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

Updated February 28, 2026 with revision to this Attachment's Attachment 3 (Inundation Technical Memorandum) correcting a data error. The results are essentially unchanged post-correction.

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.

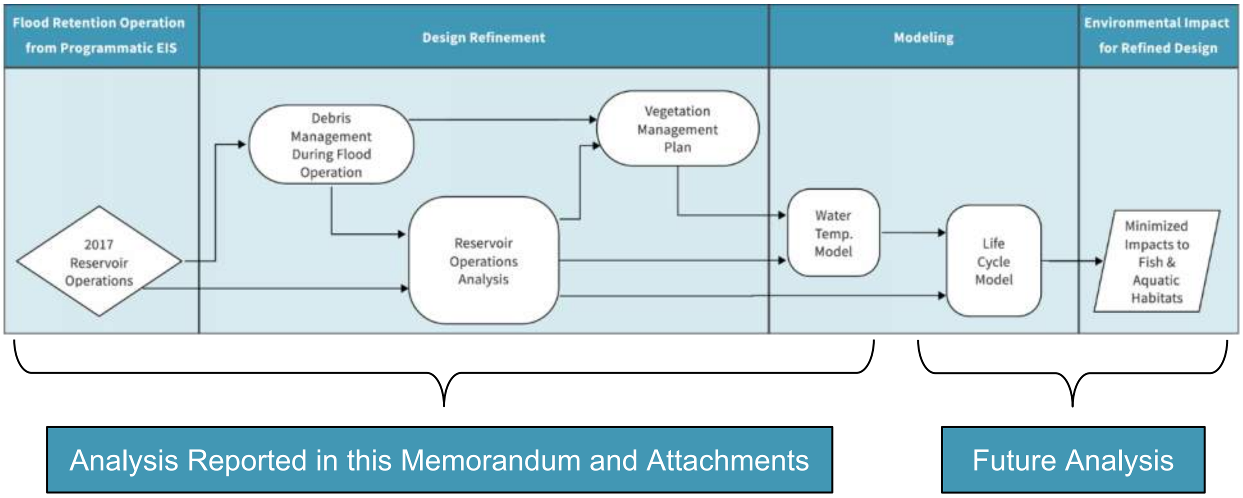
2.0 Purpose

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

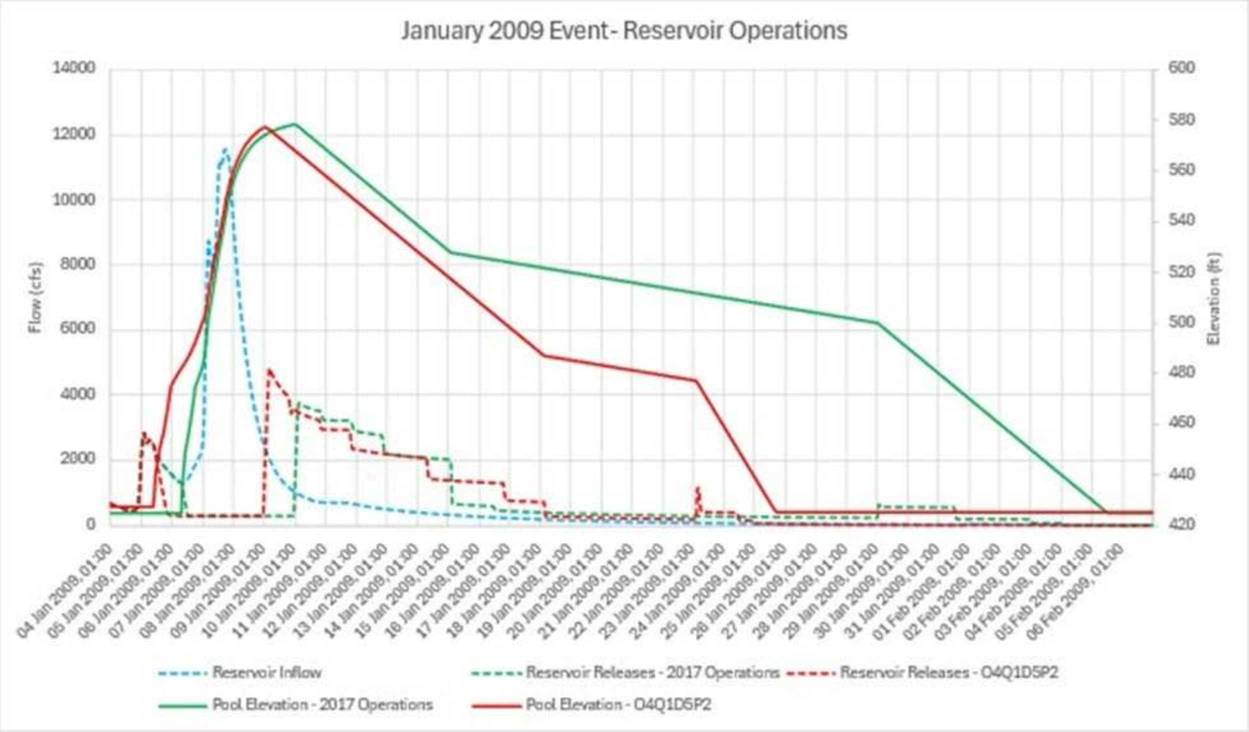
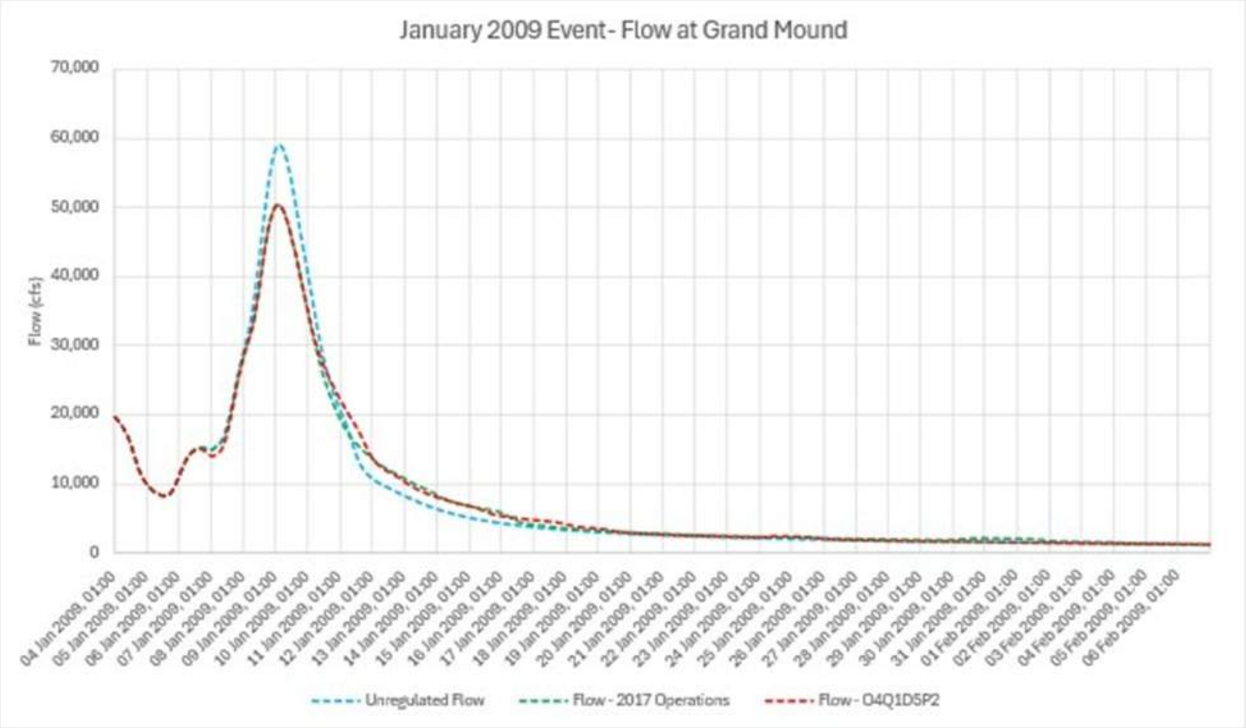


Figure 3. Flow at Grand Mound – Unregulated, 2017 Operations, and O4Q1D5P2 Operations



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^{o}Celsius (C) at the project site, whereas the 2025 Operations resulted in only 0.8^{o}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^{o}C modeled temperature increase at the project site gradually dropped to 0.2^{o}C by Jones Creek; by Elk Creek, the river would be cooler (-0.3^{o}C change), and by Adna the river would be substantially cooler (-1.2^{o}C change). For the 2025 Operations including the VMP and downstream riparian planting, the 0.8^{o}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)

February 4, 2026

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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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).

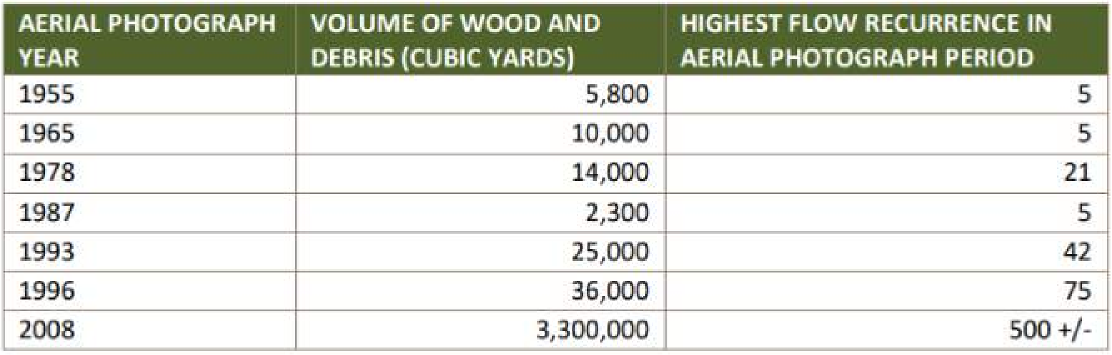
4.1 Methodology

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.

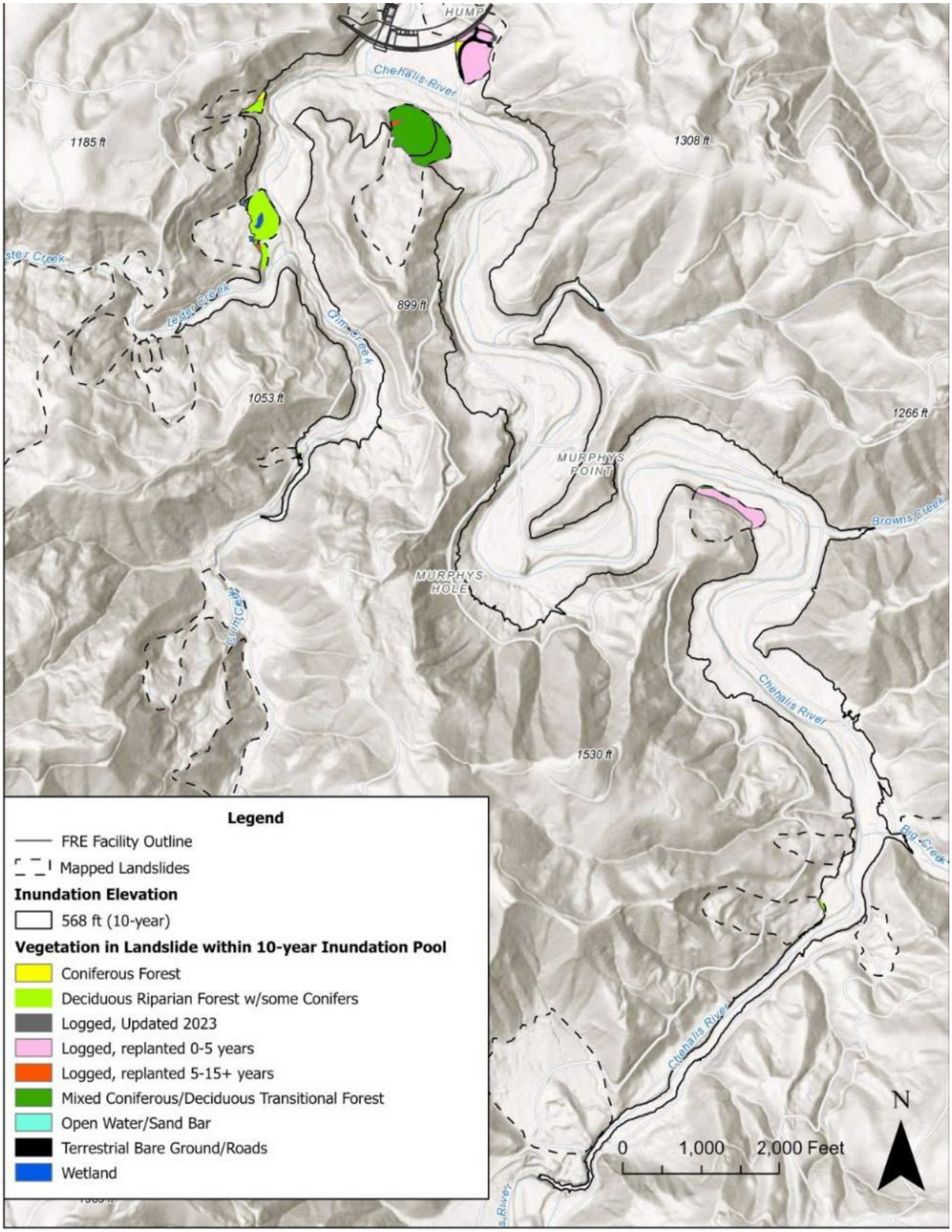
4.1.2 Debris from Landslides (Desktop Analysis) and LWM from the Chehalis River

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.

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

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

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

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

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:

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

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

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

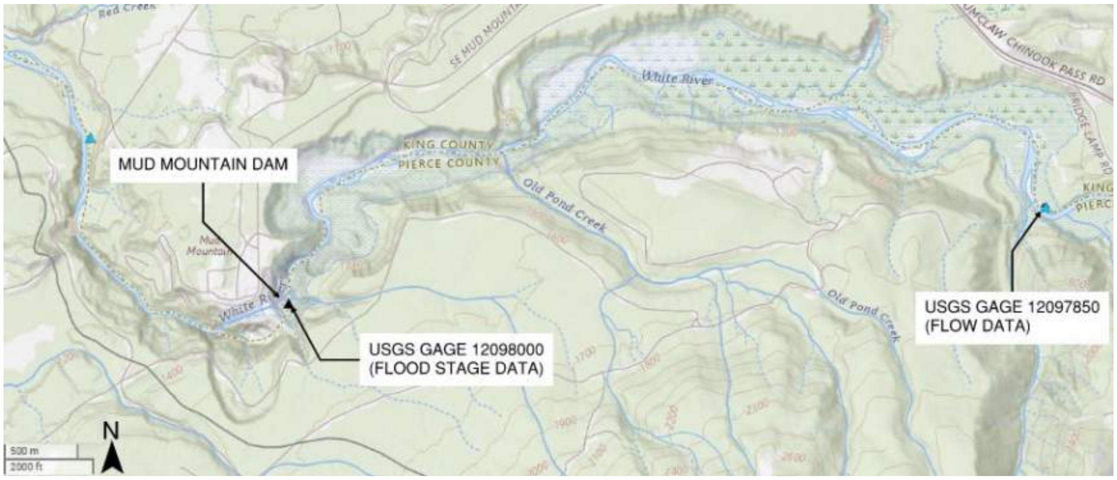
$$\frac{1{,}016\, ft^2}{43{,}560\, \frac{ft^2}{acre}} = 0.02\ acres$$

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:

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

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

$$Average = 0.00094$$

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 that 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:

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

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

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

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:

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

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:

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

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).

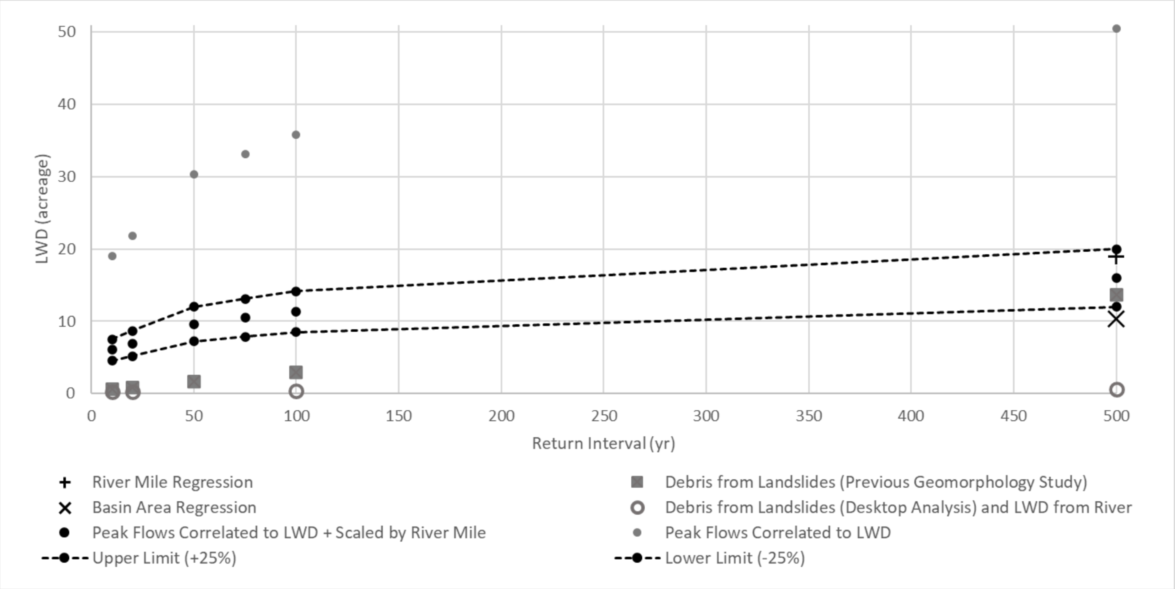
The method from Section 4.2.3 uses peak flows to scale LWM acreage estimates at MMD to the proposed FRE structure. It results in LWM acreage associated with a recurrence interval. The limitation with this result is that the peak flows do not accurately reflect the difference in basin size or river length 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.

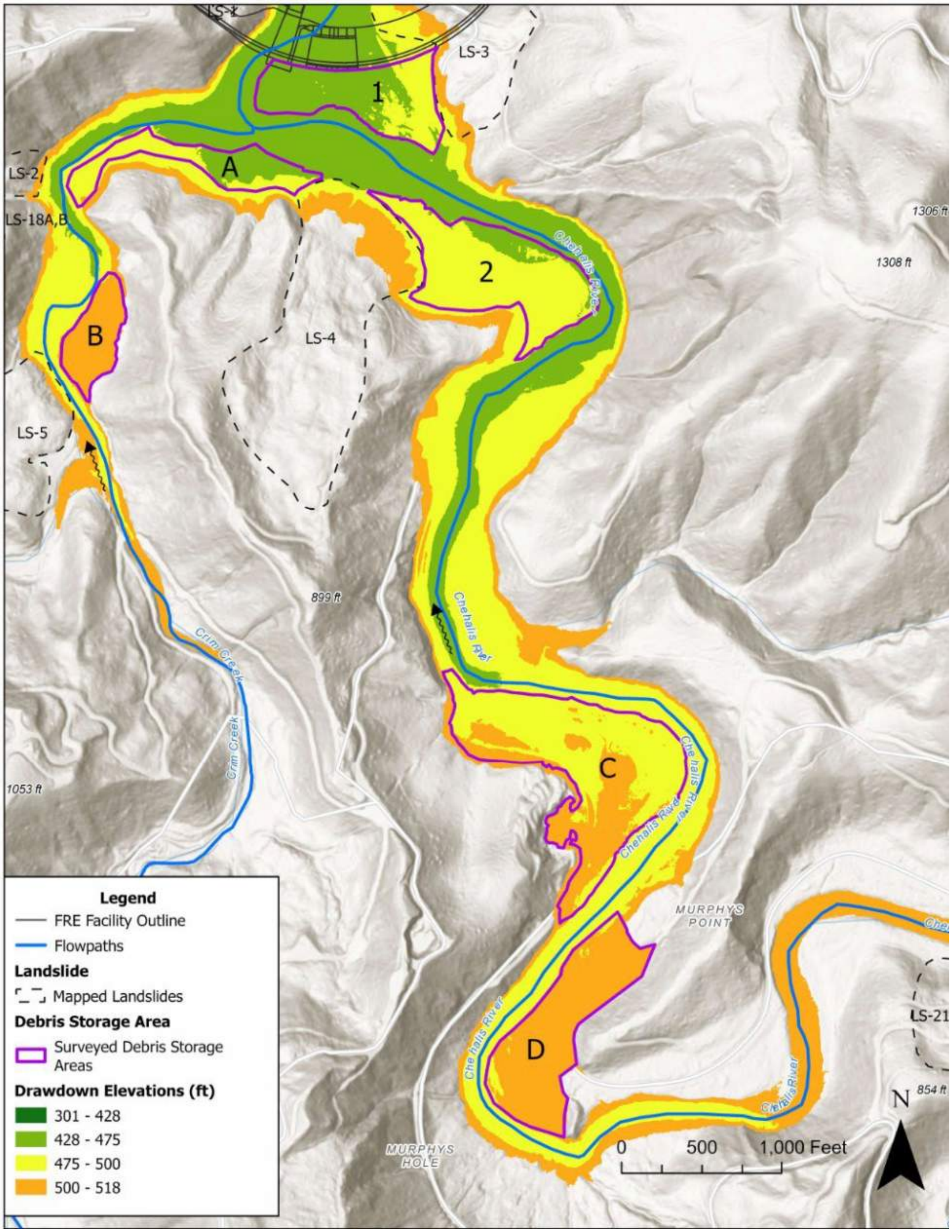
From the desktop analysis, storage areas were determined suitable based on characteristics from the existing MMD storage areas. These areas had continuous land accessible by road with slopes less than 5 percent and were accessible by boat after floods.

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.

Figure 5-1. Potential Debris Storage Areas from Reconnaissance Survey



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

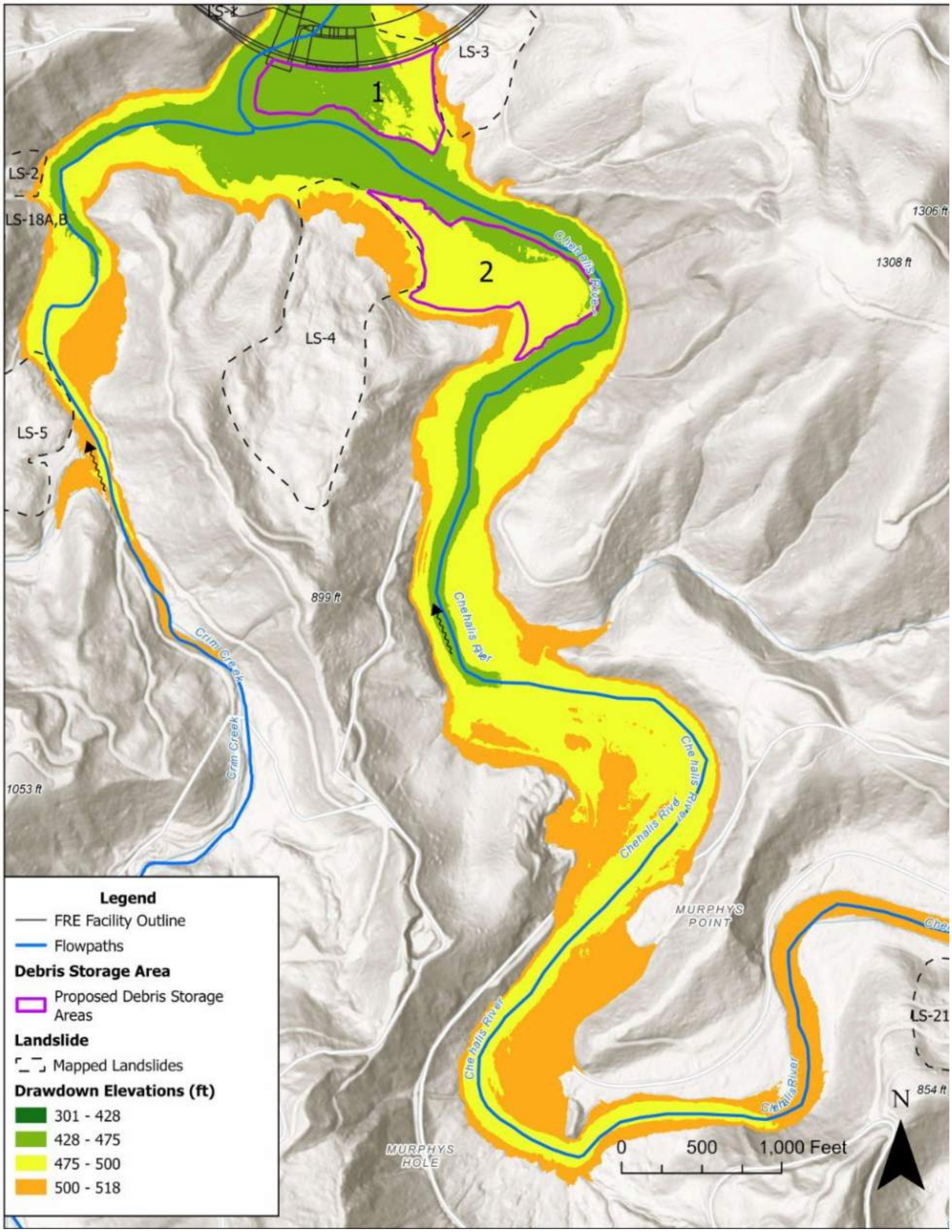
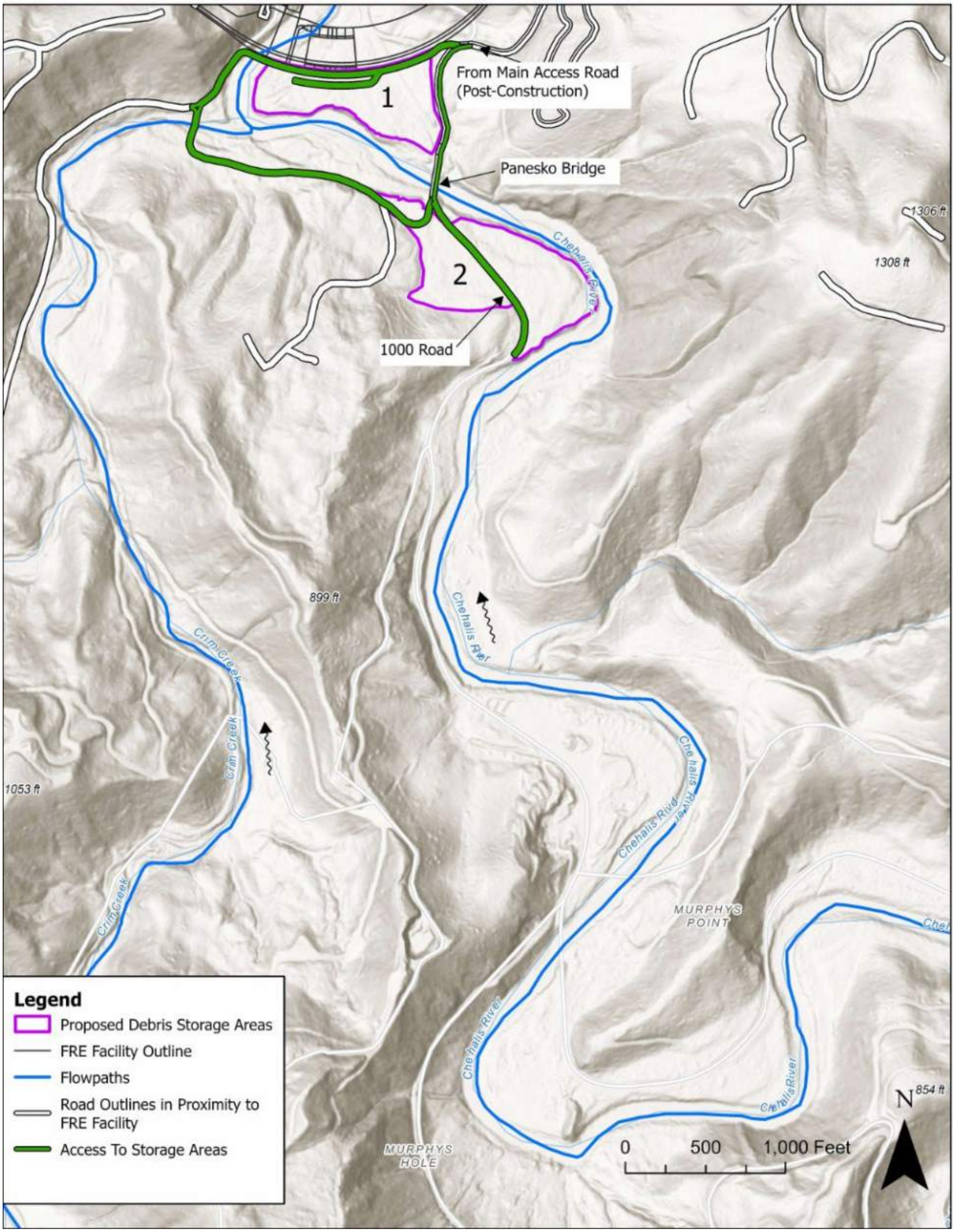


Figure 5-3. Access to Proposed Debris Storage Areas



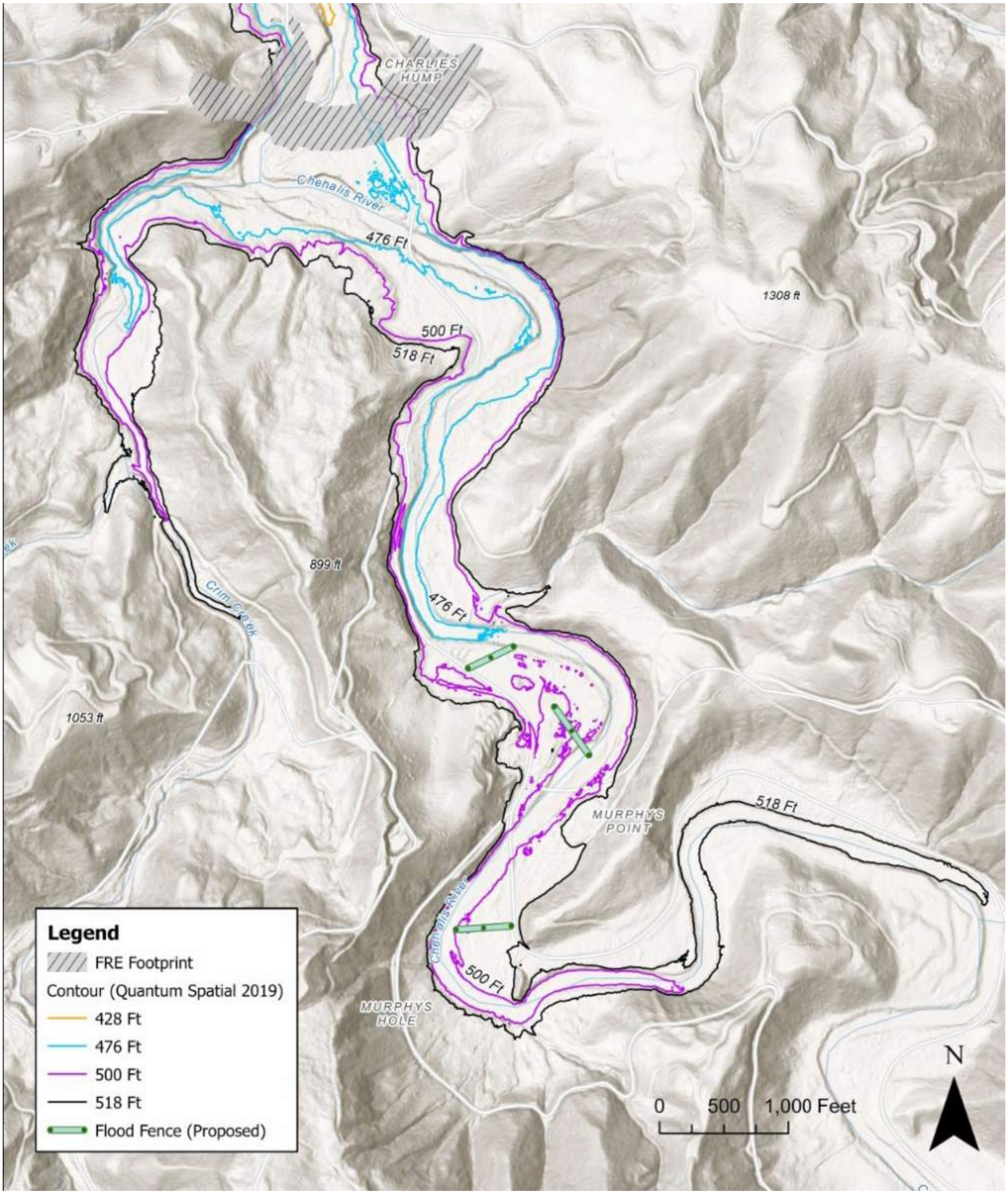
6 Debris Fences

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.

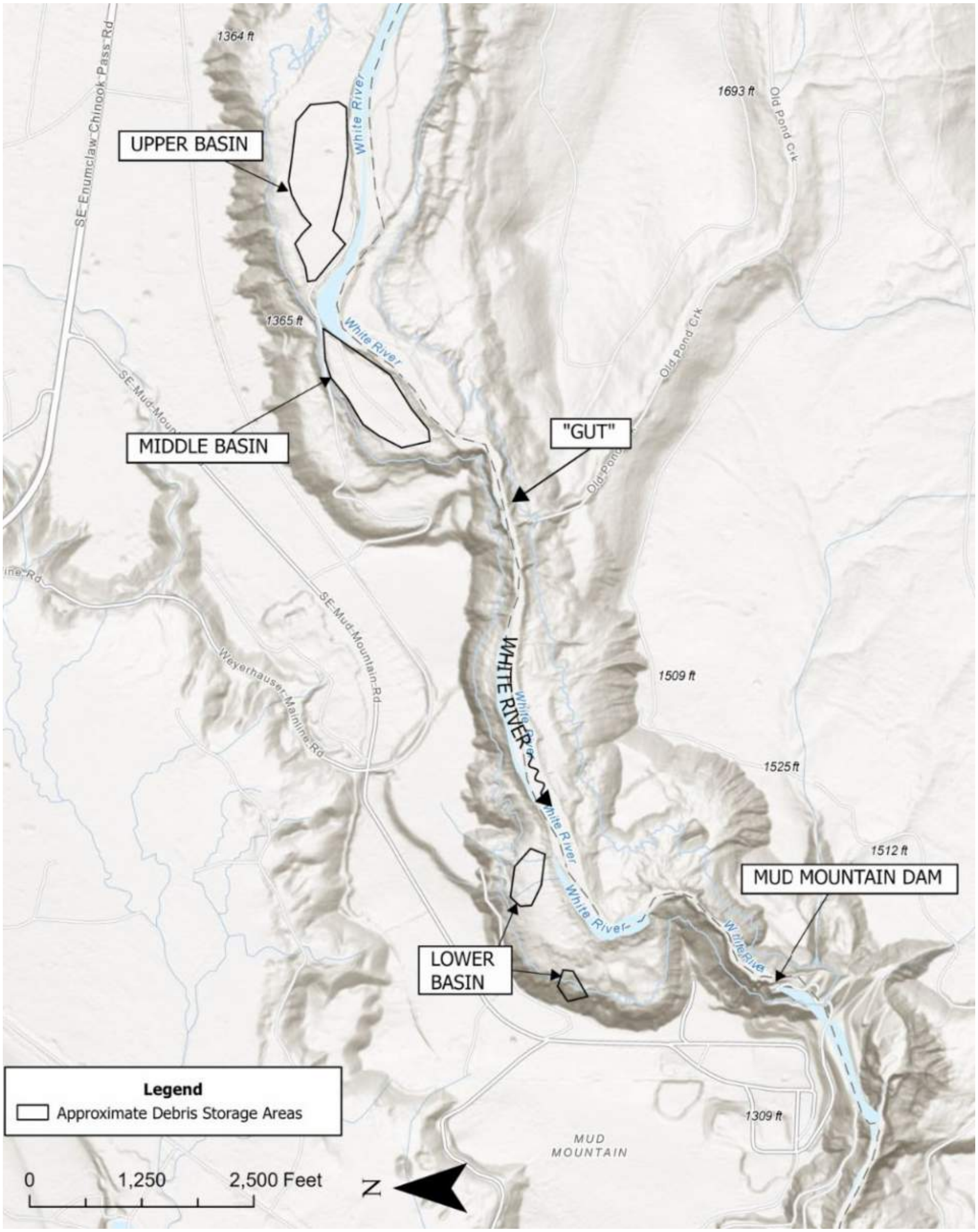
7.3 LWM Sequencing and Removal Rate

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 steal 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 bronc equipment

Note: USACE operates

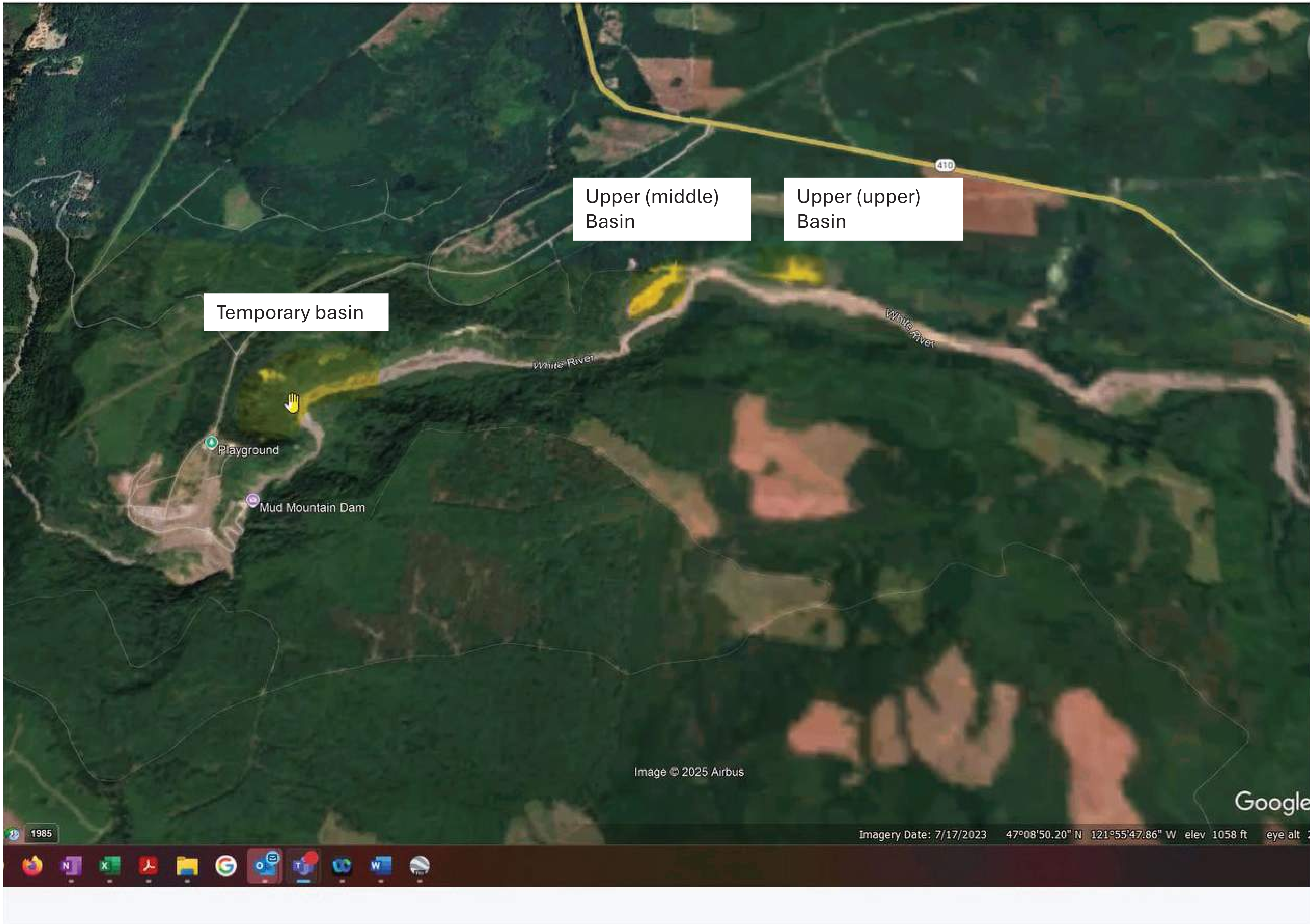
Picking LWD at the trash rack (pick the rack)

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.

