January 2023
Skookumchuck Dam Phase 2 Analysis

Summary Report

Prepared for
Office of Chehalis Basin

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ACRONYMS AND ABBREVIATIONS

AF	acre-feet
ASRP	Aquatic Species Restoration Plan
CFD	Computational Fluid Dynamics
cfs	cubic foot per second
Ecology	Washington Department of Ecology
EDT	Ecosystem Diagnosis and Treatment
FERC	Federal Energy Regulatory Commission
GSU	geographical spatial unit
HWM	high water mark
LiDAR	Light Detection and Ranging
NAIP	National Agricultural Imagery Program
NGVD	National Geodetic Vertical Datum
NMFS	National Marine Fisheries Service
NWS	National Weather Service
RM	river mile
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UW	University of Washington
WDFW	Washington Department of Fish and Wildlife
WSE	Watershed Science & Engineering
WSDOT	Washington State Department of Transportation
WY	water year

EXECUTIVE SUMMARY

This report summarizes the results of the second phase of the Skookumchuck Dam analysis as requested by the Chehalis Basin Board.

The purpose of this analysis is to identify the feasibility of making larger-scale physical or operational modifications to Skookumchuck Dam that could provide flood damage reduction and/or aquatic species benefits. This study is an important opportunity to integrate both types of benefits, and the Chehalis Basin Board would like to engage with stakeholders to understand if the dam could play a role in the overall Chehalis Basin Strategy. Any proposed major changes to the dam or its operations would need to be agreed to by TransAlta (dam owner) and the Washington Department of Fish and Wildlife (WDFW) under the auspices of the Federal Energy Regulatory Commission (FERC)-approved fish and wildlife agreement for the dam.

The first phase was conducted in 2021 (Anchor QEA et al. 2021) and examined whether there were any near-term options to modify operations at Skookumchuck Dam for flood damage reduction and/or aquatic species benefits. The Phase 1 analysis did not include detailed modeling but identified that flood damage reduction was likely in conflict with fish passage. The only potential for near-term changes to operations identified was to reduce outflows from the dam during September and early October to be closer to natural flows, which may help separate spring- and fall-run Chinook salmon spawning timing below the dam.

The first phase identified the following key questions that led to this second phase:

- How effective is downstream fish passage currently for salmonids?
- Could downstream passage for multiple salmonid species (steelhead, coho salmon, spring- and fall-run Chinook salmon) be feasible with modified operations or facilities?
- Are the current upstream fish passage facilities adequate to consider passing substantially more fish upstream than has historically occurred?[1]
- What is the quantity and quality of habitat upstream of the reservoir?
- Could the dam provide any effective flood damage reduction for either Bucoda or Centralia?
- Would modifications to the dam be cost prohibitive to accomplish either purpose?
- Would fish passage or flood storage alternatives affect downstream water rights or the operation of TransAlta's water bank?

The scope of this second phase of analysis was to answer these questions at a conceptual level by conducting a more detailed analysis of the Skookumchuck Dam and potential modifications to

[1] Currently only adult steelhead are transported upstream of the dam in small numbers in some years (fish that are excess to hatchery broodstock and other purposes). Juvenile steelhead may pass downstream through the existing fish sluice, although this has not been monitored to understand the effectiveness of the existing sluice.

the dam structure. Tasks for this analysis include developing detailed hydrology and a water budget, a detailed reservoir model, bathymetric survey of the lower river (below Bucoda), hydraulic modeling of the lower river and floodplain, a detailed model of the fish sluice, documentation of upper watershed habitat conditions (desktop only, conducted by Light Detection and Ranging [LiDAR] and high-resolution aerial photography), Ecosystem Diagnosis and Treatment (EDT) model updates and modeling of alternatives, an initial evaluation of potential impacts to water rights, and preparation of this summary report.

ES.1 Background

The Skookumchuck River is approximately 40 miles long and extends from its headwaters near Huckleberry Mountain (elevation 3,800 feet) to its confluence with the Chehalis River at Chehalis river mile (RM) 67 in Centralia (see Figure ES-1).[2] Skookumchuck Dam is a 195-foot-high earth fill dam, owned by TransAlta and located at Skookumchuck RM 21.9 that currently blocks access to all anadromous fish species to the upper half of the river. A watershed analysis prepared by Weyerhaeuser (1996) indicated that the dam may block up to 22 miles of habitat for steelhead, 8 miles for coho salmon, and 4 miles for Chinook salmon.

The dam is currently operated to store water and augment flows in the river to allow TransAlta to withdraw its water right year-round for the Centralia Steam Generation Plant from an intake on the river at RM 7.2. When reservoir elevations are above the fish sluice in the spillway (see sidebar), downstream fish passage is possible (bottom elevation of 464 feet; but to provide sufficient flow, reservoir should be in the 466-467 range); when the reservoir elevation exceeds the spillway elevation (477 feet[3]), water spills over the uncontrolled spillway crest. Water is also discharged through a multi-level intake located upstream of the dam. Water from the intake can be routed to the Skookumchuck Hatchery, the adult fish collection facility, the small hydropower turbine, or discharged through the main outlet into the river (Figure ES-2).

A **fish sluice** is a tunnel or slot in the spillway or side of a dam that can be opened or shut. It allows fish to migrate downstream when water is deep enough to flow through the sluice.

[2] All river mile references in this document use the river miles designated by the U.S. Geological Survey.
[3] All vertical elevations in this document are referenced to the National Geodetic Vertical Datum (NGVD) 1929.

Figure ES-1
Skookumchuck River and Dam Location

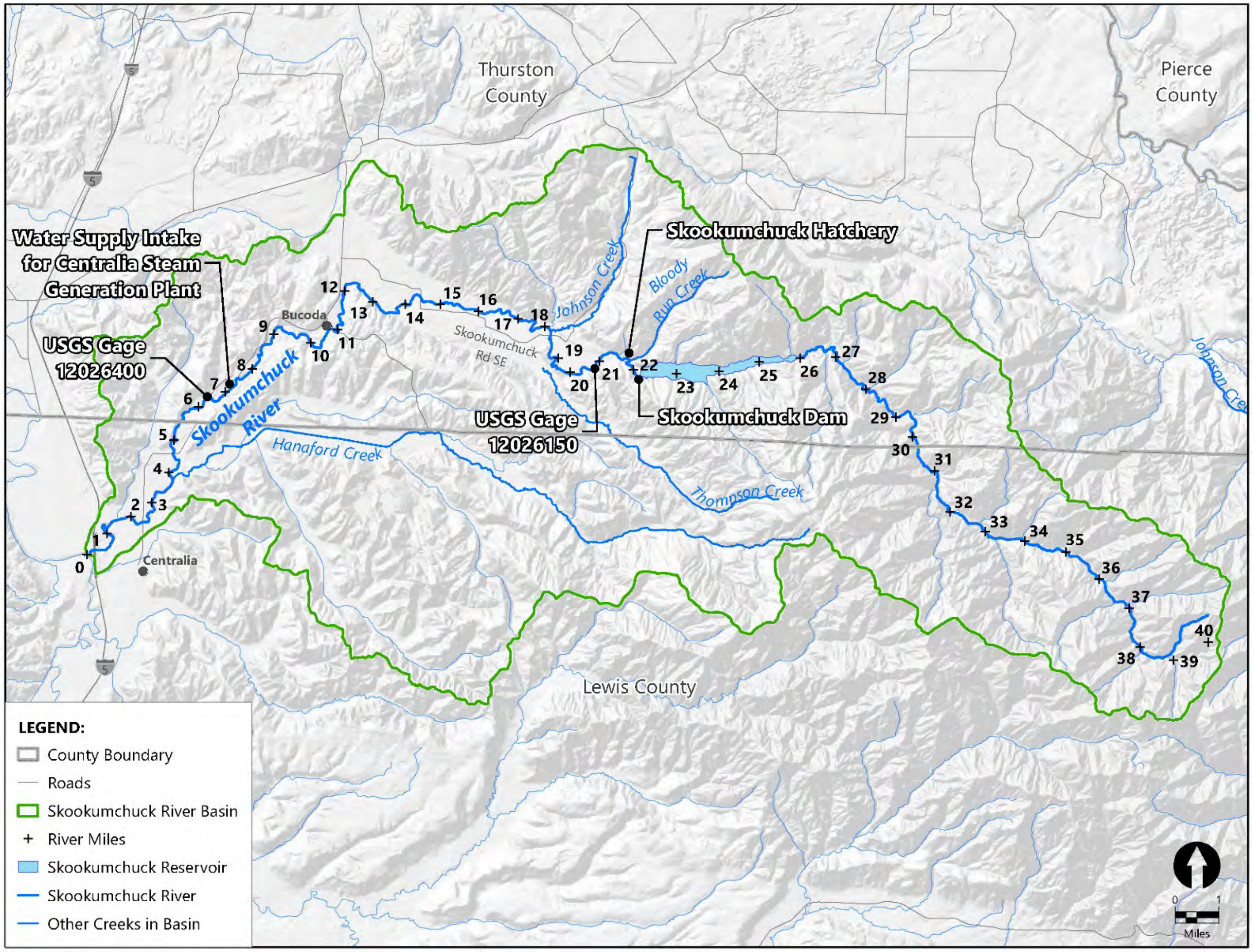
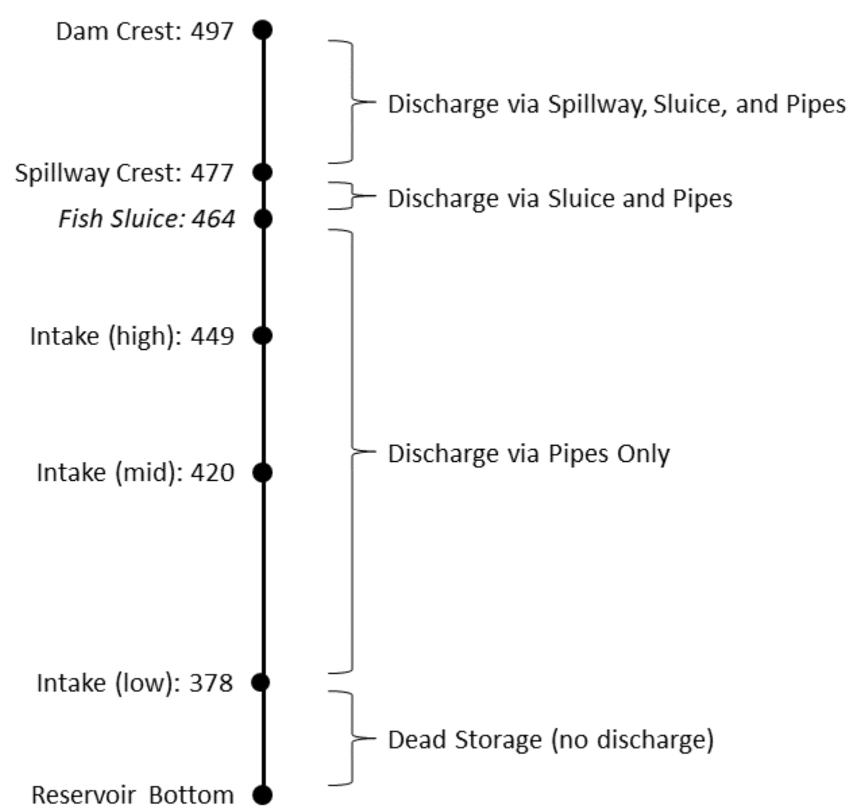


Figure ES-2
Schematic of Skookumchuck Dam Key Elevations



ES.2 Alternatives Evaluated

Multiple alternatives to improve fish passage and flood storage were evaluated in this analysis, including combinations of fish passage (salmonids) and flood storage improvements. All alternatives were also compared to the current operation of the dam (i.e., No Action). The following four most promising action alternatives were evaluated most extensively:

- **Fish Passage Only:** This alternative would create a new fish sluice that would discharge 65 cubic feet per second (cfs) year-round (migratory season of interest is from January 1 through mid-summer each year) and send fish (juvenile salmonids) to a new low-gradient flume that could either return all the way to the river downstream of the dam or end at a holding area for downstream transport of fish via tank truck.
- **Flood Storage Only:** This alternative would install a new 2,000 cfs outlet for the dam to allow more rapid release of water from the dam to hold a flood storage pocket of 20,000 acre-feet during the rainy season from November 1 to April 30.

- **Combined Fish Passage-Flood Storage:** This alternative would combine the two previous alternatives but operate for flood storage from November 1 to early March, with a target refill of the reservoir by March 15 to provide fish passage (with 50% and 75% probability of complete refill by March 15). It would also include active management to lower the reservoir in advance of forecasted storm events.
- **Dam Removal:** This alternative would either partially or fully remove the dam to restore unhindered fish passage to the river upstream.

ES.3 Methods of Analysis

Initially, several analyses and models were developed. Hydrologic and hydraulic analyses included analysis from gage data and scaled for predicted future climate conditions, plus the following models:

- HEC-ResSim: a hydraulic model of the reservoir to evaluate multiple alternatives that could store water or discharge for fish passage and other purposes
- HEC-RAS-2D and Computational Fluid Dynamics (CFD): 2-dimensional and 3-dimensional models of the fish sluice area to evaluate fish attraction and passage conditions and inform development of alternatives
- RiverFlow2D: a 2-dimensional model of the river and floodplain downstream of the dam (RiverFlow2D), updated with new bathymetry downstream of Bucoda, to evaluate potential downstream inundation depths and extents of the alternatives

The potential benefits and impacts to fish were evaluated with the EDT model with updated information for the river upstream of the reservoir provided from LiDAR and high-resolution aerial photography collected for this study.

ES.4 Results of the Alternatives Analysis

ES.4.1 Hydrologic and Hydraulic Results

This report uses computer models of the flow rates of water, based on historical data and climate change projections, to anticipate how migrating fish would benefit from or be harmed by the alternatives, and how many structures would be flooded at various depths. In general, the Dam Removal and Fish Passage Only alternatives result in slightly increased flooding but substantially improved outcomes for fish. The Flood Storage Only alternative reduces flooding severity substantially while making outcomes worse for fish, while the Combined Fish-Flood alternative also substantially reduces flooding with mixed outcomes for fish (some improved, some negatively affected).

For each alternative, flows were modeled with HEC-ResSim via discharges from the dam to the Bloody Run and Bucoda gages (12026150 and 12026400 on Figure ES-1, respectively) to see how an alternative would have changed the peak discharge based on the highest event during the gage data period.[4] Modeled peak flows for the alternatives at the Bloody Run and Bucoda gages are shown in Table ES-1. The first row shows actual discharges during the January 2009 event that was the highest flow during the gage record.[5] The remaining rows are simulated flows based on the same event but are not reflective of actual discharges from the dam during that event.

The Current Operations and Fish Passage Only alternatives have the same maximum discharge because the reservoir was modeled as close to full at the onset of this magnitude of flood in all of these alternatives.

The Dam Removal alternative would have slightly higher outflows (approximately 6% higher) than the Current Operations alternative during an event similar to the January 2009 event.

The Flood Storage Only and Combined Fish-Flood alternatives would result in lower flows at Bloody Run and Bucoda, with flows ranging from about 65% to 70% lower at Bloody Run to 50% to 65% lower at Bucoda. The additional inflows from tributaries below Bloody Run result in simulated peak flows at Bucoda with not as large of a difference between the alternatives as the flows at Bloody Run.

Table ES-1
Simulated Peak Flow at the Bloody Run Gage for the January 2009 Flood for each Alternative

SCENARIO/ALTERNATIVE	PEAK FLOW AT BLOODY RUN FOR JAN 2009 EVENT (CFS)	PEAK FLOW NEAR BUCODA FOR JAN 2009 EVENT (CFS)
Recorded Discharge	6,900	10,500
Simulated Flows		
Current Operations	12,970	17,200
Fish Passage Only	12,970	17,200
Flood Storage Only	5,590	8,840
Combined Fish-Flood: 20,000 AF & 50% probability refill	3,940	8,400
Combined Fish-Flood: 20,000 AF & 75% probability refill	4,140	7,670
Dam Removal	13,710	17,060

Note:
The Combined Fish-Flood alternatives result in slightly lower flows than the Flood Storage Only alternative because the combined alternative includes flood forecasting and reservoir drawdown in anticipation of floods due to the need to more actively manage reservoir levels to allow for refill by March 15 in any given year. This more advanced operation could also be applied to the Flood Storage Only alternative but was not modeled that way in this analysis.

