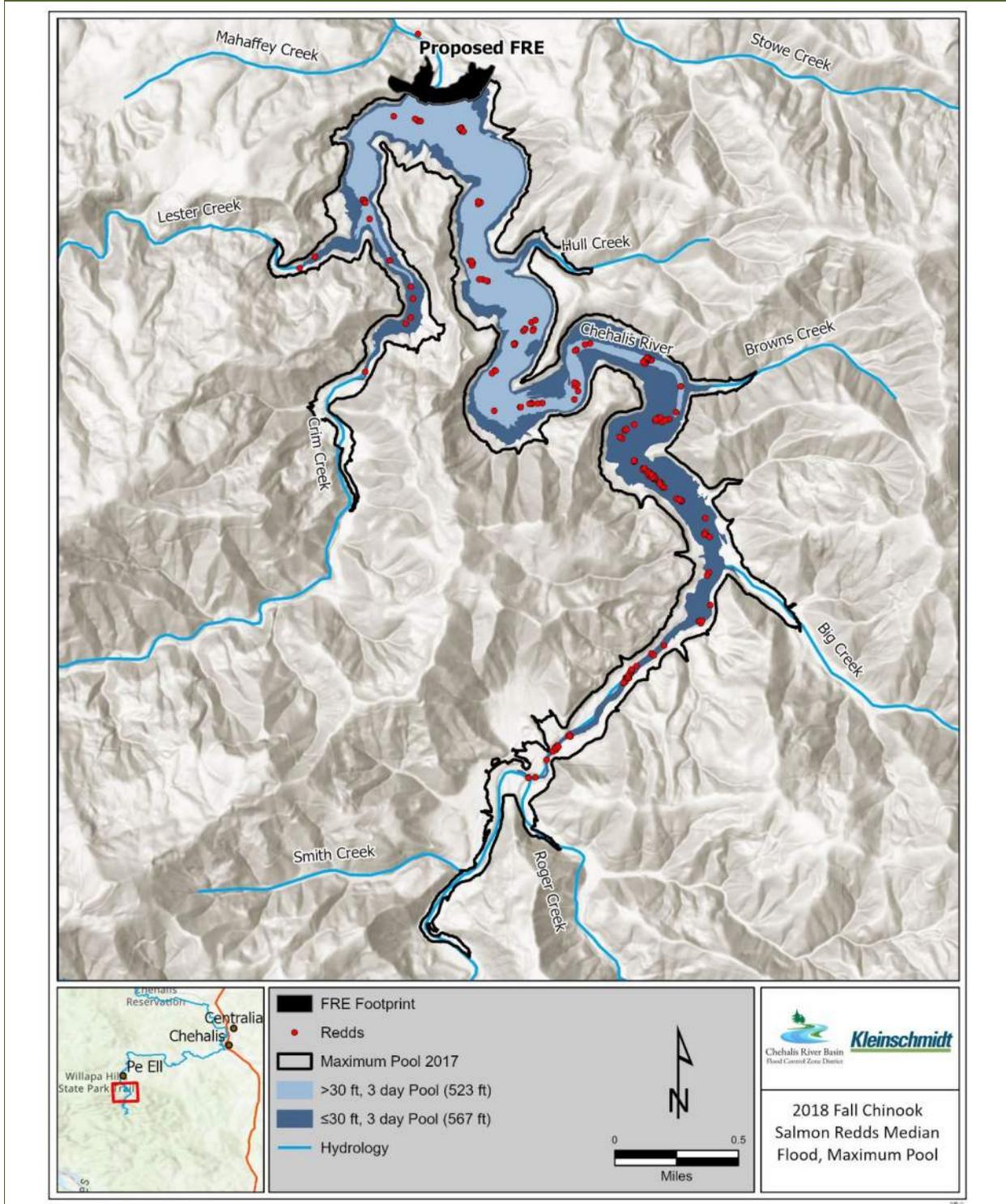
**Figure 12**  
2018 fall-run Chinook salmon redd distribution upstream and immediately downstream of the FRE facility location.



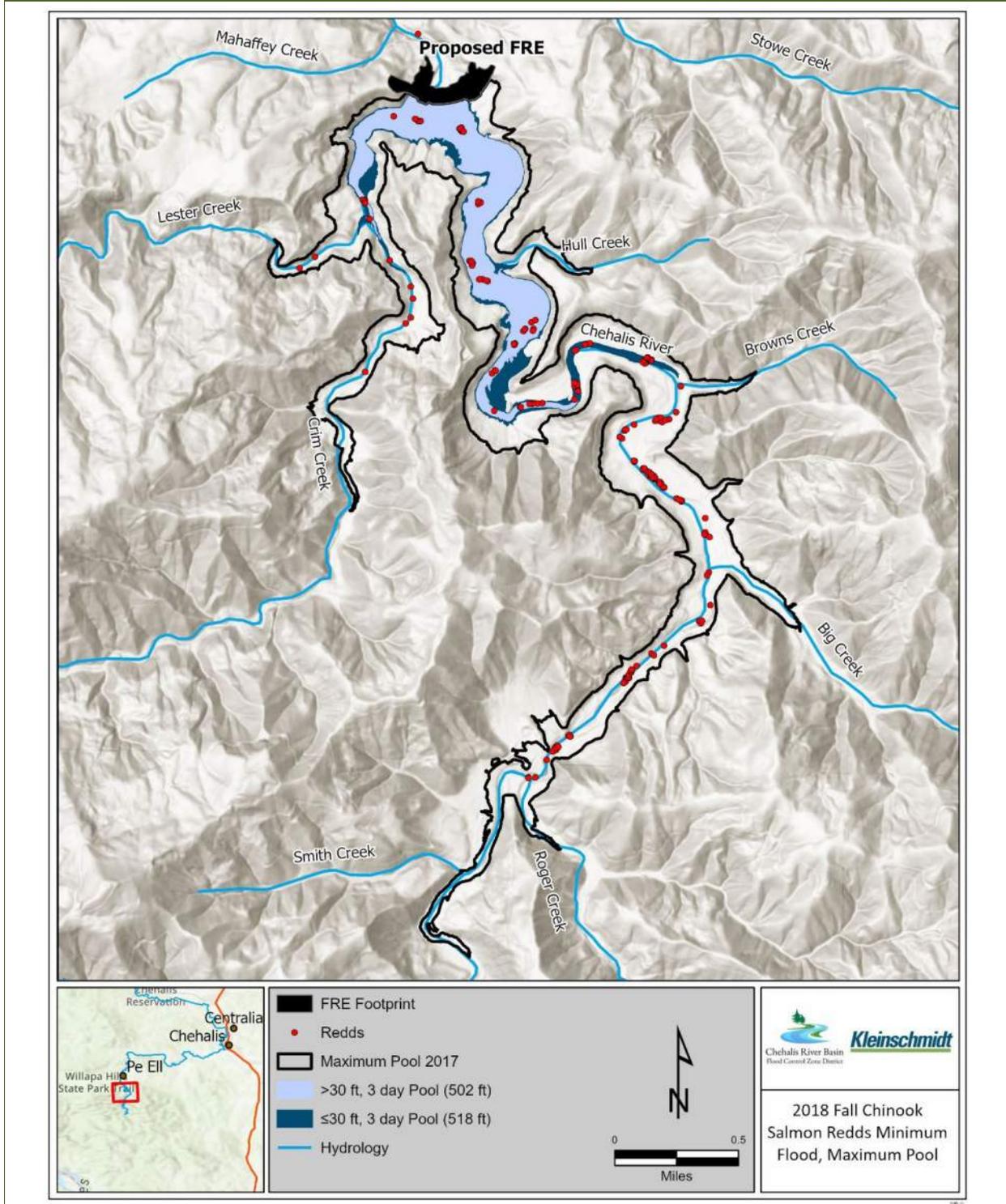
**Figure 13**  
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.



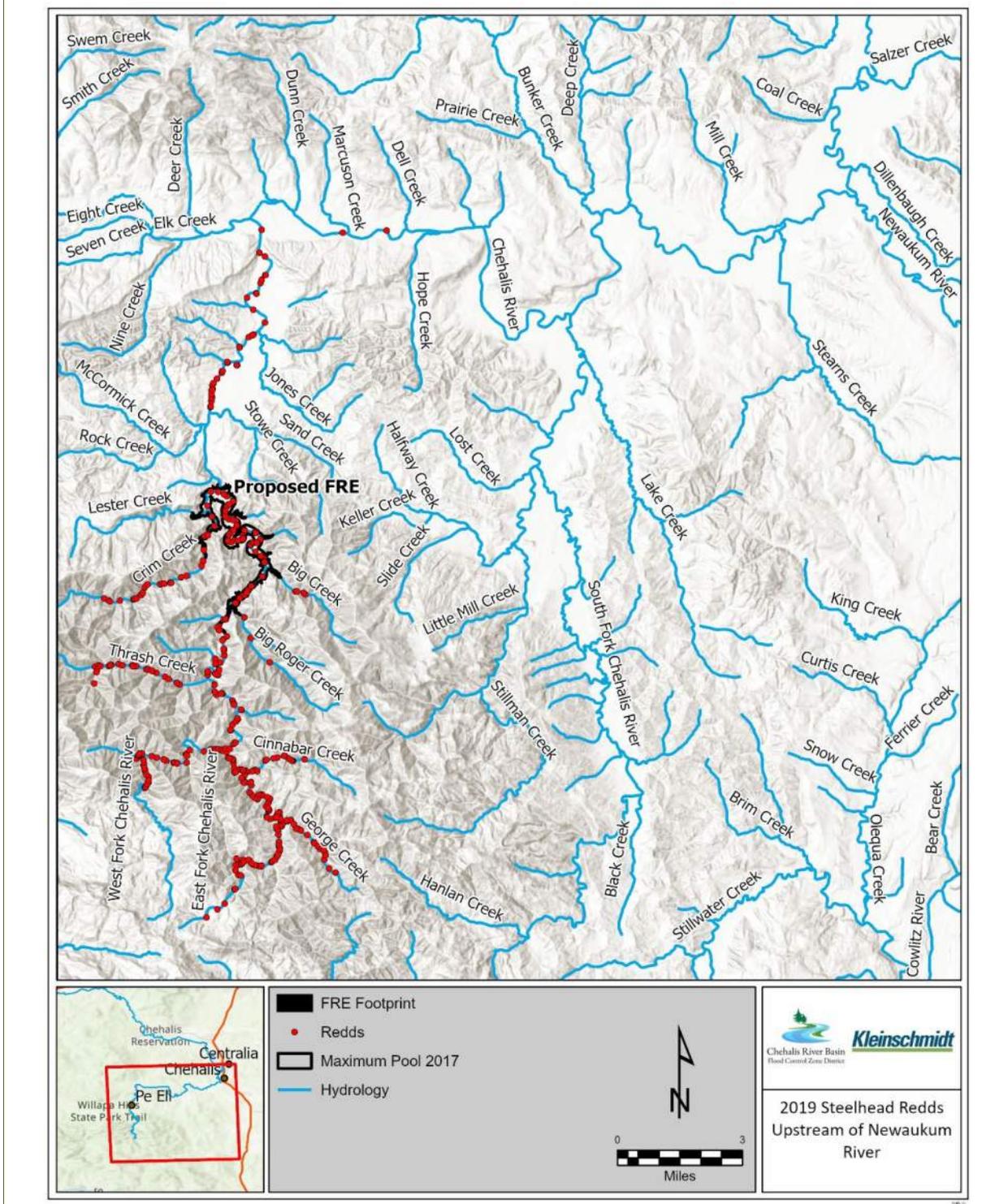
**Figure 14**  
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a median flood event.



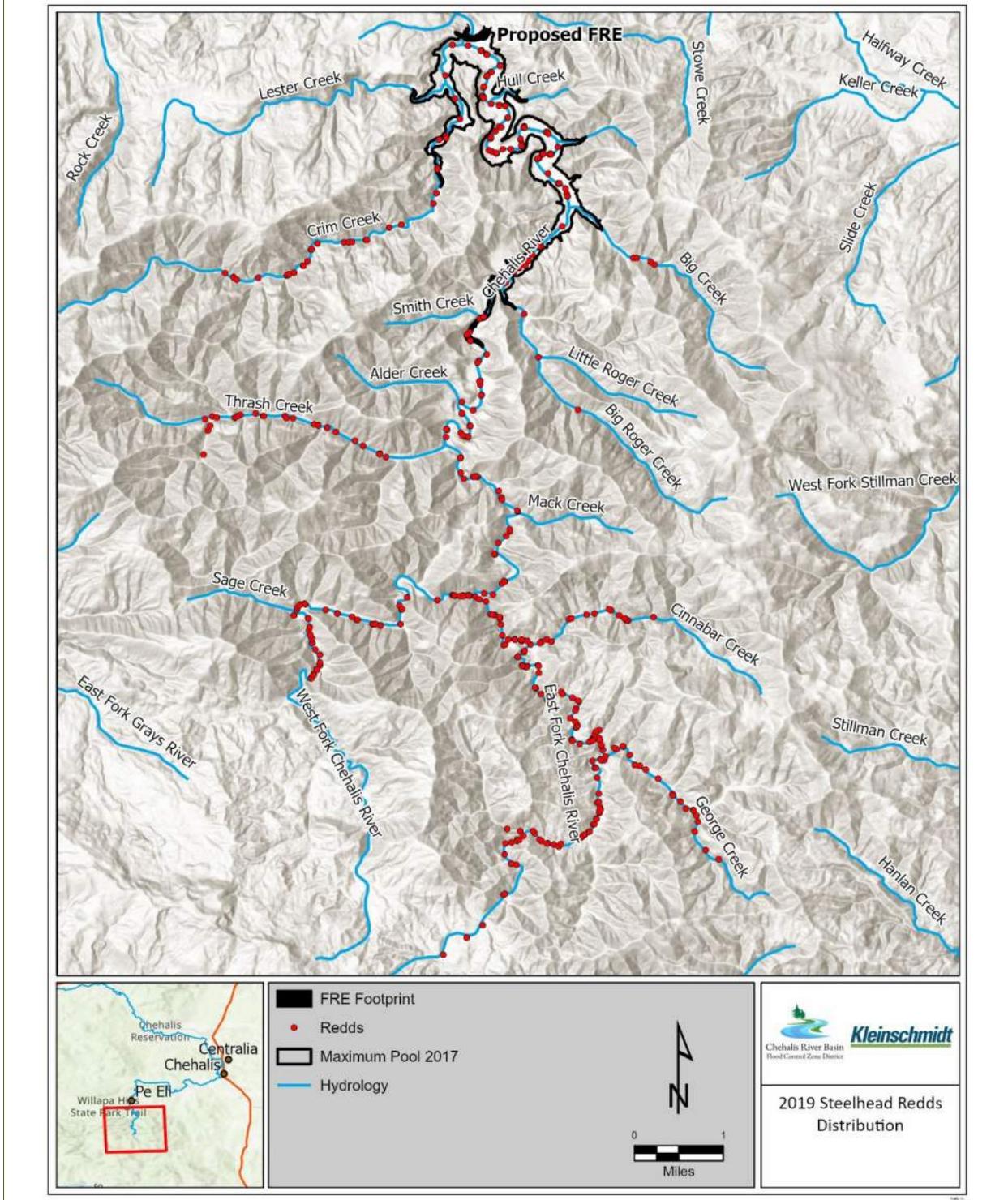
**Figure 15**  
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.



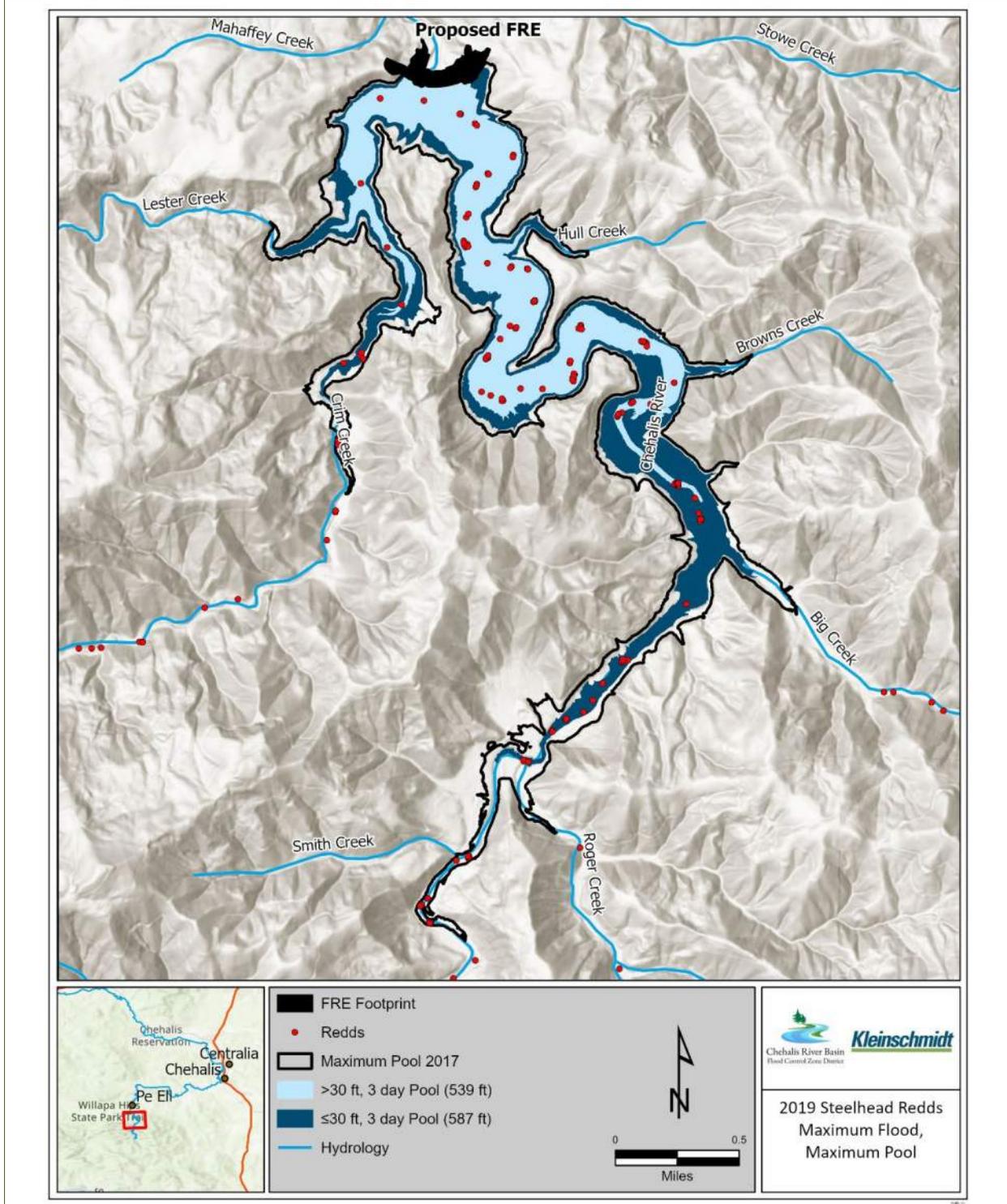
**Figure 16**  
Distribution of 2019 steelhead redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.



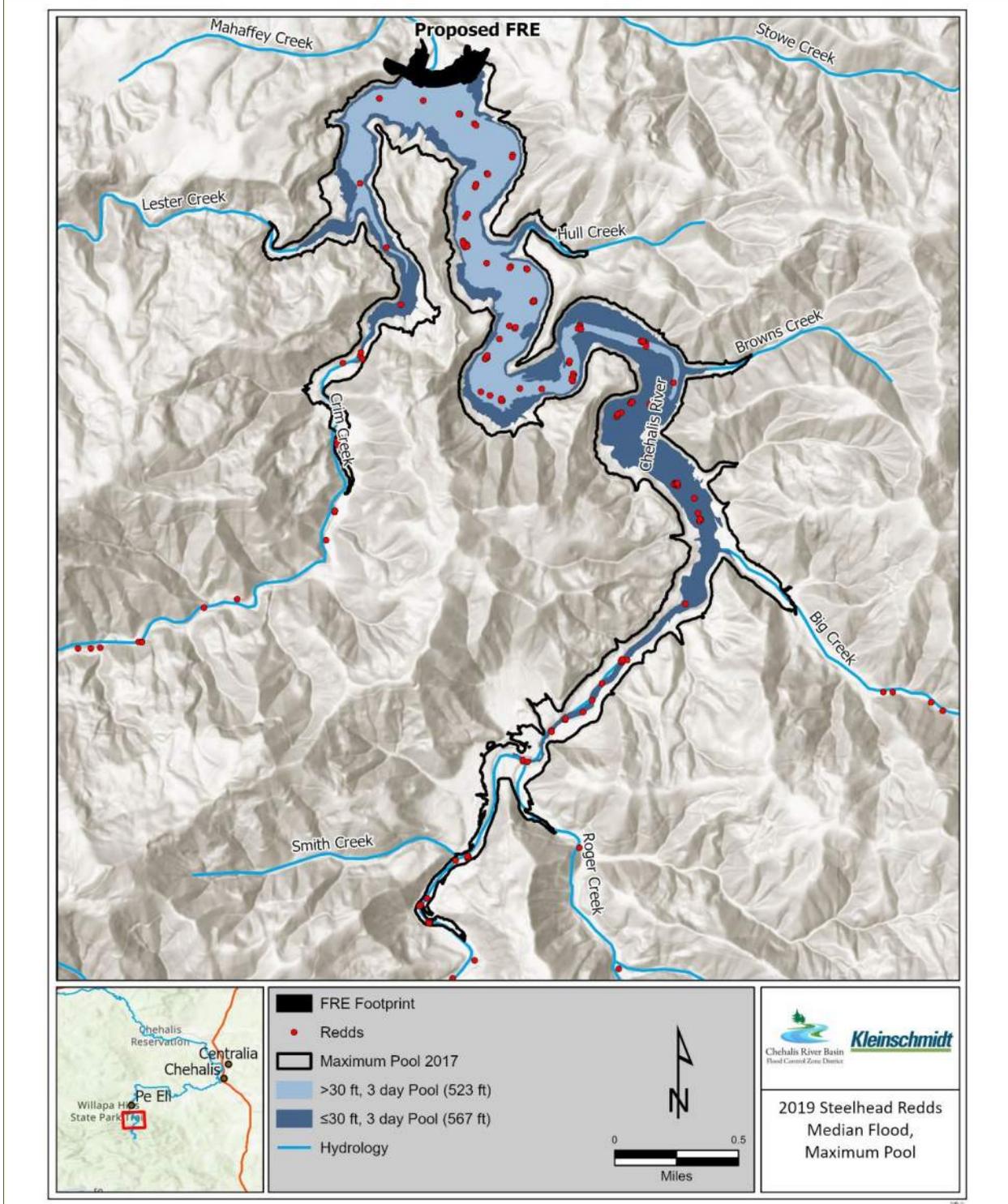
**Figure 17**  
2019 steelhead redd distribution upstream of the FRE facility location.



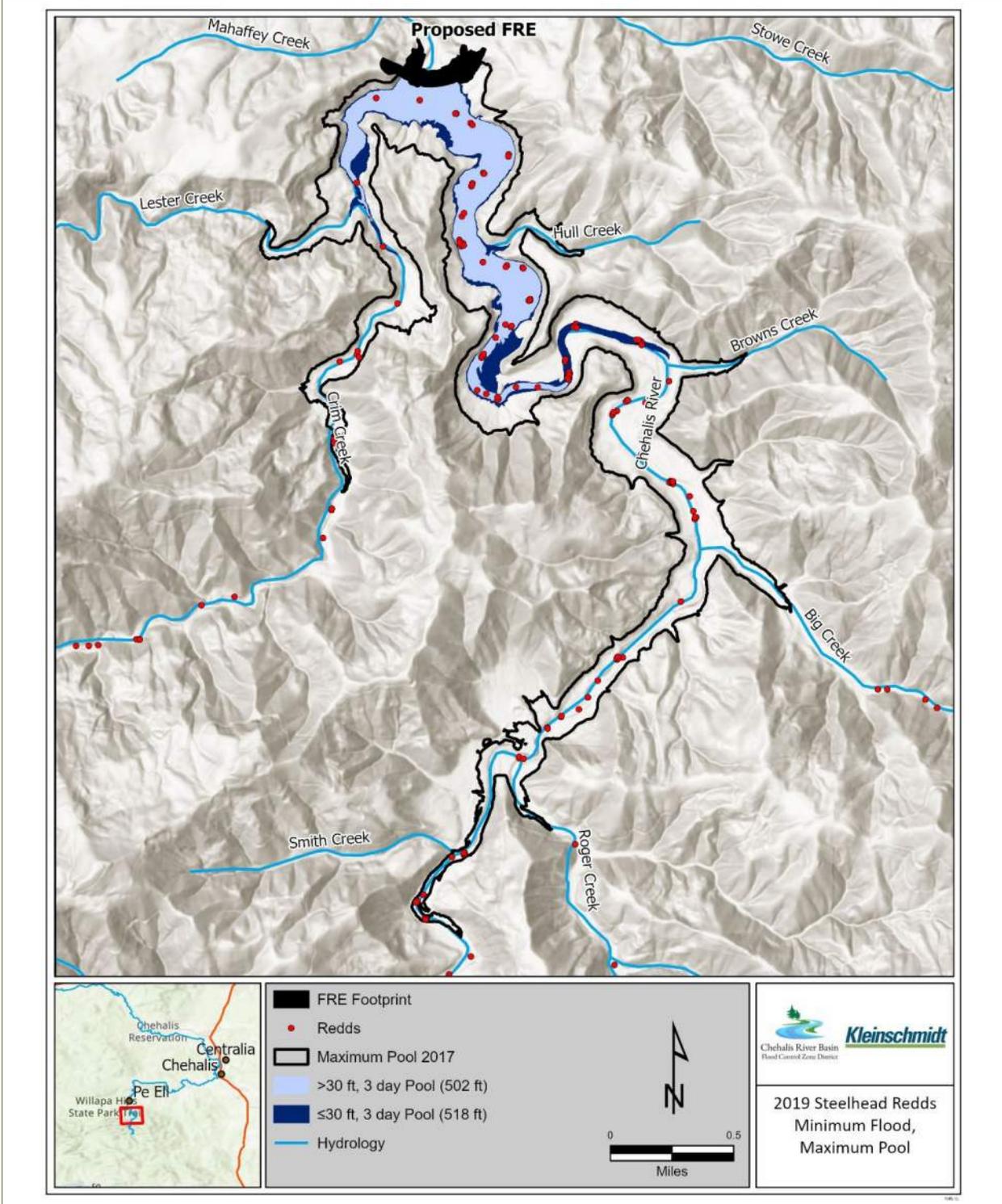
**Figure 18**  
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.



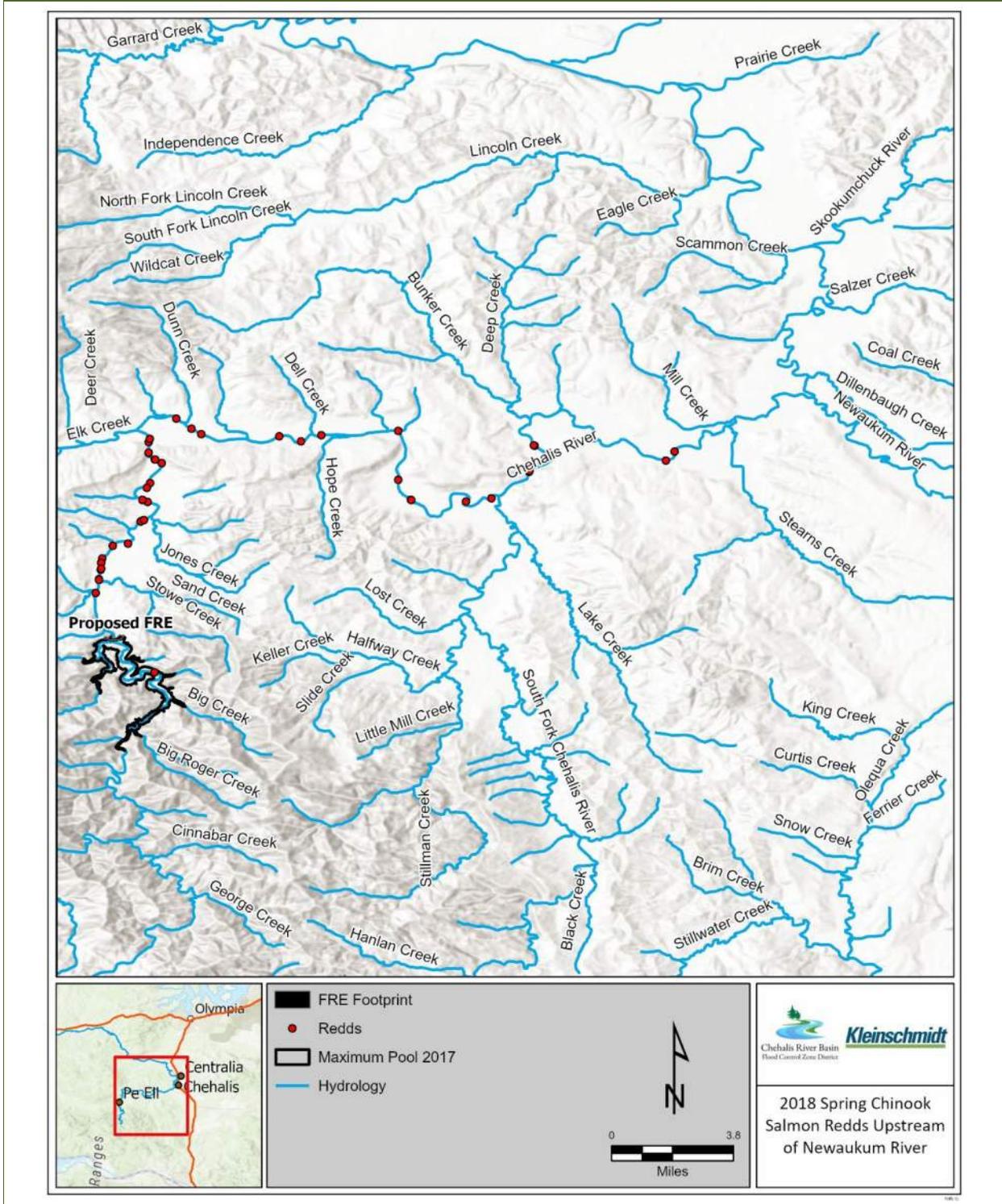
**Figure 19**  
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a median flood event.



**Figure 20**  
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.



**Figure 21**  
Distribution of 2018 spring-run Chinook salmon redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.



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# Attachment 4 – Temperature Technical Memorandum

# TECHNICAL MEMORANDUM

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**Date:** February 2, 2026  
**To:** Kathy Burnamen, Chehalis River Basin Flood Control Zone District  
**From:** Kai Steimle and MaryLouise Keefe, PhD, Kleinschmidt Associates  
**Cc:** Jason Kent, PE, PMP, Kleinschmidt Associates  
**Re:** Riparian Shade Temperature Model with 2024 Project Design and 2025 (O4P2) Operations

## Introduction

### **Background**

The Chehalis River Basin Flood Control Zone District (District) is proposing to construct a Flood Retention Expandable (FRE) facility to reduce the risk of flood damage along the mainstem Chehalis River (Figure 1). The primary purpose of the FRE facility is to reduce flooding coming from the Willapa Hills by storing floodwaters in the temporary inundation pool during major or greater floods. Thus, the FRE facility will include a temporary inundation pool that is only inundated during infrequent flood operations.

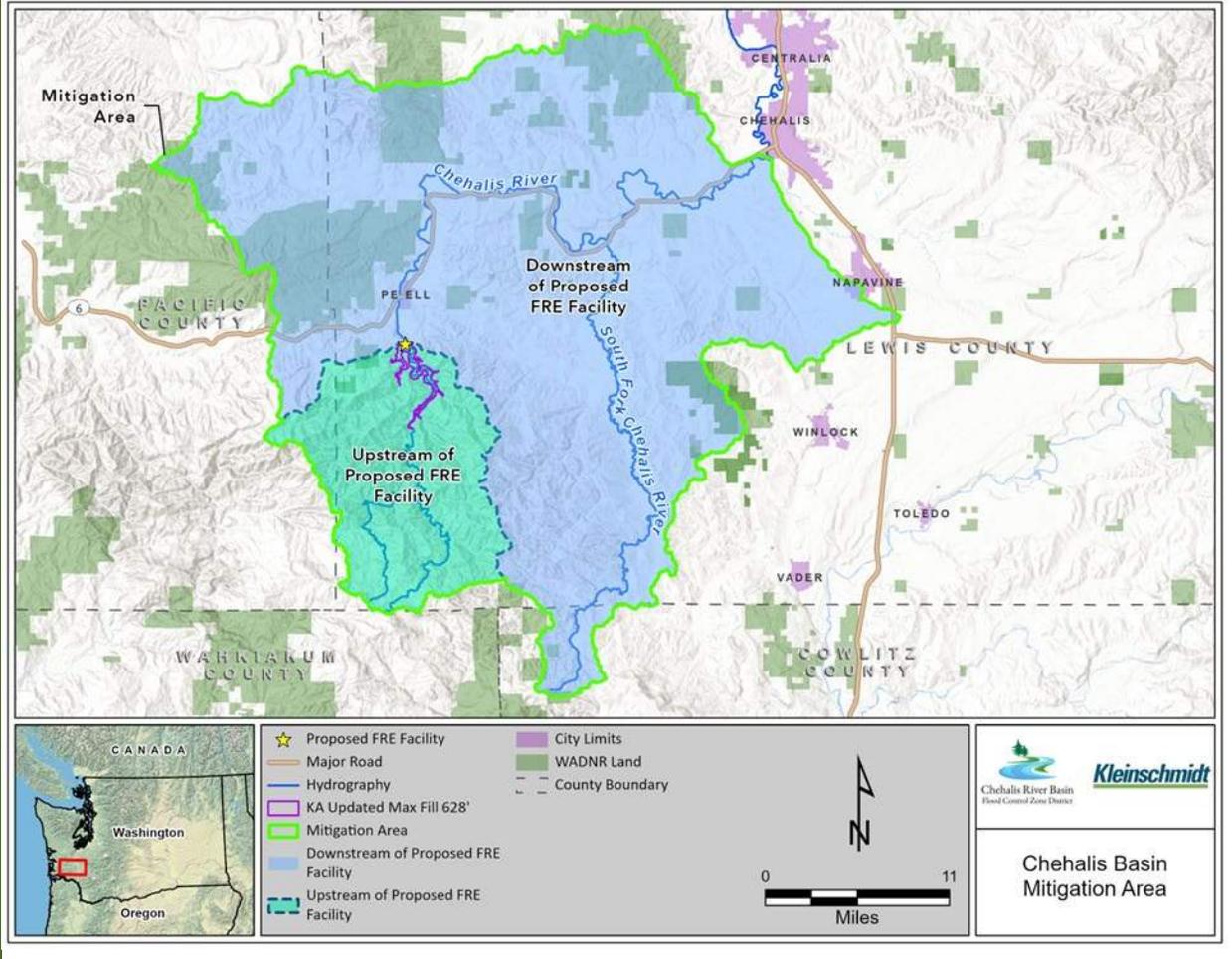
State and Federal environmental reviews of the FRE facility (Ecology 2020, 2025; Corps 2020) have determined that by temporarily storing peak flows during major flood events, operating the FRE facility would alter riparian vegetation and thereby impact riparian shade. This, in turn, was hypothesized to negatively impact water temperatures based on results from a water quality model that was refined in 2025 (PSU 2025). Due in part to the projected increases in water temperature, the environmental reviews determined that the Chehalis River Basin Flood Damage Reduction Project (Project) will have significant impacts on aquatic resources and anadromous salmonids (Ecology 2020, 2025; Corps 2020). Based on the 2025 water quality model, Ecology predicted impacts of 0.3 °C or greater downstream to approximately river mile (RM) 94.9 (downstream of Dryad, Washington) (Ecology 2025). The District's Revised Mitigation Plan (RMP; Kleinschmidt 2024a) proposed shade rehabilitation to offset potential shade loss and associated water temperature impacts. The potential for effective shade cooling is related to the interception of solar input that would otherwise increase water temperatures. For rivers, shade effectiveness is limited by the relationship between maximum tree height and the river bankfull width, with effective shading requiring tree height that is at least 1.4 times the stream width (Ecology 2007). A review of bankfull width data available for the Chehalis River in the Mitigation Area indicated that this condition would be met for the mainstem as well as major tributaries. Further, a previous sensitivity analysis by the District concluded that vegetation heights influenced modeled changes to water temperature, and that a conceptual Vegetation Management Plan (VMP) minimized temperature increases (HDR 2021).

The initial Project design located the Proposed FRE facility approximately 1.7 miles upstream from the town of Pe Ell, Washington in the upper Chehalis River watershed near RM 108.4 (Figure 1). A refined

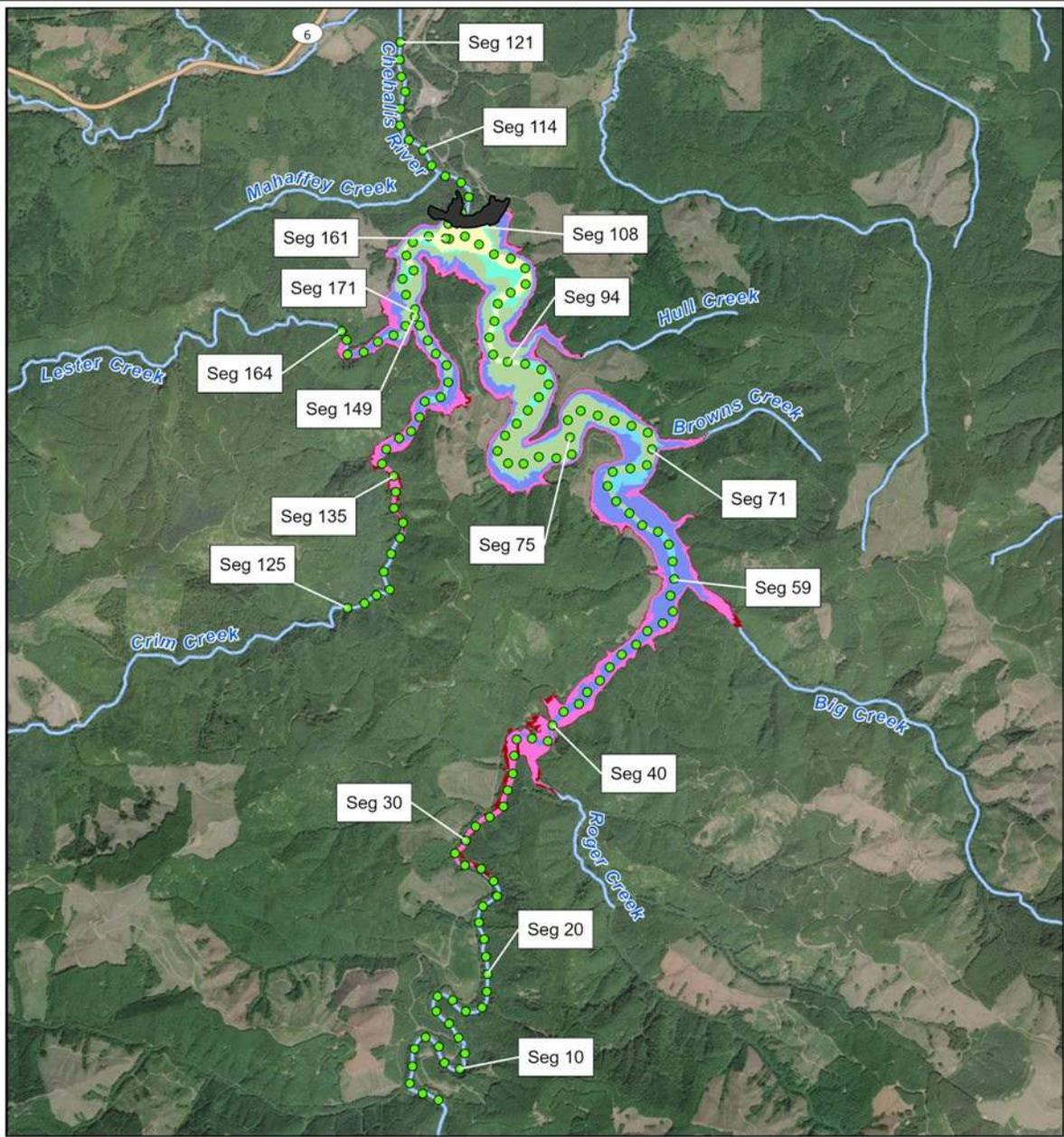
2024 Project design incorporated three changes relevant to riparian shade and water temperature as described in the main body of this report. One change, the relocation of the large wood storage sites, would require an increased area of cleared forest and would result in a reduction in riparian shade in river reaches where the sites are located. Two additional FRE facility changes would increase riparian shade and minimization impacts from 2024. The first of these two additional changes was that the FRE was moved upstream to approximately RM 108.7, thereby eliminating riparian shade impacts in the approximate 0.25 mile reach between the 2017 and 2024 FRE locations. Second, under the 2025 Project operations model (O4P2), refined operations would result in both inundation of a slightly smaller temporary inundation pool and a faster rate of temporary inundation pool evacuation (Figure 2), which would minimize tree mortality associated with mitigation.