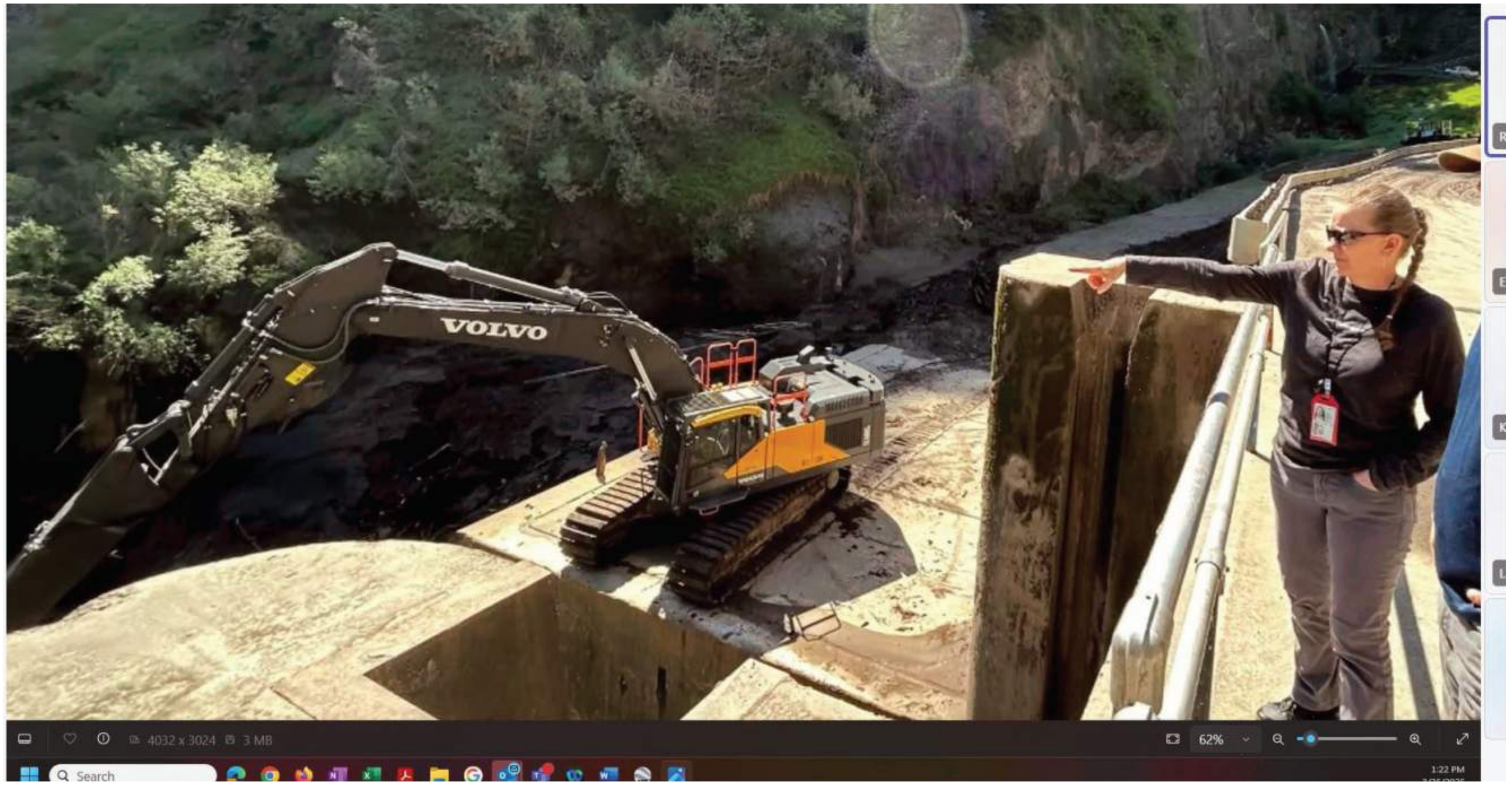
Baldi McDonald

Wood-chipper (2021)

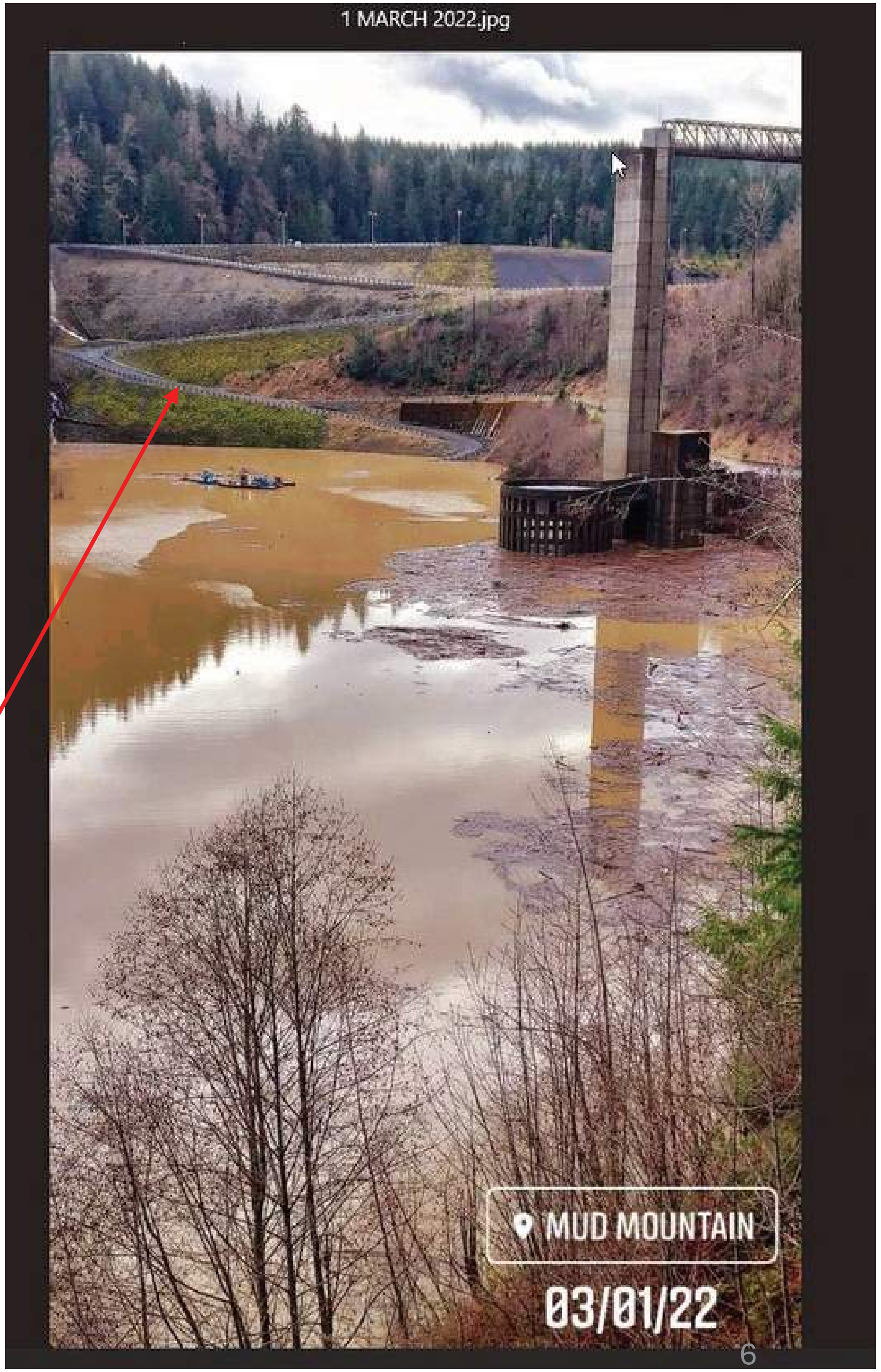
LWD stacking (18 NOV 2021)



Location of storage basins to estimate distances and sizes

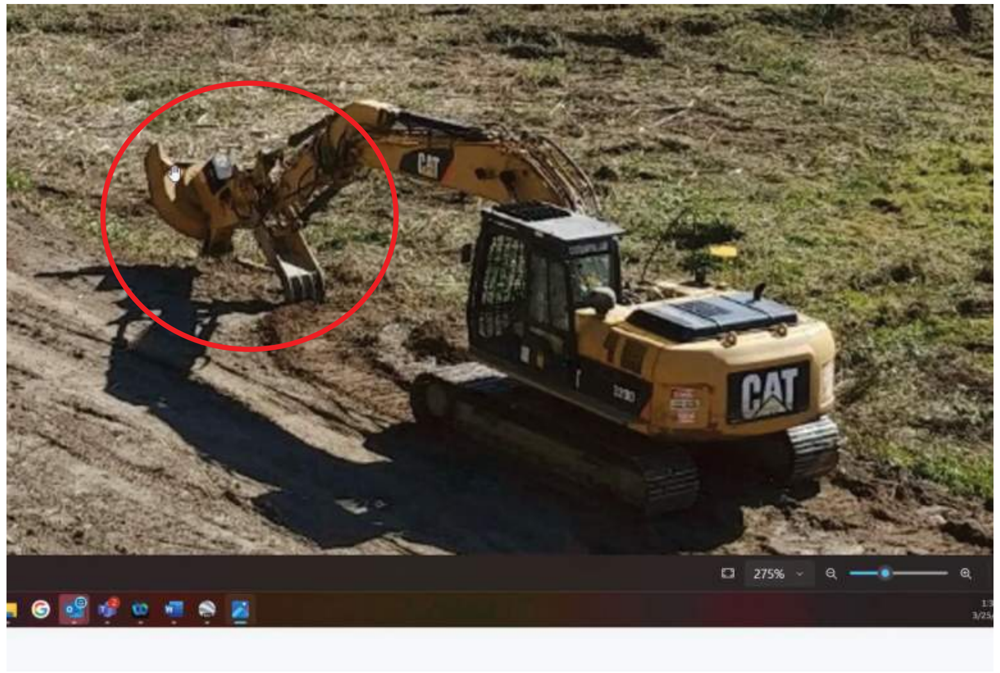


LWD removal at the trash rack w/ excavator (65ft boom arm)



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

Subject: **Reservoir Operations Analysis (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 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.

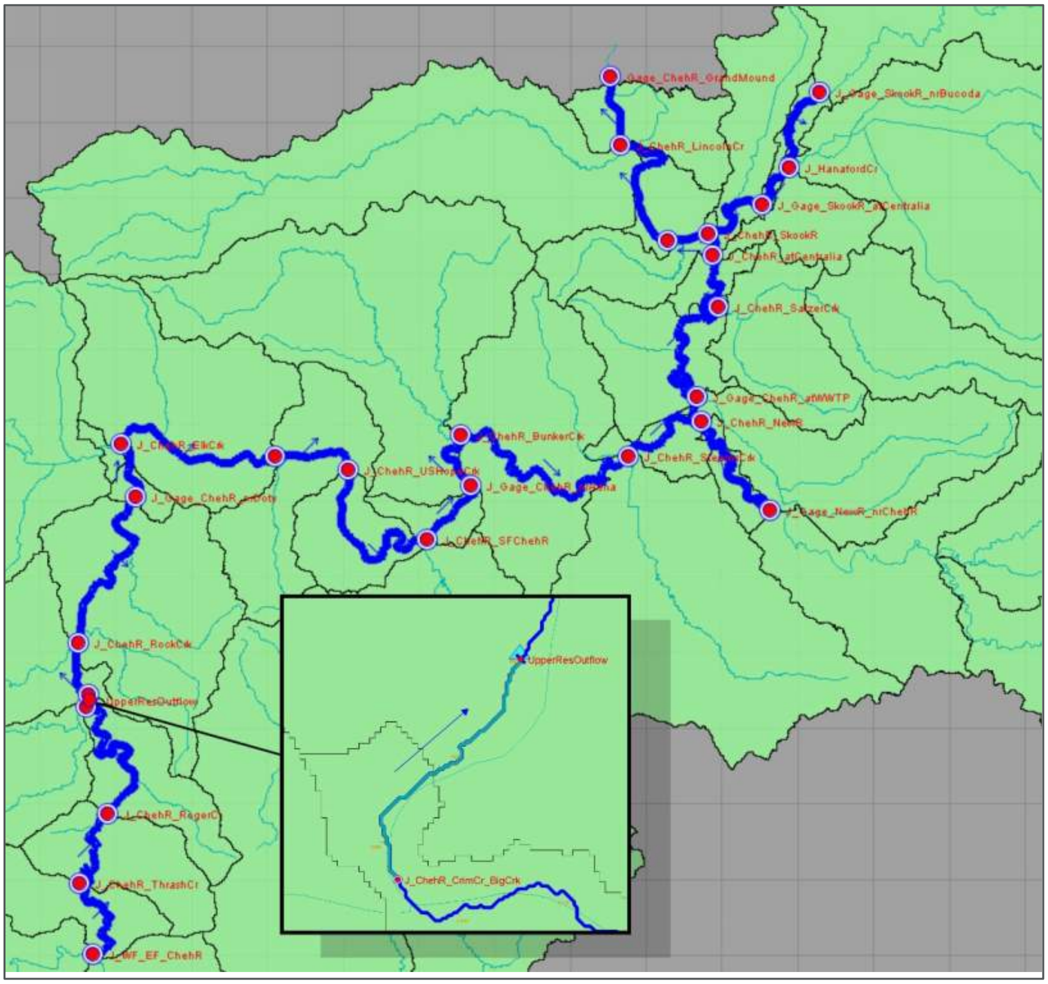
There are six key locations of interest along the Chehalis River, five are USGS gages downstream of the FRE where flood management improvements are desired, and one is the FRE site location. This enhanced HEC-ResSim model expands the extents of the Anchor QEA model using updated hydrology and multiple 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

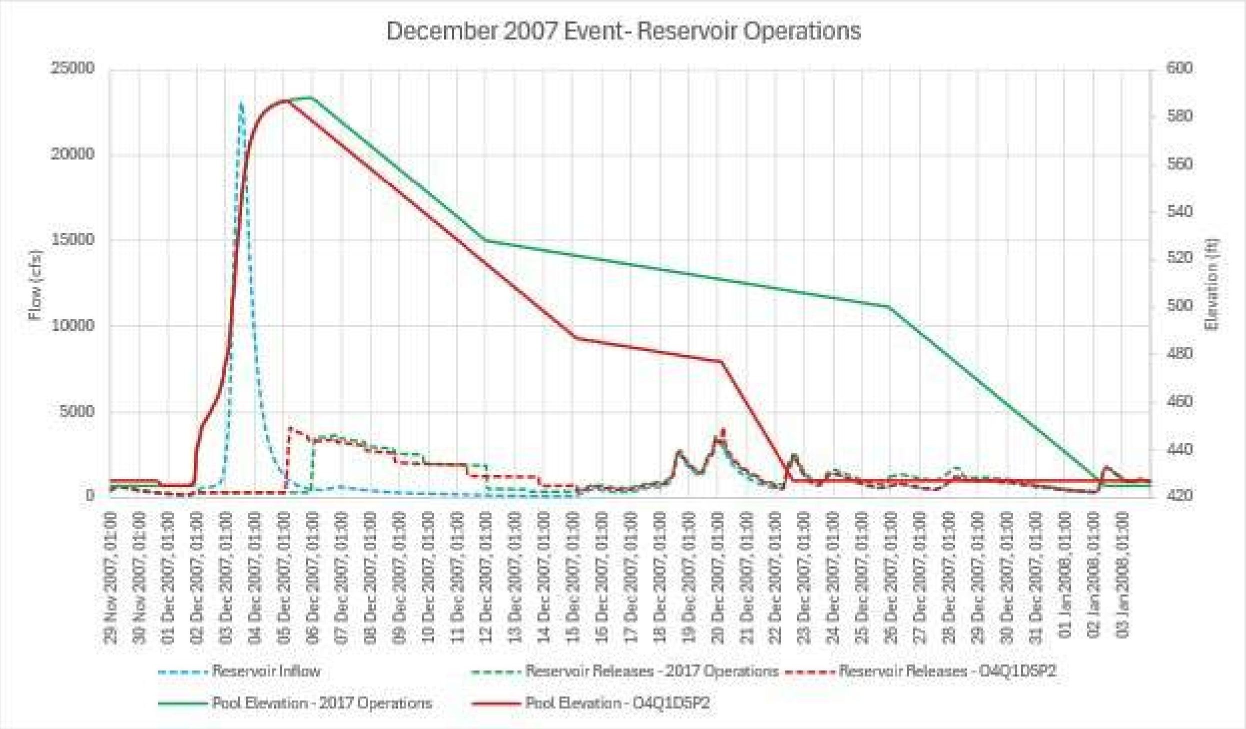
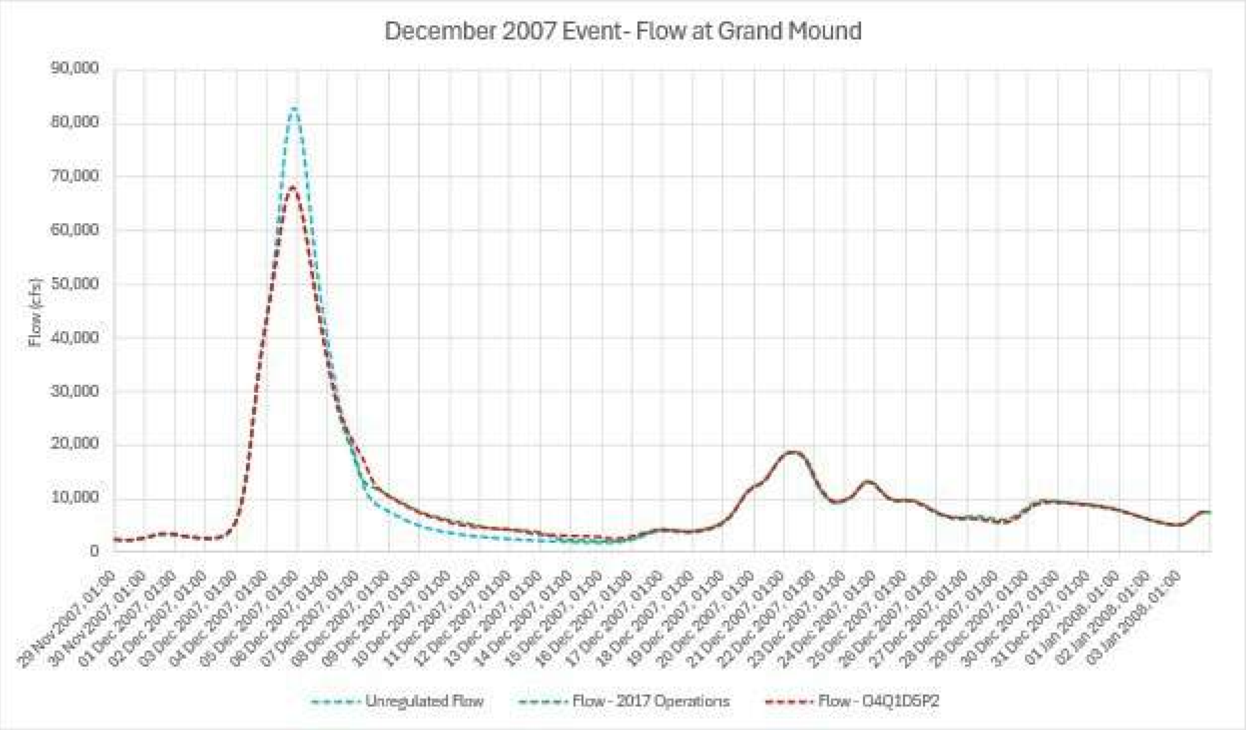


Figure 3. Modeled Flow at Grand Mound for the December 2007 Flood Event



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

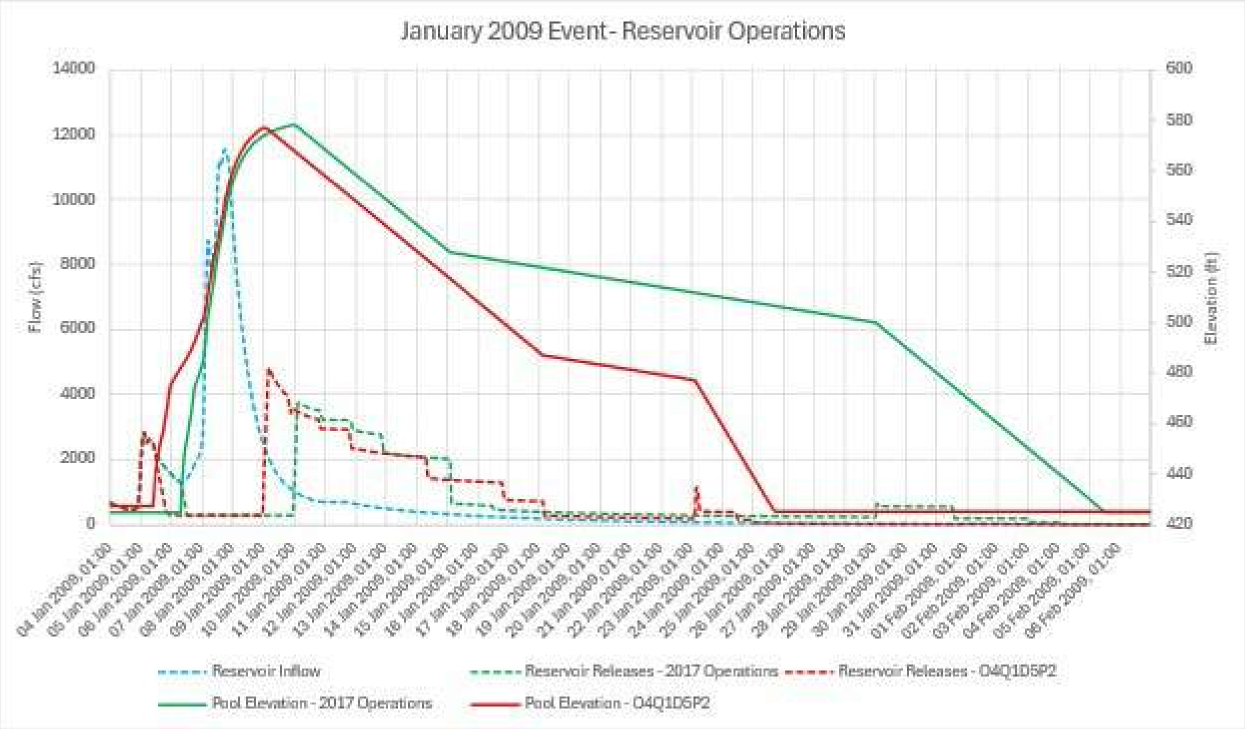
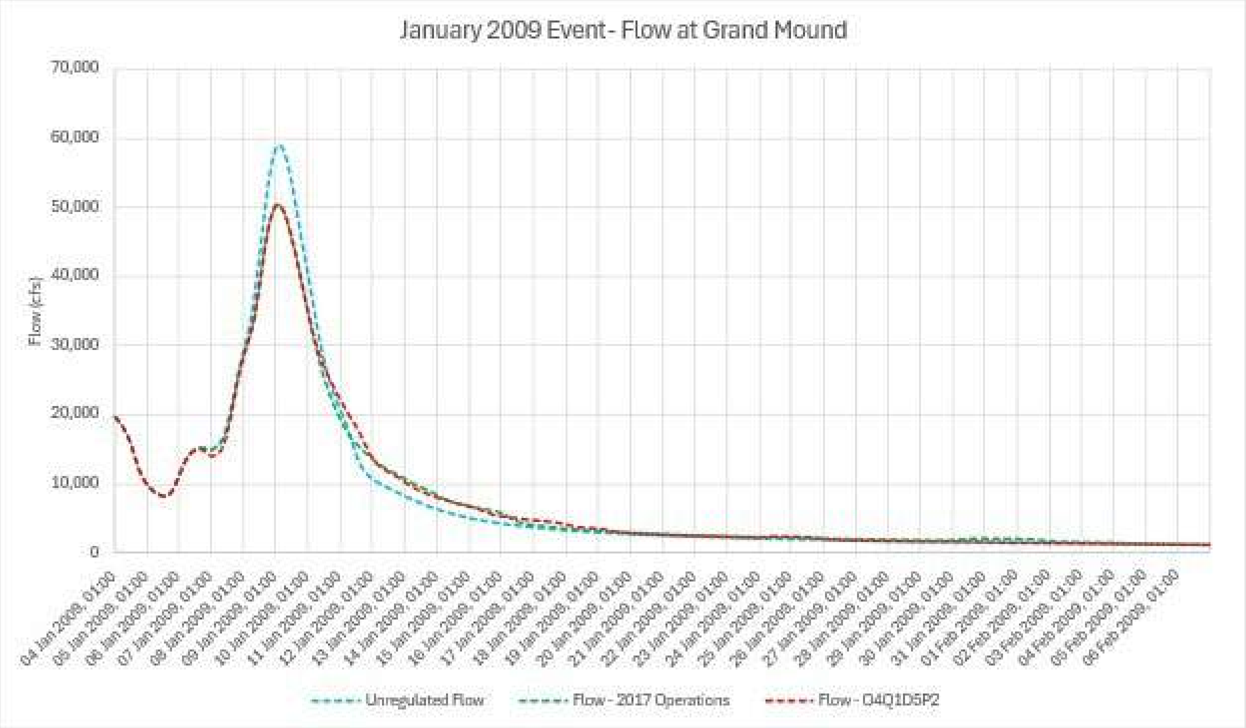


Figure 5. Modeled Flow at Grand Mound for the January 2009 Flood Event



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

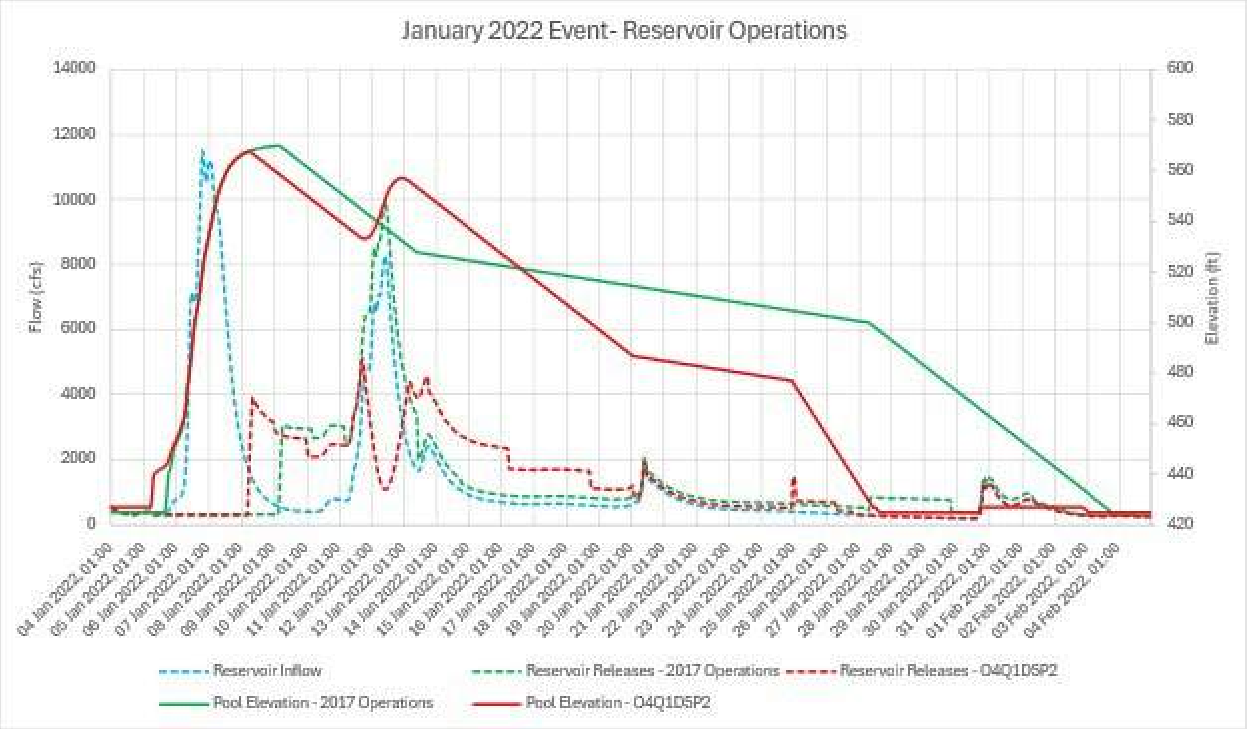
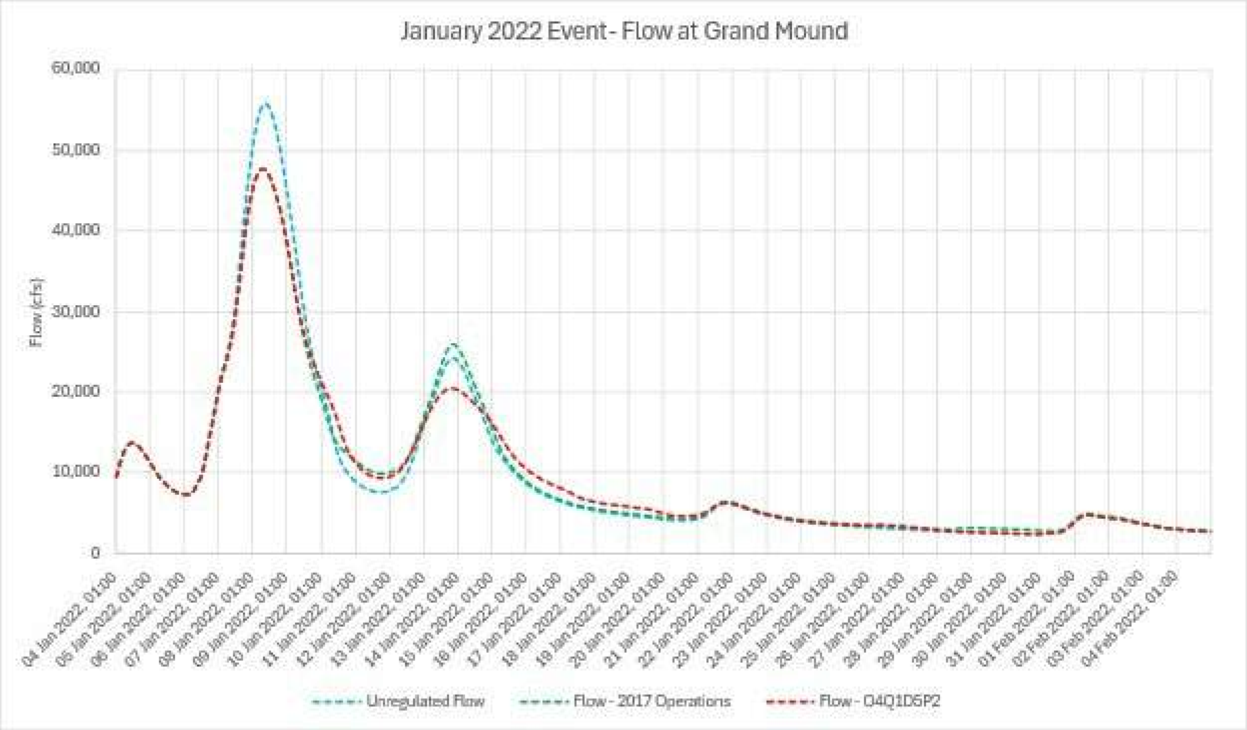


Figure 7. Modeled Flow at Grand Mound for the January 2022 Flood Event



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

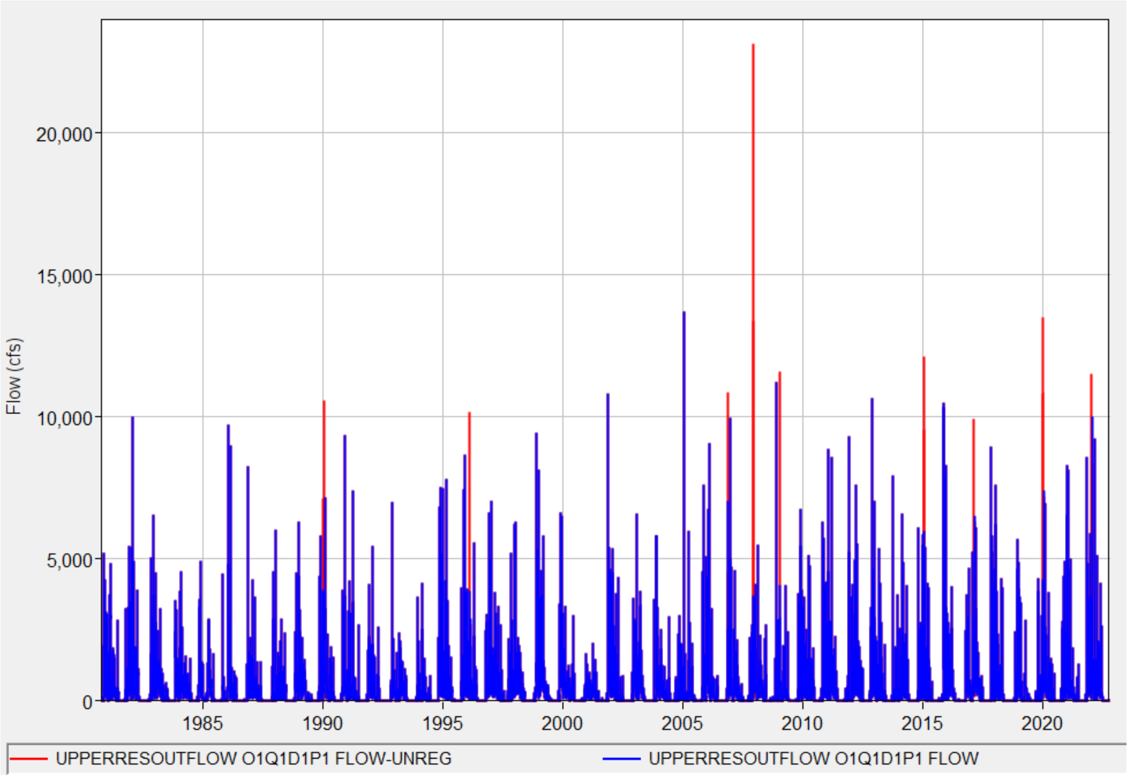
Table 8. Summary of Historical Event Routing Performance – O4Q1D5P2

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

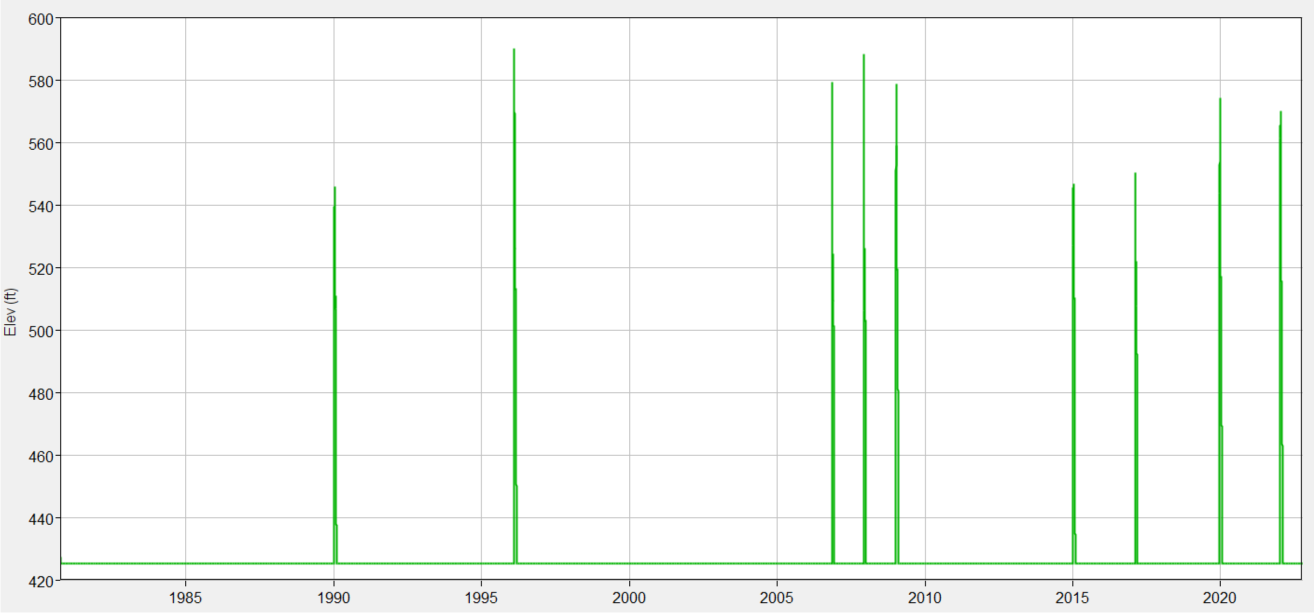
The HEC-ResSim model was run with a 42-year POR local flow time series developed in the HEC-HMS model. Figure 8 shows the results of the unregulated inflows to the reservoir and releases using the 2017 Operations.