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[4] 15-minute data were available from 1987 to 2022 at the Bloody Run gage (USGS Gage No. 12026150) and from 2007 to 2022 at the Bucoda gage (USGS Gage No. 12026400).
[5] Actual recorded discharges at the Bloody Run gage differ from the modeled (simulated) flows for current operations because there are many real-life reasons to draw the reservoir down that have occurred irregularly but cannot be accounted for in operational rules necessary to run the model.

The Fish Passage Only alternative was evaluated with the reservoir model to understand how long the reservoir could be kept high enough for juveniles and adults to use the fish sluice. In an average year there would be sufficient water at the fish sluice until mid-September, which would fully encompass the migration period for steelhead, coho salmon, and Chinook salmon juveniles. During drier years, the reservoir would drop below the elevation required for fish passage by early August, which would still encompass the migration period for steelhead, coho salmon, and Chinook salmon juveniles.

The modeled discharges from the dam were then used as inputs into the RiverFlow2D model to show how the floodplain extent and depths could vary between the alternatives. Figures ES-3 and ES-4 show the modeled 100-year floodplain extents for the alternatives under existing climate conditions.[6] The Current Operation and Fish Passage Only alternatives (blue) have the same outflows from the dam and essentially identical effects downstream and inundate a wider floodplain area (combined width of Flood Storage Only, Combined Fish-Flood, and blue area).

The Flood Storage Only (beige) and Combined Fish-Flood (green) alternatives result in significant reductions in inundated area (shown as the narrowest inundation area), while the Dam Removal (red) option generally results in a slightly larger floodplain extent beyond the blue floodplain shown for Current Operations/Fish Passage Only along portions of the Skookumchuck River.

The Riverflow2D model was also run for late-century climate change conditions by scaling existing conditions flows up by 60%. The 60% increase for Skookumchuck River flows was based on the analyses done by Watershed Science & Engineering (WSE) and the University of Washington (UW) Climate Impacts Group for the Chehalis Basin (CIG 2021) as the high-end scenario for climate change. Figure ES-5 shows that all the alternatives inundate essentially the same area (the entire valley) under late-century 100-year flood conditions, although depths of flooding would differ between alternatives.

[6] Current Operations and Fish Passage are shown in the same color because they have the same downstream effects.

Figure ES-3
Modeled Existing Climate 100-Year Flood Event Inundation Extent for Four Operating Alternatives

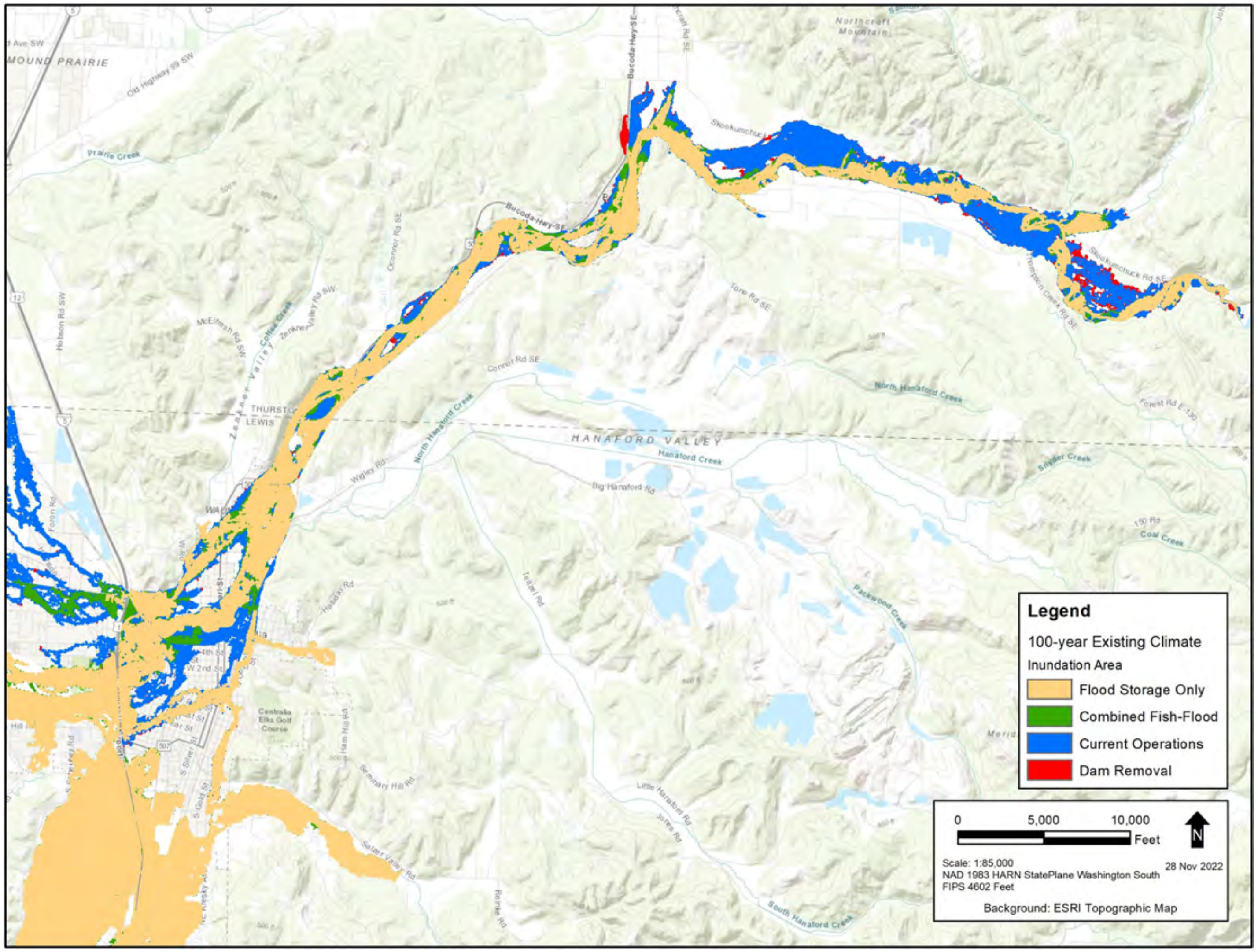
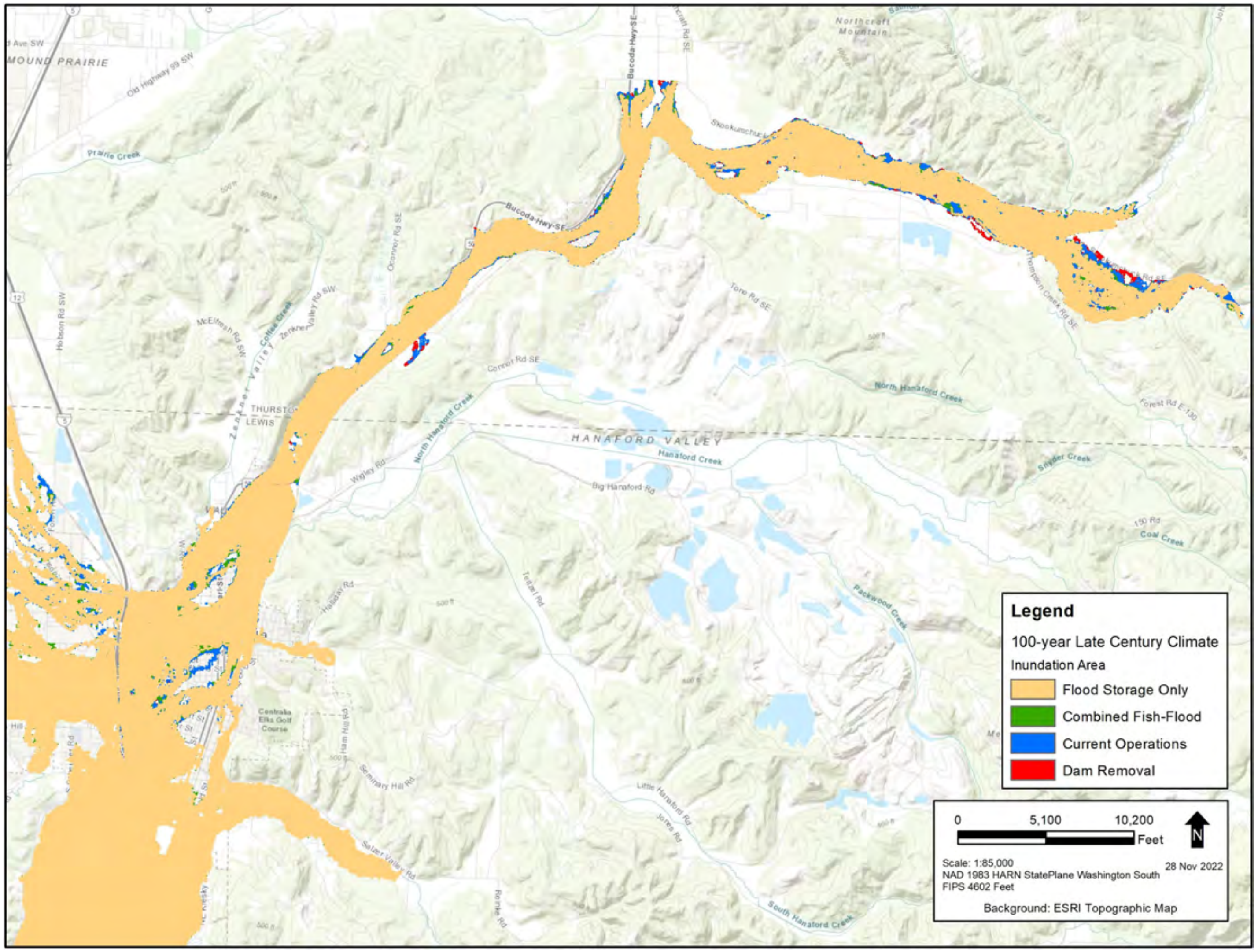


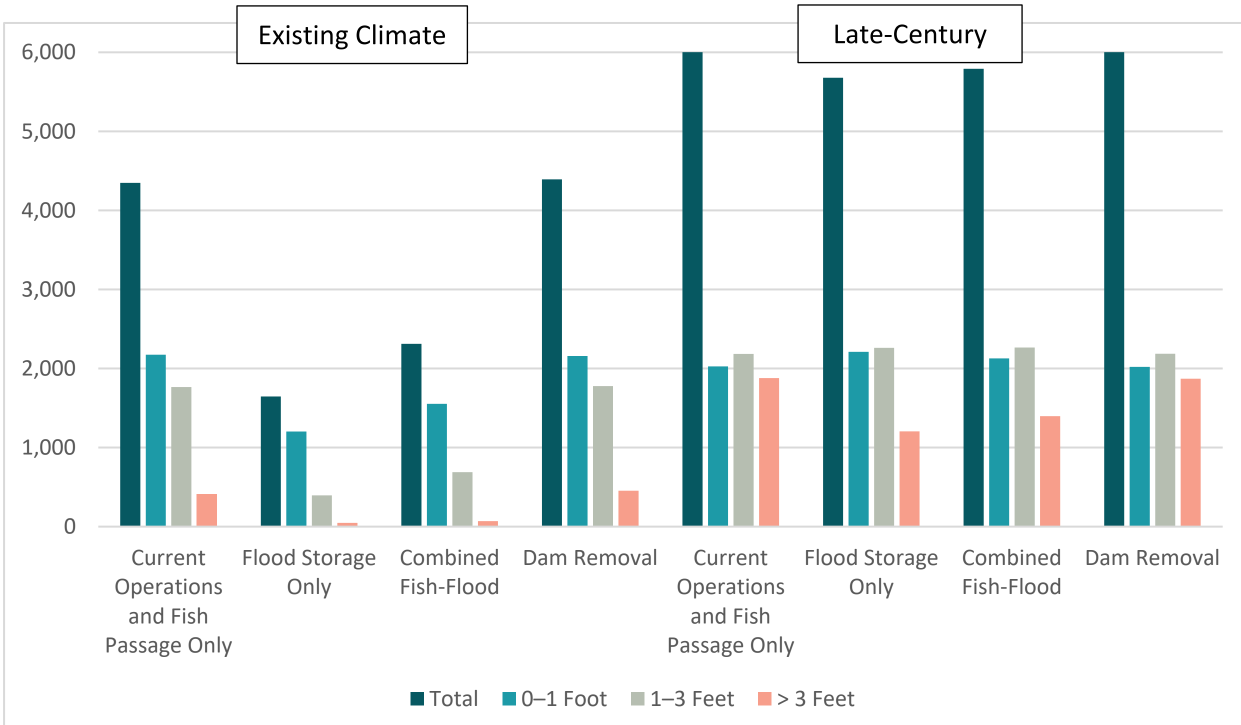
Figure ES-4
Modeled Late-Century Climate 100-Year Flood Event Inundation Extents for Four Operating Alternatives



Under current climate conditions, the alternatives change both the *total* number of structures inundated and the number of structures subject to *major* inundation. Under late-century climate conditions, the alternatives only change the number of structures subject to *major* flooding.

Figure ES-5 shows the total number of structures flooded in the modeled 100-year flood for the existing and late-century climate scenarios (dark blue bars that are the sum of the depth bars to the right for each alternative). For existing climate with the Flood Storage Only and Combined Fish-Flood alternatives, the number of structures flooded greater than 1 foot (gray and light orange bars) is substantially reduced from the Current Operations and the Fish Passage Only alternatives. In particular, the number of structures flooded greater than 3 feet in depth (light orange bars) is reduced by 80% to 90% for the Flood Storage Only and Combined Fish-Flood alternatives compared to Current Operations or Fish Passage Only, and the deeper depths are those most likely to cause damages. Dam Removal results in only slight increases in the number of structures inundated at any depth under existing climate conditions.

Figure ES-5
Number of Structures Flooded in 100-Year Recurrence Flood for Existing and Late-Century Climate for the Alternatives



While Figure ES-3 shows little difference in inundated area between alternatives for the late-century conditions, there are still significant differences in flood depths. Figure ES-5 shows substantially more structures are flooded under projected late-century climate conditions than for existing climate conditions (dark blue bars), as well as the number flooded by more than by more than 1 foot (gray and light orange bars).

The Flood Storage Only and Combined Fish-Flood alternatives result in a significant reduction in the number of structures flooded more than 3 feet deep (light orange bar), but proportionally the reductions are not as large as under existing climate conditions. The Combined Fish-Flood alternative reduces the number of structures flooded more than 3 feet deep by 83% under existing climate conditions, but under the late-century climate conditions the corresponding reduction is only 26%. Nevertheless, the reduction in the number of structures flooded is significant (483 structures fewer that are flooded greater than 3 feet), even under the late-century climate conditions.

The Dam Removal alternative results in virtually the same number of structures inundated as for Current Operations and Fish Passage Only alternatives under late-century conditions.

ES.4.2 Fish Results

In the Skookumchuck River, the most abundant salmonid run is coho salmon, followed by fall-run Chinook salmon, then spring-run Chinook salmon, with wild steelhead making up the smallest proportion (Table ES-2).

Table ES-2
Summary of EDT Modeled Fish Equilibrium Abundance by Alternative for the Current and Late-Century Climate

ALTERNATIVE	EQUILIBRIUM ABUNDANCE OF FISH SPECIES IN THE SKOOKUMCHUCK RIVER BASIN			
	Steelhead	Coho Salmon	Spring-Run Chinook Salmon	Fall-Run Chinook Salmon
Existing Climate				
Current Operations	77	1,255	751	1,584
Fish Passage Only[1]	219 / 470	1,597	754	1,601
Flood Storage Only	80	1,106	491	1,015
Combined Fish-Flood[1]	221 / 472	1,562	662	1,188
Dam Removal	751	1,873	1,001	2,314
Late-Century Climate				
Current Operations	42	861	315	720
Fish Passage Only[1]	138 / 312	1,168	301	739
Flood Storage Only	43	765	207	344
Combined Fish-Flood[1]	140 / 314	1,180	237	522
Dam Removal	482	1,289	420	1,170

Note:
1. Fish Passage Only and Combined Fish-Flood alternatives modeled with 33% and 90% upstream adult steelhead passage at the dam; results shown are for those two scenarios, respectively.

EDT modeling estimates that the Fish Passage Only and especially the Dam Removal options would proportionally benefit steelhead the most. The runs generally benefit the most from the Dam Removal alternative and more modestly (or not at all) from the Fish Passage Only alternative. The coho and Chinook salmon runs are harmed by the Flood Storage Only option but the steelhead run is not harmed.