To evaluate potential shade impact from the revised FRE facility and 2025 operations, the District developed a 2025 Shade-a-lator model to estimate potential shade reductions and a 2025 CE-QUAL-W2 water temperature model to evaluate water temperature changes associated with the Proposed FRE facility, the implementation of a VMP, and riparian reforestation mitigation actions. The base CE-QUAL-W2 models modified for this analysis were obtained online from Portland State University (PSU) and had been developed for use in the National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (DEIS) analyses, as well as in a temperature sensitivity analysis conducted by the District (HDR 2021). Modifications to the PSU models were made to include shade input parameters that were identified from application of the Shade-a-lator model as described in the 2024 Riparian Shade Temperature Model Technical Memorandum (TM) (Kleinschmidt 2024b). This TM describes the updates made to the 2025 shade and temperature model as well as water temperature predictions based on 2024 Project operations.

Figure 1  
Chehalis Basin Mitigation Area



**Figure 2**  
**Footprint Model Canopy Height Zones Under O4P2 Operations**



● Model Segments	■ Debris - 487 ft
■ FRE Facility Footprint	■ Initial - 537.5 ft
— State Route 6	■ Initial - 543.8 ft
— Hydrography	■ Initial - 586.7 ft
■ Final - 477 ft	■ Initial - 620 ft
	■ Catastrophic - 628 ft

0 0.5  
Miles

Chehalis River Basin  
 Flood Control Zone District

**Footprint Model  
 Canopy Height Zones  
 O4P2 Operations**

## **Study Area**

The study area for both shade modeling and water temperature impacts included the temporary inundation pool upstream of the FRE facility to approximately Fisk Falls and downstream in the Chehalis River from the FRE facility to the confluence of the Chehalis River and the Newaukum River, near Chehalis RM 75.2.

## **Shade Model**

The District revised their 2024 Shade-a-lator modeling tool (Boyd and Kasper 2003; Kleinschmidt 2024b) to develop a 2025 site-specific riparian shade model that reflected the 2024 project description and revised operations and mitigation actions as proposed in the 2024 RMP (Kleinschmidt 2024b). The 2025 Shade-a-lator model provided more recent information about the existing vegetation within the temporary inundation pool than the previous version, so it was used to update the 2022 Current Conditions scenario. It also incorporated refined shade parameters for the temporary inundation pool that were consistent with new expectation for vegetation heights of future plant communities using 2025 operations and implementation of the VMP (Appendix D in Kleinschmidt 2024a). The shade benefits of mitigation actions downstream of the FRE facility were quantified with Shade-a-lator. Detailed modeling methods including a description of the Shade-a-lator model and its application to development of the riparian planting mitigation actions, the CE-QUAL-W2 Model and relevant input parameters for shade, and development of the models of the Project and Mitigation Area are summarized in the Riparian Shade Temperature Model TM (Kleinschmidt 2024b).

## **Methods**

### **CE-QUAL Model Inputs**

As described above, the water temperature analysis was restricted to changing shade parameters within the previously developed CE-QUAL-W2 models. The shade generated by riparian vegetation is modeled in CE-QUAL-W2 using inputs describing vegetation height, distance from the stream centerline, and vegetation density or opacity (Kleinschmidt 2024b). These parameters were developed at the model segment scale for each bank. Vegetation heights were extracted from Light Detection and Ranging (LiDAR) data and used as model inputs to capture shade. Development of the modeling inputs for analysis of the 2024 Project included two updates to the previous methods. First, bankline vegetation heights were sampled along a line 6 feet shoreward of the bank, rather than along the bankline itself, to avoid underestimating riparian shade. Second, updated LiDAR was used to generate a DTM that markedly reduced the estimates of the distance between the stream centerline and riparian vegetation in Crim Creek (Washington Geological Survey 2024a, 2024b).

### **Model Scenarios and Assumptions**

In 2024, the District modeled four scenarios under the 2017 operations model, including 2022 Current Conditions, No Vegetation, Vegetation Management Plan (VMP5), and Vegetation Management Plan

and Riparian Reforestation (Kleinschmidt 2024b). Canopy height predictions used in the VMP scenarios developed for the 2017 operations model are summarized in Table 1.

In 2025, the District modeled four new scenarios to characterize potential impacts to water temperature from inundation-induced mortality of riparian vegetation, and potential minimization through implementation of the VMP and riparian shade mitigation downstream of the FRE. The 2025 model scenarios are described in Table 2. These scenarios reflect three differences. First, in 2025 the reservoir zones shifted upstream in elevation due to Project refinements. Second, because 2025 FRE operations reduced the extent and duration of inundation as compared to 2017, this changed vegetation viability and growth. Third, these scenarios reflect consideration of both a major and catastrophic flood, whereas the 2024 analysis was limited to a catastrophic flood scenario.

**Table 1**  
**Canopy Height Surfaces Modeled in VMP Scenarios Under 2017 Operations**

RESERVOIR EVACUATION AREA	FINAL	DEBRIS MANAGEMENT	INITIAL	INITIAL WATER SURFACE ELEVATION >620.0 FEET
Upper Canopy Height (feet)	NA	NA	100	Existing
Upper Canopy Cover (%)	0	0	25	Existing
Lower Canopy Height (feet)	8	8	25	Existing
Lower Canopy Cover (%)	100	100	75	Existing

**Table 2**  
**2025 Temperature Model Scenarios under 2025 (O4P2) Operations**

OPERATIONAL SCENARIO	DESCRIPTION
Scenario 1: With Project, No Mitigation (1996 Flood Event [FE])	Vegetation after catastrophic flood operation
Scenario 2: With Project, No Mitigation (2015 Flood Event [FE])	Vegetation after major flood operation
Scenario 3: Vegetation Management Plan and Riparian Reforestation (1996 FE)	Vegetation after catastrophic flood operation, with implementation of Vegetation Management Plan upstream of FRE and Riparian Reforestation downstream of the FRE
Scenario 4: Vegetation Management Plan and Riparian Reforestation (2015 FE)	Vegetation after major flood operation with implementation of Vegetation Management Plan upstream of FRE and Riparian Reforestation downstream of the FRE

**Current Conditions: Existing Riparian Vegetation**

This analysis updated LiDAR-based baseline vegetation conditions (Washington Geological Survey 2024a, 2024b) using remote imagery. The current land designation of the temporary inundation pool and the surrounding land is forest reserve land, and its primary use is commercial forestry. Under active timber management, additional vegetative changes have occurred since the LiDAR data collection. These changes were digitized in ArcPro at a scale of 1:2000 using Maxar satellite imagery from July 2022 and used to update the Digital Surface Model for the temporary inundation pool (Maxar Technologies 2022). This scenario was named the 2022 Current Conditions scenario.

**2025 Project Operations**

**Scenario 1: With Project, No Mitigation (1996 FE)**

The District developed an estimate of future vegetation conditions, *without the VMP*, applying vegetation survival predictions based on the depth and duration of the temporary inundation pool when the FRE facility would operate. The three evacuation zones would be subject to increased frequency and duration of inundation: the Initial Evacuation Area, the Debris Management Evacuation Area, and the Final Reservoir Evacuation Area. However, the 2025 operations model lowered the upstream extent of each zone (Table 3). Trees that were inundated for more than 7 days were not expected to survive, based on observations at Mud Mountain (Appendix D in Kleinschmidt 2024a). Where inundation duration would be less than 7 days, tree survival was predicted to be selective such that shorter deciduous tree species would have higher inundation tolerance than evergreen species that grow much taller. The 1996 flood event (FE) represents an infrequent and catastrophic-type flood where the upstream extent of the temporary inundation pool would be at an elevation of 586.7 feet. The elevation threshold for inundation less than one week would be 537.5 feet (Figure 2, above). For the reach of the temporary inundation pool from 537.5 feet to 586.7 feet, the canopy height was modeled as the existing canopy height, up to 50 feet.

**Table 3**  
**Canopy Height Surface Modeled in Scenario 1 for 1996 FE Under 2025 (O4P2) Operations**

RESERVOIR EVACUATION AREA	INUNDATION DURATION BY FLOOD EVENT (FE)	ELEV. RANGE (FEET)	CANOPY HEIGHT (FEET)
FINAL	>1 week 1996 FE	425.0-477.0	0
DEBRIS MANAGEMENT	>1 week 1996 FE	477.0-487.0	0
INITIAL	>1 week 1996 FE	487.0-537.5	0
	<1 week 2015 FE < 1 week 1996 FE	537.5-543.8	Existing, up to 50
	<1 week 1996 FE	537.5-586.7	Existing, up to 50
CATASTROPHIC	None 1996 FE	586.7-628.0	Existing

**Scenario 2: With Project, No Mitigation (2015 FE)**

The 2015 flood event represents a flood-type that has been classified as a major flood and would be expected more frequently than a catastrophic flood. This flood type would result in shorter inundation durations and a smaller inundation extent for the FRE facility’s temporary inundation pool than predicted for a catastrophic flood. Vegetation was modeled similarly to 1996 WY, except that the upstream extent of the temporary inundation pool would be at 543.8 feet, and the elevation threshold for 7 days of inundation would be at 487.0 feet (Table 4, Figure 2). The elevation range that would be inundated for 7 days in 1996 FE was assumed to have a canopy height of 25 feet due given the opportunity for growth between inundation by catastrophic flood events (Table 4).

**Table 4  
Canopy Height Surfaces Modeled in Scenario 2 for 2015 FE Under 2025 (O4P2) Operations**

RESERVOIR EVACUATION AREA	INUNDATION DURATION BY FLOOD EVENT (FE)	ELEV. RANGE (FEET)	CANOPY HEIGHT (FEET)
FINAL	>1 week 2015 FE	425.0-477.0	0
DEBRIS MANAGEMENT	>1 week 2015 FE	477.0-487.0	0
INITIAL	<1 week 2015 FE >1 week 1996 FE	487.0-537.5	25
	<1 week 2015 FE <1 week 1996 FE	537.5-543.8	Existing, up to 50
	<1 week 1996 FE	537.5-586.7	Existing, up to 50
CATASTROPHIC	None 1996 FE est	586.7-628.0	Existing

**Scenario 3: Vegetation Management Plan and Riparian Reforestation (1996 FE)**

The District developed an estimate of future vegetation conditions upstream of the FRE, based on active vegetation management under the VMP that would promote regrowth after inundation. The predictions of future canopy height were similar to previous modeling based on areas of inundation, but the elevations of each zone were lowered as described above. Under the VMP, the portion of the Initial Evacuation Area inundated for less than 7 days (the upstream-most area above an elevation of 537.5 feet) would be actively managed to promote taller vegetation, and taller trees could be expected to tolerate the flooding conditions anticipated in this area. An upper canopy cover of 25 percent at 100 feet was assumed with a lower canopy cover of 75 percent at a height of 25 feet (Table 5). As described above, it was assumed that vegetation could survive infrequent and short-duration inundation and no changes to existing canopy heights were assumed in the Initial Evacuation Area upstream of the inundation limit for the 1996 flood (586.7 feet). The Debris Management Evacuation Area (the middle portion of the temporary inundation pool between 477.0 to 487.0 feet) and the Final Reservoir Evacuation Area (the lowest part of the temporary inundation pool, from 425.0 to 477.0 feet, that would be inundated for the greatest duration) were modeled with the same vegetation. It was assumed that any upper canopy of standing dead trees would have fallen, so no upper canopy was assumed (reflected

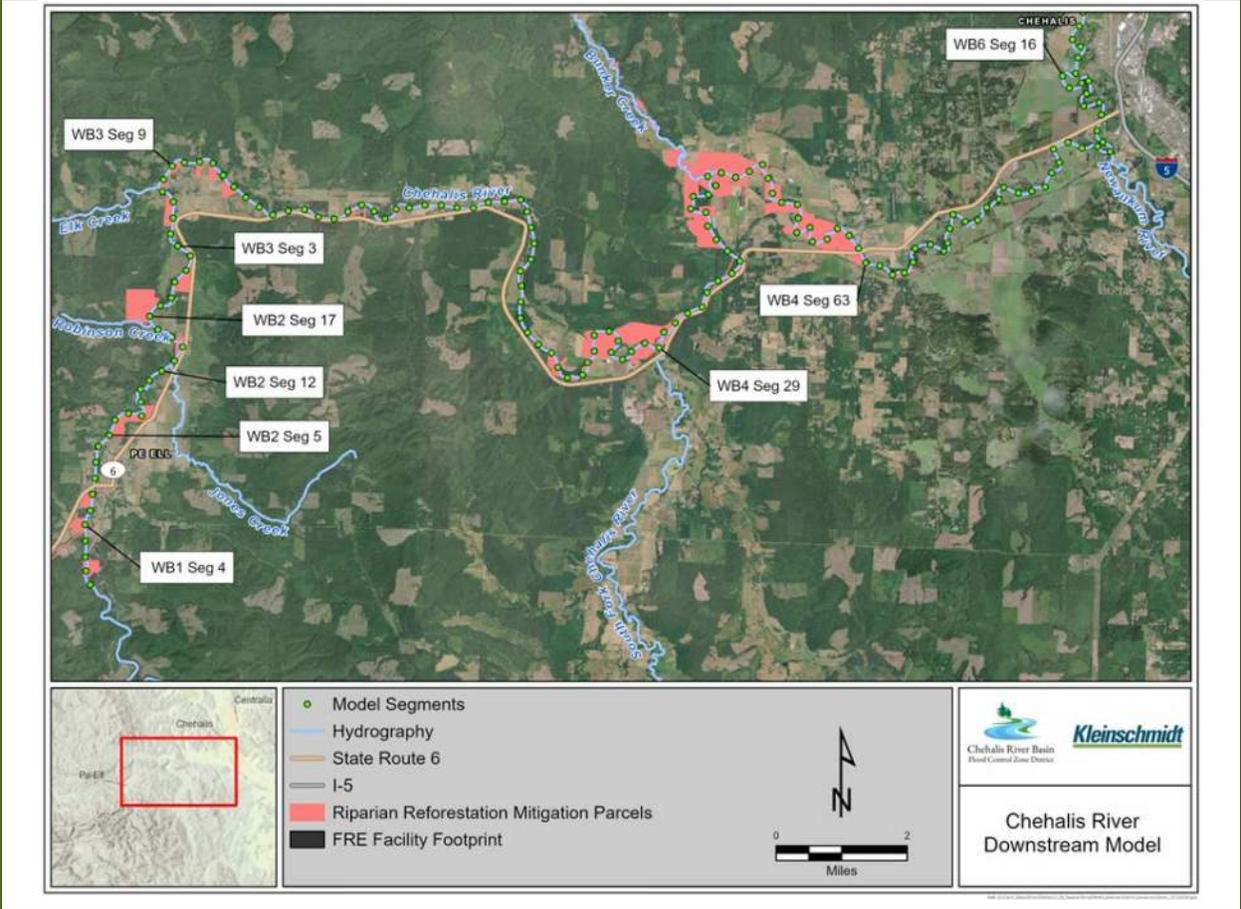
as 0 percent cover in Table 5) and the lower canopy was modeled at 8 feet, based on estimated tree regrowth rates in the VMP.

**Table 5**  
**Canopy Height Surfaces Modeled in VMP Scenario for 1996 FE Under 2025 (O4P2) Operations**

RESERVOIR EVACUATION AREA	INUNDATION DURATION BY FLOOD EVENT (FE)	ELEV. RANGE (FEET)	UPPER CANOPY HEIGHT (FEET)	LOWER CANOPY HEIGHT (FEET)	LOWER CANOPY COVER (%)
FINAL	>1 week 1996 FE	425.0-477.0	NA	8	100
DEBRIS MANAGEMENT	>1 week 1996 FE	477.0-487.0	NA	8	100
INITIAL	>1 week 1996 FE	487.0-537.5	NA	8	100
	<1 week 2015 FE < 1 week 1996 FE	537.5-543.8	100	25	75
	<1 week 1996 FE	537.5-586.7	100	25	75
CATASTROPHIC	None 1996 FE	586.7-628.0	Existing	Existing	Existing

Downstream of the FRE, the District’s proposed mitigation for temperature impacts is reforestation of existing degraded habitats with native riparian trees and shrubs that will enhance tree canopy and shade conditions as the vegetation matures (Figure 3). Vegetation parameters for riparian restoration sites were based on ecologically relevant planting plans that included a high diversity of native trees and shrubs that contribute to riparian ecological function. Dominant shade-producing species included black cottonwood (*Populus trichocarpa*) and red alder (*Alnus rubra*). Tree heights of 98 feet (30 meters) were based on species characteristics and the system potential vegetation identified in previous total maximum daily load modeling in analogous Northwest river systems (ODEQ 2006). Mitigation plantings were modeled within a 60-foot buffer along each streambank. This future conditions scenario was integrated into a modified continuous raster surface model.

**Figure 3**  
**Chehalis River Downstream Model Segments**



**Scenario 4: Vegetation Management Plan and Riparian Reforestation (2015 FE)**

For 2015 FE, future vegetation conditions upstream of the FRE with active vegetation management under the VMP included higher canopy heights for the additional portion of the temporary inundation pool that would be inundated for less than 7 days (water surface elevations between 537.5 and 487.0 feet; Figure 2). An upper canopy cover of 25 percent at 50 feet was assumed with a lower canopy height of 25 feet (Table 6). In addition, regrowth in the area upstream of the maximum extent of the temporary inundation pool (543.8 feet) was assumed such that the lower canopy height could increase to 45 feet. No revisions were made to the future vegetation heights in the Debris Management Evacuation Area and the Final Reservoir Evacuation Area; similar to other scenarios, the lower canopy was modeled at 8 feet, based on estimated tree regrowth rates in the VMP.

Riparian reforestation downstream of the FRE will be unchanged across flood events and was modeled as described above.

**Table 6**

**Canopy Height Surfaces Modeled in VMP Scenario for 2015 FE Under 2025 (O4P2) Operations**

RESERVOIR EVACUATION AREA	INUNDATION DURATION BY FLOOD EVENT (FE)	ELEV. RANGE (FEET)	UPPER CANOPY HEIGHT (FEET)	LOWER CANOPY HEIGHT (FEET)	LOWER CANOPY COVER (%)
FINAL	>1 week 2015 FE	425.0-477.0	NA	8	100
DEBRIS MANAGEMENT	>1 week 2015 FE	477.0-487.0	NA	8	100
INITIAL	<1 week 2015 FE >1 week 1996 FE	487.0-537.5	50	25	75
	<1 week 2015 FE <1 week 1996 FE	537.5-543.8	100	25	75
	<1 week 1996 FE	537.5-586.7	100	45	75
CATASTROPHIC	None 1996 FE	586.7-628.0	Existing	Existing	Existing

### **CE-QUAL-W2 Model Outputs and Analysis**

The CE-QUAL-W2 models can be set to output water temperature for any segment, time-step, or depth in the water column. For this analysis, water temperatures were output at select segments relevant to evaluating Project effects at time steps of 2.4 hours (0.1 days). The Footprint Model was configured to output temperatures at the downstream extent of Crim Creek (Segment 161) and at the location of the FRE at the time of the DEIS (Segment 114) (Figure 2). The Chehalis River Downstream Model was configured to output temperatures downstream of the FRE (WB1 Segment 4), upstream of Jones Creek (WB2 Segment 12), near Robinson Creek (WB2 Segment 17), near Elk Creek (WB3 Segment 9), at the confluence with the South Fork Chehalis River (WB4 Segment 29), and near Adna, Washington (WB4 Segment 63) (Figure 3).

Both latitude and day of the year affect the solar path and associated incoming solar radiation. When evaluating riparian revegetation effects on water temperature, it can be helpful to understand conditions both during periods of relatively high temperatures (summer) and periods when riparian shade is most effective at reducing incoming solar radiation (fall). The late summer months are when the DEISs identified water temperature increases to be greatest. The CE-QUAL-W2 model temperature outputs for the Chehalis River were summarized for the period between June 20, 2014 and September 22, 2014.

### **Results**

The following sections describe outputs from the CE-QUAL-W2 temperature modeling for potential Project effects on riparian shade in the temporary inundation pool under the 2025 (O4P2) operations model, the effectiveness of the VMP in avoiding and minimizing those effects, and the potential for

riparian shade mitigation to address unavoided impacts downstream of the FRE. Results of the 2017 shade related temperature modeling are presented in table format for comparative purposes and to demonstrate any changes associated with the refined FRE facility location, 2025 operations, and model (Table 7).

### ***Temperature Within the Temporary Inundation Pool Footprint***

Modeling in the temporary inundation pool predicted changes in water temperature under summer low-flow conditions under 2024 Project designs and associated scenarios (Table 7). All temperature changes are characterized as the maximum change in the 7-day average of the daily maximum water temperature (7-DADMax) in degrees Celsius.

#### ***2024 Project***

The 2022 Current Conditions scenario was maintained in the 2025 model as the basis for comparison with the four new future scenarios considered for the 2024 Project design. From that baseline, District-proposed avoidance and minimization measures further reduced the predicted temperature increases. The new LiDAR data used for this model depicted more accurate estimates of channel width for Crim Creek that resulted in current conditions temperature changes that also effects both potential impact and minimization temperatures at that location.

The differences in daily estimates of 7-DADMax for the summer low-flow period of June 20, 2024 to September 22, 2024 at the mouth of Crim Creek and near the FRE are presented in Figures 4 and 5. Under the With Project, No Mitigation scenarios (1996 FE, 2015 FE), removing all vegetation inundated longer than 7 days would increase stream temperatures near the FRE above the 2022 condition by up to 1.6 °C for 1996 FE and 1.2 °C for 2015 FE (Table 7). Stream temperatures at the mouth of Crim Creek under these scenarios would increase by up to 4.7 °C and 3.4 °C, respectively.

Implementing the VMP would avoid up to 1.6 °C of temperature increase at the mouth of Crim Creek and up to 0.7 °C of temperature increase near the FRE. Based on the VMP5 scenario, the residual water temperature effect (total increase to current conditions with all vegetation removed minus VMP shade reduction) for a 1996 FE event is predicted to be up to 3.1 °C at the mouth of Crim Creek and 1.0 °C near the FRE (Table 7). Although the relative change in water temperature at the mouth of Crim Creek was larger than in previous analyses, this was due to a reduction in the estimate of current conditions rather than an increase in the estimate of future 7-DADMax stream temperatures (Figure 4). Further information about this appears in the Discussion section, below. This change at the mouth of Crim Creek was not reflected in conditions at the FRE location downstream, presumable due to relatively small flow contribution of Crim Creek to the Chehalis River during summer months (Figure 5).

**Table 7**

**Maximum Change in Modeled 7-DADMax Water Temperature During Low-flow Summer Conditions (June 20, 2014 to September 22, 2014) at the Mouth of Crim Creek and at the FRE Under Shade Scenarios**

SCENARIO	2017 PROJECT		2024 PROJECT / 2025 OPERATIONS			
	NO VEGETATION	VMP5	WITH PROJECT, NO MITIGATION	1996 FE	2015 FE	VMP AND RIPARIAN REFORESTATION
LOCATION	RELATIVE TO 2022 CURRENT CONDITIONS (2024 MODEL)		RELATIVE TO 2022 CURRENT CONDITIONS (2025 MODEL)			
At Mouth of Crim Creek	3.6 °C <sup>1</sup>	1.6 °C <sup>1</sup>	4.7 °C	3.4 °C	3.1 °C	2.4 °C
At FRE Facility (RM 108.4/108.7)	1.9 °C	1.2 °C	1.6 °C	1.2 °C	0.8 °C	0.8 °C

<sup>1</sup> Water temperature estimates for 2017 Project in Crim Creek were based on outdated terrain model and are not directly comparable to other temperature estimates.

**Figure 4**

**7-DADMax Water Temperatures at the Mouth of Crim Creek for Model Scenarios**

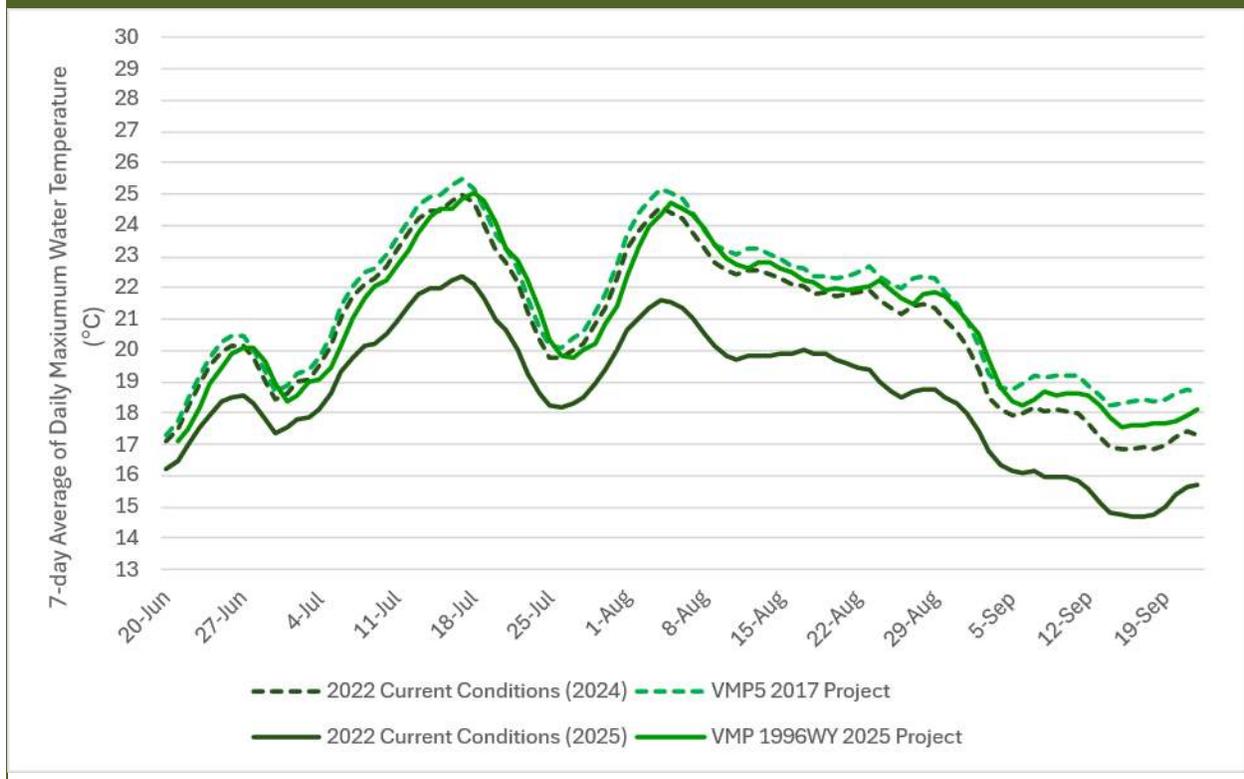
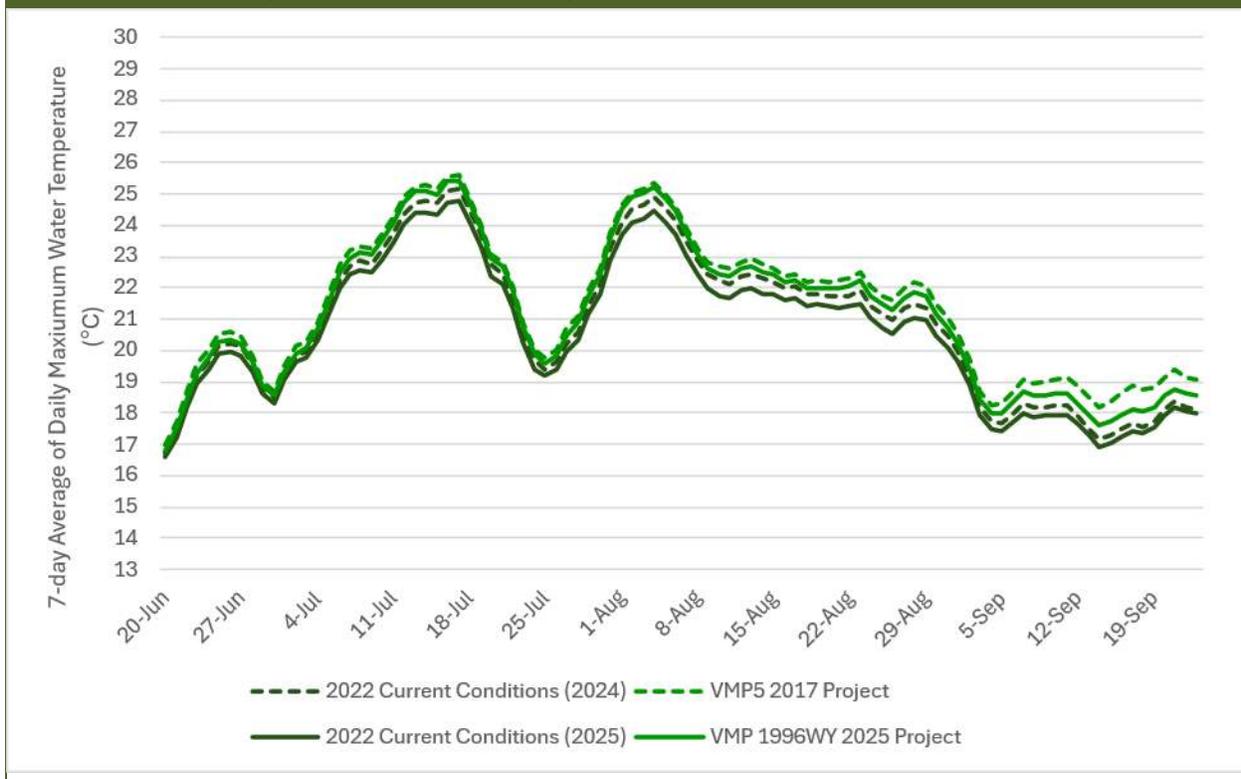


Figure 5

7-DADMax Water Temperatures at the FRE Facility for Model Scenarios



### Riparian Reforestation Mitigation

In 2024, temperature modeling of the 2017 Project for the Mitigation Area downstream of the FRE facility evaluated changes in summer water temperatures under four scenarios : 2022 Current Conditions scenario, No Vegetation scenario, VMP5 scenario, and the VMP5 with Mitigation scenario (Table 8). In this 2025 temperature model, scenarios were analyzed for the refined 2024 Project: 2022 Current Conditions, With Project, No Mitigation (1996 FE); With Project, No Mitigation (2015 FE); VMP and Riparian Reforestation (1996 FE); and VMP and Riparian Reforestation (2015 FE). All temperature changes were characterized as the change in the 7-DADMax in degrees Celsius from the 2022 Current Conditions scenario. The District selected 131 parcels along the upper Chehalis River and Bunker Creek for riparian shade enhancement mitigation. The proposed riparian planting areas are along the mainstem Chehalis River between the FRE facility and Adna, Washington.

Analysis of the 2017 Project demonstrated that the No Vegetation scenario described in the SEPA DEIS (Ecology 2020), including removing all vegetation in the temporary inundation pool, would increase stream temperatures downstream of the FRE above the 2022 Current Conditions scenario by up to 1.2 °C, increase temperatures near Elk Creek up to 0.3 °C, and increase stream temperatures downstream of the South Fork Chehalis by up to 0.1 °C (Table 8). Implementing the VMP would avoid up to 0.5 °C of

temperature increase downstream of the FRE, 0.1 °C near Elk Creek, and 0.1 °C downstream of the South Fork Chehalis. Model results of the VMP5 scenario predicted reduced effects on summer water temperature, with predicted residual effects of 0.7 °C downstream of the FRE, 0.2 °C near Elk Creek (RM 100.2), and 0.0 °C downstream of the South Fork Chehalis (RM 88). Modeling of the shade mitigation downstream showed that stream temperatures downstream of the FRE would still be predicted to increase above the 2022 Current Conditions scenario by up to 0.7 °C, but the temperature increases decrease at locations downstream. With mitigation, temperature increases would be reduced to approximately 0.2 °C near the mouth of Jones Creek (RM 103.7), while no temperature effect was predicted at the confluence of Elk Creek and a small net cooling effect of -0.3 °C was predicted near the confluence of Robinson Creek increasing downstream through the mitigation planting area.

Analysis of the 2024 Project demonstrated that the refined Project design reduced the model temperature impacts. The With Project, No Mitigation scenario for 1996 FE, including mortality of all riparian vegetation inundated for longer than 7 days in the temporary inundation pool, would increase stream temperatures downstream of the FRE above the 2022 Current Conditions scenario by up to 0.6 °C and cause no increase in temperatures near Elk Creek and downstream (Table 9). Implementing the VMP and riparian reforestation along the mainstem Chehalis River would avoid up to 0.3 °C of temperature increase downstream of the FRE, and result in a net reduction of stream temperatures near Jones Creek and downstream. Modeling predicted a maximum cooling effect of between -0.3 °C and -0.5 °C between Jones Creek (RM 104) and the confluence of the South Fork Chehalis River (RM 88), with a maximum cooling of -1.2 degrees near Adna, Washington (RM 81) (Table 9). The predicted thermal benefits of shade mitigation were greatest in late September when sun angles were lower and trees blocked solar input for a greater portion of the day.

**Table 8**  
**Maximum Change in Modeled 7-DADMax Water Temperature During Low-flow Summer Conditions (June 20, 2024 to September 22, 2024) at Locations Along the Chehalis River Downstream of the FRE Under 2017 Project Scenarios**

LOCATION	SEGMENT	VEGETATION		
		NO VEGETATION	MANAGEMENT PLAN (VMP)	VMP + RIPARIAN REFORESTATION
RELATIVE TO 2022 CURRENT CONDITIONS				
Mouth of Crim Cr.	161	3.6 °C	1.6 °C	NA
FRE Facility (RM 108.4)	114	1.9 °C	1.2 °C	NA
Downstream of FRE (RM 106.9)	WB1 Segment 4	1.2 °C	0.7 °C	0.7 °C
Upstream of Jones Cr. (RM 104)	WB2 Segment 12	0.8 °C	0.5 °C	0.2 °C
Near Robinson Cr. (RM 102.7)	WB2 Segment 17	0.6 °C	0.4 °C	-0.3 °C
Near Elk Cr. (RM 100)	WB3 Segment 9	0.3 °C	0.2 °C	-0.3 °C
Near South Fork Chehalis (RM 88)	WB4 Segment 29	0.1 °C	0.0 °C	-0.5 °C
Near Adna, Washington (RM 81)	WB4 Segment 63	0.1 °C	0.0 °C	-1.2 °C

**Table 9**  
**Maximum Change in Modeled 7-DADMax Water Temperature During Low-flow Summer Conditions (June 20, 2024 to September 22, 2024) at Locations Along the Chehalis River Downstream of the FRE Under 2024 Project Scenarios**

LOCATION	SEGMENT	WITH PROJECT, NO MITIGATION		VEGETATION MANAGEMENT PLAN (VMP) & RIPARIAN REFORESTATION	
		1996 FE	2015 FE	1996 FE	2015 FE
		NO VEGETATION WHERE INUNDATED >7 DAYS, RELATIVE TO 2022 CURRENT CONDITIONS		RELATIVE TO 2022 CURRENT CONDITIONS	
Mouth of Crim Cr.	161	4.7 °C	3.4 °C	3.1 °C	2.4 °C
FRE Facility (RM 108.4)	114	1.6 °C	1.2 °C	0.8 °C	0.8 °C
Downstream of FRE (RM 106.9)	WB1 Segment 4	0.6 °C	0.3 °C	0.3 °C	0.1 °C
Upstream of Jones Cr. (RM 104)	WB2 Segment 12	0.5 °C	0.3 °C	-0.5 °C	-0.6 °C
Near Robinson Cr. (RM 102.7)	WB2 Segment 17	0.4 °C	0.2 °C	-0.4 °C	-0.5 °C
Near Elk Cr. (RM 100)	WB3 Segment 9	0.2 °C	0.1 °C	-0.3 °C	-0.4 °C
Near South Fork Chehalis (RM 88)	WB4 Segment 29	0.0 °C	0.0 °C	-0.5 °C	-0.5 °C
Near Adna, Washington (RM 81)	WB4 Segment 63	0.0 °C	0.0 °C	-1.2 °C	-1.2 °C

## Discussion

The NEPA and SEPA DEISs indicated that the Project summer water temperatures would increase as the result of tree mortality and loss of shade in the temporary inundation pool. The 2024 CE-QUAL-W2 model updated the prediction of that potential effect based on 2022 conditions of the timberlands around the upper Chehalis River mainstem. The 2024 model results predicted that the construction and operation of the flow-through dam would be similar to, but slightly less than the DEIS impacts both at the FRE location and downstream. These results provide validation that the District’s model is depicting a similar level of contribution of existing shade and shade loss to the water temperature in the Mitigation Area.

The District’s modeling of mitigation measures outlined in the 2024 RMP predicted that shade restoration associated with the implementation of the VMP and operating the Project as characterized by 2017 operations. The 2024 refined Project design and 2025 (O4P2) operations have reduced the scale and extent of potential temperature impacts further. The O4P2 operations slightly reduced the temperature impacts of a catastrophic flood (1996 FE), and modeling of a more typical major flood (2015 FE) quantified even smaller temperature changes. When compared to the 2017 design, smaller residual temperature effects for the 2024 Project design at the FRE translated to a reduced downstream extent of temperature changes in the Chehalis River, and increased the size and extent of water temperature cooling associated with the proposed riparian reforestation between the FRE and Adna, Washington.

Although overall temperature effects were smaller for the 2024 Project and 2025 operations, a notable exception was at the mouth of Crim Creek. The Ecology temperature model, and District's analysis of the 2017 Project using that model, estimated a temperature increase of 3.6 °C for a No Vegetation scenario and a residual increase of 1.6 °C with the VMP (Table 8); the 2025 model predicted an increase of 4.7 °C for the With Project, No Mitigation (1996 FE) scenario and a residual increase of 3.1 °C with the Vegetation Management Plan and Riparian Reforestation (1996 FE) (Table 9). In investigating the cause of this counterintuitive change, the District identified that the updated terrain model reflected topography with a much narrower channel width, which increases the impact of vegetation changes on stream temperature. This temperature change reflects an improvement of model accuracy related to more current LiDAR data, rather than an increased impact of the 2024 Project design and operations model.

The model scenarios with the VMP and riparian reforestation downstream predicted that the shade-related temperature benefit would be greater in later summer months (August and September). This result is related to the arc of the sun being lower in the sky in September as compared to July and thus, increases the extent of riparian shade across the width of the river. This finding is particularly important for adult Chinook salmon, which spawn in the upper Chehalis River in September.

Similar to other riverine systems throughout the Pacific Northwest, the current riparian shade conditions of the upper Chehalis River between RMs 108 and 86 are substantially degraded and offer ample opportunity for shade enhancement that can mitigate for the residual impact upstream. The results of this temperature modeling exercise in combination with the shade supply analysis presented in the RMP (Appendix G of Kleinschmidt 2024a) demonstrate the feasibility of mitigation to offset temperature effects by restoring riparian shade and reducing the thermal input to the river from the sun.

Shade rehabilitation as mitigation to offset temperature impact has become an accepted practice in the Pacific Northwest. It has been successfully applied in Oregon to offset temperature impacts on the Tualatin, Clackamas, and Rogue rivers. The Tualatin River program has been ongoing the longest and is considered the gold standard for shade mitigation (CWS 2024) The successes achieved in each of these programs exceeded expectations with benefits that extended beyond the intended temperature reduction and included improved water quality from run off, increased counts of adult salmon, increased value of wildlife habitat, and improved recreational and esthetic values. There is every reason to expect that these ancillary benefits of native riparian habitat enhancement also will occur along the upper Chehalis River as a consequence of the proposed shade mitigation.

Ecology has guidelines applicable for this type of temperature mitigation, which the District relied upon to determine the quantity of shade mitigation proposed. As indicated in the RMP and detailed in the 2024 Mitigation Contingency plans TM, there is more shade supply available both along the mainstem river and in tributaries than what is required for mitigation. As this Project advances, it would be

possible to consider alternative configurations of shade mitigation parcels and to evaluate how to maximize the potential benefits of shade mitigation with the modeling tools developed by the District.

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**Attachment 3:**  
**Fish Passage Design Report to Inform SEPA**  
Chehalis River Basin Flood Control Zone District  
February 4, 2026



# Fish Passage Design Report to Inform SEPA

Chehalis River Basin Flood Damage Reduction  
Project

*Lewis County, Washington*

**February 4, 2026**





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## Acronyms

AWS	auxiliary water supply
cfs	cubic feet per second
Ecology	Washington state Department of Ecology
FFPF	Flood Fish Passage Facility
ft/s	feet per second
FRE	Flood Retention Expandable
FRFA	Flood Retention Flow Augmentation
ft-lbs/sec/ft <sup>3</sup>	foot-pounds per second per cubic foot
gpm	gallons per minute
HDR	HDR Engineering, Inc.
NOAA	National Oceanic and Atmospheric Administration
RDEIS	Revised Draft Environmental Impact Statement
RPDR	Revised Project Description Report
SEPA	State Environmental Policy Act
Subcommittee	Fish Passage Subcommittee
TM	Technical Memo
TWG	Technical Working Group
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	U.S. Geologic Survey
WDFW	Washington Department of Fish and Wildlife

# 1 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Cosmopolis during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

Following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), a Chehalis River Basin Flood Damage Reduction draft Preliminary Design Report (PDR) was initiated to document ongoing draft design refinements, as the design process iterates toward a future 30 percent design that will be documented in a completed PDR. The draft PDR records ongoing draft design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements and collects technical details of the main features of the Proposed Project elements as they continue to develop.