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. [1] 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

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[1] 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 overstoring 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 Ground 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

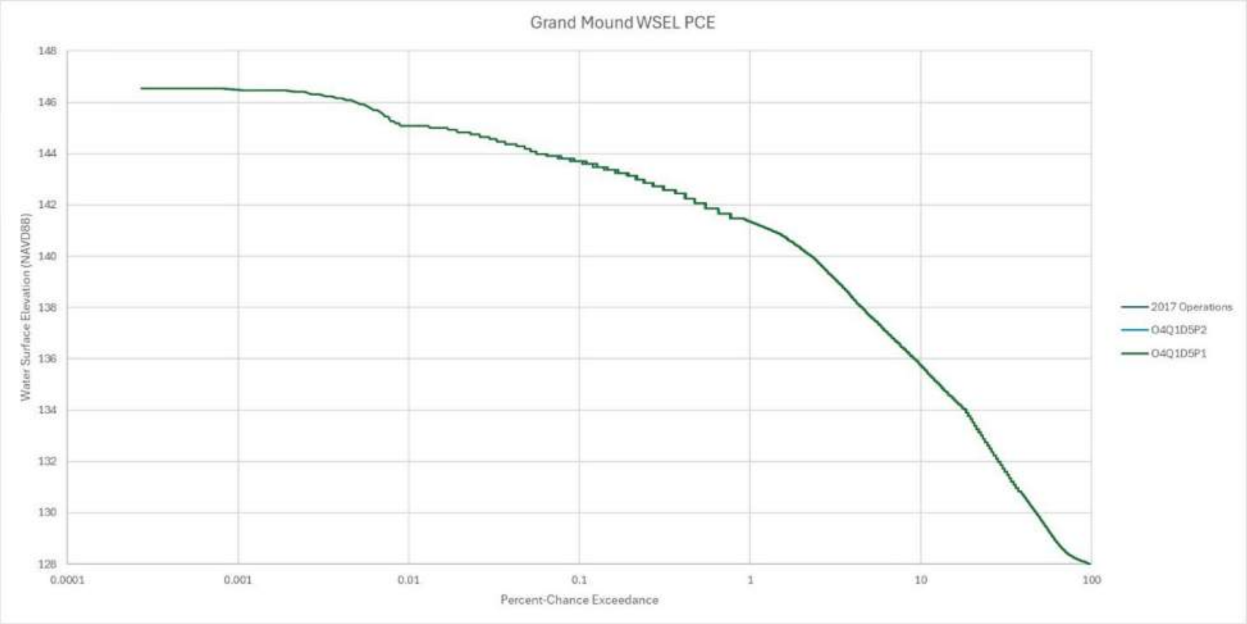
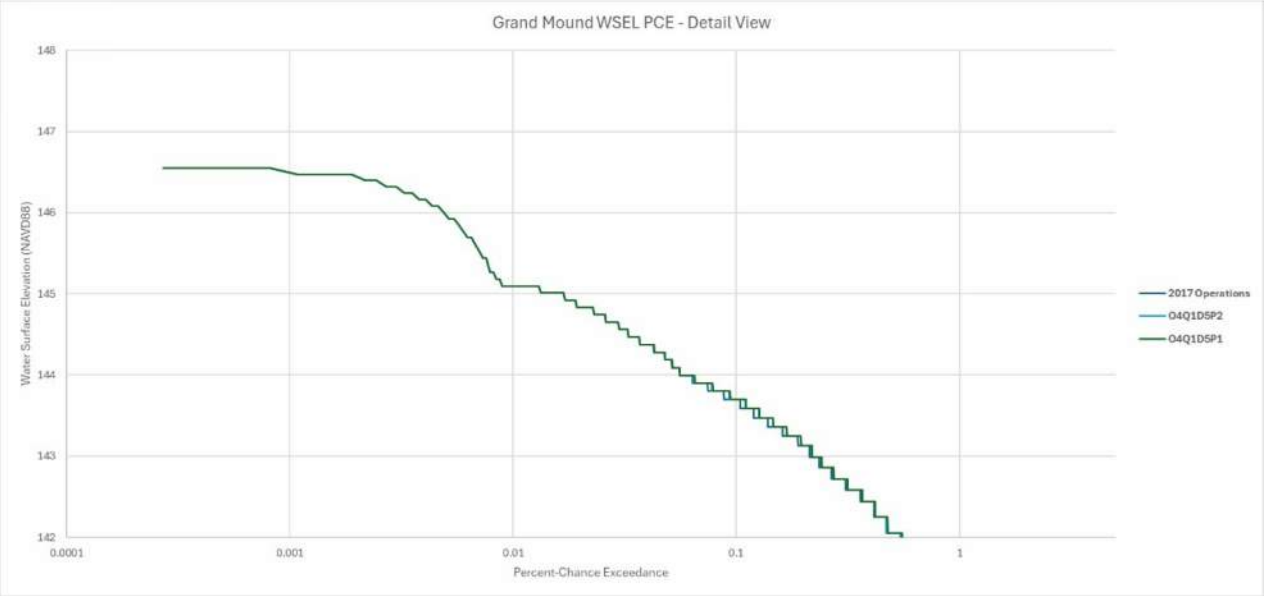


Figure 11. Grand Mound Water Surface Elevation Percent-Chance Exceedance – Detailed View



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)

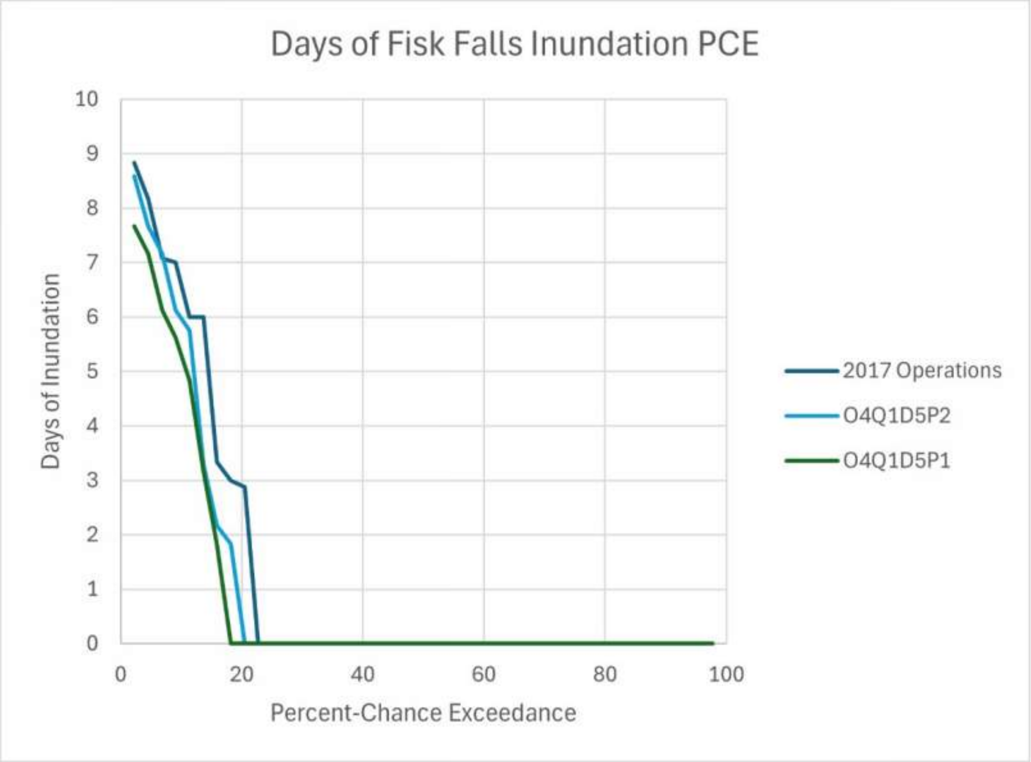


Figure 13. Fisk Falls Inundation (above WSEL 532) Annual Percent-Chance Exceedance for Historic POR (1980–2022) - Detailed View

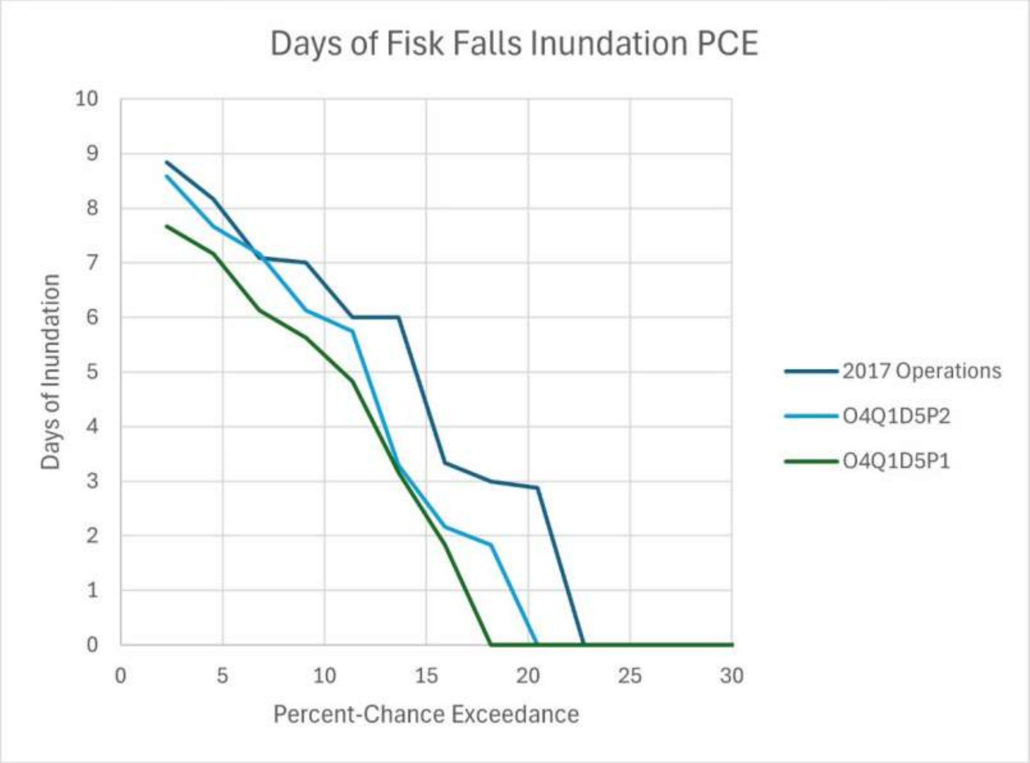
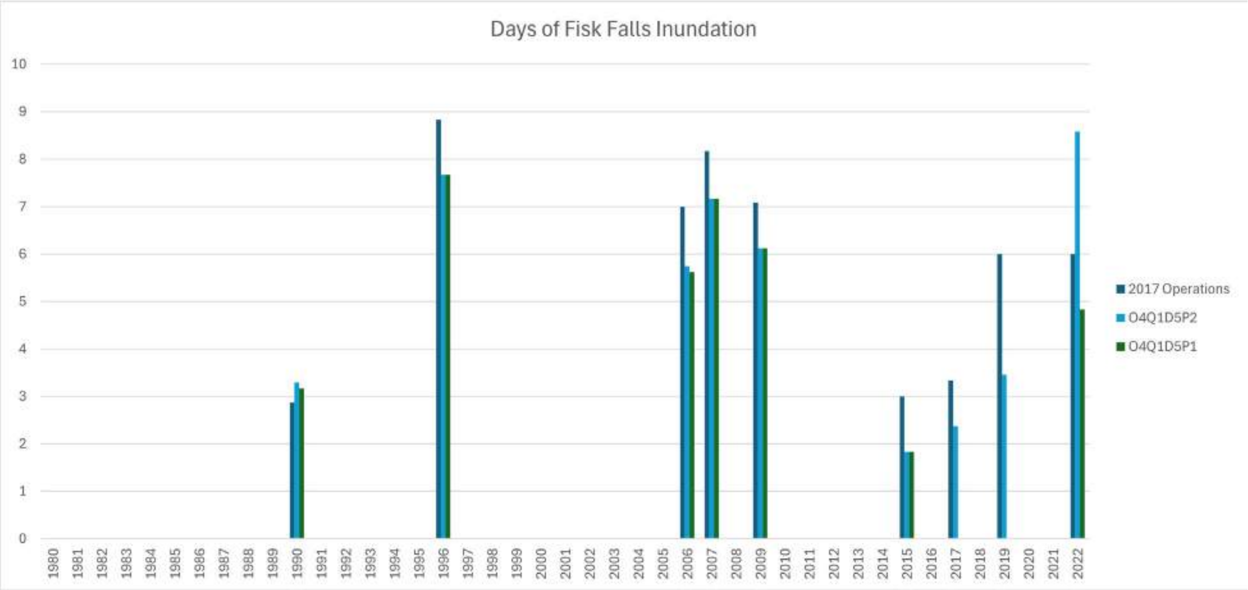


Figure 14. Days of Inundation at Fisk Falls (above WSEL 532) by Calendar Year



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

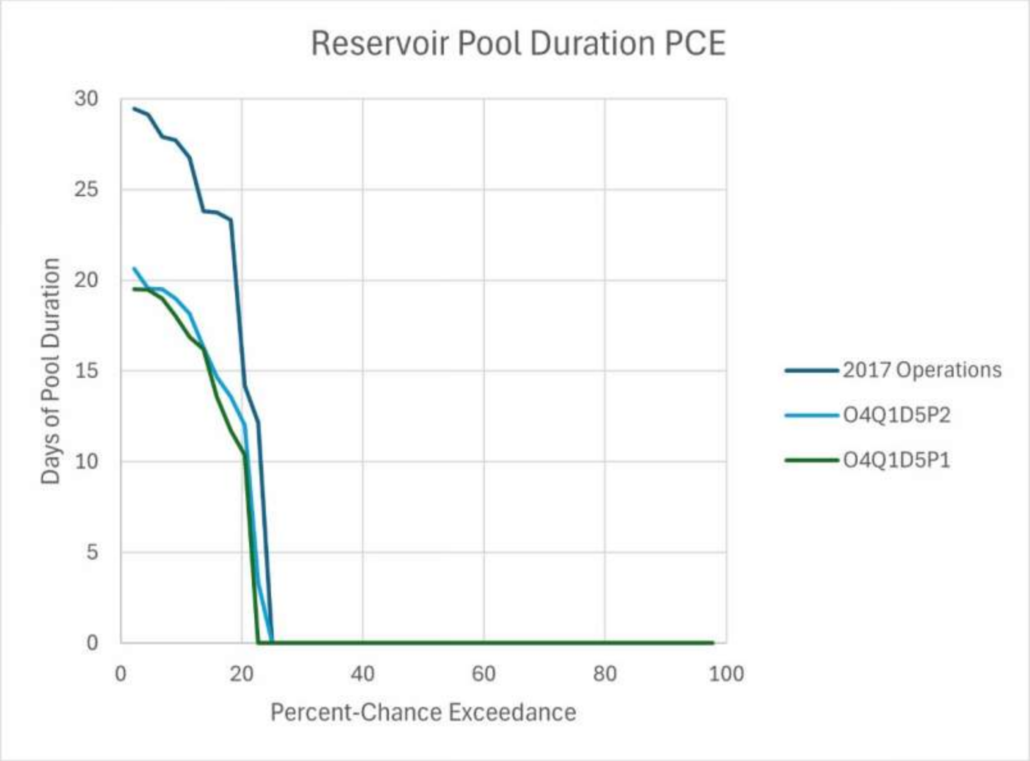


Figure 16. Reservoir Pool Duration (above WSEL 447) Percent-Chance Exceedance – Detailed View

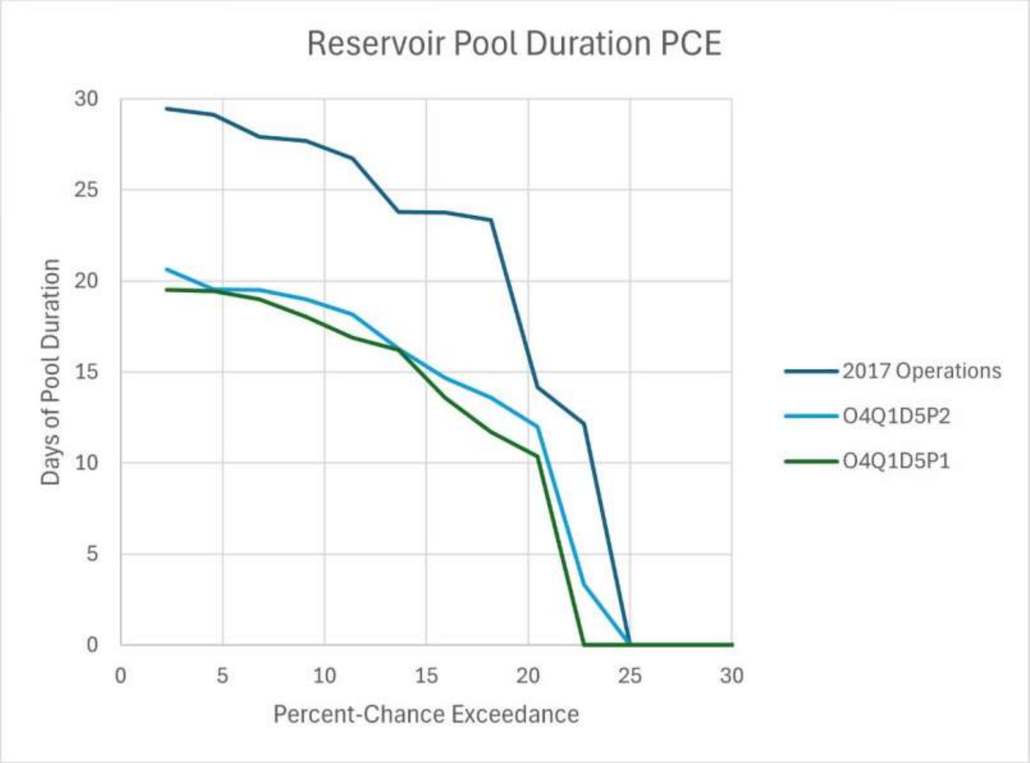
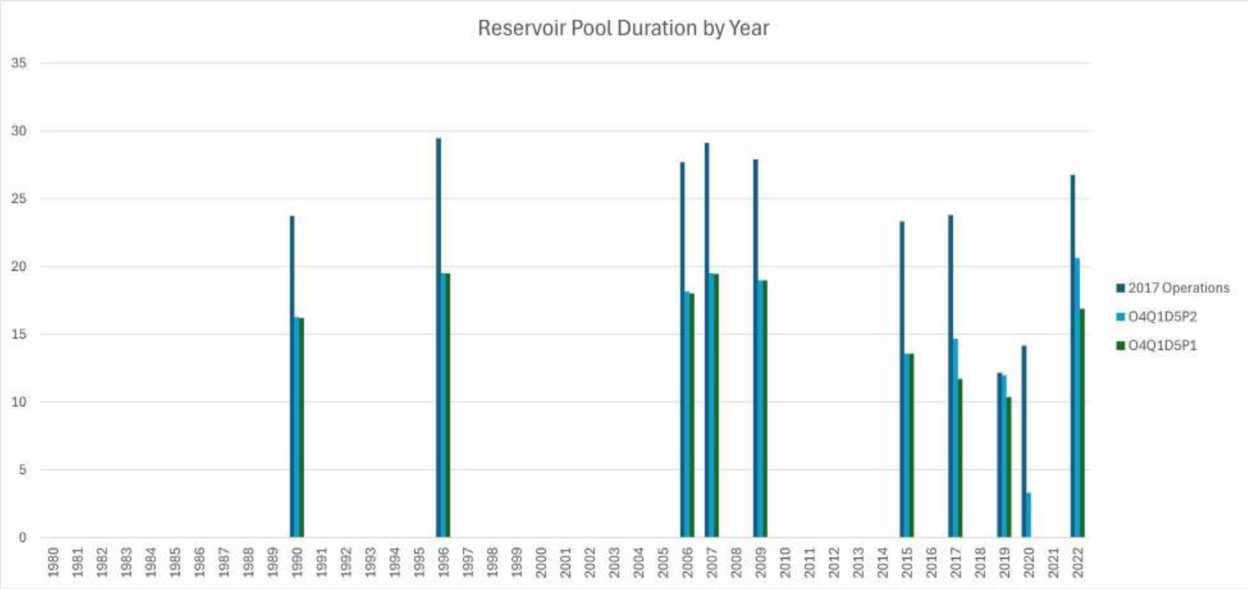


Figure 17. Reservoir Pool Duration (above WSEL 447) by Calendar Year



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
AVERAGE:	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
AVERAGE:	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

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1993 Engineering Manual [EM]-1110-2-1415, Engineering and Design Hydrologic Frequency Analysis. March 5, 1993.

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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