The Fish Passage Only alternative would increase steelhead (+510%) and coho salmon (+27%) equilibrium abundance under the existing climate. Spring Chinook salmon would have limited benefit (<1%) because much of their potential spawning habitat is under the reservoir footprint, with limited additional suitable habitat available upstream. Fall Chinook salmon would not be passed upstream (to help separate spring- and fall-run Chinook salmon) so they would not benefit.

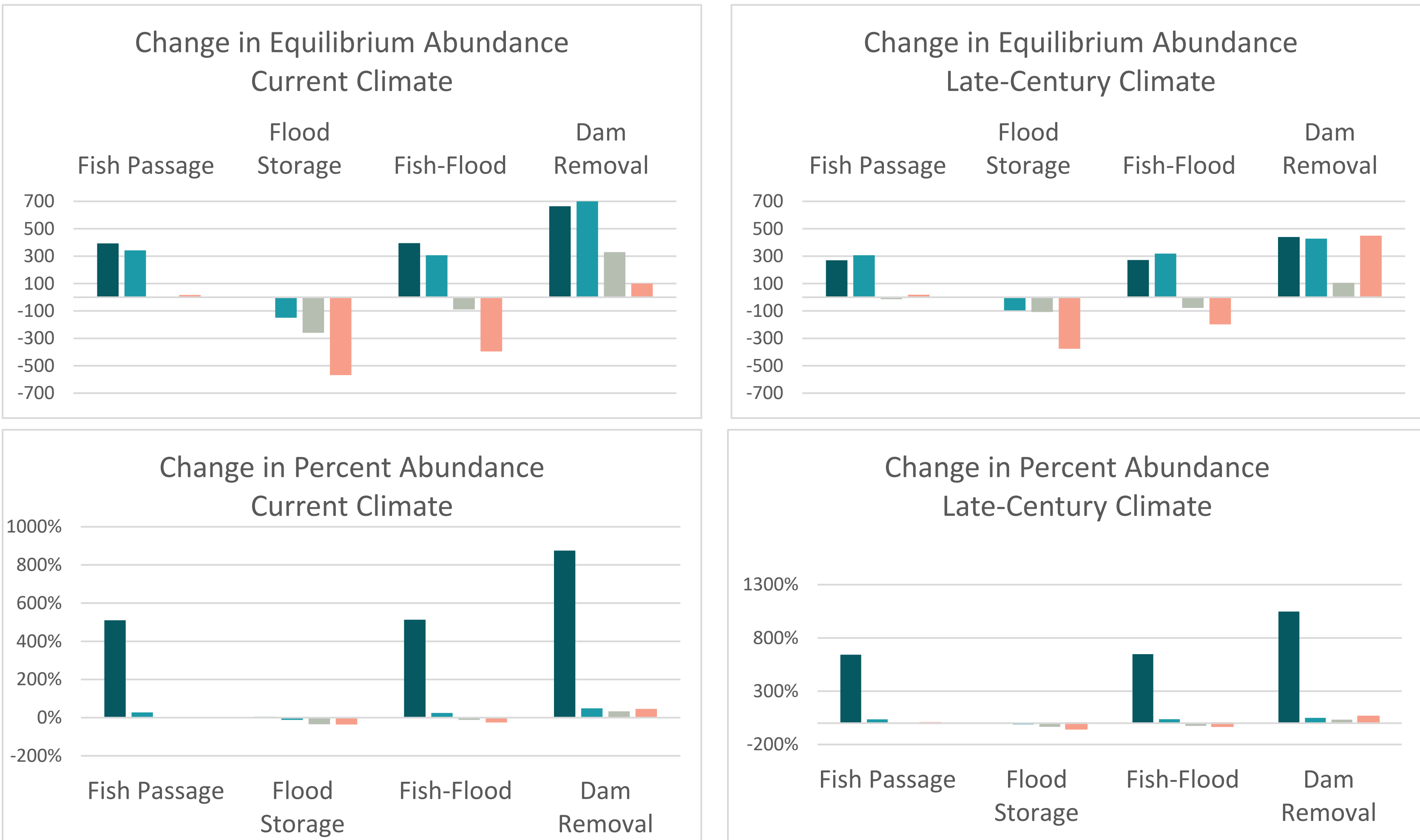
The Dam Removal alternative would have substantial benefits for all species; steelhead (+875%), coho salmon (+49%), spring-run Chinook salmon (+33%), and fall-run Chinook salmon (+46%).

The Flood Storage Only alternative would have little change for steelhead (+4%) but substantial negative effects for coho salmon (-12%), spring-run Chinook salmon (-35%), and fall-run Chinook salmon (-36%) as a result of winter flow reductions that reduce downstream in-channel and off-channel habitats.

The Combined Fish-Flood alternative has similar results to the Fish Passage Only alternative for steelhead (+513%), and coho salmon (+24%) but moderate declines for spring-run Chinook salmon (-12%), and fall-run Chinook salmon (-25%) due to negative effects on downstream habitats.

For the late-century climate, the results are similar, but with lower equilibrium abundance numbers for all species due to climate change effects such as high water temperatures and changes in peak and low flows that affect the species across their entire life history. Only steelhead are predicted to have an increase in comparison to current abundance by either the Fish Passage Only (+305%) or Dam Removal (+526%) alternatives. Coho salmon have a slight increase with Dam Removal (+3%), but spring-run Chinook salmon, and fall-run Chinook salmon are predicted to decline by 26% to 60% compared to current equilibrium abundance with either the Fish Passage Only or the Dam Removal alternatives. The potential fish effects of the alternatives are shown in Figure ES-6.

Figure ES-6
EDT Predicted Change in Equilibrium Abundance and Percent Change of Salmonid Species Under Existing and Late-Century Conditions



Note: Changes in equilibrium abundance and percent abundance are in comparison to current operations.

ES.4.3 Potential Effects on Water Rights

Water rights in the Skookumchuck River can generally be lumped as TransAlta water rights and all other water rights. TransAlta's right is the largest single right in the basin and is tied directly to the operations of the dam and reservoir, unlike the other rights. TransAlta's right was granted in 1966 in anticipation of construction of the dam; many, but not all, of the remaining rights along the Skookumchuck River were pre-existing to the construction of the dam. A newly established water bank grants TransAlta the ability to sell "mitigation credits," which will allow new water right applicants to purchase and use a portion of the established TransAlta water right to demonstrate water availability; the water bank and mitigation credits would require Skookumchuck Dam to remain in place in order to have water available for use.

To understand how flows change downstream of the dam across each month of the year, a water budget was developed based on the Bloody Run and Bucoda gages and scaling inflows from tributaries. The lowest median flows occur in summer, which is also the season when irrigation and other water rights are used the most. Inflows to the dam/reservoir are also shown for comparison based on the Vail gage and scaling inflows from tributaries below Vail. Current Operations can generally allow for all water rights to be exercised in all but extreme drought years. In extreme drought years, junior water rights may be reduced or curtailed. If water rights from the water bank were transferred to water users further downstream (e.g., Centralia) from the current TransAlta diversion, meeting minimum flows at the Bucoda gage would be more likely, but such a scenario could warrant a change in the location for minimum flow measurement/ requirement to further downstream. At this time, it is not known where water bank rights might be sold or exercised.

With the Fish Passage Only alternative, discharges from the dam would be slightly reduced from Current Operations (on the order of 10 cfs) to maximize the time period when fish can migrate out through the fish sluice. This would reduce the median flows in the summer months, and in drought years it could be more difficult to meet minimum flows (e.g., 35 cfs at Bucoda). Operational decisions between water rights and downstream fish migration would have to be made in those years but could result in a greater frequency of years in which junior water rights (rights junior in priority date to Washington Administrative Code 173-523) could be reduced or curtailed. This also could extend to the mainstem Chehalis River water rights holders downstream of the Skookumchuck River confluence that rely to some extent on the flows coming from the Skookumchuck River.

The Combined Fish-Flood alternative would also result in similar lower summer discharges to maximize fish passage and would have similar results to the Fish Passage Only alternative.

The Flood Storage Only alternative would maintain similar discharges from the dam during summer months as Current Operations except in drought years when it would not be possible to refill the dam due to drier spring conditions after the flood season. This would also likely result in a greater frequency of years in which junior water rights could be reduced or curtailed.

The Dam Removal alternative would result in lower median monthly flows in July, August, and September because there would be no flow augmentation from the reservoir and only natural flow coming from the upper Skookumchuck River and tributaries. This would likely result in a much higher frequency of years in which junior water rights holders could be required to reduce or curtail their withdrawals. This may extinguish the viability of many water rights and may require compensation for the loss of water rights and use(s). Dam Removal is also incompatible with TransAlta's newly established water bank and is not supported by TransAlta.

ES.4.4 Costs of the Alternatives

Preliminary cost estimates were developed for each of the alternatives. The costs of the alternatives are shown in Table ES-3. These costs are only intended to provide an order of magnitude cost at this early stage. The Fish Passage Only alternative is the least cost in the approximately $8 million range. The Flood Storage Only and Combined Fish-Flood alternatives are in the $40 to $50 million range. The partial or full Dam Removal alternatives are in the $25 to $35 million range for construction, but because dam removal could eliminate numerous water rights downstream of the dam (including the water bank), there would be a need for compensation or replacement of water rights that could add up to $80 million.

Table ES-3
Cost Estimates for the Alternatives

ALTERNATIVE	CLASS 5 COST ESTIMATE
Current Operations	N/A
Fish Passage Only	$8.3 million
Flood Storage Only	$42.2 million
Combined Fish-Flood	$50.5 million[1]
Partial Dam Removal[2]	$24.9 million (median) + $80 million (water rights)
Full Dam Removal[2]	$34.6 million (median) + $80 million (water rights)

Notes:
1. Combined Fish-Flood alternative is not separately calculated; value provided is the sum of Fish Passage Only and Flood Storage Only alternatives.
2. Dam removal costs are carried forward from the Phase 1 analysis (Anchor QEA et al. 2021) and are the median of potential construction costs in 2021 dollars.

ES.5 Summary of Alternatives

In summary, each of the alternatives can contribute to either fish or flood damage reduction benefits. However, none of the alternatives clearly maximize both fish and flood objectives. For example, even the Combined Fish-Flood alternative does not fully achieve both fish and flood damage reduction objectives because it would provide only limited benefit for coho salmon, spring-run Chinook salmon, and fall-run Chinook salmon. Table ES-4 shows a side-by-side comparison of the alternatives.

Table ES-4
Alternatives Comparison of Analyzed Effects

ALTERNATIVE	FISH ABUNDANCE	FLOOD EFFECTS	WATER RIGHTS	COST
Current Operation	No change	No change	No change	N/A
Fish Passage Only	Steelhead **+** Coho **+** Spring Chinook **=** Fall Chinook **=**	No change	Small but increased risk of water rights curtailments in drought years	$8.3 million
Flood Storage Only	Steelhead **=** Coho **-** Spring Chinook **-** Fall Chinook **-**	Substantial reductions in flood extent and depth; less benefit in late-century	Small but increased risk of water rights curtailments in drought years	$42.2 million
Combined Fish-Flood	Steelhead **+** Coho **+** Spring Chinook **-** Fall Chinook **-**	Substantial reductions in flood extent in depth; less benefit in late-century	Small but increased risk of water rights curtailments in drought years	$50.5 million
Dam Removal	Steelhead **++** Coho **+** Spring Chinook **+** Fall Chinook **+**	Small increases in flood extent and depths	Higher risk of water rights curtailments in drought years	$25–$35 million (median) +$80 million (water rights)

Steelhead and coho salmon are predicted to benefit from the Fish Passage Only alternative. However, there would be no increased flood benefits and a slightly increased risk of junior water rights curtailment in drought years, although TransAlta could continue to operate their water bank and support most water rights in most years. This is the least cost alternative of approximately $8.3 million.

The Flood Storage Only alternative would have little effect on steelhead but moderate to substantial negative effects on coho salmon, spring-run Chinook salmon, and fall-run Chinook salmon. There would be substantial flood damage reduction benefits in both existing and late-century climate conditions, particularly a reduction in the number of structures inundated by 3 feet or more in depth. There is a slightly increased risk of junior water rights curtailment in drought years, although TransAlta could continue to operate their water bank and support most water rights in most years. The cost of this alternative is approximately $42.2 million.

The Combined Fish-Flood alternative would substantially benefit steelhead and coho salmon but result in moderate declines for spring and fall-run Chinook salmon. There would also be substantial flood damage reduction benefits in both existing and late-century climate conditions. There is a slightly increased risk of junior water rights curtailment in drought years, although TransAlta could continue to operate their water bank and support most water rights in most years. The cost of this alternative is approximately $50.5 million.

All fish species would benefit from the Dam Removal alternative, with steelhead, coho salmon and spring-run Chinook salmon likely to benefit very significantly. There would be modest increases in flooding under the existing climate, although this effect is lessened in late-century when all alternatives have increased flooding. This alternative could be the highest cost, with construction costs ranging from $25 to $35 million, and, because it would have substantial effects on water rights, compensation for water rights could add up to $80 million, although this number is very preliminary. The current dam owner and operator (TransAlta) and the downstream cities have also indicated that dam removal is not an option that they would be interested in pursuing because it would eliminate the water bank.

Next Steps

The results of this second phase of analysis have indicated that each of the alternatives is theoretically feasible, but each alternative results in differing benefits or impacts to fish access/habitat or flood damage reduction. Many questions still remain that would need to be investigated to determine design and cost feasibility, such as if modifications to the dam could be achieved without negatively affecting the geotechnical and structural integrity of the dam, and to optimize dam operations to maximize flood and/or fish benefits. For dam removal, a detailed accounting of effects to water rights and feasible options to mitigate effects would need to be conducted.

The Chehalis Basin Board could consider a third phase of analysis that could include the following:

- Continue the Skookumchuck Dam working group and coordination with TransAlta.
- Continue the experimental flow study to assess if reducing fall flows to be more reflective of current natural inflows to the dam can help separate spring- and fall-run Chinook salmon spawning timing and minimize hybridization. This could lead to additional flow management recommendations based on the results of the study.
- Conduct a geotechnical investigation to determine if tunneling through the dam and adjacent bedrock is feasible or if there are other feasible method(s) to modify the dam for fish or flood purposes.
- Develop structure finished floor elevation data using the methods described by WSE (2016) to more accurately predict flood depths and damages (and/or avoidance of damages) downstream of the dam.
- Conduct gaging of flows on Big Hanaford Creek to more accurately predict both low and peak flows downstream of Big Hanaford Creek.
- Collect low-flow observations in multiple reaches of the Skookumchuck River to inform groundwater recharge and discharge (e.g., gaining reaches) and refine computed local inflows.

- Determine estimated water rights withdrawals and timing by month to develop detailed accounting of potential effects on water rights by alternatives or other operational changes in flows.
- Develop further detailed structural and hydraulic design of the fish sluice and low-level outlet.
- Conduct additional hydraulic modeling to optimize fish and/or flood operational rule curves and benefits.
- Conduct further analysis of downstream flood effects based on refined options and additional data collected, as identified previously.
- Conduct an economic analysis of the potential flood damage reduction benefits compared to the costs.
- Conduct an on-the-ground habitat survey upstream of the reservoir to refine fish benefit predictions.
- Install water quality gages in the reservoir to determine the source of turbidity that is discharged downstream.
- Conduct fisheries studies to assess juvenile fish passage survival under current conditions, including reservoir survival, travel time, survivability through the dam, and passage-related survivability for a relevant reach below the dam; the presence of predators/predation impacts in the reservoir (and if any impacts might be addressed); and tracking of adults to suitable spawning habitats.
- Conduct further investigation of Chinook and coho salmon juvenile out-migration timing and potential effects on feasibility of passage.
- Conduct geomorphic assessment of downstream conditions relative to reduced transport of sediment and large wood from upstream of the dam.
- Evaluate possible design refinements for downstream fish passage that could include lowering the elevation of the fish sluice.
- Develop preliminary designs to advance fish passage or flood storage elements that are feasible based on the preceding technical evaluations.

Budget options have been provided to the Chehalis Basin Board for the next phase of work that could fund some or many of these elements. At whatever funding level is provided, some of the work could move forward, with the highest priority elements including the geotechnical investigation and continued work with stakeholders and TransAlta.

1 INTRODUCTION

1.1 Background

This memorandum summarizes the results of the second phase of the Skookumchuck Dam analysis as requested by the Chehalis Basin Board. The first phase was conducted in 2021 (Anchor QEA et al.) and examined near-term options to modify operations at Skookumchuck Dam for flood damage reduction and/or aquatic species benefits. The purpose of this second phase is to identify the feasibility of physical or operational modifications to Skookumchuck Dam to provide flood damage reduction and/or aquatic species benefits.