A SEPA Revised Draft Environmental Impact Statement (RDEIS) for the Proposed Project was issued on November 20, 2025 with comments due February 4, 2026. To support the submission of comments on the SEPA RDEIS, some draft design elements are being formalized in reports and memoranda to describe the current state of the project design. While still not at a full 30 percent preliminary design level, these elements are at a point at which they can reasonably inform tribal governments, state and federal agencies, partners, stakeholders, and the public about the nature of the project.

# 2 Introduction

The proposed FRE structure includes the following fish passage components, designed to provide passage for a range of species and life stages:

- Flood Fish Passage Facility (FFPF)
- Fishways
- Fish passage conduits
- Temporary channels
- Permanent channels

The fish passage design documented herein focuses on the design updates to the outlet works, which includes the fishways and fish passage conduits. Design updates to these features include updates to the design criteria to comply with current standards and updates to previous concept-level design development. This document also includes a performance and survival assessment for fish passage during normal flow-through operation, flood retention operation, and construction. Finally, the document provides a brief description of a plan and timeline to advance the fish passage design to inform the final Biological Assessment. These activities were performed in collaboration with

Washington Department of Fish and Wildlife (WDFW) and National Oceanic and Atmospheric Administration (NOAA) Fisheries and in conjunction with other physical, biological, and engineering studies and analyses to refine the FRE Proposed Project design, evaluate potential flood damage reduction, and minimize and avoid environmental impact. The Fish Passage Technical Working Group (TWG) also provided input through design update meetings.

## 3 Purpose and Intent

The integration of fish passage systems is a central component of the flood damage reduction structure design. Washington State's regulatory authority defined in Revised Code of Washington 77.57.030, (Fishways required in dams, obstructions – Penalties, remedies for failure) requires that dam owners provide safe and timely fish passage for all fish species and fish life stages present in an affected area. No aquatic species are federally listed as endangered or threatened on this part of the Chehalis River. However, spring and fall Chinook salmon are prey items for the endangered Southern Resident Killer Whale.

Fish passage facility design has occurred simultaneously with facility design efforts throughout the development of the Revised Project Description Report (RPDR). This report summarizes the results and conclusions for select, critical elements of fish passage concept development performed in previous documents, including the RPDR and identifies a roadmap for fish passage design development. The information provided in and appended to this document is intended to be used by the Washington Department of Ecology (Ecology) in development of the final State Environmental Policy Act Environmental Impact Statement.

## 4 Design Criteria

This section describes the criteria used for the preliminary design of fish passage components for the Proposed Project. Previous development identified design criteria based on contemporary design guidance, collaboration with regulatory agencies and nonregulatory entities, and contemporary science. The previously developed design criteria have been updated to reflect current design guidance, science, and collaboration. Future design development will use contemporary guidelines, and the design will be updated accordingly. Refer to Section 7 for additional information regarding potential design criteria revision.

This section notes design criteria that have been confirmed, added to, removed from, or revised from previously published documents.

### 4.1 Collaboration with Technical Committees

From 2016 to 2017, the fish passage design team and members of the Chehalis Basin Strategy Flood Damage Reduction Technical Committee held nine Fish Passage Subcommittee (Subcommittee) meetings. During development of the RPDR in 2023 and

2024, the Fish Passage TWG was formed to continue coordination with members of the Subcommittee. Two TWG meetings were held during development of this study.

The TWG meetings were forums for information transfer, detailed discussion, and making recommendations to the District about the biological and technical aspects of the fish passage facility alternative development. Of primary importance were the discussion, interpretation, and formulation of design criteria.

Participants attending the Subcommittee and TWG meetings included representatives from the following organizations:

- WDFW (Subcommittee and TWG participant)
- U.S. Fish and Wildlife Service (USFWS) (Subcommittee and TWG participant)
- USACE (Subcommittee and TWG participant)
- NOAA Fisheries (Subcommittee and TWG participant)
- Washington Department of Ecology (Subcommittee and TWG participant)
- Quinault Indian Nation (Subcommittee participant; invited to participate in TWG)
- Cowlitz Indian Tribe (invited to participate in TWG)
- State of Washington Consultant Study Team (Subcommittee and TWG participant)

The Quinault Indian Nation and Confederated Tribes of the Chehalis Reservation have been invited to participate in the TWG; but at the time this document was written, neither has attended or participated in these meetings.

In addition to the Subcommittee and TWG meetings, the District's design team met separately with WDFW and NOAA Fisheries to discuss specific design aspects. From 2023 through 2025 the District's design team met with NOAA Fisheries 16 times to gather input from NOAA Fisheries on the proposed design refinements. Topics discussed in the meetings included implementation of the NOAA Fisheries climate change design guidance (NOAA Fisheries 2023a); one, two, and three-dimensional hydraulic modeling results of the proposed conduits, fishways, modifications to the permanent river channel, construction bypass channels, and existing river reaches; dual dedicated fishways; and fish sounding (Appendix B) and lighting (Appendix C). NOAA Fisheries input is reflected in the fish passage design documented in this report.

## 4.2 Biological Design Criteria

In 2016, the Washington State legislature created the Chehalis Basin Strategy, tasking participants with “designing and implementing on-the-ground projects to restore aquatic habitats and protect residents from flood damage.” As part of the Chehalis Basin Strategy, WDFW has led an extensive field sampling program to collect data and better understand the phenology, abundance, habitat requirements, distribution, and migration patterns of fish present within the Chehalis River and, more specifically, in the potentially affected areas of the FRE structure and temporary inundation limits. Using new and historically available data, WDFW assisted the Subcommittee with biological criteria

development, including the following three primary types with the most influence on facility type, size, and configuration:

- **Selected Species and Migration Timing:** Informs the selection of species and life stages targeted for fish passage design and their seasonality, anticipated hydrologic conditions, and the timing of when the target fish species may be expected to migrate upstream and/or downstream of the facility location.
- **Species Abundance:** Informs the annual number of fish and peak daily rate of migration that the facility is designed to pass and that influences facility size and operation requirements. For clarity, species abundance numbers used in designing the fishway *do not represent current or predicted future species abundance* in the Proposed Project vicinity. Rather, these numbers were used to provide a conservative passage design that will meet passage needs under a variety of potential future fish abundance conditions.
- **Trapping and Holding Criteria:** Informs the requirements for fish trapping and holding volume, duration, temperature, and water supply.

Biological design criteria, including the above-listed bullet points, are discussed in the following subsections.

## 4.2.1 General Biological Design Criteria

General biological design criteria apply to all project components where fish passage must be maintained (i.e., dedicated fishways, fish passage conduits, FFPP, permanent Chehalis River and Crim Creek channels, and Chehalis River and Crim Creek construction bypass channels), unless stated otherwise.

### 4.2.1.1 Selected Species and Migration Timing

The selection of fish species and life stages for fish passage design was derived from field-specific data obtained by WDFW in 2015 and 2016 and readily available historical documentation developed for the Chehalis Basin. In general, Washington State interprets the Revised Code of Washington 77.57.030 to require provisions for passage of all fish and fish life stages believed to be present in the system.

For development of the general upstream and downstream fish passage criteria, anadromous and resident species known to occur in the vicinity of the FRE structure, in the temporary inundation area, and upstream of the temporary inundation area were selected as target species. These target species and their known swimming and leaping abilities were used to develop specific technical design criteria. Of the target species, salmonids, cutthroat trout, and lamprey were identified as priority species due to the greater abundance of biological, swim, and leaping data available for them as well as their importance to federal regulators and indigenous peoples. Other species known to occur downstream of the FRE site were selected for consideration but did not directly influence the development of specific technical design criteria.

The life histories and specific life stages of each target species were also considered relative to their known occurrence, distribution, and movement through the FRE site. Life

stages of specific species were selected if they have been observed moving or are believed to move through the FRE site (either upstream or downstream).

Table 1 presents the selected target fish species and their respective life stages.

**Table 1. Target Fish Species and Life Stages Selected for Design Development**

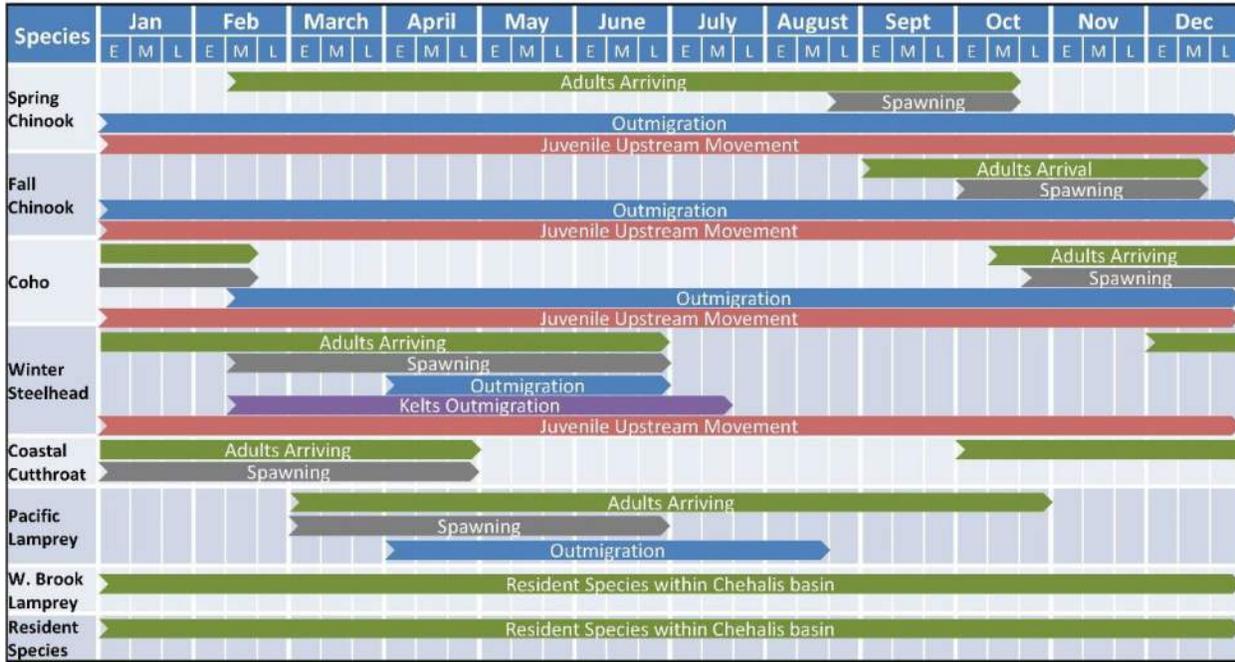
Species	Upstream	Downstream
Spring-run Chinook Salmon	Adult, juvenile	Juvenile
Fall-run Chinook Salmon	Adult, juvenile	Juvenile
Coho Salmon	Adult, juvenile	Juvenile
Winter-run Steelhead	Adult, juvenile	Adult, juvenile
Coastal Cutthroat Trout	Adult, juvenile	Adult, juvenile
Pacific Lamprey	Adult	Ammocoetes, Macrophthalmia
Western Brook Lamprey	Adult	Ammocoetes, Macrophthalmia
<b>Resident Fish:</b> river lamprey, largescale sucker, Salish sucker, torrent sculpin, reticulate sculpin, riffle sculpin, prickly sculpin, speckled dace, longnose dace, peamouth, northern pikeminnow, redside shiner, rainbow trout, mountain whitefish	Adult	Adult

Passage technologies for lamprey are relatively new, and few facilities exist in the western United States for passage or collection and transport above dams. Where applicable, readily available best practices, lessons learned from experimental facilities on the Columbia River, and interviews with researchers who specialize in understanding lamprey behavior and navigational capabilities were used to inform lamprey passage facility requirements and anticipated performance. In addition to salmonids and the anadromous Pacific lamprey, multiple resident fish species and two species of resident lamprey (Western Brook and River) are believed to inhabit and transit the proposed FRE area (Table 1). Therefore, these resident species are also included as target species.

Many of the target species have unique migration behaviors and are believed to pass upstream or downstream through the FRE site at specific times of the year. Fish species migration timing and duration influence the design and operation of proposed fish passage facilities by defining the physical, operational, and environmental conditions expected to occur while passage is required. The migration timing and duration for each selected fish species and life stage were discussed at Subcommittee/TWG meetings as new information was collected in the field and from literature sources. The resulting conclusions were used in fish passage design development (Figure 1). The selected values in Figure 1 summarize upstream migration, spawning, and outmigration periods suitable to inform robust fish passage designs. The periods shown in Figure 1

incorporate anecdotal data of species presence at the extreme ends of known movement periods and thereby are anticipated to be broader than what may actually be found in the river. Aquatic target species' actual migration and spawning periods are far more complicated and nuanced.

Figure 1. Anticipated Migration Periods of the Targeted Species and Life Stages (Periodicity)



#### 4.2.1.2 Species Abundance

Fish abundance numbers for use in designing the Proposed Project's fish passage were evaluated by WDFW and discussed during Subcommittee meetings. As previously noted, species abundance numbers used in designing the fishway *do not represent current or predicted future species abundance* in the Proposed Project vicinity. Rather, these numbers were used to provide a conservative passage design that will meet passage needs under a variety of potential future fish abundance conditions. Specifically, abundance was described for the design in terms of peak annual and peak daily rates of migration. The peak daily rate of migration for upstream and downstream migrating fish influences the size of many fish passage components. Documents and information provided by WDFW (2016a and 2016b) during Subcommittee meetings were used in the design development of FFPF component sizes and capacities. The species abundance used in design are summarized in the subsections below.

#### Upstream Migration

Upstream migration rates developed for fish passage design are based on two factors: 1) historic data relative to adult spawner survey results and escapement records, and 2) proposed annual peak goals after project implementation and potential habitat restoration. Table 2 provides the design peak rate for annual migration of adult salmonids moving upstream.

**Table 2. Peak Annual Upstream Migration Numbers Used to Inform FFPF Design**

Species	Peak Annual Migration Numbers Informing FFPF Design
Spring-run Chinook Salmon	1,350
Fall-run Chinook Salmon	3,900
Coho Salmon	12,900
Winter-run Steelhead	5,630

The numbers for adult upstream-migrating Pacific lamprey, cutthroat trout, resident fish, and juvenile salmonids were not developed for fish passage design. Although these species are an important influence on the overall design of each fish passage alternative, their peak rate of migration is currently unknown and not anticipated to materially influence facility size, which is based on adult salmonids.

The peak daily counts of salmon and Steelhead migrating upstream were estimated as 10 percent of the maximum annual run (WDFW 1993), and peak hourly counts were estimated as 20 percent of the peak daily count based on Bell (1991) and as cited in NOAA Fisheries (2011). When both criteria results are applied, the peak hourly count is 2 percent of the annual run for each species. Using this methodology and based on the run timing information in Figure 1, a combined peak daily count of roughly 2,000 adult salmonids and a peak hourly count of 400 adult salmonids were used for design purposes.

### Downstream Migration

Table 3 summarizes the total juvenile abundance numbers recommended by the TWG for use in the design of downstream fish passage for juvenile salmon and Steelhead, representing sub-adult fish produced upstream of the location selected for the FRE.

**Table 3. Abundance<sup>1</sup> of Juvenile Salmon and Steelhead Downstream Migrants from Freshwater Habitat above River Mile 108 of the Chehalis River used to inform FFPF Design**

Species	Life Stage	Migration Period	Maximum Abundance Number for FFPF Design
Coho Salmon	Fall parr	September–December	340,000
	Spring smolt	March–June	17,000

<sup>1</sup> Species abundance numbers used in designing the fishway *do not represent current or predicted future species abundance* in the Project vicinity. Rather, these numbers were used to provide a conservative passage design that will meet passage needs under a variety of potential future fish abundance conditions



Species	Life Stage	Migration Period	Maximum Abundance Number for FFPF Design
Steelhead Trout	Fall parr	September–December	97,000
	Spring smolt	March–June	14,500
Chinook Salmon	Subyearling (fry)	January–April	229,000
	Subyearling (parr/smolt)	May–August	114,500
	Yearling	March–June	11,000
Other Species	Data unavailable to support conclusions regarding downstream migration.		

For spring smolts, freshwater capacity and migration timing were used to predict total daily arrivals between January and August using two example migration curves originating from other river systems. Timing curve 1 represented a free-flowing river (Coweeman River), whereas timing curve 2 represented a dammed river where smolts rear in cooler stream temperatures and navigate a reservoir during their downstream migration (Cowlitz River). The daily numbers (mean and maximum values) of downstream migrants used for fish passage design were similar between the two migration timing curves when the considered species were included. However, when only Coho salmon and Steelhead trout were included, mean and maximum values were higher under timing curve 1 than timing curve 2. The difference between the two scenarios results from the smolts of Coho salmon and Steelhead trout having a more protracted migration timing under timing curve 2 than timing curve 1.

For fall migrants, timing curves were not available, and daily numbers were approximated for the design based on available information (WDFW 2016a and 2016b). Daily numbers of fall migrants used for fish passage design were based on the maximum daily values derived for spring smolts of Coho salmon and Steelhead trout increased by a multiplier of 17.0. The resulting maximum daily abundance selected for design purposes is 55,505 smolts as indicated in Table 4. As noted above, these numbers do not represent current or predicted smolt daily abundance numbers and were used to inform FFPF design features only.

**Table 4. Daily Numbers of Downstream Migrant Fish Species Used to Inform FFPF Design<sup>2</sup>**

Data include: juvenile salmon and steelhead from freshwater habitat upstream of river mile 108 in the Chehalis River.

Daily Metric	Spring Smolts (Jan–Aug)		Spring Smolts (Jan–Aug) Coho and Steelhead Only		Fall Smolts (Sep–Dec) Coho and Steelhead Only	
	Daily Abundance to Inform FFPF Design					
	Timing 1	Timing 2	Timing 1	Timing 2	Timing 1	Timing 2
Mean	1,919	1,882	203	82	3,451	1,394
Maximum	11,013	10,935	3,265	668	55,505	11,356

#### 4.2.1.3 Resident Fish

NOAA Fisheries (2023a) and WDFW (2000a, 2000b) have established guidelines for salmonid passage facility design, but little data exists regarding the passage of lamprey and resident fish species through fish passage facilities. The Subcommittee, with support from the team’s USFWS representative, assembled relevant biological data for the target resident species, lamprey, and salmonids but was unable to find data about all target resident species. A summary of the data compiled for each species is provided in Table 5. Through continued collaboration with the TWG, fish passage is being designed to accommodate the resident species listed in Table 5 to the extent possible, without adversely affecting facility performance for priority species (salmonids, cutthroat trout, and lamprey).

**Table 5. Locomotive and Biological Data Availability**

Species		Data Collected*	
Life Stage	Common Name	Swim Speed	Jump Height
Adult	Spring-run Chinook Salmon	•	•
Adult	Fall-run Chinook Salmon	•	•
Adult	Coho Salmon	•	•
Adult	Winter-run Steelhead	•	•
Juvenile	Spring-run Chinook Salmon	•	•
Juvenile	Fall-run Chinook Salmon	•	•
Juvenile	Coho Salmon	•	•
Juvenile	Winter-run Steelhead	•	•

<sup>2</sup> Species abundance numbers used in designing the fishway *do not represent current or predicted future species abundance* in the Project vicinity. Rather, these numbers were used to provide a conservative passage design that will meet passage needs under a variety of potential future fish abundance conditions

Species		Data Collected*	
Life Stage	Common Name	Swim Speed	Jump Height
Adult	Coastal Cutthroat Trout	●	●
Adult	Pacific Lamprey	●	Not applicable
Adult	Western Brook Lamprey	●	Not applicable
Adult	River Lamprey	●	Not applicable
Adult	Largescale Sucker	●	No data found
Adult	Salish Sucker	●	No data found
Adult	Torrent Sculpin	Not applicable	No data found
Adult	Reticulate Sculpin	Not applicable	No data found
Adult	Riffle Sculpin	Not applicable	No data found
Adult	Prickly Sculpin	Not applicable	No data found
Adult	Speckled Dace	●	No data found
Adult	Longnose Dace	●	No data found
Adult	Peamouth	●	No data found
Adult	Northern Pikeminnow	●	No data found
Adult	Redside Shiner	●	No data found
Adult	Rainbow Trout	●	No data found
Adult	Mountain Whitefish	●	No data found

● = Indicates a data source was identified

### 4.3 Technical Design Criteria

This section identifies technical design criteria, sources, and guidance for the development of fish passage designs. Technical fish facility design criteria typically fall into two categories: criteria and guidelines. Criteria are specific standards for fish passage design that require an approved variance from the governing state or federal agency before a design can deviate from the established criteria. Deviating from an agency-established criterion requires establishing a site-specific, biological- or physical-based rationale for the deviation.

In contrast, guidelines provide a range of values or specific values the designer should seek to achieve but that can be adjusted for project-specific conditions to achieve the overall fish passage objectives by supporting better performance or solving site-specific issues. Governing agencies may request adjustments to a design during development.

The technical design criteria used in the RPDR were primarily developed in previous design phases and documented in previous design documents. The NOAA Fisheries fish passage design guidance has been updated since the previous design documents. The design criteria in this report and appendices reflects design criteria from the current NOAA Fisheries guidance (2023a). If two or more agencies provide differing guidance on a design criterion, the most conservative guidance for fish passage and protection will be followed. The following documents provide the guidelines used during the previous conceptual design and the current design:

- NOAA Fisheries WCR Anadromous Salmonid Design Manual. (NOAA Fisheries 2023a)
- NOAA Fisheries WCR Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change (NOAA Fisheries 2023c)
- Anadromous Salmonid Passage Facility Design (NOAA Fisheries 2011)
- Best Management Practices to Minimize Adverse Effects to Pacific Lamprey (USFWS 2010)
- Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual (WDFW 2009)
- Fishway Guidelines for Washington State (WDFW 2000a)
- Fish Protection Screen Guidelines for Washington State (WDFW 2000b)
- Water Crossing Design Guidelines (WDFW 2013)

### 4.3.1 General Technical Design Criteria

Technical design criteria for each fish passage component of the Proposed Project are discussed in the following subsections. General fish passage criteria apply to project components where fish passage must be maintained (i.e., conduits, fishways, FFPF, and construction bypass), unless shown otherwise.

#### 4.3.1.1 Fish Passage Design Flows

Fish passage design flow criteria influence several factors associated with fish passage facility size and complexity. NOAA Fisheries and WDFW provide guidelines for the selection of high and low flows to be used in the design of fish passage facilities. These guidelines are based on exceedance calculations of mean daily flows but can be modified to accommodate site-specific requirements. The exceedance flows statistically represent the flow equaled or exceeded during certain percentages of the time when migrating fish may be present. The established guidelines are used to set instream flow depths, flow velocities, debris and bedload conditions, fish attraction requirements, tailwater fluctuations, and numerous other factors that a facility may experience while target fish species are migrating.

NOAA Fisheries (2023a) requires the high fish passage design flow to be the mean daily stream flow that is exceeded 5 percent of the time during periods when target fish species are migrating using the 90th percentile t-distribution of the late-century ensemble

climate change projection. WDFW (2000b) suggests a 10 percent exceedance flow be used as a high design flow using hydrologic analysis of the historic period of record. NOAA Fisheries (2023a) requires a low fish passage design flow equal to the mean daily stream flow that is exceeded 95 percent of the time during periods when migrating fish are typically present using the 90th percentile t-distribution of the late-century ensemble climate change projection. Because using the 90th percentile t-distribution for the 95 percent exceedance resulted in increased, not decreased flows, NOAA Fisheries agreed that the 95 percent exceedance should be based on the late-century ensemble mean. WDFW recommends that a low flow be established based on site-specific conditions using hydrologic analysis of the historic period of record. A flow range between the 95 and 5 percent exceedance flows based on the late-century ensemble of climate change models provides the widest range of flows for which facilities should be capable of passing fish. Therefore, this flow range is set as the design criterion for the proposed facilities.

Per *NOAA Fisheries WCR Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change* (NOAA Fisheries 2023c), the effects of climate change need to be considered when establishing fish passage design flows. As the fish passage conduits have a life expectancy of more than 10 years, the Proposed Project must follow the process for long-term projects defined in Section 2.3 of the guidance. This nine-step process is underway and collaboration with NOAA Fisheries is ongoing at document publication. The current process ends with final design. A NOAA Long-Term Project Climate Change TM (HDR 2026) documents the first seven steps and is available to Ecology upon request. On September 26, 2025, NOAA Fisheries established the fish passage design flows based on this process. The high and low fish passage design flows are 3,200 and 11 cfs, respectively.

#### 4.3.1.2 Sediment Continuity Design Flow

The Chehalis River Basin Flood Control Zone District has committed to maintaining the continuity of movement for spawning gravels passing downstream through the FRE structure. This commitment includes passing river flow at levels capable of mobilizing and transporting spawning gravel in an open channel(s) through the FRE structure. The river flow “capable of fully mobilizing the surface armor layer of spawning substrates...” is identified as the current climate 2-year flood event (Kleinschmidt 2024). Kleinschmidt states the river flow mobilizing spawning gravel is about 6,976 cfs, which corresponds to about a 2-year flood event according to the hydrologic analysis they cite. Recent hydrologic analysis by HDR has identified the Chehalis River flow for the current climate 2-year flood as 9,500 cfs (HDR 2025). The conduits are designed to pass 13,700 cfs, well above 9,500 cfs, in an open channel condition, more than is needed to pass the sediment mobilizing river flow identified by Kleinschmidt.

#### 4.3.1.3 Fish Passage Conduits

At the time of Subcommittee consultations, the fish passage conduits were intended to provide primary, year-round, safe, volitional upstream and downstream passage for migrating adult salmon and Steelhead, resident fish, and lamprey for the full range of fish passage flow conditions as required by NOAA Fisheries criteria. During a 2014 study by

HDR, criteria used to assess the fish passage conduits was based on the 2013 *Water Crossing Design Guidelines* document, which suggests that a minimum hydraulic design target of 0.8 feet of water depth and maximum flow velocity of 2 feet per second (ft/s) be used for water crossing structures with lengths of approximately 200 feet. However, in consultation with members of the Subcommittee in 2015 and 2016, it was determined that the natural flow characteristics in this reach of the river were more restrictive to passage than WDFW's guidelines. It was agreed that the hydraulic conditions in the natural channel upstream and downstream of the passage tunnels (fish passage conduits) would negate the passage benefit of designing the tunnels to WDFW's guidelines. Therefore, the Subcommittee concluded that the proposed flow velocity and depth through the conduits mimic the flow velocity and depth occurring naturally through the existing river reach at the FRE. This premise influenced the overall approach for designing and evaluating performance of upstream and downstream passage through the conduits. As such, the proposed approach cannot be categorized as the hydraulic design method or the stream simulation method but rather a site-specific approach that incorporates elements of both.

This design approach was revisited and presented to WDFW, NOAA Fisheries, and the TWG during the course of this study, who raised no objections. The location of the existing rock-incised channel was shared with the TWG on January 17, 2024.

#### 4.3.1.4 Swimming Capability

Swimming and leaping capabilities for target species were used in developing the draft hydraulic fish passage criteria. The Subcommittee decided fish passage through the FRE during run-of-river conditions must mimic the hydraulic conditions of the existing rock canyon located immediately downstream of the proposed FRE. Specific, measurable criteria to this effect were defined during an April 4, 2025 meeting with NOAA Fisheries. The specific hydraulic design criteria were based on the swim speed of the target species. A table of species' swim speeds was shared and discussed with NOAA Fisheries in a meeting with NOAA Fisheries on March 4, 2025. Discussion in this meeting led to establishing the hydraulic criteria. The hydraulic criteria are grouped into three ranges of river velocity based on the swim capabilities of the target species and life stages:

- 0 to < 1.5 feet per second (ft/s) resident/juvenile salmonid prolonged
- 1.5 to < 3.5 ft/s adult salmonid sustained
- 3.5 to 7 ft/s adult salmonid prolonged

These river velocity ranges and the specific fish passage requirements associated with them have not been finalized with NOAA Fisheries. For this evaluation, the following **draft passage criteria** were used where the river flow was within the fish passage design flow range:

- 0 to < 1.5 ft/s resident/juvenile salmonid prolonged and 1.5 to < 3.5 ft/s adult salmonid sustained.
- A continuous flow pathway **must be provided** through the proposed FRE structure with flow velocities within these ranges where three-dimensional computational fluid

dynamic modeling indicates a continuous pathway exists for this velocity range through the existing rock canyon 3.5 to 7 ft/s adult salmonid prolonged.

- A continuous flow pathway is **preferred but not required** through the proposed FRE structure with flow velocities within these ranges where three-dimensional computational fluid dynamic modeling indicates a continuous pathway exists for this velocity range through the existing rock canyon.

#### 4.3.1.5 Juvenile Fish Sounding

Appendix B (Juvenile Fish Sounding TM) summarizes the research and findings related to the potential risk of juvenile entrainment in the unscreened, high velocity evacuation conduits at this location on the Chehalis River. The research and findings in this Technical Memo (TM) were discussed with NOAA Fisheries in 2025. The TM concludes that most juvenile salmonids likely would not sound deeper than 30 feet in a temporary inundation pool at the FRE structure and would have limited exposure to potential entrainment and flood operation conditions at the FRE. A hydraulic outlet that does not exclude fish or provide safe downstream passage through hydraulically favorable conditions must only discharge flow during flood retention operation when the water surface is 30 feet or more above the top of the same hydraulic outlet. Hydraulic outlets that discharge when the water depth is less than 30 feet must have a smooth inlet transition, such as curved entrances and radial gates. Accordingly, evacuation conduits will remain unscreened and the 30-foot depth threshold be used to govern evacuation operations.

#### 4.3.1.6 Fishways

The original concept of fish passage conduits relied on multiple conduits, arrayed at staggered invert elevations, with different sizing and roughness features to support passage hydraulics across the range of fish passage design discharge. Additionally, these conduits are subject to evaluation criteria related to temporary inundation area evacuation and passage of the 2-year event, which conflict with attempts to optimize for fish passage. To meet design criteria and deconflict competing requirements, a revised conduit and stilling basin configuration is proposed to support fish passage and provide more reliable sediment throughput. This design revision includes dual outboard technical fish ladders as fishways (Figure 3; Section 5.1).

#### 4.3.1.7 Lamprey Passage

As requested by participating resource agencies and Indian Tribes, the best available science for lamprey passage was considered throughout the design. Lessons learned from experimental facilities on the Columbia River, and interviews with researchers who specialize in understanding lamprey behavior and navigational capabilities were used to inform lamprey passage facility requirements, which are summarized in Table 6.

The following resources outline several best practices that were used to form a basis of design for lamprey passage technologies and measures:

- Technical White Paper: Practical Guidelines for Incorporating Adult Pacific Lamprey Passage at Fishways, Version 2.0 (Lamprey Technical Workgroup 2022)
- Use of Adult Pacific Lamprey Passage Structures at Bonneville and John Day Dams (USACE 2019)
- Passage Guidelines for Select Native Pacific Northwest Fish, USFW Region 1, Version 2.0 (USFW 2025)
- Technical Report 2015-5: Design Guidelines for Pacific Lamprey Passage Structures, Portland District (USACE 2015)
- Barriers to Adult Pacific Lamprey at Road Crossings: Guidelines for Evaluating and Providing Passage, Version 1.0 (Lamprey Technical Workgroup 2020)

**Table 6. Lamprey Upstream Passage Criteria**

Criteria	Value	Reference
Free swimming flow velocity	<2.95-3.9 ft/s	Lamprey Technical Workgroup 2022
Max burst free swimming flow velocity	<8.2-9.8 ft/s	Lamprey Technical Workgroup 2022
Ramp width	1.0 ft, min 2.0 ft, min	Lamprey Technical Workgroup 2022, USACE 2015
Resting area velocity	2.95 ft/s, max	Lamprey Technical Workgroup 2022
Water depth in ramp	1 foot, min	Lamprey Technical Workgroup 2020, USFWS 2025
Wetted Surface Finish	Smooth, 1.2 inch gap, max	USFWS 2025
Diffuser Grating	0.5 inches or less	Lamprey Technical Workgroup 2022

#### 4.3.1.8 Trashracks

Trashracks are commonly used at fishway exits and entrances to prevent large debris from entering fish passage facilities. They are also used at fish passage conduits. Table 7 lists the design criteria for trashracks.

**Table 7. Trashrack Criteria**

Criteria	Value	Reference
Velocity	1.5 ft/s, maximum	NOAA Fisheries 2023a
Water depth	Equal to fish ladder exit pool depth	

Criteria	Value	Reference
Bar spacing	10 inches, minimum	
Support bar spacing	24 inches, minimum	
Slope	1 horizontal 5 vertical	

#### 4.3.1.9 Constructed Channels

A reference reach design approach to be used for the permanent Chehalis River approach and discharge channels, for Crim Creek confluence, and for the construction phase Chehalis River and Crim Creek bypass channels (WDFW 2013, NOAA Fisheries 2023b). This approach was presented to WDFW, NOAA Fisheries, and the TWG during the course of this study, who raised no objections. The locations of the reference reaches were shown in slides at the January 17, 2024 TWG meeting.

#### 4.3.2 General Operating Criteria

Operational trigger, rules, and frequency for impoundment events is described in the Environmental Impact Reduction Due to Refinement of Proposed Reservoir Operations and Debris Management During Retention Operations TM which is appended to the District’s comments on the SEPA RDEIS. “Impoundment events” refer to flood operations triggered by high flows at Grand Mound but do not include backwater events. Backwater events are infrequent events where the river flow exceeds the open-channel capacity of the conduits, and some water is retained upstream of the FRE structure. The number and duration of backwater events that would have occurred during the historic period of record is described in Appendix D - Backwater Analysis Pool Frequency with Conduit Gates Open (Draft) TM.

During impoundment events that coincide with flood retention activities, downstream passage of outmigrating fish will be delayed. During Flood Retention Operations, the conduit gates will be operated to control flow release and retain water upstream of the facility. Outmigrating fish entering the temporary inundation area at this time will also be temporarily delayed until the pool drains and open channel river flow resumes. When the inundation pool depth is lower than the juvenile fish sounding depth, either early as the inundation pool begins filling or when it is almost fully drained, flow must be released through gates designed for fish passage or through outlets that exclude fish passage in accordance with federal and state criteria. When the inundation pool is below sounding depth, some fish may choose to pass downstream via gates designed for fish passage. Downstream passage through conduits with fully open gates will resume when normal operation resumes.

Note that backwater is expected to occur when the river’s natural flow is greater than the capacity of the fish passage conduits but not enough at Grand Mound to trigger an impoundment event. Backwater is expected to occur once river flow reaches 13,700 cfs. River flow data was analyzed for the historic period 1982–2022. For this historic period, backwater events are estimated to have occurred on average once every 3.3 years and

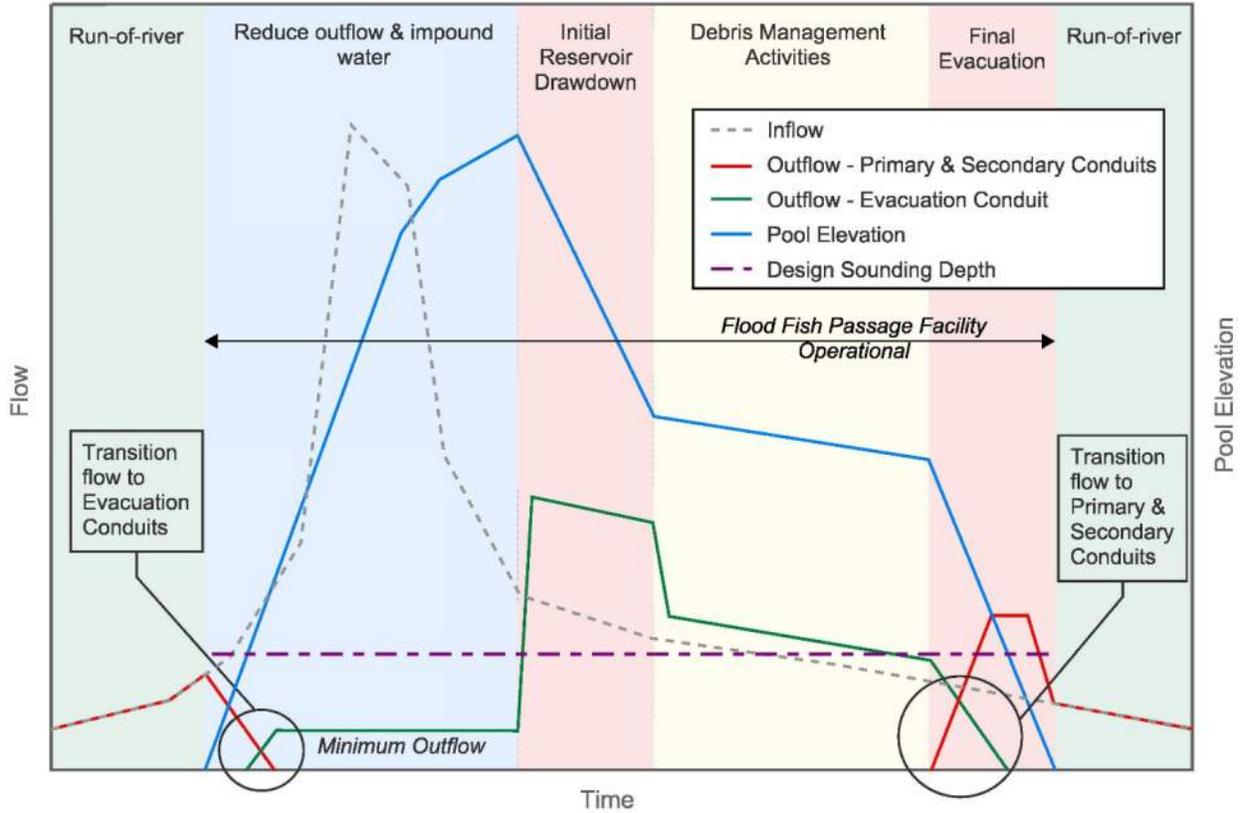
last an average of 3.6 hours, with the maximum duration being 6.5 hours (Appendix D). Backwater is expected to occur for flows well above the range of flows during which the project must provide fish passage (11 to 3,200 cfs; Section 4.3.1.1). During these temporary pooling (backwater) events, the fish passage conduit gates will not be operated and will remain fully open, and operation of the FFPF will not be required. Fish are anticipated to reside or shelter below the facility during such events (which are short in duration) and continue passage once conditions improve.

#### 4.3.2.1 Water Supply

Water supply for the AWS and FFPF can be provided by pump station or via gravity. The Subcommittee agreed AWS may be provided solely via gravity from the impoundment pool when the impoundment pool depth exceeds the juvenile fish sounding depth. A literature review of juvenile sounding depth was conducted and discussed with NOAA Fisheries. The sounding depth used in the current design, as agreed upon with NOAA Fisheries, is discussed in Section 4.3.1.5, and documented in Appendix B. When the water depth in the inundation pool is less than the design sounding depth, water from the inundation pool must either be screened to exclude fish in accordance with NOAA Fisheries (2023a) and WDFW (2000b) guidance or provided from another source meeting the same screening requirements, such as from a pump station. Figure 2 is a graphed impoundment event example showing unscreened discharge (evacuation conduits) only being used when the impoundment pool depth exceeds the design sounding depth.

The amount of attraction flow required varies with changes in river flow. During FFPF operation all river flow at the FFPF location comes from inundation pool discharge. When the inundation pool discharge is greater than the high fish passage design river flow (refer to Section 4.3.1.1), the FFPF will continue to operate and attraction flow is not required to exceed 300 cfs. Attraction flow must be greater than 5 percent of the river flow for flows below the high fish passage design flow. AWS may not be necessary to meet this requirement at lower river flows as operational flows from the fish ladder may be sufficient to meet attraction flow requirements.

Figure 2. Attraction Water and Auxiliary Water Supply Durations During a Sample Impoundment Event



## 5 Fish Passage Outlet Works Design

This section summarizes the fish passage outlet works design.

FRE facility operation occurs in two main operational states:

- **Normal Operation:** When the fish passage and hydraulic outlet gates are open and the Chehalis River flows through the FRE unimpeded.
- **Flood Retention Operation:** When the fish passage gates are closed and openings on the hydraulic outlets are reduced to impound incoming floodwaters behind the FRE.

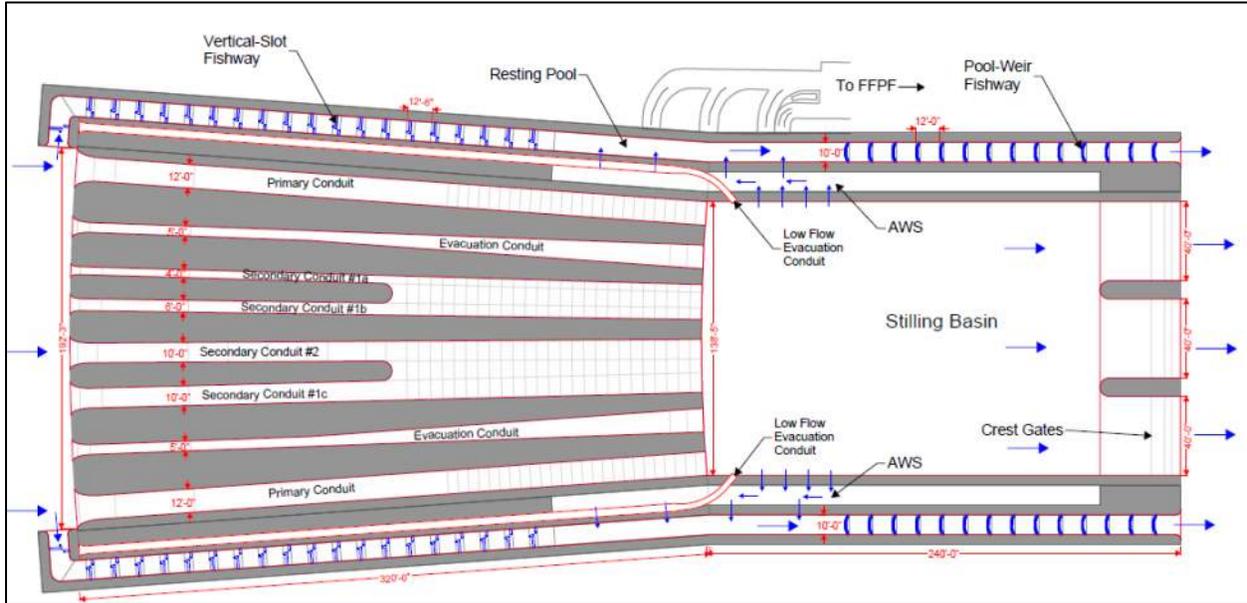
Upstream fish passage during Normal Operation is primarily provided by dual fishways located adjacent to the FRE outlet works. Passage conduits serve as secondary upstream passage pathways and the primary downstream pathway.