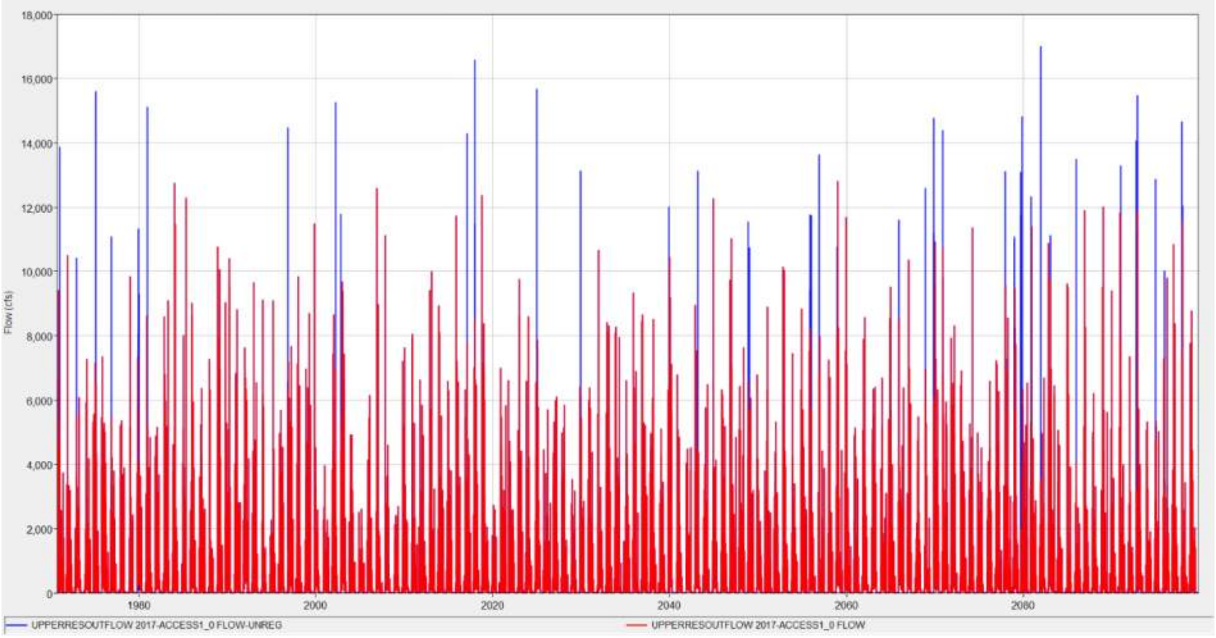


Figure 1-2. Access 1.0 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

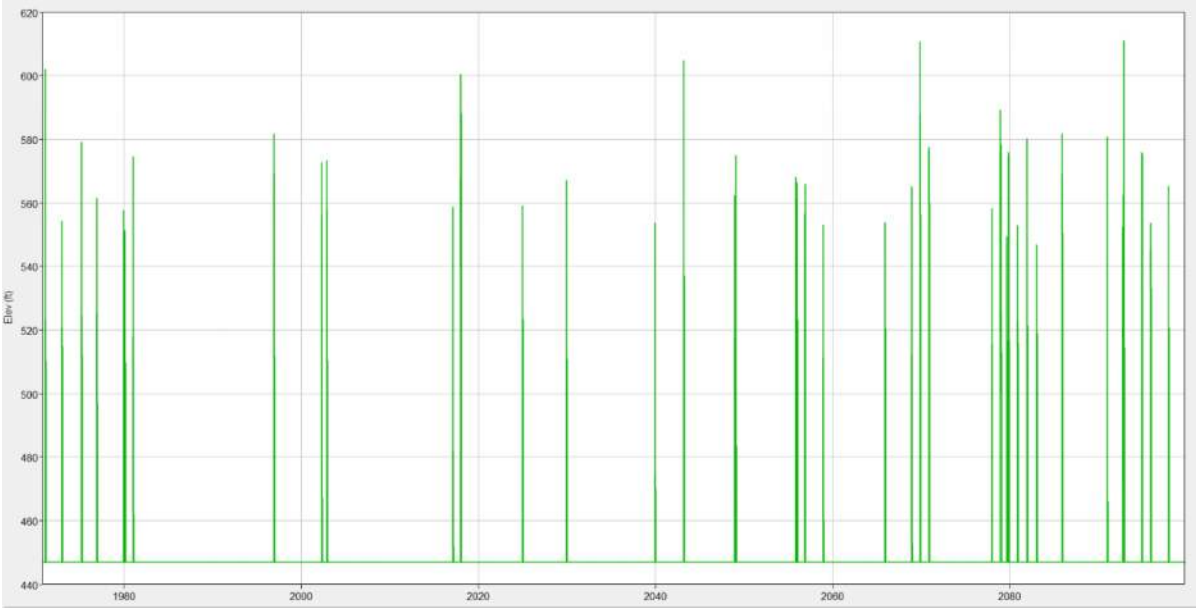


Figure 1-3. Access 1.3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

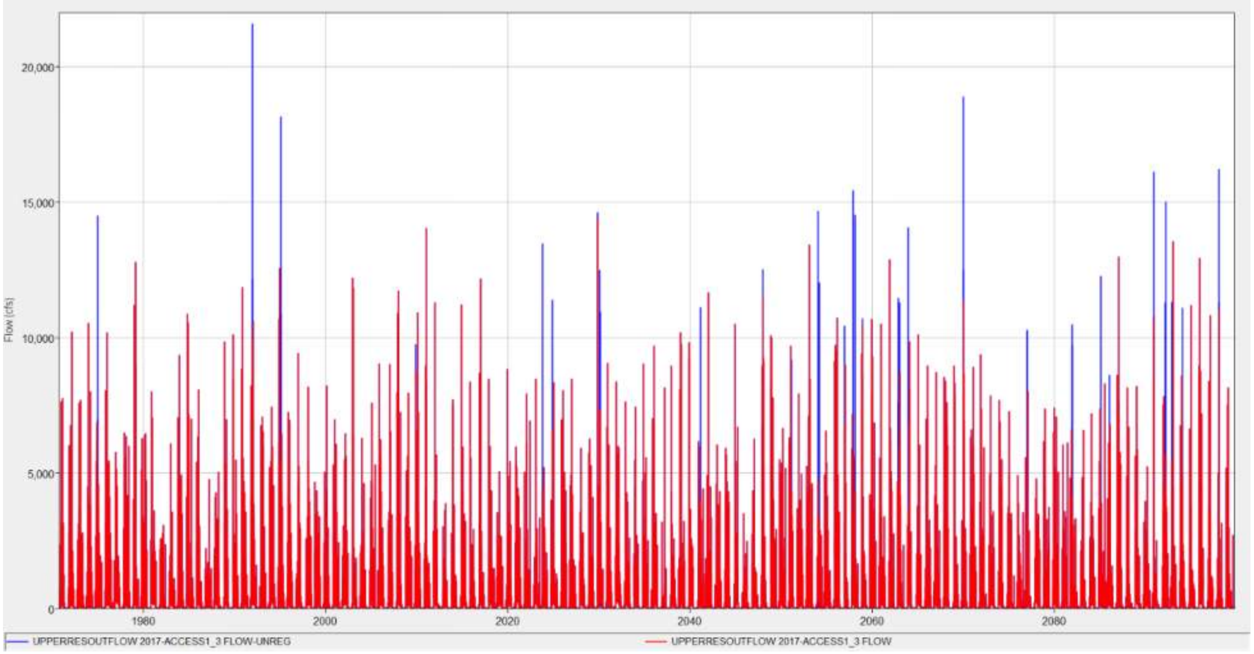


Figure 1-4. Access 1.3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

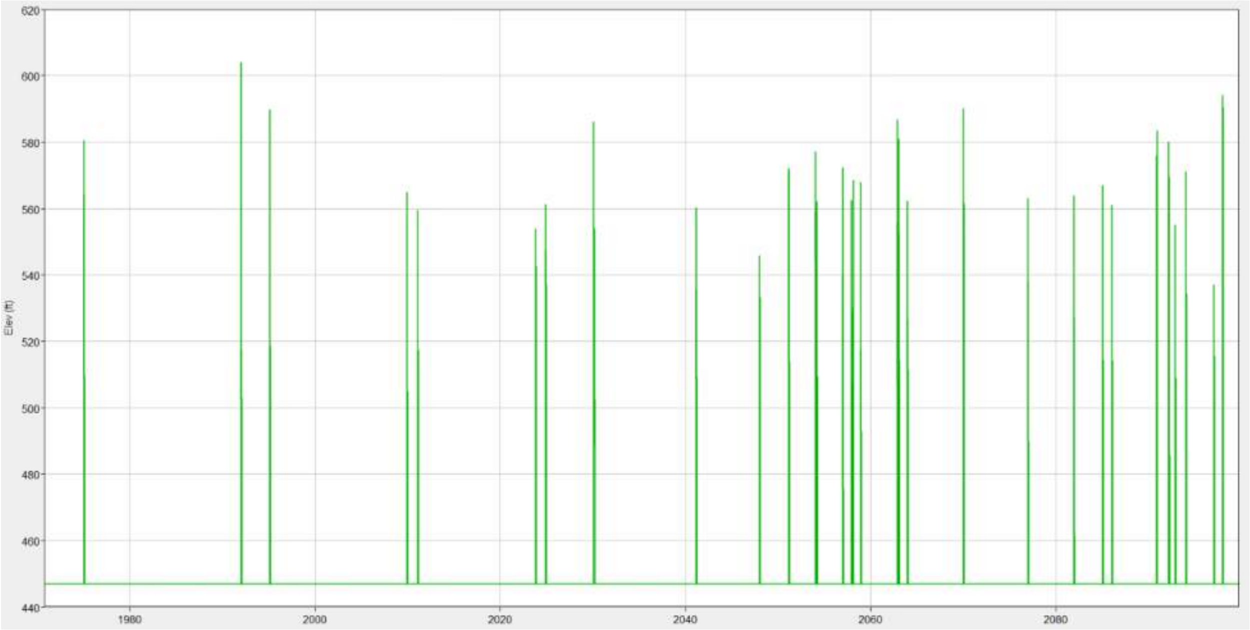


Figure 1-5. BCC-CSM 1.1 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

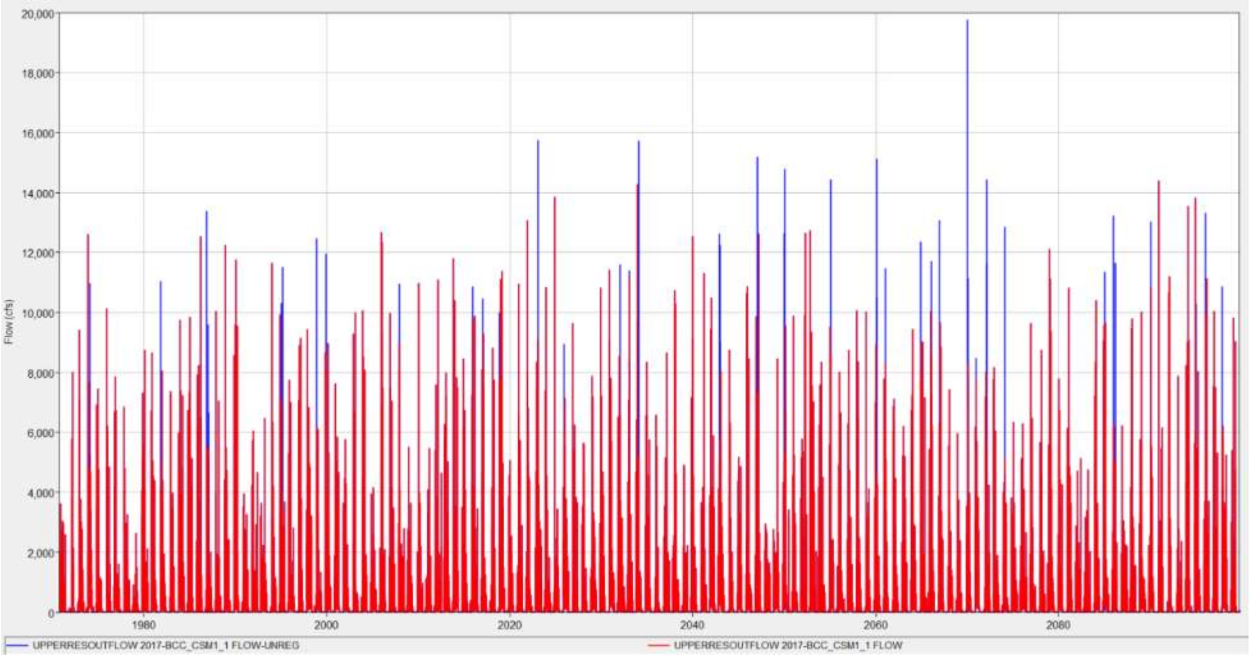


Figure 1-6. BCC-CSM 1.1 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

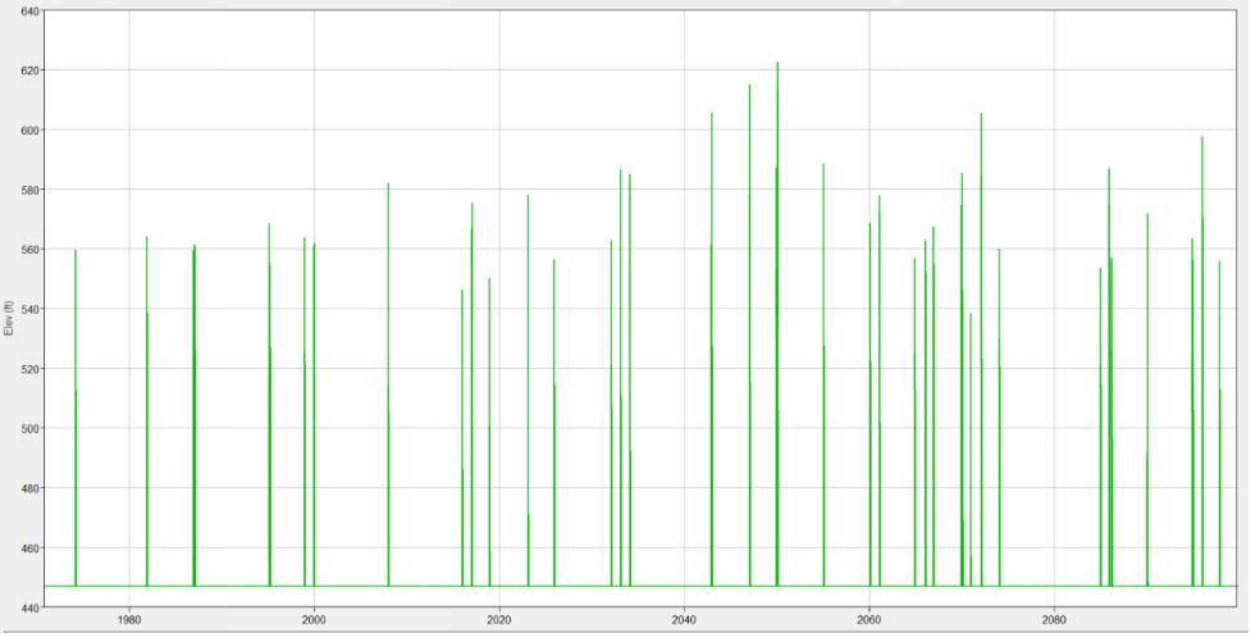


Figure 1-7. CanESM2 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

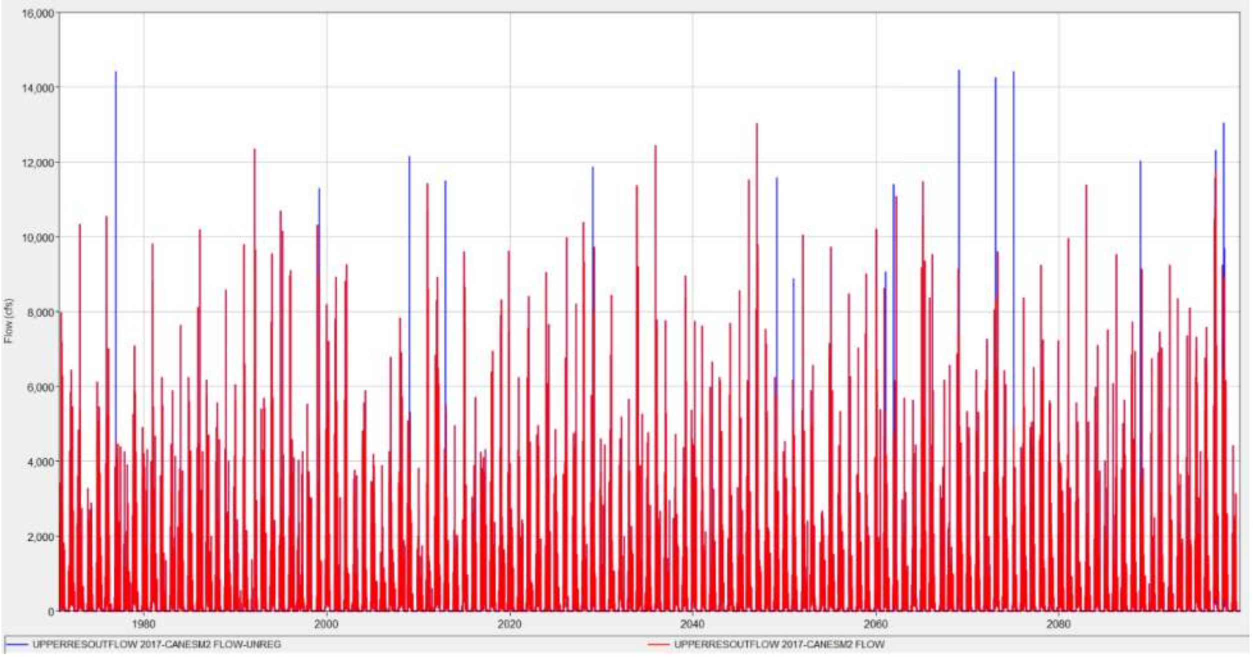


Figure 1-8. CanESM2 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

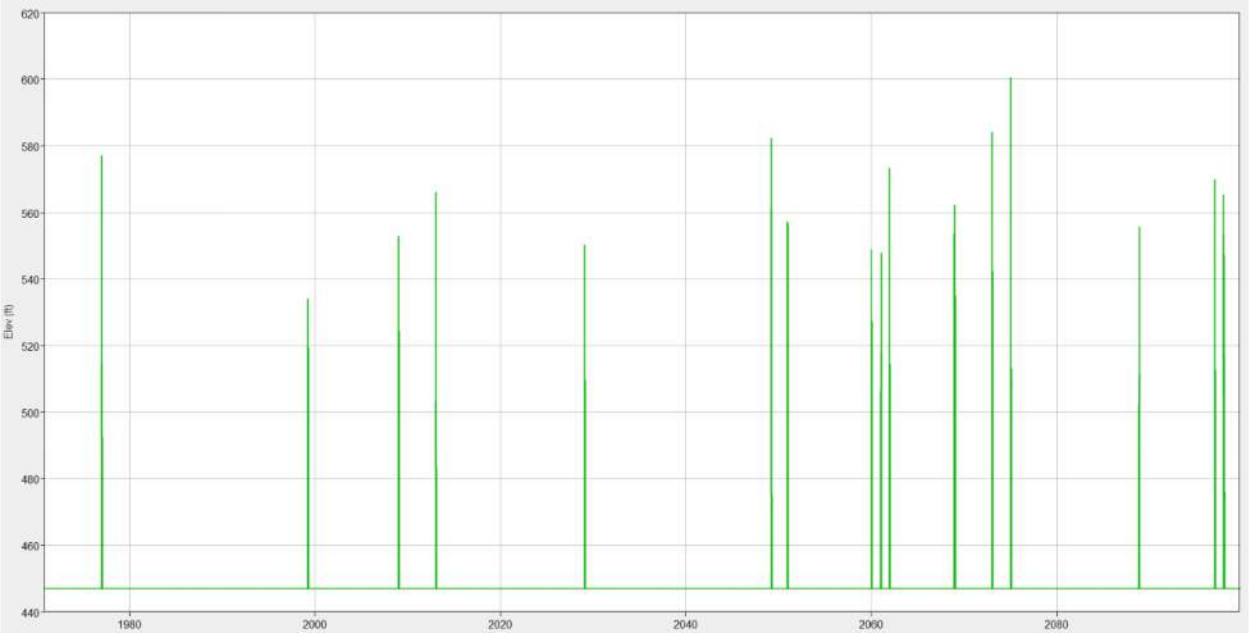


Figure 1-9. CCSM4 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

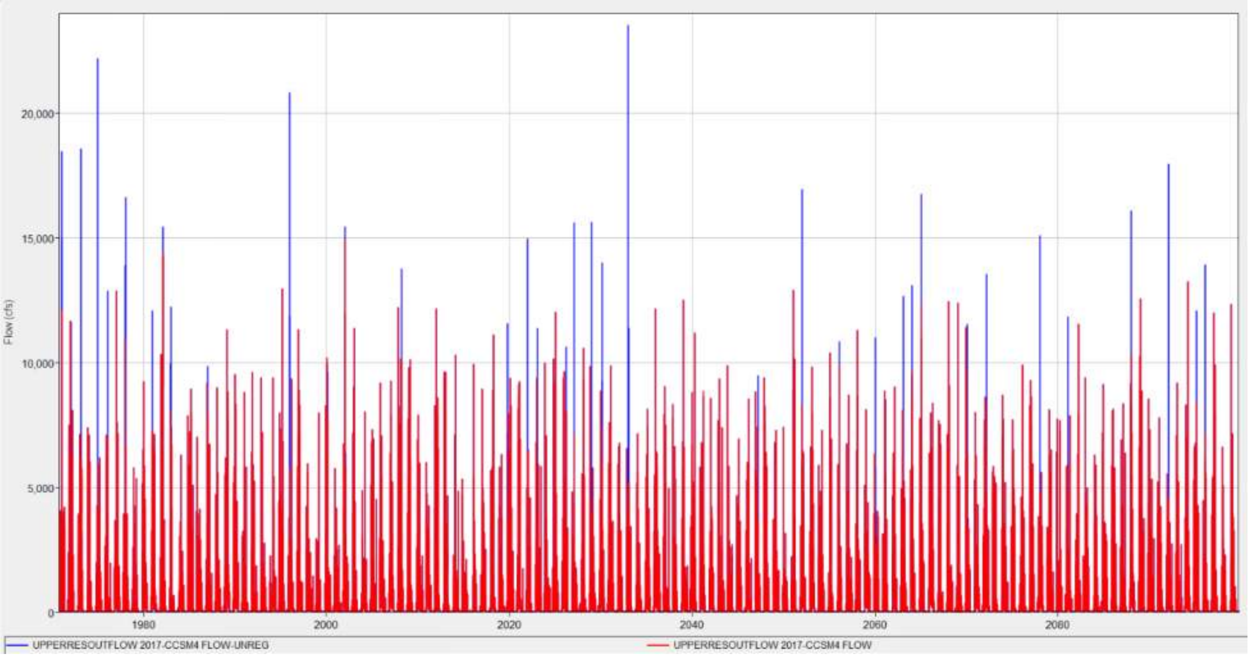


Figure 1-10. CCSM4 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

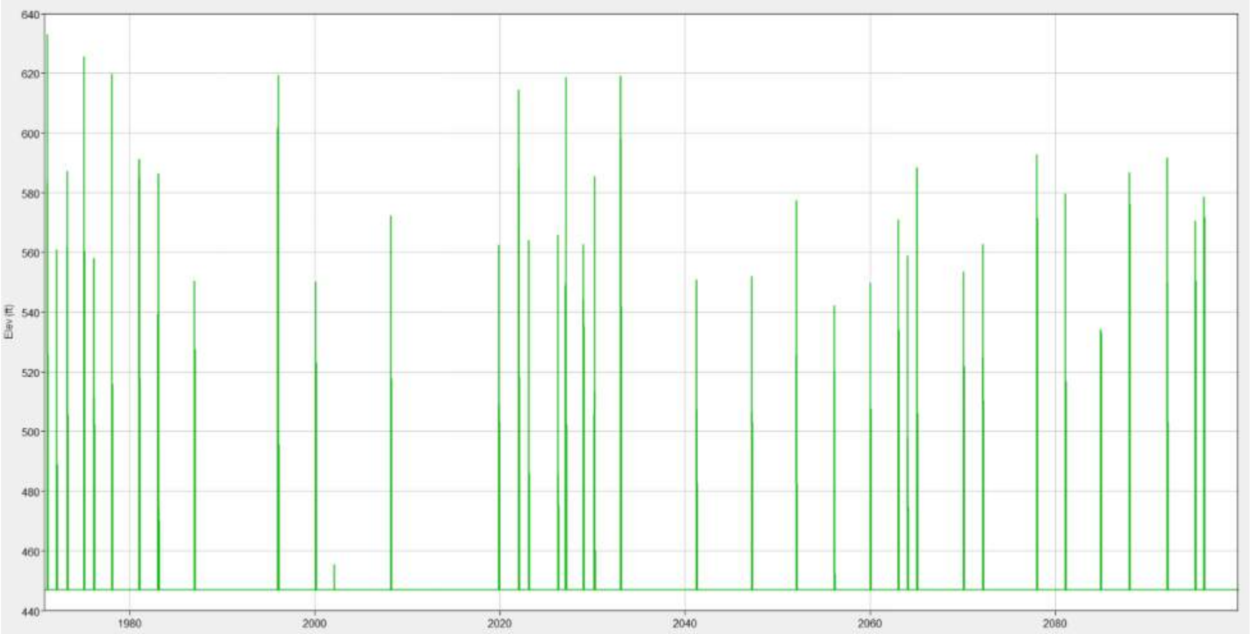


Figure 1-11. Csiro-mk3_6_0 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

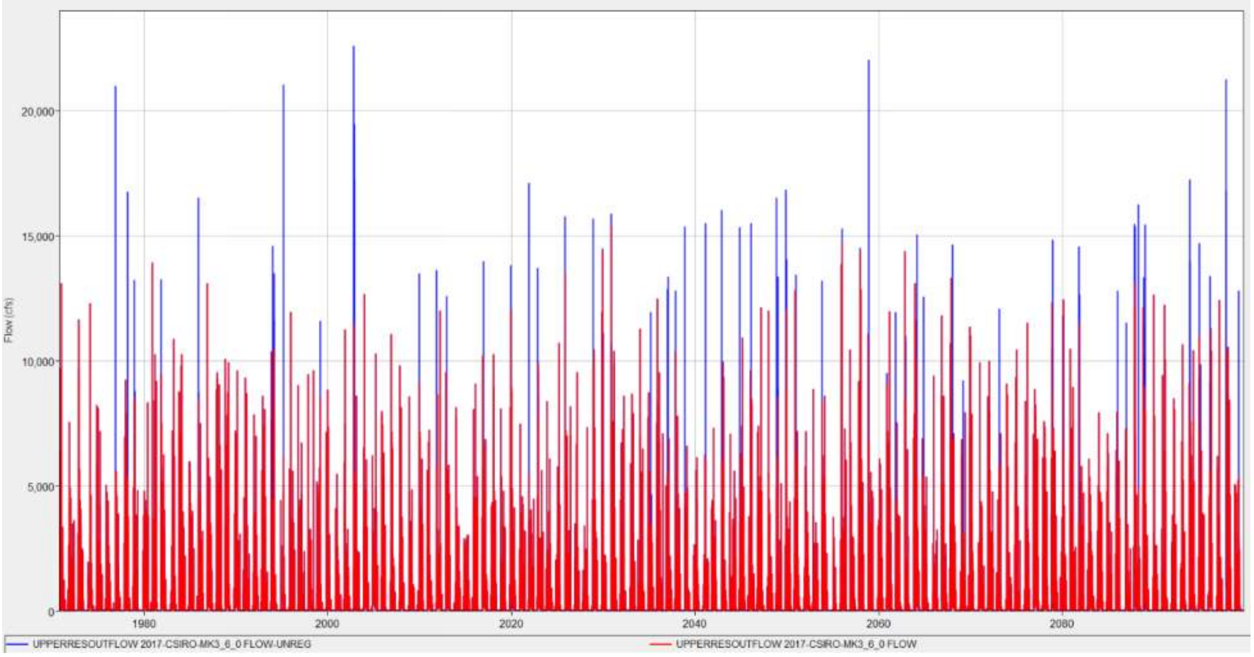


Figure 1-12. Csiro-mk3_6_0 CCSM4 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

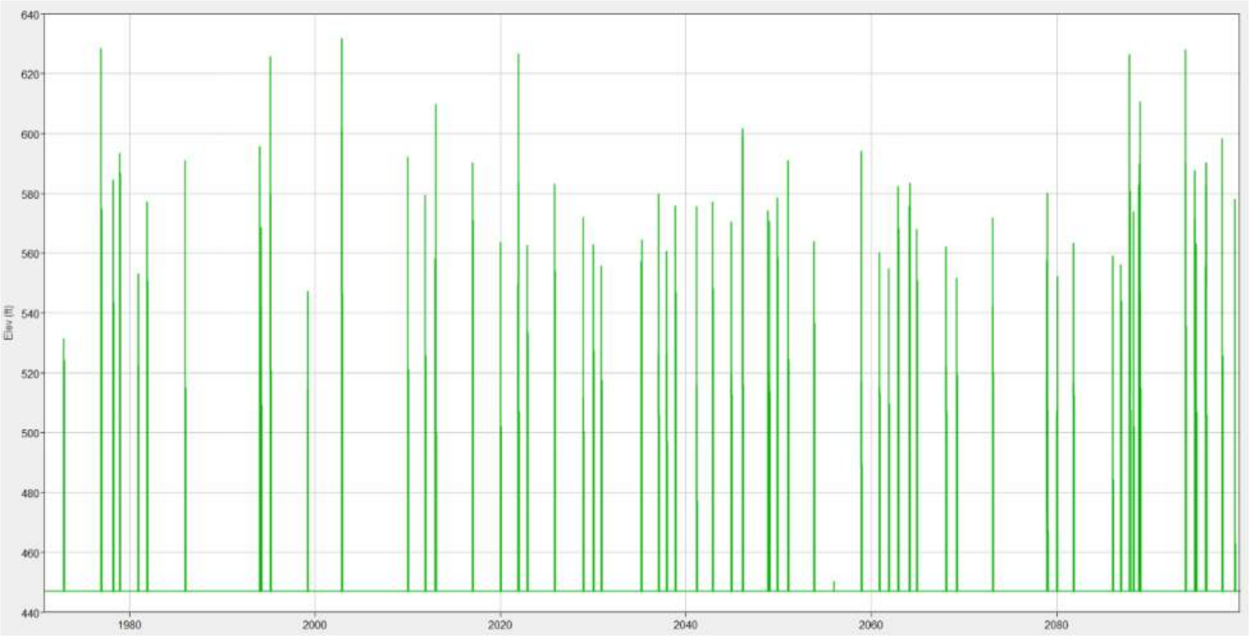


Figure 1-13. FGOALS-g2 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

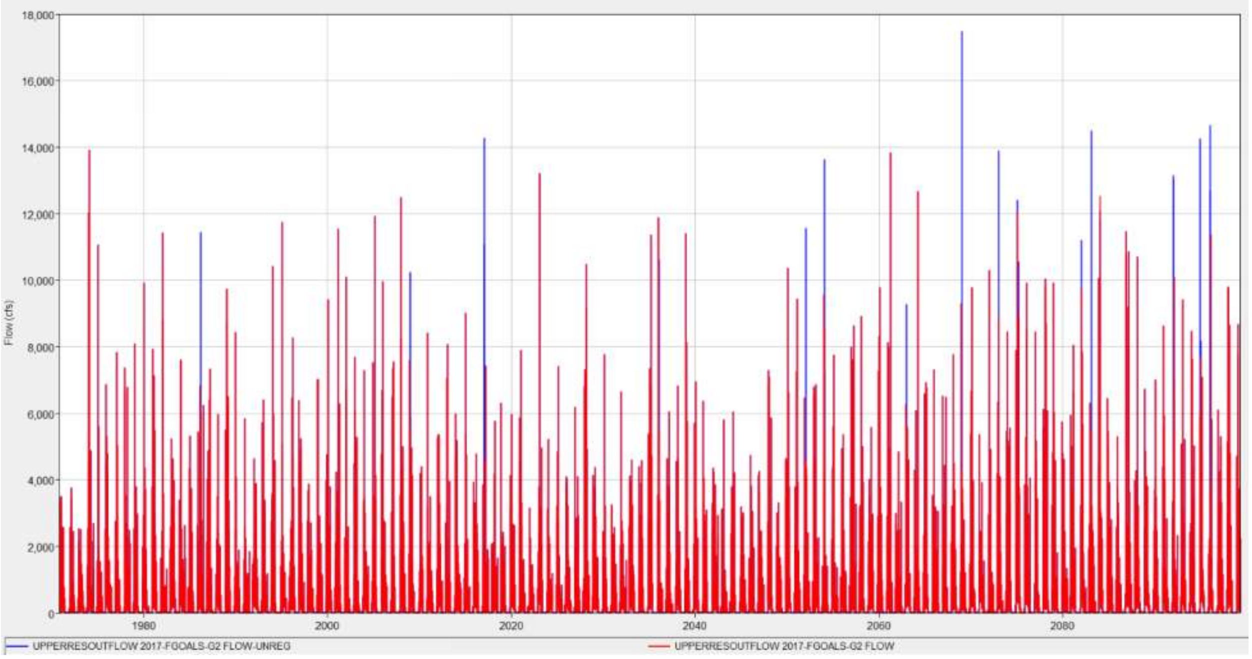


Figure 1-14. FGOALS-g2 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

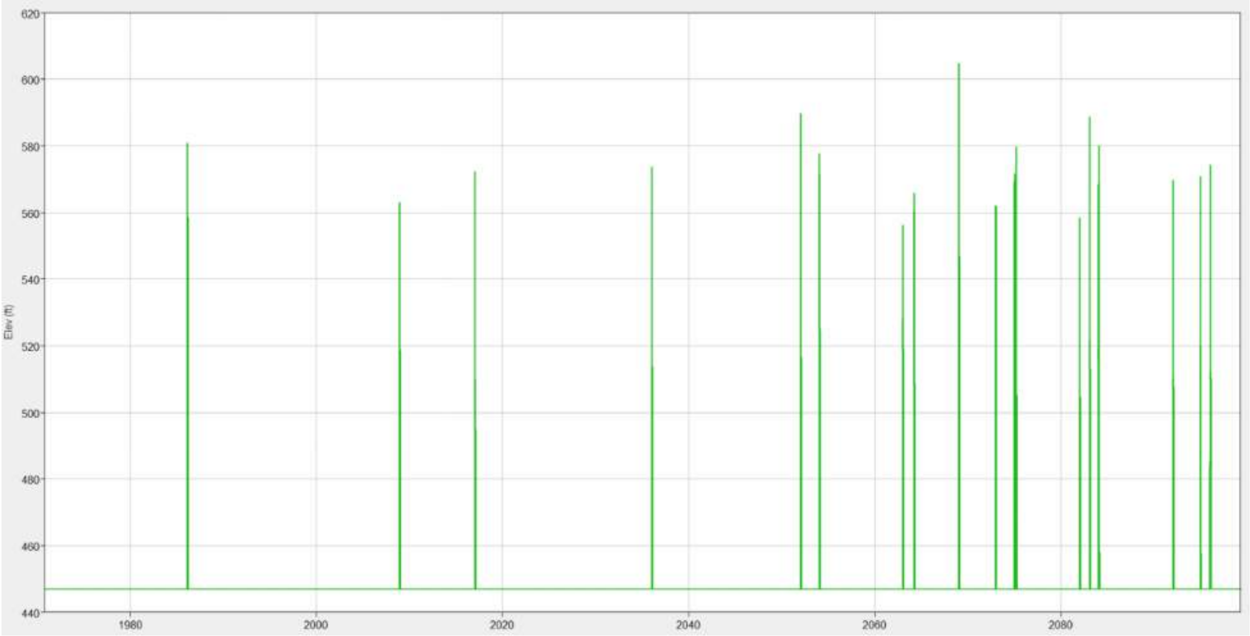


Figure 1-15. GFDL-CM3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

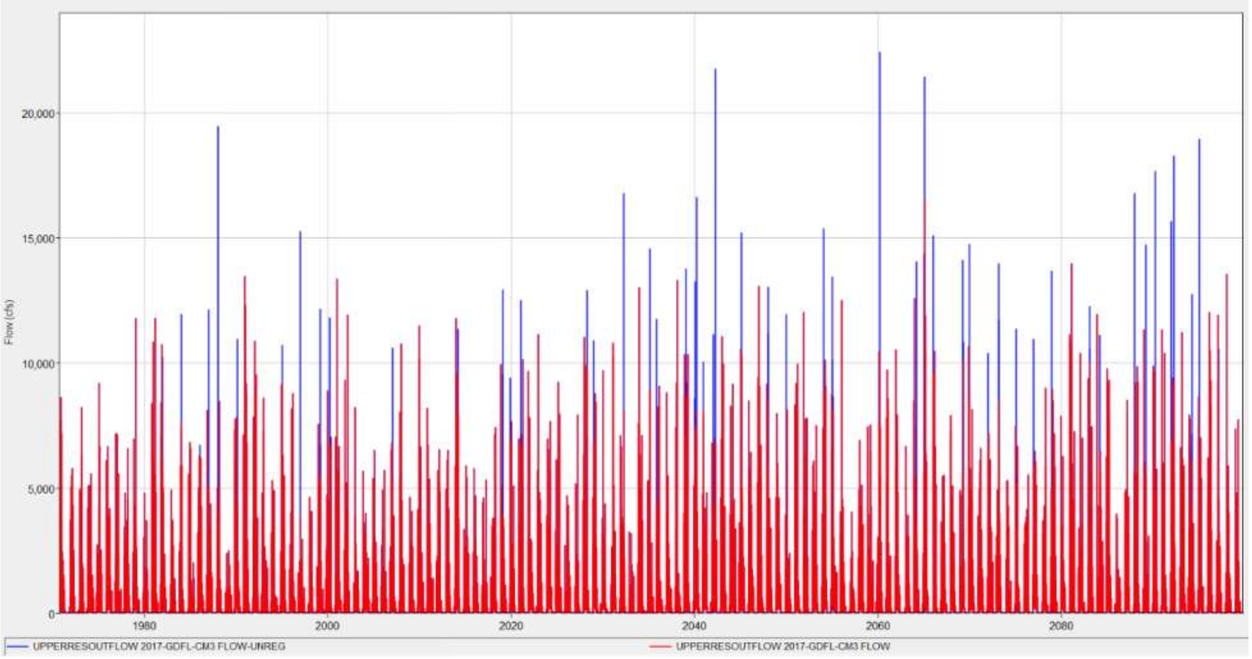


Figure 1-16. GFDL-CM3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

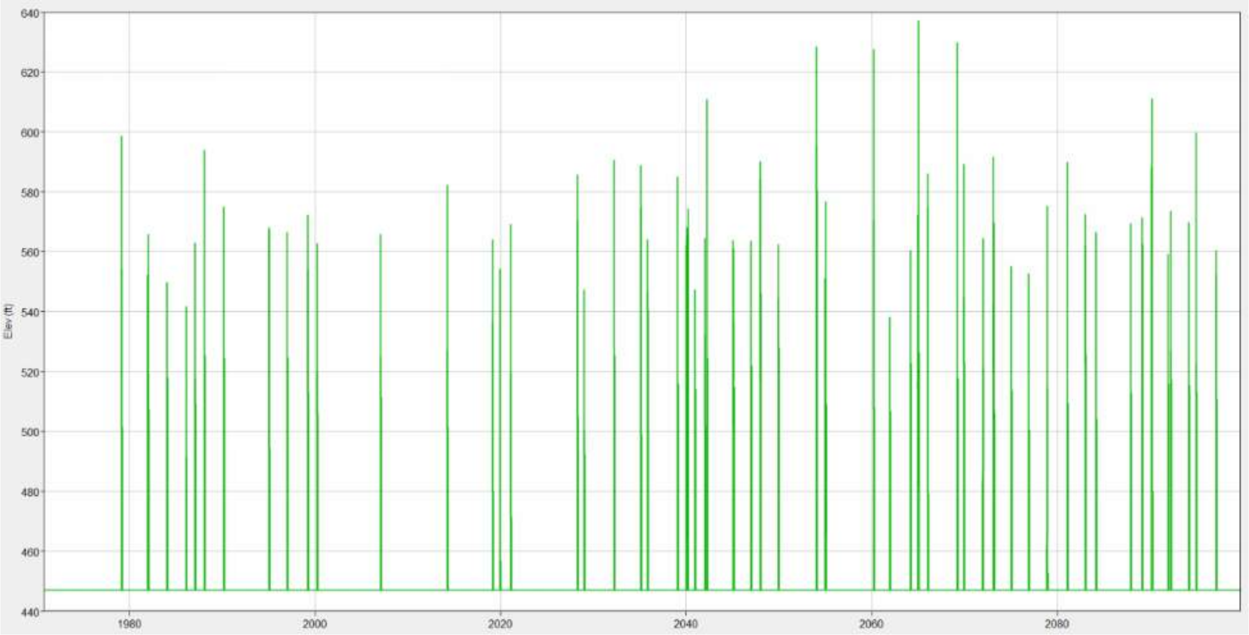


Figure 1-17. GISS-E2-H Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

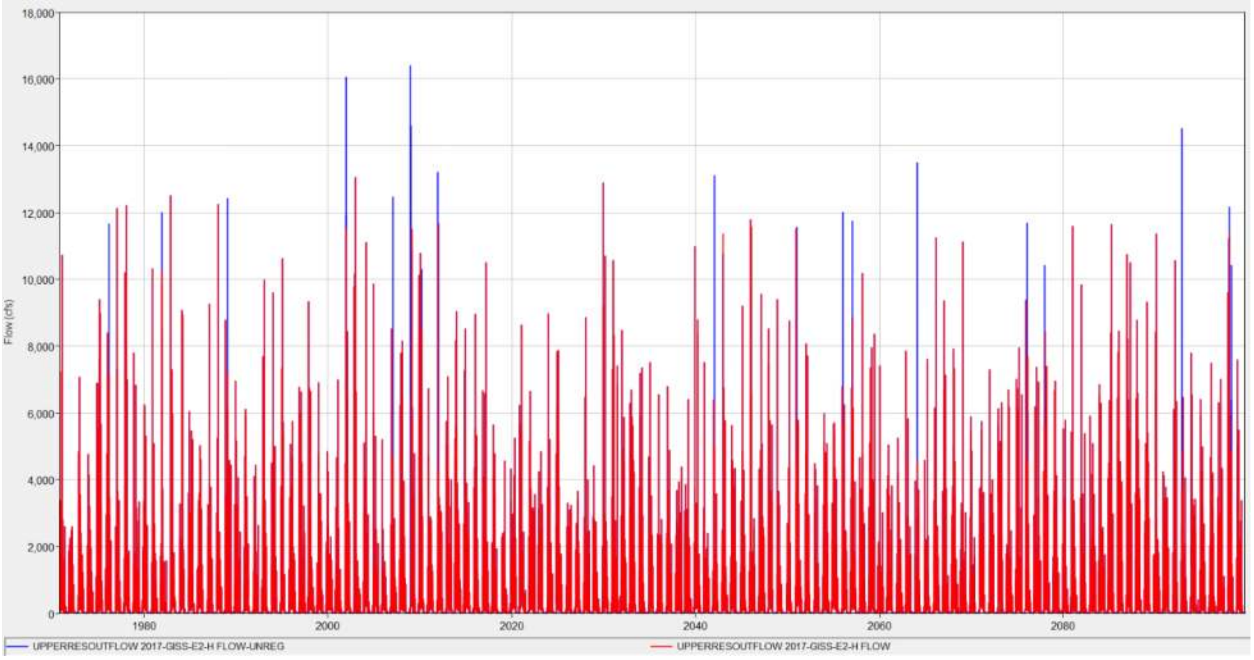


Figure 1-18. GISS-E2-H Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

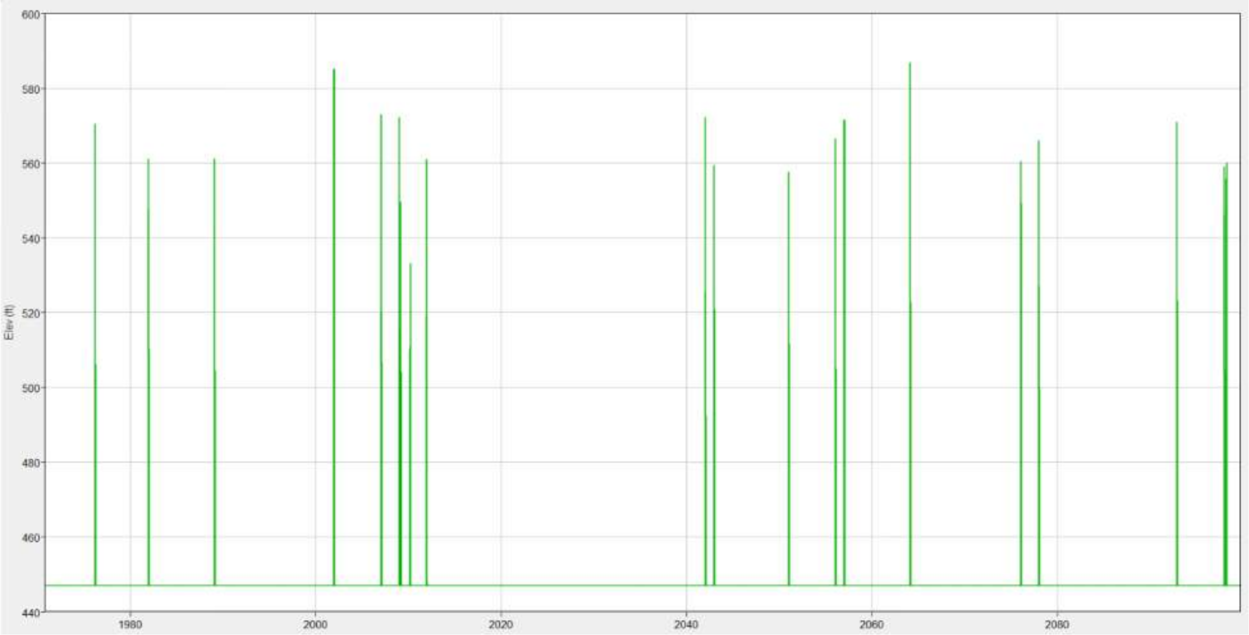


Figure 1-19. MIROC5 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

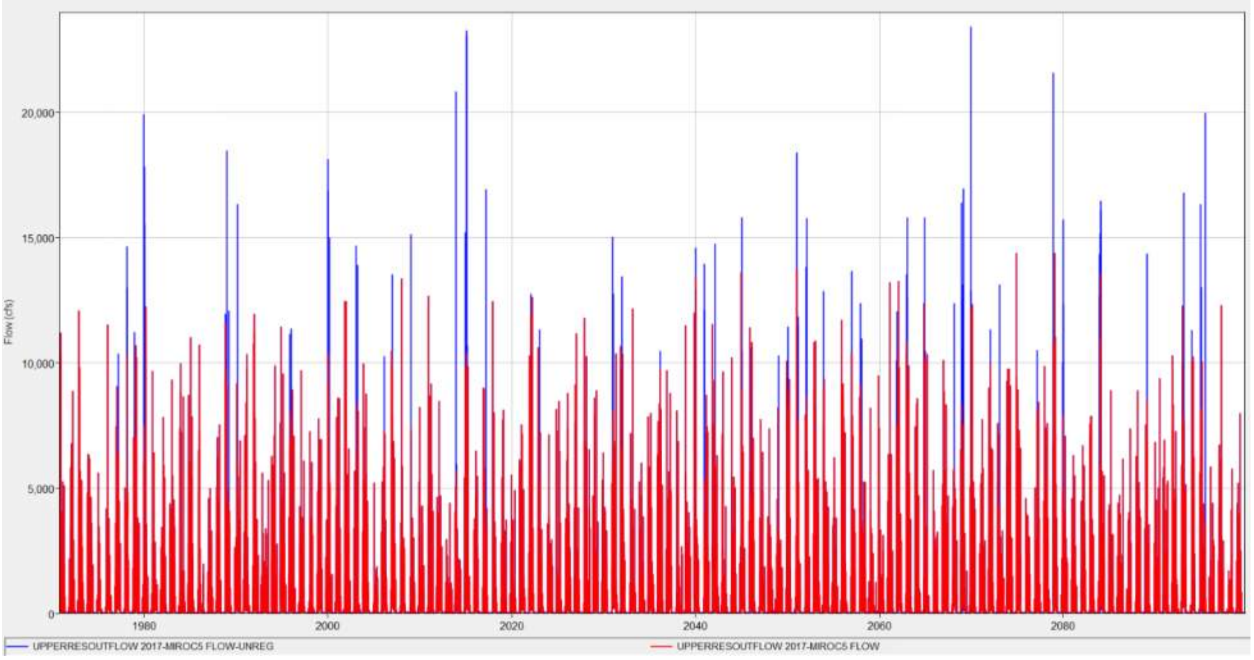


Figure 1-20. MIROC5 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

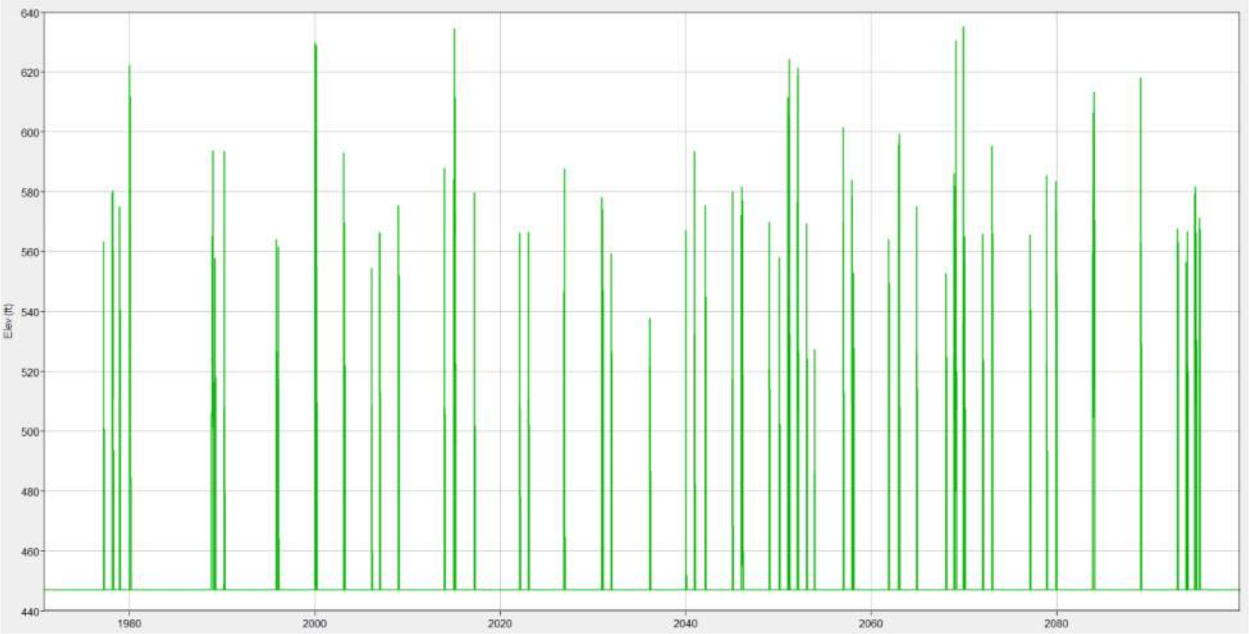


Figure 1-21. MRI-CGCM3 Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

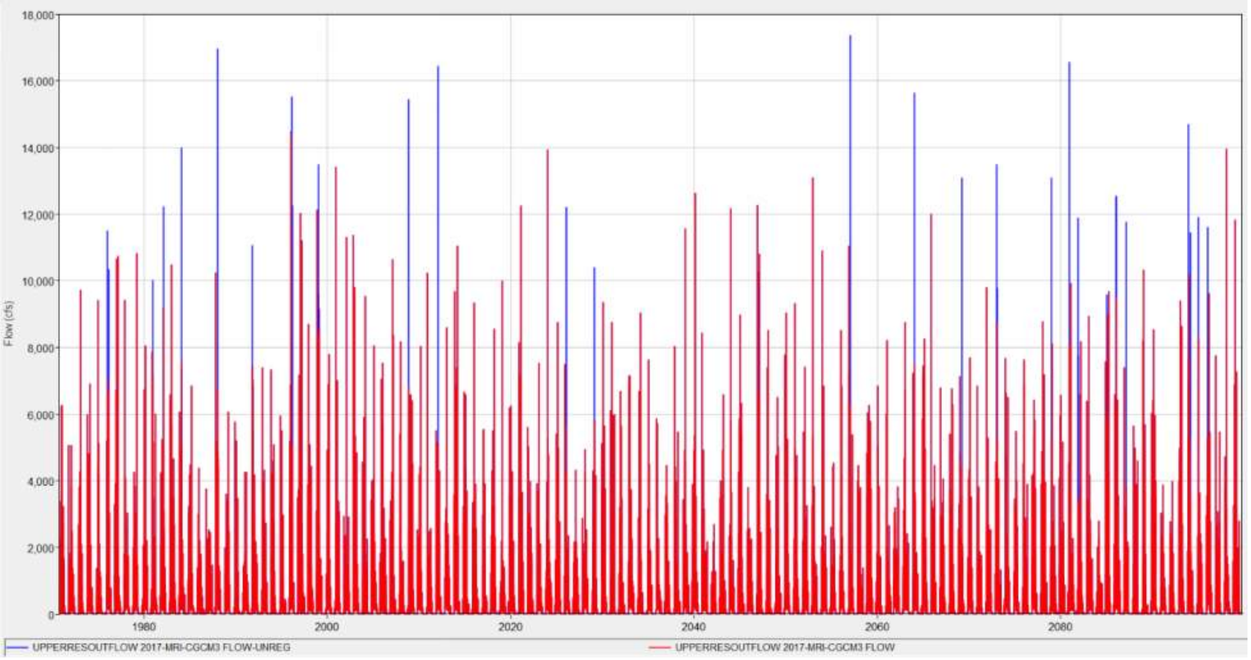


Figure 1-22. MRI-CGCM3 Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site

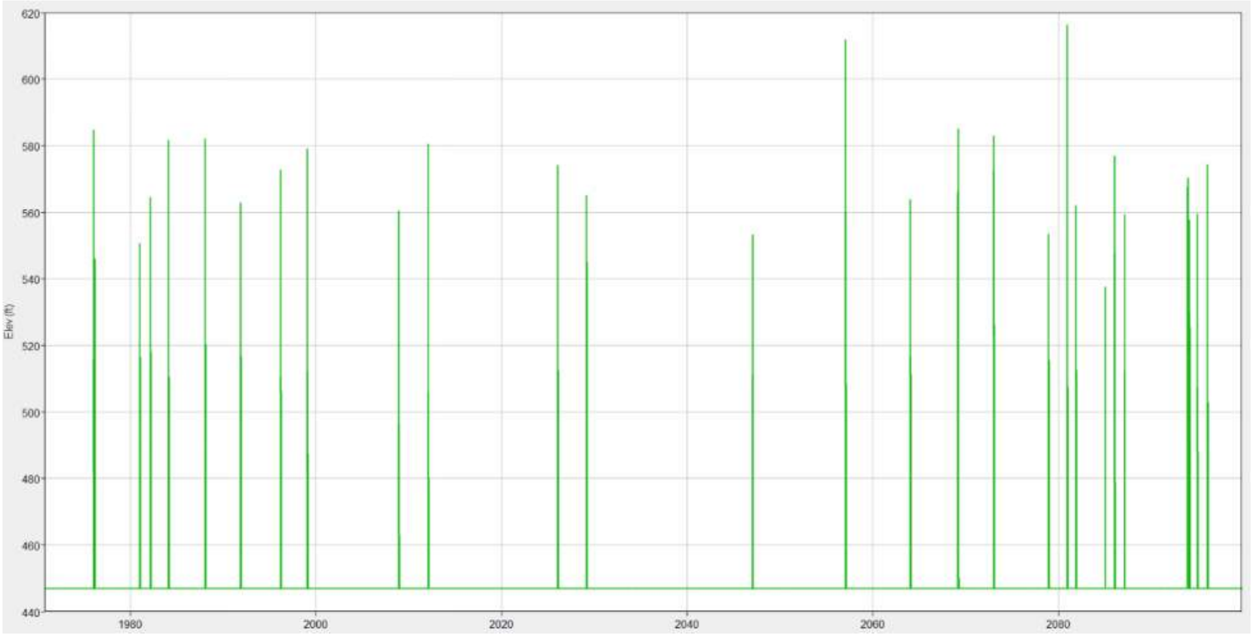


Figure 1-23. NorESM1-M Unregulated and Regulated (2017 Operations) Flows Through the Reservoir Site