The Skookumchuck River is approximately 40 miles long and extends from its headwaters near Huckleberry Mountain (elevation 3,800 feet) to its confluence with the Chehalis River at river mile (RM) 67 in Centralia (see Figure ES-1). Skookumchuck Dam is a 195-foot-high earth fill dam located at RM 21.9 that currently blocks access to all anadromous fish species to the upper half of the watershed. A watershed analysis prepared by Weyerhaeuser (1996) indicated that the dam may block up to 22 miles of habitat for steelhead, 8 miles for coho salmon, and 4 miles for Chinook salmon. References cited in the watershed analysis indicated that nearly half of the spawning habitat in the river was rendered inaccessible by the dam. Resident cutthroat and rainbow trout are also present in the upper watershed.

Constructed in 1970 by a consortium comprising Pacific Power and Light and several other utilities, Skookumchuck Dam stores water for augmenting flows downstream to allow withdrawal of water for the Centralia Steam Plant. The dam enabled the current owner, TransAlta, to exercise its water right certificate S2-14966C for 51.6 cubic feet per second (cfs) and 28,033 acre-feet; that has now been superseded by the water bank that TransAlta has created and that was approved by the Washington Department of Ecology (Ecology; certificate CS2-14966@1). TransAlta currently has a water right to withdraw 27 cfs and 12,000 acre-feet (certificate S2-30773); that right is anticipated to be added to the water bank after the planned shutdown of the Centralia Steam Plant in 2025. The dam is regulated by the Federal Energy Regulatory Commission (FERC) but is exempt from a license because it has a small (1-megawatt) hydroelectric power generator (installed in 1990). Water is also provided directly from the dam to the Washington Department of Fish and Wildlife (WDFW) fish hatchery (20 cfs continuously). As part of the mitigation agreement between TransAlta and WDFW, discharges from the dam are intended to provide beneficial conditions in-river for fish and also meet downstream minimum flows (see Table 3). The reservoir has a surface area of approximately 550 acres and extends 4 miles upstream of the dam.

Major features of the dam include the multi-level intakes, the spillway and its forebay, the downstream fish sluice passageway, the chute that returns fish and flows to the river, and the adult fish collection facility and steelhead rearing pond (see Figure 1).

Figure 1
Major Site Features of Skookumchuck Dam

1.2 Phase 1 Results Summary

The Phase 1 analysis (Anchor QEA et al. 2021) identified that the current dam configuration and operation can provide some flood storage early in the rainy season. However, once a larger storm event or multiple smaller storm events occur, the outlet system capacity cannot discharge enough flow to keep the reservoir low throughout the winter and early spring. As a result, there is not enough space to capture flood events in the middle or later part of the rainy season in most years. In the driest years, the reservoir could be held to a moderately low level to provide some flood storage throughout the rainy season (November through April) while still meeting downstream minimum flows.

The dam has an existing fish collection facility that is used to collect steelhead for hatchery broodstock and other purposes and is also used to trap and transport adult steelhead upstream of the reservoir in some years. The dam also has an existing fish sluice located in the spillway that allows for downstream passage of juvenile steelhead when the reservoir elevation is above 464 feet. The dam could be operated to discharge flow through the fish sluice during the peak out-migration season in late spring for juvenile steelhead in most years by reducing the discharge through the main outlet and changing operations to discharge the majority of flow through the fish sluice. This could be accomplished while still providing water supply to the hatchery and meeting water storage objectives and downstream minimum flows. While the existing fish trap suitably functions for the purpose of upstream passage, downstream passage through the existing fish sluice appears to have multiple problems related to high velocities, turbulence, and debris blockage and is explored further in this second phase of analysis.

A near-term operational change that was identified for consideration is changing the volume of dam releases for mid-August to mid-October flows to provide better separation between the arrival and spawning timing of spring- and fall-run Chinook salmon. Fall Chinook salmon migration and spawning could be delayed for a few weeks by eliminating the currently required ramp-up in flows that occurs in September and October and instead keeping flows as close to minimum flows (35 cfs) as feasible at the Bucoda gage and allowing flows to naturally increase as the rainy season begins. This option is currently being implemented in fall 2022 as part of an experimental study of adult Chinook salmon migration timing and results will be available in 2023.

The primary takeaway from the Phase 1 analysis was that operations for flood storage would likely conflict with operations for juvenile steelhead passage. This is because the reservoir would need to be held as low as possible throughout the winter and spring for flood storage, whereas the reservoir should be held as full as possible to allow passage through the fish sluice for downstream juvenile steelhead.

Larger-scale modifications were not investigated in detail during the first phase; however, the cost estimate prepared by the U.S. Army Corps of Engineers (USACE) to provide flood storage at Skookumchuck Dam (USACE 2003) was reviewed and the costs were escalated to 2021 dollars to provide an initial estimate of the costs to modify the dam. Costs range from approximately $22.3 to $27.5 million (2021 dollars) for the USACE proposal for 11,000 to 20,000 acre-feet of storage, respectively. Operational costs were not included.

Dam removal costs from other recent dam removals in the Pacific Northwest were also reviewed to identify an initial range of estimated costs for full or partial dam removal, with primarily revegetation upstream in the reservoir footprint, of $27.7 to $46.8 million for full removal or $20 to $33.7 million for partial removal (2021 dollars). It was also identified that dam removal would affect downstream water rights and would have to be analyzed in significantly more detail.

The Phase 1 analysis, while answering some questions, also raised the following additional questions that led to the development of this Phase 2 analysis:

- How effective is downstream fish passage currently?
- Could downstream passage for salmon species in the Skookumchuck River (steelhead, coho salmon, spring- and fall-run Chinook salmon) be feasible?
- Is the current upstream fish passage adequate to consider passing substantially more fish upstream?
- What is the quantity and quality of habitat upstream of the reservoir?
- Could the dam provide any effective flood damage reduction for either Bucoda or Centralia?
- Would modifications to the dam be cost prohibitive to accomplish either purpose?
- Would fish passage or flood storage alternatives affect downstream water rights or the operation of TransAlta's water bank?

1.3 Scope of Analysis for Phase 2

To answer the key questions identified from the Phase 1 analysis, the scope of this Phase 2 analysis includes several tasks to further evaluate the feasibility of operational and dam modification options to address flood damage reduction, aquatic species benefits, and the combination of both purposes. The following elements are included in the Phase 2 analysis:

- Three hydraulic models were developed to evaluate reservoir operation and dam modification or removal scenarios:
  - Computational Fluid Dynamics (CFD) modeling to evaluate detailed hydraulics within and near the fish sluice using a combination of FLOW-3D and HEC-RAS 2D
  - HEC-ResSim modeling of the upper river basin to quantify reservoir inflows, dam outflows, and downstream hydrologic routing
  - RiverFlow2D channel and floodplain modeling downstream of the dam (which included additional bathymetric surveying of the river downstream of Bucoda) to evaluate downstream hydraulic conditions resulting from the various scenarios
- To analyze aquatic species benefits, high-resolution aerial photography and Light Detection and Ranging (LiDAR) were obtained for the Skookumchuck River upstream of the reservoir to provide a desktop analysis of existing river habitat conditions, and

Ecosystem Diagnosis and Treatment (EDT) modeling was conducted to identify the potential benefits to fish from the various scenarios.

- A conceptual design was developed to modify the fish sluice to improve downstream juvenile salmonid passage.
- Further qualitative analysis was conducted of potential effects to water rights downstream in the Skookumchuck River that could be affected from the scenarios.
- Initial cost estimates were developed for the fish sluice improvements and reconfiguring the dam to increase the outlet capacity for flood storage.

1.4 Modeling Tools

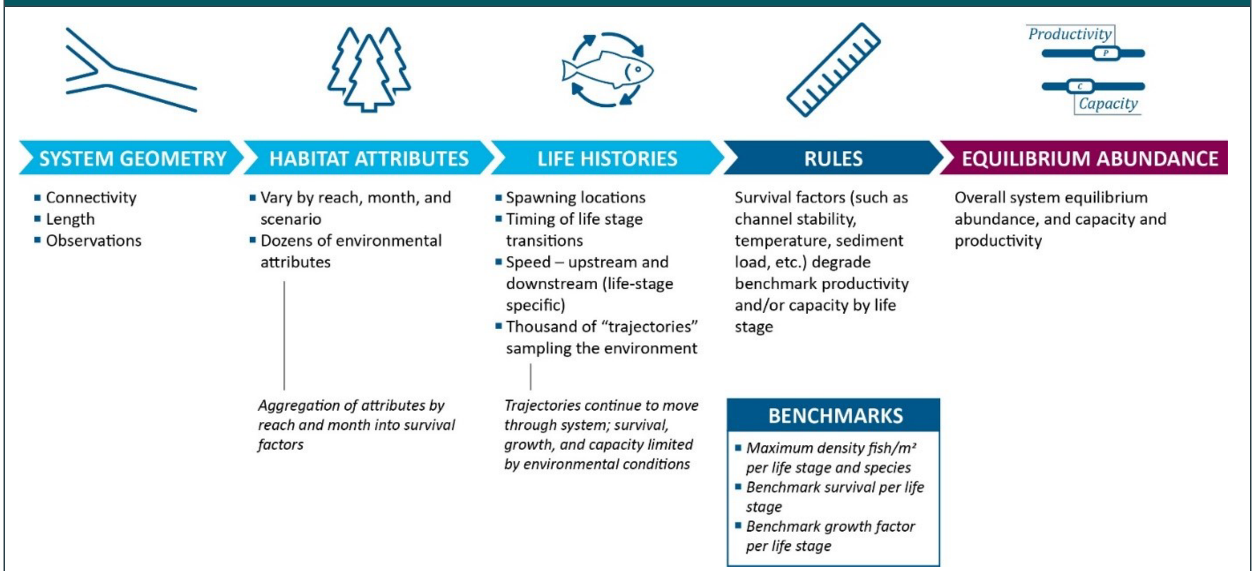
A number of computer models were developed and used to evaluate hydrologic and hydraulic conditions of the Skookumchuck Dam, reservoir, and the downstream Skookumchuck River. Each of these models is summarized here and described in greater detail in subsequent sections:

- **Computational Fluid Dynamics:** CFD modeling is based on the principles of fluid mechanics, utilizing numerical methods and algorithms to solve problems that involve fluid flows. In the case of Skookumchuck Dam, two different models were used: HEC-RAS 2D for evaluating hydraulic conditions in the approach to the dam spillway, and FLOW-3D for evaluating detailed hydraulic conditions immediately around the dam's fish sluice. HEC-RAS is a numerical simulation software package developed by the USACE (HEC 2021a). For this project, the 2D unsteady state capabilities of HEC-RAS were used. FLOW-3D is a proprietary software package for 3D hydraulic modeling developed and marketed by Flow Science (FLOW-3D 2018). Development of the FLOW-3D model and linking to the HEC-RAS 2D model is described in detail below.
- **Reservoir routing:** Reservoir routing was performed using the USACE HEC-ResSim model (HEC 2021b). HEC-ResSim provides tools to model reservoir operations for a variety of operational goals and constraints. The software simulates reservoir operations for flood management, low-flow augmentation, water supply, and a range of other purposes. HEC-ResSim represents the reservoir and river system through a network of elements (e.g., dams, reservoirs, junctions, routing reaches, diversions) that the user builds. The software can simulate single events or a full period-of-record at a user specified time-step. Development and application of the HEC-ResSim model to evaluate current and proposed operations at Skookumchuck Dam is described in detail below.
- **Hydraulic routing and analysis:** Hydraulic analysis of the Skookumchuck River and floodplain downstream of Skookumchuck dam was performed using Hydronia's RiverFlow2D Plus finite volume modeling program (Hydronia 2021). RiverFlow2D is an advanced 2D flexible-mesh hydraulic model, offering a high-performance finite-volume engine for rapid, accurate, and volume-conservative hydraulic computations. RiverFlow2D generates detailed hydraulic data for simulations of rivers and floodplains including areas of initially dry terrain. RiverFlow2D outputs include water surface elevation, flow depth,

flow velocity, bed shear, and other hydraulic variables of interest. RiverFlow2D has previously been used to simulate the entire Chehalis Basin and key tributaries for the Chehalis Basin Strategy as described in an earlier technical memorandum (WSE 2019). In this analysis, the Skookumchuck River portion of the Chehalis River model was updated and calibrated to recent flood observations. Model updates, calibration, and application for this project are described in detail below.

- **Habitat modeling:** The EDT model is a spatially explicit deterministic model used to evaluate habitat conditions relevant to the life stages of the modeled fish (salmonid) species in river reaches used or passed through during the life cycle of the species (Blair et al. 2009). EDT 3.0 is the current version used for this study. Overall, three basic components are used that contribute to characterization of EDT for a watershed: the system geometry (i.e., river network), habitat attributes, and the life histories of the fish species evaluated (Figure 2).

Figure 2
EDT Framework



The EDT model used for the Aquatic Species Restoration Plan was used as the basis for this analysis and was updated to include existing and late-century climate change habitat conditions in the Skookumchuck River with simulated hydraulic data and estimated upstream and downstream passage values at the Skookumchuck Dam to evaluate metrics and indicators of habitat conditions to characterize habitat status and trends in terms of the change in habitat performance for fish species of interest. EDT model results include population level estimates of capacity, productivity, diversity, and equilibrium abundance by scenario. For the purposes of this report, equilibrium abundance is the primary result shown as well as productivity and diversity.

1.5 Alternatives Evaluated in Phase 2

Multiple alternatives were developed and evaluated to identify the potential flood damage reduction and fish benefit objectives including fish passage alternatives, flood storage alternatives, combined fish passage-flood storage alternatives, and dam removal. Current reservoir operations were also simulated as a baseline for comparison to the alternatives, and all alternatives were evaluated under both existing and projected future climate conditions. The following alternatives were initially developed, and then the most promising alternatives for each potential purpose were carried further through detailed modeling. Note, these alternatives are hypothetical and would require more detailed design to ensure feasibility.

1. **Fish Passage Only Alternatives:** These alternatives were developed to focus solely on improving downstream fish passage and would require maintaining reservoir water levels as high as possible throughout the fish migration period (January 1 through mid-summer). Several possible discharge volumes through a fish sluice that are likely to provide sufficient attraction flows and velocities for juvenile fish to find the fish sluice were considered at constant flow rates of 25, 40, 65, or 120 cfs. These alternatives were modeled by only discharging flow through the fish sluice, plus 20 cfs through the intakes for hatchery water supply for total discharges of 45, 60, 85, or 140 cfs from the dam, year-round (except what passes over the spillway when the reservoir is above the spillway crest). This allowed an analysis of the duration at which the reservoir can be maintained at elevations higher than 467 feet to allow the fish sluice to operate with sufficient flow and depth for optimal fish passage.
2. **Flood Storage Only Alternatives:** These alternatives were developed to focus solely on flood storage by increasing the discharge capacity of the dam outlet so that the reservoir elevation could be maintained low enough during the flood season (generally October 1 to April 30) to reserve a portion of the reservoir storage solely for flood control. Flood storage capacities of 11,900 acre-feet, 20,000 acre-feet, and 35,000 acre-feet were paired with hypothetical outlet discharge capacities of 1,000 cfs, 2,000 cfs, or 3,000 cfs for evaluation.
3. **Combined Fish and Flood Alternatives:** The most effective Fish Passage Only and Flood Storage Only alternatives were combined to develop alternatives that provide both Fish and Flood benefits to understand to what extent both objectives could be achieved. Combined alternatives included the allocation of 14,000 or 20,000 acre-feet of reservoir storage to flood storage between October 1 and January 1, with 2,000 cfs of discharge capacity via a low-level outlet. To address fish passage, the reservoir was targeted to refill to full pool each spring with 50% or 75% probabilities of refill by March 15 and then ramping back dam discharges to provide discharge through the fish sluice only 65 cfs (plus 20 cfs to the hatchery) starting on March 15 and extending as long as possible through the summer.
4. **Dam Removal Alternative:** This alternative was carried forward from the Phase 1 analysis (Anchor QEA et al. 2021), which identifies partial or full removal of the dam restoring the current reservoir footprint to riverine conditions and a return to pre-dam hydraulic conditions with all flows from upstream of the dam passing unhindered downstream.