### 5.1 Fishways and Conduits

During Normal Operation, dual fishways serve as the primary feature facilitating upstream fish passage (Figure 3). The entrances to the fishways are located adjacent to the stilling basin endsill crest gates. Following input from NMFS during consultation, these gates are raised for flows within the fish passage design discharge range to serve

as a vertical passage barrier. The passage conduits remain open, except under low flow conditions, but function primarily to provide downstream passage to the stilling basin and beyond. Within the range of fish passage flows, the passage conduits will be able to support upstream escape for fish in the stilling basin due to fallback.

**Figure 3. Fishway and Passage Conduit Layout**

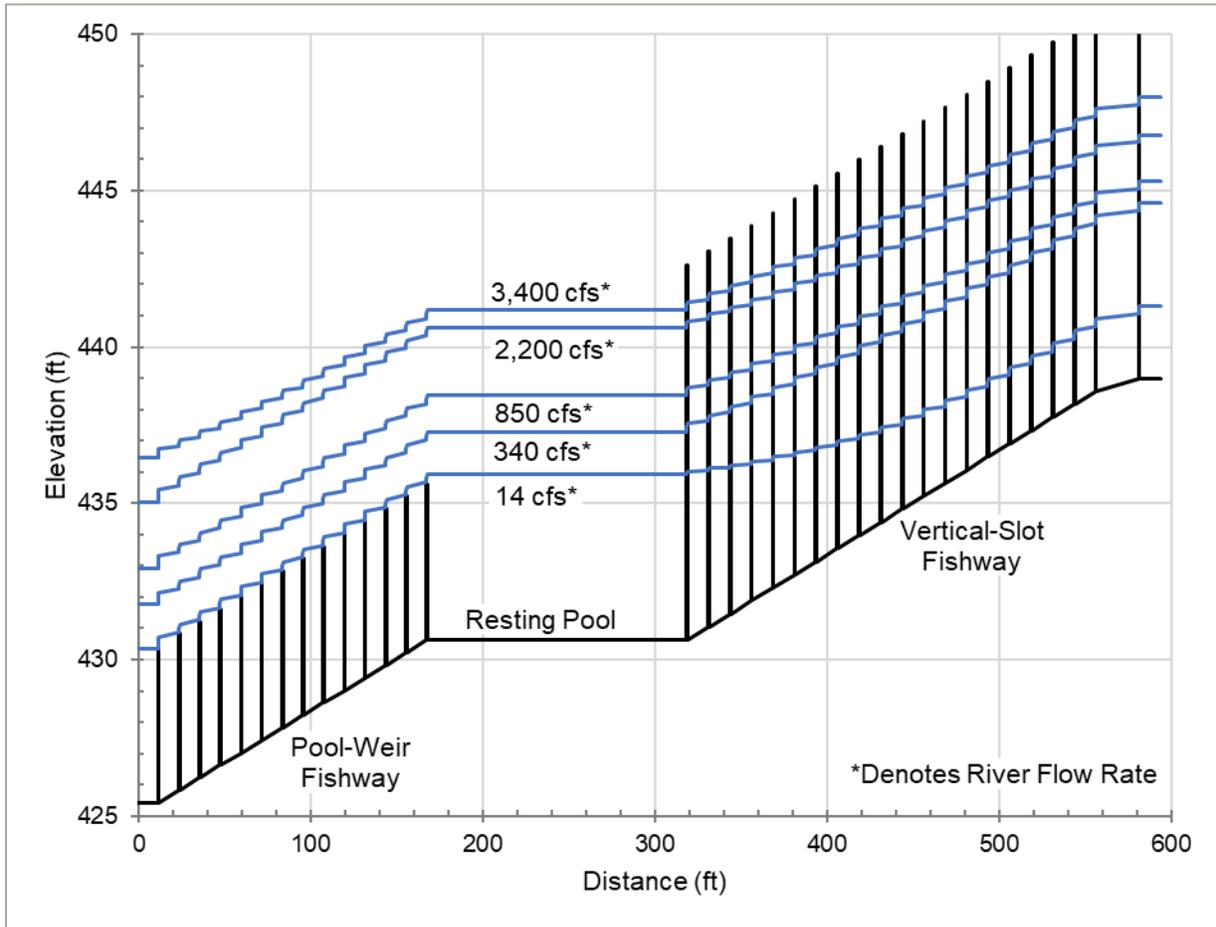


### 5.1.1 Fishways

Technical fish ladders consist of a concrete fish ladder passing through the FRE structure. The design target hydraulic differential between baffles in the ladder will follow standard agency design guidelines for the upstream passage of juvenile salmonids. Pool geometry will be established using NOAA Fisheries (2023a) guidelines and consider the specific baffle type selected for the ladder. A fish ladder will be composed of typical pools which may include resting pools, turning pools, and potentially multiple exit pools to account for temporary inundation area stage fluctuations. This technology requires consideration of guidance, attraction, and collection strategies for the fish ladder entrance as well as debris, temperature, and flow control provisions.

There will be two fishways on either side of the conduits to provide reliable fish passage upstream of the FRE. The fishways will consist of three main components: the pool-weir, resting pool, and vertical-slot sections. The fishway will be 10 feet wide through all the different sections. The pool-weir section will be at the fish entrance and contain a bent weir with a 90-degree V-notch for low flows. The resting pool will contain a vertical screen for additional flow from the AWS, and fish entrances on the left fishway for the FFPF. The vertical-slot section will continue through to the fish exit and have a slot width of 1.25 feet. Figure 4 shows the water surface elevations through the fishway.

Figure 4. Fishway Water Surface Profiles



### 5.1.2 Conduits

The fish passage primary and secondary conduits will operate with gates open for downstream fish passage and sediment transport but be closed for Flood Retention Operation. There are some instances where gates are closed to facilitate fish passage at lower flows, when only the fishways are in operation. During initial phases of flood retention, the passage conduit gates will be used to regulate the flow until flow control is transferred to the evacuation conduits. After the passage conduit gates are closed, the evacuation conduit will be used for reservoir releases. The secondary conduits will be used for emergency flood releases or reservoir drawdown when the required capacity is insufficient to meet the required flow.

The passage conduit sizing and configuration will support upstream passage for the fish passage design flow range. Under these conditions, the stilling basin endsill is raised to serve as the tailwater control necessary to support the requisite passage depth and velocity criteria.

### 5.1.2.1 Controlling Flow Design Scenarios

The controlling flow design scenarios were compiled to better understand and evaluate the effectiveness of the primary, secondary, and evacuation conduits to meet the potential flow requirements. During flow-through conditions, all the gates are fully open, except for during very low flow when only the fishways are operating. During flood retention, the gates are throttled or closed. Special considerations are included to ensure downstream fish passage at sounding depths under a throttled gate. The minimum flow during flood retention can occur at any elevation up to the spillway crest elevation. Design provisions include adding a narrower secondary conduit to facilitate minimum releases at lower pool elevations, and a low-flow evacuation conduit to make minimum releases at pool elevations near the spillway crest elevation. The maximum flow during flood retention is accommodated using the two evacuation conduits. If additional flow is required, then the secondary conduits will be used to supplement the maximum flow. Table 8 provides a high level summary of the controlling flow design scenarios.

**Table 8. Controlling Flow Design Scenarios**

Description		Value (cfs)
Flood Retention Gates Regulate Outflow	Minimum Flow	300
	Maximum Flow	10,000
Flow-Through Gates Fully Open	Fish Passage Flows	14 – 3,400
	Sediment Mobilization Flow	7,000 – 9,500
	Maximum Flow	13,700

cfs = cubic feet per second.

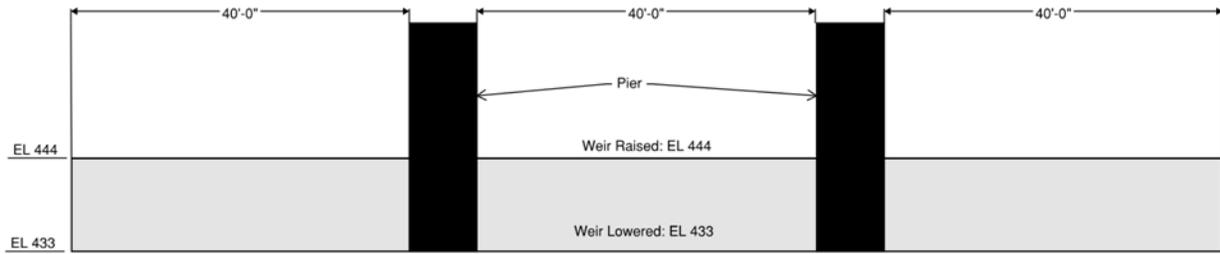
### 5.1.2.2 Primary and Secondary Conduits

The primary and secondary conduit features, described from downstream to upstream include the end sill, stilling basin, conduit profiles, and conduit entrance.

#### End Sill Crest Gates

The end sill is intended to provide sufficient backwater to prevent a hydraulic jump from forming within the conduits, thus limiting the velocity in the conduits and providing sufficient depth for fish passage. The end sill will also provide sufficient water depth in the stilling basin to provide the AWS (auxiliary water supply) to the fishways via gravity flow. Lastly, the end sill directs fish toward the fishways providing connectivity to the upstream channel. The end sill will have three 40-foot bays with two piers to house the adjustable crest gates that can be raised or lowered during times of sediment mobilization or fish passage conditions. Figure 5 shows the adjustable end sill crest gates concept.

**Figure 5. End Sill Configuration**

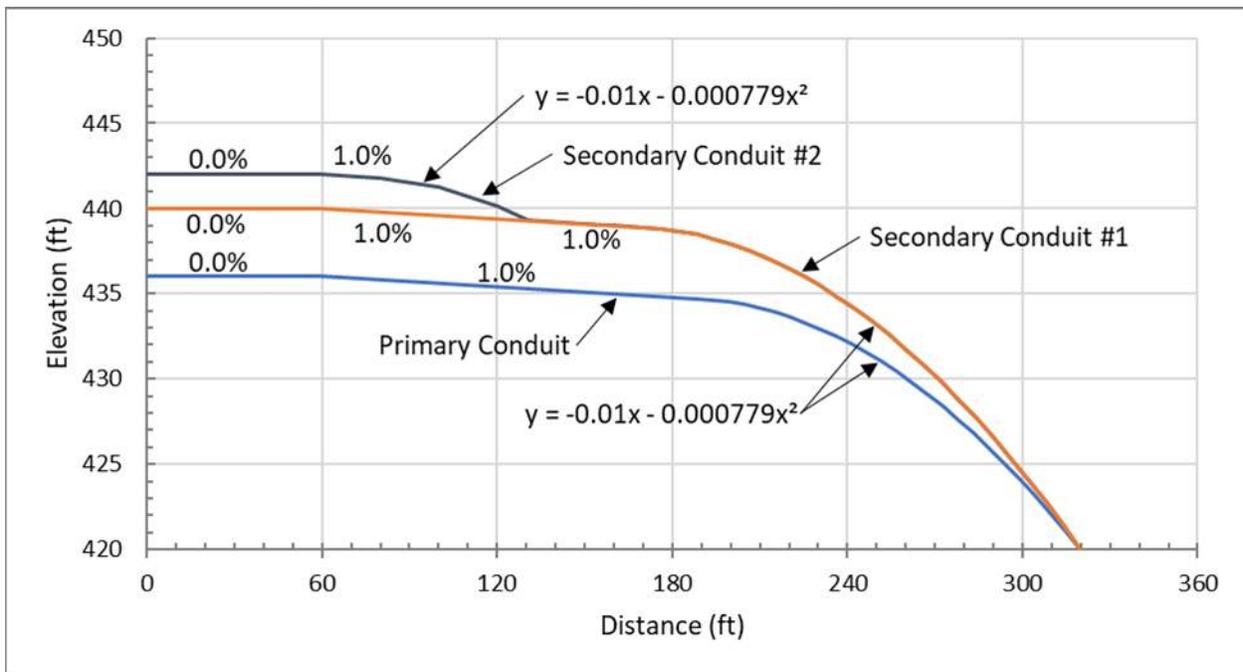


EL: elevation.

### Conduit Profiles

The conduit profile is based on three sections, the horizontal section through the gates, a 1 percent slope, and a parabolic profile transitioning the conduit invert elevation into the stilling basin elevation. The parabolic profile is based on the trajectory of a jet under the gravitational forces based on calculated velocities during gate-controlled flows, which provides positive pressures on the invert during all flow events. Figure 6 shows the profile for the primary and secondary conduits.

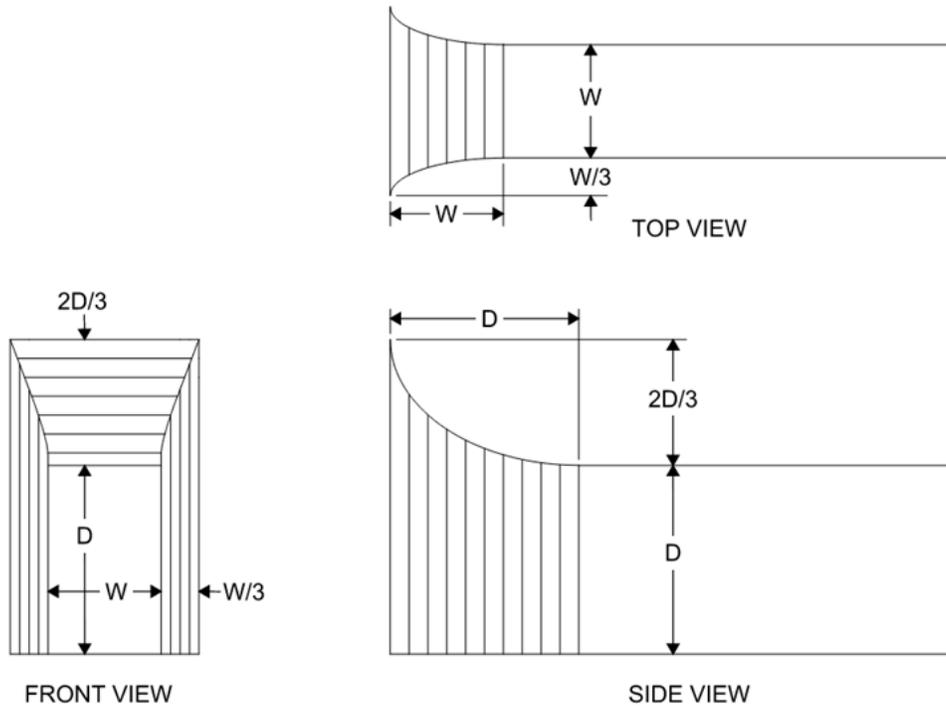
**Figure 6. Profiles for Primary and Secondary Conduits**



### Conduit Entrance Curves

To avoid flow separation and unsatisfactory pressure conditions, a roof curve and sidewall curves were added to the primary and secondary conduit entrances. The roof and sidewall curves are based on an elliptical curve. Figure 7 shows the profile view of the elliptical roof and sidewall entrance curves based on the primary and secondary conduit height and width.

Figure 7. Plan and Section View of Entrance Curves



### Conduit Water Surface Profiles

During flow-through conditions, the gates will be fully open with the flow in an open channel state through the structure. Figure 8 through Figure 10 contain the water surface profiles in each of the conduits at different river flow rates from the climate fish low flows to the 2-year (50 percent Annual Exceedance Probability) flow. The downstream end sill will sufficiently backwater the conduits to reduce conduit velocities and provide sufficient depth for the AWS flow to the neighboring fishway via a vertical diffuser screen. At the 2-year flow, the end sill crest gates will be lowered and a hydraulic jump will form within the conduits. The conduits will operate in an open channel condition for flows up to and including the 2-year event.

Figure 8. Primary Conduit Water Surface Profiles

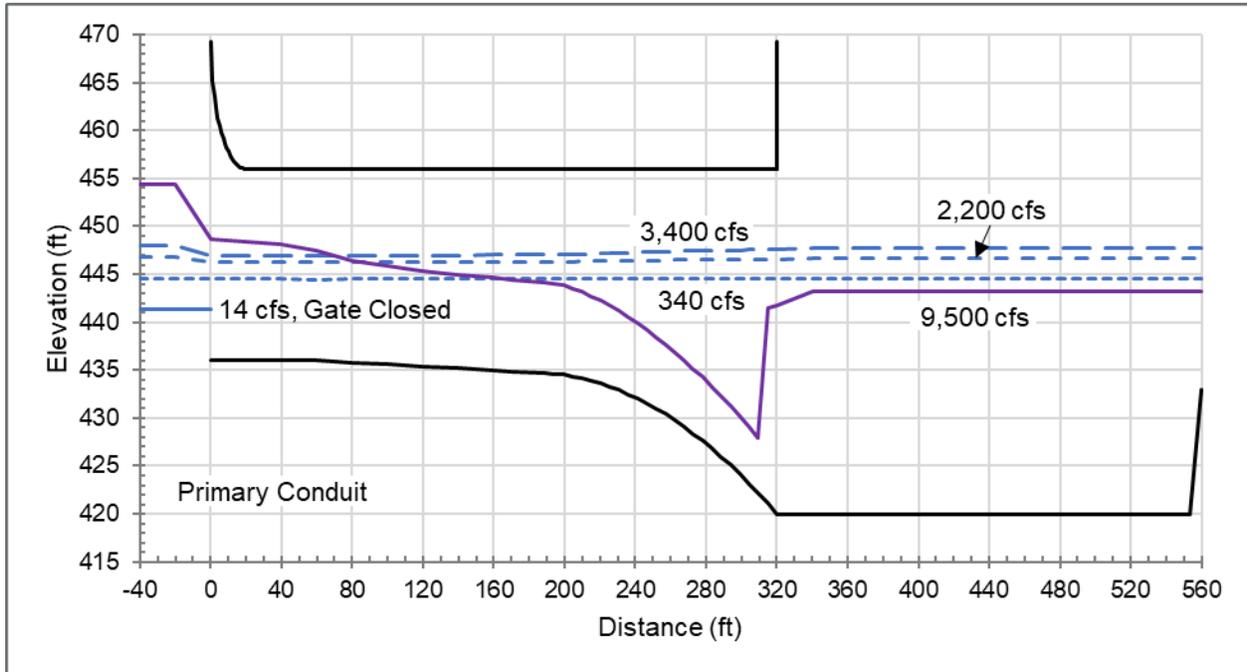


Figure 9. Secondary Conduit Number 1 Water Surface Profiles

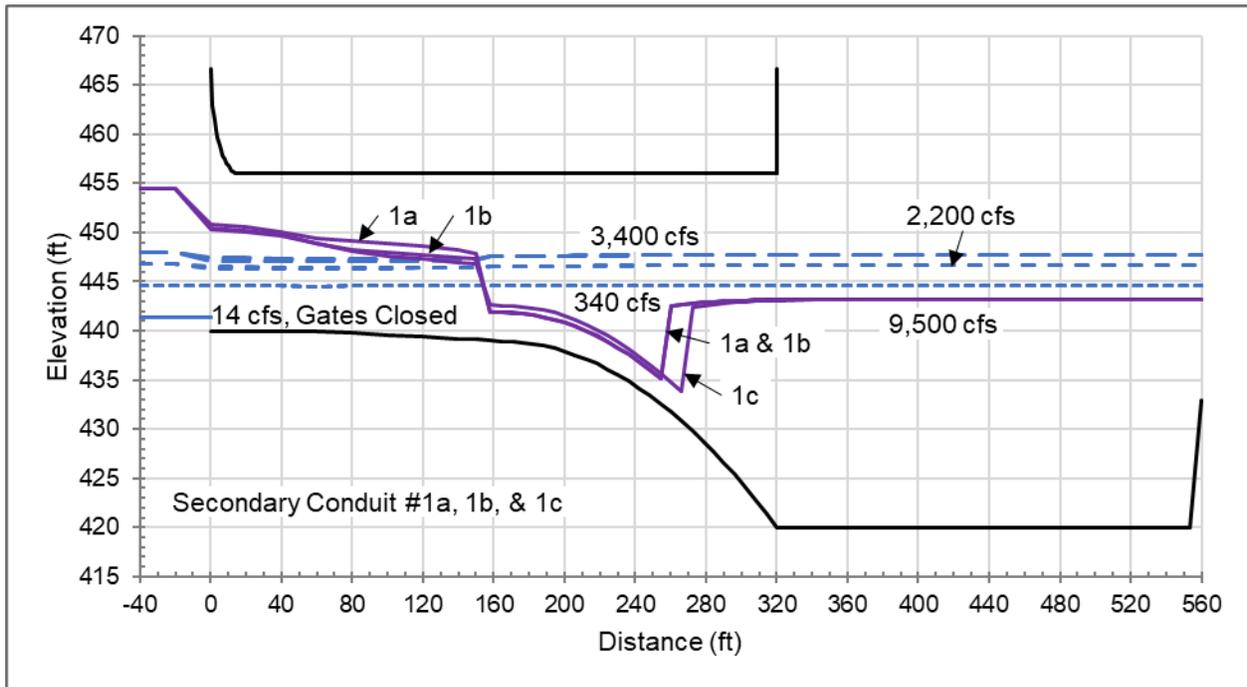
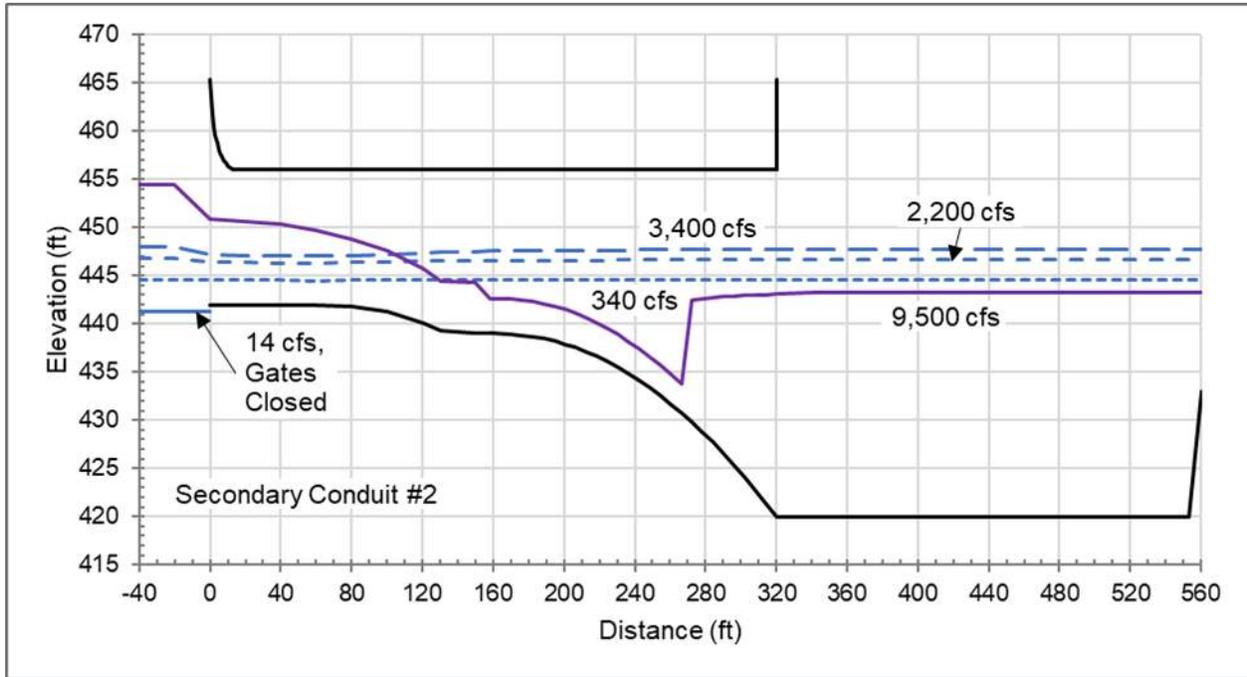


Figure 10. Secondary Conduit Number 2 Water Surface Profiles



**Gate Control Flow Capacity for 10% to 80% Open**

During flood retention, the primary and secondary conduit gates will be throttled or closed. Figure 11 to Figure 15 provide the gate-controlled flow for the primary and secondary conduits at gate openings between 10 and 80 percent open. The gate-controlled flows are intended to inform operations on specific gates that will best suit the desired flow rates while considering fish sounding depths before transitioning flows to the evacuation conduits.

Figure 11. Primary Conduit Gate-Controlled Flow Rates

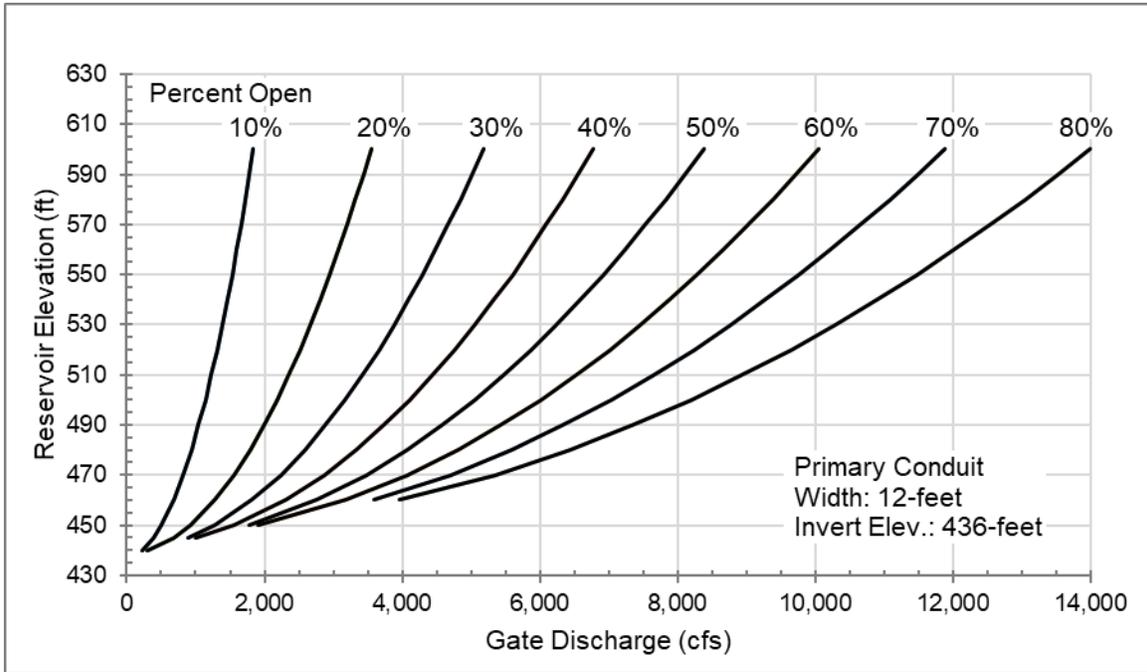


Figure 12. Secondary Conduit 1a Gate-Controlled Flow Rates

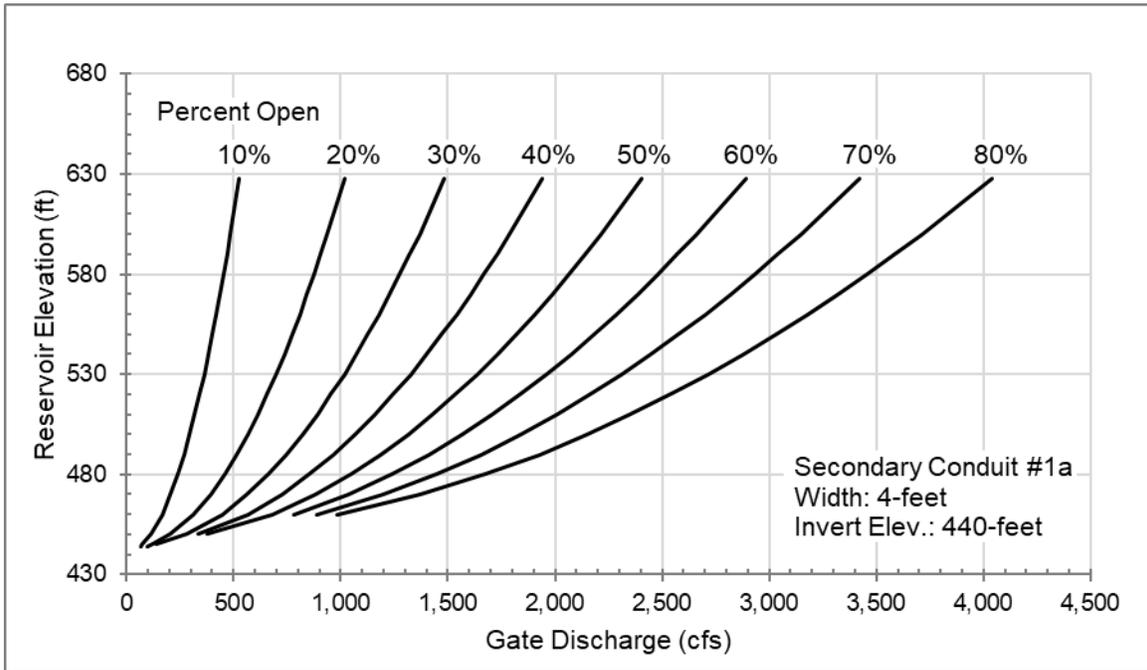


Figure 13. Secondary Conduit 1b Gate-Controlled Flow Rates

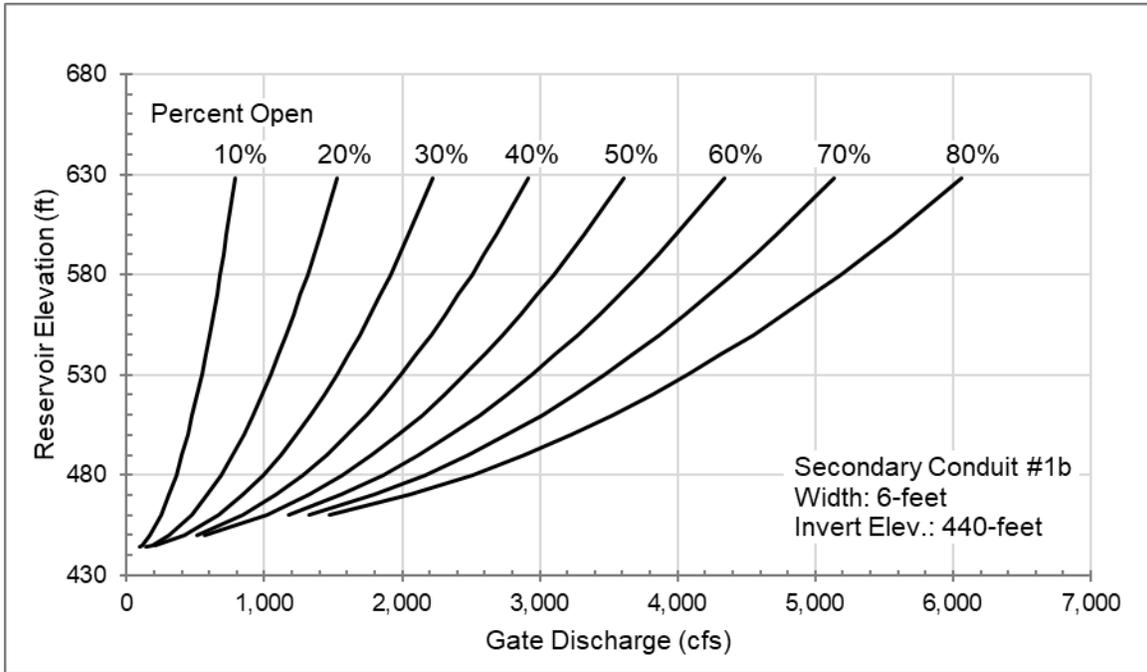


Figure 14. Secondary Conduit 1c Gate-Controlled Flow Rates

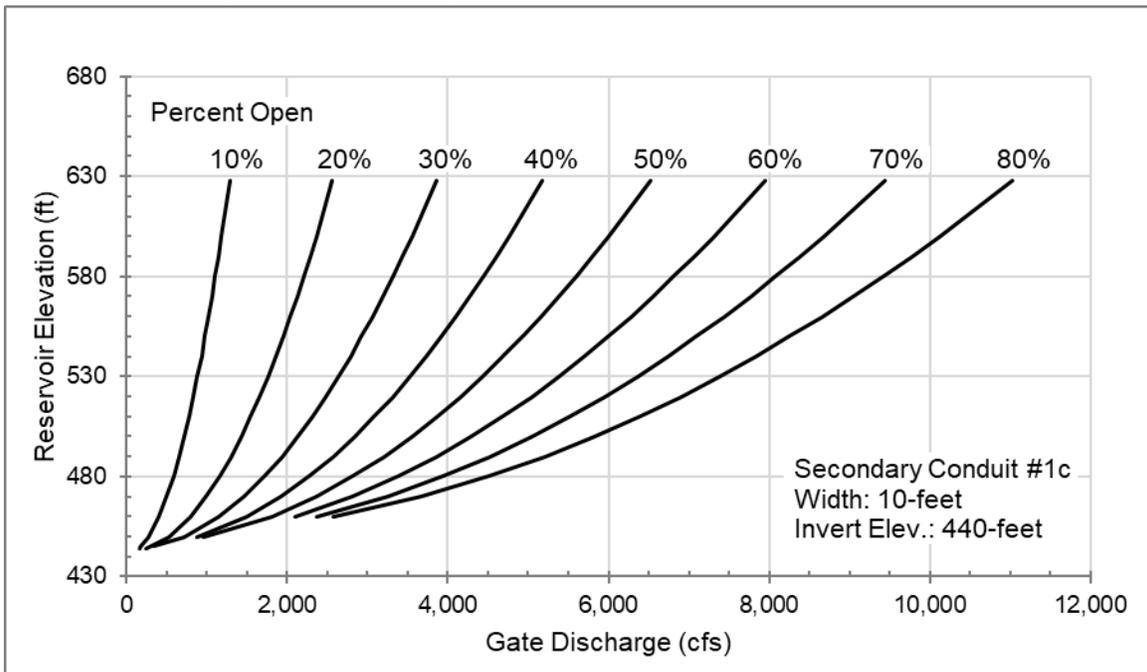
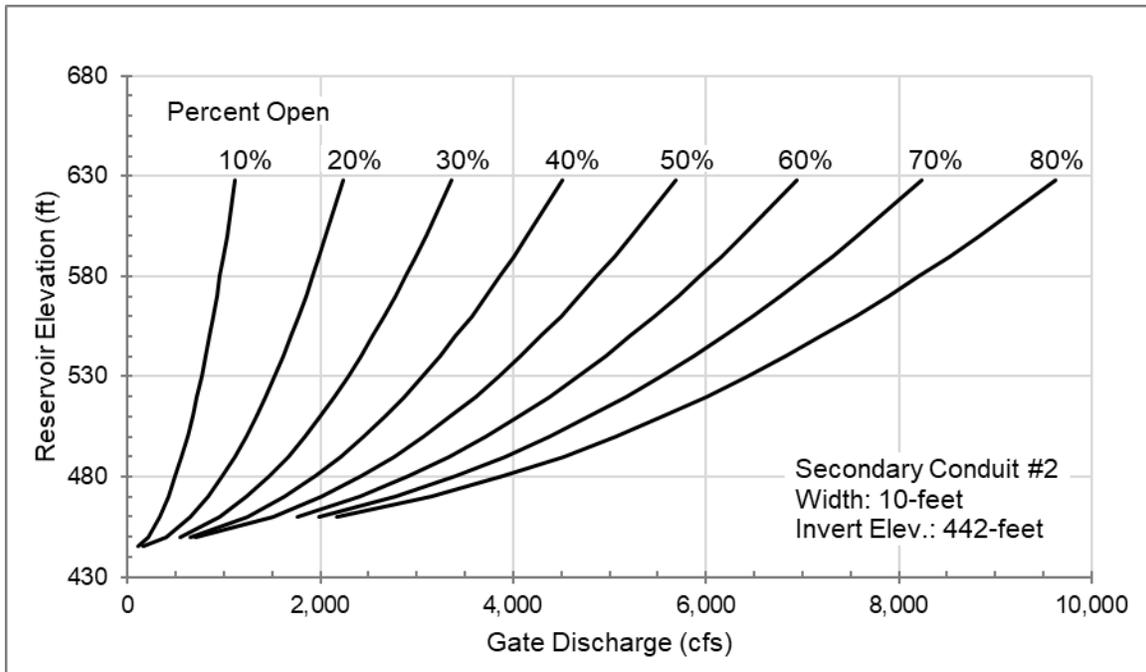


Figure 15. Secondary Conduit 2 Gate-Controlled Flow Rates



### 5.1.2.3 Stilling Basin Endsill and Vertical Barrier

The fishway entrance is located near the stilling basin endsill. Unlike the original concepts, the stilling basin endsill will be variable with Obermeyer weir or similar overflow concept. This endsill will be in the upright condition during normal river operations and serve as a vertical barrier. In this way, the fishway entrances will serve as the exclusive pathway for upstream movement during these periods, following input from NMFS during consultation. The variable endsill will be operated for fish exclusion during non-FRE operational periods and for conduit hydraulic capacity during evacuation operations. Detailed design of the endsill to accommodate the low fish passage design flow will occur in future phases of design development.

### 5.1.2.4 Evacuation Conduits

After the conduit gates are closed for flood retention, the reservoir evacuation conduits will be used for reservoir releases but only at elevations exceeding the defined fish sounding depth to provide safe downstream passage through hydraulically favorable gate conditions. The estimated sounding depth reported in the Juvenile Fish Sounding TM (Appendix B) is 30 feet. There will be two main types of evacuation conduits, one for high flows and the other for low flows. The high flow conduits will be rectangular, 5 feet wide and 9 feet tall. The low flow conduits will be a 3-foot-diameter hooded fixed cone valve supplied from a 4-foot-diameter conduit. Each of the evacuation conduits will use the stilling basin as an energy dissipater. During the maximum flow requirement, and when the upstream head is insufficient, the secondary conduits will be used to increase the release capacity. Figure 16 and Figure 17 show the gate-controlled flow rates for the evacuation and low-flow evacuation conduits, respectively.