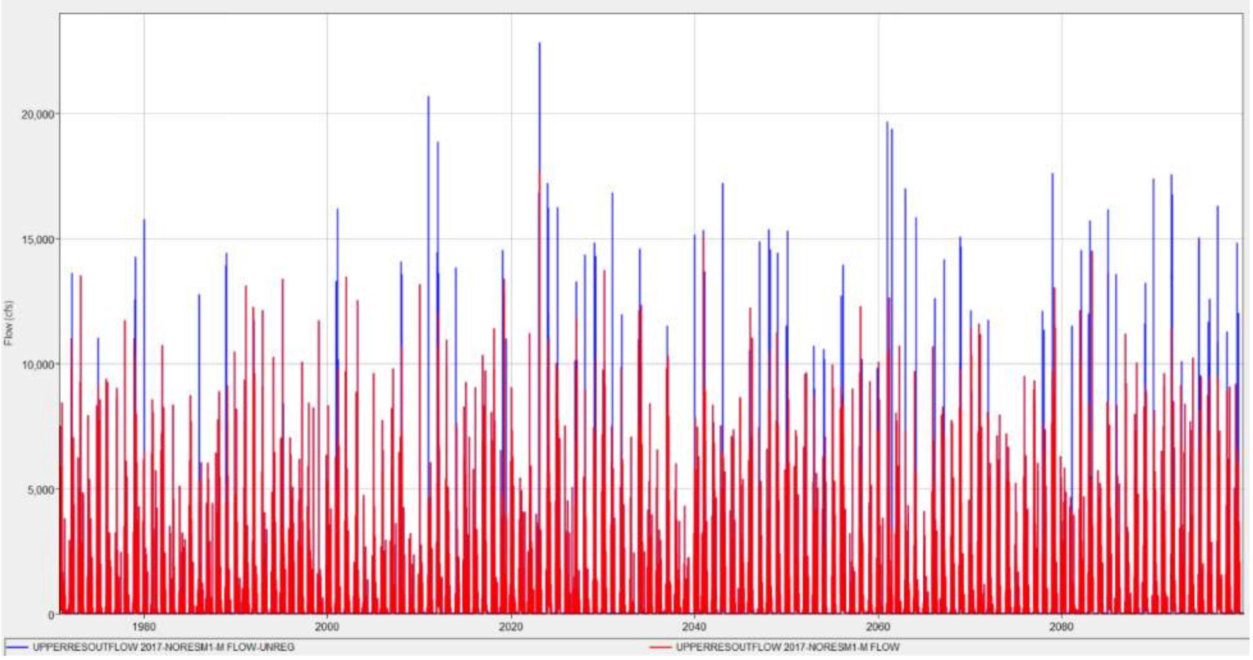
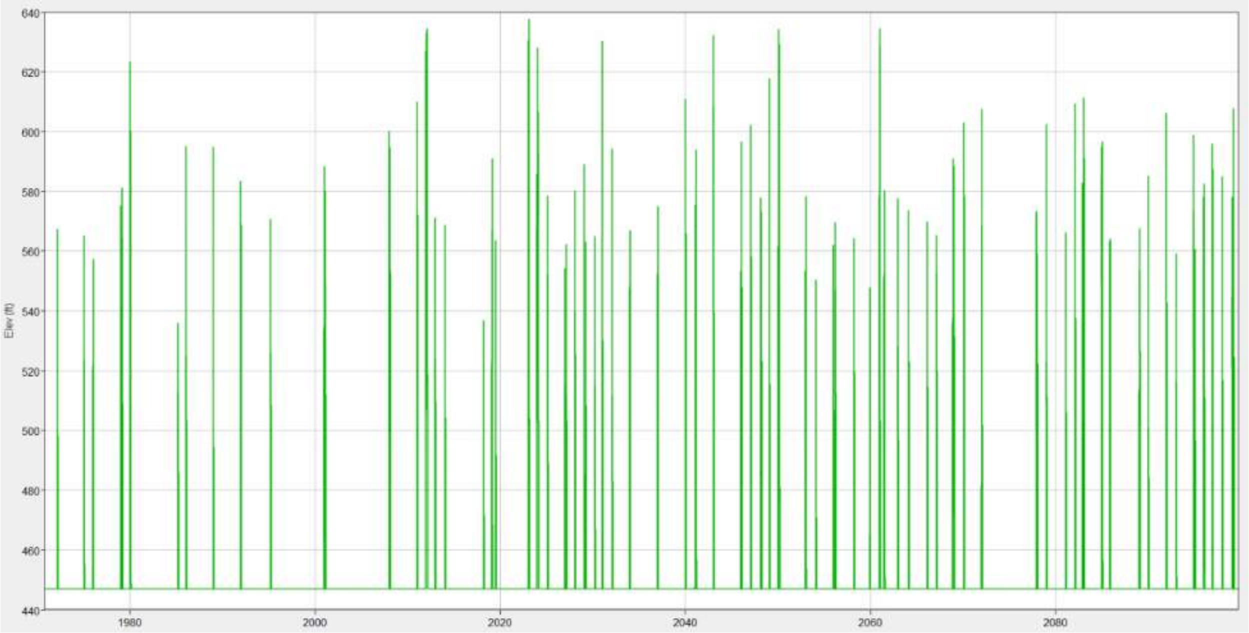


Figure 1-24. NorESM1-M Regulated (2017 Operations) Reservoir Pool Elevation at the FRE Site



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

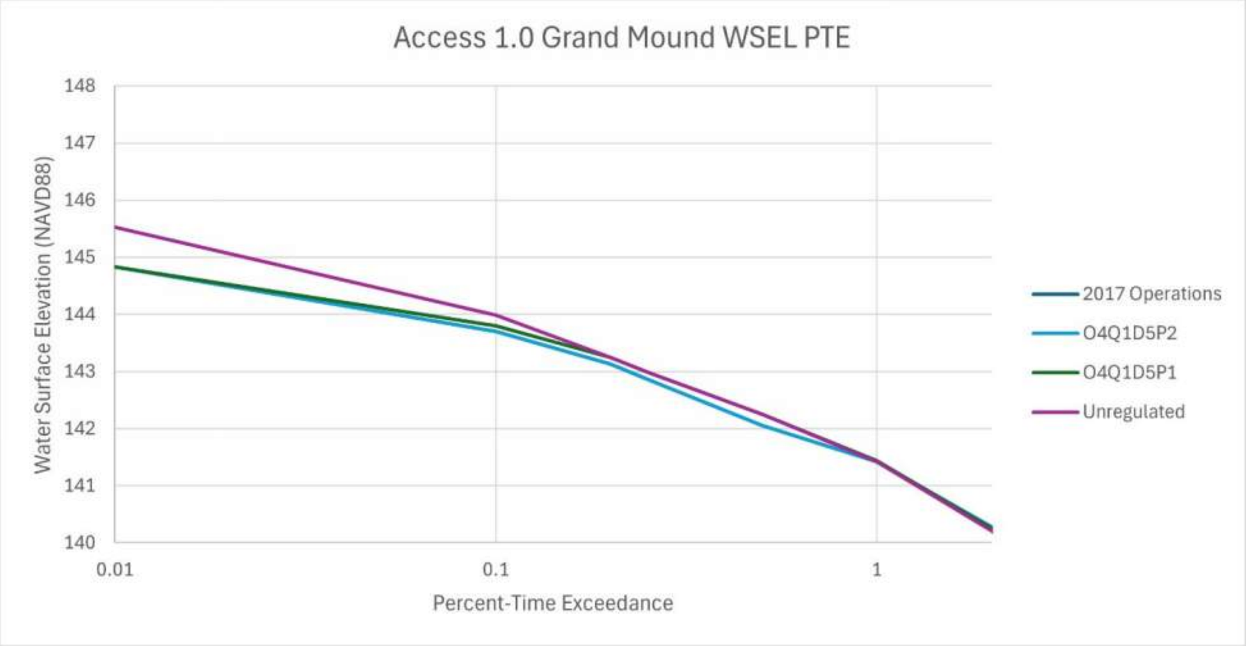


Figure 2-2. Access 1.3 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet

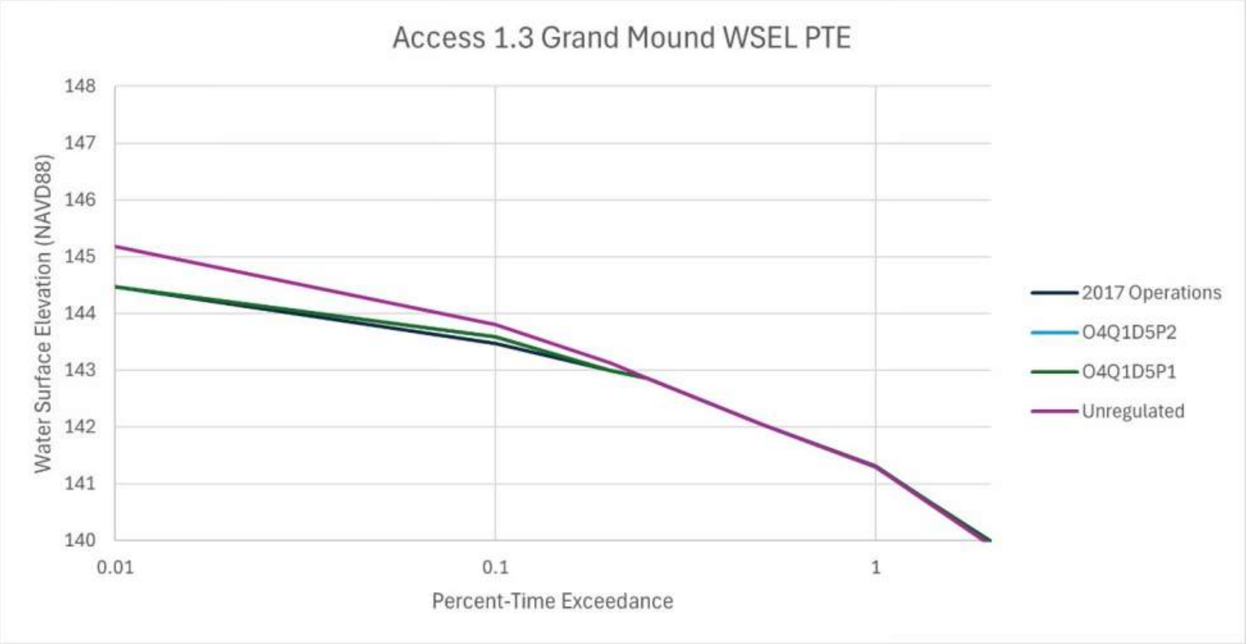


Figure 2-3. BCC_CSM 1.1 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet

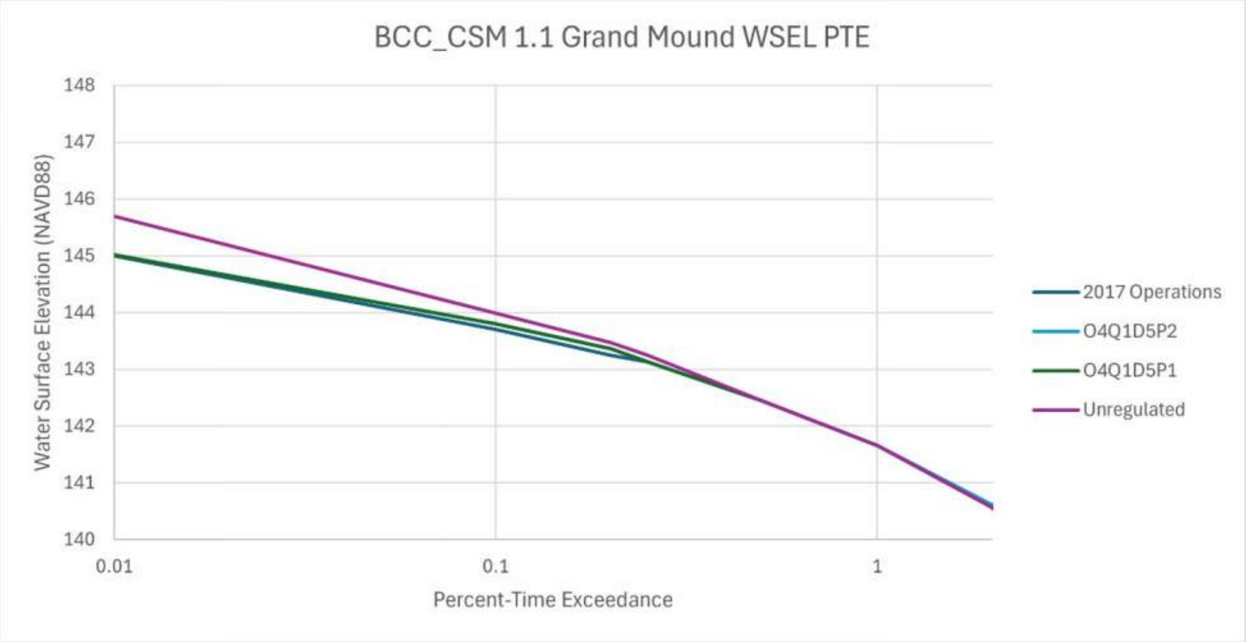


Figure 2-4. canESM2 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet

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

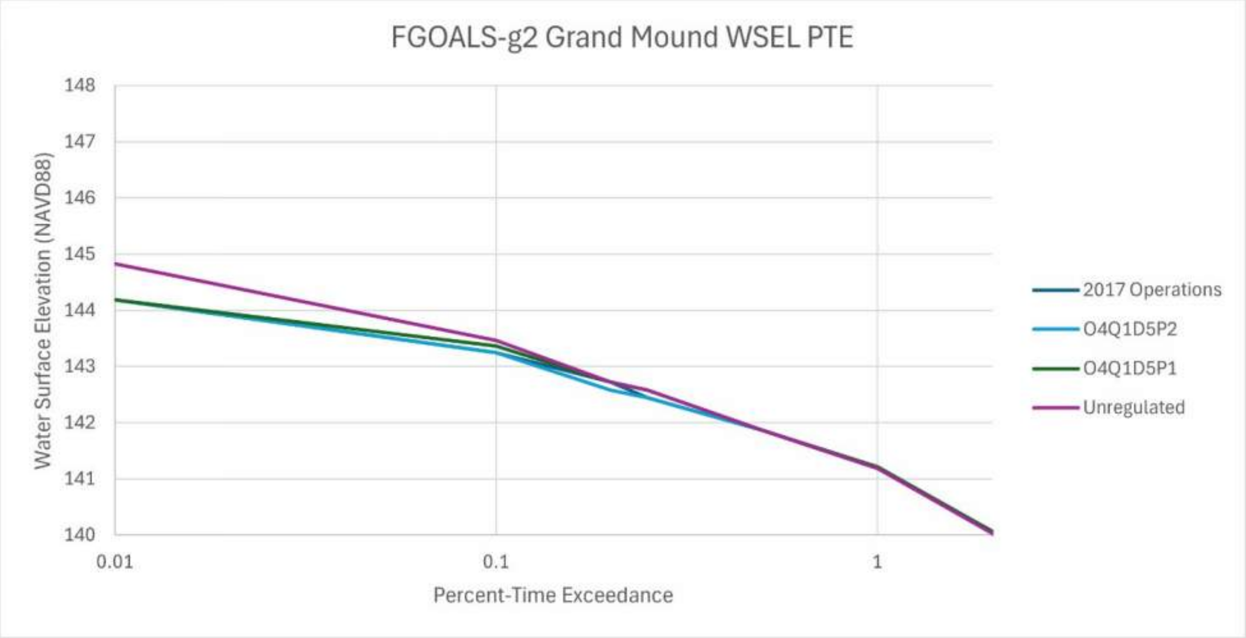


Figure 2-8. GFDL-CM3 Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet

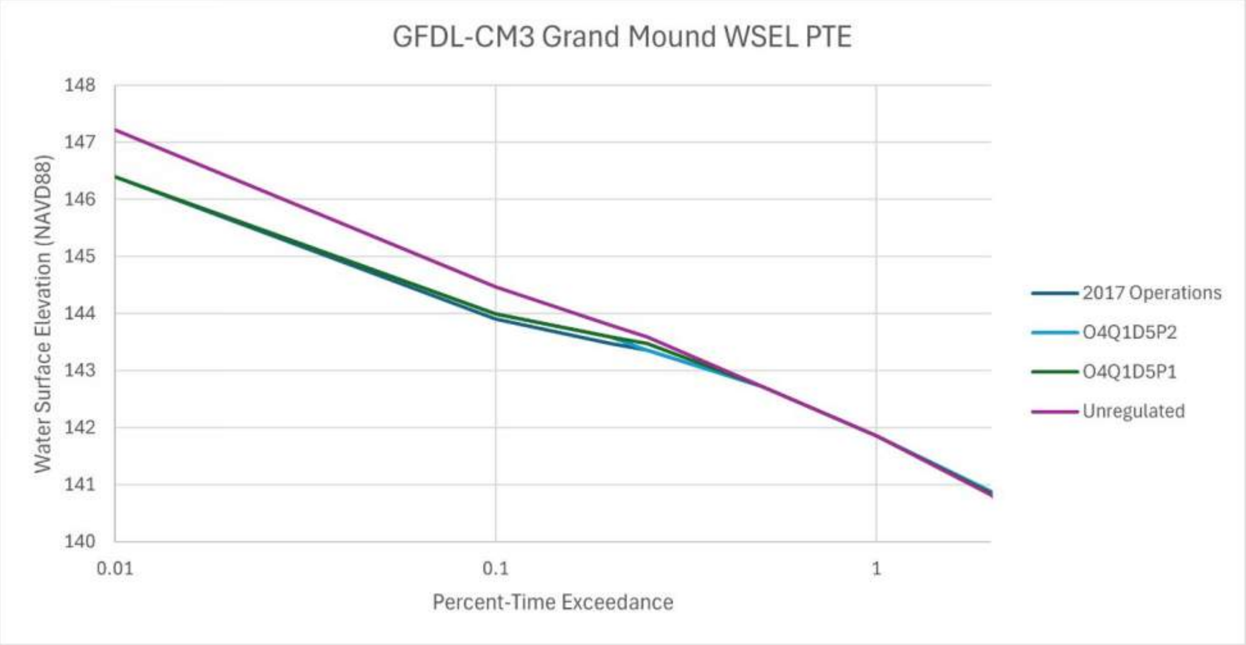
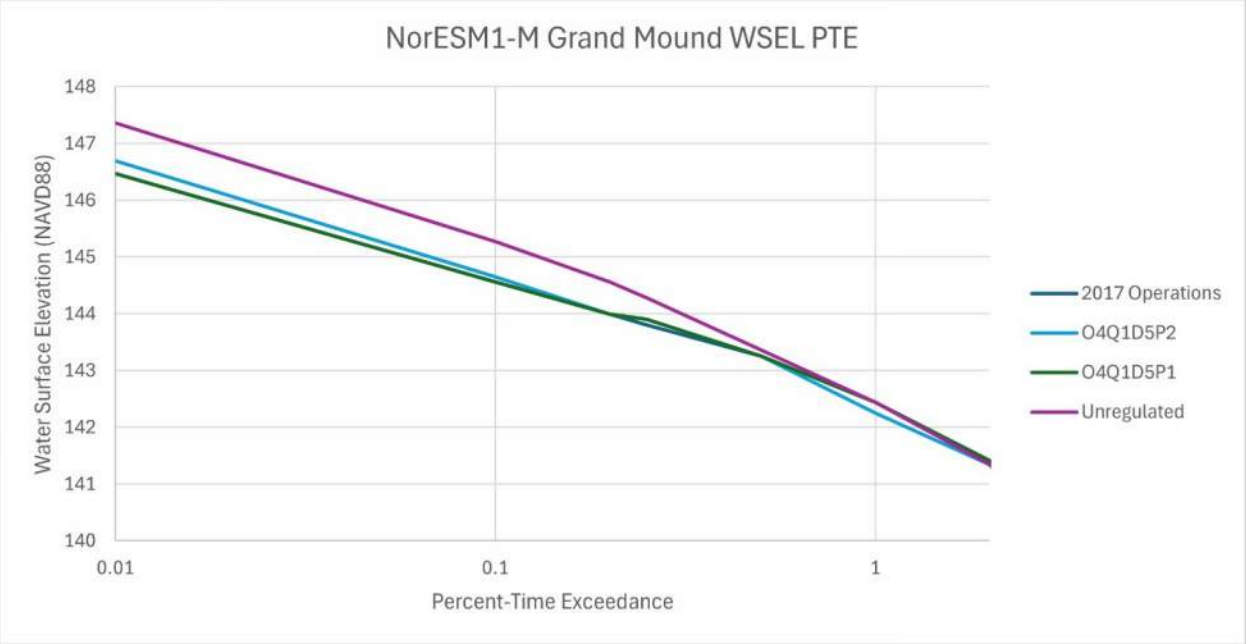