2 HYDROLOGIC ANALYSIS

The modeling of Skookumchuck Dam alternatives requires hydrologic data as input to the hydraulic models. Current operations at the dam are intended to meet dam discharge requirements from the operating agreement between TransAlta and WDFW as measured at Bloody Run and minimum instream flow requirements as measured at Bucoda, and provide water for TransAlta diversions to the Centralia Steam Generation Power Plant. Therefore, detailed hydrologic data are needed to define inflows to the dam, local inflows downstream of the dam, and diversions by TransAlta and other water rights holders. The U.S. Geological Survey (USGS) operates several streamflow gaging stations in the basin including gages near Vail, near Bloody Run Creek, and near Bucoda. In addition to the USGS gages, TransAlta maintains records of diversions from the Skookumchuck River to the Centralia Steam Plant. Additional flow diversions are made by other water rights holders based on their water rights. Approximate locations for these other diversions are known, but the amount being diverted at any time is not known. For purposes of this analysis, it is assumed that these smaller diversions operate at full capacity at all times, a conservative assumption. Table 1 summarizes streamflow and other data used to develop the hydrologic data for the analysis.

Table 1
Data Sources for Hydrologic Analysis

GAGE ID	DESCRIPTION	PERIOD OF RECORD		
		15-minute Data	Daily Data	Peak Flow Data
12025700	Skookumchuck River Near Vail, WA	WY 1988 – present	WY 1968 – present	WY 1968 – present
12026150	Skookumchuck River Bloody Run Creek Near Centralia, WA	WY 1988 – present	WY 1970 – present	WY 1940 – present
12026400	Skookumchuck River Near Bucoda, WA	WY 2008 – present	WY 1968 – present	WY 1969 – present
N/A	TransAlta Diversions	none	2008–2022[1]	none
N/A	Other Diversions[2]	none	none	none

Notes:
1. TransAlta diversion records include daily data with a short period of monthly data. All data were resampled to a 15-minute time step for HEC-ResSim modeling.
2. Total of other surface water diversions is approximately 10.3 cfs, not including the Town of Bucoda's surface water right of 11.1 cfs as it is our understanding that this right is only used intermittently. The 10.3 cfs of other water rights were conservatively assumed to be diverted at the maximum allowable rate throughout the year, although it is expected that withdrawals primarily occur during the summer months.

Hydrologic data for the hydraulic analyses were developed in several steps (see details in Appendix A). First, the analysis used the 15-minute data from the Vail, WA, gage (USGS 12025700) for the period from October 1987 to the beginning of March 2022 and inflows were scaled for tributaries between the Vail gage and Skookumchuck Dam using basin area and mean annual precipitation. The ungaged tributary inflows are slightly more than 45% of the Vail flows. Next, data were used from the Skookumchuck River below Bloody Run Creek, WA, gage (USGS 12026150) and the Skookumchuck River near Bucoda, WA, gage (USGS gage 12026400) to compute a time series of local inflows downstream of the dam. Diversion data for TransAlta and other diversions between the two gages were subtracted from the upstream flows. Once the total local inflows between Bloody Run and Bucoda were calculated, they were apportioned to discrete reaches along the Skookumchuck River and adjusted to account for routing time between the two gages. Figure 3 shows a schematic of the Skookumchuck River with reach locations, and Table 2 shows computed median monthly flows over the period of analysis (water year [WY] 2008 to 2022). There are no USGS gages downstream of Bucoda on the Skookumchuck River[7], so local inflows downstream of Bucoda were scaled from the upstream local inflow data in the same manner as the upstream tributaries. An additional step was taken for Hanaford Creek inflows. The Hanaford Valley is broad and has a very low gradient, and previous modeling has shown that discharges from Hanaford Creek to the Skookumchuck River are attenuated by the significant floodplain storage available on this tributary (WSE 2014). To account for this, calculated local inflows from Hanaford Creek were first adjusted by level pool routing[8] before being discharged to the Skookumchuck River. Parameters for the level pool routing, specifically the stage-storage-discharge relationship, were taken from earlier HEC-RAS modeling of Hanaford Creek (WSE 2014).

In addition to creating long time series of reservoir and local inflows as described above, hypothetical design flood event hydrographs were also developed. To generate these hydrographs, flow frequency analyses were performed on the 15-minute historical flow data for the Vail gage (WY 1988 to 2022) and for the local inflows computed as described above (WY 2008 to 2022). Flow frequency analyses were conducted for annual instantaneous peak flows and for 24-hour, 3-day, 7-day, and 15-day durations. The computed flow frequency data were then used in HEC-SSP (HEC 2022), together with the flow pattern of the January 2022 flood event, to create "balanced" inflow hydrographs corresponding to the 2-, 10-, 20-, and 100-year recurrence intervals.

A second set of data was developed corresponding to projected late-century climate change. For the design flood events, late-century flows were developed by scaling existing conditions flows up by 60% and then making the flow adjustments and apportioning the flows as described above for existing conditions. The 60% increase for Skookumchuck River flows was based on previous

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[7] There is a gage in Centralia, currently operated by the National Weather Service, but it was not used in the analysis because it only has stage data available.
[8] Level pool routing is a simplified flow routing technique that assumes water in storage (i.e., the pool) has a level water surface, and discharges can therefore be defined based solely on the volume versus outflow rate of the pool.

analyses done by WSE and the UW Climate Impacts Group for the Chehalis Basin (CIG 2021) that represents a high-end climate change scenario. Using the same scalar for Skookumchuck River flows as is being used in other Chehalis Basin Strategy investigations ensures consistency between the studies. For seasonal and low-flow analyses, a different scaling approach was applied. Winter flows (November through April) were scaled up by 17% and summer flows (May through October) were scaled down by 30%. These scalars match the adjustments being used for seasonal and low-flow analyses throughout the Chehalis Basin as described in Anchor QEA (2021). Climate adjusted hydrologic data as described herein were used to simulate operational alternatives and evaluate performance of the alternatives under the projected late-century conditions. The results of the analysis with flows adjusted for projected climate change are described below.

2.1 Water Budget

The process described above was used to develop hydrologic data for modeling and analysis of the Skookumchuck River. These data were also used to create a water budget for the Skookumchuck River. Using HEC-ResSim, a routing model was configured to simulate flows along the mainstem Skookumchuck River from the Bloody Run gage to the mouth of the river. Upstream inflows to the model were taken directly from the Skookumchuck River below Bloody Run gage (USGS 12026150). The HEC-ResSim model routed flows down the river to match the observed attenuation of flows between the Bloody Run and Bucoda gage locations.

Distributed local inflows were added to the model and diversions subtracted at the appropriate locations. The result of this process was a 15-minute time series of discharges for ten reaches along the Skookumchuck River downstream of the Bloody Run gage. It should be noted that there is considerable uncertainty in the 15-minute data due to a number of factors including: TransAlta diversion records being limited to daily or monthly data, lack of detailed diversion data for non-TransAlta water rights diversions, uncertainties in the USGS gage data, lack of observed flow data downstream of the Bucoda gage, variations in travel time and attenuation not captured by the channel routing, and a lack of any detailed information on groundwater discharges or recharge in the study reaches. Given these uncertainties, it was reasonable to use the computed flow data to estimate a monthly water budget for the Skookumchuck River, but the data should not be used for detailed analysis of historical conditions at shorter time intervals.

Table 2 summarizes median monthly flows by reach for the recorded historical data from October 2008 to February 2022. Inflows to the reservoir are also shown for reference. As noted previously, the historical condition uses observed historical discharges at the Bloody Run gage (October 2007 to February 2022 records), together with computed local inflows and diversions downstream of Bloody Run, to define flows throughout the study area. It is important to note that the reservoir has been drawn down on occasion in the past for other purposes (such as inspections) that affected the discharge of peak flows from the dam in past years. For the modeling of the reservoir, specific rules were applied to ensure discharges met a WDFW operating agreement and Ecology-mandated minimum flows, but these rules do not account for these types of drawdowns and typically result in higher predicted discharges from the dam than what has been historically measured at the gages.

In addition to the historical condition, water budget analyses were also conducted on modeled conditions from the HEC-ResSim model using the above model rules), and on a scenario assuming Skookumchuck Dam removal paired with eliminating the TransAlta diversion (using computed flows from Vail gage upstream of the reservoir and scaled tributary flows). HEC-ResSim modeling of these scenarios is described in detail later in this report. The resultant median monthly flows by reach for the current operations and dam removal conditions are also shown in Table 2. Appendix A provides a more comprehensive summary of the flow data, including the median monthly flows as well as the 10% and 90% exceedance flows by month.

As shown in Table 2, the historical condition and current operating scenario result in similar flows in each of the downstream reaches. Median monthly flows tend to reach their minimums in July and August, while these median flows rise again starting in September, with the onset of winter rains in many years. Differences in median monthly low flows between the historical and current operating scenarios are likely due to the factors mentioned previously, as well as due to reduced historical outflows during some drought years as a result of negotiations between TransAlta and WDFW and Ecology. The dam removal scenario generally results in lower median monthly flows in summer months (June, July, August, September) and higher median monthly flows the rest of the year, compared to either the historical condition or the current operations. Increases in median flows with dam removal are particularly large in November when the reservoir is generally refilling under either the historical or current operations.

Table 2

Skookumchuck River Water Budget (Median Monthly Flow in cfs, Based on October 2007 through February 2022 Data)

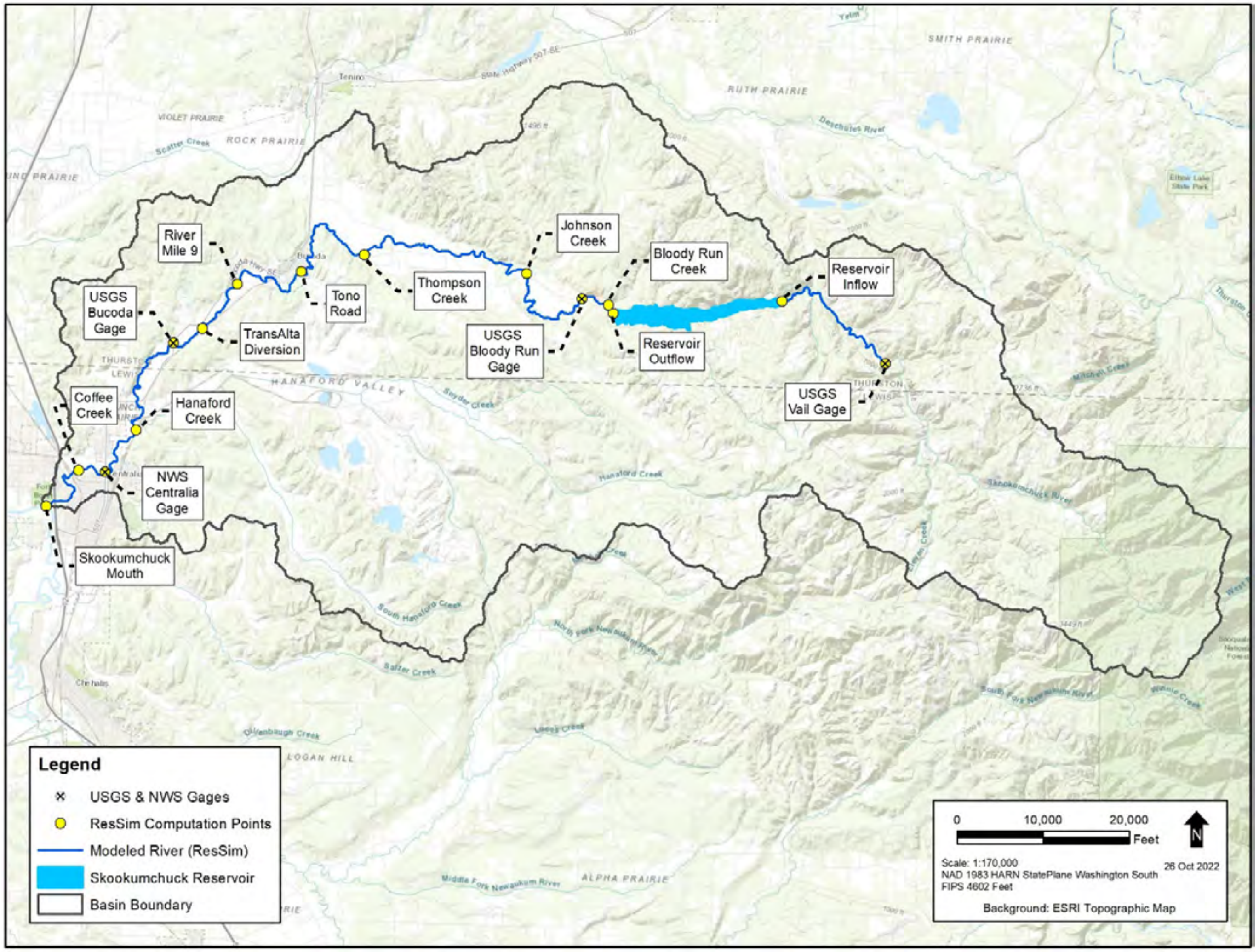
MONTH	INFLOW TO DAM, ALL SCENARIOS	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RM 9	RM 9 TO TRANSALTA DIVERSION	TRANSALTA DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
Historical Conditions Using Observed Flows at Bloody Run Gage as Upstream Model Inflow[1]											
January	620	573	661	744	799	822	821	820	1,252	1,252	1,269
February	427	405	505	583	623	639	639	638	930	930	942
March	355	289	330	371	392	400	394	394	568	568	577
April	379	340	391	441	467	477	463	464	652	652	660
May	173	202	221	241	250	254	237	237	292	292	294
June	88	133	137	143	147	149	143	142	179	178	181
July	50	99	100	112	118	120	90	90	107	106	107
August	36	88	91	95	97	97	64	63	78	78	79
September	33	114	119	118	117	116	91	90	97	97	98
October	153	123	130	138	139	139	109	108	121	120	120
November	508	204	249	307	337	349	325	323	543	543	550
December	490	438	519	587	622	636	617	615	869	868	878
Current Conditions Using HEC-ResSim Simulated Outflows from Skookumchuck Dam Under Minimum Instream Flow Requirements as Upstream Model Inflow											
January	620	670	791	883	928	944	921	919	1,259	1,258	1,276
February	427	465	546	624	665	681	681	681	973	973	985
March	355	371	413	453	474	482	476	476	635	634	641
April	379	402	468	517	543	553	539	539	728	728	736
May	173	179	197	216	225	228	212	210	281	281	283
June	88	103	110	120	125	127	114	114	145	145	147
July	50	97	100	104	105	105	77	76	91	91	91
August	36	96	99	104	106	106	72	71	87	87	87
September	33	141	144	148	150	150	118	117	128	128	128
October	153	131	136	141	143	143	117	116	140	139	140
November	508	363	415	465	491	501	463	461	652	651	658
December	490	495	568	639	675	689	652	650	904	903	913
Dam Removal Conditions Using Computed Historical Flows from Vail Gage as Upstream Model Inflow											
January	620	655	776	890	934	951	950	948	1,269	1,268	1,281
February	427	450	531	608	648	664	663	662	954	954	965
March	355	375	417	457	478	486	486	485	666	665	674
April	379	401	462	511	538	548	548	548	737	737	745
May	173	181	200	218	228	231	230	229	300	299	302

MONTH	INFLOW TO DAM, ALL SCENARIOS	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RM 9	RM 9 TO TRANSALTA DIVERSION	TRANSALTA DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
June	88	93	99	105	108	109	109	109	134	134	136
July	50	52	55	60	62	62	62	61	78	78	79
August	36	37	41	45	47	47	46	46	60	59	60
September	33	34	38	44	45	45	45	44	56	56	57
October	153	155	153	155	160	161	161	160	193	193	194
November	508	535	590	644	671	682	682	681	863	862	868
December	490	519	572	642	678	692	691	689	944	943	953

Note:

1. Historical conditions are equivalent to currently observed and recorded conditions from gage data.

Figure 3
Skookumchuck River HEC-ResSim Model Layout with Computation Points/Local Inflows



Note: The location of the National Weather Service (NWS) Centralia Gage is shown, but data were not used in this analysis.

3 HYDRAULIC MODELING OF ALTERNATIVES

As identified in Section 1.4, several hydraulic models were developed and used to help answer the following key questions that resulted from the Phase 1 analysis:

- How effective is downstream fish passage currently?
- Could downstream passage for salmon species in the Skookumchuck River (steelhead, coho salmon, spring- and fall-run Chinook salmon) be feasible?
- Could the dam provide any effective flood damage reduction for either Bucoda or Centralia?

3.1 Reservoir Modeling

To address questions about downstream fish passage and flood storage, a reservoir routing model of Skookumchuck Dam, Reservoir, and River was developed using the USACE HEC-ResSim software. This allowed the project team to explore to what extent discharges from the dam would need to be reduced to keep the reservoir full during the juvenile salmon migration and to what extent discharges from the dam would need to be increased to keep the reservoir low enough to store flood water to provide measurable downstream flood damage reduction. In addition, a combination of fish passage and flood storage was evaluated to identify if both purposes could be accomplished, and to what extent.