Figure 16. Evacuation Conduit Gate-Controlled Flow Rates

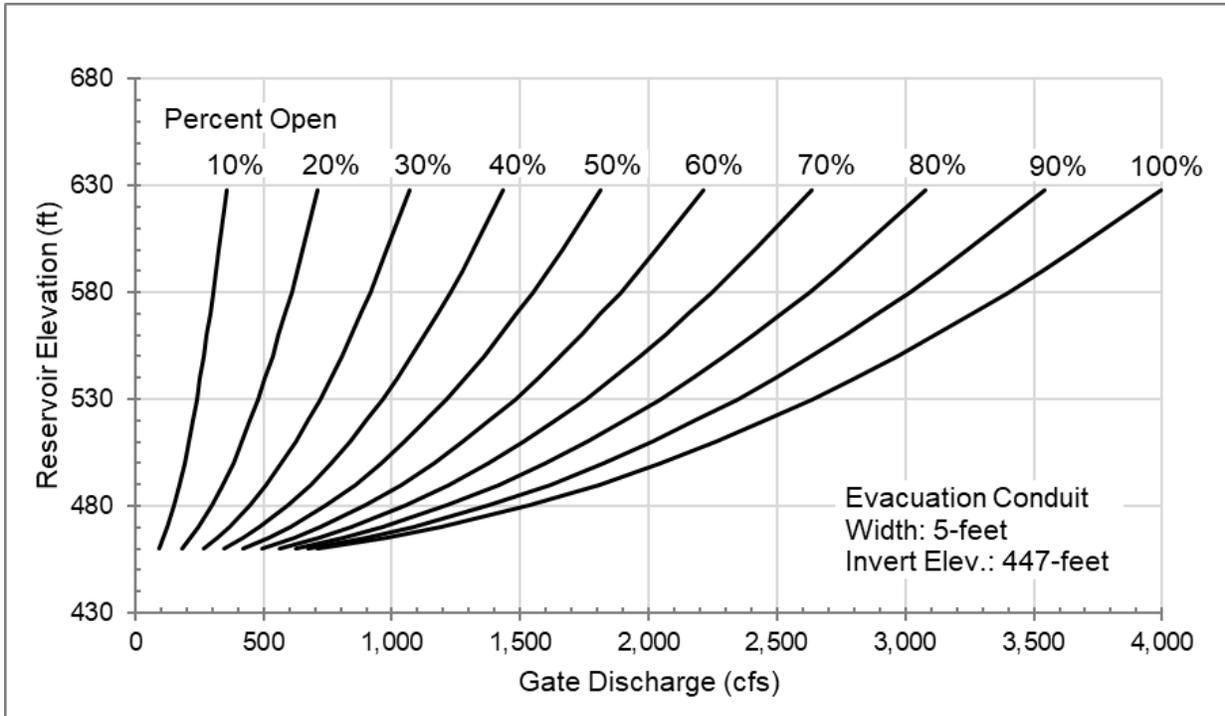
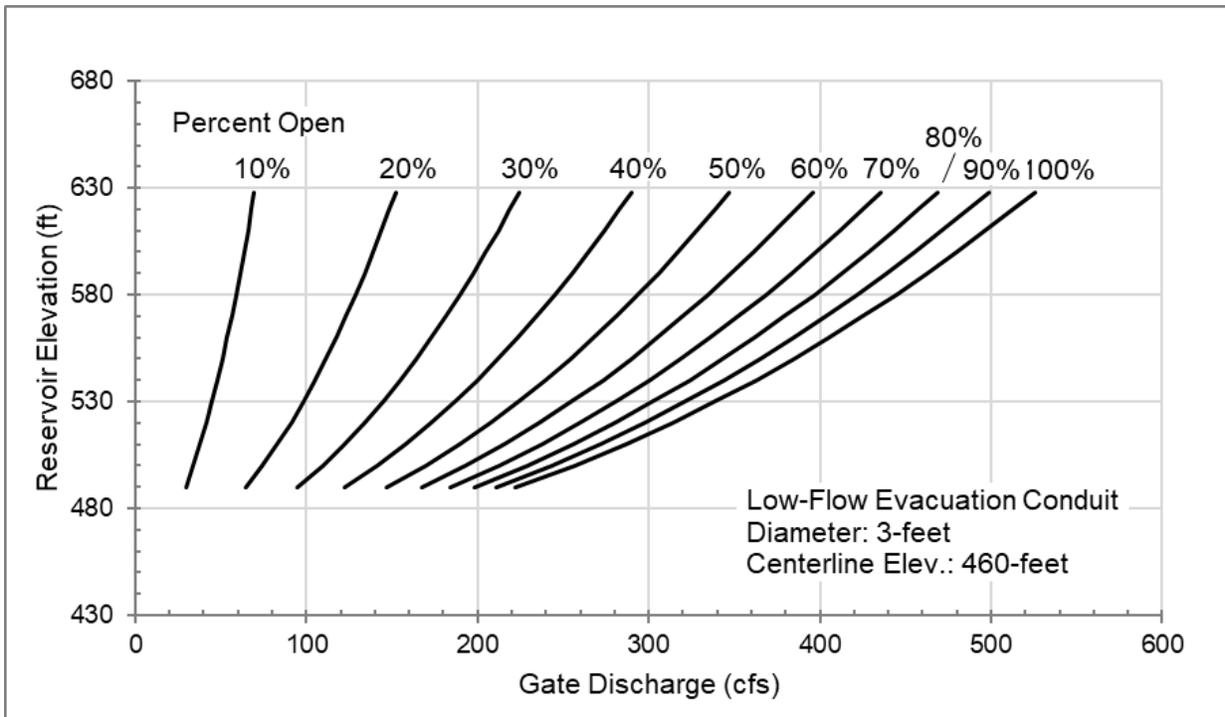


Figure 17. Low-Flow Evacuation Conduit Gate-Controlled Flow Rates



### 5.1.2.5 Lighting of Fish Passage Conduits

Appendix C (Fishway Lighting TM) describes the potential for artificial lighting within the passage conduits (primary and secondary conduits and the section of each fishway passing through the FRE structure) and considered literature describing the benefits and adverse effects of lighting, under different circumstances. Concern regarding fish delay or holding due to the length of the fish passage conduits if they remain unlit was shared during the January 17, 2024, TWG meeting. The TM concludes that lighting is beneficial only under certain circumstances. Accordingly, the design will not include lighting but seek to accommodate future installation of lighting based on demonstrated need. An integrated monitoring plan should be prepared to assess the need for artificial ambient lighting and evaluate its effects if implemented.

## 6 Fish Passage Performance

Fishways and other fish passage technologies are designed to provide continuous fish passage at the location of an instream barrier. Performance at fish passage facilities is generally characterized by the proportion of fish that can locate and traverse a fish passage facility from one side to the other. Research on fish passage performance is largely limited to facilities that consist of structures such as fish ladders or floating surface collectors, or facilities composed of natural materials (e.g., rocks and boulders), such as nature-like fishways and roughened channels. Provided herein is an assessment based on current project understanding with regards to anticipated fish passage operations and outcomes. Several terms are used to characterize the effectiveness of fish passage facilities. The term ‘performance’ is how efficiently fish are able to pass a facility, with rapid upstream movement being the most desirable outcome. Individuals may effectively move through a passage facility (“performance”) but can encounter challenges such as fallback after passing the facility, delay entering the facility, or displacement (not being able to access desirable locations). “Mortality” indicates the complete loss of an individual. Mortality is not necessarily a direct outcome of performance. The inability to reproduce is also included as mortality if long-term displacement leads to segregation from the spawning population. The inverse of mortality is considered “survival.” Generally stated, survival is the proportion of individuals that move on to contribute to the population after encountering the fish passage facility as they otherwise naturally would.

Therefore, caution is urged when considering performance versus survival as the resilience of fish species can lead to survival, including reproduction, with imperfect conditions, such as not effectively moving through a passage facility. Based on the current design progress and available data, modeling is unable to provide direct scientifically supported estimates of mortality versus short-term displacement. It is inaccurate to assume that fish that do not move through a fish passage facility are lost to the local fish population. Fish not ascending or falling back in a fishway may hold for some time and move upstream later or may choose to not ascend but remain productive members of the population downstream of the passage facility. Therefore, populations are defined as “unaffected” or “potentially affected” to more accurately represent current

project understanding. It is anticipated that most of the affected fish will survive (as reflected in the survival estimate) but may be affected as discussed above (i.e., fallback, temporary delay, or displacement). A full discussion of unaffected and potentially affected fish for the Proposed Project is provided in Section 6.1 below.

During Normal Operation, fish passage and hydraulic outlet gates are open and the Chehalis River flows through the FRE unimpeded. During Flood Retention Operation, fish passage gates are closed, and hydraulic outlet openings are reduced to temporarily impound floodwaters upstream.

During Normal Operation, upstream passage is provided primarily by dual fishways adjacent to the FRE outlet works, while passage conduits serve as secondary upstream pathways and the primary downstream passage route. The passage conduits typically remain open and convey downstream migrants to the stilling basin and downstream river reach; within the range of fish passage flows, they may also support upstream escape from the stilling basin due to fallback. During Flood Retention Operation, upstream passage is provided by the FFPPF. Downstream migrants may experience delay once the temporary inundation area exceeds approximately 30 feet above the evacuation conduits; prior to this depth, during initial retention and final evacuation, downstream passage is supported by the passage conduits. During FRE construction, the existing river, temporary bypass channels, and the completed dual fishways, conduits, and stilling basin will provide upstream and downstream passage on the Chehalis River and Crim Creek.

Several models of fish population use anticipated survival percentages to estimate potential impacts of projects on future fish populations. The discussion above and later in this section explain how it is important to account for changes to the location and timing of fish movement and reproduction and avoid potential mischaracterization of such changes as mortality. For convenience, Table 9 is provided to summarize the estimated percentage of fish encountering and passing the FRE structure and construction location and surviving beyond the structure/project area during construction and operation of the FRE facility. As noted, these survival numbers do not include fish that do not pass the FRE structure/construction location. Fish that do not pass the FRE structure should be accounted for elsewhere.

**Table 9. Estimated Percentage of Fish Passing the FRE Facility/Construction Location and Surviving Beyond the FRE Facility Location for Construction and Operation of the FRE Facility<sup>1</sup>**

Life Stage	Direction	During Construction <sup>2</sup>	Non-Flood Retention	Flood Retention
		(%)		
<b>Spring-Run Chinook Salmon</b>				
Adult	Upstream	98	95	86
Juvenile	Upstream	88	64	50
Juvenile	Downstream	99	95	60
<b>Fall-Run Chinook Salmon</b>				
Adult	Upstream	97	92	86
Juvenile	Upstream	88	64	50
Juvenile	Downstream	99	98	60
<b>Coho Salmon</b>				
Adult	Upstream	98	95	90
Juvenile <sup>3</sup>	Upstream	88	64	50
Juvenile <sup>3</sup>	Downstream	99	98	60
<b>Steelhead<sup>4</sup></b>				
Adult	Upstream	98	95	90
Adult	Downstream	98	95	75
Juvenile	Upstream	93	79	55
Juvenile	Downstream	99	98	70
<b>Coastal Cutthroat</b>				
Adult	Upstream	95	85	55
Adult	Downstream	98	95	75
Juvenile	Upstream	88	64	45
Juvenile	Downstream	99	98	55
<b>Pacific Lamprey</b>				
Adult	Upstream	99	96	70 estimated <sup>6</sup>
Juvenile <sup>5</sup>	Downstream	98	95	40

Life Stage	Direction	During Construction <sup>2</sup>	Non-Flood Retention	Flood Retention
		(%)		
<b>Western Brook Lamprey</b>				
Adult	Upstream	99	96	70 estimated <sup>6</sup>
Juvenile <sup>5</sup>	Downstream	98	95	40

Notes

1. The percentages in this table reflect fish that reach the FRE facility location in their movement upstream and downstream, pass the facility location, and survive beyond the facility location. This does not mean that all fish outside these percentages die or fail to contribute to species population. For example, of the 45 percent of juvenile steelhead moving upstream during a flood retention event some may elect to hold until the retention event concludes then move and successfully continue their life history upstream during flow-through operation, some may successfully complete their life-history downstream of the FRE facility location, some may remain downstream of the FRE facility without successfully contributing to the species population, and some may move upstream when flow-through operation resumes without successfully contributing to the species population.
2. “During Construction” estimates are averaged across all phases of construction, including Non-Flood Retention phase.
3. Includes Coho salmon fry, transitional, and smolt life stages.
4. Downstream survival of adult steelhead was estimated because a high proportion of adults migrate downstream to re-enter the ocean and return to their natal stream to spawn again; downstream survival of adult salmon was not estimated because adults die after spawning.
5. Includes ammocoetes and macrophthalmia.
6. Pending more information being provided by the District regarding the low-velocity FFPF entrance; the proposed design is a prototype and has not been developed beyond the 30% level, nor has the prototype been installed or evaluated.

## 6.1 Unaffected and Potentially Affected Fish

Although the anticipated number of Potentially Affected fish presented in Table 10 (Section 6.3) and Table 11 (Section 6.4) could be lower in reality due to fish adaptability to varying environmental conditions. The species profiles below provide additional context on their resilience and ability to withstand suboptimal conditions including delayed migration to survive.

### 6.1.1 Steelhead and Cutthroat Trout

Steelhead or rainbow trout (*Oncorhynchus mykiss*) was one of the species evaluated. *O. mykiss* exhibits one of the most complex suites of life-history traits among Pacific salmonids (Quinn 2005). The anadromous form, which migrates to the ocean, is referred to as steelhead, whereas the resident, freshwater form is referred to as rainbow trout. Because both life-history expressions belong to the same species, they are hereafter collectively referred to as *O. mykiss* unless distinction is required. The two forms interbreed regularly, and their offspring may adopt either anadromous or resident life histories (Zimmerman and Reeves 2000; Pearse et al. 2019). Offspring of two steelhead may remain resident, and offspring of two resident parents may adopt an anadromous life history (USFWS 2026), consistent with empirical findings demonstrating significant

plasticity in migratory propensity within *O. mykiss* populations (Satterthwaite et al. 2010; Kelson et al. 2020).

Another important life-history attribute of *O. mykiss* is iteroparity (the capability to spawn more than once) whereas other *Oncorhynchus* species assessed for fish passage performance, such as Chinook (*O. tshawytscha*) and Coho salmon (*O. kisutch*), are semelparous and die after a single spawning event (Fleming and Reynolds 2004; Busby et al. 1996). Coastal cutthroat trout (*O. clarkii clarkii*), also present in the Chehalis River Basin, exhibit life histories similar to *O. mykiss*, including migration and iteroparity (Trotter 2008; Johnson et al. 1999).

During Phase 2 of construction and associated flood operations, upstream spawning migrations of adult *O. mykiss* may experience temporary delays. Individuals may require additional time to navigate modified hydraulic conditions, seek temporary refuge until passage conditions improve, spawn downstream of the FFPP, or delay spawning to a later year when hydrologic or ecological cues indicate more suitable passage conditions. Such behavioral plasticity, including flexible migration timing and variable holding behavior, is a well-documented adaptive trait in *O. mykiss* and contributes to long-term persistence of steelhead populations in dynamic and variable river environments (Sykes et al. 2009; Kendall et al. 2015). Delay in migration represents a behavioral response that enhances survival potential and should not be interpreted as mortality.

Given the documented behavioral and physiological adaptability of *O. mykiss*, as well as *O. clarkii clarkii*, it is reasonable to conclude that the performance, survival, unaffected, and potentially affected estimates presented in Table 10 and Table 11 are conservative. This behavioral flexibility is expressed by both juvenile fish navigating the system and adult fish migrating to natal grounds to spawn, and it is recognized as a key component of the species' resilience under different environmental conditions (Satterthwaite & Carlson 2015; Kendall et al. 2021).

### 6.1.2 Coho Salmon and Chinook Salmon

Chinook salmon (*Oncorhynchus tshawytscha*) and Coho salmon (*O. kisutch*) are two other anadromous Pacific salmon species evaluated for fish passage performance. Both species exhibit complex migration ecology involving freshwater, estuarine, and marine environments. Unlike *O. mykiss*, Chinook and Coho salmon are semelparous, meaning they reproduce once and die following spawning (EPA [2021] for Chinook; NPS [2025] for Coho). Chinook and Coho populations display substantial diversity in run timing and migration rates, traits that are influenced by climatic, hydrologic, and habitat conditions (Crozier et al. 2008; NOAA 2024a review).

During Phase 2 of construction and associated flood operations, downstream migrations of juvenile Chinook and Coho salmon may experience temporary delays. Behavioral studies demonstrate that juvenile Chinook salmon rear and feed in freshwater and migrate to the ocean within a few months of hatching as young-of-year or may choose to stay in freshwater for a full year (NOAA 2024b). In northern portions of their range, spring Chinook commonly remain in freshwater for approximately one year, but in less productive streams where growth is slower, juveniles often prolong their freshwater residency (WDFW 2026).

Migration timing in Chinook has been shown to shift with river temperature, flow, and other environmental cues—reflecting behavioral adaptation in response to environmental variability (Keefer et al. 2025; Di Prinzio et al. 2023).

As far as adult Coho salmon are concerned, they have been observed to delay movement until favorable combinations of streamflow and temperature occur, holding downstream until environmental thresholds for migration are met (Flitcroft 2022; USDA Forest Service 2001).

These migration delays represent adaptive behavioral responses, not mortality. Adult fall run Chinook salmon routinely pause migration to slow down movement until conditions improve (Gonia et al. 2006). Coho salmon similarly demonstrate condition dependent migration timing (Flitcroft 2022). Such environmentally mediated holding behavior is a well-documented aspect of Pacific salmon migration ecology.

Although Chinook and Coho salmon exhibit less life history plasticity than *O. mykiss* due to their semelparous strategy, both species show significant variation in run timing, freshwater residence, and movement strategies that enhances resilience in dynamic river systems (Hill et al. 2003; NOAA 2024). Recent research also highlights alternative juvenile migration strategies in Chinook and Coho that increase population stability (Apgar et al. 2020; Baker et al. 2025), suggesting these species retain considerable behavioral flexibility despite their reproductive constraints.

Given this natural behavioral adaptability, it is reasonable to infer that the performance and survival values reported in Table 10 and Table 11 for Chinook and Coho salmon are conservative. Similar to *O. mykiss* and cutthroat trout discussed above, migration delays should be interpreted as part of the species' adaptive response to suboptimal environmental conditions rather than as indicators of mortality.

## 6.2 Fish Passage Hydraulic Modeling Results

Hydraulic model results for fish passage conduits and permanent and construction bypass channels demonstrate depths and velocities at the high and low fish passage design flows similar to their analogous and reference reaches.

Two-dimensional hydraulic modeling of the construction bypass channels and the permanent river channels (RPDR Appendix D) confirm that at the fish passage design flows, flow depth and velocity within these channels are similar to, or more favorable than the reference reaches used to design the channels. At the current level of design, there is no evidence to suggest that fish passage performance through the channels will be negatively impacted by the channels themselves, when compared to the existing river at the Proposed Project location. Therefore, fish passage performance and survival through the proposed channels is assumed to match that of the existing natural channel.

Three-dimensional hydraulic modeling of the passage conduits, stilling basin, and end sill was conducted to evaluate passage hydraulics through the conduits through fish passage design flow range. While the passage conduits are not the primary migration pathway, model results depicted favorable conditions in the event of upstream migrant fallback or failure of the vertical barrier.

For an abbreviated summary of anticipated fish passage hydraulic results through the fish passage conduits, see Section 5.1, above.

### 6.3 Fish Passage Performance During Flood Retention Operation

During flood events, the FFPF will continue to provide upstream passage for adult salmonids and lamprey, juvenile salmonids, and resident fish. Downstream-migrating juveniles and adult species are expected to hold in the mainstem Chehalis River above the temporary inundation pool, tributaries, and the temporary inundation pool until the temporary inundation pool recedes to a level fish choose to safely move downstream through the conduits or until normal flow-through operation resumes.

A temporary impoundment event of short duration may briefly hold fish upstream, preventing downstream movement. While fish are temporarily delayed, the short-term nature of these events limits detrimental consequences to fish mortality. Predatory species generally do not have sufficient time to recruit, establish, or significantly increase in abundance during brief periods of impoundment, though opportunities for predation may occur on occasion. Importantly, a temporary passage delay does not equate to a mortality event. Because the duration is limited, key mortality drivers, such as prolonged food limitation, physiological stress, or resource depletion, are expected to remain minimal, and impounded fish can typically resume normal movement and behavior once flows return to baseline.

Upstream-migrating juvenile fish were assigned lower performance and survival values in Table 10 than adults due to uncertainties associated with their attraction to ladder entrances, greater vulnerability to predation, and variable motivation to ascend into holding galleries. Additional engineered measures that could improve juvenile attraction and safe collection include multiple low-head entrances, reduced head differentials between ladder pools, and segregation zones in holding galleries to decrease predation.

**Table 10. Anticipated Upstream and Downstream Fish Passage Performance, Survival, Unaffected, and Potentially Affected Values during Flood Retention Operation**

Target Species	Performance <sup>1</sup>	Survival <sup>2</sup>	Unaffected <sup>3</sup>	Potentially Affected <sup>4</sup>
	(%)			
<b>Adult Upstream</b>				
Spring Chinook	93	86	80	20
Fall Chinook	93	86	91	9
Coho	93	90	91	9
Winter Steelhead	93	90	91	9
Coastal Cutthroat	88	55	86	18
Pacific Lamprey	60	70	54	46
Western Brook Lamprey	60	70	54	46

Target Species	Performance <sup>1</sup>	Survival <sup>2</sup>	Unaffected <sup>3</sup>	Potentially Affected <sup>4</sup>
	(%)			
<b>Adult Downstream</b>				
Winter Steelhead	NA	75	NA	NA
Coastal Cutthroat	NA	75	NA	NA
<b>Juvenile Upstream</b>				
Spring Chinook	60	50	30	70
Fall Chinook	60	50	30	70
Coho	60	50	30	70
Winter Steelhead	65	55	36	64
Coastal Cutthroat	60	45	27	73
Pacific Lamprey	NA	NA	NA	NA
Western Brook Lamprey	NA	NA	NA	NA
<b>Juvenile Downstream</b>				
Spring Chinook	>90	60	54	46
Fall Chinook	>90	60	54	46
Coho	>90	60	54	46
Winter Steelhead	>90	70	63	57
Coastal Cutthroat	>90	55	50	50
Pacific Lamprey	>90	40	36	64
Western Brook Lamprey	>90	40	36	64

NA – Juvenile lamprey are neutrally buoyant and do not move under their own power so upstream movement of juvenile lamprey is not applicable.

<sup>1</sup> Performance, the proportion of fish expected to meet route-specific behavioral passage criteria (e.g., finding/entering the route and completing the passage) estimates for adult and juvenile upstream passage are derived from HDR (2017). Juvenile downstream performance estimates are supported by analogous pressurized conduit systems with less than 30 feet of water depth, documented in the Rocky Reach Hydro Project and Clackamas River Hydroelectric Project (Chelan County N.D.; NOAA 2018).

<sup>2</sup> Survival, the proportion of fish that survive the passage event, estimates provided in HDR (2017).

<sup>3</sup> Unaffected, the proportion of the total population expected to pass successfully and survive the passage operation.

<sup>4</sup> The remainder of the population that may experience delay, increased predation risk, physiological stress, or mortality.

The following paragraphs apply specifically to periods when downstream passage occurs during short duration temporary impoundment events in which the inundation pool depth remains less than the juvenile salmonid sounding depth (approximately 30 feet). Under these shallow, short-term conditions, fish continue to encounter engineered passage

routes without the protracted delays associated with deeper pools, and the survival expectations described below pertain only to these less than 30-foot events.

Downstream survival during flood retention events must consider the short duration (~4 weeks or less) and infrequent occurrence (once every 5 years to about > once per year) when a temporary pool is held upstream of the FRE structure and must consider the high passage performance through the pressurized conduits when the pool depth is below the fish sounding depth (less than 1 atmosphere). Empirical studies of juvenile passage systems throughout the Pacific Northwest consistently show that engineered bypass conduits and pipelines achieve survival rates of approximately 95 to 99 percent, corresponding to mortality of roughly 1 to 5 percent. Paired-release Passive Integrated Transponder-tag experiments in the Columbia–Snake system document survival of 95.3 to 99.4 percent for yearling Chinook and steelhead passing through pressurized bypass routes (Muir et al. 2001; Ploskey et al. 2011). NOAA and Pacific Northwest National Laboratories (Ploskey et al. 2011) analyses further report dam-passage survival near or above 96 to 98 percent across multiple years (Ploskey et al. 2011). Additional compilations from Bonneville Power Administration and NOAA annual survival programs corroborate these findings and consistently show juvenile bypass systems among the highest-survival passage routes in the hydrosystem (Muir et al. 2001; Ploskey et al. 2011).

Concerns about latent mortality associated with bypass encounters have been raised, primarily relating to stress physiology and size-selective collection. The Independent Scientific Advisory Board (2021) reviewed these hypotheses; however, even under these considerations, direct route-specific survival for bypass passage remains high, and no evidence supports immediate mortality near 15 percent. NOAA analyses similarly find little evidence of significant latent penalties attributable solely to bypass exposure (NOAA Fisheries 2018).

Juvenile downstream survival at the Proposed Project is expected to remain high, though mortality may be slightly elevated relative to fully enclosed conduit systems due to the trashrack at the downstream collection entrance. Trashrack slats are approximately 2 feet wide, with approach velocities beginning near 1.0 ft/s and increasing gradually, producing hydraulics similar to river like conditions commonly encountered by juvenile salmonids. Additional risk can occur if debris accumulates and alters approach velocities or strike potential. Accumulated debris, large woody material, and plant matter, may provide structural habitat for predatory species, increasing predation risk. Predatory species can also use large woody material or floating debris as rafts for dispersal to new locations and ambush predation. Operational mitigation measures remove debris as needed, reducing hydraulic and predator-related risks. Accordingly, any incremental mortality associated with the trashrack and debris is expected to be small, well mitigated, and within survival ranges documented for high performing bypass systems (NOAA Fisheries 2018; Muir et al. 2001; Ploskey et al. 2011).

Data is less readily available for mortality due to short-duration holding in temporary pools. Upon assessing the hydraulic modeling of the Proposed Project under multiple scenarios (see Section 6.2), a critical review was undertaken relative to standard passage criteria (NOAA 2023a-c), past design experience and outcomes, along with project-specific understanding. The result of that review led to the prescribed

downstream survival rates, shown in Table 10, in the 60 to 70 percent range based on the compilation of existing information and professional judgement. The rates provided do not fall outside of other research and findings within the literature but provide an incrementally improved and tailored assessment specific to the Proposed Project.

Recent studies from the mid-Columbia and Yakima River systems indicate improved monitoring of adult and juvenile lamprey movements, though these datasets have not yet been fully integrated into survival or performance estimates for trap and transport applications (Liedtke et al. 2022; Grote and Lampman 2025). Evidence from Tribal translocation programs indicates that adult lamprey can survive collection and transport with generally low mortality and contribute to subsequent generations; however, variable passage efficiency at salmonid-designed facilities and limited juvenile-specific data warrant conservative assumptions (Hess et al. 2023; Lampman 2021).

Adult Pacific lamprey moved upstream using trap-and-haul or lamprey-specific passage structures show strong performance, with Tribal programs demonstrating low mortality and successful reproduction that supports values higher than legacy assumptions (Hess et al. 2023; USFWS 2023; CRITFC 2025). For this assessment, adult upstream survival is represented with a value of 70. Downstream migrants will move through conduit systems modeled on tube- and culvert-type designs that have shown high volitional passage efficiency in the Pacific Northwest (Frick et al. 2017; Goodman and Reid 2017; Cates et al. 2020). Regional closed-conduit studies indicate survival typically near the upper end of bypass performance (NOAA Fisheries 2018; Muir et al. 2001; Ploskey et al. 2011; U.S. Geologic Survey [USGS] 2022), but given limited lamprey-specific data, juvenile downstream estimates are conservatively set at 40 for survival while still reflecting fish-friendly routing and analogous system performance.

## 6.4 Fish Passage Performance During Normal Operation

Fish passage during normal operation is provided through fishways for upstream passage of adults, juveniles, and resident fish and through conduits for downstream passage of all aquatic species and life stages. Survival numbers developed in 2016 to 2017 for the Flood Retention Flow Augmentation (FRFA) dam fish ladder alternative remain appropriate, but performance values should be reconsidered. The FRFA dam fish ladder alternative developed in support of the Programmatic EIS assumed a large permanent reservoir and therefore anticipated reduced upstream fishway performance due to delayed attraction. Under the current configuration, fishways transition directly into the flowing Chehalis River, meaning the performance percentages previously established must be reconsidered.

Adult salmonids migrating upstream through technical fishways at the Columbia and Snake River Dams exhibit high passage efficiency and effective passage performance. According to Keefer et al. (2021), performance rates of upstream passage through technical fishways at the Columbia River and Snake River Dams ranged from 92 to 99 percent across a range of species, seasonal runs, and dams considered. This study considered collected data from an 8-year period for fall and spring Chinook, Sockeye, and steelhead. The mean fishway passage efficiency was determined to be 98 percent.

Upstream juvenile passage values have been added to Table 11 to reflect the possibility that juveniles may enter fishways, while acknowledging that upstream juvenile movement is exploratory rather than required for their life history. Consistent with the 2017 Subcommittee rationale, juvenile performance values are lower than adult values due to uncertainties related to attraction, motivation, and predation risk within fishways. Conditional survival remains high, in the range of 90 percent, consistent with regional juvenile studies. Juveniles that do not enter the fishways remain downstream, and because non-entry is not equivalent to mortality, total survival (a previous considered metric by others representing ‘performance survival’, which indicated any performance issue lead to mortality) is not applied to juveniles in Table 11 as it is not supported that any juvenile affected by performance would lead directly to mortality.

**Table 11. Anticipated Upstream and Downstream Fish Passage Performance, Survival, Unaffected, and Potentially Affected Values during Normal Operation**

Target Species	Performance <sup>1</sup>	Survival <sup>2</sup>	Unaffected <sup>3</sup>	Potentially Affected <sup>4</sup>
	(%)			
<b>Adult Upstream</b>				
Spring Chinook	95	95	90	10
Fall Chinook	95	92	85	15
Coho	95	95	90	10
Winter Steelhead	97	95	92	8
Coastal Cutthroat	93	85	79	21
Pacific Lamprey	97	96	93	7
Western Brook Lamprey	97	96	93	7
<b>Adult Downstream</b>				
Winter Steelhead	98	95	93	7
Coastal Cutthroat	98	95	93	7
<b>Juvenile Upstream</b>				
Spring Chinook	65	64	42	58
Fall Chinook	65	64	42	58
Coho	65	64	42	58
Winter Steelhead	80	79	63	37
Coastal Cutthroat	65	64	42	58
Pacific Lamprey	NA	NA	NA	NA
Western Brook Lamprey	NA	NA	NA	NA
<b>Juvenile Downstream</b>				
Spring Chinook	>90	98	59	41

Target Species	Performance <sup>1</sup>	Survival <sup>2</sup>	Unaffected <sup>3</sup>	Potentially Affected <sup>4</sup>
	(%)			
Fall Chinook	>90	98	59	41
Coho	>90	98	59	41
Winter Steelhead	>90	98	64	36
Coastal Cutthroat	>90	98	59	41
Pacific Lamprey	>90	95	NA	NA
Western Brook Lamprey	>90	95	NA	NA

NA – Juvenile lamprey are neutrally buoyant and do not move under their own power so upstream movement of juvenile lamprey is not applicable.

<sup>1</sup> Performance, the proportion of fish expected to meet route-specific behavioral passage criteria (e.g., finding/entering the route and completing the passage) estimates for adult and juvenile downstream passage and juvenile upstream passage are derived from HDR (2017). Adult upstream performance estimates are based on performance values for technical fishways at Columbia and Snake River Dams.

<sup>2</sup> Survival, the proportion of fish that survive the passage event (HDR 2017).

<sup>3</sup> Unaffected, the proportion of the total population expected to pass successfully and survive the passage operation.

<sup>4</sup> The remainder of the population that may experience delay, increased predation risk, physiological stress, or mortality.

Downstream adult passage percentages from the 2017 Combined Dam and Fish Passage Report for winter steelhead and cutthroat trout are still applicable (HDR 2017). These values represent the best available performance estimates for downstream movement through fish-friendly conduits under normal operation. The Fish Passage Subgroup should confirm that including the 2017 values is acceptable for the SEPA EIS.

Downstream juvenile passage through conduits remains highly effective. During normal operation, the entire river passes through fish-friendly conduit structures, resulting in near-complete passage performance (approximately 100 percent). This is consistent with conclusions from the 2017 Subcommittee rationale. Regional data show that juvenile salmonid survival through spillways, sluiceways, and bypass conduits routinely exceeds 90 percent and often falls within the 95 to 99 percent range, as demonstrated by Muir et al. (2001) and USGS (2011). Closed-conduit systems, such as the Clackamas River bypass pipeline, achieve juvenile survival near 97 percent, which aligns with federal performance requirements. Since 2017, conduit designs have been refined and modeled to demonstrate better hydraulic conditions for downstream passage as discussed in Section 6.2, providing additional confidence that downstream survival rates are more likely to be better than those estimated by the Subcommittee in 2017 and closer to those in Muir et al. (2001) and USGS (2011). Based on these findings, downstream juvenile passage is considered approximately 100 percent, with a conservative survival estimate of approximately 98 percent.

Downstream juvenile lamprey passage has been expanded to reflect the current understanding of lamprey behavior and movement. Recent acoustic telemetry work by the USGS in the Yakima River demonstrates that juvenile lamprey have specific

movement timing and behavior but does not contradict the expectation that fish-friendly conduit structures can safely pass lamprey during downstream migration. Therefore, juvenile lamprey passage performance remains approximately 100 percent, with a survival value of approximately 95 percent to remain conservative and consistent with both the 2017 Subcommittee assumptions and contemporary regional research.

## 6.5 Fish Passage Performance During Construction

The construction bypass channels and permanent approach and discharge channels function differently from traditional fish passage structures and are more comparable to restoration channel designs. Their design approach is based on creating physical and hydraulic conditions that replicate those in the Chehalis River and Crim Creek near the Proposed Project. This includes matching slope, channel form, bed material, and habitat complexity along with creating depth, velocity, and flow paths consistent with adjacent natural reaches. Design guidance for this approach is provided both by NOAA Fisheries (2023a, 2023b) and WDFW (2012), with WDFW (2012) stating that this design approach “usually insures fish passage.” The constructed channels are therefore intended to support passage for all species and life stages, with passage performance and survival expected to match baseline conditions in the adjacent natural channel.

Design guidance documents published by WDFW and NOAA Fisheries reinforce that passage performance through the construction bypass channels should be evaluated using design criteria that reflect natural hydraulic complexity, appropriate roughness elements, and sufficient velocity refugia based on the reference reach. The construction bypass and permanent channels have been hydraulically modeled to demonstrate that the channels achieve hydraulic conditions suitable for upstream and downstream passage as discussed in Section 6.2. As the design progresses, channel hydraulics will be analyzed through hydraulic modeling to confirm that water depths, flow velocities, and channel roughness remain within the envelope of conditions known to support fish movement. The construction bypass channel will be required to meet state and federal fish passage and permit requirements, and passage performance reflects a project that will be designed and constructed to those standards.

Fish passage during construction varies by phase. In all phases, fish passage routes provide volitional upstream and downstream fish passage for all species and life stages. During Phase 1, passage occurs in the existing natural channel, which is unimpacted by construction activities therefore no reduction in survival or performance is anticipated in this Phase. During Phase 2, passage occurs through the construction bypass channels described above. As stated above, upstream and downstream passage performance and survival for all species and life stages is anticipated to match that of the existing natural channel. During Phases 3 and 4, upstream and downstream fish passage for all species and life stages occurs through the completed fishways, conduits, and stilling basin. Passage performance and survival for these phases is therefore consistent with the values described for fish passage during Normal Operation (Section 6.4). The combined approach provides passage conditions that remain consistent with or similar to baseline conditions during early construction phases and transition to the permanent fish passage facilities as they are brought online. Passage survival values during construction are an average of the three passage routes described in this paragraph and listed in Table 9.

## 7 Roadmap for Future Fish Passage Design

Fish passage design continues to be refined in discussion with NOAA Fisheries and, in future discussion, with WDFW, USFWS, and other state, federal, and indigenous members. The fish passage design will be integrated and compatible with the overall facility design. Future design phases will incorporate cross-discipline design development, design evaluations and analyses, coordination meetings, and configuration decisions to achieve a complete project. Some aspects of fish passage design that will be refined include:

- NOAA climate change guidance for long-term projects (2023a)
- FFPF
- Primary and secondary conduits
- Conduit stilling basin and adjustable end sills
- Dual dedicated fishways
- Construction bypass channels
- Permanent river and creek channels immediately upstream and downstream of the FRE structure
- Two- and three-dimensional hydraulic modeling

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## Appendix A. In-Water Work Steps During Construction TM

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# Technical Memorandum

Date: Oct 11, 2024

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Project: Chehalis River Basin Flood Damage Reduction Project

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To: Chehalis Basin Flood Control Zone District

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From: Jacob Hyles, PE

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Subject: **In-Water Work Steps During Construction**

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## 1.0 Introduction

### 1.1 Background

The Chehalis River Basin Flood Damage Reduction project (Project) objective is to develop recommendations for a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of the town of Pe Ell.

The Chehalis River Basin Flood Damage Reduction, Revised Project Description Report (RPDR) is a supplemental report documenting the relocation of and changes to the FRE facility as originally documented within the Combined Dam and Fish Passage Conceptual Design Report (HDR Engineering, Inc. [HDR] 2017) and FRE Dam Alternative Report (HDR 2018).

The RPDR describes, supports, contrasts, and illustrates the changes to the proposed upstream FRE in a single comprehensive document.

### 1.2 Document Purpose

As a standalone attachment to Appendix K: Constructability Report to the RPDR, this technical memorandum (TM) provides additional detail to describe flow diversion aspects of construction phasing to include:

- Major elements of in-water work associated with flow diversion,
- Planned steps to transition construction phases,
- Conditions based requirements to progress from one step to the next, and
- Discussion of next steps and items for future consideration.



### 1.3 Previous Related Documentation

The RPDR provides a revised project description, and details activities and studies related to new and revised project elements. In addition to Appendix K, two additional appendices provide information related to the proposed channel diversion during construction.

#### Appendix D2: Hydraulic Design of Fish Passage and Evacuation Conduits TM

This TM documents the hydraulic analysis of the fish passage and evacuation conduits. The TM includes the permanent approach and discharge channels. The Approach Channel connects existing reaches of Crim Creek and the Chehalis River to the FRE passage conduits. The Discharge Channel connects the passage conduit stilling basin to the Chehalis River downstream. Both channels constitute the proposed project condition but are preliminary concepts only.

#### Appendix D3: Chehalis Construction Bypass Hydraulic Modeling TM

This TM documents the hydraulic analysis of the proposed Chehalis River and Crim Creek construction bypass channels (Bypass Channel), which characterizes hydraulic conditions (i.e., depth, velocity) within the proposed channels in relation to cost estimating, constructability, and fish passage. The preliminary designs are based upon existing conditions within reference reaches in the vicinity of the project. The proposed Bypass Channel mimics the hydraulics of these reference reaches to support upstream and downstream movement of aquatic organisms. The Bypass Channel can contain the 25-year annual exceedance probability (AEP) discharge.

## 2.0 Construction Sequence Overview

### 2.1 FRE Construction Sequence

The general FRE construction sequence consists of five phases presented in Table 1. In order to maintain volitional fish passage in the Chehalis River throughout the overall construction period, the dam structure will be constructed in three segments. A bypass channel will be installed to maintain river flows during construction of the second segment of the facility in Phase 2. This flow will be transitioned into the permanent channel and through the FRE conduits for remaining construction during phases 3 and 4. Additional discussion is included in the RPDR.

**Table 1. Construction Sequence Summary**

Phase	Work	Duration (months)
0	Preliminary work independent of the river	6-12
1	Site preparation, right side foundation construction, Chehalis and Crim Creek bypass channel construction	10-12



2	Outlet works and conduit construction, left side foundation construction, grading	20-24
3	Remove bypass channel and restore vegetation, foundation closure - connect left and right foundations	10-12
4	Complete facility construction, finishing touches, finalize the facility for use	6-12

## 2.2 Construction Phase Transitions

The transitions between construction phases are based upon several criteria being met. For the purposes of this TM, the transitions presented here are defined by the conditions surrounding the diversion and handling of the Chehalis River and Crim Creek. Specifically, this TM details the conceptual transitions from Phase 1 to Phase 2 and from Phase 2 to Phase 3.

## 2.3 In-water Work Window

Based on the project design it is anticipated that permitting variances will be required to extend normal in-water work windows. The Washington State Department of Fish and Wildlife (WDFW) approved in-water work window for the Chehalis Basin upstream of the South Fork is August 1 to August 31, and the US Army Corps of Engineers (USACE) approved in-water work window for the same river reach is July 1 to August 31. To minimize impacts during construction by making use of the optimal hydrologic conditions as previously described, and to avoid impacts from continuous construction over a longer period of time, an extension of the in-water work window from July 1 to September 30 will be requested from WDFW and USACE.

## 2.4 In-water Work Items

### **Diversion structures**

In-water work will include structures constructed to divert flows from one flow path to another to facilitate construction activities. These structures have not been designed, but temporary berms may need to be structurally designed, lined, or otherwise stable and suitable for sustained flows and favorable to support dewatering needs. Temporary diversion methods may be employed to reduce in-water work duration to allow for more permanent structures to be constructed.

### **Aquatic Species Stranding and Fish Rescue Surveys**

Avoiding stranding of aquatic species is an essential activity during the in-water activities. While flow diversion activities will be planned and executed to limit stranding potential, monitoring teams will be in place to identify, recover, and re-locate stranded fish as flows recede and as conveyance channels are de-watered. As water depths reduce, corralling and seining of remaining individuals will be conducted towards the downstream channel connection. As flows become shallower, electrofishing and relocation will be conducted. Mussel salvage and relocation activities will be completed once water levels allow.

Salvage and relocation may only be conducted by personnel deemed qualified by the governing fisheries regulatory agencies. Fish salvage or relocation personnel may be government staff or private professionals, employed by the government or by the Chehalis Basin Flood Control

Zone District (District), as mutually agreed upon by the District and governing fisheries regulatory agencies. The District's construction contractor will be responsible for fish exclusion, as well as coordination with and physical support of fish salvage/relocation personnel and the governing fisheries agencies. The District will require the contractor to adhere to typical construction BMPs for the protection of fish including:

- Adherence to the agency approved in-water work window.
- Coordination with agencies to implement fish salvage plans for each stage of in-water work.
- Fish salvage would be conducted in accordance with WSDOT fish exclusion protocols (WSDOT 2016).
- Electroshocking would occur in accordance with National Marine Fisheries Service (NMFS) (2000) electrofishing guidelines.
- All electrofishing will be conducted by a person with electrofishing training on-site to direct all electrofishing activities.
- All captured and collected fish will be transported to the upstream end of the project area and released at a location sufficient for fish to recover and re-orientate to the stream environment (slow moving pool habitat).
- Monitoring of temperature and dissolved oxygen during operations and subsequent refill periods.
- Screening of intakes - pump intakes must be screened compliant with NOAA-Fisheries and WDFW requirements.
- Maintaining fish screen to prevent injury or entrapment of fish.

### **Screened De-watering**

De-watering (i.e., removing water from a surface hole or collection) may be required during brief periods and in limited locations when diversions are made from one phase to the next. De-watering will be slow, deliberate, and screened to facilitate safe and timely removal of any fish trapped in pools. The rate of dewatering will be commensurate with permit requirements from WDFW or as defined during Endangered Species Act (ESA) consultation. Contractor will be required to implement a specific de-watering rate to avoid stranding and to allow adequate aquatic species relocation.