Figure 2-9. GISS-E2-H Grand Mound WSEL PTE Detailed View of WSEL 140–148 feet

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

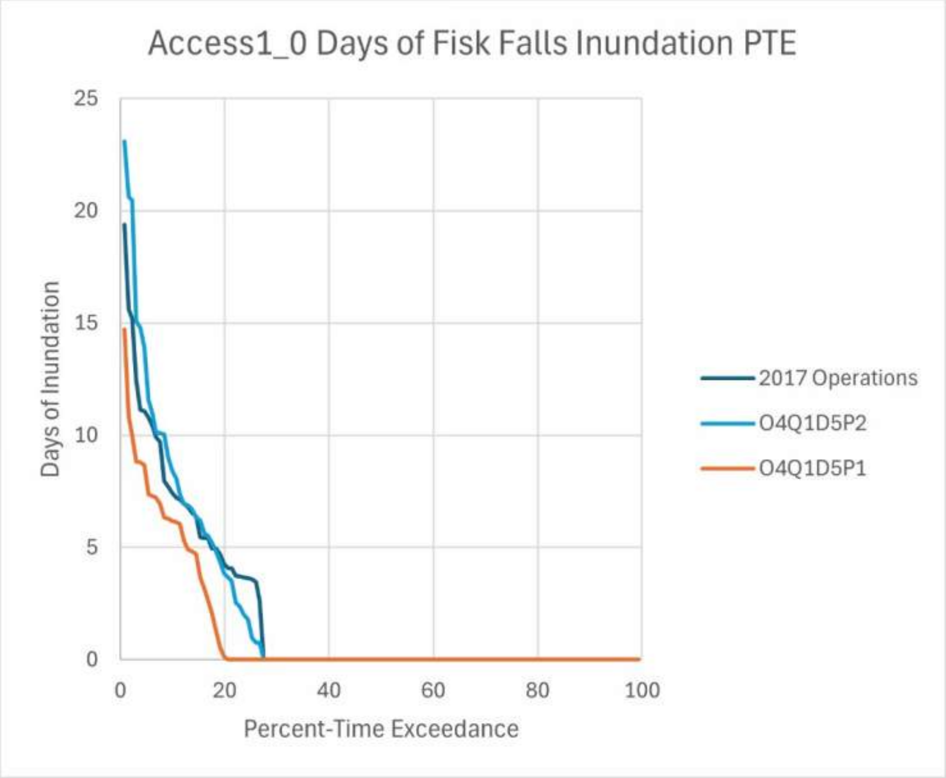


Figure 3-2. Access1_3 Days of Fisk Falls Inundation PTE

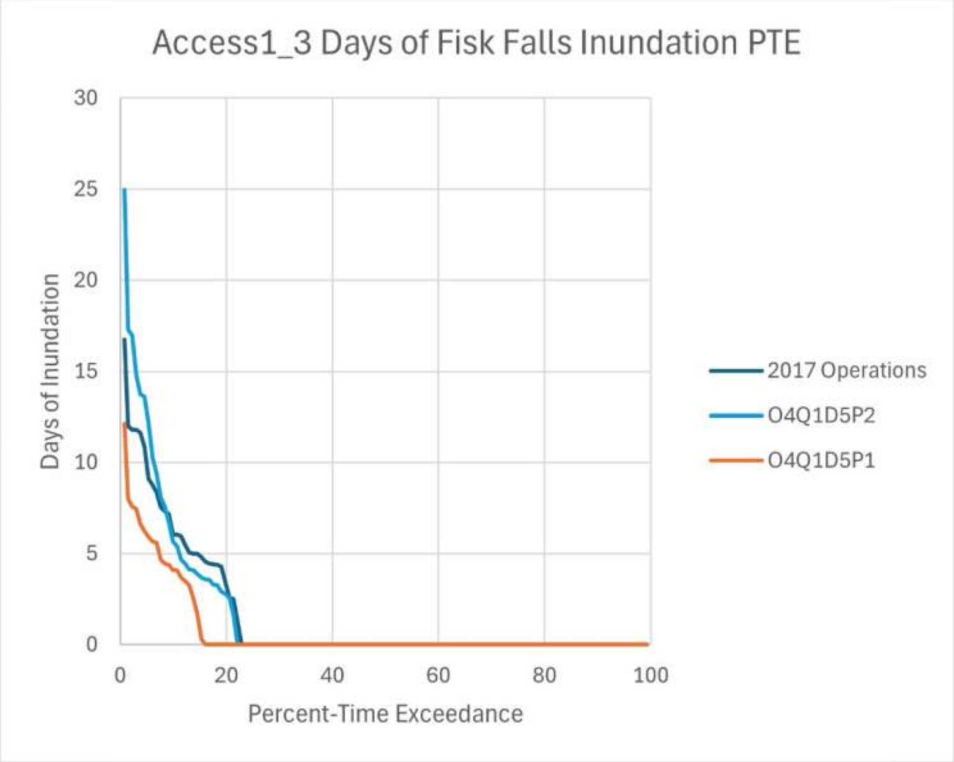


Figure 3-3. Bcc_csm1-1 Days of Fisk Falls Inundation PTE

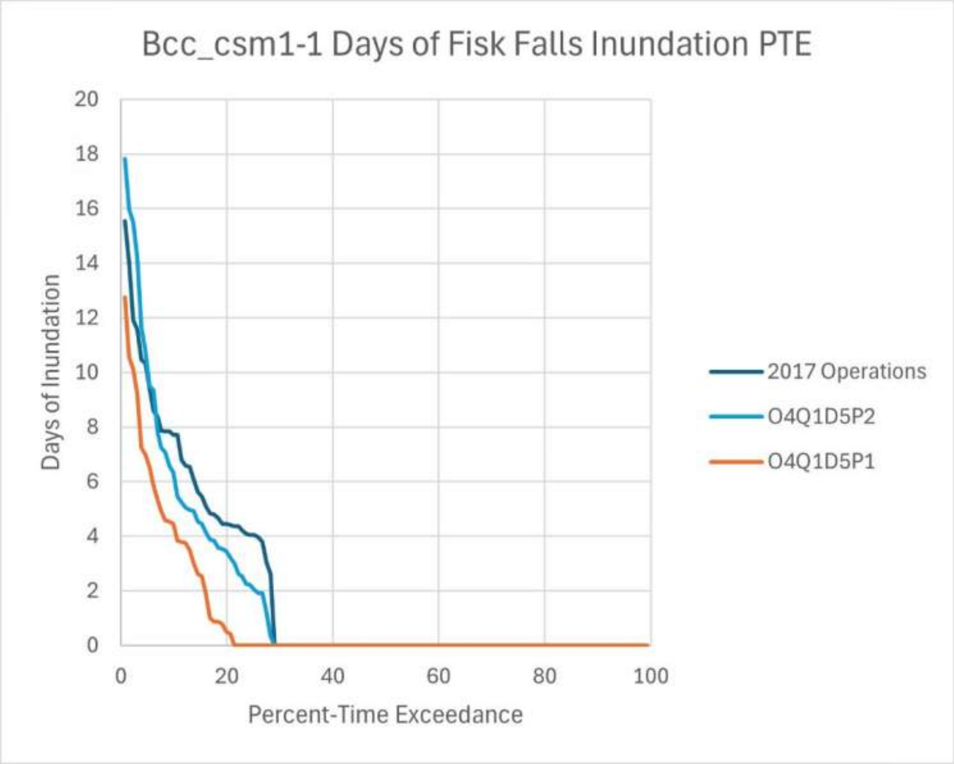


Figure 3-4. canESM2 Days of Fisk Falls Inundation PTE

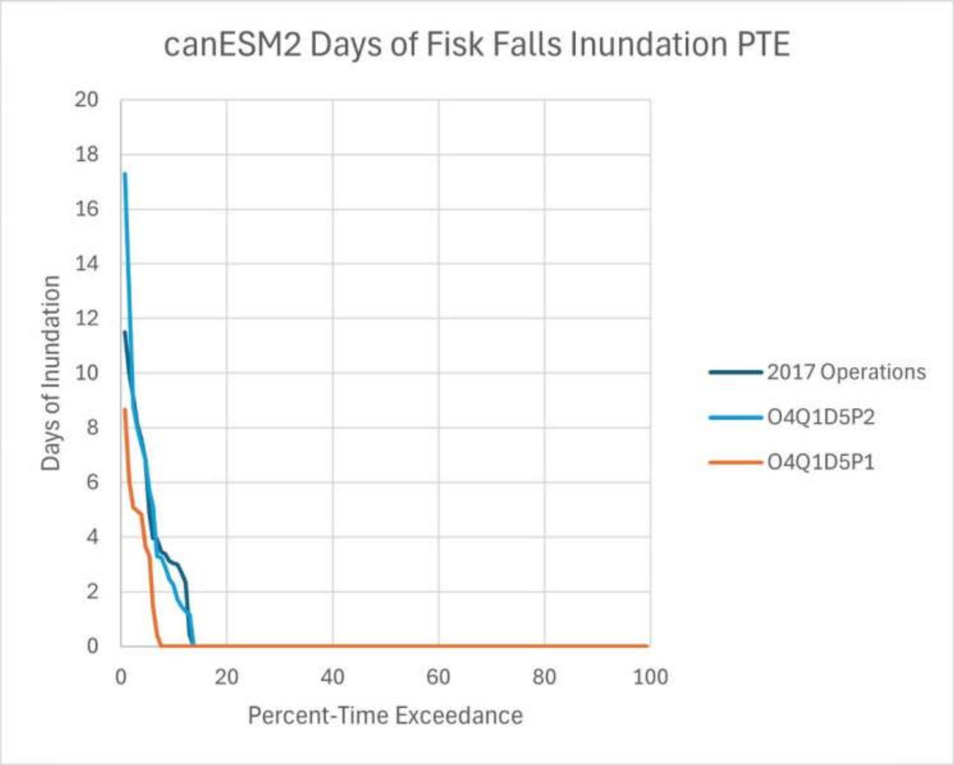


Figure 3-5. CCSM4 Days of Fisk Falls Inundation PTE

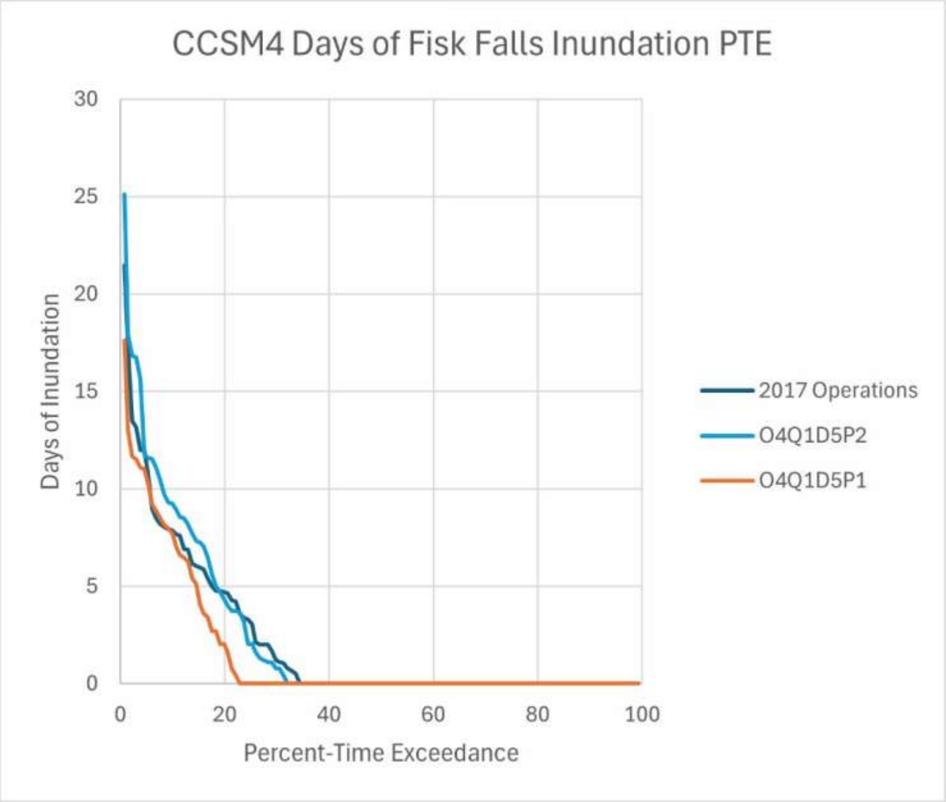


Figure 3-6. CSIRO-Mk3-6-0 Days of Fisk Falls Inundation PTE

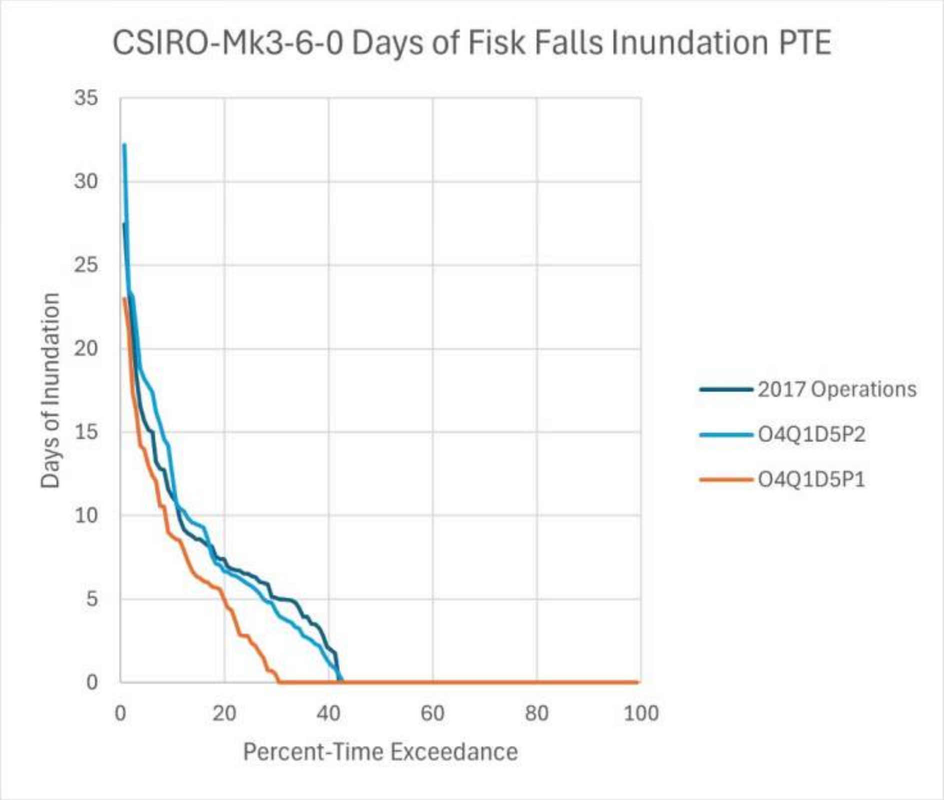


Figure 3-7. FGOALS-g2 Days of Fisk Falls Inundation PTE

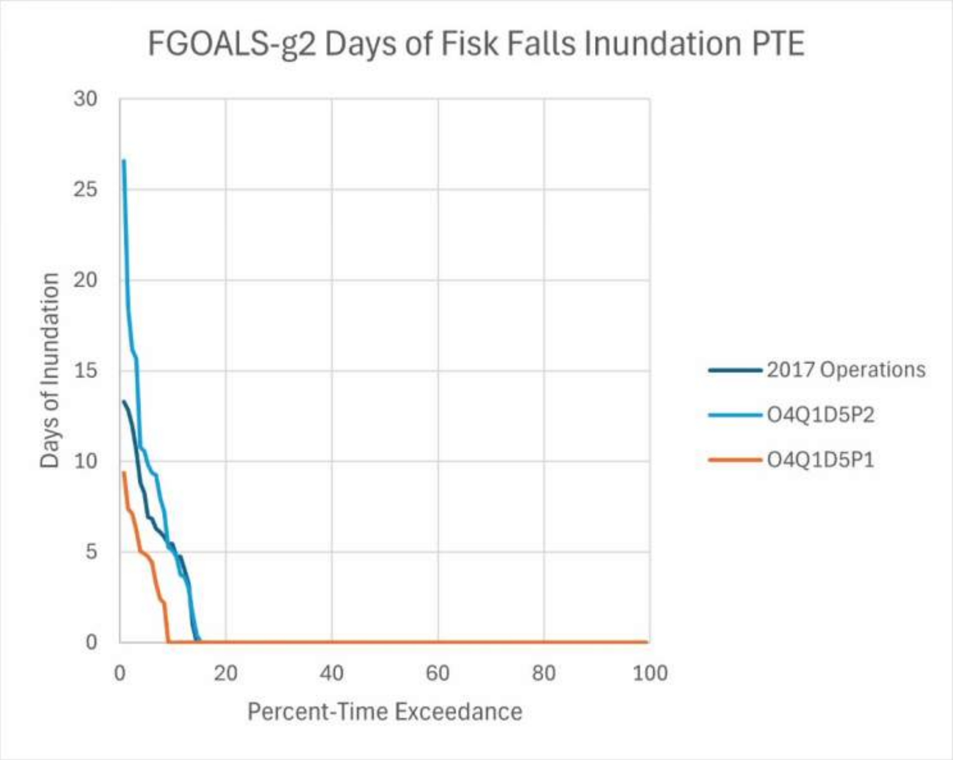


Figure 3-8. GFDL-CM3 Days of Fisk Falls Inundation PTE

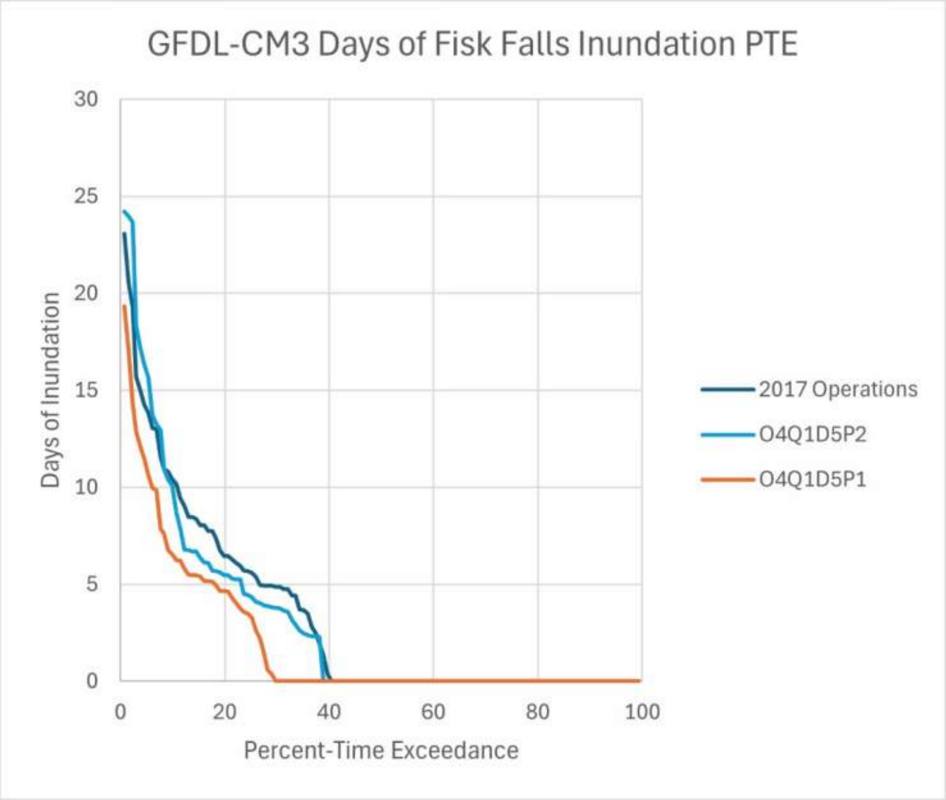


Figure 3-9. GISS-E2-H Days of Fisk Falls Inundation PTE

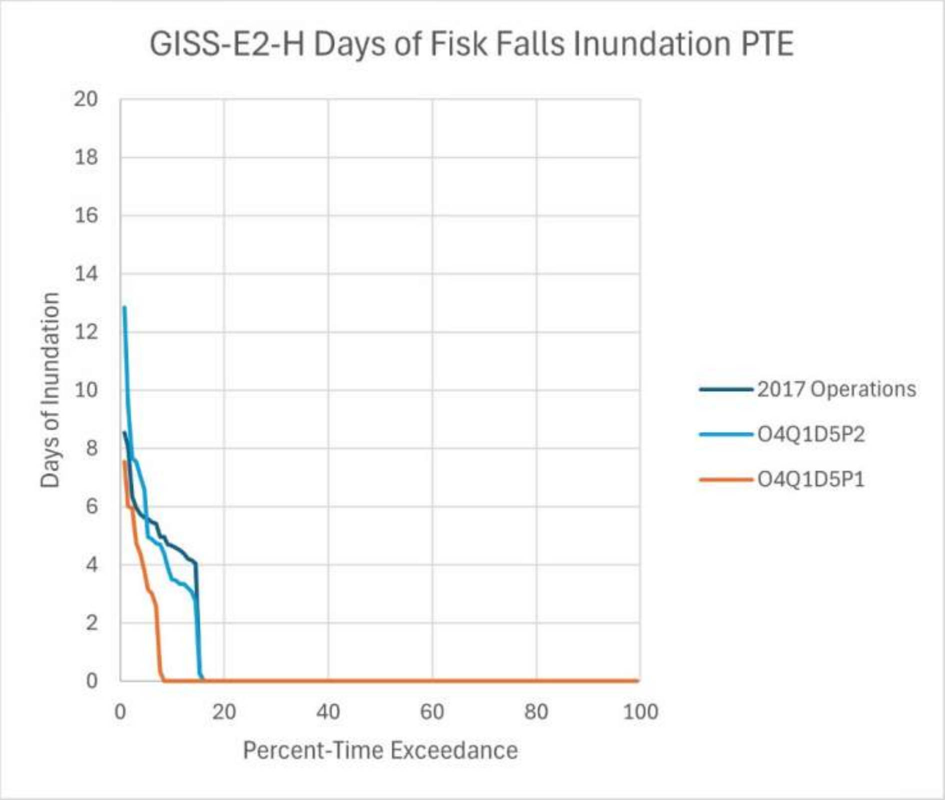


Figure 3-10. MIROC5 Days of Fisk Falls Inundation PTE

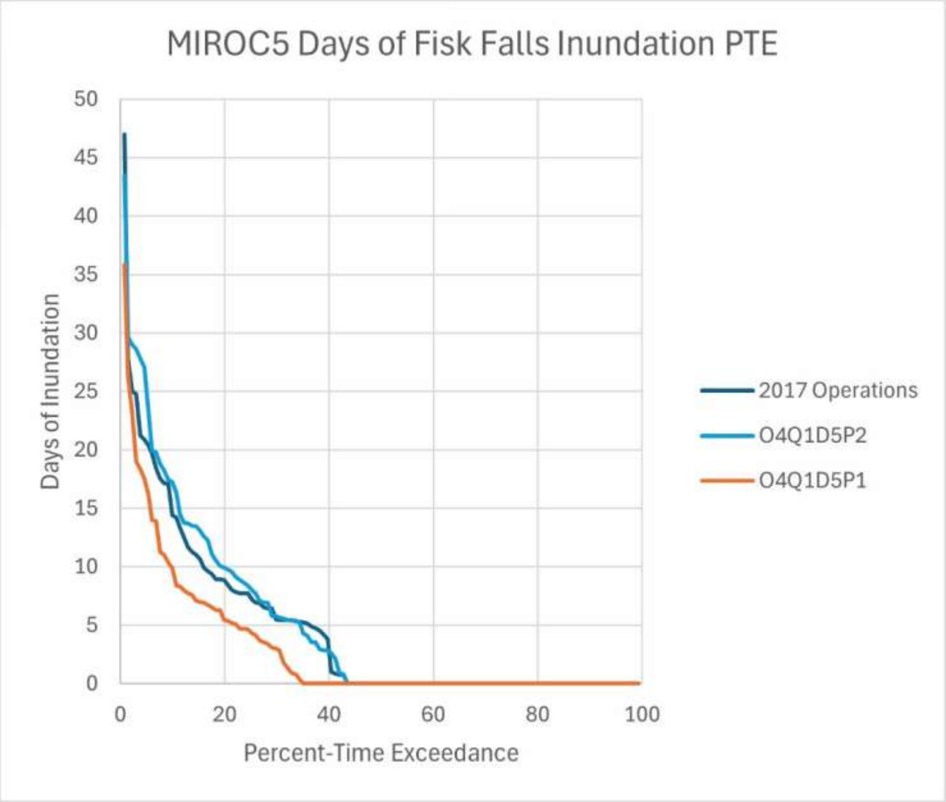


Figure 3-11. MRI-CGCM3 Days of Fisk Falls Inundation PTE

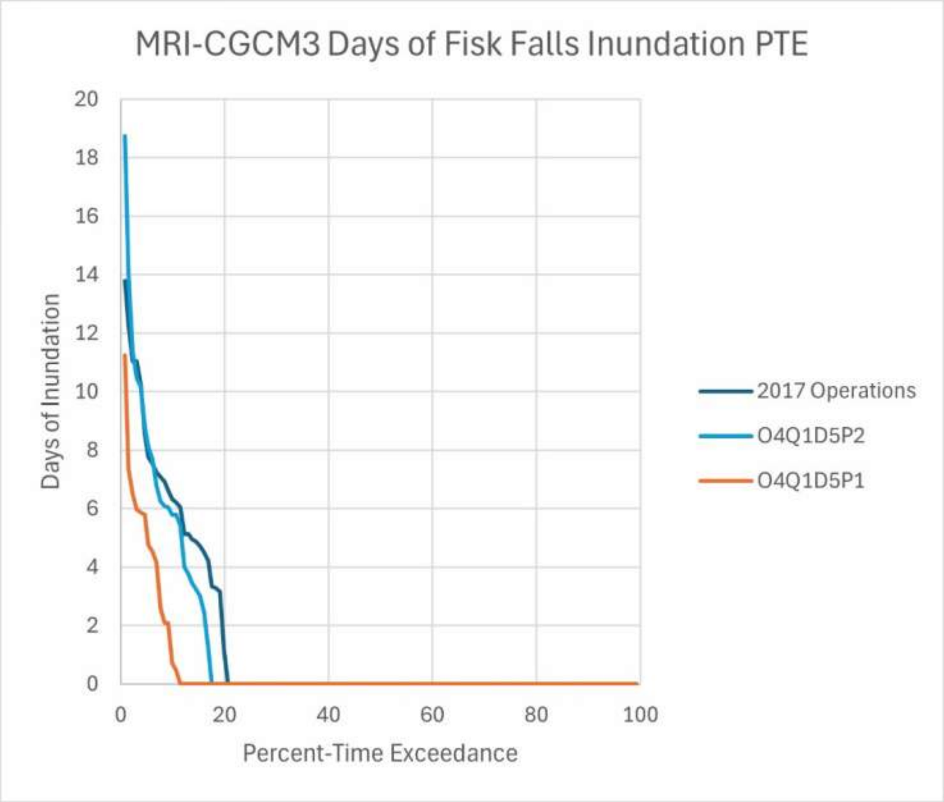
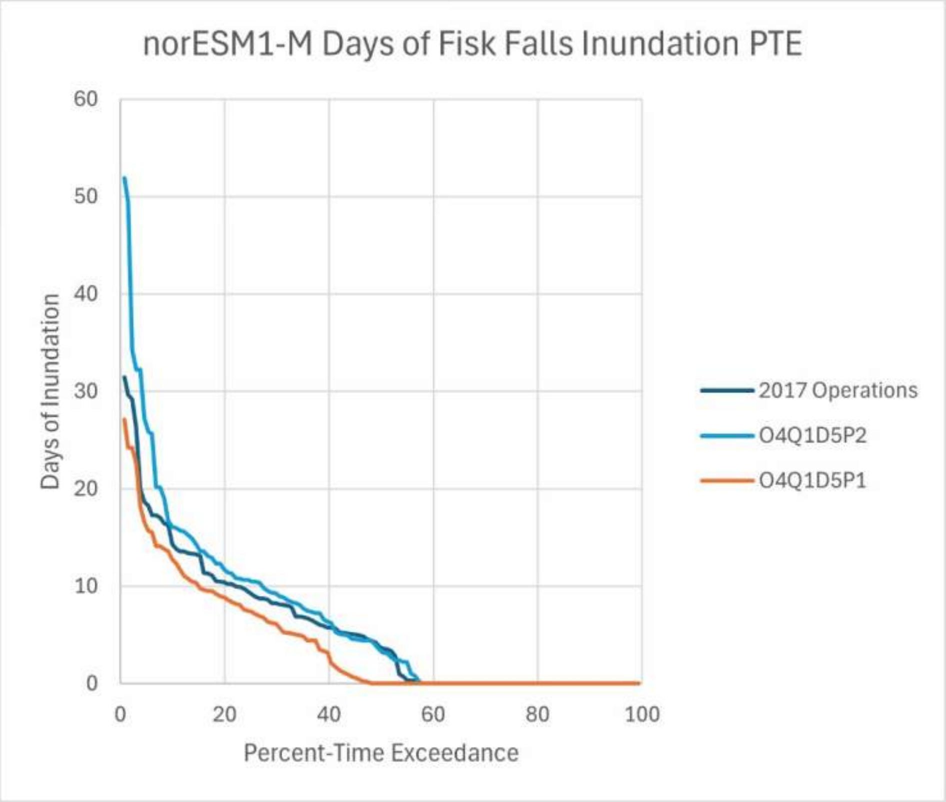


Figure 3-12. norESM1-M Days of Fisk Falls Inundation PTE



Attachment 3 – Inundation Technical Memorandum

TECHNICAL MEMORANDUM

Date: February 26, 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. Under O4P2 operations, the temporary pool starts filling as the FRE gates are necked down; the pool crests at a maximum extent which will be different for different floods; and then, after cresting, pool evacuation begins. 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).[1]

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. Both operational models set evacuation rates that vary within distinct portions of the pool resulting in three different evacuation zones. 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

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[1] 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; Ground 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.

evacuated. The extent of the 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. Redd surveys were also conducted downstream of the FRE facility in the 2017 and 2018 survey seasons for Chinook and coho salmon and in the 2018 and 2019 survey seasons for steelhead (Ronne et al. 2020), and provided more extensive data for this analysis. 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.

	ELEVATION BAND IN FEET (NAVD 88)		
RIVER ZONE	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[1]	447 – 477	425 – 500	Within Max Inundation Pool
Debris Management[1]	477 – 487	500 – 528	Within Max Inundation Pool
Initial Evacuation – 2025 Operations[1]	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

[1] 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.

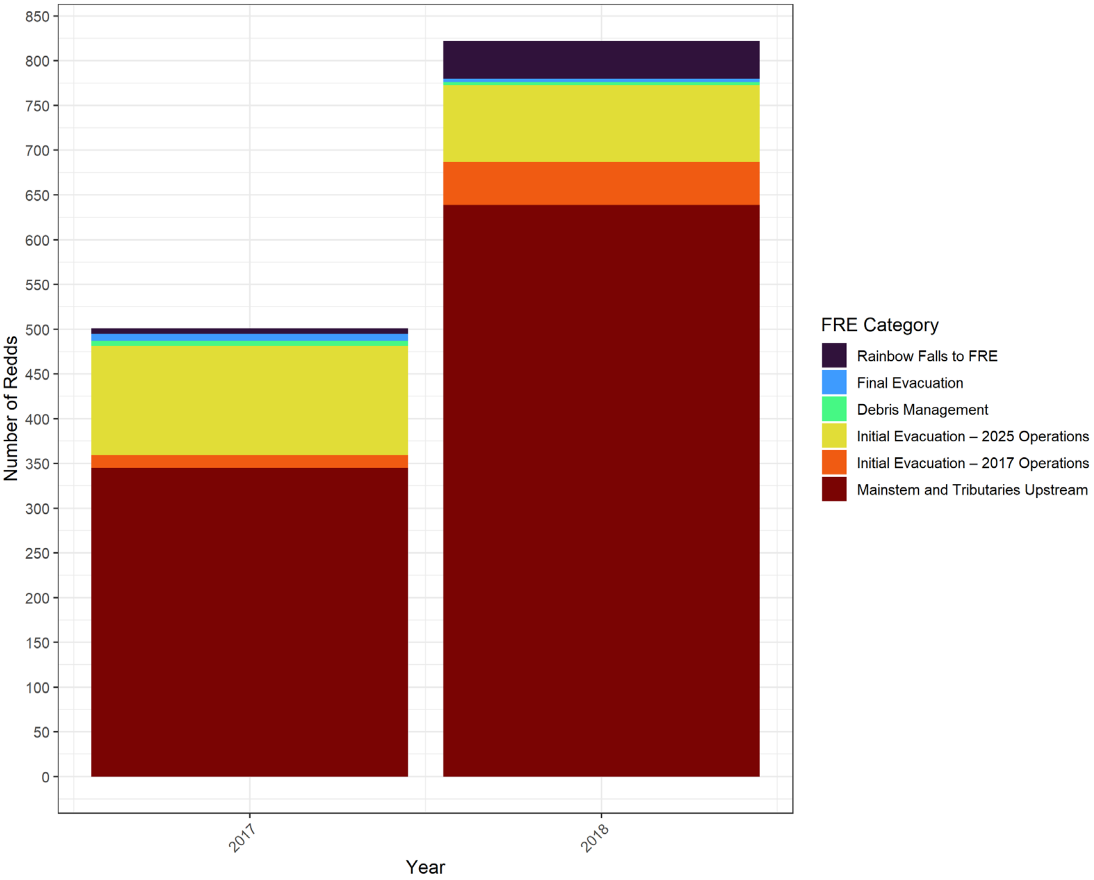
Results and Discussion

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, O4P2 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 percent.

Figure 1

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



[1] 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.

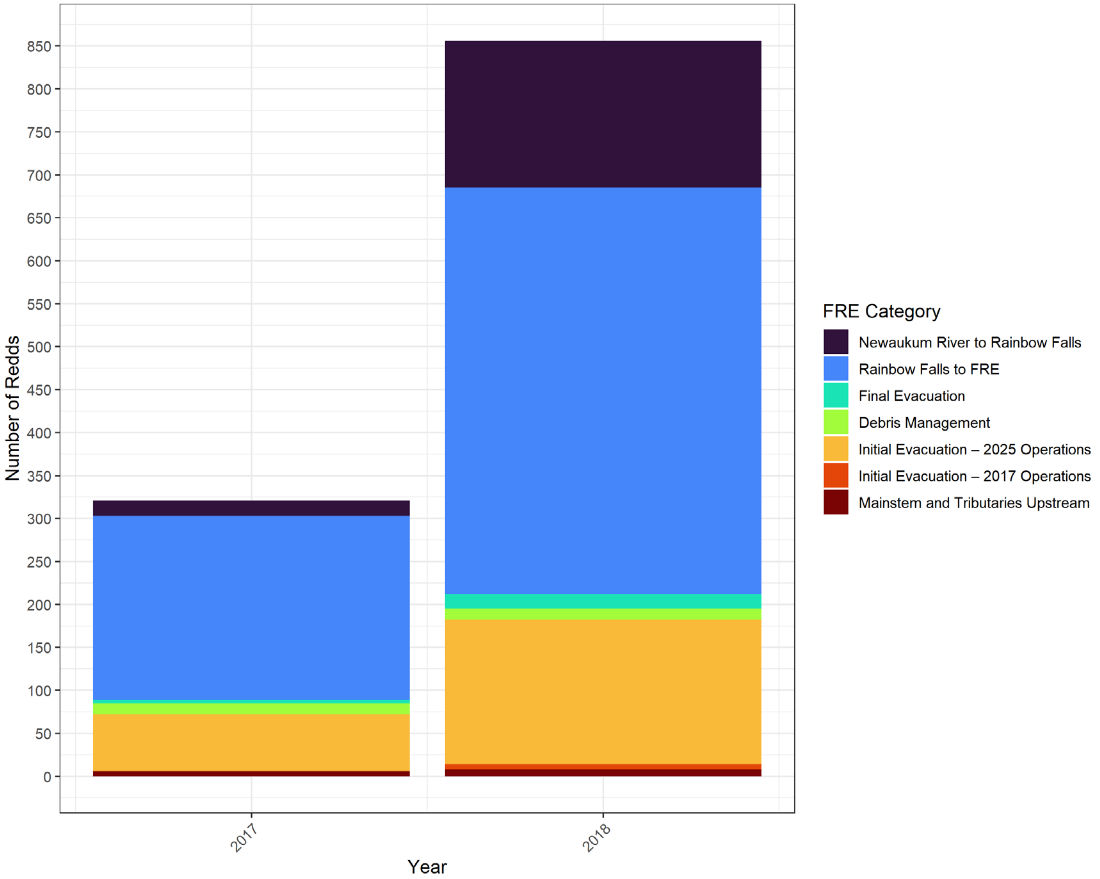


Figure 3
2017 and 2018 redd distribution for spring-run Chinook salmon in the mainstem Chehalis River upstream of the Newaukum to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.

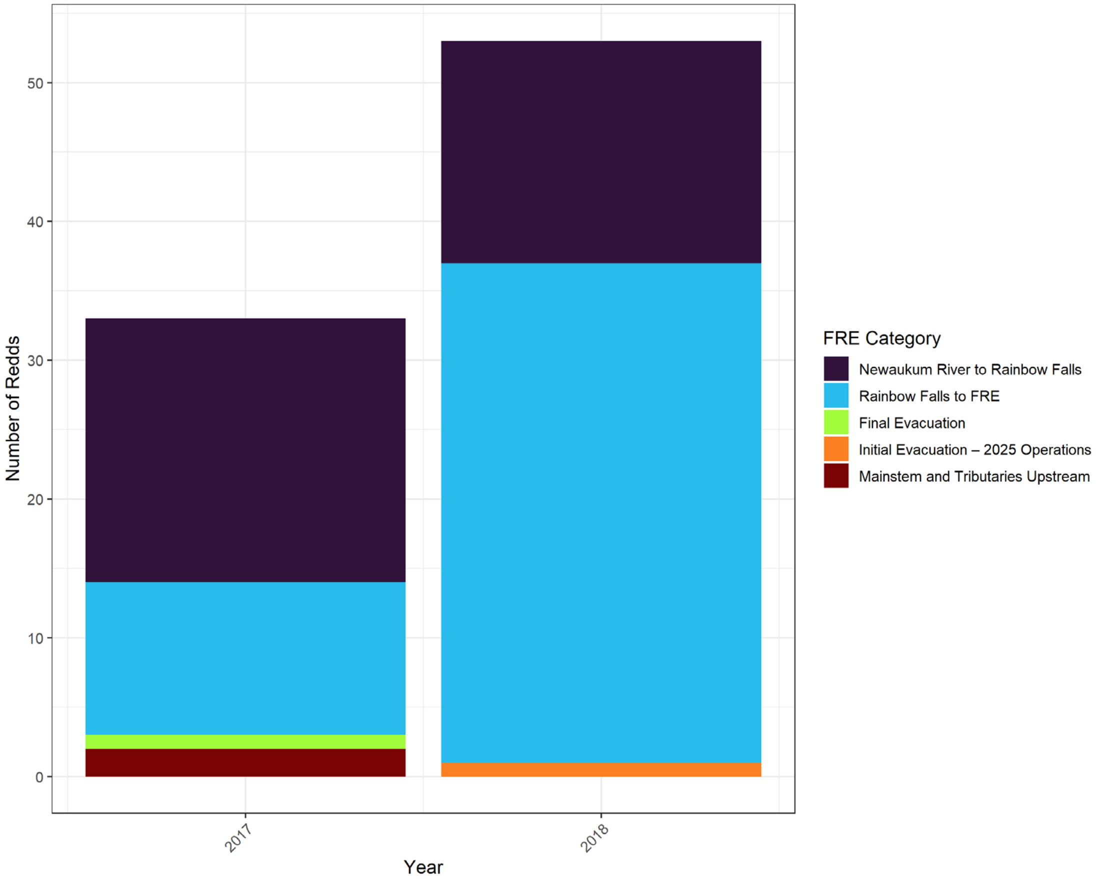


Figure 4
2018 and 2019 redd distribution for steelhead in the mainstem Chehalis River upstream of the Newaukum to the East and West forks. FRE evacuation zones reflect 2024 alignment and 2025 (O4P2) operations; 447 feet elevation is below the FRE.

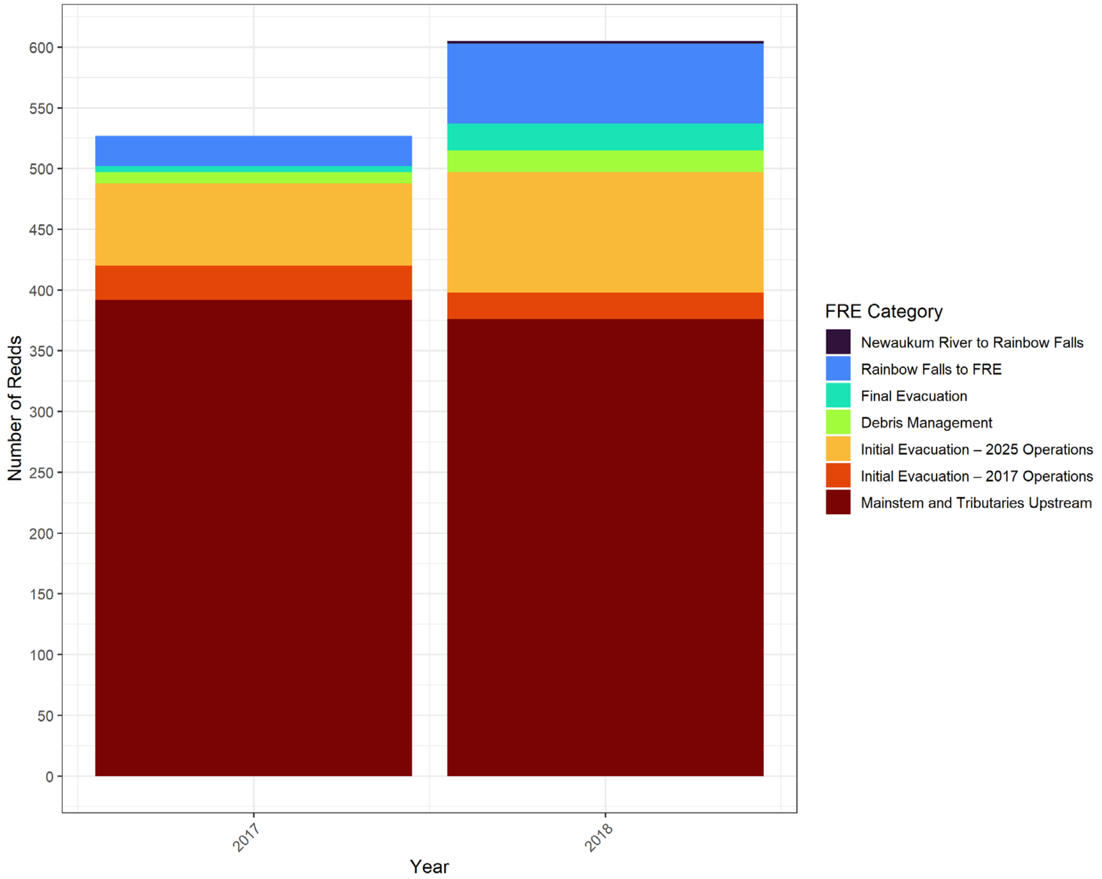


Table 3
Changes to coho salmon and steelhead redd distribution by species under 2017 operations and 2024 FRE design and 2025 (O4P2) operations.

	NUMBER OF REDDS OBSERVED IN 2018					
	COHO SALMON			STEELHEAD		
RIVER ZONE	O4P2	2017	DIFFERENCE	O4P2	2017	DIFFERENCE
Newaukum River to Rainbow Falls	0	0	0	2	2	0
Rainbow Falls to FRE	42	39	3	66	65	1
Final Evacuation[1]	4	10	-6	22	48	-26
Debris Management[1]	3	12	-9	18	37	-19
Initial Evacuation – 2025 Operations[1]	86	74	12	99	55	44
Initial Evacuation – 2017 Operations	48	48	0	22	22	0
Mainstem and Tributaries Upstream	639	639	0	376	376	0

[1] 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 2018					
	SPRING-RUN CHINOOK SALMON			FALL-RUN CHINOOK SALMON		
	O4P2	2017	DIFFERENCE	O4P2	2017	DIFFERENCE
Newaukum River to Rainbow Falls	16	16	0	171	171	0
Rainbow Falls to FRE	36	36	0	473	459	14
Final Evacuation[1]	0	0	0	17	48	-31
Debris Management[1]	0	1	-1	13	42	-29
Initial Evacuation – 2025 Operations[1]	1	0	1	168	122	46
Initial Evacuation – 2017 Operations	0	0	0	6	6	0
Mainstem and Tributaries Upstream	0	0	0	8	8	0

[1] 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 18 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.

Redd distributions by river zone were similar between 2025 (O4P2) and 2017 operations (Tables 5 and 6). Approximately 2 percent more of the fall-run Chinook redds were located downstream of the FRE facility at its new FRE location, while the difference was less than 1 percent for the other species/runs, and 24.7 percent were located upstream of the FRE facility (Table 5). For all species/runs the proportion of redds within the FRE zones that would be inundated by a catastrophic flood represents less than 25 percent of the total redd count; for spring-run Chinook salmon, it is less than 3 percent.

Table 5

Percentage of total redds observed from September 2018 – June 2019 redds by FRE zone and species under the 2025 (O4P2) operations.

RIVER ZONE	COHO SALMON (N = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
Newaukum River to Rainbow Falls	0.0%	20.0%	30.2%	0.3%
Rainbow Falls to FRE	5.1%	55.3%	67.9%	10.9%
Final Evacuation[1]	0.5%	2.0%	0.0%	3.6%
Debris Management[1]	0.4%	1.5%	0.0%	3.0%
Initial Evacuation – 2025 Operations[1]	10.5%	19.6%	1.9%	16.4%
Initial Evacuation – 2017 Operations	5.8%	0.7%	0.0%	3.6%
Mainstem and Tributaries Upstream	77.7%	0.9%	0.0%	62.1%

Table 6

Percentage of total redds observed from September 2018 – June 2019 by FRE zone and species under the 2017 operations.

RIVER ZONE	COHO SALMON (N = 822)	FALL-RUN CHINOOK SALMON (N = 855)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
Newaukum River to Rainbow Falls	0.0%	20.0%	30.2%	0.3%
Rainbow Falls to FRE	4.7%	53.6%	67.9%	10.7%
Final Evacuation[1]	1.2%	5.6%	0.0%	7.9%
Debris Management[1]	1.5%	4.9%	1.9%	6.1%
Initial Evacuation – 2025 Operations[1]	9.0%	14.3%	0.0%	9.1%
Initial Evacuation – 2017 Operations	5.8%	0.7%	0.0%	3.6%
Mainstem and Tributaries Upstream	77.7%	0.9%	0.0%	62.1%

[1] 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 Zone (Tables 7 and 8). The variation in coho salmon and fall-run Chinook salmon redd mortality decreased from 2017 to O4P2 operations, and there were small reductions in the percentage of redds that would be impacted by zone. For steelhead, an overall decrease in redd mortality was evident for all zones combined; however, the changes shift in zone boundaries resulted in zone specific changes in redd viability with more mortality occurring upstream in the Initial Evacuation Zone and less in the Final Evacuation Zone.

Table 7

Estimated impacts to observed redds from September 2018 – June 2019 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 for that run or species.

RIVER ZONE	COHO SALMON (N = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
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[1]	0.5-0.5%	2.0-2.0%	0.0-0.0%	3.6-3.6%
Debris Management[1]	0.4-0.4%	1.5-1.5%	0.0-0.0%	3.0-3.0%
Initial Evacuation – 2025 Operations[1]	0.0-2.2%	0.0-7.0%	0.0-1.9%	0.0-9.8%
Initial Evacuation – 2017 Operations	No Risk	No Risk	No Risk	No Risk
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

[1] 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 observed redds from September 2018 – June 2019 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 for that run or species.

RIVER ZONE	COHO SALMON (N = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
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[1]	0.9-0.9%	4.0-4.0%	0.0-0.0%	7.8-7.8%
Debris Management[1]	0.0-1.5%	0.1-4.9%	0.0-1.9%	0.2-6.1%
Initial Evacuation – 2025 Operations[1]	0.0-2.4%	0.0-7.6%	0.0-0.0%	0.0-5.6%
Initial Evacuation – 2017 Operations	No Risk	No Risk	No Risk	No Risk
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

[1] 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 16.5 percent 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 10.5 percent (Table 9). The percentage of nonviable redds would also be reduced from 4.8 percent to 3.1 percent for coho salmon and from 19.5 percent to 16.4 percent for steelhead (Table 9).

The risk of egg mortality would be expected to vary across years with different redd distributions upstream of the FRE facility and across levels of flooding that trigger FRE operation. As an example, the percentage of nonviable redds using 2018 steelhead distribution would have been less at 11.2 percent. Furthermore, 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 percent.

Table 9
Catastrophic flood event (e.g., 1996) impacts to observed redds from September 2018 – June 2019 redds under 2025 (O4P2) operations. Percentages represent percent of total observed redds.

RIVER ZONE	COHO SALMON (N = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
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[1]	0.5%	2.0%	0.0%	3.6%
Debris Management[1]	0.4%	1.5%	0.0%	3.0%
Initial Evacuation – 2025 Operations[1]	2.2%	7.0%	1.9%	9.8%
Initial Evacuation – 2017 Operations	No Risk	No Risk	No Risk	No Risk
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

[1] 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[2]

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 4.6 percent of fall-run Chinook salmon, 0.9 percent of coho salmon, and 8.0 percent 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 8.9 percent of fall-run Chinook salmon redds, 2.4 percent of coho salmon redds, 1.9 percent of spring-run Chinook salmon redds, and 7.1 percent 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.

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[2] 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.

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 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 = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
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[1]	0.5%	2.0%	0.0%	4.3%
Debris Management[1]	0.4%	1.5%	0.0%	1.8%
Initial Evacuation – 2025 Operations[1]	0.0%	1.1%	0.0%	2.6%
Initial Evacuation – 2017 Operations	No Risk	No Risk	No Risk	No Risk
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

[1] 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 = 822)	FALL-RUN CHINOOK SALMON (N = 856)	SPRING-RUN CHINOOK SALMON (N = 53)	STEELHEAD (N = 605)
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[1]	0.5%	2.0%	0.0%	4.3%
Debris Management[1]	0.4%	1.5%	0.0%	1.8%
Initial Evacuation – 2025 Operations[1]	1.5%	5.4%	1.9%	7.1%
Initial Evacuation – 2017 Operations	No Risk	No Risk	No Risk	No Risk
Mainstem and Tributaries Upstream	No Risk	No Risk	No Risk	No Risk

[1] 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[1]	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

[1] 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 percent) and about 1.0 RM in a major flood (about 64 percent). 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.

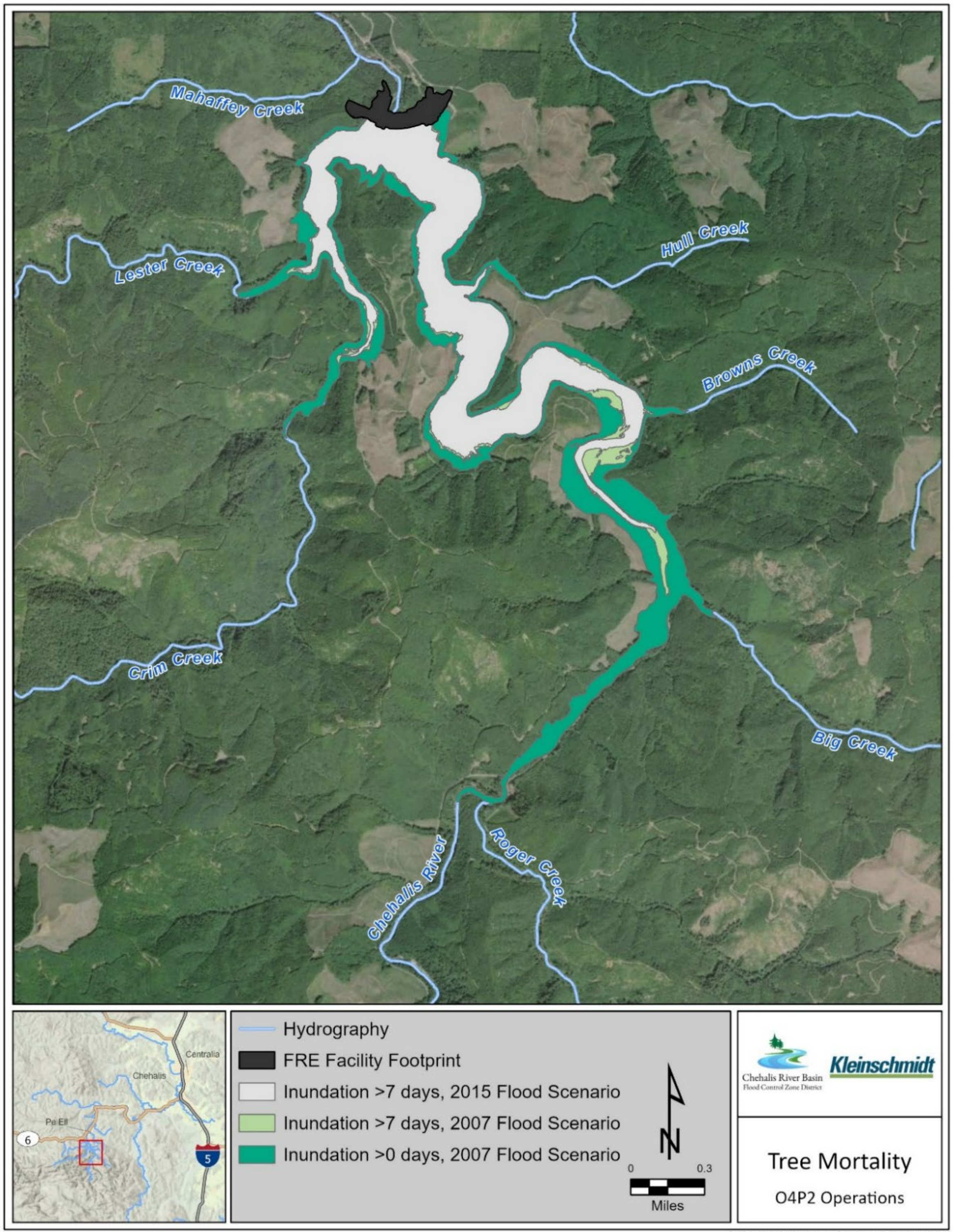


Figure 6
Distribution of 2018 coho salmon redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.