HEC-ResSim provides tools to model reservoir operations to meet specific flow management objectives. HEC-ResSim represents the reservoir and river system as a connected network of elements (river reaches, diversions, reservoirs). The software considers reservoir inflows, operations, and downstream conditions, and can simulate individual flow events or a full period-of-record at any desired time step, limited only by the availability of flow data.

For Skookumchuck Dam, the baseline HEC-ResSim model was configured to include the dam, main outlet, flow to the Skookumchuck fish hatchery, fish sluice, and uncontrolled flow over the spillway. Hydrologic inputs to the HEC-ResSim model were developed as described in Section 2. Inflows were developed for the basin upstream of the reservoir and for local inflows downstream of the dam to the mouth of the Skookumchuck River. Recorded diversion data were also used to account for the TransAlta diversion in the model, and water rights information was used to adjust flows in other downstream reaches for non-TransAlta diversions. Existing hydrologic conditions and conditions with projected late-century high-end climate change were evaluated. The HEC-ResSim model extends from the Vail USGS gage to the confluence with the Chehalis River. The routing of flows in reaches downstream of the dam was included in the model and calibrated by comparing simulated to observed flows at the Bucoda gage (see Appendix A).

Reservoir routing in the HEC-ResSim model was performed using level pool routing.[9] Data defining the relationship between stage and storage volume in the reservoir were provided by TransAlta and configured in the model. Outflows were determined based on the reservoir operating rules and subject to the hydraulic capacities of the various outlets. The baseline (current conditions) model operating rules require that 20 cfs of flow be discharged to the fish hatchery at all times. This water was assumed to pass through the hatchery and be discharged back to the river upstream of the Bloody Run gage. The second priority for reservoir operations was to meet minimum instream flow requirements as listed in Table 3. These included the WDFW operating agreement minimum required discharges from the dam (as measured at the Bloody Run gage) and the Ecology-designated minimum instream flow requirements at the Bucoda gage. The only time that minimum instream flows would not be met in the model is if the reservoir dropped below the elevation needed to provide adequate discharge through the main outlet. There were no other required releases from the reservoir beyond the fish hatchery and minimum instream flow releases. However, additional user-specified discharges for fish passage would be made when reservoir levels were high enough to discharge through the fish sluice. TransAlta provided a manual record of fish sluice gate openings that was adjusted to resolve gaps and apparent errors, then converted into a time series for use in the model. The sluice gate was operated according to the TransAlta record. When reservoir inflows exceeded the capacity of the fish sluice and main outlet, the reservoir pool would continue to rise until it reached the crest of the spillway at elevation 477 feet. Additional flow was then discharged over the spillway according to the spillway rating curve until inflows receded and the reservoir water surface elevations dropped below the spillway crest.

Table 3
Skookumchuck River Flow Requirements for Current Dam Operations in ResSim

ANNUAL DATE	DISCHARGE REQUIRED FROM DAM AT BLOODY RUN (CFS)	MINIMUM WDFW APPROVED DROUGHT FLOW AT BLOODY RUN (CFS)	ECOLOGY-DESIGNATED MINIMUM FLOW AT BUCODA (CFS)
December 1 – May 1	95	-	160
By May 15	95	80	130
By June 1	95	65	103
By June 15	95	65	83
By July 1	95	65	67
By July 15	95	65	54
By August 1	95	65	43
By August 15	95	65	35
By November 1	100–140 [1]	-	59
By November 15	95	-	96
By December 1	95	-	160

Note:
1. Higher spawning flows depending on reservoir elevation (September 1 to October 20)

[9] Level pool routing is a simplified flow routing technique that assumes water in storage (i.e., the pool) has a level water surface, and discharges can therefore be defined based solely on the volume versus outflow rate of the pool.

The current baseline operations HEC-ResSim model was validated against observed data by comparing simulated with observed reservoir water levels, and by comparing simulated downstream flows to gaged flows at Bloody Run and Bucoda. The following operating scenarios were evaluated in HEC-ResSim:

1. Fish Passage Only (4 alternatives) with the following criteria:
    a. Make constant discharges to the fish hatchery of 20 cfs year-round.
    b. Maintain reservoir water levels as high as possible throughout the year to provide water for fish sluice operations.
    c. Target fish sluice discharges via the existing sluice gate at a constant rate of 25, 40, 65, or 120 cfs (4 variations) year-round (downstream fish migration season of interest is January 1 through mid-summer).
    d. Continue fish sluice discharges at specified rate as long as water supply allows.
    e. Do not provide additional discharges solely to meet current minimum instream flow requirements.
2. Flood Storage Only (9 alternatives) with the following criteria:
    a. Make constant discharges to the fish hatchery of 20 cfs year-round.
    b. Continue to meet current minimum instream flow requirements.
    c. Allocate a portion of the reservoir storage for flood control. Flood storage capacities of 11,900 acre-feet, 20,000 acre-feet, and 35,000 acre-feet were evaluated (3 variations).
    d. Construct a new low-level high-flow outlet with a hydraulic capacity of 1,000 cfs, 2,000 cfs, or 3,000 cfs (3 variations).
    e. Simulate conditions with each combination of storage and discharge capacity (9 combinations).
3. Combined Fish-Flood (4 alternatives) with the following criteria:
    a. Combine key aspects of the fish and flood alternatives.
    b. Allocate 14,000 or 20,000 acre-feet of reservoir storage to flood control between October 1 and January 1 or later (2 variations).
    c. Add a new low-level outlet with a 2,000 cfs discharge capacity at an inlet elevation based on the reservoir storage allocation above.
    d. Assume high reservoir inflows, exceeding 2,000 cfs, can be forecast with certainty up to 60 hours in advance and use this information to make preemptive releases from the reservoir to provide targeted flood storage.
    e. Target refilling the reservoir to full pool by March 15 of each year and select a date to start refilling based on a 50% or 75% probability of refill by March 15 (2 variations).

   f. Start fish sluice discharges of 65 cfs on March 15 or when reservoir levels are high enough to provide 65 cfs through the sluice and continue as long as the reservoir is high enough, target of mid-summer.
   g. Simulate conditions for each storage volume (2) with each probability of refill (2) for a total of 4 alternatives.
4. Dam Removal (1 alternative) with the following criteria:
   a. Assume complete removal of the dam and reservoir and a return to pre-dam hydraulic conditions (i.e., natural channel routing only).
   b. Eliminate TransAlta flow diversions.

A total of 19 scenarios were considered as described above, including current operations (i.e., No Action) and 18 alternatives within the 4 categories. For each alternative, flows were simulated through the dam and as far as the Bloody Run gage for the period October 1987 through March 2022. Simulated annual peak flows at the Bloody Run gage are shown in Table 4 (the January 2009 flood was the largest flood in all scenarios). Frequency analyses were also conducted on a subset of the alternatives, and results of the frequency analysis are provided in Appendix A. As described in Section 2, due to data limitations at the Bucoda gage, modeling of flows downstream of the Bloody Run gage could only be done for the period October 2007 to March 2022. HEC-ResSim modeling of the entire river to its mouth for the 19 alternatives was conducted for the 2007 to 2022 period, and simulated peak flows at the Bucoda gage were reviewed to verify the model routing and provide additional insight into the performance of the alternatives. Table 4 shows the simulated peak flows near Bucoda for the January 2009 flood event. As seen in Table 4, there is a wide range in simulated flows at Bloody Run, ranging from a low of 1,820 cfs for the most aggressive flood reduction option (with 35,000 acre-feet of dedicated flood storage) to 13,710 cfs for the dam removal scenario. The Current Operations and Fish Passage Only alternatives have the same maximum discharge because the reservoir was modeled to be essentially full at the onset of this flood in all of these alternatives and thus flow attenuation was minimal. The dam removal scenario would have slightly higher outflows (approximately 6% higher) than the current operations for an event similar to the January 2009 event. All of the Flood Storage Only and Combined Fish-Flood alternatives would result in lower peak flows at Bloody Run, although some would only be marginally lower. The combination alternatives result in a 63% to 70% reduction in peak flows at Bloody Run.

The simulated peak flows at Bucoda for the different alternatives do not show as large a difference as the flows at Bloody Run. The range in flows at the Bucoda gage is only 6,290 cfs to 17,200 cfs. The dam removal scenario results in similar flows at Bucoda as the Current Operations. The Combined Fish-Flood alternatives result in about a 50% reduction in flows at Bucoda relative to the Current Operations. The difference in the responses at the Bloody Run and Bucoda gages is caused by the additional inflows and routing effects in the river reaches between them, which reduce the impact of flood storage at the dam at Bucoda.

Table 4
Simulated Peak Flows at the Bloody Run Gage for the January 2009 Flood for each Alternative

SCENARIO/ALTERNATIVE	PEAK FLOW AT BLOODY RUN FOR JAN 2009 EVENT (CFS)	PEAK FLOW NEAR BUCODA FOR JAN 2009 EVENT (CFS)
Actual Recorded Discharge	6,900	10,500
Simulated Flows		
Current Operations	12,970	17,200
Fish Passage: Max 25 cfs through sluice	12,970	17,200
Fish Passage: Max 40 cfs through sluice	12,970	17,200
Fish Passage: Max 65 cfs through sluice	12,970	17,200
Fish Passage: Max 120 cfs through sluice	12,970	17,200
Flood Storage: 11,900 AF & 1,000 cfs outlet	12,060	16,160
Flood Storage: 11,900 AF & 2,000 cfs outlet	11,170	15,110
Flood Storage: 11,900 AF & 3,000 cfs outlet	10,430	14,250
Flood Storage: 20,000 AF & 1,000 cfs outlet	8,660	11,940
Flood Storage: 20,000 AF & 2,000 cfs outlet	5,590	8,840
Flood Storage: 20,000 AF & 3,000 cfs outlet	4,310	8,410
Flood Storage: 35,000 AF & 1,000 cfs outlet	1,820	6,290
Flood Storage: 35,000 AF & 2,000 cfs outlet	2,680	7,140
Flood Storage: 35,000 AF & 3,000 cfs outlet	3,480	7,920
Combined: 14,000 AF & 50% probability refill	4,820	8,590
Combined: 14,000 AF & 75% probability refill	4,820	8,590
Combined: 20,000 AF & 50% probability refill	3,940	8,400
Combined: 20,000 AF & 75% probability refill	4,140	7,670
Dam Removal	13,710	17,060

3.2 Hydraulic Modeling of Skookumchuck River Downstream of Dam

To address questions relating to whether measurable flood damage reduction could be provided to either Bucoda or Centralia, a RiverFlow2D hydraulic model was developed and applied to simulate channel and floodplain hydraulic conditions downstream of Skookumchuck Dam. This allowed the project team to understand the potential changes in the extent of flooding across the floodplain and the depth of flooding for the various alternatives.

RiverFlow2D is an advanced 2D flexible-mesh hydraulic model, which generates detailed hydraulic data from simulations of rivers and floodplains under time varying hydrologic conditions. Model outputs of interest for this study include water surface elevation, flow depth, and flow velocity. RiverFlow2D has previously been used to simulate the entire Chehalis Basin and key tributaries as described in an earlier technical memorandum (WSE 2019). The current project included trimming the Chehalis River model to the Skookumchuck study area, updating the model configuration within the basin to use newer topography and bathymetry, and calibrating the model to recent flood observations. Model updates and calibration are briefly summarized here, and described in more detail in Appendix A.

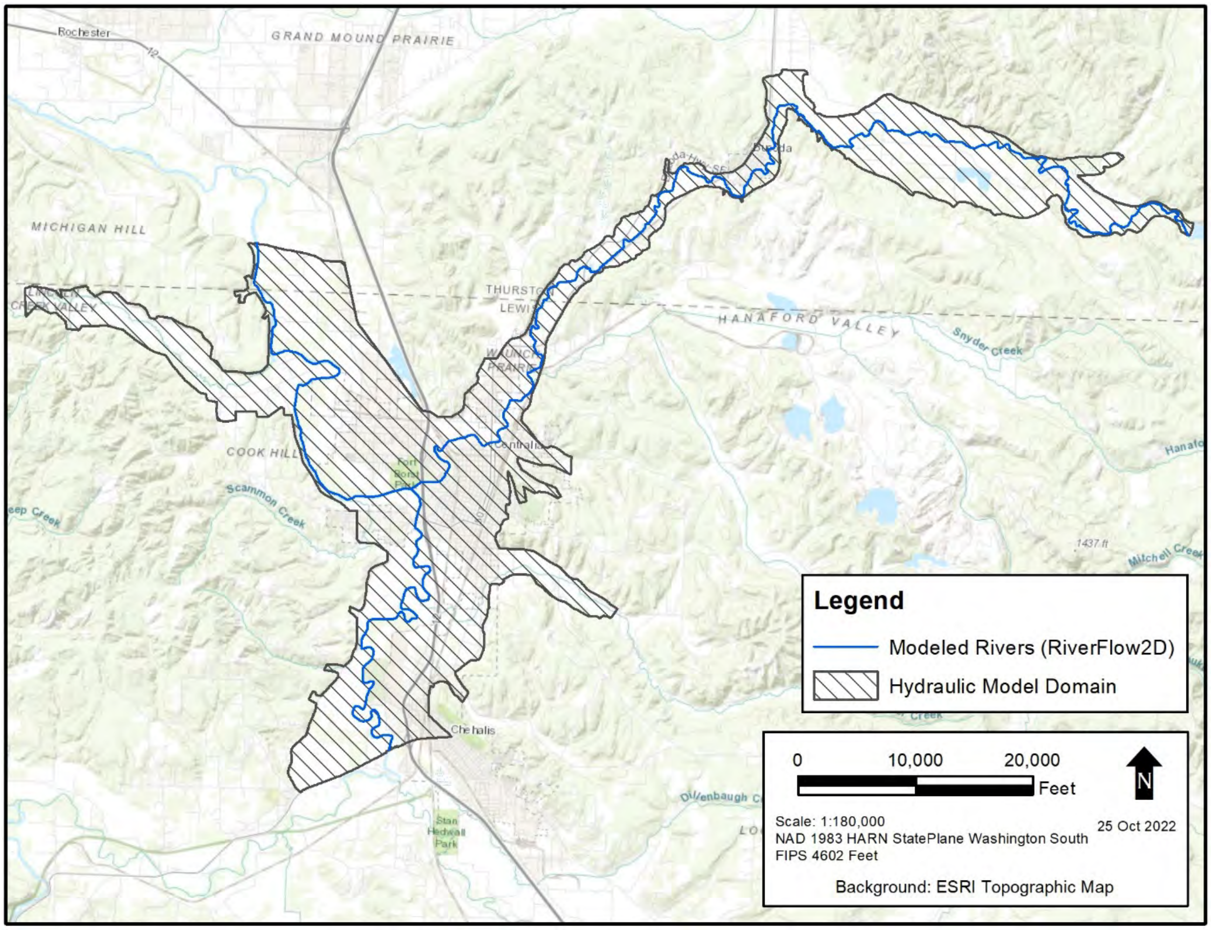
3.2.1 RiverFlow2D Model Development

The existing Chehalis River RiverFlow2D model (WSE 2019) was used as the starting point for this analysis. The first step in the process was to pare the Chehalis River model down to just the area of interest for this study, primarily the Skookumchuck River. Because flooding in the Lower Skookumchuck River can be affected by flows on the Chehalis River, the model for this study needed to include a section of the Chehalis River. Based on analysis of earlier Chehalis River modeling, it was determined that a model domain including the entire Skookumchuck River downstream of Skookumchuck Dam as well as the Chehalis River from upstream of the airport levee to the Grand Mound USGS gage was adequate. Figure 4 shows the model domain included in this study. After trimming the model, new topographic data were used to update the model, including new cross sections surveyed by Gravity Marine LLC in December 2021 for the reach from Bucoda to the mouth, channel cross sections through Bucoda from a 2014 survey, and newer LiDAR data including: for the reach just below the dam from the Aquatic Species Restoration Plan (ASRP; 2017), Grays Harbor County (2012), SWAA (2017), and Thurston County (2011).