## **2.5 In-water Work Tenets**

The conceptual process of flow diversions as it relates to transitioning construction phases was developed with several tenets, which guide the timing and sequencing of the proposed steps. These tenets include:

1. **Limit in-water work.** Regardless of mitigation measures in-place, in-water work has the potential to be detrimental to the function and health of the river and its ecology. Reducing the duration of in-water work reduces this risk for impacts. Performing in-water work concurrently, instead of a long sequence of steps, is one way to reduce work duration.
2. **Prevent abrupt dewatering.** To limit the risk of fish stranding, diverting river flow from one active channel to another should not result in the rapid dewatering of the once active

channel. Closure of the active change, via constructed berm or other approved methodology, should allow for deliberate reduction of flows to allow fish to safely vacate.

3. **Maintain control.** Deliberate and methodical execution of the process of diverting flows is critical to diversion success and worker safety. New channels should be first opened from the downstream end. Upstream berms should be opened at a similar rate to the closure of the channels to be abandoned.
4. **Aquatic species salvage is continuous.** Pro-active efforts to exclude and remove aquatic species is a priority. Actions of each in-water work steps must be planned and executed in support of aquatic species salvage efforts as required under permit documentation.

## 3.0 Construction Phase Transition and In-water Work Steps

### 3.1 Phase 1 to Phase 2 Transition

The flows from the Chehalis River and Crim Creek will first be diverted from the existing channels during the transition from Phase 1 to Phase 2. The combined flows will be diverted from their current channels into the Bypass Channel designed and constructed for use during Phase 2 and Phase 3 of construction. This transition includes three steps and ends when the combined flows are fully diverted and when fish salvage and de-watering operations have concluded. Each step is described below, to include the conditions at the beginning and end of each step and the major actions taken during the step. An exhibit for each step is attached.

#### 3.1.1 Step 1

**Begins:** Chehalis River flows through the FRE project site in the existing channel. Crim Creek flows join the Chehalis River at the existing confluence location. The Bypass Channel is constructed and ready for use, but stream flows are precluded by the natural bank serving as a barrier to flow.

**Actions Taken:**

Actions during this step are limited to the work necessary to remove the existing riverbank at the downstream end of the Bypass Channel. This embankment will be removed in such a manner as to reduce the duration of in-water activity. This would include excavation as much of the existing channel bank from the dry Bypass Channel, and only breaching the embankment at the end of the operation.

**Ends:** This step ends when the existing riverbank at the downstream end of the Bypass Channel is fully breached and flow is allowed to backwater into the Bypass Channel.

#### 3.1.2 Step 2

**Begins:** This step begins when the existing riverbank at the downstream end of the Bypass Channel is fully breached and flow is allowed to backwater into the Bypass Channel. The Chehalis River flows through the FRE project site in the existing channel. Crim Creek flows join the Chehalis River at the existing confluence location.

#### Actions Taken:

This step is characterized primarily by the actual diversion of flows into the Bypass Channel. The specific actions include:

- Initial breach of the channel embankments to allow flow into the Bypass Channel via the Crim Creek and Chehalis River flow paths.
- Concurrent to the initial breach of the channel embankments, construction of the flow diversion features at Crim Creek and Chehalis River will be initiated. These diversion structures have yet to be engineered, but could include earthen/rock berms, piling, super sacks or other methods.
- The Bypass Channel embankment breaches are widened, allowing for a gradual increase in flow into the Bypass Channel. Simultaneously, the diversion features continues to reduce flow into existing Chehalis Channel.
- As flow in the Existing Channel is reduced, aquatic species salvage commences.
- Diversion structures will isolate the existing river channel between the Crim Creek and Chehalis flow paths into the Bypass Channel. Aquatic species salvage will be conducted, followed by dewatering, as necessary.

Ends: This step ends when Chehalis River and Crim Creek flows are completely diverted into the constructed bypass. The existing Chehalis River channel is closed at Crim Creek. The existing channel located between the Crim Creek and Chehalis portions of the Bypass is closed to stream flow and aquatic species salvage is complete. The downstream end of the Existing Channel, adjacent to the Bypass Channel outfall, is open.

#### 3.1.3 Step 3

Begins: This step begins when Chehalis River and Crim Creek flows are completely diverted into the constructed Bypass Channel. The upstream end of the existing Chehalis River channel is closed at Crim Creek, but remains open at the downstream end, adjacent to the Bypass Channel.

#### Actions Taken:

This step consists of the downstream closure of the existing Chehalis River channel. The specific actions include:

- With complete diversion of streamflow into the Bypass Channel, the downstream end of the existing Chehalis River channel can be closed. This closure will be gradual and in-concert with aquatic species salvage efforts in the channel.
- As the existing Chehalis River channel will be subject to backwater conditions only, the final closure will isolate a final pool of water within the channel. This pool will be gradually dewatered via screened pumps, at a rate necessary to support aquatic species salvage as required in the approved in-water work plan.

Ends: This step ends when the existing river channel between Crim Creek and the downstream end of the Bypass Channel is closed to streamflow. De-watering is complete. Aquatic species salvage efforts are complete.

### **3.2 Phase 2 to Phase 3 Transition**

The transition from Phase 2 to Phase 3 is the second and last proposed diversion of Chehalis River and Crim Creek flows construction. The combined flows will be diverted from the Bypass Channel into the Approach Channel. Flows from the Approach Channel will pass through the FRE via the passage conduits and stilling basin and into the Discharge Channel. The Discharge Channel will pass the combined flows back into the downstream, existing reach of the Chehalis. This transition includes three steps and ends when the combined flows are fully diverted and when fish salvage and unwatering operations have concluded.

#### **3.2.1 Step 1**

Begins: Chehalis River and Crim Creek flows pass through the FRE project site via the Bypass Channel. The FRE conduits and stilling basin are constructed and ready to receive flow. The permanent Approach Channel upstream and the Discharge Channel downstream of the FRE conduits are constructed and ready to receive flow, but flow is precluded by constructed berms at the upstream and downstream ends.

Actions Taken:

Actions during this step are limited to the work necessary to remove the constructed embankment at the downstream end of the permanent Discharge Channel.

Ends: This step ends when the berm at the downstream end of the Discharge Channel is fully breached and flow is allowed to backwater into the Discharge Channel.

#### **3.2.2 Step 2**

Begins: This step begins when the berm at the downstream end of the Discharge Channel is breached and flow is allowed to backwater into the Discharge Channel.

Actions Taken:

This step is characterized primarily by the actual diversion of flows into the permanent Approach Channel. The specific actions include:

- Initial breach of the diversion structures to allow flow into the Approach Channel via the Crim Creek and Chehalis River flow paths. This includes breaching the diversion structures isolating the portion of the existing Chehalis River channel between the Crim Creek and Chehalis River entrances to the Bypass Channel.
- Concurrent to degrading the diversion structures of the Bypass Channel, new diversion structures at the Crim Creek and Chehalis River entrances to the Bypass Channel will be initiated in order to gradually reduce flow into the Bypass Channel.
- As flow in the Bypass Channel is reduced, aquatic species salvage commences.

Ends: This step ends when Chehalis River and Crim Creek flows are completely diverted into the Approach Channel. The upstream end of the Bypass Channel is closed but remains open at the downstream end.

### 3.2.3 Step 3

Begins: This step begins when Chehalis River and Crim Creek flows are completely diverted into the Engineered Channel, passage conduits, and stilling basin. The Bypass Channel is closed at the upstream end but remains open at the downstream end.

Actions Taken:

This step consists of the downstream closure of the Bypass Channel. The specific actions include:

- With complete diversion of streamflow into the Approach Channel, the downstream end of the Bypass Channel can be closed. This closure will be gradual and in-concert with aquatic species salvage efforts in the channel.
- As the Bypass Channel will be subject to backwater conditions only, the final closure will isolate a final pool of water within the channel. This pool will be gradually dewatered via screened pumps, at a rate necessary to support aquatic species salvage.

Ends: This step ends when the Bypass Channel is closed to streamflow at both ends. Dewatering is complete. Aquatic species salvage efforts are complete.

## 4.0 Next Steps

Construction activities, timing, and sequencing are still under development. Means and methods of diversion activities have yet to be determined, but should support the tenets provided here-in. The in-water work sequencing presented herein is a feasible option; however, the selected contractor may develop alternative plans which will be subject to review by the District and regulatory agencies to ensure consistency with existing environmental authorizations.

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## 6.0 Acronyms/Abbreviations

AEP	Annual Exceedance Probability
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
FFPF	Flood Fish Passage Facility
FRE	Flood Retention Expandable
HDR	HDR Engineering, Inc.
NMFS	National Marine Fisheries Service
RPDR	Revised Project Description Report
USACE	US Army Corps of Engineers
WDFW	Washington State Department of Fish and Wildlife

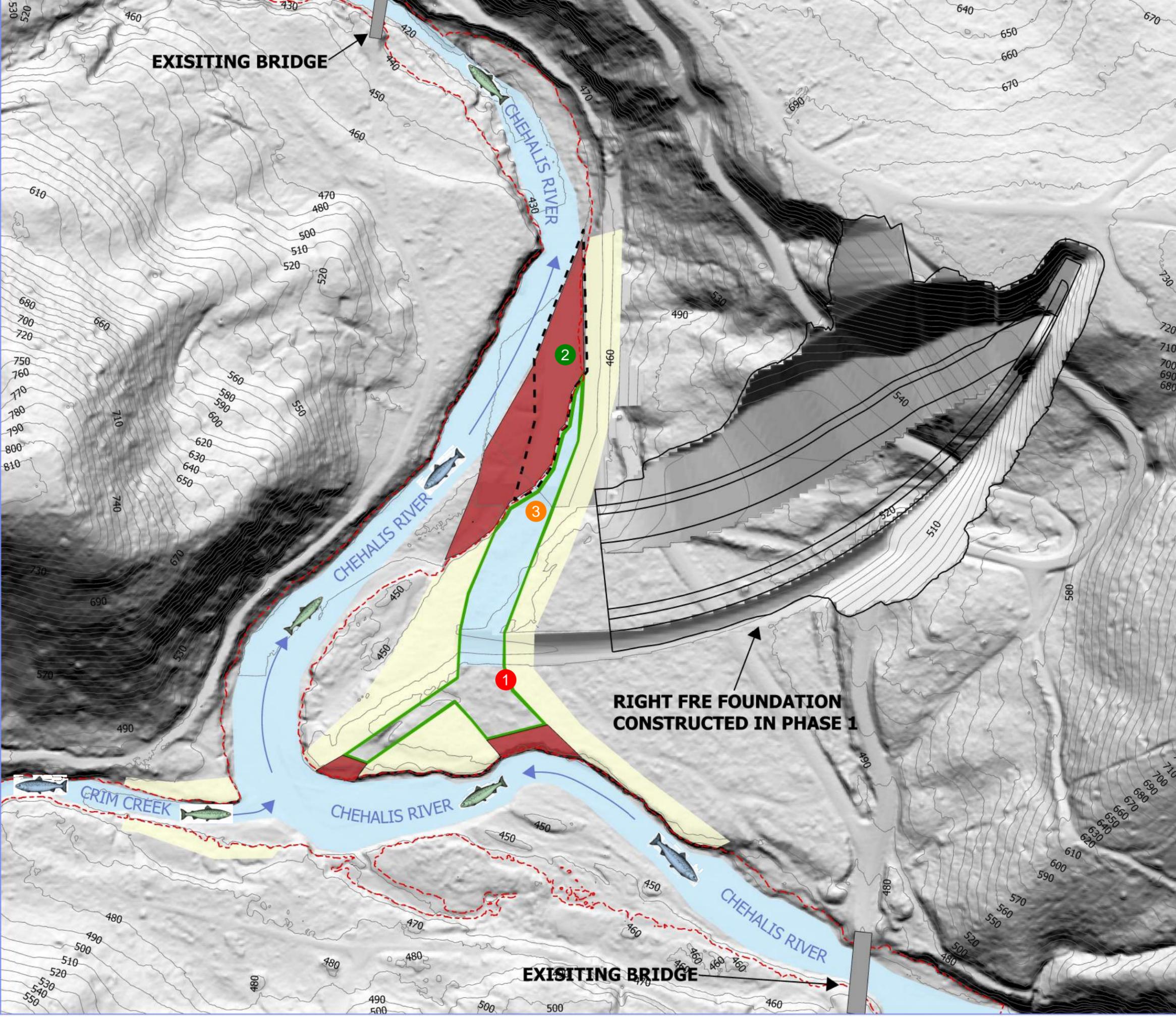
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# Attachment A. Phase 1-2 Transition, Step 1

# CONSTRUCTION IN-WATER WORK STEPS

YEAR 1  
IN-WATER WORK WINDOW 1  
TRANSITION FROM PHASE 1 TO PHASE 2  
STEP 1

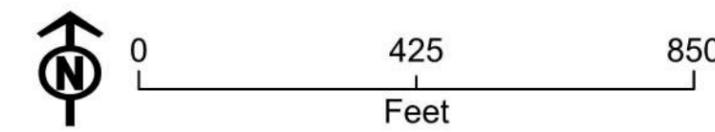


## Legend

- FRE FACILITY
- EXISTING OHWM - 2YR WSEL
- 10 FT CONTOUR
- CHANNEL BREACH
- DIRECTION OF FLOW
- UPSTREAM FISH PASSAGE ROUTE
- DOWNSTREAM FISH PASSAGE ROUTE
- EXISTING RIVER BANK
- BYPASS CHANNEL EMBANKMENT
- BYPASS CHANNEL APPROX.
- SUMMERTIME WETTED AREA

- 1** BYPASS CHANNEL AND BYPASS CHANNEL EMBANKMENT ABOVE OHWM CONSTRUCTED IN THE DRY, BEHIND THE EXISTING RIVER BANK, PRIOR TO STEP 1.
- 2** EXISTING RIVER BANK BREACHED DURING STEP 1, CONNECTING BYPASS CHANNEL TO EXISTING CHEHALIS RIVER. BYPASS CHANNEL BACKWATERED BY CHEHALIS RIVER. AQUATIC SPECIES EXCLUDED AND REMOVED FROM WORK AREA PRIOR TO CONSTRUCTION BELOW OHWM.
- 3** AQUATIC SPECIES EXCLUSION REMOVED FROM WORK AREA FOLLOWING CONSTRUCTION BELOW OHWM. AQUATIC SPECIES HAVE ACCESS TO BACKWATERED BYPASS CHANNEL.

**NOTES**  
 1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
 2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONTRUCTION.





## Attachment B. Phase 1-2 Transition, Step 2

# CONSTRUCTION IN-WATER WORK STEPS

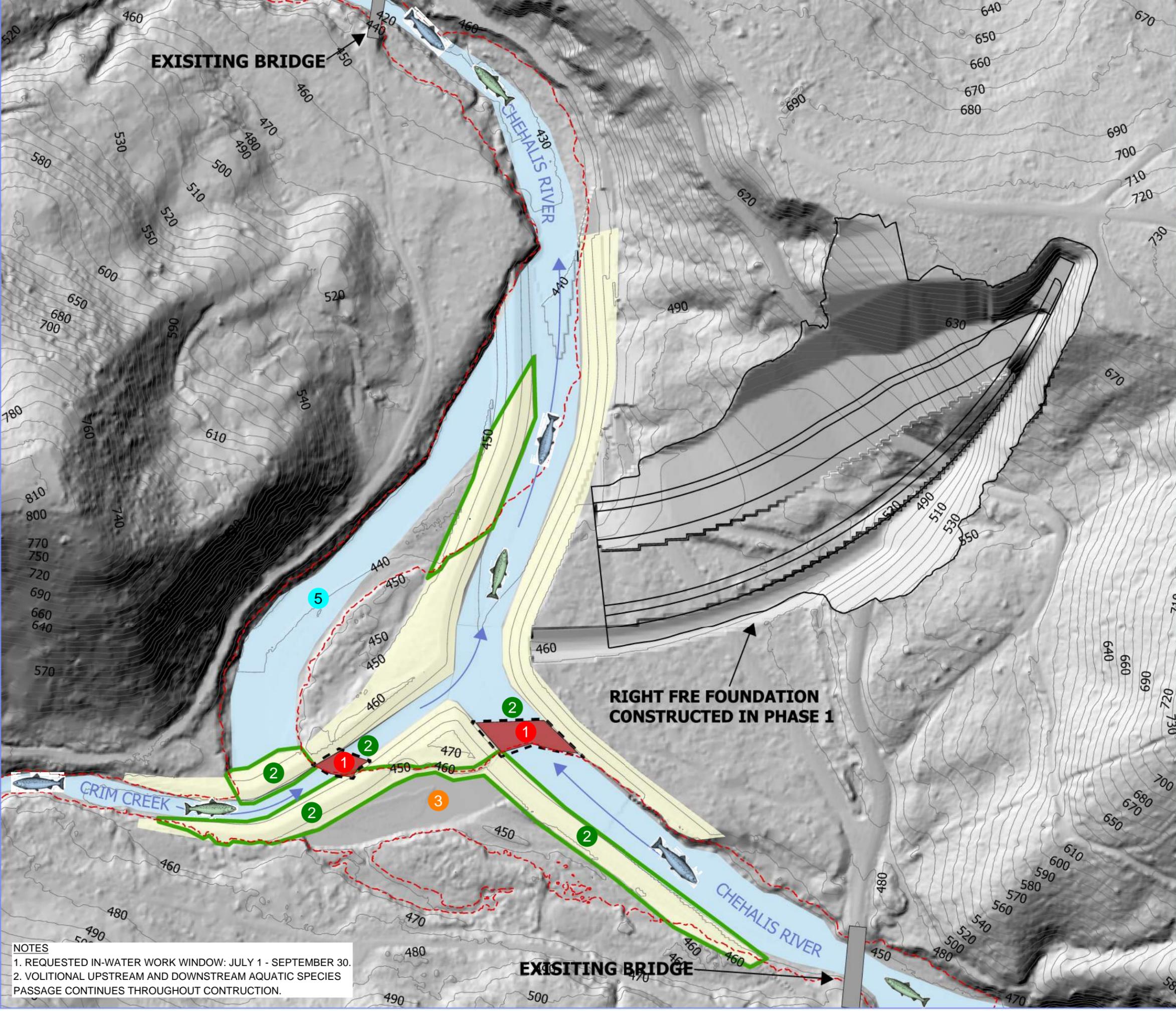
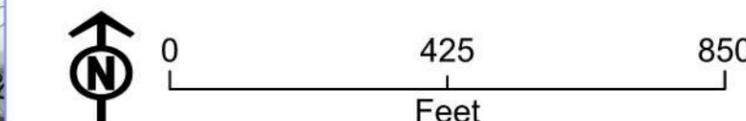
YEAR 1  
IN-WATER WORK WINDOW 1  
TRANSITION FROM PHASE 1 TO PHASE 2  
STEP 2

## Legend

- FRE FACILITY
- EXISTING
- - - OHWM - 2YR WSEL
- 10 FT CONTOUR
- - - CHANNEL BREACH
- ← DIRECTION OF FLOW
- EXISTING RIVER BANK
- ▭ CONSTRUCTED EMBANKMENT
- BYPASS CHANNEL EMBANKMENT APPROX.
- SUMMERTIME WETTED AREA

-  UPSTREAM FISH PASSAGE ROUTE
-  DOWNSTREAM FISH PASSAGE ROUTE

- 1** PERFORM INITIAL BREACH OF EXISTING RIVER BANKS TO ALLOW CHEHALIS RIVER AND CRIM CREEK INTO THE BYPASS CHANNEL.
- 2** GRADUALLY WIDEN BREACHES OF EXISTING RIVER EMBANKMENTS WHILE SIMULTANEOUSLY CONSTRUCTING BYPASS CHANNEL EMBANKMENTS. AS FLOW GRADUALLY DIVERTS INTO THE BYPASS CHANNEL THE WSEL IN THE EXISTING CHEHALIS RIVER WILL SLOWLY LOWER. PERFORM AQUATIC SPECIES RELOCATION CONTINUOUSLY THROUGHOUT IN-WATER WORK. WORK CONTINUES UNTIL EXISTING CHANNEL AREAS WITHIN THE FINAL BYPASS FOOTPRINT ARE FULLY BREACHED, BYPASS EMBANKMENTS ARE COMPLETE, AND FLOW IS FULLY DIVERTED FROM THE EXISTING CHEHALIS RIVER AND CRIM CREEK TO THE BYPASS CHANNEL.
- 3** RELOCATE AQUATIC SPECIES FROM THE EXISTING RIVER CHANNEL AS WSEL DROPS. PUMP OUT REMAINING WATER AND RELOCATE FISH SIMULTANEOUSLY UNTIL CHANNEL IS DRY.
- 4** CONSTRUCT PART OF DOWNSTREAM, LEFT BANK BYPASS CHANNEL EMBANKMENT. EXCLUDE AND RELOCATE AQUATIC SPECIES PRIOR TO STARTING IN-WATER WORK.
- 5** AQUATIC SPECIES HAVE ACCESS TO BACKWATERED EXISTING CHEHALIS RIVER CHANNEL.



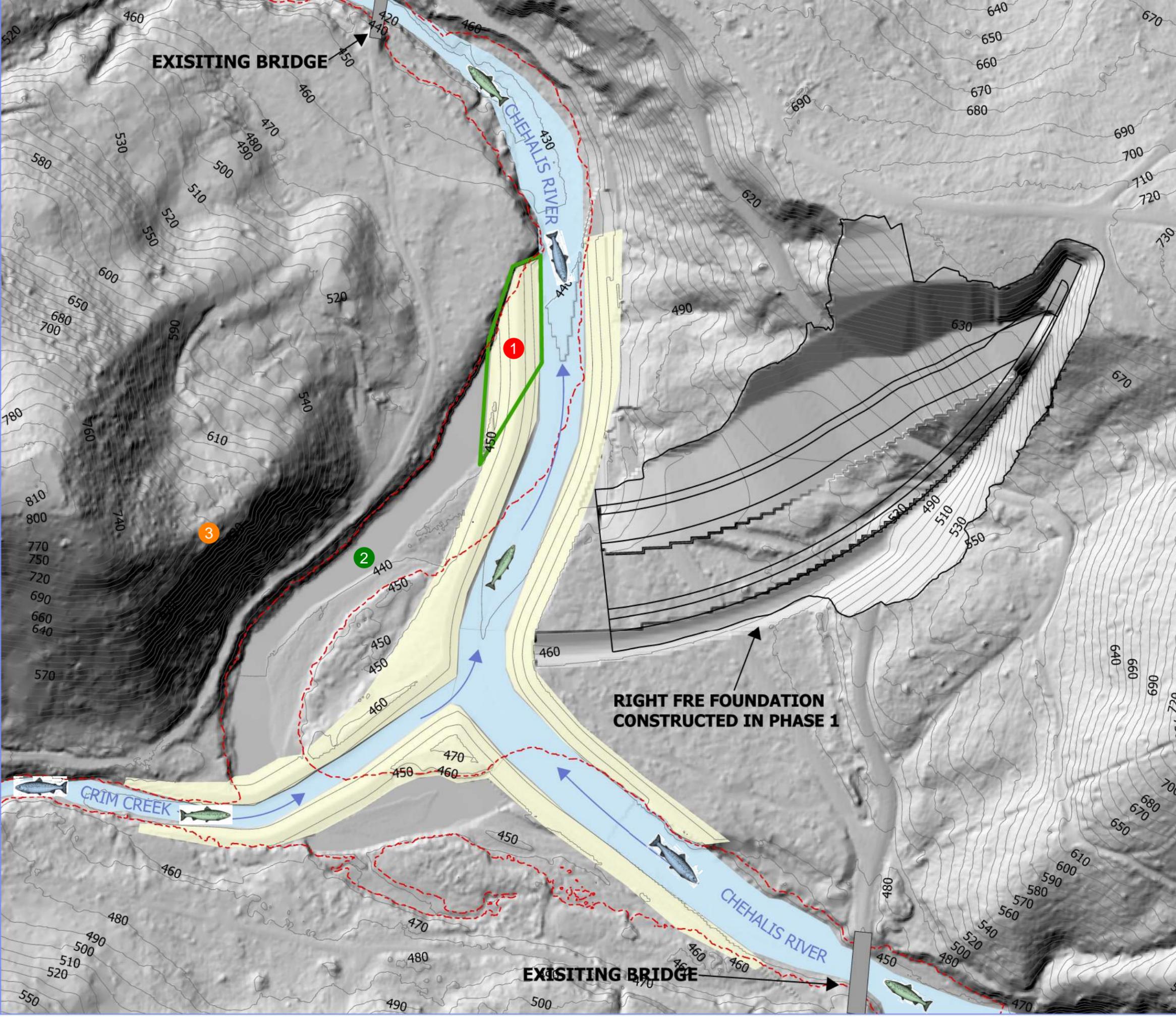
**NOTES**  
1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONSTRUCTION.



## Attachment C. Phase 1-2 Transition, Step 3

# CONSTRUCTION IN-WATER WORK STEPS

YEAR 1  
IN-WATER WORK WINDOW 1  
TRANSITION FROM PHASE 1 TO PHASE 2  
STEP 3



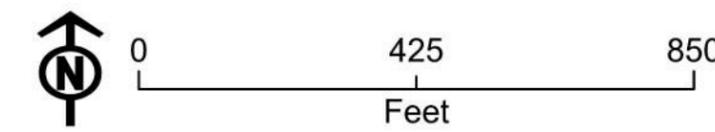
## Legend

- FRE FACILITY EXISTING
- OHWM - 2YR WSEL
- 10 FT CONTOUR
- ← DIRECTION OF FLOW
- ▭ CONSTRUCTED EMBANKMENT
- ▭ BYPASS CHANNEL EMBANKMENT
- ▭ APPROX. SUMMERTIME WETTED AREA

- UPSTREAM FISH PASSAGE ROUTE
- DOWNSTREAM FISH PASSAGE ROUTE

- 1** EXCLUDE AQUATIC SPECIES FROM THE WORK AREA. GRADUALLY CONSTRUCT FINAL BYPASS CHANNEL EMBANKMENT SIMULTANEOUSLY WITH AQUATIC SPECIES RELOCATION.
- 2** RELOCATE AQUATIC SPECIES FROM THE EXISTING RIVER CHANNEL AS WSEL DROPS WHILE FINAL BYPASS CHANNEL EMBANKMENT IS CONSTRUCTED. PUMP OUT REMAINING WATER AND RELOCATE AQUATIC SPECIES SIMULTANEOUSLY UNTIL OLD CHEHALIS RIVER CHANNEL IS DRY AND AQUATIC SPECIES ARE SAFELY RELOCATED.
- 3** PHASE 2 WORK COMMENCES FOLLOWING CONCLUSION OF IN-WATER WORK WINDOW 1.

**NOTES**  
1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONTRUCTION.

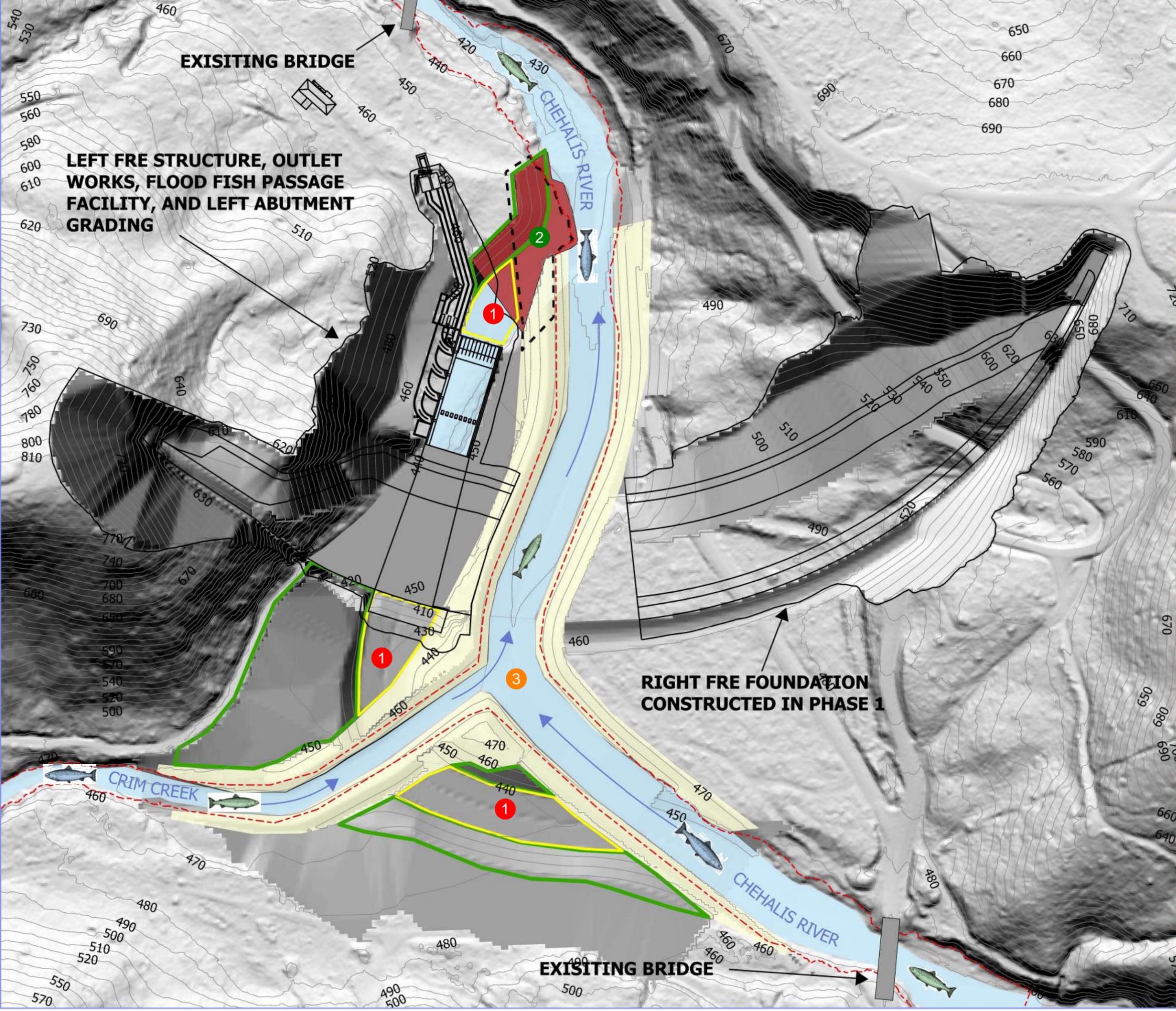




# Attachment D. Phase 2-3 Transition, Step 1

# CONSTRUCTION IN-WATER WORK STEPS

YEAR 3  
IN-WATER WORK WINDOW 2  
TRANSITION FROM PHASE 2 TO PHASE 3  
STEP 1

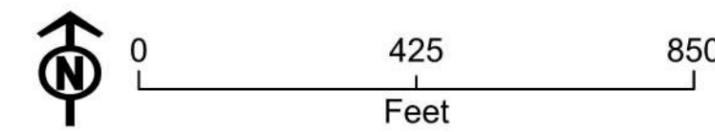


## Legend

- FRE FACILITY
- OHWM - 2YR WSEL
- 10 FT CONTOUR
- - - CHANNEL BREACH
- ▭ CONSTRUCTED EMBANKMENT
- ← DIRECTION OF FLOW
- 🐟 UPSTREAM FISH PASSAGE ROUTE
- 🐟 DOWNSTREAM FISH PASSAGE ROUTE
- ▭ BYPASS CHANNEL EMBANKMENT
- ▭ APPROX. SUMMERTIME WETTED AREA
- ▭ EXISTING RIVER BANK
- ▭ PERMANENT CHANNEL

- 1** PERMANENT RIVER CHANNEL CONSTRUCTED IN THE DRY IN PHASE 2, PRIOR TO IN-WATER WORK WINDOW 2.
- 2** CHANNEL EMBANKMENT CONSTRUCTED AND EXISTING RIVER BANK BREACHED DURING STEP 1. CHEHALIS RIVER CONNECTED TO PERMANENT CHANNEL AND FISH PASSAGE CONDUIT STILLING BASIN BY BREACH. FISH PASSAGE CONDUIT STILLING BASIN AND PERMANENT CHANNEL DOWNSTREAM BACKWATERED BY CHEHALIS RIVER. AQUATIC SPECIES EXCLUDED AND REMOVED FROM WORK AREA PRIOR TO CONSTRUCTION BELOW OHWM. AQUATIC SPECIES EXCLUDED FROM FISH PASSAGE CONDUIT STILLING BASIN THROUGHOUT STEP 1.
- 3** UPSTREAM AND DOWNSTREAM VOLITIONAL AQUATIC SPECIES PASSAGE CONTINUES VIA BYPASS CHANNEL.

**NOTES**  
1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONSTRUCTION.

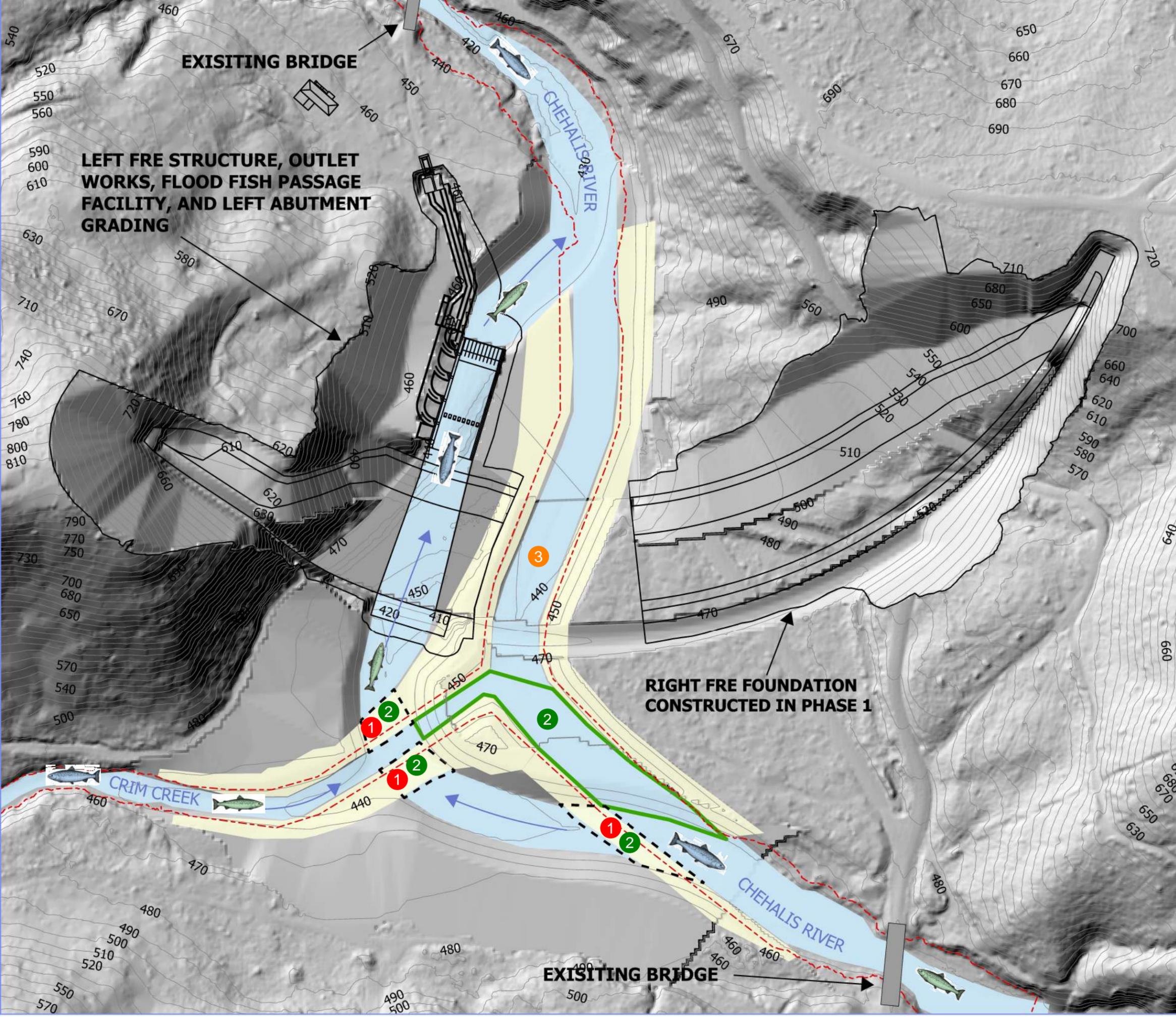




## Attachment E. Phase 2-3 Transition, Step 2

# CONSTRUCTION IN-WATER WORK STEPS

YEAR 3  
IN-WATER WORK WINDOW 2  
TRANSITION FROM PHASE 2 TO PHASE 3  
STEP 2

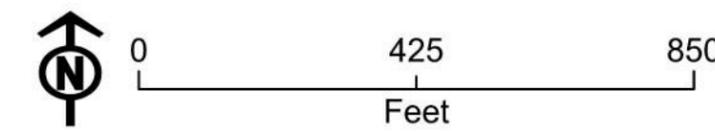


## Legend

- FRE FACILITY
- BYPASS CHANNEL EMBANKMENT
- 10 FT CONTOUR
- - - CHANNEL BREACH
- ← DIRECTION OF FLOW
- 🐟 UPSTREAM FISH PASSAGE ROUTE
- 🐟 DOWNSTREAM FISH PASSAGE ROUTE
- APPROX. SUMMERTIME WETTED AREA
- OHWM - 2YR WSEL
- CONSTRUCTED EMBANKMENT

- 1** PERFORM INITIAL BREACH OF BYPASS CHANNEL TO ALLOW CHEHALIS RIVER AND CRIM CREEK INTO THE PERMANENT CHEHALIS RIVER CHANNEL.
- 2** GRADUALLY WIDEN BREACHES OF BYPASS CHANNEL EMBANKMENTS WHILE SIMULTANEOUSLY CONSTRUCTING PERMANENT CHANNEL EMBANKMENTS. AS FLOW GRADUALLY DIVERTS INTO THE PERMANENT RIVER CHANNEL THE WSEL IN THE BYPASS CHANNEL WILL SLOWLY LOWER. PERFORM AQUATIC SPECIES RELOCATION CONTINUOUSLY THROUGHOUT IN-WATER WORK. WORK CONTINUES UNTIL BYPASS EMBANKMENT AREAS WITHIN THE PERMANENT CHANNEL FOOTPRINT ARE FULLY BREACHED, PERMANENT EMBANKMENTS ARE COMPLETE, AND FLOW IS FULLY DIVERTED FROM THE BYPASS CHANNEL TO THE PERMANENT CHANNEL.
- 3** AQUATIC SPECIES HAVE ACCESS TO BACKWATERED EXISTING CHEHALIS RIVER CHANNEL.

NOTES  
1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONSTRUCTION.