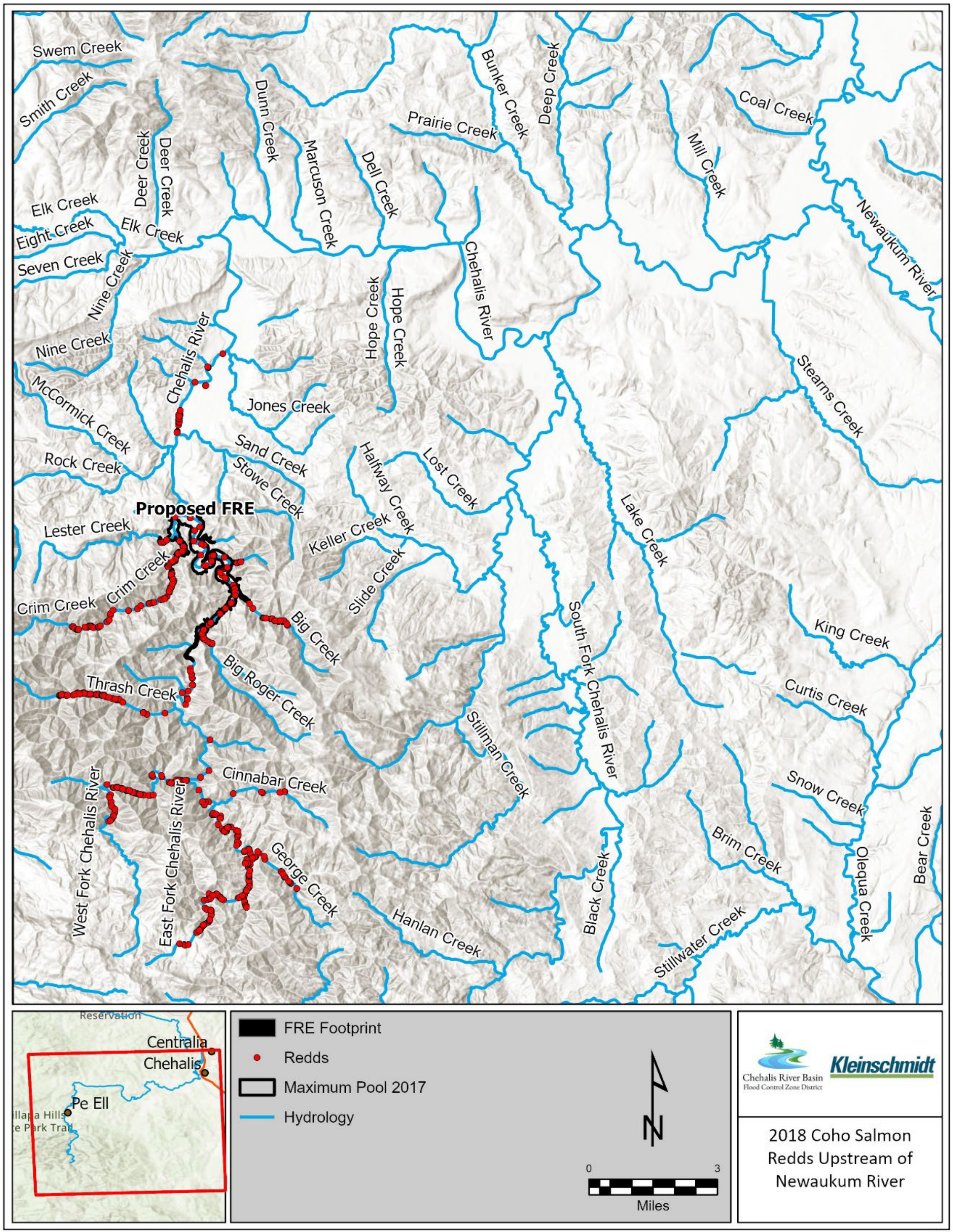


Figure 7
2018 coho salmon redd distribution upstream and immediately downstream of the FRE facility location.

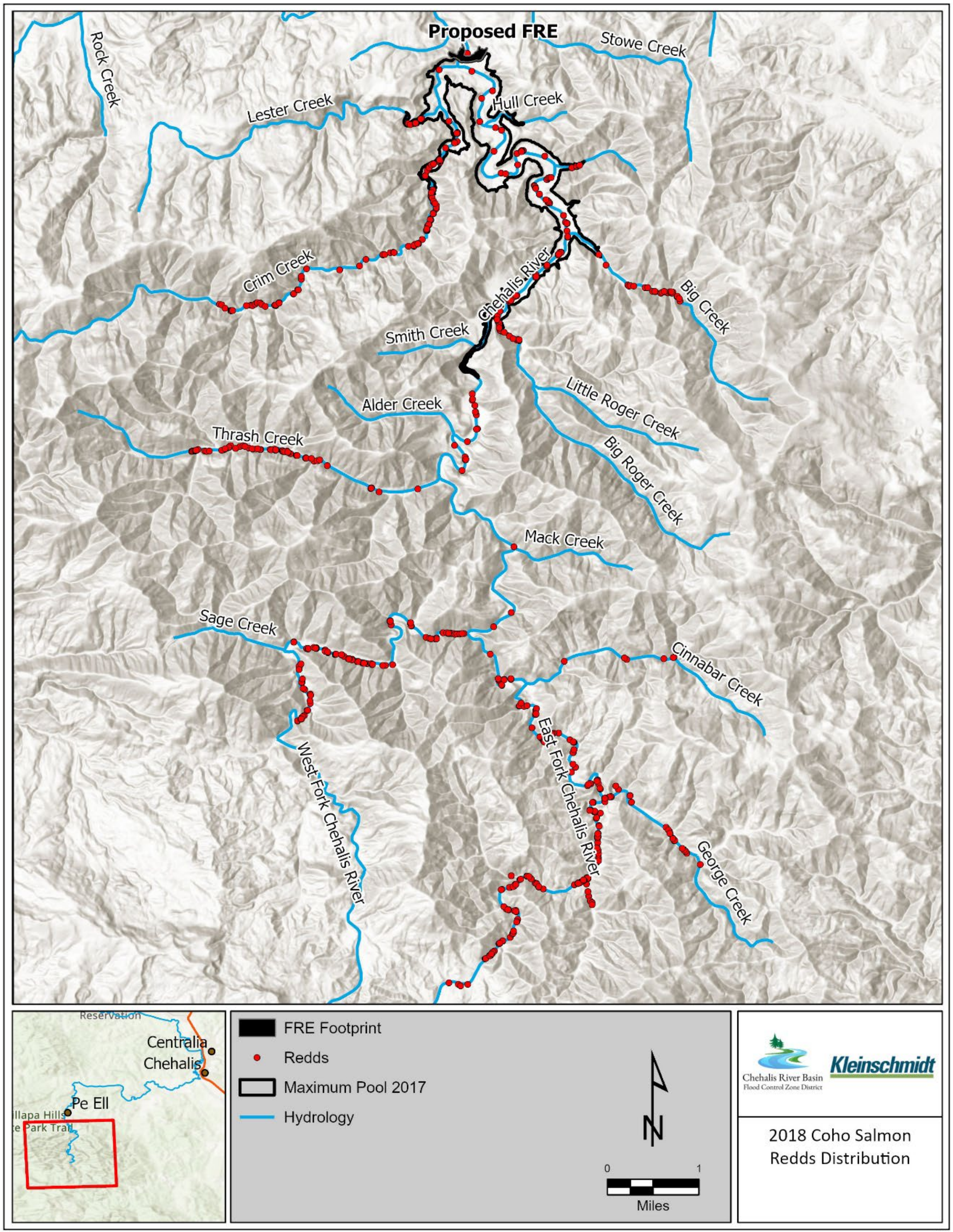


Figure 8
2018 coho salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.

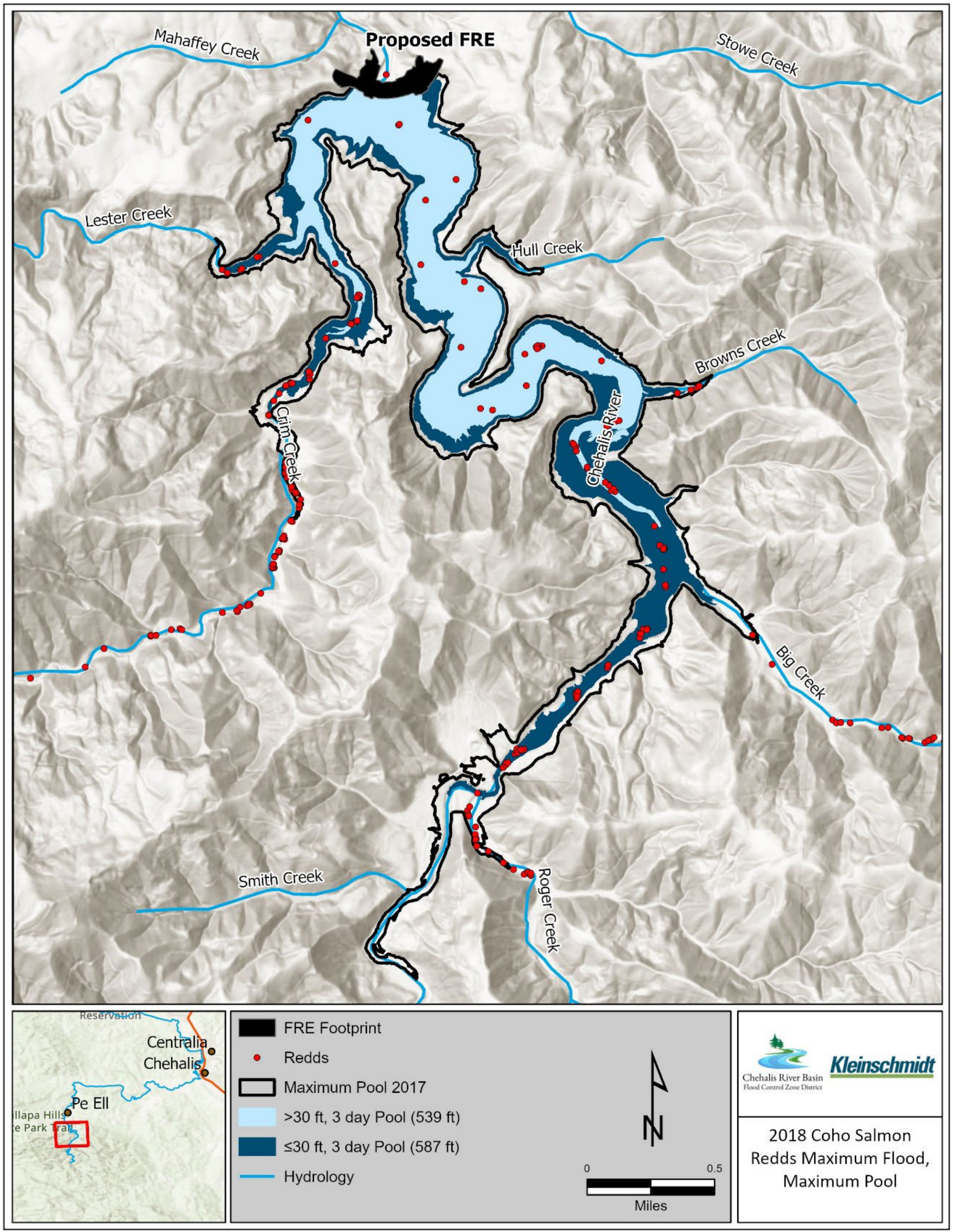


Figure 9
2018 coho salmon redds across portions of the temporary less than or greater than 30 feet deep for 3 days with a median flood event.

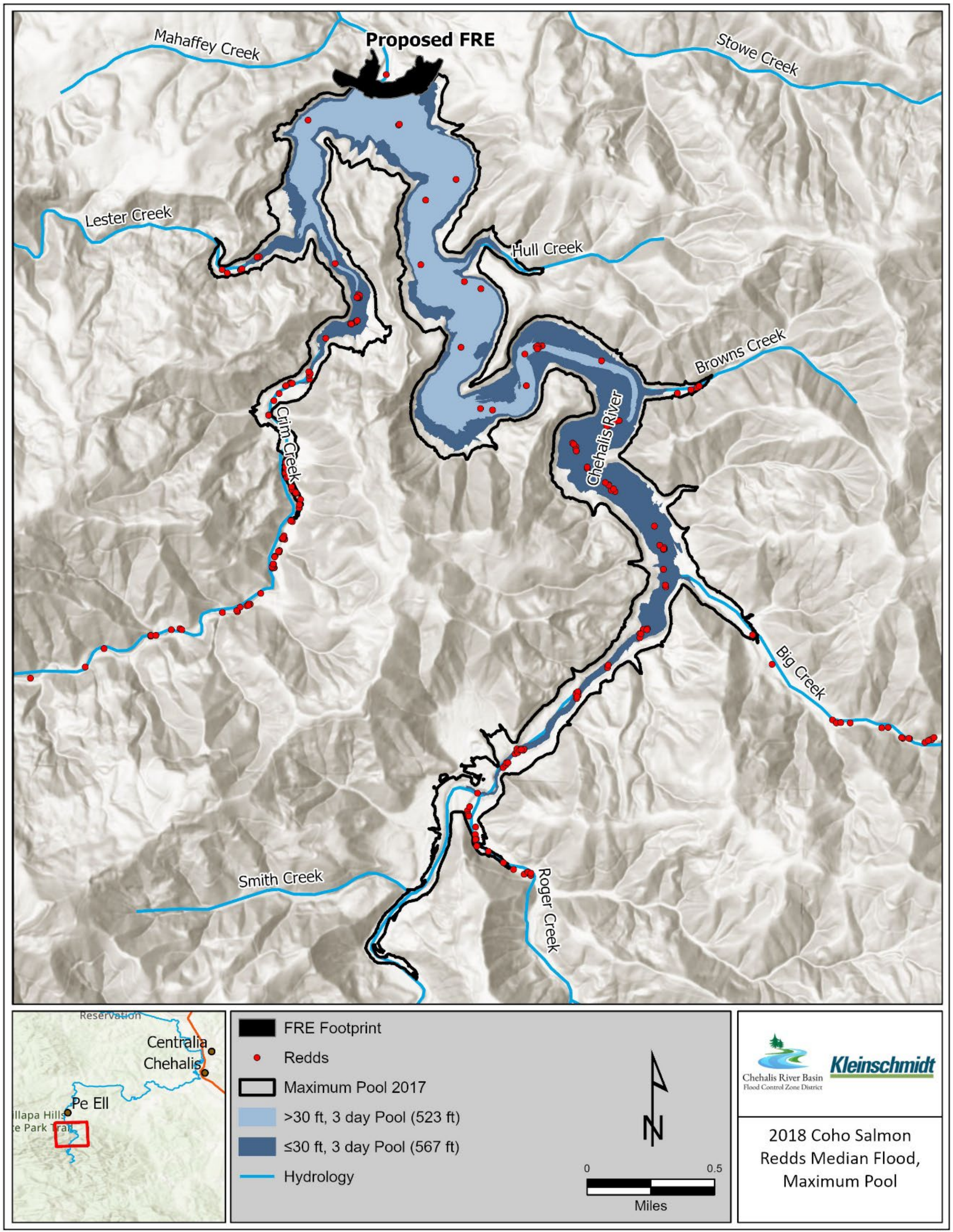


Figure 10
2018 coho salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.

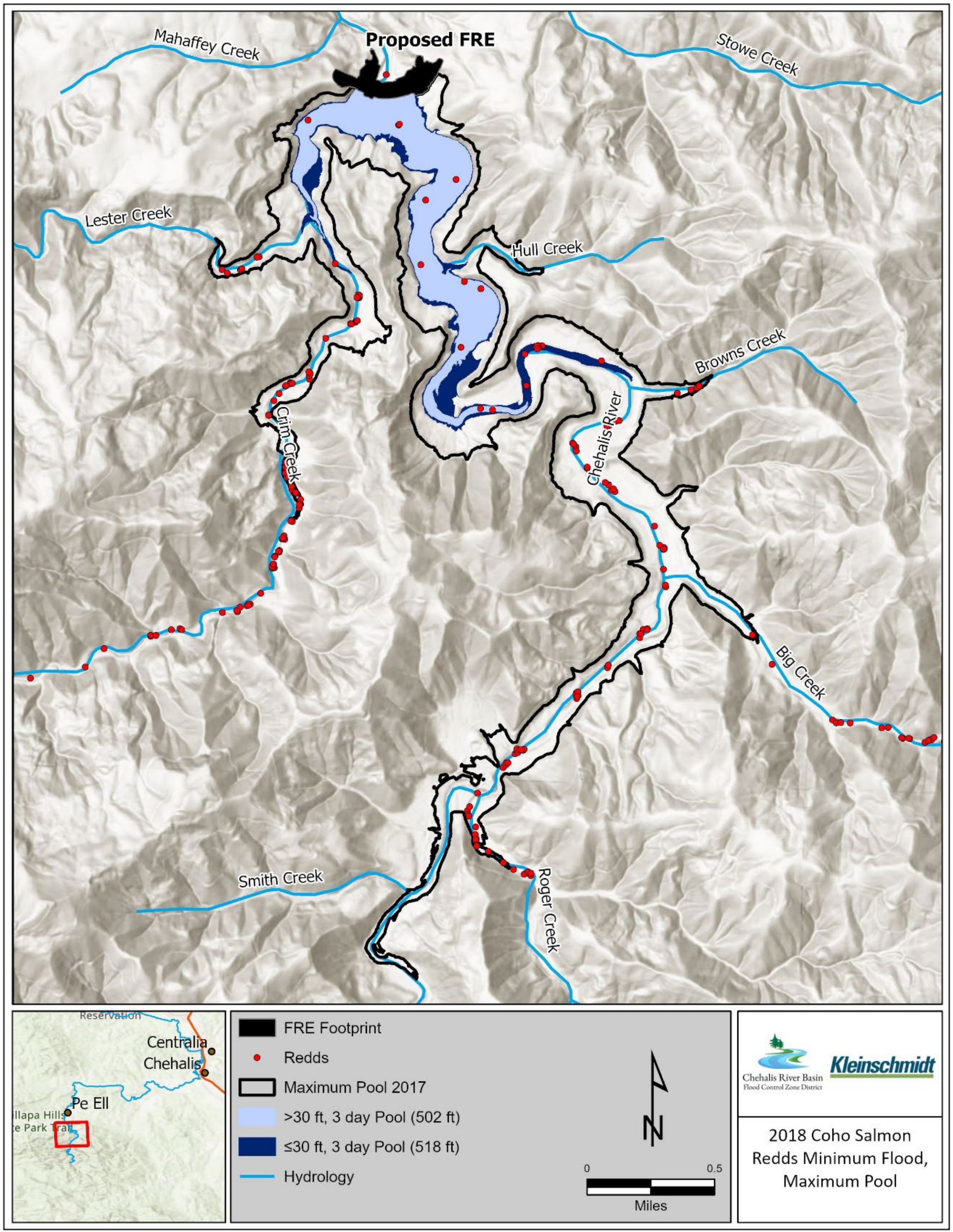


Figure 11

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.

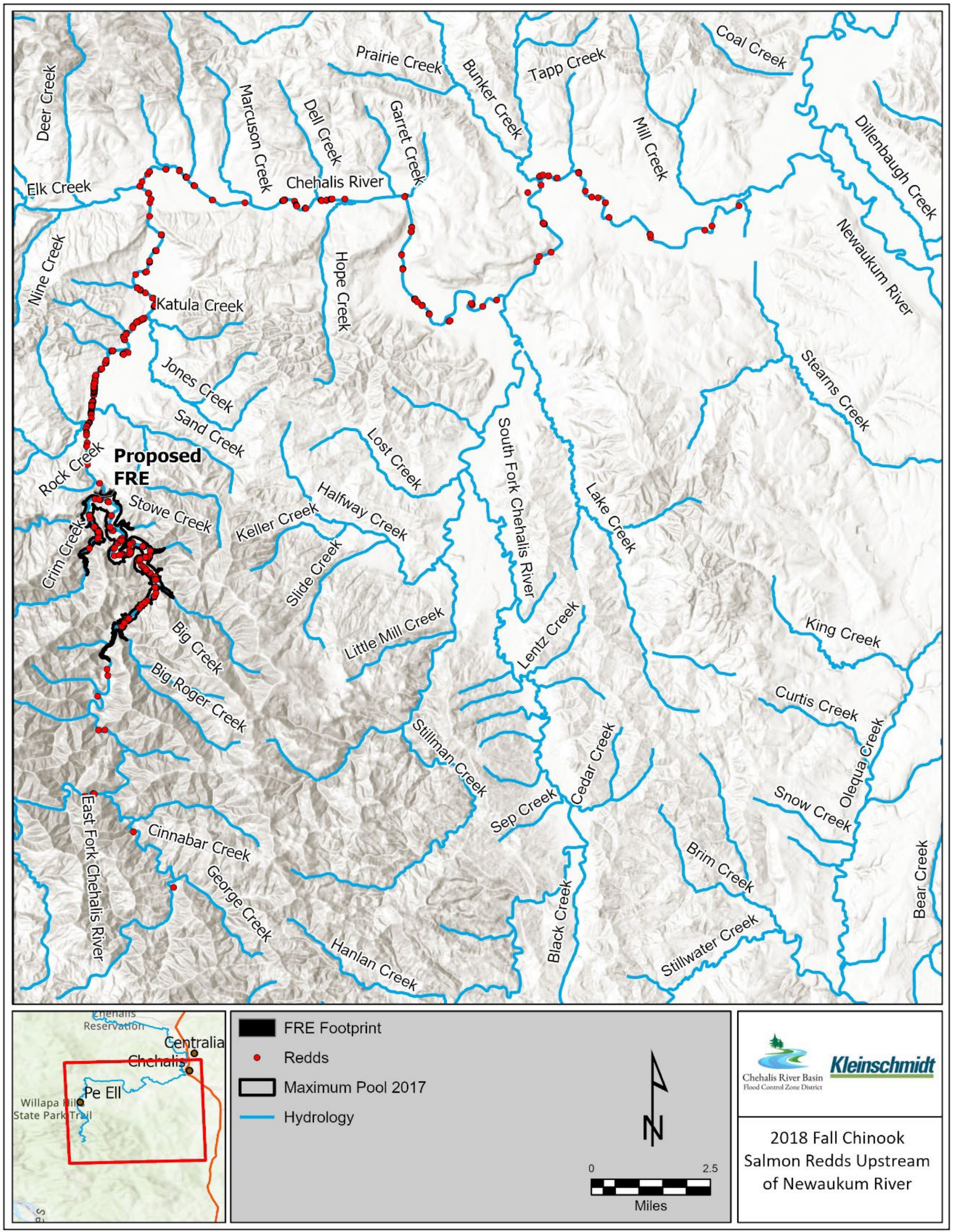


Figure 12
2018 fall-run Chinook salmon redd distribution upstream and immediately downstream of the FRE facility location.

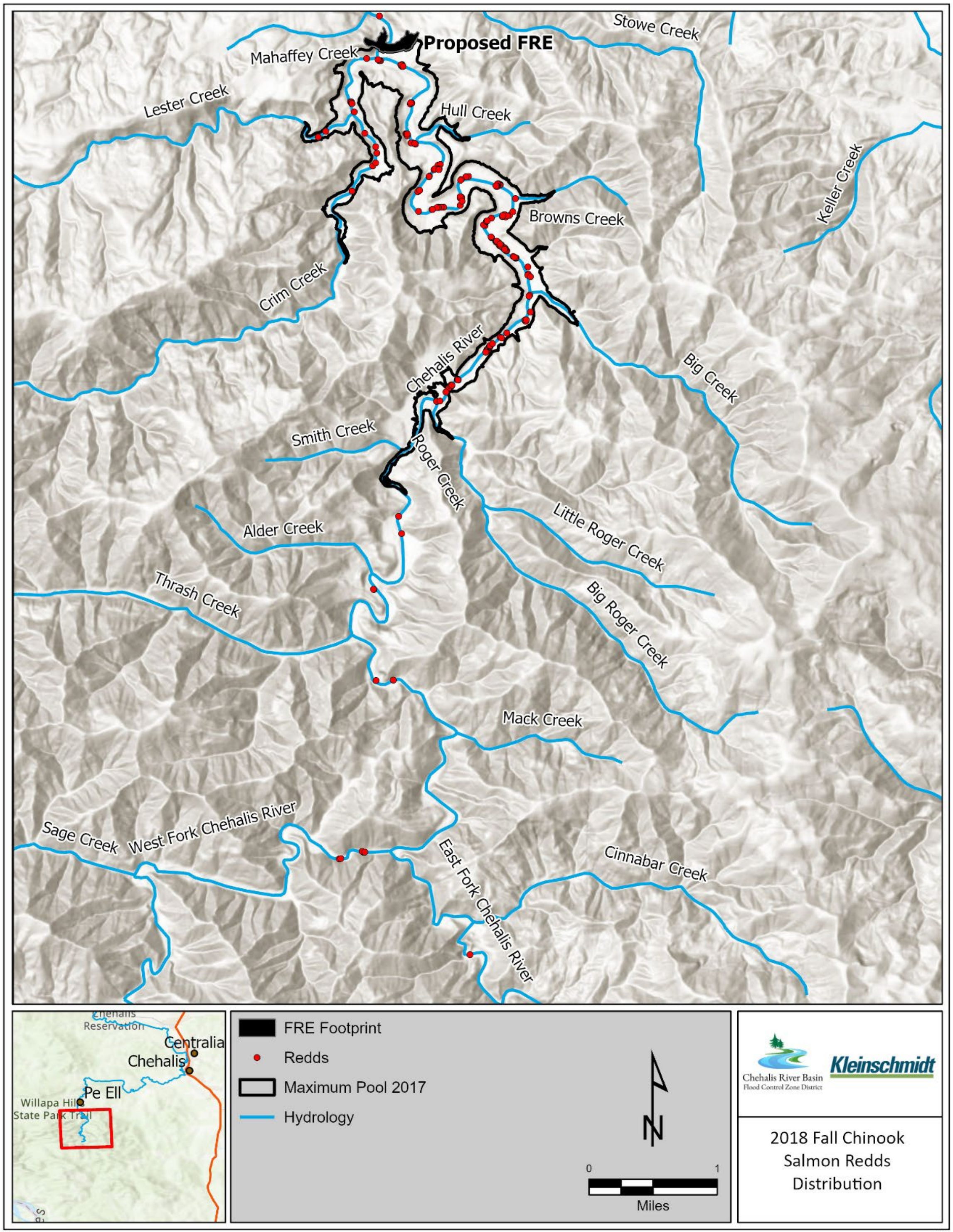


Figure 13
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.

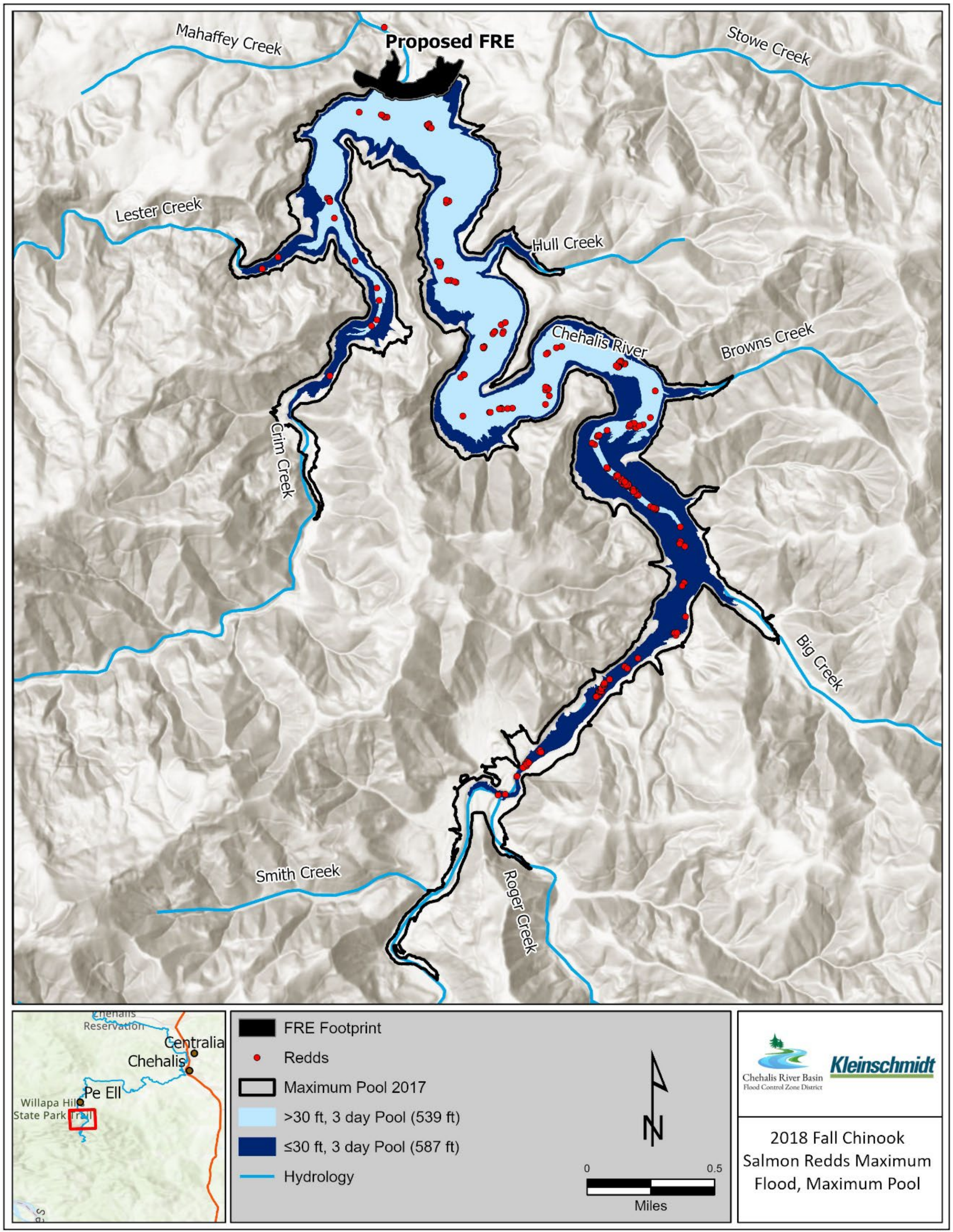


Figure 14
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a median flood event.

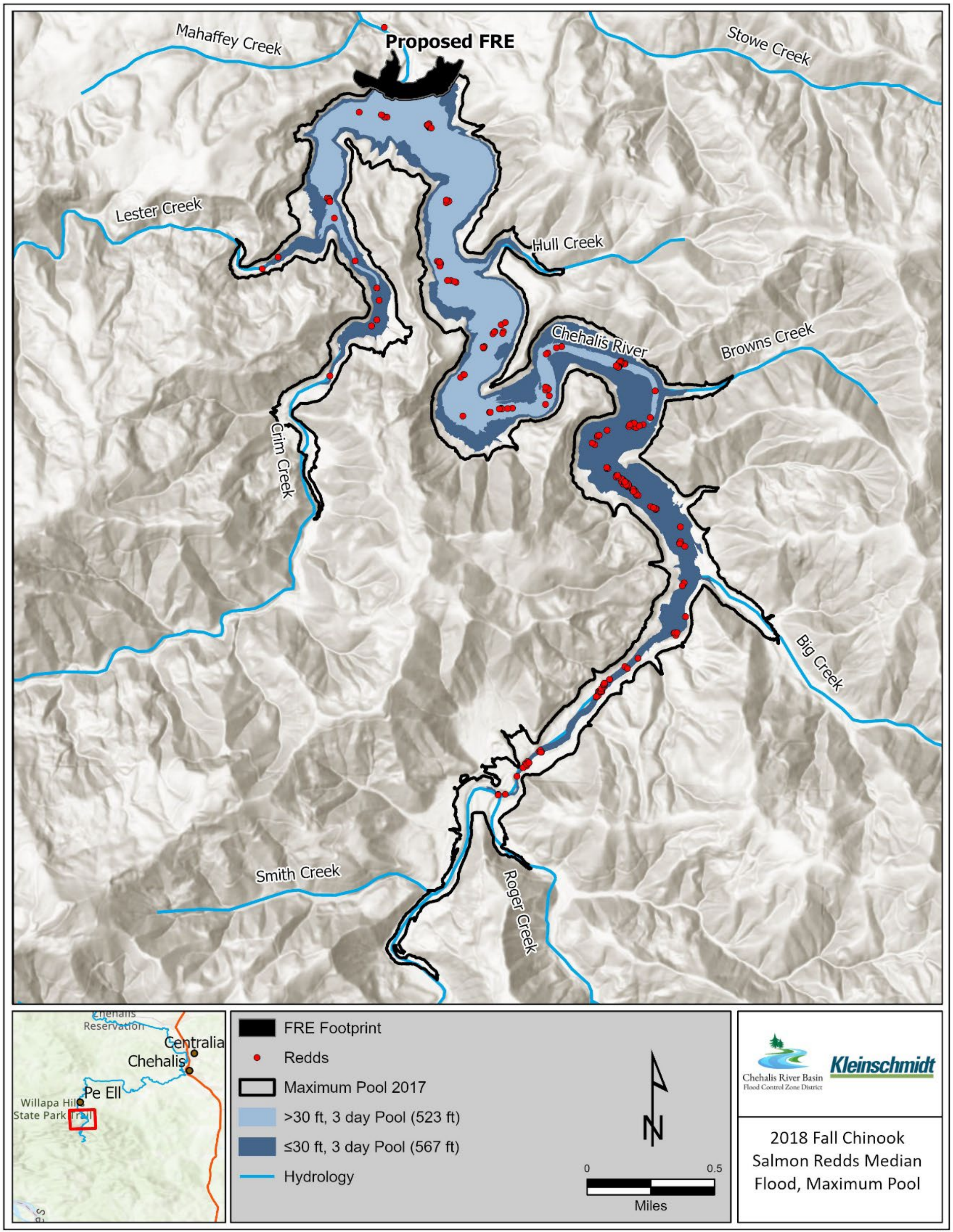


Figure 15
2018 fall-run Chinook salmon redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.

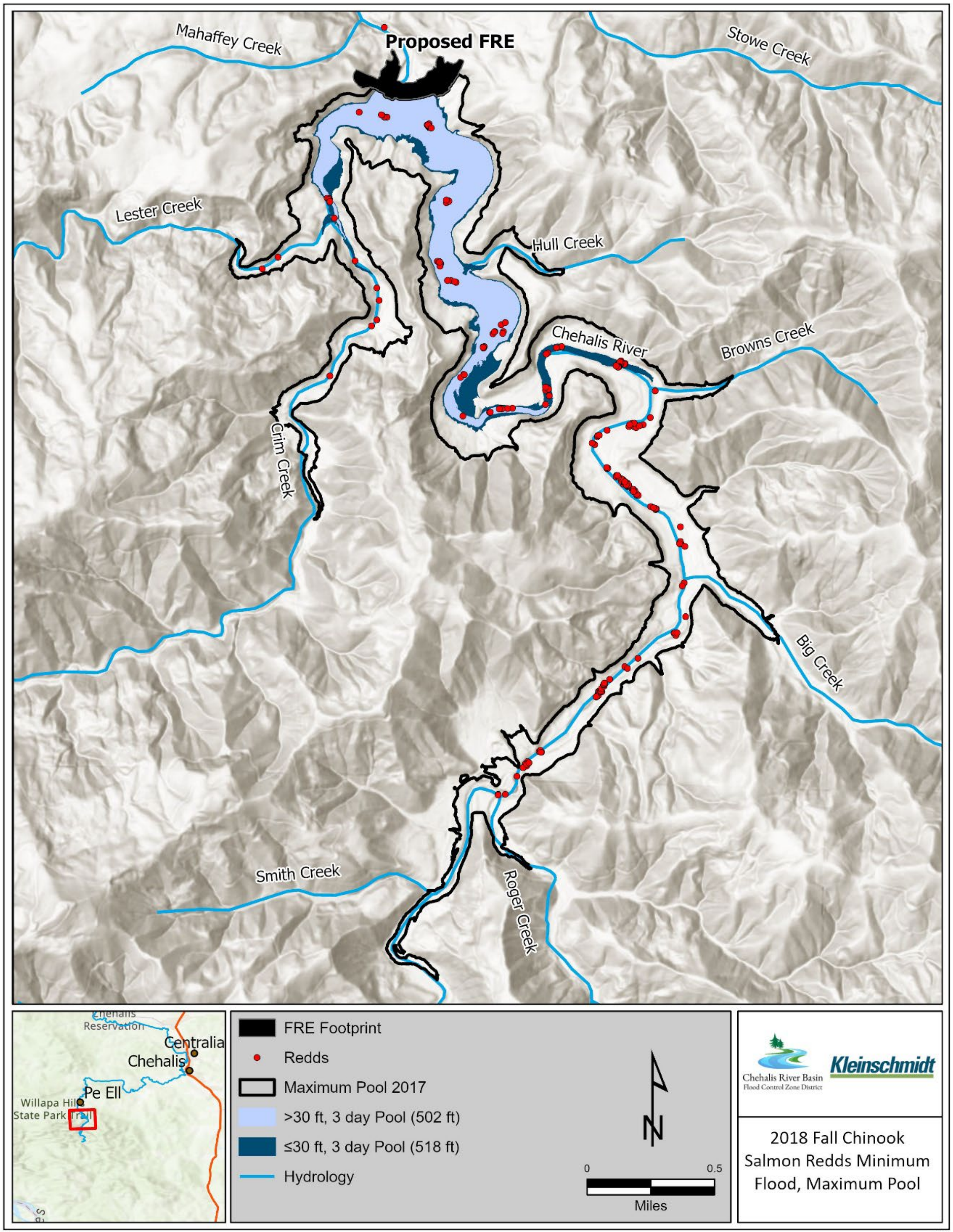


Figure 16

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.

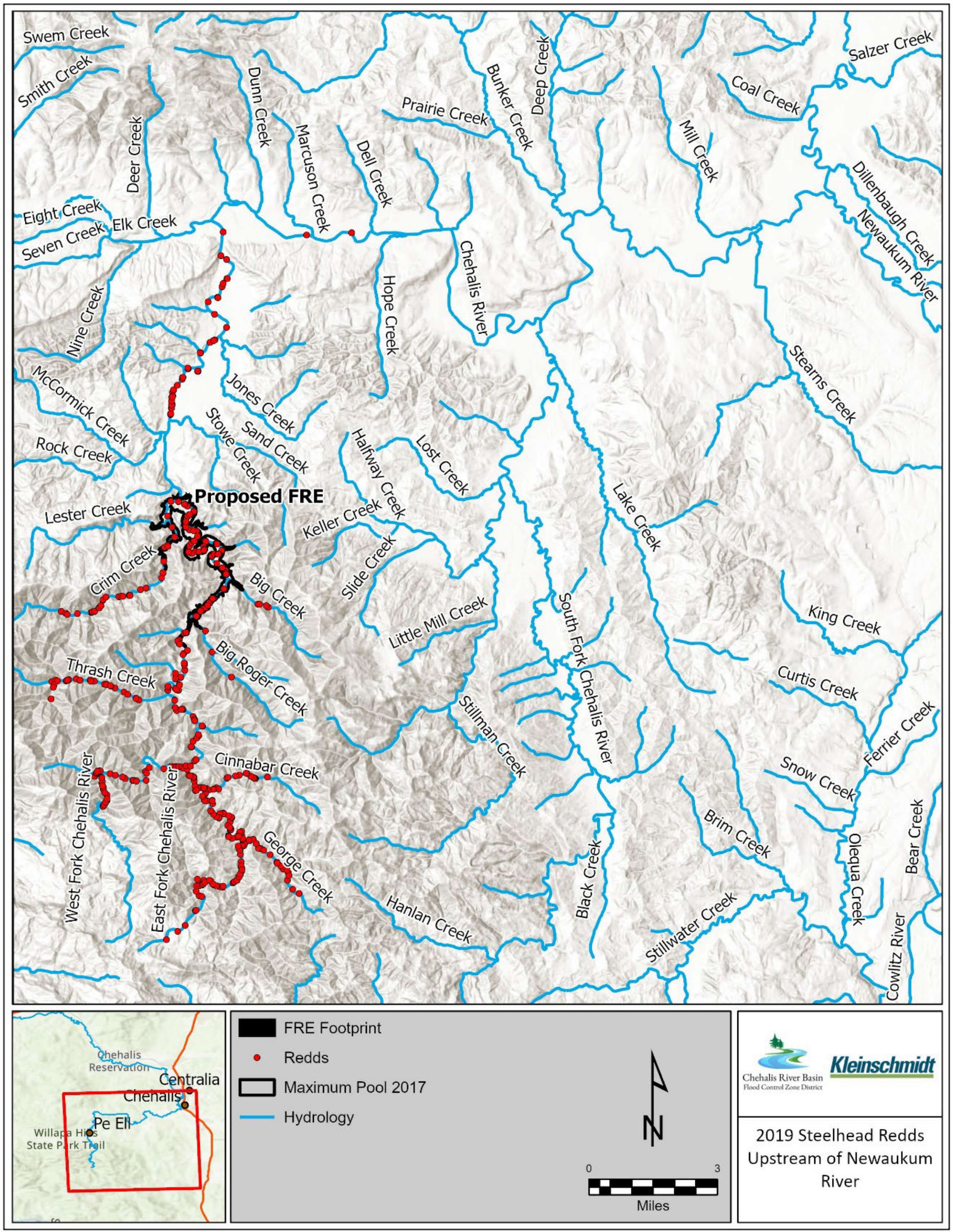


Figure 17
2019 steelhead redd distribution upstream of the FRE facility location.