3.2.1.1 RiverFlow2D Model Inflows

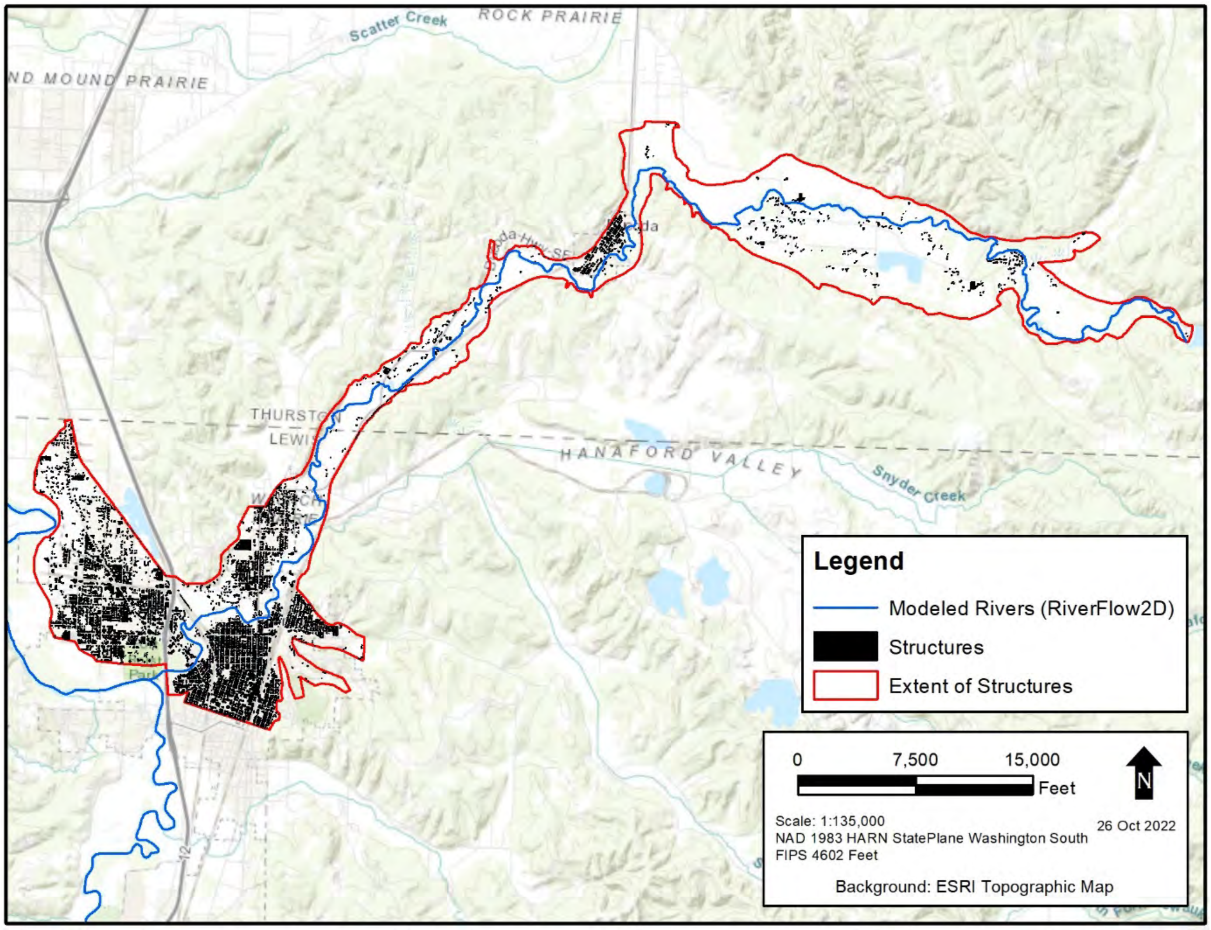
Inflows to the RiverFlow2D model were taken from the HEC-ResSim simulations. For historical conditions including the January 2022 calibration event, upstream inflows were taken from the USGS gage below Bloody Run Creek. For current operations and operating alternatives at Skookumchuck Dam, inflows to the RiverFlow2D model at Bloody Run were extracted from the HEC-ResSim model. All local inflows downstream of the Skookumchuck Dam were obtained from the hydrologic analysis previously described. The 2-, 10-, 20-, and 100-year design events were modeled in HEC-ResSim for each of the operating alternatives and then used as input to the RiverFlow2D model. Hydrologic inputs for the most promising four selected alternatives from the original 19 were modeled in RiverFlow2D: 1) Current Operations and Fish Passage Only (65 cfs); 2) Flood Storage Only (20,000 acre-feet and 2,000 cfs outlet); 3) Combined Fish-Flood; and 4) Dam Removal. The combinations of four operating alternatives and four design events resulted in 16 RiverFlow2D simulations for existing hydrologic conditions. An additional 16 HEC-ResSim and RiverFlow2D simulations were completed for late-century hydrologic conditions. RiverFlow2D boundary conditions on the Chehalis River for all of the simulations were taken directly from earlier Chehalis River simulations of the 2-, 10-, 20-, and 100-year existing and future climate conditions (WSE 2019).

Figure 4
RiverFlow2D Hydraulic Model Domain with Modeled River Segments



Potential reductions in flooding were evaluated using changes in downstream flows and the number of structures inundated in each combination of alternative and flow scenario. A structure database covering the model domain was developed from the existing 2016 Chehalis Basin structure database (WSE 2016) and expanded using 2020 Microsoft Building Footprints not already in the 2016 database. Structures less than 100 square feet were removed from the database under the assumption that these were likely sheds or other minor outbuildings and not habitable structures. The database was then trimmed to include only the structures likely to be affected by Skookumchuck River flooding. Figure 5 shows the bounding polygon used to define the potential Skookumchuck River flooding evaluation area and the structures within it.

Figure 5
Distribution and Extent of Structures Used for Inundation Analysis



3.2.2 Current Operations and Fish Passage Only Alternatives

Based on the HEC-ResSim modeling, the Fish Passage Only alternatives would all result in the same peak outflow from the dam, and these would be approximately the same as the peak outflow simulated for the Current Operations scenario. Peaks outflows from the dam for the Fish Passage Only scenarios were the same as Current Operations because they all focus on holding water in the reservoir. Current operations maintain reservoir levels high to ensure that minimum instream flow and withdrawal requirements could be met throughout the year. Fish passage only alternatives also keep the reservoir as full as possible to allow the fish sluice to operate for the longest possible period through the summer. In both cases, the high reservoir levels result in similar flood flow discharges via the uncontrolled spillway during flood events because little reservoir storage is available to attenuate floods. For these reasons, Current Operations and Fish Passage Only scenarios were simulated with the same model run in RiverFlow2D.

Figure 6 shows the RiverFlow2D simulated inundation extents for the 2-, 10-, 20-, and 100-year existing climate flood events for the Current Operations and Fish Passage Only alternatives. As seen in Figure 6, significant overbank inundation starts at about the 10-year flood under these alternatives. Overbank flooding increases significantly for the 20- and 100-year flood events, including additional overbank flow paths just downstream of the dam and through areas of Centralia west of Interstate 5. Figure 7 shows RiverFlow2D simulated flood depths for the 100-year flood for the Current Operations and Fish Passage Only alternatives. Figure 7 also shows structures in the floodplain. The modeling indicates that a total of approximately 4,349 structures would be within the 100-year floodplain of the Skookumchuck River for the Current Operations and Fish Passage Only alternatives, with 1,766 structures having maximum flood depths between 1 and 3 feet and 409 structures having maximum flood depths greater than 3 feet.

Simulation using projected flows under late-century high-end climate change showed the number of flooded structures in the 100-year floodplain would increase to 6,091, with 2,184 having flood depths between 1 and 3 feet and 1,880 having flood depths greater than 3 feet. Figure 8 shows the late-century 100-year floodplain with the structures overlay.

Summary tables of structures within the 2-, 10-, 20-, and 100-year floodplains of the Skookumchuck River for existing and late-century climate conditions for all alternatives are provided below (Tables 5 and 6).

Figure 6
Inundation Extents for the Existing Climate Condition 2-, 10-, 20-, and 100-Year Flood Events for Current Operations

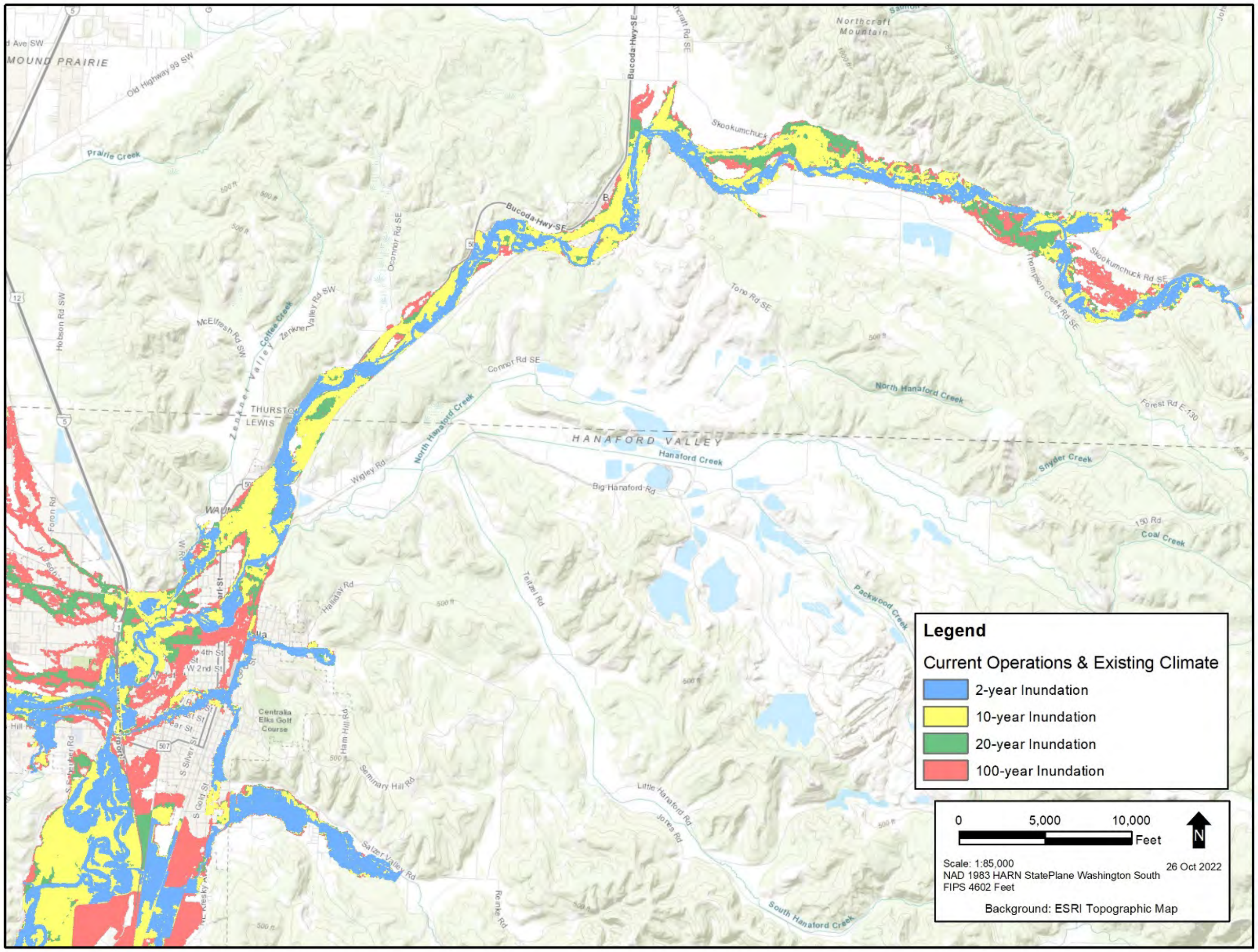


Figure 7
Modeled Existing Climate Condition 100-Year Flood Depth for Current Operations and Fish Passage Only Alternatives

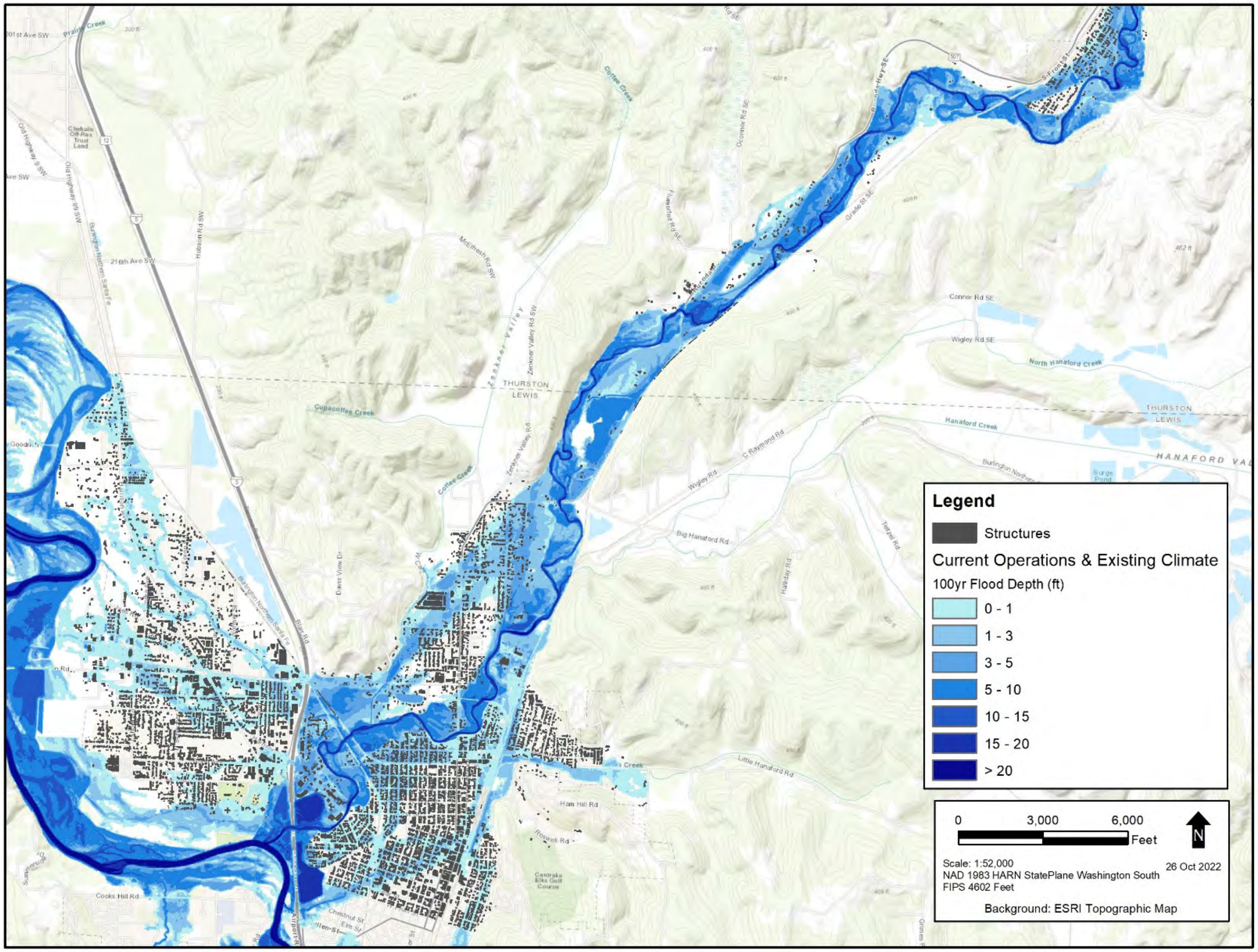
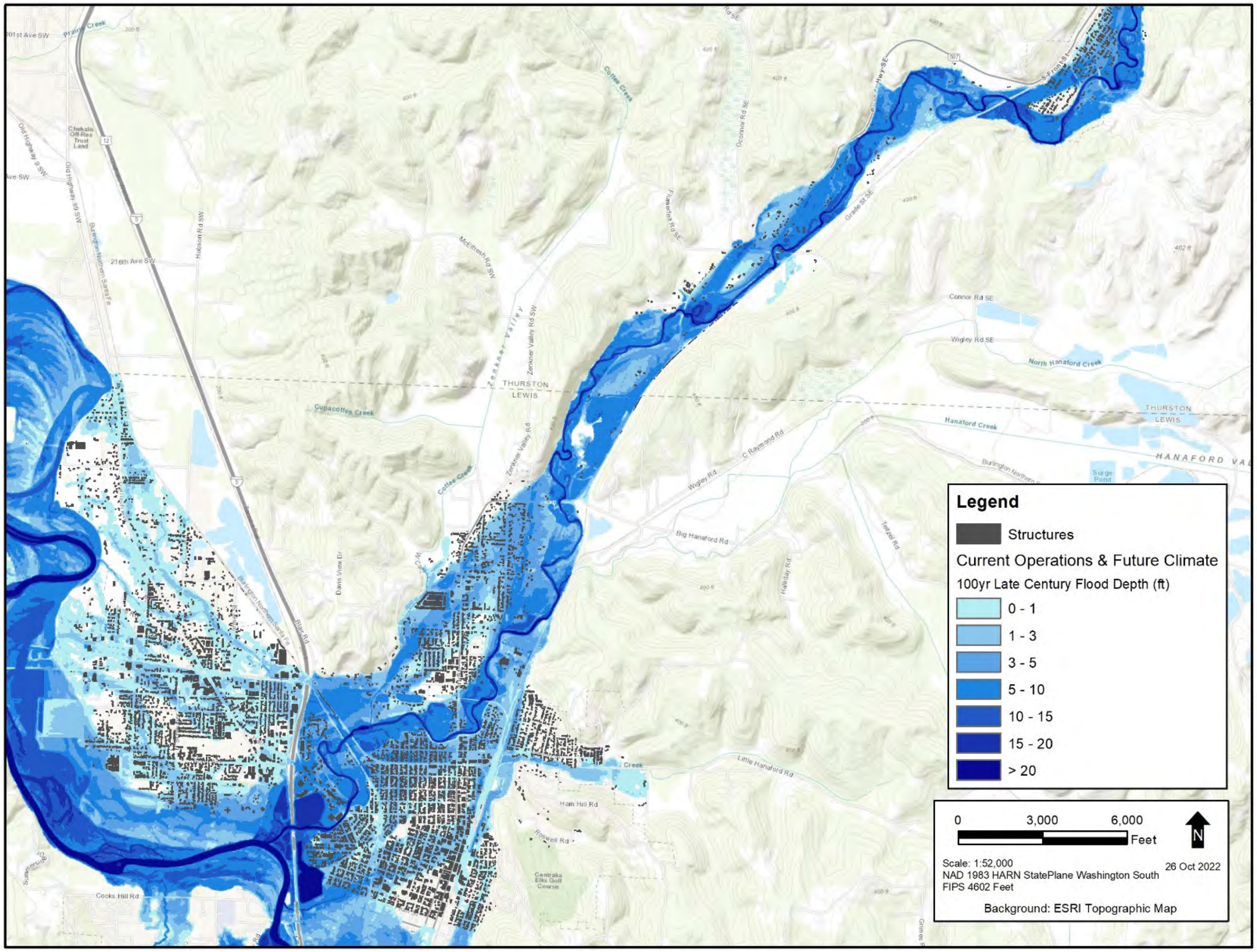