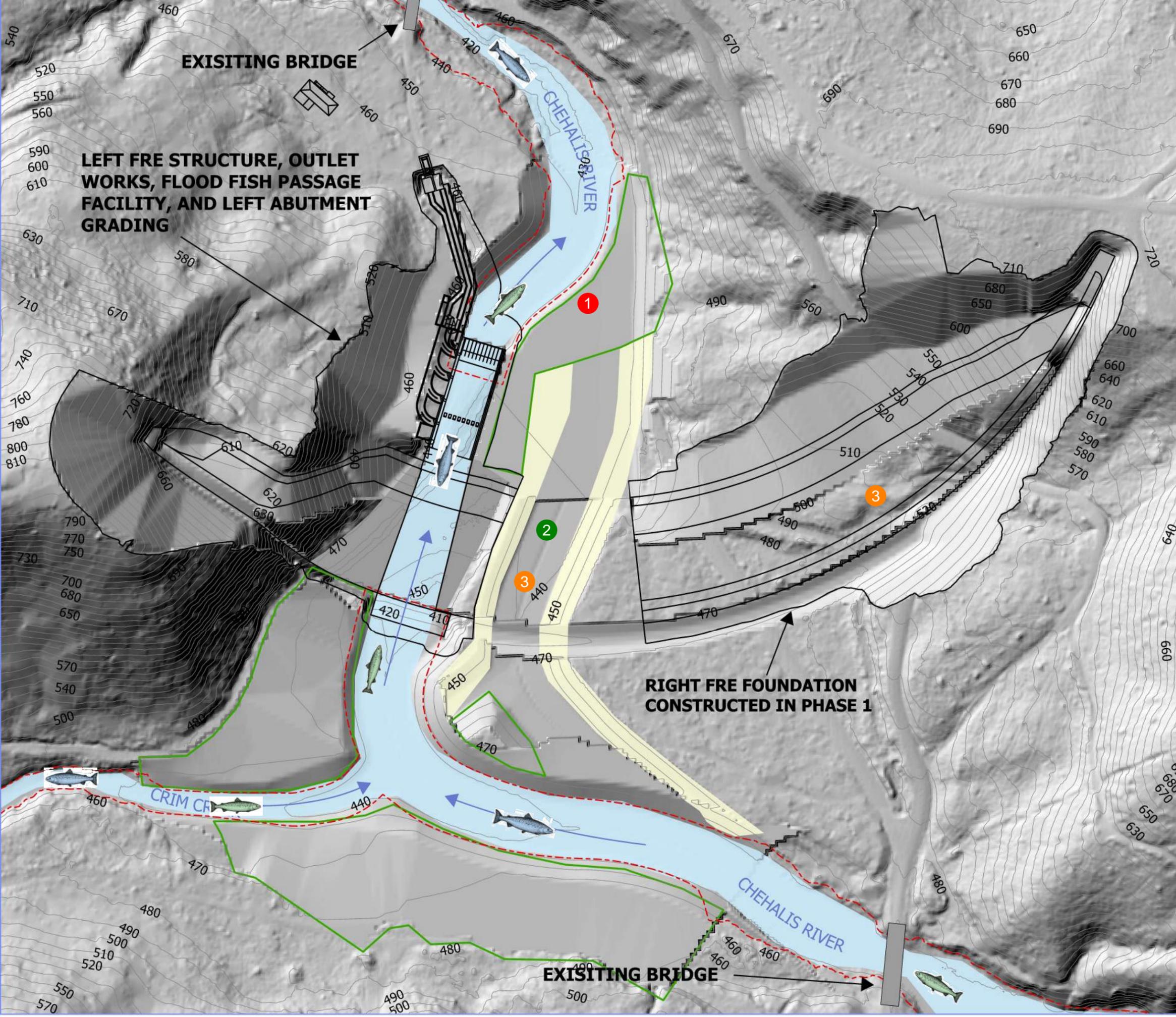




## Attachment F. Phase 2-3 Transition, Step 3

# CONSTRUCTION IN-WATER WORK STEPS

YEAR 3  
IN-WATER WORK WINDOW 2  
TRANSITION FROM PHASE 2 TO PHASE 3  
STEP 3

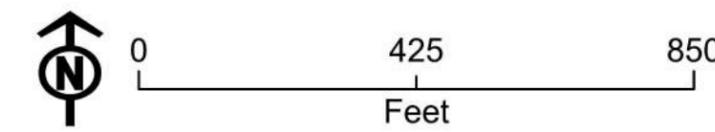


## Legend

- FRE FACILITY PROPOSED
- - - OHHM - 2YR WSEL
- 10 FT CONTOUR
- ← DIRECTION OF FLOW
- UPSTREAM FISH PASSAGE ROUTE
- DOWNSTREAM FISH PASSAGE ROUTE
- CONSTRUCTED EMBANKMENT
- BYPASS CHANNEL EMBANKMENT
- APPROX. SUMMERTIME WETTED AREA

- 1** EXCLUDE FISH FROM THE WORK AREA. GRADUALLY CONSTRUCT FINAL PERMANENT CHANNEL EMBANKMENT SIMULTANEOUSLY WITH AQUATIC SPECIES RELOCATION.
- 2** RELOCATE AQUATIC SPECIES FROM THE BYPASS CHANNEL AS WSEL DROPS WHILE PERMANENT EMBANKMENT IS CONSTRUCTED. PUMP REMAINING WATER OUT OF BYPASS CHANNEL AND RELOCATE AQUATIC SPECIES SIMULTANEOUSLY UNTIL BYPASS CHANNEL IS DRY AND FISH ARE SAFELY RELOCATED.
- 3** PHASE 3, INCLUDING CONSTRUCTION OF RIGHT SIDE OF FRE STRUCTURE AND FILLING OF DRY BYPASS CHANNEL, COMMENCES FOLLOWING CONCLUSION OF IN-WATER WORK WINDOW 2.

**NOTES**  
1. REQUESTED IN-WATER WORK WINDOW: JULY 1 - SEPTEMBER 30.  
2. VOLITIONAL UPSTREAM AND DOWNSTREAM AQUATIC SPECIES PASSAGE CONTINUES THROUGHOUT CONSTRUCTION.



**LEFT FRE STRUCTURE, OUTLET WORKS, FLOOD FISH PASSAGE FACILITY, AND LEFT ABUTMENT GRADING**

**RIGHT FRE FOUNDATION CONSTRUCTED IN PHASE 1**

**EXISTING BRIDGE**

**EXISTING BRIDGE**

CHEHALIS RIVER

CHEHALIS RIVER

CRIM CR

## Appendix B. Juvenile Fish Sounding TM

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# Technical Memorandum

Date: November 21, 2025

Project: Chehalis River Basin Flood Damage Reduction Project

To: Chehalis Basin Flood Control Zone District

From: Cheyenne Ginther, HDR, Environmental Scientist  
Peter Drobny, HDR, Senior Fisheries Scientist  
Norm Ponferrada, HDR, Senior Fisheries Project Manager

---

Subject: **Juvenile Fish Sounding (Draft)**

---

## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

The Proposed Project's draft Preliminary Design Report (PDR) documents development of the preliminary design of the FRE facility and related elements. Development of the draft PDR began following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), which was used as the baseline for the draft PDR, submitted for information-only purposes on June 30, 2025 (HDR 2025a). This draft PDR reflects design development that has occurred since submittal of the June 30, 2025, draft PDR.

The draft PDR documents the design basis for each Proposed Project element, including a record of design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements. The draft PDR also presents the technical details of the main features of the Proposed Project elements..

## 2.0 Introduction

The Chehalis River Basin Flood Control Zone District is proposing the construction and operation of an FRE structure at river mile (RM) 108.4 near the town of Pe Ell, Washington to reduce damage during a major flood. FRE facility designs, construction methods, and operation plans presented herein are subject to updates during future design phases.

The Proposed Project involves construction and operation of a flow-through dam for flood control, which is unlike a traditional detention dam. The Proposed Project's hydraulic outlets and fish passage structures will be built at the same height as the existing riverbed. Except during

operations for infrequent major storm events (defined in Section 3.0), the mainstem of the Chehalis River will flow freely through the fish passage structure system. Because flow-through dams minimally affect a river's natural flow under normal conditions, consequences such as blocking fish migration routes, accumulating sediment, restricting water flow to downstream communities, and other negative fish impacts are avoided or minimized.

The Proposed Project will not involve a permanent pool or reservoir. Rather, an area behind the dam will be inundated only temporarily when the structure is being operated for downstream flood reduction. Following passage of the peak flood flow, the inundated area will be drained and flow-through conditions re-established. There is a risk that juveniles may be entrained into hydraulic outlets while the temporary inundation pool is drained. Entrained juveniles may be at risk of injury or death if the outlets are unscreened or not hydraulically conducive to safe fish passage.

## 2.1 Purpose and Scope of the Memorandum

This memorandum presents available research to inform design and recommend potentially appropriate depths for hydraulic outlets to limit the risk of entrainment to fish moving downstream during temporary impoundment events. This recommendation is reached by assessing the juvenile outmigrant entrainment risk during evacuation of the temporary reservoir. The memo describes the potential risk of entrainment into the hydraulic outlet gates opening at depth due to “juvenile fish sounding” or movement into deeper water toward the end of the temporary inundation area.

The analyses focuses on salmonids, primarily spring-run and fall-run Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*) and winter-run steelhead (*O. mykiss*) which are prey items for the endangered Southern Resident Killer Whale (*Orcinus orca*), resulting in their coverage under Section 7 of the federal Endangered Species Act (ESA). While this document focuses on salmonids, the project overall is designed to be relevant for a wide range of other aquatic species and life stages. Therefore, the research presented in this technical memorandum may have some applicability to other species listed in Table 1 that may be impacted by the flood retention operations due to research on the other species being limited or non-existent.

## 2.2 Proposed Project Overview

The FRE structure includes fish passage and hydraulic outlet gates. When a temporary reservoir is held upstream of the FRE structure, the fish passage gates are closed, and the hydraulic outlet gates will be used for reservoir releases.

## 3.0 Characterization of Facility Operation

For this technical memorandum, operation of the FRE facility occurs in two main operational states:

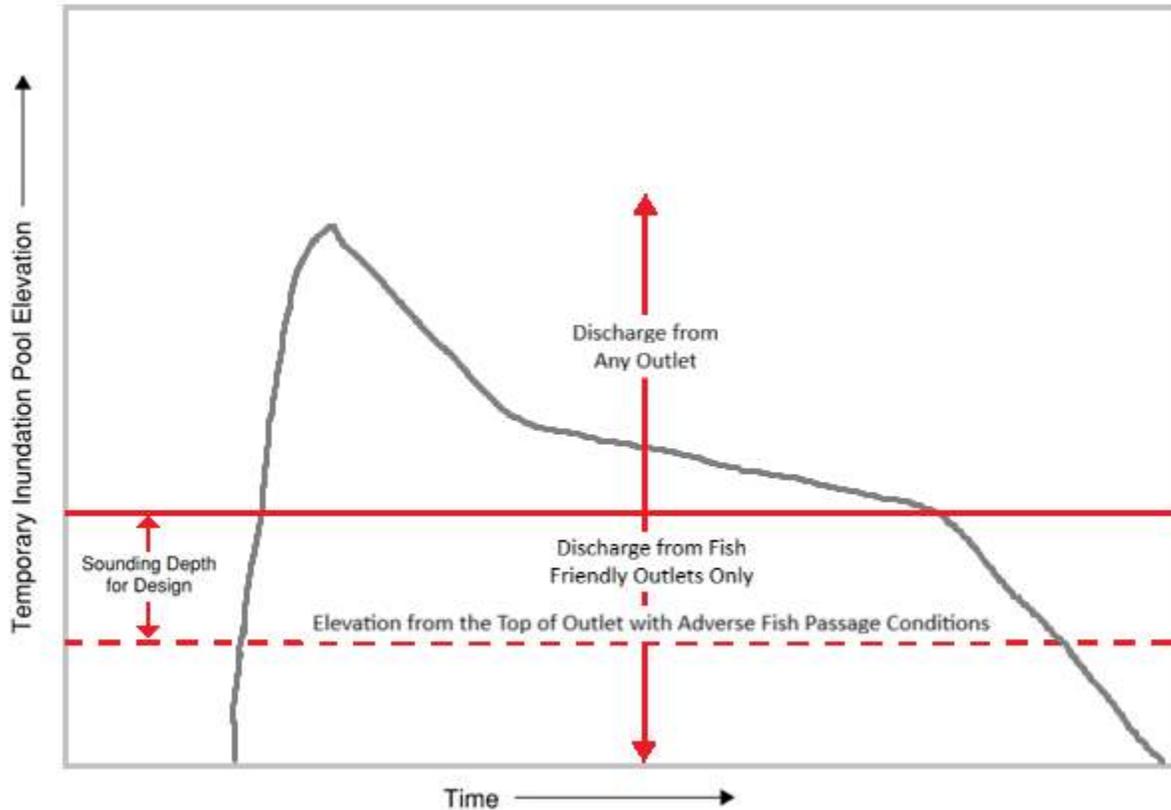
- **Normal Flow-Through Operation:** When the fish passage and hydraulic outlet gates are open and the Chehalis River flows through the FRE unimpeded.

- **Flood Retention Operation:** When the fish passage gates are closed and openings on the hydraulic outlets are reduced to impound incoming floodwaters behind the FRE.

Flood retention operation will occur when operational rules triggered. For example, an operational trigger may be that a specific flow is forecast for the Chehalis River at a specific location or river mile. Based on the hydraulic record, the hydrologic and operations modeling indicates that these events are expected to trigger flood retention operations every 4 to 5 years between the months of November to February. Flood retention operations are likely to increase every 2 to 3 years in frequency over time, during the months of November to April, due to climate changes by the year 2080 (HDR 2024b).

**Error! Reference source not found.** Figure 1 shows that when an impoundment event occurs, flood retention operations will trigger the fish passage gates to be closed, resulting in the reservoir elevation rising to store water and reduce flooding downstream. When the temporary reservoir elevation exceeds the depths for which fish are more likely to dive or sound, water will be released through unscreened, high-velocity hydraulic outlets. As the reservoir elevation drops, the flood retention operations eventually will switch to hydraulic outlets that exclude fish or provide hydraulically favorable conditions for downstream passage. Discharge through these “fish friendly” hydraulic outlets will continue as the facility transitions from flood retention operations to normal flow-through operations. Managing which hydraulic outlets are used based on reservoir depth will reduce the risk of entrainment to fish because discharge through any outlet will be at depths greater where fish are less likely to sound.

**Figure 1. Hydraulic Outlet Operation and Sounding Depth for Design When Holding a Temporary Inundation Pool**



Temperature stratification of the temporary inundation pool is not expected due to the temporary nature of the flood retention operations. Filling and draining rates for the temporary pool, and high flow rates of the Chehalis River entering the pool during and following storm events, are expected to result in high levels of mixing and turbidity, which prevent the conditions necessary for stratification. In addition, extended periods of time with low levels of mixing are necessary for stratification to occur. Impoundment events are anticipated to be of short duration – less than six weeks. This is supported by recent operations modeling. Such durations, with the high levels of mixing expected, make stratification further unlikely especially given that impoundment events are most likely to occur during the winter months when fish are less likely to sound deeper seeking cooler water temperatures. Target Species of Concern

The Proposed Project is being developed for fish passage to address fish species that use the Chehalis River, as indicated in Table 1. Although no aquatic species are federally listed as endangered or threatened in this part of the Chehalis River, under Section 7 of the federal ESA, spring-run and fall-run Chinook Salmon, Coho Salmon, and winter-run steelhead are species known to be prey items for the endangered Southern Resident Killer Whale. Therefore, this technical memorandum will focus on these three salmonid species that may indirectly impact Southern Resident Killer Whales due to potential entrainment during flood retention operations.



**Table 1. Fish Species and Life Stages Selected for Fish Passage Design**

Species	Upstream Passage	Downstream Passage
Spring-run and Fall-run Chinook Salmon ( <i>Oncorhynchus tshawytscha</i> )	Adult, juvenile	Juvenile
Coho Salmon ( <i>Oncorhynchus kisutch</i> )	Adult, juvenile	Juvenile
Winter-run Steelhead ( <i>Oncorhynchus mykiss</i> )	Adult, juvenile	Adult, juvenile
Coastal Cutthroat Trout ( <i>Oncorhynchus clarkii clarkii</i> )	Adult, juvenile	Adult, juvenile
Pacific Lamprey ( <i>Entosphenus tridentatus</i> )	Adult	Larvae
Western Brook Lamprey ( <i>Lampetra richardsoni</i> )	Adult	Larvae
Resident fish: River Lamprey, Largescale Sucker, Salish Sucker, Torrent Sculpin, Reticulate Sculpin, Riffle Sculpin, Prickly Sculpin, Speckled Dace, Longnose Dace, Peamouth, Northern Pikeminnow, Redside Shiner, Rainbow Trout, Mountain Whitefish	Adult	Adult

Source: HDR 2018

The target salmonid species (Chinook Salmon, Coho Salmon, and steelhead) are known to have unique migration behaviors that allow them to pass upstream or downstream through the FRE site at specific times of the year. As presented in Figure 2, fish species migration timing and duration influence the design and operation of proposed fish passage facilities by defining the physical, operational, and environmental conditions expected to occur while passage is required. The timing and duration of migration for these fish species and life stages were discussed at the 2016-2017 Fish Passage Subcommittee meetings (Appendix I: Fish Passage Report; HDR 2025b) as new information was aggregated and analyzed. The periods shown in Figure 2 incorporate anecdotal data of species’ presence at the extreme ends of known movement periods and are potentially likely broader than what may be found in the river.

**Figure 2. Anticipated Migration Periods of the Targeted Species and Life Stages (Periodicity)**



The following sections focus on general information for Chinook Salmon, Coho Salmon, and steelhead in the Chehalis Basin, detailing each species’ juvenile outmigration, which has a greater potential to be affected by implementation of the flood retention operations due to entrainment.

### 3.1 Chinook Salmon

The Chehalis Basin has both spring- and fall-run Chinook Salmon which are part of the Washington Coast Evolutionarily Significant Unit (ESU). Spawn timing is distinguished between spring- and fall-run Chinook Salmon in the Chehalis River Basin. While timing may overlap, for practical purposes, October 15th is the current accepted spawning date used to differentiate the spring-run from the fall-run Chinook Salmon (Ashcraft et al. 2017). Brown et al. (2017) found Skookumchuck and upper Chehalis Rivers spring-run Chinook Salmon introgressed with the fall-run and timing may not reflect actual run type. Brown et al. (2017) revealed that fall and spring runs were not genetically distinct and found slight differentiation between downstream and upstream collections (i.e., those upstream and downstream of the confluence with the Skookumchuck River), and states that “this was likely driven by isolation by distance.” Based on this information from Brown et al. (2017), individuals that spawn upstream of the FRE have “a low degree of differentiation” from those that spawn in the mainstem Chehalis River upstream of the confluence with the Skookumchuck River (RM 67).

Most Chinook Salmon in the Chehalis Basin exhibit ocean-type life histories (Smith and Wenger 2001). Most spring- and fall-run Chinook Salmon juveniles emerge the following spring, distribute downstream, and emigrate in their first spring. A small proportion are assumed to delay emigration until the following spring to emigrate as yearlings. The following are juvenile life-history patterns for spring- and fall-run Chinook Salmon including their allocation across the modeled life-history trajectories (McConnaha et al. 2017):

- **Fry Migrant (45 percent):** Rapid downstream migrant about 3 weeks after emerging between January to mid-March. Extended residence in the estuary.

- **Fingerling Migrant (45 percent):** Conventional ocean-type Chinook Salmon. Soon after emergence, they begin moving downstream slowly, eventually increasing speed to enter the estuary in late spring between April to July.
- **Yearling Migrant (10 percent):** Stream type. Spends winter in or near natal reach, eventually goes through a smoltification process (i.e., change in osmoregulation to be able to transition from freshwater to saline or ocean environments) the following spring and moves rapidly downstream to the estuary.

### 3.2 Coho Salmon

Coho Salmon in the Chehalis River are part of the Southwest Washington Coho Salmon ESU, for which no major spawning groups have been specified (WDFW 2019). In a genetic study of Coho Salmon in the Chehalis Basin, Seamons et al. (2019) found genetic differences between groups of Coho Salmon from the same spawning location, among spawning tributaries, and based on run timing (early and late). Coho Salmon in the upper Chehalis Basin (i.e., upstream of the proposed FRE site) were genetically distinct from Coho Salmon spawning in other locations, suggesting population differences among subbasins (Seamons et al. 2019).

Coho Salmon in the Chehalis Basin were assumed to follow a standard Coho Salmon stream-type life history (Smith and Wenger 2001). Juveniles emerge in the spring between February to May and spend the next year in various habitats within the Chehalis River Basin which includes side channels, beaver ponds, floodplain wetlands, and backwaters for overwintering and summer rearing. Emigration from the system typically occurs in the second spring after one year in freshwater between March to June. The following are juvenile life-history patterns for Coho Salmon including their allocation across the modeled life-history trajectories (McConnaha et al. 2017):

- **Resident (50 percent):** Migrates no more than 40 kilometers (24 miles) downstream of natal reach during juvenile rearing, moves rapidly downstream in the second spring-run to the estuary.
- **Migrant (50 percent):** Extended downstream movement including fall-run redistribution downstream. Could migrate almost to the estuary during juvenile rearing, reaching the estuary in second spring-run.

Juvenile Coho Salmon have been documented to move upstream up to a few kilometers (more than 1 mile) in some Chehalis Basin tributaries. Upstream movements primarily occurred during warmer months, which may indicate a need to access cold water refugia (Winkowski et al. 2018). Warm summer stream temperatures and the presence of competitive cyprinids in lower reaches appear to limit the amount of suitable juvenile rearing habitat in the Chehalis Basin (Winkowski et al. 2018; Winkowski and Zimmerman 2019). During 2015, juvenile salmon distribution surveys conducted upstream of the FRE site, Winkowski et al. (2016) found juvenile Coho Salmon throughout the maximum modeled FRE temporary inundation area.

### 3.3 Steelhead

Winter-run steelhead are present throughout the Chehalis River. The upper Chehalis River supports a relatively large number of wild winter-run steelhead (Ashcraft et al. 2017). Winter-run

steelhead spend the greatest amount of time in freshwater compared to other anadromous salmonids. Fry start to emerge from the gravels between May to September and freshwater rearing ranges from 1 to 3 years before emigration in the summer between April to August. Fry use low-velocity margin habitats after emergence and juveniles move into areas of fast water and large substrate as they grow. Like Coho Salmon, more structurally complex habitats (e.g., with more wood) can support more juvenile steelhead. The following are Juvenile life-history patterns for steelhead including their allocation across the modeled life-history trajectories (McConnaha et al. 2017):

- 85 percent spend 2 years in freshwater; 15 percent spend 3 years in freshwater.
- **Resident (50 percent):** Stays relatively close to natal reach before smolting.
- **Transient (50 percent):** Alternating periods of rearing and migration throughout the summer rearing period in all pre-smolting years.

## 4.0 Fish Sounding Behavior

Juvenile fish passage through the FRE structure and expected juvenile fish migration depths when faced with a temporary passage barrier are discussed in the following sections.

### 4.1 Downstream Juvenile Salmonid Fish Passage at FRE

When open during Normal Operations, the fish passage gates will help facilitate the downstream juvenile salmonid passage. When closed during Flood Retention Operations, a small number of outmigrating fish could potentially sound to 30 feet or more depending on outmigrant size of the temporary inundation area is evacuated, there is a risk that juvenile salmonids may be entrained into the evacuation conduits outmigrants and length of impoundment, which if (i.e., 0 or greater) may put them at risk of entrainment in the hydraulic outlets (Dauble et al. 1989; Li et al. 2015; Smith 1974). The depth at which fish are likely to sound is further described in Section 5.2. It is important to understand that the FRE is being designed to reduce the impact on juvenile salmonids during the flood retention operations (as stated in Section 3.0), which would be expected to typically occur outside outmigration timing (as shown in Figure 2).

Coho Salmon and steelhead rear in the Chehalis River for more than 1 year and up to 2 years, respectively, before outmigrating. In contrast, both spring and fall Chinook Salmon from the upper Chehalis Basin outmigrate to the estuary as parr, or, in limited cases, fry (Campbell et al. 2017). According to Miller-Nelson et al. (2024), a juvenile salmonid monitoring study in 2023 using a rotary screw trap at RM 94.3 on the upper Chehalis River mainstem near Pe Ell determined the following:

- Of 820 Coho Salmon captured, 274 scale samples were collected, with 95.6 percent being successfully aged finding that the outmigrants were predominantly of the yearling (or 1+) age class (98.5 percent) with a small group of 2+ year-old (1.5 percent) outmigrating.
- Of 591 steelhead captured, 250 scale samples were collected, with 79.6 percent being successfully aged finding that the migrants had a mix of Age-1 representing 33.7 percent,

Age-2 representing 65.3 percent, and Age-3 representing 1 percent of juveniles outmigrating.

- A total of 7,723 Chinook Salmon outmigrants were captured, and no scale samples were taken because they were all assumed to be subyearlings based on their fork length between 45 to 150 millimeters.

When comparing the data derived from McConnaha et al. (2017), the authors used an Ecosystem Diagnosis and Treatment model to evaluate the biological significance of environmental changes regarding the potential of the basin to support salmonids at basin and sub-basin scales due to flood damage reduction and habitat restoration actions. Whereas Miller-Nelson et al. (2024) focused on captured salmonids in the upper Chehalis Basin downstream of the proposed FRE, both assumed juvenile Coho Salmon and steelhead are highly mobile during the summer low-flow period in the upper mainstem Chehalis River due to the variable ages observed in outmigrants throughout the Chehalis River. Therefore, these age ranges should be considered as larger, older fish may distribute deeper into the water column compared to smaller, younger fish, leaving them more vulnerable to entrainment during flood retention operations.

Findings from McConnaha et al. (2017) and Nelson et al. (2024) are further corroborated by local data collected in summer 2015 where juvenile salmon distributions were surveyed around and within the inundation area of the proposed temporary reservoir, in the upper mainstem Chehalis River near the upper extent of the reservoir inundation area at RM 116 and extending approximately 10 RM upstream (Winkowski et al. 2016). Juvenile Coho Salmon and trout (cutthroat and rainbow/steelhead) were found throughout the proposed temporary reservoir inundation area, which includes stretches of the upper mainstem Chehalis River and 10 RM of several small tributary creeks. Juvenile Coho Salmon and trout were also observed in reaches above the proposed temporary reservoir inundation area. Subyearling and yearling steelhead rear in the area throughout the summer, moving frequently upstream and downstream at the proposed FRE facility site, presumably to forage and maintain optimal body temperature and condition (Winkowski and Zimmerman 2017). Unlike Coho Salmon and steelhead which rear for longer periods in freshwater, subyearling juvenile Chinook Salmon rear in the upper Chehalis River above the proposed FRE facility during their first spring and summer with outmigration from the upper Chehalis Basin generally complete by August (Winkowski and Zimmerman 2017).

Most juvenile salmon and steelhead in the Chehalis River will likely will have migrated downstream from the headwaters to rear in other freshwater habitats in the lower mainstem, off-channel, or floodplain wetlands prior to migrating to the ocean (Schroeder et al. 2025). Ocean migration would occur during the typical outmigration window between February to August, depending on species as detailed in Section 4, outside expected impoundment events that would be expected to occur between November to February that would trigger flood retention operations. This has been observed in other coastal rivers, but this behavior is not well defined for the Chehalis River populations. Juvenile Coho Salmon and steelhead that reside in freshwater longer compared to juvenile Chinook Salmon are likely to be most impacted by the expected impoundment events because they may use upstream rearing sites and need to

access habitats downstream during these high winter flood events, which provide foraging opportunities and refuge from predators and other environmental stressors. Additionally, climate change may also impact timing of these impoundment events (i.e., more variable weather pattern timing), which would result in all other juvenile salmonid species potentially being affected by impoundment events if the flood retention operations occurred during their typical outmigration timing, increasing their risk of entrainment.

## 4.2 Juvenile Migration Depths

Operation of the FRE for flood control may have unintended consequences when activated to prevent downstream flooding as it can increase juvenile salmonids' potential risk of entrainment into the hydraulic outlets that operate at depths deeper than the fish passage outlets. The ability of juvenile fish to redistribute, both upstream and downstream, into favorable rearing habitats, has also been deemed important to the continued viability of many stocks. Fish migration and passage behaviors have a strong influence on the selection of routes associated with depth, especially for juvenile salmonids which typically prefer to stay in the top 20 feet of the water column as they migrate downstream (NOAA Fisheries 2019). However, according to Ploskey et al. (2006), vertical distribution data usually showed that more than 80 percent of the fish were in the upper 49 feet of the water column.

Faber et al. (2005) looked at smolt-sized fish which included Chinook Salmon, steelhead, Coho Salmon, and Sockeye Salmon (*Oncorhynchus nerka*) at The Dalles Dam on the Columbia River. During the spring, 80 percent of fish were above 5.6 meters (18.4 feet) and 4.7 meters (15.4 feet) of depth during the day and night, respectively. During summer, fish were similarly distributed in the day and night with 80 percent of the fish in the upper 4.5 meters (14.8 feet) and 4.7 meters (15.4 feet) of the water column, respectively. The vertical distribution of smolt-sized fish was also found to be skewed toward the upper water column for all season/diel categories. They also found that smolt-sized fish were distributed deeper in the water column in the center of the channel than near the edges.

A study focused on juvenile Coho Salmon at the Merwin Dam on the Lewis River found that 72 percent of Coho Salmon distributed from the surface to the upper 10 feet (Erho 1964). However, the incidence of Coho Salmon in deeper nets increased as the season progressed with only 52 percent distributing from the surface to the upper 10 feet and 40 percent distributing from 10 to 20 feet by June. It was theorized that surface temperature rising from 5.6 degrees Celsius (°C) in March to 14.7°C in June may have resulted in Coho Salmon distributing deeper into the water column.

Another study focused on the Lower Monumental Dam on the Snake River, which has a reservoir with a maximum depth of 115 feet, had two sampling stations established: one station sampled to a depth of 48 feet and one sampled to a depth of 96 feet. The study found that 58 percent of juvenile Chinook Salmon and 36 percent of juvenile steelhead traveled in the upper 12 feet of the reservoir as shown in Table 2 (Smith 1974). Of fish caught in the upper 12 feet, most were predominantly found between the surface and 6 feet.



**Table 2. Vertical Distribution of Juvenile Chinook Salmon and Steelhead Caught at Shallow and Deep Stations in the Forebay of the Lower Monumental Dam in 1973**

Shallow and Deep Stations Combined				
Depth (feet)	Chinook Salmon		Steelhead	
	# of Fish	Percent	# of Fish	Percent
0 – 12	143	58	441	36
12 – 24	63	26	291	24
24 – 36	19	8	189	15
36 - 48	4	2	106	8
48 – 60	3	1	61	5
60 – 72	6	2	62	6
72 – 84	2	1	32	2
84 – 96	5	2	48	4

Source: Smith (1974)

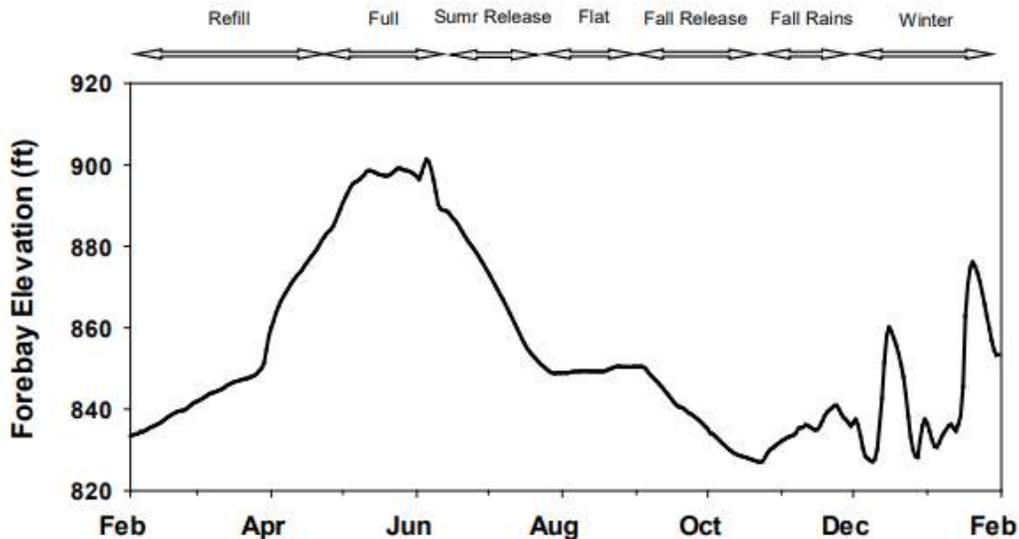
Vertical fish distribution was also examined to determine changes between day and night periods. Smith (1974) found that juvenile Chinook Salmon were observed to be more surface-oriented at night, with 60 percent being captured in the upper 24 feet of the reservoir. Steelhead were observed to be more surface-oriented during the day, with 74 percent being captured in the upper 24 feet of the reservoir. Therefore, steelhead were found to be more surface-oriented during the day whereas juvenile Chinook Salmon were more surface-oriented at night.

A study by Li et al. (2015) focused on juvenile Chinook Salmon and steelhead and compared data across two years (2012 and 2013) in the forebays of two dams on the Snake River, Little Goose Dam and Lower Monumental Dam. The study found that the median depth at which juvenile salmonids approached turbines ranged from 2.8 to 12.2 meters (9.2 to 40 feet), with depths varying by species/life history, year, location (which dam) and diel period (denoting a 24-hour period). The study also showed that fish with estimated deeper vertical depth distributions resided deeper in the forebay prior to passing through the turbines ( $\leq 18.4$  meters [ $\leq 60.4$  feet] at Little Goose Dam and 17.0 meters [55.8 feet] at Lower Monumental Dam) compared to those passing through the juvenile bypass system ( $\leq 13.0$  meters [ $\leq 42.7$  feet] at Little Goose Dam and 13.8 meters [45.3 feet] at Lower Monumental Dam (Li et al. 2015). This was reconfirmed by Li et al. (2018) where they found that juvenile salmonids that passed through deeper routes swam deeper in the water column when approaching the dams which increased the probability of powerhouse passage (i.e., turbine) significantly. While subyearling Chinook salmon that were detected at least once shallower than 12.5 meters (41 feet) were more likely to be guided by the spillway weir.

Li et al. (2015) also noted that most (75 percent) of the fish that passed at night had acclimation depths of  $\leq 7.0$  meters ( $\leq 30.0$  feet), while most of the fish passing during the day had acclimation depths of  $\leq 5.0$  meters ( $\leq 16.4$  feet). For all three species in 2012 and 2013, there were higher percentages of fish acclimated at depths  $> 10$  meters ( $> 32.8$  feet) for night- versus day-passed fish. Therefore, if operation of the FRE to control flooding occurred during the night, fish are assumed to be more likely to be able to handle passing through the hydraulic outlets at a deeper depth than those that approach the FRE during the day.

While it does appear juvenile salmonids are capable of acclimating to greater depths, Khan et al. (2012) found that juvenile Chinook Salmon and steelhead remained surface-oriented (i.e., above 10 meters [32.8 feet]) 62 percent of the time during the refill and full pool periods to 80 percent of the time during the flat elevation and fall release periods at the Lookout Point Dam on the Middle Fork Willamette River. During these periods, water temperatures from the surface to 5 meters (16.4 feet) ranged from 19.5°C in August to 12.1°C in November and were much cooler at depth, ranging from 11.7°C in August to 10.6°C in November, at 30 to 35 meters (98.4 to 114.8 feet) depth. Figure 3 shows the daily average surface elevation level of the forebay at the Lookout Point Dam from February 2010 to January 2011. The surface elevation level at the forebay paired with the water temperature may indicate why fish are more likely to remain surface-oriented versus diving deeper as typically when reservoir water temperatures are high in surface water, fish tend to move to deeper, cooler water. Regardless of temperature, the highest percentage of fish (30 to 60 percent) remained between 5 and 10 meters (16.4 and 32.8 feet) which was a prevalent behavior for juvenile salmonids.

**Figure 3. Daily Average Surface Elevation (feet above mean sea level) of the Forebay at the Lookout Point Dam from February 2010 to January 2011**



Source: Khan et al. (2012)

Lastly, Beeman et al. (2014) studied in-reservoir movements and dam passage of juvenile Chinook Salmon and steelhead at the Detroit Reservoir and Dam, near Detroit, Oregon. They

found that the depths of tagged fish within 25 meters of the dam varied between species, reservoir elevation, and diel period. When the reservoir elevation was greater than the spillway ogee of 1,541 feet during the spring study period, the mean hourly depths of Chinook Salmon ranged from 10.4 to 29.1 feet and were slightly deeper during the day than during the night. When the reservoir elevation was less than 1,541 feet during the spring study period, which occurred as the reservoir was filling in March and April, Chinook Salmon showed a large variation in depth-distribution across a 24-hour period; however, only eight tagged fish were present during that condition. Their individual mean hourly depths ranged from 16.0 to 139.0 feet, with mean values of 104.5 feet during the day and 28.5 feet during the night. Steelhead depths were shallower and less variable than Chinook Salmon depths during the spring study period. Their mean hourly estimated depths ranged from the surface to 7.1 feet and were similar during the day and night.

### 4.3 Biological Mechanisms Influencing Fish Depth

To better understand why juvenile fish are distributed in the upper portions of the water column, biological mechanisms should also be reviewed. Juvenile fish activity is largely focused on survival and growth due to the limited physical resources they have in younger life stages (developing muscles, minimal fat stores). Bioenergetics is a research area that describes the balance of fish activity in a biological way.

Fish bioenergetics can be described as an energy budget where fish balance energy gained from *I* (ingestion: total energy gained) and lost through *G* (growth: increase in length and weight over time), *A* (activity: physical movements such as swimming, foraging, social interactions, evading predators, and search for suitable habitats), *M* (metabolism: chemical processes that convert food into energy in order to maintain life), *R* (reproduction: development of gonads: ovaries & testes and production of gametes: eggs & sperm), *E* (excretion: expelling or removal of metabolic waste through fecal matters, ammonia, urea, or uric acid), and *SDA* (specific dynamic action: digestive processes, nutrient absorption and assimilation; Mayfield and Cech 2004). A simplified bioenergetics equation is modeled below:

$$I = G + A + M + R + E + SDA$$

The bioenergetic demands of juvenile salmonids typically increase with activity level during foraging and searching for suitable habitats (Hartman & Hayward 2007). The presence of predators increases stress levels, as well as burst swimming to evade these predators lead to exhaustion which carries significant bioenergetic costs to juvenile salmonids. As a result, fish tend to inhabit waters with easily accessible and ample amounts of prey items for consumption to continue to have high amounts of stored energy for maintenance, growth, and reproduction to increase survival. This physiological ecology and response reflect the dynamic nature of adjustments aimed at optimizing the bioenergetic balance between consumption and expenditure across changing environmental conditions. More simply stated, bioenergetic success is represented by feeding with minimal effort.

The vertical habitat preferences of juvenile salmonids are generally driven by bioenergetics requirements that ensure that energy intake is maximized, and energy expenditure is minimized.

Since salmonids are primarily visual feeders, occupying the upper portions of water column maximizes energy intake relative to the cost of foraging. In addition, the upper water column tends to be better oxygenated, which supports aerobic metabolism and reduces the energy cost of respiration (Brett 1971, Quinn 2018). By remaining near the top of the water column where prey density is higher, juvenile salmonids can maximize foraging efficiency and achieve a positive energy balance that supports growth. Conversely, deeper portions of the water column often provide fewer prey resources and reduced light for visual feeding, which lowers potential for prey interaction and consumption. Additionally, deeper habitats may increase metabolic rates by swimming against stronger currents and respiratory demands if dissolved oxygen levels are reduced at depth (Gregory and Levings 1998). Vertical distribution of juvenile salmonids is not fixed, but instead reflects dynamic adjustments aimed at optimizing the bioenergetic balance between consumption and expenditure across changing environmental conditions.

The bioenergetics of salmon biology support that juvenile fish do not regularly invest in energetic activity to reach dark, less productive, water depths with little overall potential for benefit (i.e., feeding). Because impoundment of the dam is only expected to occur during flood events over short periods of time, high turbidity would be expected with low penetration of sunlight into the reservoir. With the photic zone (penetration of sunlight to support photosynthesis) being shallow, growth of primary producers (e.g., phytoplankton) and zooplankton at depth is limited, which limits food resources and habitat for macroinvertebrates. Therefore, juvenile fish would tend to occupy the upper water column near the surface to forage on macroinvertebrates associated with the presence of lower trophic level organisms.

While juveniles may infrequently occur at greater depths largely due to passive drift in larger rivers (undertow) or predator avoidance (being chased), the biological drivers behind their bioenergetic 'budget' of a juvenile salmon largely results in occupying shallower biologically productive water depths relative to the proposed project diversion.

## 5.0 Conclusion

Effects on juvenile fish outmigrating downstream in the Chehalis River are expected when flood retention operation occurs, and discharge from outlet gates is reduced to impound floodwater behind the FRE structure. During the portion of flood retention operations when the temporary inundation pool elevation is high the pool is evacuated using unscreened, high velocity hydraulic outlets. Pool evacuation using unscreened, high velocity outlets poses a risk of injury or death to juvenile outmigrants that may become entrained into these hydraulic outlets.

There is a depth at which the risk of fish entrainment is low enough to allow discharge through unscreened, high velocity outlets. It is critical to understand the vertical migratory behavior of fish as they approach the outlets so the hydraulic outlets can be design to operate to reduce risk to juvenile fish. Vertical migration is a typical phenomenon for salmonids and vertical distribution factors during downstream migration vary within reservoirs (e.g., species, diel changes, seasonally, annually, location, temperature, reservoir elevation). To reduce the risk to outmigrants, reservoir releases should occur via unscreened, hydraulic-only outlets at pool depths with low risk of entrainment or via outlets that exclude fish or provide safe downstream

passage through hydraulically favorable conditions. The temporary reservoir elevation at which the depth above an active, unscreened, hydraulic-only outlet has an acceptably low risk of potential entrainment is shown in Figure 1 and described in Section 3 for a typical impoundment event.

In general, the research summarized in this document supports that juvenile salmonids (i.e., Chinook Salmon, Coho Salmon, and steelhead) typically prefer to stay in the top 20 feet of the water column as they migrate. However, study results vary, showing most fish observations from the surface down to maximum depths ranging from approximately 15 to 49 feet. The deeper depths at which are found to sound to are more likely to occur if fish are given time to acclimatize to deeper water columns. Fish are unlikely to acclimatize at the FRE given that storm events are sudden and the impoundment of water behind the FRE structure will be brief and infrequent. Ultimately, water depth preferences are driven largely by bioenergetics requirements, which dramatically reduce entrainment risk into the hydraulic outlets at depths greater than around approximately 20 to 30 feet with reducing risk as depth increases (Sections 4.1 and 4.2).

At a 30-foot depth, the differential ratio of the intake opening to the surface area near the dam is conservatively <0.01 percent. This mitigates much of the risk of entrainment, and even continues to decrease significantly at greater depths. However, an unknown but likely small percentage of fish could sound to depths greater than 30 feet if impoundment conditions persist long enough depending on species, specific life stages (e.g., fry, juvenile, etc.), water temperatures, time of day, and other factors. Additionally, flood retention operation is anticipated to occur about once every 4-to-5-years when the facility first begins operations and increase to once every 2-to-3-years based on recent climate projections. Further, operations are modeled to potentially occur between the months of November to February early in the life of the project and may occur between November and April by the year 2080. which would further increase juvenile salmonids' risk of entrainment. Most juvenile salmon and steelhead in the river will outmigrate after potential flood retention operations may occur early in the project's life (February to August), thus reducing exposure to potential entrainment even further. Exposure to potential entrainment may increase under future climate conditions, but would only increase potential exposure for two additional months of the seven month outmigration period.