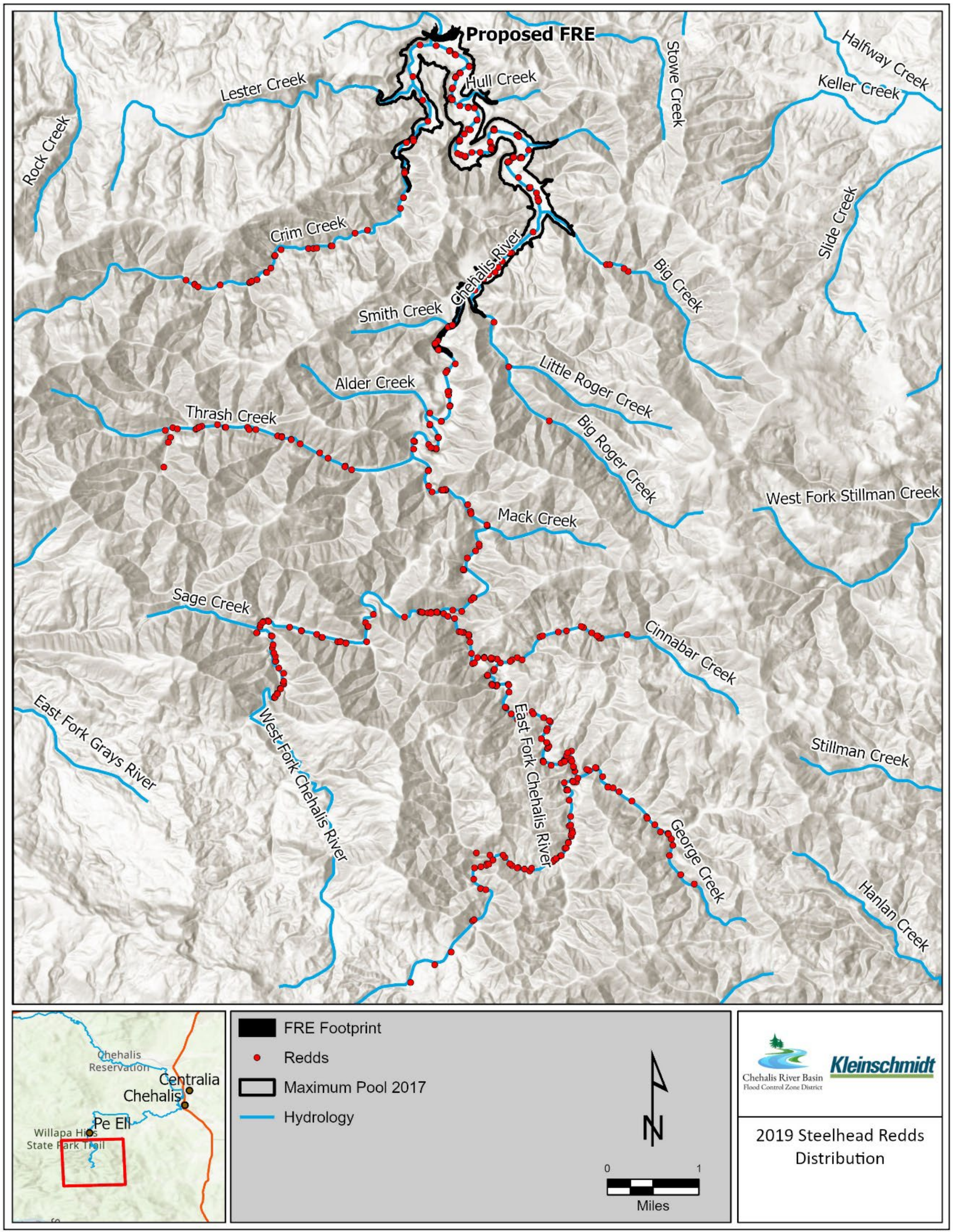


Figure 18
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a maximum flood event.

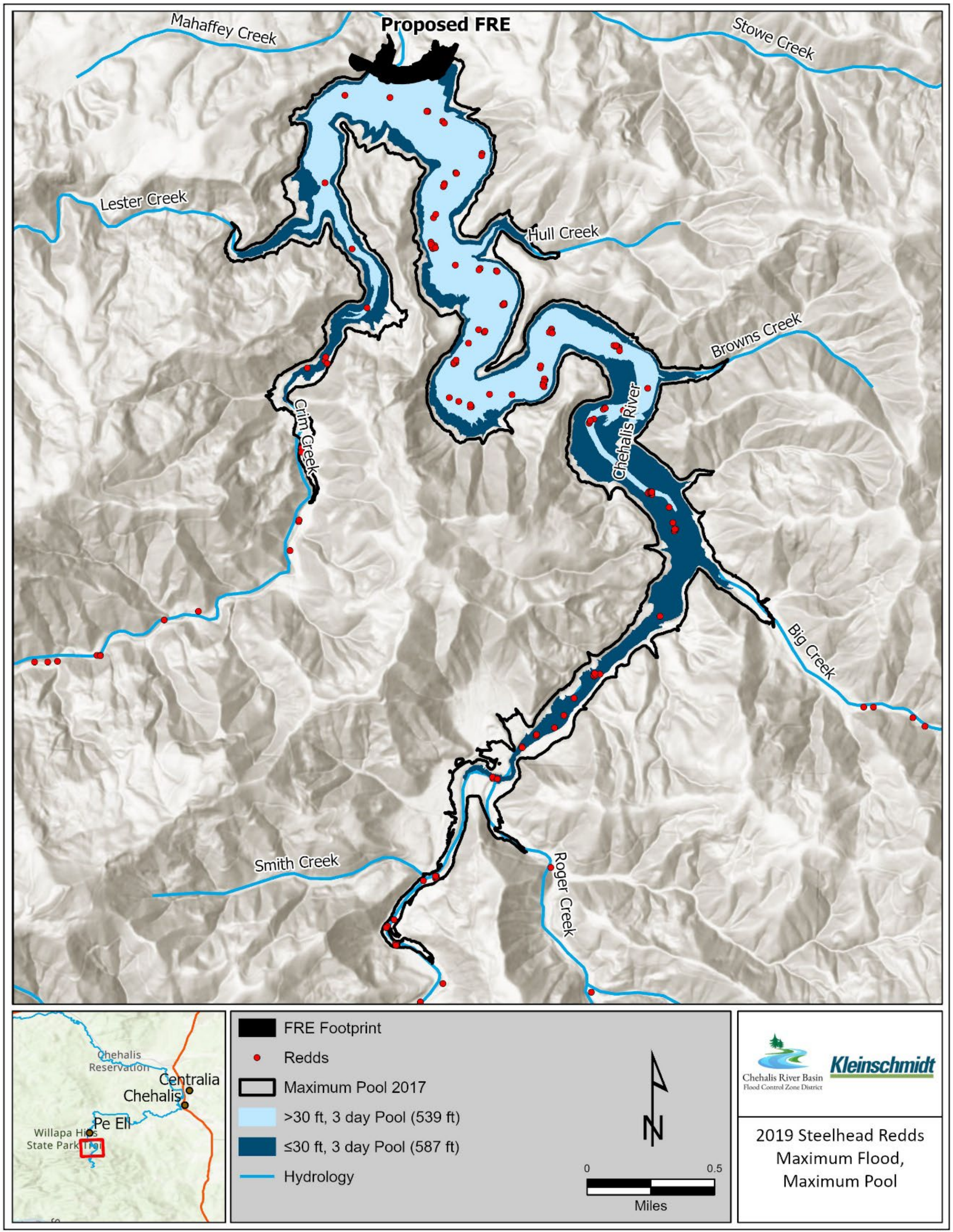


Figure 19
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a median flood event.

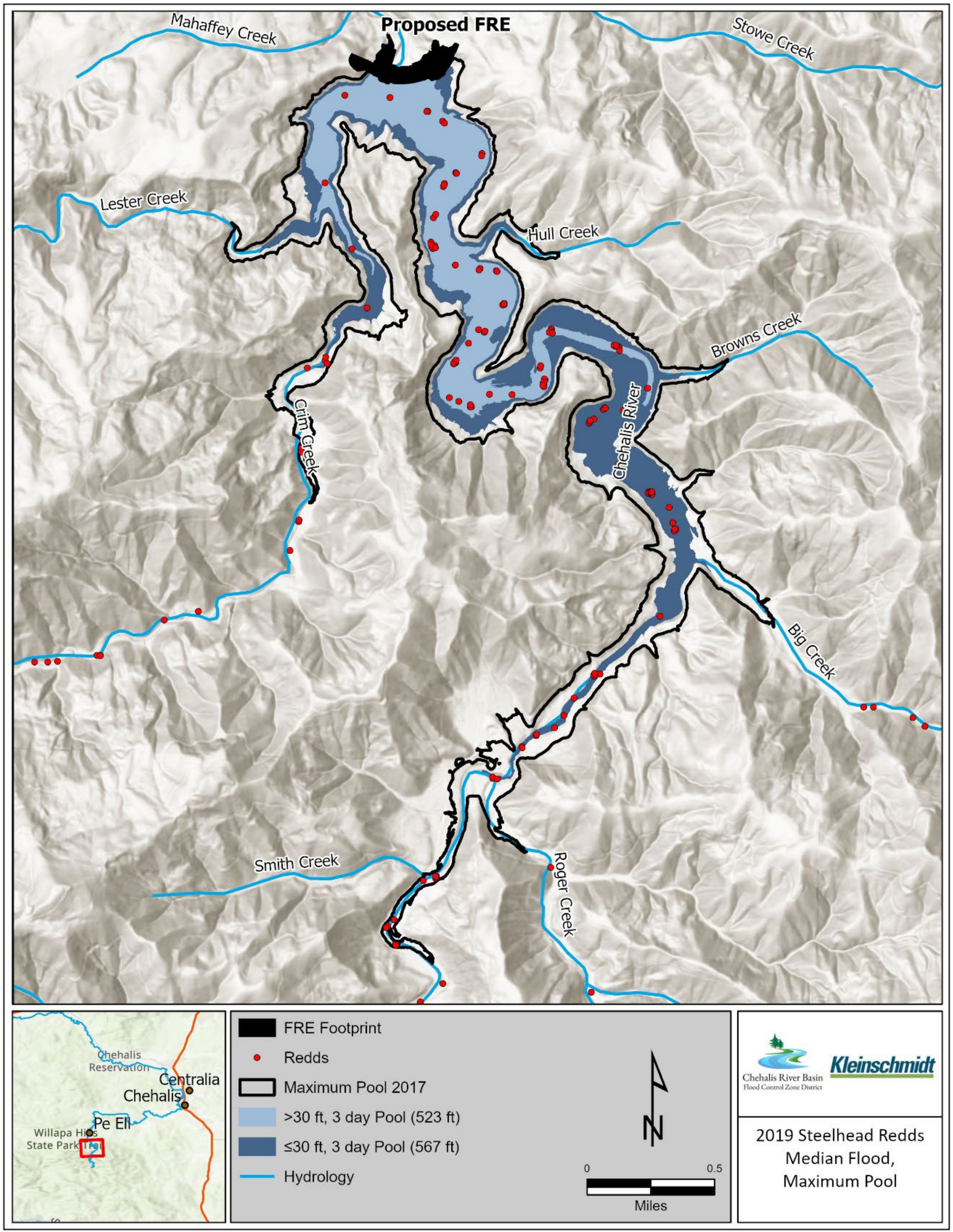


Figure 20
2019 steelhead redds across portions of the temporary pool less than or greater than 30 feet deep for 3 days with a minimum flood event.

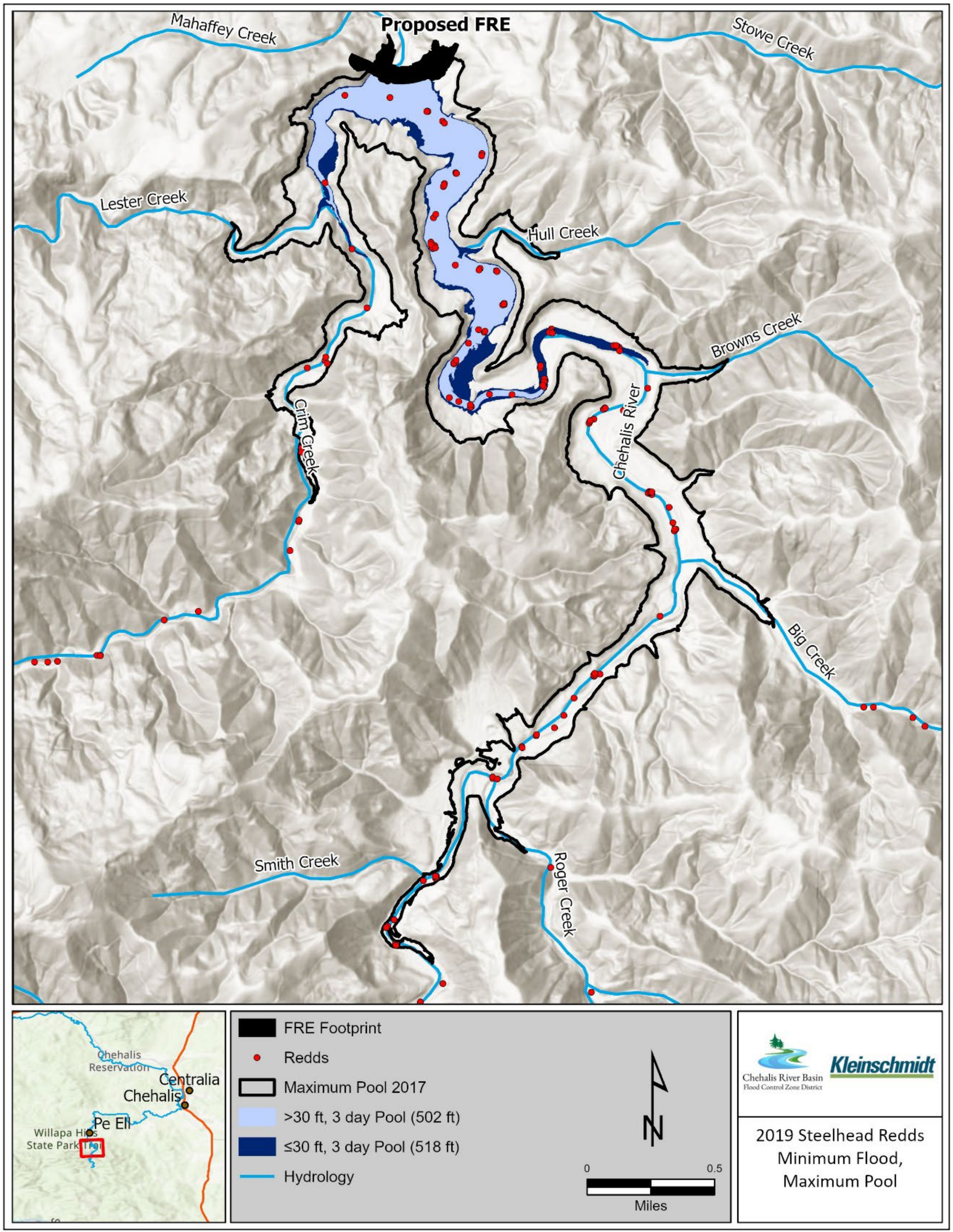
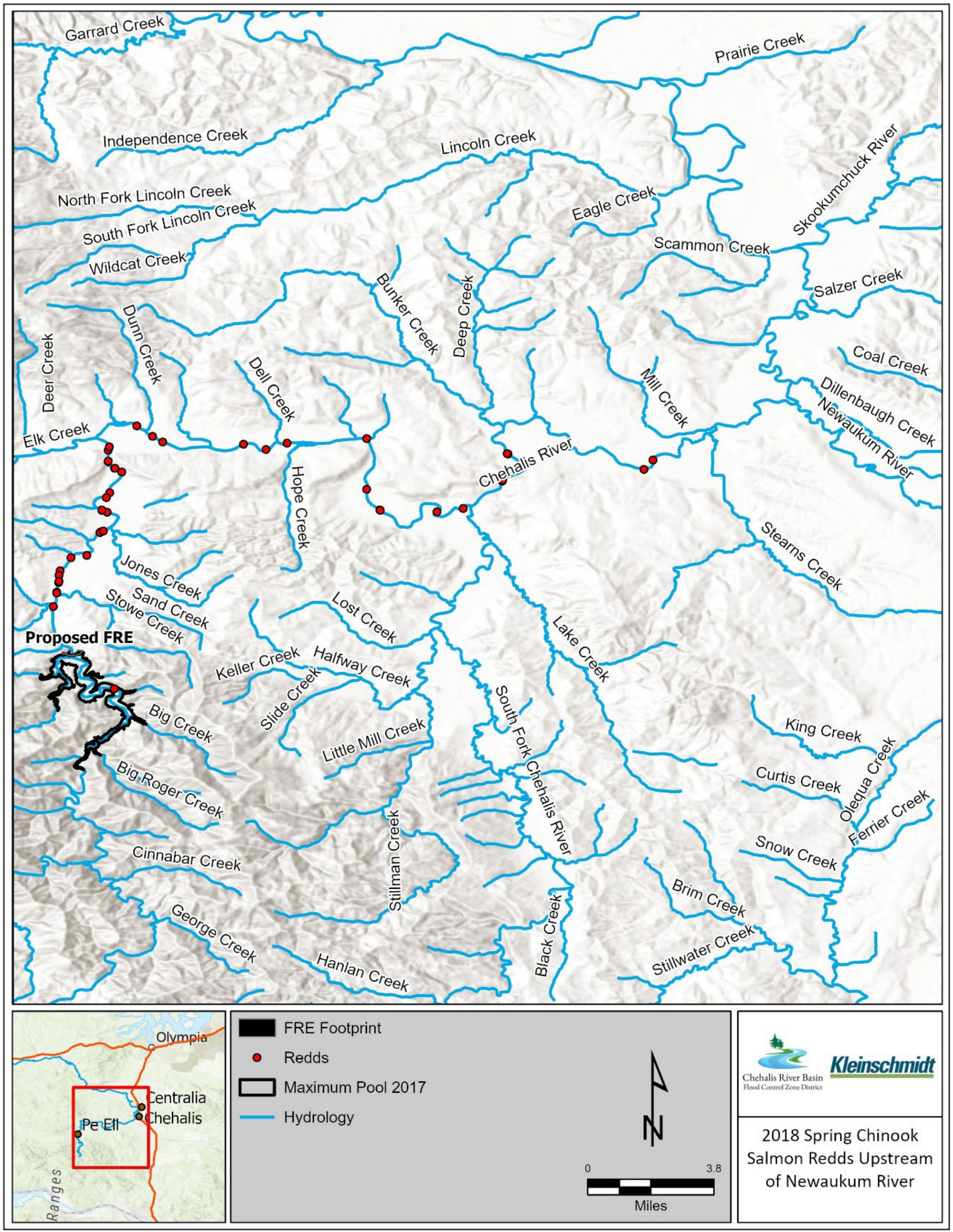


Figure 21
Distribution of 2018 spring-run Chinook salmon redds in the mainstem Chehalis River from the confluence of the Newaukum River upstream to the Forks and including tributaries upstream of Crim Creek.



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Attachment 4 – Temperature Technical Memorandum

TECHNICAL MEMORANDUM

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

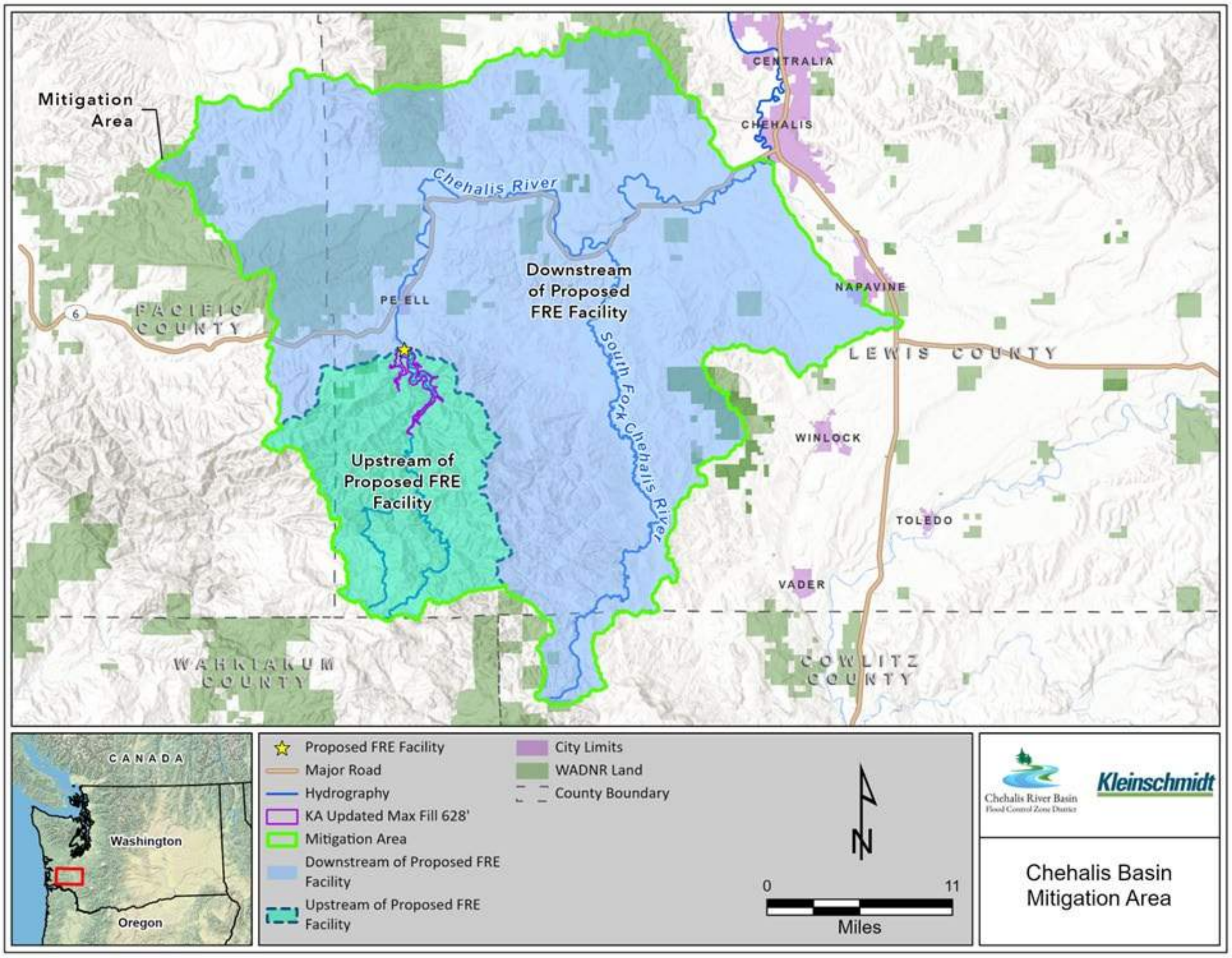
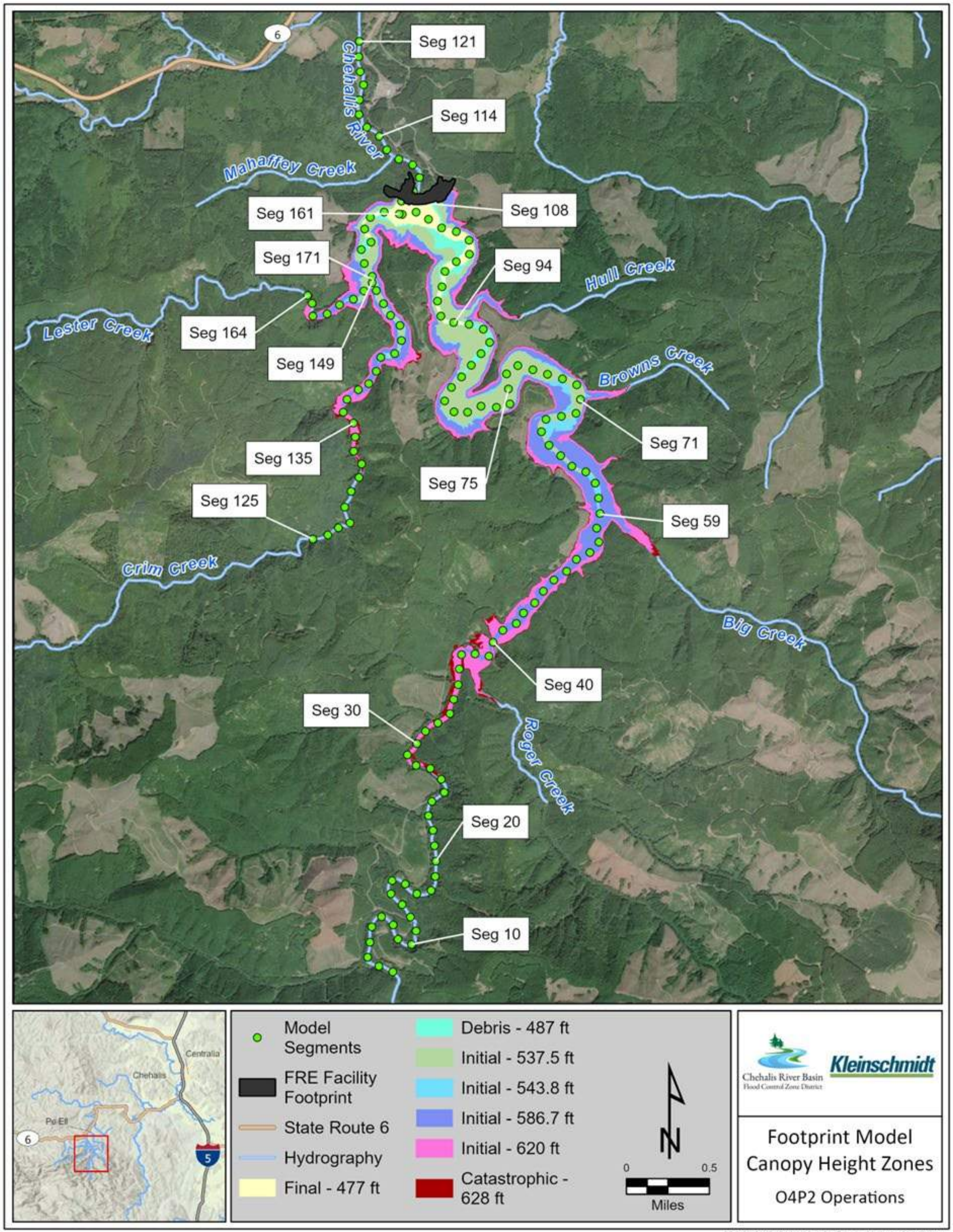


Figure 2

Footprint Model Canopy Height Zones Under O4P2 Operations



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)

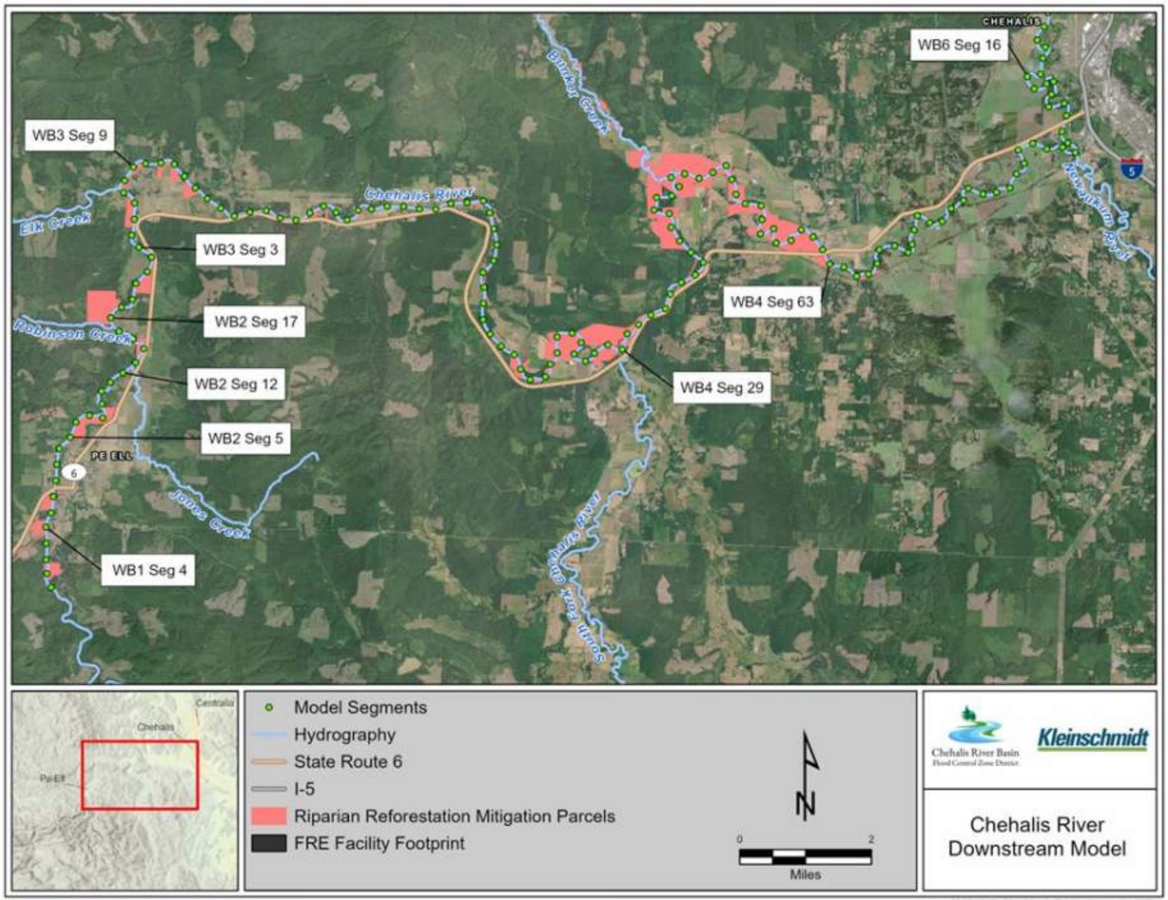
The District developed an estimate of future vegetation conditions upstream of the FRE, based on active vegetation management under the VMP that would promote regrowth after inundation. The predictions of future canopy height were similar to previous modeling based on areas of inundation, but the elevations 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

	2017 PROJECT		2024 PROJECT / 2025 OPERATIONS			
SCENARIO	NO VEGETATION	VMP5	WITH PROJECT, NO MITIGATION		VMP AND RIPARIAN REFORESTATION	
			1996 FE	2015 FE	1996 FE	2015 FE
LOCATION	RELATIVE TO 2022 CURRENT CONDITIONS (2024 MODEL)		RELATIVE TO 2022 CURRENT CONDITIONS (2025 MODEL)			
At Mouth of Crim Creek	3.6 °C[1]	1.6 °C[1]	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

[1] 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

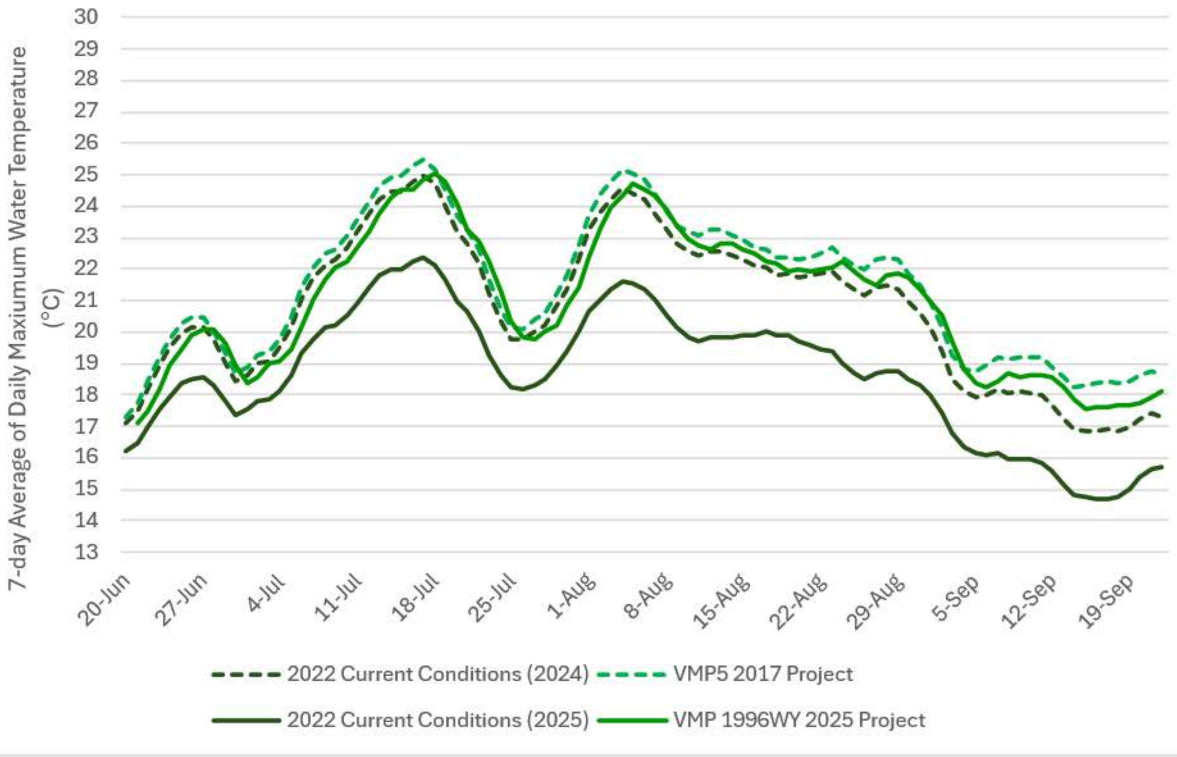
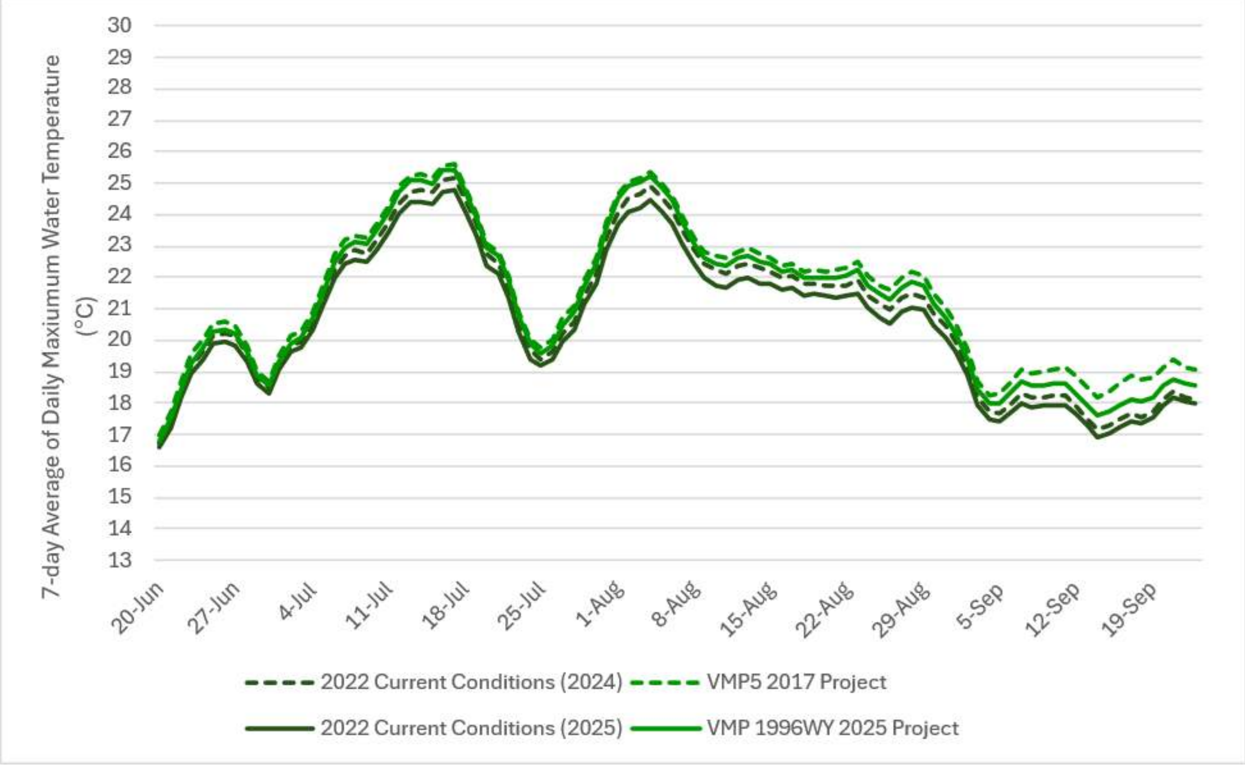


Figure 5
7-DADMax Water Temperatures at the FRE Facility for Model Scenarios



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	NO VEGETATION	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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