HDR discussed the research and findings in this memo with NOAA Fisheries in 2025 (HDR 2025b; Appendix A). It was agreed that most juvenile salmonids likely would not sound deeper than 30 feet in a temporary inundation pool at the FRE structure and would have limited exposure to potential entrainment and flood operation conditions at the FRE. A hydraulic outlet that does not exclude fish or provide safe downstream passage through hydraulically favorable conditions must only discharge flow during flood retention operation when the water surface is 30 feet or more above the top of the same hydraulic outlet. Hydraulic outlets that discharge when the water depth is less than 30 feet must have a smooth inlet transition, such as curved entrances and radial gates. The design direction agreed upon in the meeting, summarized here, is consistent with and supported by the findings documented in this memo and will be incorporated into the project design.

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## 7.0 Acronyms

°C	degrees Celsius
FRE	Flood Retention Expandable
HDR	HDR Engineering, Inc.
NOAA	National Oceanic and Atmospheric Administration
PDR	Preliminary Design Report
Proposed Project	Proposed Chehalis River Basin Flood Damage Reduction project
RM	river mile
RPDR	Revised Project Description Report
USFWS	United States Department of Fish and Wildlife
WDFW	Washington Department of Fish and Wildlife
WSEL	water surface elevation level

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## Appendix C. Fishway Lighting TM

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# Technical Memorandum

Date: November 21, 2025

Project: Chehalis River Basin Flood Damage Reduction Project

To: Chehalis Basin Flood Control Zone District

From: HDR

Subject: **Fishway Lighting (Draft)**

## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

The Proposed Project's draft Preliminary Design Report (PDR) documents development of the preliminary design of the FRE facility and related elements. Development of the draft PDR began following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), which was used as the baseline for the draft PDR, submitted for information-only purposes on June 30, 2025 (HDR 2025). This draft PDR reflects design development that has occurred since submittal of the June 30, 2025, draft PDR.

The draft PDR documents the design basis for each Proposed Project element, including a record of design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements. The draft PDR also presents the technical details of the main features of the Proposed Project elements.

## 2.0 Introduction

The draft PDR also presents the technical details of the main features of the Proposed Project elements. The FRE structure includes the following fish passage components, designed to provide passage for a range of species and life stages:

- Flood Fish Passage Facility
- Outlet Works, including Fish Passage Structures
- Temporary Channels
- Permanent Channels

Both upstream and downstream passage are considered to include all life-stages of the species listed in Table 1 (Section 4.0).

As used in this Technical Memorandum, “fish passage structures” refers to the pathways designed for upstream and downstream fish passage in the facility. These may be dedicated fishways, the facility’s primary or secondary conduits designed to accommodate fish passage, or other structures that accommodate fish passage. The broader term “fish passage structures” is used because the lighting concerns for these pathways are generally the same regardless of the type of pathway.

### 3.0 Fishway Lighting

The outlet works consist of conduits and fishways through the base of the FRE structure allowing the Chehalis River to pass through during normal flow-through operation (normal operation). The conduit and fishway gates are normally open for fish passage and only closed for flood retention. When the FRE structure operates to retain flood water (flood retention operation) the fishway gates are closed and the conduits are used for reservoir releases. During flood retention operation fish passage through the outlet works ceases. Fish passage during flood retention operation is described in Appendix I: Fish Passage Report (HDR 2025).

Artificial lighting of the fish passage structures, including pathways through the outlet works, was investigated as a potential mitigation strategy to improve fish passage throughout the year during normal operation. This technical memorandum includes a review of relevant literature to understand how lighting may be used to improve fish passage through the fish passage structures. The affected region of the Chehalis River Basin is characterized by migratory anadromous and other native fish species with reportedly varying levels of behavioral response to artificial light frequency and intensity. Given the varied responses of fish to light, knowledge gaps exist and need to be locally examined prior to final design recommendations. This technical memorandum offers a literature-informed review of artificial lighting impacts on fish passage, drawing from peer-reviewed studies and existing reports on species behavior and light sensitivity. While localized information and studies are key to understanding the benefit of lighting, the results of several studies provided herein highlight the potential outcomes of incorporating lighting to improve fish passage.

Artificial illumination around fish passage systems has been reported to assist and improve fish passage efficiency and restore longitudinal riverine connectivity. Several research and case studies emphasize the need for a holistic approach towards designing a functional fishway, including fish interactions with their environment. In a 2012 study, Vowles and Kemp argue that understanding the relationship between hydrodynamic cues and various environmental stimuli are critical towards implementing safe and successful lighting approaches (Vowles and Kemp 2012). However, there are mixed reviews on the effects of artificial light at night (ALAN) with researchers and industry members often noting an increased effect of predation on smolt or juvenile salmonids when exposed to high light levels at night. Other research studies have posted that varying light levels can act as an attractant or a deterrent (Table 2).

Evidence from Mueller and Simmons (2008), Tetard et al. (2019), Vowles and Kemp (2012), and others shows that juvenile salmonids may be attracted to low-intensity lighting (~0.25 lux, equivalent to moonlight) but startled or deterred by intensities above 400 lux. For some species

(e.g., Topeka shiner, fathead minnow), studies found no significant behavioral change in response to culvert lighting, highlighting the need for site-specific observation (Table 3).

The 2022, National Oceanic and Atmospheric Administration (NOAA) Fisheries West Coast Region Anadromous Salmonid Design Manual (National Marine Fisheries Service [NMFS] 2022) states:

*“Ambient lighting should be provided throughout the fishway, and abrupt lighting changes should be avoided (Bell 1991). In enclosed systems, such as transport tunnels, provisions for artificial lighting should be included. In cases where artificial lighting is required, lighting in the blue-green spectral range should be provided. Artificial lighting should be designed to operate under all environmental conditions at the installation. These lighting criteria are based in part on laboratory studies where a majority of Chinook and sockeye salmon and steelhead entered the lighted orifice when given a choice between a dark experimental orifice and a lighted control orifice where head was equal between the two orifices (Weaver et al. 1976).”*

NMFS (2022) recommendations also state that “lighting conditions upstream of a bypass entrance should be ambient and extend downstream to the structure or device controlling bypass flow.”

Therefore, according to NMFS guidance, provisions for artificial lighting should be provided in transport tunnels, such as fish passage structures that pass through the base of the FRE structure, but does not require that artificial lighting be used. The recommendation to install provisions for artificial lighting but nor specifically recommending its use is consistent with the variability in outcomes noted in the studies described above and the need to understand the specific environmental conditions and potential impacts of lighting unique to each project and situation. Where artificial lighting is used, should be designed to mimic ambient light conditions, avoiding high-intensity illumination and minimizing abrupt light transitions. In applications such as orifice or fishway entry lighting, night-time light levels should not exceed 0.25–3.3 lux, depending on target species and context, as recommended by field-tested studies (Mueller and Simmons 2008; Tetard et al. 2019; Vowles and Kemp 2012).

Determining appropriate lighting conditions requires localized investigation. Fish behavior should be evaluated continuously across seasons and flow regimes, potentially including passive integrated transponder or acoustic telemetry, underwater cameras, or eDNA. These data are integral in building a species- and site-specific knowledge base. Developing and creating a system that provides light timing and intensity flexibility would allow for this monitoring to occur and adjustments to be made following construction of the facility. To avoid disrupting natural behavior, lighting should not be used to attract fish unless supported by empirical evidence local to the fishway. If used, lighting should be integrated thoughtfully with other components to enhance passage efficiency.

Table 1 lists target fish species and illustrates the varied response of species and life stage to different ambient lighting strategies across relevant studies as evidence to support the need for

fishway lighting. While some reports reveal a negative (deterrent) response to artificial light, others show specific frequencies/wavelengths can assist fish passage by acting as an attractant.

**Table 1. Target Fish Species and Life Stages Selected for Design Development**

Species	Upstream	Downstream
Spring-run Chinook salmon	Adult, Juvenile	Juvenile
Fall-run Chinook salmon	Adult, Juvenile	Juvenile
Coho salmon	Adult, Juvenile	Juvenile
Winter-run Steelhead	Adult, Juvenile	Adult, Juvenile
Coastal cutthroat trout	Adult, Juvenile	Adult, Juvenile
Pacific lamprey	Adult	Ammocoetes, Macrophthalmia
Western brook lamprey	Adult	Ammocoetes, Macrophthalmia
Resident fish, including river lamprey, largescale sucker, Salish sucker, torrent sculpin, reticulate sculpin, riffle sculpin, prickly sculpin, speckled dace, longnose dace, peamouth, northern pikeminnow, redbreast shiner, rainbow trout, mountain whitefish	Adult	Adult

Table 2 documents behavioral responses of key native fish species to artificial lighting or shaded conditions across various life stages. Findings are paraphrased for clarity and based on peer-reviewed and agency reports. Table 3 provides observed responses of non-target or related fish species to artificial lighting or shaded environments (included for comparative context).

**Table 2. Light Response of Target Fish Species**

Family	Species	Life Stage	Key Finding	Citation
Cottidae	Torrent Sculpin, Reticulate Sculpin, Riffle Sculpin, Prickly Sculpin	Adult	No behavioral response to light recorded.	No Data
Cyprinidae	Northern Pikeminnow, Speckled Dace, Longnose Dace, Northern Pikeminnow, Peamouth, Redside Shiner	Adult/ Other	Behavioral changes under artificial light, including altered passage or detection. No significant behavioral avoidance to reduced light conditions in culverts.	Celedonia et al. 2008; Kozarek et al. 2017
Salmonidae	Coastal Cutthroat Trout, Mountain Whitefish, Rainbow trout, Winter-run Steelhead, Brown Trout	Juvenile	Context-dependent responses to artificial light in that they were often attracted to low-intensity light (<50 lux) but startled by or avoided high-intensity light (>100 lux). Behavior included increased aggregation near illuminated structures, delayed migration, altered diel patterns, and elevated stress under continuous exposure. Some studies also observed optimal swimming and welfare at moderate light levels.	Mueller and Simmons 2008; Tétard et al. 2019; Kemp et al. 2006; Liu et al. 2025; Tabor et al. 2004; Jensen 2023
Salmonidae	Chinook, Coho, and Sockeye Salmon	All	Light influenced movement or habitat selection across life stages. Avoidance of high-velocity acceleration zones under light may reflect stress or risk sensitivity.	Celedonia et al. 2008; Jensen 2023; Kemp et al. 2006; Mueller and Simmons 2008; Tabor et al. 2004; Tetard et al. 2019
Salmonidae	Juvenile Salmonids	Smolt	Experienced delays or disrupted movement under ALAN.	Mueller and Simmons 2008
Salmonidae	Steelhead trout	Smolt	Higher passage under light; larger fish favored short weir under light	Kemp et al. 2006

**Table 3. Light Response of Related Fish Species**

Family	Species	Life Stage	Key Finding	Citation
Anguillidae	European Eel ( <i>Anguilla anguilla</i> )	Silver eel	Tended to avoid illuminated areas, possibly to reduce predation risk.	Vega et al. 2024
Centrarchidae	Carnivorous Fish (e.g., <i>Micropterus salmoides</i> )	Mixed	Carnivorous species had higher mean detection rate and relative read abundance under ALAN; <i>Micropterus salmoides</i> only detected under ALAN.	Oyabu et al. 2023
Cyprinidae	European Gudgeon ( <i>Gobio gobio</i> )	Adult	Experienced delays or disrupted movement under artificial light exposure	Tarena et al. 2024
Cyprinidae	Italian Riffle Dace ( <i>Telestes muticellus</i> )	Adult	Showed no significant behavioral response to light or shade.	Tarena et al. 2024
Cyprinidae	Himalayan trout <i>Schizothorax waltoni</i>	Adult	Strong attraction to green and blue light, repulsion from red and yellow light. Suggests green/blue for guidance to safe areas, red/yellow for deterrence.	Xu et al. 2022
Gadidae	Cod ( <i>Gadus morhua</i> )	Juvenile	Light reduces upper codend entry only at night; No effect of illumination during the day.	O'Neill et al. 2022
Gadidae	Haddock ( <i>Melanogrammus aeglefinus</i> )	Juvenile	Fewer enter upper codend under illumination and at night; Illumination and diel cycle reduce the proportion entering upper codend. Significant length interaction observed.	O'Neill et al. 2022
Salmonidae	Atlantic Salmon and European Eel ( <i>Salmo salar</i> ; <i>Anguilla anguilla</i> )	Fry; Migratory	Experienced delays or disrupted movement under artificial light exposure.	Vega et al. 2024; Riley et al. 2013
Salmonidae	Atlantic Salmon ( <i>Salmo salar</i> )	Adult	Despite expectations, successfully navigated a dark, low-velocity tunnel without lighting. Upstream migration confirmed via resistivity counter, even under sub-optimal hydraulic condition.	Rogers and Cane 1979

Family	Species	Life Stage	Key Finding	Citation
Salmonidae	Atlantic Salmon ( <i>Salmo salar</i> )	Smolt (Early Migration)	Reduced entry into lit bypass zone, but increased passage rate; experienced delays or disrupted movement under artificial light exposure.	Tétard et al. 2019; Vega et al. 2024
Cyprinidae	Fathead Minnow, Topeka Shiner ( <i>Pimephales promelas</i> ; <i>Notropis topeka</i> )	Adult	No statistically significant trend in selection or movement through shaded versus unshaded areas.	Kozarek et al. 2017
Salmonidae	Sea Trout ( <i>Salmo trutta</i> )	Adult	Successfully passed through the long, dark tunnel. Performance not improved by lighting; illumination deemed unnecessary.	Rogers and Cane 1979

## 4.0 Conclusion and Recommendations

Ultimately, this memo concludes that lighting is beneficial only under certain circumstances. Therefore, lighting is not proposed as a stand-alone solution for fishways. Instead, it should serve as a supportive element within a broader passage design. The design should allow for lighting to be installed post-construction, so that as literature and knowledge on this subject evolve, lighting can be added based on demonstrated need.

There is a body of evidence from empirical research to suggest positive benefits and describe a need for fishway lighting, but only under specific conditions. However, the evidence also suggests that artificial lighting used in inappropriate conditions can negatively impact fish behavior. NMFS (2022) specifically states the need for ambient lighting provisions throughout a fish passage. In instances where rates of passage are recorded, or otherwise known, to be sub-optimal, ambient fishway lighting should be included based on best available practices and NOAA guidelines. In these instances, adaptive lighting and management plans should be strongly considered, and a fish passage monitoring program established. To avoid disruption in natural fish behavior, fishway lighting to attract fish when there is no data to support this need, should be avoided. The goal is for lighting to be one of many fishway system components that act in concert to optimize and regulate fish passage for critical periods such as out-migration and should only be used when a conduit or tunnel system is disallowing or detracting fish away from traveling through the system.

Due to the equivocal benefit of lighting unless it is tailored to specific locales, fish populations, and conditions, ambient fishway lighting will be considered during design of the FRE passage conduits and fishways to ensure lighting solutions can be reasonably added post-construction. An integrated monitoring plan should be prepared to assess the need for artificial ambient lighting. While lighting is not currently proposed, the design should allow for lighting to be added if future monitoring or evolving literature demonstrates a need. If lighting is installed, its effectiveness and potential adverse effects will be evaluated. This issue can be addressed through permitting as knowledge on the subject continues to develop. Lighting conditions should be expected to fluctuate annually. Understanding water velocity rates in conjunction with the light intensity during specific times of year to monitor and manipulate light presence and intensity, is integral for facilitating effective fish passage.

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## 6.0 Acronyms/Abbreviations

ALAN	artificial light at night
HDR	HDR Engineering, Inc.
FRE	Flood Retention Expandable
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PDR	Preliminary Design Report

## Appendix D. Backwater Analysis Pool Frequency with Conduit Gates Open (Draft) TM

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# Technical Memorandum

Date: January 9, 2026

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Project: Chehalis River Basin Flood Damage Reduction Project

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To: Chehalis Basin Flood Control Zone District

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From: HDR

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Subject: **Backwater Analysis Pool Frequency with Conduit Gates Open (Draft)**

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## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

The Chehalis River Basin Flood Damage Reduction, draft Preliminary Design Report (PDR) documents development of the preliminary design of the FRE facility and related elements. Development of the draft PDR began following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), which was used as the baseline for the draft PDR. This draft PDR reflects design development that has occurred since submittal of the June 30, 2025 draft PDR (HDR 2025).

The draft PDR documents the design basis for each Proposed Project element, including a record of design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements. The draft PDR also presents the technical details of the main features of the Proposed Project elements.

## 2.0 Introduction and Purpose

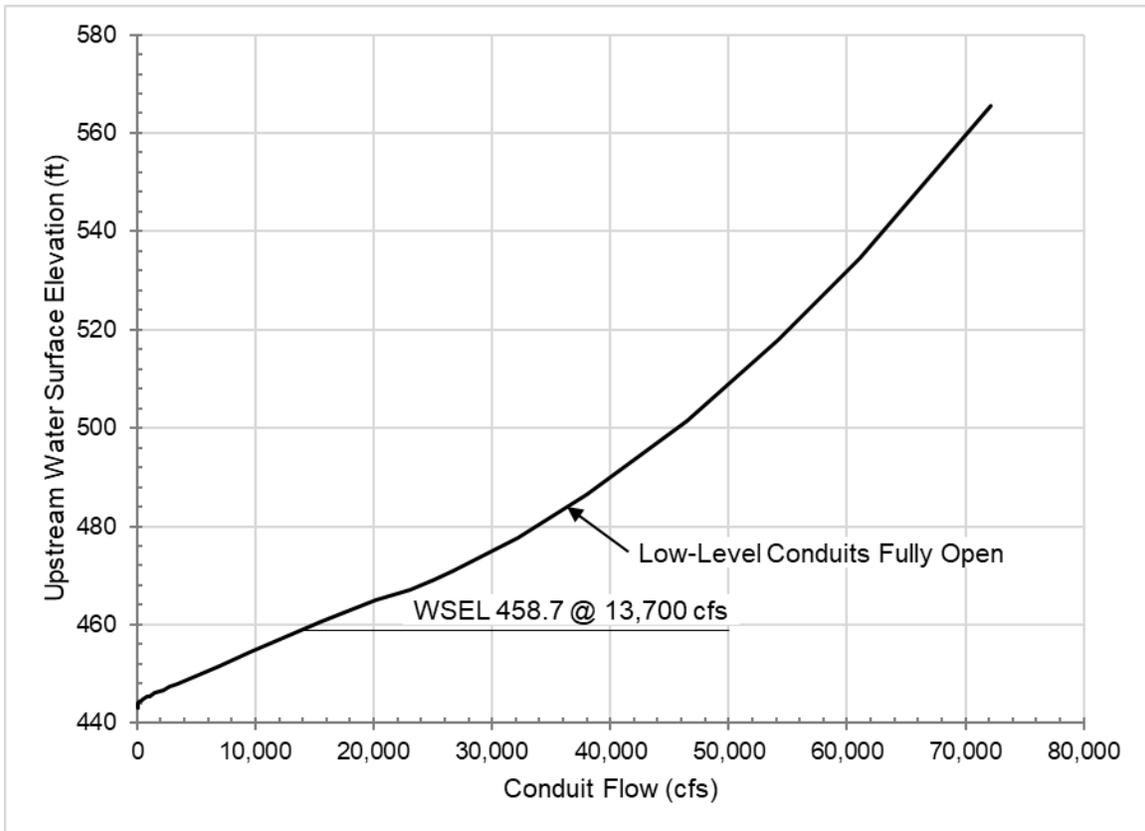
The Chehalis Basin Flood Control Zone District is proposing to construct a new flood retention structure to reduce damage to life and property along the Chehalis River (Proposed Project). Design of the proposed FRE structure is at a preliminary level of development.

This Technical Memorandum documents the hydraulic analysis of the frequency and time duration of when a backwater is created, with the conduit gates fully open, when river flows exceed 13,700 cubic feet per second (cfs).

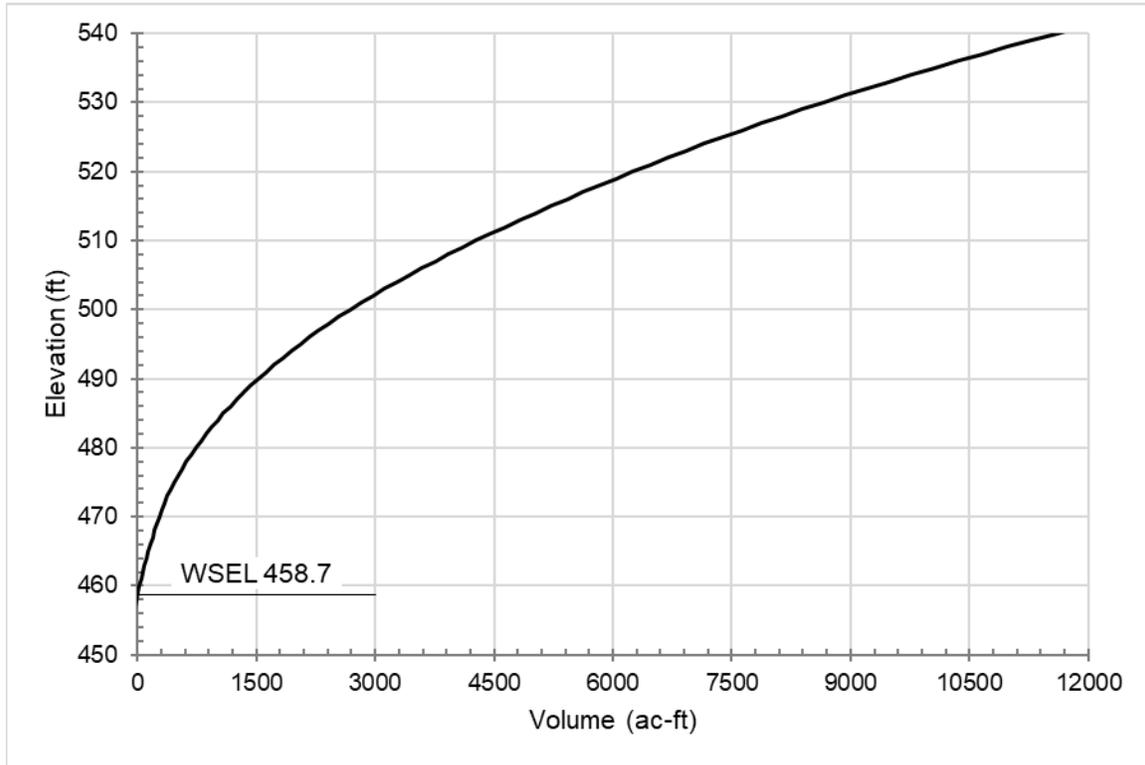
### 3.0 Level Pool Routing

River flow data was analyzed from 1982 to 2022 for when river flows exceeded 13,700 cfs. The conduits begin to flow full and create a backwater at flows greater than 13,700 cfs. Dates identified where the gates were triggered to close for flood retention were not included in this analysis. A level pool routing analysis was conducted for each time the river flow exceeded 13,700 cfs. Figure 1 shows the estimated conduit capacity with the gates fully open. Figure 2 shows the storage volume upstream in relation to when the conduits begin to create a backwater. Using the river flow as the inflow and the conduit capacity as the outflow, the change in storage was, or backwater, evaluated, and the time required for the backwater to dissipate was calculated. Table 1 shows the results of the level pool routing for each event that exceeds 13,700 cfs. The duration between the 12 events range from 1.2 hour to 6.5 hours, with the average being 3.6 hours.

**Figure 1. Estimated Conduit Capacity with Gates Fully Open**



**Figure 2. Storage Volume in Relation to Conduit Capacity at 13,700 cfs**



**Table 1. Routing Results for each Flow Condition Exceeding 13,700 cfs**

Starting Date	Duration (hours)	Peak Inflow (cfs)	Max River Elevation (feet)	Max Storage (ac-ft)	Max Additional Area Due to Storage (ac)
2/23/1986	1.2	13,909	458.9	3.3	0.3
11/25/1998	2.5	14,335	459.3	11.8	0.7
11/14/2001	3.8	16,075	461.1	46.8	2.4
1/17/2005	6.5	16,297	461.3	51.8	2.7
12/14/2006	1.6	14,152	459.1	7.2	0.5
11/12/2008	1.2	13,765	458.8	1.0	0.1
11/19/2012	5.1	14,764	459.8	21.0	1.1
1/5/2015	5.8	16,326	461.3	52.7	2.7
10/31/2015	4.7	16,427	461.4	55.0	2.8
11/13/2015	3.5	15,900	460.9	42.9	2.3
2/9/2017	3.4	14,792	459.8	20.7	1.1
12/19/2019	3.7	14,053	459.1	6.5	0.5

ac = acre; ac-ft = acre-feet

## 4.0 References

HDR Engineering, Inc. (HDR)

- 2024 *Revised Project Description Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Control Zone District, Lewis County, Washington. April 2024.
- 2025 *Draft Preliminary Design Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Damage Reduction Project, Lewis County, Washington, June 30, 2025.

## 5.0 Acronyms/Abbreviations

ac	acre
ac-ft	acre-feet
cfs	cubic feet per second
FRE	Flood Retention Expandable
HDR	HDR Engineering, Inc.
PDR	Preliminary Design Report
Proposed Project	Proposed Chehalis River Basin Flood Damage Reduction project

**Attachment 4:**  
**Water Demand During Construction (Draft) Technical  
Memorandum**

**Chehalis River Basin Flood Control Zone District**

**February 4, 2026**

# Technical Memo

Date: February 4, 2026

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Project: Chehalis River Basin Flood Damage Reduction Project

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To: Chehalis Basin Flood Control Zone District

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From: HDR

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Subject: **Water Demand During Construction (Draft)**

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## 1.0 Background

The Proposed Chehalis River Basin Flood Damage Reduction project (Proposed Project) objective is to implement a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Cosmopolis during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of Pe Ell, Washington.

Following submittal of the Revised Project Description Report (HDR Engineering, Inc. [HDR] 2024), a Chehalis River Basin Flood Damage Reduction draft Preliminary Design Report (PDR) was initiated to document ongoing draft design refinements, as the design process iterates toward a future 30 percent design that will be documented in a completed PDR. The draft PDR records ongoing draft design decisions, assumptions, and methods related to the development of the design of the FRE structure and related elements and collects technical details of the main features of the Proposed Project elements as they continue to develop.

A SEPA Revised Draft Environmental Impact Statement (RDEIS) for the Proposed Project was issued on November 20, 2025 with comments due February 4, 2026. To support the submission of comments on the SEPA RDEIS, some draft design elements are being formalized in reports and memoranda to describe the current state of the project design. While still not at a full 30 percent preliminary design level, these elements are at a point at which they can reasonably inform tribal governments, state and federal agencies, partners, stakeholders, and the public about the nature of the project.

## 2.0 Introduction

This Technical Memorandum documents a construction water demand assessment to inform evaluation of the Proposed Project's environmental impacts. The water demand assessment includes the evaluation of the peak and average water demand anticipated throughout construction. This document concludes with suggested next steps in the development of this portion of the project's design.

### 3.0 Water Demand During Construction

#### 3.1 Introduction

Construction will require water to support concrete production, aggregate processing, embankment compaction, construction offices, and various other requirements. The demand flow rate for construction water will vary throughout the construction period. Seasonal influences will also affect water demand. HDR evaluated the average monthly and annual water demand as well as a potential peak demand based on construction operations for the Proposed Project. This chapter introduces key assumptions for these water demands.

#### 3.2 Peak Daily Demand

The peak construction water demand is based on mixing and placement of roller-compacted concrete (RCC) and conventionally placed concrete (CVC) at the same time. Production rates are based on HDR’s project experience from other similar projects. The daily peak water demand for these activities is uncertain. A likely daily peak would be approximately 0.54 cubic feet per second (cfs). A conservatively low daily peak estimate should not be considered to be lower than 0.49 cfs. Similarly, a conservatively high daily peak estimate is unlikely to be more than 1.08 cfs. Uncertainty comes from RCC production variability, seasonal weather variability, contractor water storage facilities, RCC temperature requirements and the placement season, and other potentially significant factors. The water use estimates seek to reasonably assess peak uses that should be expected at this early stage of design and planning. Peak demand per month (1.08 cfs) for an average month (22 working days) equals 47 acre-feet (ac-ft).

**Table 1. Peak Water Demand Assumptions**

Assumptions
14,000 cubic yards (cy) RCC/day
10% Water/cy RCC
1,000 CVC cy/day
60 lb water/cy CVC

**Table 2. Peak Daily Water Demand Volumes**

100%	90%	200%
0.54 cfs	0.49 cfs	1.08 cfs

### 3.3 Average Monthly Demand

To preliminarily assess the water demand, HDR identified 17 activities throughout construction that cause most of the water consumption during construction. The construction water demand varies by activity over the duration of the project. The activities are listed as follows:

- Haul Road Dust Control
- Excavation/Embankment and Staging Area Dust Control
- Embankment and Borrow Moisture Conditioning
- Potable Water for Warehouses, Offices, Shops
- Staging and Work Area Maintenance
- Dam Foundation Cleaning
- Foundation Drilling and Grouting
- Slope Stabilization
- Drilling for Instrumentation
- Aggregate Crushing/Dust Control
- Aggregate Wet Screening/Washing
- RCC Mixing
- RCC Mix Cooling (Aggregate/ Equipment)
- RCC Curing
- CVC Mix Cooling
- CVC Mixing and Delivery
- Project/Equipment Cleaning and Maintenance

Each of the activities has water consumption, quantity, and duration assigned. These values are based on HDR's construction professionals' judgments of similar activities during other construction projects as well as the FRE Opinion of Probable Construction Cost and unfinished draft biological assessment.

The summary of key assumptions of all 17 activities is provided in Table 3. Each activity's water demand has a low and high range. The low range is typically 80 percent of the calculated water demand, the high range is about 150 percent respectively.

**Table 3. Key Water Consumption Assumptions Associated with Each Construction Activity**

Summary of Tasks that Require Water		Quantity		Consumption Rate		Application Frequency		Duration	
1	Haul Road Dust Control	696,960	sq ft	0.1	ga/sq ft/pass	2	passes/shift	750	shifts
2	Excavation/Embankment and Staging Area Dust Control	1,150,000	sq ft	0.1	ga/sq ft/pass	2	passes/shift	425	shifts
3	Embankment and Borrow Moisture Conditioning	12,516	ton	3.0	% per dry weight	22	each/month	5	months
4	Potable Warehouses, Offices, Shops	75	ppl	15.0	gpd/person	–	–	1,500	days
5	Staging and Work Area Maintenance	3,632,920	sq ft	0.0	ga/sq ft/pass	1	passes/shift	1,500	shifts
6	Dam Foundation Cleaning	600,000	sq ft	200.0	each	1.2	ga/min	100	shifts
7	Foundation Drilling and Grouting	80,000	ft	50.0	ga/LF	–	–	–	–
8	Slope Stabilization	520	LF	5.0	ga/LF	–	–	–	–
9	Drilling for Instrumentation	4,000	ft	5.0	ga/LF	–	–	–	–
10	Aggregate Crushing / Dust Control	–	–	100.0	gpd	–	–	558	days
11	Aggregate Wet Screening / Washing	–	–	21,600.0	gpd	–	–	–	–
12	RCC Mixing	1,815,000	cy	33.0	ga/cy RCC	–	–	–	–
13	RCC Mix Cooling (Aggregate/ Equipment)	217,800	cy	–	–	20	ga/cy	–	–
14	RCC Curing	43,578,720	sq ft	0.1	ga/sq ft of lift	–	–	–	–
15	CVC Mix Cooling	19,320	cy	–	–	20	ga/cy	–	–
16	CVC Mixing and Delivery	161,000	cy	50.3	ga/cy CVC	–	–	–	–
17	Project/Equipment Cleaning and Maintenance	–	–	423.3	gpd AVER	–	–	–	–

Notes: sq ft: square feet; LF: linear feet; cy: cubic yards; ga: gallon(s); gpd: gallons per day; ppl: people

Each activity is then assigned a schedule. The construction schedule is 5 years. The water demand schedule is shown in Attachment 1. The total high water demand of each activity is divided by the number of months of that activity occurring. Table 4 provides the monthly high water demand by month. The maximum monthly high water demand for each month is selected for further analysis. Restoration activities will continue in Year 6 with 40 ac-ft to cover dust control, plant watering, and equipment cleaning.

**Table 4. Monthly High Water Demand**

Month	Y1	Y2	Y3	Y4	Y5	MAX
	(ac-ft)					
January	3.1	5.2	16.2	3.1	16.0	16
February	6.9	5.2	16.2	3.1	16.0	16
March	6.9	5.2	18.2	3.1	16.0	18
April	25.1	5.2	18.2	21.3	27.0	27
May	36.1	36.4	29.2	32.3	27.0	36
June	36.1	36.4	29.2	32.3	27.4	36
July	32.3	52.6	34.7	32.3	14.1	53
August	32.3	34.3	34.7	34.2	14.1	35
September	32.3	29.1	29.6	34.2	14.1	34
October	32.3	27.2	29.2	47.3	3.1	47
November	3.1	16.2	18.2	18.0	3.1	18
December	5.2	16.2	18.2	17.8	3.1	18

### 3.4 Summary of Preliminary Monthly Demand

HDR assumes a weighted average of 70 percent of the high monthly average demand and 30 percent of the peak monthly demand to cover the average and peak demand throughout construction. The weighted average of the maximum average monthly demand and peak monthly demand is shown in Table 5. The demand volume over the course of a peak demand year is broken down into periods corresponding with the minimum instream flow periods (Table 19 below) to facilitate direct comparison. Weighted average volumes below are also provided in units of acre-feet for general size comparison to the proposed, full temporary inundation pool for the permanent project (62,000 ac-ft). The weighted average January water demand of 25.5 ac-ft, for example, originates from 70 percent of 16.2 ac-ft plus 30 percent of 47.3 ac-ft.

**Table 5. Weighted Average Peak Water Demand During Construction**

Periods	70%	30%	Weighted Average Demand (ac-ft)	Weighted Average Demand (cfs)*
	Needed By Month (MAX) (ac-ft/period)	Needed Assuming 22d x Peak (ac-ft/period)		
Jan 1–Jan 31	16.2	47.3	25.5	0.43
Feb 1–Feb 28	16.2	42.5	24.1	0.45
Mar 1–Mar 31	18.2	47.3	26.9	0.45
Apr 1–Apr 30	27.0	45.7	32.6	0.57
May 1–May 14	16.3	20.5	17.6	0.68
May 15–May 31	20.1	25.2	21.6	0.68
Jun 1–Jun 14	16.9	20.5	18.0	0.70
Jun 15–Jun 30	19.5	23.6	20.7	0.70
Jul 1–Jul 14	23.6	20.5	22.6	0.88
Jul 15–Jul 31	29.0	25.2	27.9	0.88
Aug 1–Aug 14	15.5	20.5	17.0	0.66
Aug 15–Aug 31	19.1	25.2	20.9	0.66
Sep 1–Sep 30	34.2	45.7	37.6	0.65
Oct 1–Oct 14	21.2	20.5	21.0	0.81
Oct 15–Oct 31	26.1	25.2	25.8	0.81
Nov 1–Nov 14	8.4	20.5	12.0	0.47
Nov 15–Nov 30	9.7	23.6	13.9	0.47
Dec 1–Dec 30	18.2	45.7	26.4	0.46
<b>Average</b>	<b>19.7</b>	<b>30.3</b>	<b>22.9</b>	<b>0.63</b>

\* Assumed 24hr/day for every day in the period

Note: Periods are chosen to match WAC Base Inflow Requirement Periods

Source: Washington State Legislature (2023)

### 3.5 Buffer Factor and Peak Demand Conclusion

Although construction water demands per period are not expected to exceed weighted peak estimates (Table 5), it is technically possible that multiple needs and factors will align concurrently. Such conditions may occur if mixing and placement of roller-compacted concrete (RCC) and conventionally placed concrete (CVC) are completed simultaneously, and compounding conditions requiring more water are present, such as elevated air temperatures. While it is reasonably certain to conclude that the weighted average peak values presented in Table 5 will support construction needs, in the unlikely event that all compounding factors occur simultaneously, a conservative estimate is that these conditions could occur for up to 10 days per construction year, requiring up to 20 percent of water in addition to the weighted average peak estimates.

As an example, for the month of January, the weighted average peak construction water need is 0.43cfs. In a highly unlikely scenario in which multiple high water-use activities occurred simultaneously, application of a 20 percent buffer would result in the need for up to 0.52 cfs for that construction day, returning to the average high or average weighted peak requirement the following day. For the month of July, when average weight peak construction water needs are expected to be the greatest (0.88 cfs), application of an additional 20 percent buffer on top of the already-conservative weighted average peak would equate to approximately 1.06 cfs for that month only. The Yearly Average weighted average peak construction water need is 0.63 cfs per Table 5, and 0.76 cfs respectively with the applied buffer.

## 4.0 Next Steps

Future phases of design development should continue to analyze sources of water supply in relation to demand, in conjunction with a water rights legal consultant, to develop a plan for construction water supply and potential mitigation. Potential multi-purpose and temporary-turned-permanent water storage options should be considered as they may have the potential to provide mitigation benefits at longer timescales than temporary storage needed for construction.

Future phases of design development should also include a risk analysis considering natural variability in water supply availability. A risk analysis for different exceedance flow rates should include how risks could be mitigated in future. The risk analysis should refine and identify potential water supply sources and consider the process for obtaining temporary water rights through the Washington State Department of Ecology. Risk mitigation should consider how much risk is delegated to the construction contractor, how much risk the owner/operator will take on, and what risk mitigation measures and temporary infrastructure to include in the design documents. Possible scenarios, including risk reduction and mitigation measures, should be considered for cost and schedule impacts.

## 5.0 References

HDR Engineering, Inc. (HDR)

- 2024 *Revised Project Description Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Control Zone District, Lewis County, Washington. April.
- 2025 *Draft Preliminary Design Report: Flood Retention Expandable Structure*, Chehalis River Basin Flood Damage Reduction Project, Lewis County, Washington, June 30.

Washington State Legislature

- 2023 Washington Administrative Code 173-522-020 Establishment of Base Flows.  
<https://app.leg.wa.gov/WAC/default.aspx?cite=173-522-020>. Certified on February 20.

## 6.0 Acronyms/Abbreviations

ac-ft	acre-feet
cfs	cubic feet per second
CVC	conventionally placed concrete
cy	cubic yards
HDR	HDR Engineering, Inc.
RCC	roller-compacted concrete
FRE	Flood Retention Expandable
PDR	Preliminary Design Report
RDEIS	Revised Draft Environmental Impact Statement

# Attachment 1. Construction Activities and Schedule

	Year 1												Year 2											
	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
1 <a href="#">Haul Road Maintenance</a>					X	X	X	X	X	X						X	X	X	X	X	X			
2 Excavation/Embankment Dust Control				X	X	X	X	X	X	X														
3 Embankment and Borrow Moisture Conditioning		X	X	X	X	X	X	X	X	X						X	X	X						
4 <a href="#">Potable Warehouses, Offices, Shops</a>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
5 Staging and Work Area Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
6 Dam Foundation Cleaning																		X	X					
7 Foundation Drilling and Grouting															X	X	X	X	X					
8 Slope Stabilization																	X	X						
9 Drilling for Instrumentation																								
10 Aggregate Crushing / Dust Control												X	X	X	X	X	X	X	X	X	X	X	X	
11 Aggregate Wet Screening / Washing												X	X	X	X	X	X	X	X	X	X	X	X	
12 RCC Mixing																		X	X	X	X	X	X	
13 RCC Mix Cooling (Aggregate/ Equipment)																		X	X					
14 RCC Curing																		X	X	X	X	X	X	
15 CVC Mix Cooling																								
16 CVC Mixing and Delivery																								
17 Project/Equipment Cleaning and Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
18 Demolition and Saw Cutting Dust Control																								

	Year 3												Year 4											
	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
1 <a href="#">Haul Road Maintenance</a>					X	X	X	X	X	X						X	X	X	X	X	X			
2 Excavation/Embankment Dust Control																								
3 Embankment and Borrow Moisture Conditioning																								
4 <a href="#">Potable Warehouses, Offices, Shops</a>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
5 Staging and Work Area Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
6 Dam Foundation Cleaning																					X	X		
7 Foundation Drilling and Grouting																			X	X	X	X	X	
8 Slope Stabilization																					X	X		
9 Drilling for Instrumentation																								
10 Aggregate Crushing / Dust Control	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
11 Aggregate Wet Screening / Washing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
12 RCC Mixing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
13 RCC Mix Cooling (Aggregate/ Equipment)								X	X															
14 RCC Curing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
15 CVC Mix Cooling								X	X	X														
16 CVC Mixing and Delivery				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
17 Project/Equipment Cleaning and Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

		Year 5												
		January	February	March	April	May	June	July	August	September	October	November	December	January
1	<a href="#">Haul Road Maintenance</a>				x	x								
2	Excavation/Embankment Dust Control													
3	Embankment and Borrow Moisture Conditioning													
4	<a href="#">Potable Warehouses, Offices, Shops</a>	x	x	x	x	x	x	x	x	x	x	x	x	x
5	Staging and Work Area Maintenance	x	x	x	x	x	x	x	x	x	x	x	x	x
6	Dam Foundation Cleaning													
7	Foundation Drilling and Grouting													
8	Slope Stabilization													
9	Drilling for Instrumentation											x	x	
10	Aggregate Crushing / Dust Control													
11	Aggregate Wet Screening / Washing													
12	RCC Mixing	x	x	x	x	x	x							
13	RCC Mix Cooling (Aggregate/ Equipment)													
14	RCC Curing	x	x	x	x	x	x							
15	CVC Mix Cooling						x							
16	CVC Mixing and Delivery	x	x	x	x	x	x							
17	Project/Equipment Cleaning and Maintenance	x	x	x	x	x	x	x	x	x	x	x	x	x