Figure 8
Modeled Future Climate Condition 100-Year Flood Depth for Current Operations and Fish Passage Only Alternatives



3.2.3 Flood Storage Only Alternative

In contrast to the Fish Passage Only alternatives, the Flood Storage Only alternatives target holding the reservoir pool low to allow flood flows to be captured in the reservoir and reduce outflows and downstream flooding. HEC-ResSim modeling of the flood storage only alternatives showed that providing at least 20,000 acre-feet of flood storage and adding a new low-level outlet with at least 2,000 cfs of hydraulic capacity were needed to provide effective flood flow reductions. Allocating this storage volume and adding discharge capacity, the 100-year discharge at the Bloody Run gage location could be reduced from the current operations value of 12,970 cfs to approximately 5,590 cfs.

The reduction in flows results in significant reductions in the number of inundated structures. The RiverFlow2D modeling indicated that a total of 1,646 structures would remain within the 100-year floodplain under the Flood Storage Only alternative, with 396 having maximum flood depths between 1 and 3 feet and 47 structures having maximum flood depths greater than 3 feet. Simulations using projected flows under climate change showed the number of flooded structures in the late-century 100-year flood would increase to 5,679, with 2,261 having flood depths between 1 and 3 feet and 1,206 having depths greater than 3 feet. Tables 5 and 6 below summarize structures in the floodplain for all alternatives and flood events for existing and late-century hydrologic conditions.

3.2.4 Combination of Fish Passage and Flood Storage

As described previously, the Combined Fish-Flood alternatives developed to evaluate if the benefits of both the Fish Passage Only and Flood Storage Only alternatives could be achieved. By maintaining the reservoir pool low during most of the flood season, flood flows could be effectively reduced relative to current operations. Conversely, by starting to refill the reservoir late in the flood season (late January to early February), the reservoir could be refilled by March 15 to operate the fish sluice until mid-summer. Because the Combined Fish-Flood alternatives began to refill during the tail end of the flood season, there would be some late season flood events when the reservoir would not provide as much flood storage as included in the Flood Storage Only alternatives. As a result, the downstream flood flows and inundation extents were slightly greater for the Combined Fish-Flood alternative than for the Flood Storage Only alternative.

The RiverFlow2D modeling indicated that a total of 2,313 structures would be within the 100-year Skookumchuck River floodplain with 689 having maximum depths of flooding between 1 and 3 feet and 70 structures having maximum flood depths greater than 3 feet. Simulation using projected flows under climate change showed the number of flooded structures in the late-century 100-year flood would increase to 5,792, with 2,266 having flood depths between 1 and 3 feet and 1,397 having flood depths greater than 3 feet. Tables 5 and 6 below summarize structures in the floodplain for all alternatives and flood events for existing and late-century hydrologic conditions.

3.2.5 Dam Removal

Dam removal was the simplest option to conceptualize and model. The HEC-ResSim model was modified to remove the dam, reservoir, and associated operational rules. These were replaced by a natural channel reach with characteristics defined based on pre-dam topographic conditions. The TransAlta diversion was also eliminated in the dam removal scenario. HEC-ResSim modeling of the period from October 1987 to March 2022 shows that dam removal would result in slightly higher flood flows than the current operating conditions. This is because the existing reservoir, even when full, provides greater attenuation of flows than the natural river channel, due to a larger storage volume and a flatter water surface slope. Hydrographs generated by HEC-ResSim for the Dam Removal scenario were routed through the downstream corridor using RiverFlow2D.

The RiverFlow2D modeling indicated that a total of 4,392 structures would be within the 100-year floodplain of the Skookumchuck River with 1,779 having maximum depths of flooding between 1 and 3 feet and 455 having maximum flood depths greater than 3 feet. Simulation using projected flows under climate change showed the number of flooded structures in the late-century 100-year flood would increase to 6,080, with 2,187 having flood depths between 1 and 3 feet and 1,872 having depths greater than 3 feet. Tables 5 and 6 below summarize structures in the floodplain for all alternatives and flood events for existing and late-century hydrologic conditions.

One unexpected finding of the Dam Removal alternative flood depth analysis was that 100-year water levels along a short stretch of the Skookumchuck River, generally from Hanaford Creek to about Pearl Street, are actually slightly lower in the Dam Removal alternative than in the Current Operations scenario. Detailed review of the modeling showed that this was the result of timing differences between peak flows on the Skookumchuck under these two alternatives and the peak flows coming from Hanaford Creek. The slightly attenuated flows in the Current Operations alternative actually coincide closer to the Hanaford Creek peak flows than flows in the Dam Removal alternative, and thus, even though the peak Skookumchuck River flow upstream of Hanaford Creek is higher with Dam Removal, peak flows in the reach just downstream of Hanaford Creek are actually lower. Downstream of Pearl Street Bridge additional inflows from Coffee Creek as well as return flows from an overbank flow path reenter the Skookumchuck, and the reduced water levels due to the Hanaford Creek timing difference are no longer seen.

3.2.6 Comparison of Alternatives

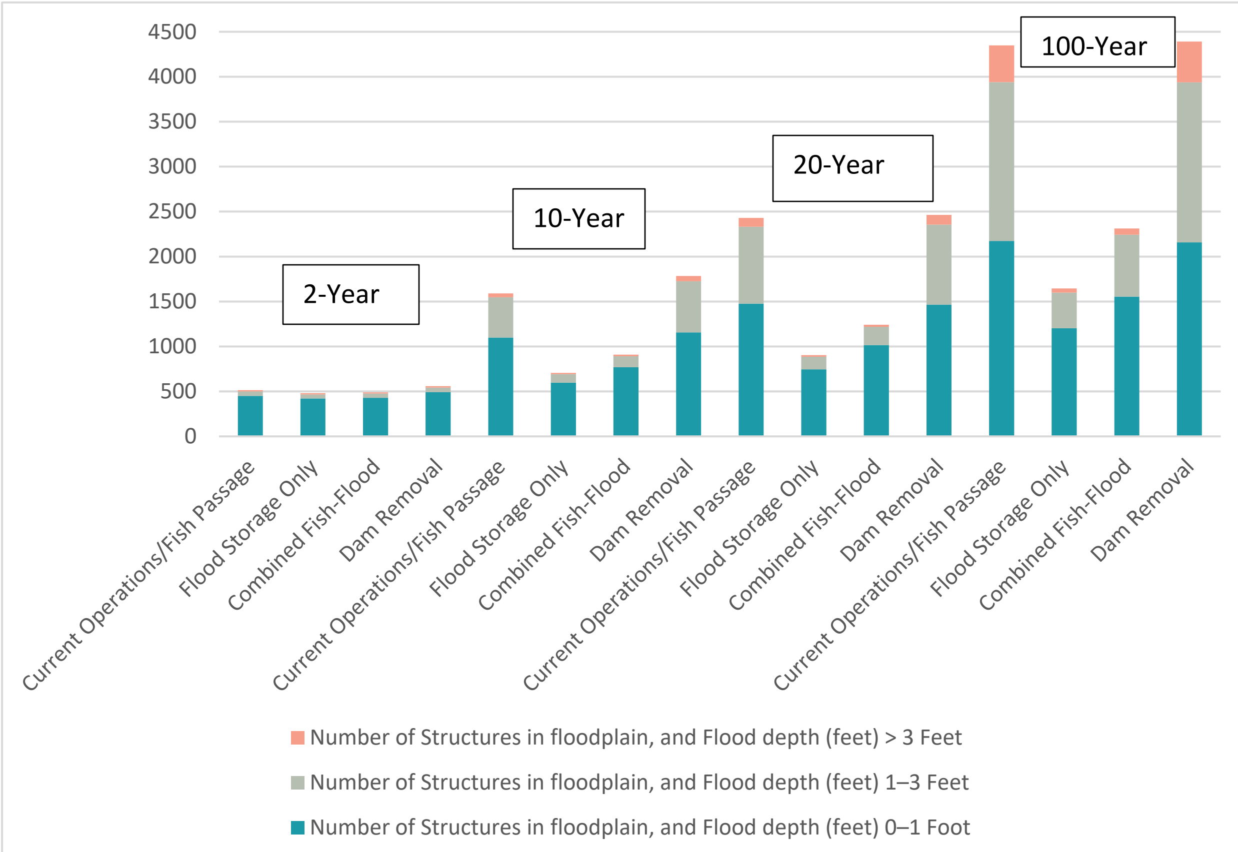
Figure 11 displays the simulated 100-year inundation extents for the four modeled alternatives, layered in order from smallest to largest extents. As seen in Figure 9, the Flood Storage Only and Combined Fish-Flood alternatives result in significant reductions in inundated area, while the Dam Removal option generally results in a slightly larger floodplain along the Skookumchuck. Figures 12 to 14 compare simulated depths of flooding in the Flood Storage Only, Combined Fish-Flood, and Dam Removal alternatives to the Current Operations. Flood alternatives delay the peak flows to coincide more with mainstem Chehalis River flooding, resulting in slight increases in depth on the Chehalis River. Table 5 summarizes the number of structures inundated under each alternative for each flood event modeled. The flood depths shown in Table 5 are referenced to the lowest ground elevations at each structure. Generally, it can be assumed that flood depths less than 1 foot are unlikely to flood above the finished floor. Flood damages likely begin in the 1- to 3-foot depth category and are likely significant for depths greater than 3 feet.

As seen in Table 5 and Figure 9, the number of structures flooded by more than 1 foot in a 2-year flood event is relatively small and is similar for all alternatives. For the 10-, 20-, and 100-year floods, however, the number of structures flooded at least 1 foot deep increases significantly under the Current Operations and Dam Removal alternatives. Under the Flood Storage Only and Combined Fish-Flood alternatives, the number of structures flooded greater than 1 foot increases with increasing flood return period but is far lower than the Current Operations alternative—the number of structures flooded greater than 3 feet is much lower (approximately 10% to 20% of the number under Current Operations).

Table 5
Summary of Flooded Structures by Alternative and Existing Climate Conditions Flood Event

ALTERNATIVE AND FLOOD EVENT	NUMBER OF STRUCTURES IN FLOODPLAIN, AND FLOOD DEPTH (FEET)			
	Total	**0–1 Foot**	**1–3 Feet**	**> 3 Feet**
2-YEAR EXISTING CONDITIONS FLOOD				
Current Operations and Fish Passage Only	514	450	50	14
Flood Storage Only	480	421	46	13
Combined Fish-Flood	490	429	48	13
Dam Removal	558	493	49	16
10-YEAR EXISTING CONDITIONS FLOOD				
Current Operations and Fish Passage Only	1,591	1,099	449	43
Flood Storage Only	706	597	95	14
Combined Fish-Flood	909	769	122	18
Dam Removal	1,784	1,156	570	58
20-YEAR EXISTING CONDITIONS FLOOD				
Current Operations and Fish Passage Only	2,429	1,476	856	97
Flood Storage Only	904	746	140	18
Combined Fish-Flood	1,242	1,016	203	23
Dam Removal	2,463	1,465	890	108
100-YEAR EXISTING CONDITIONS FLOOD				
Current Operations and Fish Passage Only	4,349	2,174	1,766	409
Flood Storage Only	1,646	1,203	396	47
Combined Fish-Flood	2,313	1,554	689	70
Dam Removal	4,392	2,158	1,779	455

Figure 9
Number of Structures Inundated under Existing Climate for the Alternatives



As seen in Figure 15, all of the alternatives inundate approximately the same area under late-century 100-year flood conditions. This is because the projected late-century flow increases of 60% result in 100-year flooding essentially from valley wall to valley wall along the Skookumchuck. Despite there being little change in the inundated area between alternatives for the late-century hydrologic conditions, there are still significant differences in flood depths. Table 6 and Figure 10 show the number of structures inundated for late-century climate conditions. As seen in Table 6, the total number of structures flooded under projected late-century climate conditions, as well as the number flooded by more than by more than 1 foot, rises dramatically at all flood recurrence intervals. The Flood Storage Only alternatives still result in a significant reduction in the number of structures flooded more than 3 feet deep, but proportionally the reductions are not as significant as under existing conditions. For the 100-year flood, for example, the Combined Fish-Flood alternative reduces the number of structures flooded more than 3 feet deep by 83% under existing conditions, but under the late-century conditions the corresponding reduction is only 26%. Nevertheless, the reduction in the number of structures flooded is significant, even under the late-century conditions.

Table 6
Summary of Flooded Structures by Alternative and Late-Century Climate Conditions Flood Event

ALTERNATIVE AND FLOOD EVENT	NUMBER OF STRUCTURES IN FLOODPLAIN, AND FLOOD DEPTH (FEET)			
	Total	0–1 Foot	1–3 Feet	> 3 Feet
2-YEAR LATE-CENTURY CONDITIONS FLOOD				
Current Operations and Fish Passage Only	1,261	1,044	194	23
Flood Storage Only	662	567	82	13
Combined Fish-Flood	719	619	84	16
Dam Removal	1,354	1,069	258	27
10-YEAR LATE-CENTURY CONDITIONS FLOOD				
Current Operations and Fish Passage Only	4,215	2,172	1,693	350
Flood Storage Only	2,654	1,653	905	96
Combined Fish-Flood	2,351	1,572	706	73
Dam Removal	4,293	2,153	1,758	382
20-YEAR LATE-CENTURY CONDITIONS FLOOD				
Current Operations and Fish Passage Only	4,906	2,155	1,951	800
Flood Storage Only	4,003	2,176	1,590	237
Combined Fish-Flood	4,238	2,226	1,722	290
Dam Removal	4,902	2,169	1,955	778
100-YEAR LATE-CENTURY CONDITIONS FLOOD				
Current Operations and Fish Passage Only	6,091	2,027	2,184	1,880
Flood Storage Only	5,679	2,212	2,261	1,206
Combined Fish-Flood	5,792	2,129	2,266	1,397
Dam Removal	6,080	2,021	2,187	1,872

Figure 10
Number of Structures Inundated under Late-Century Climate for the Alternatives

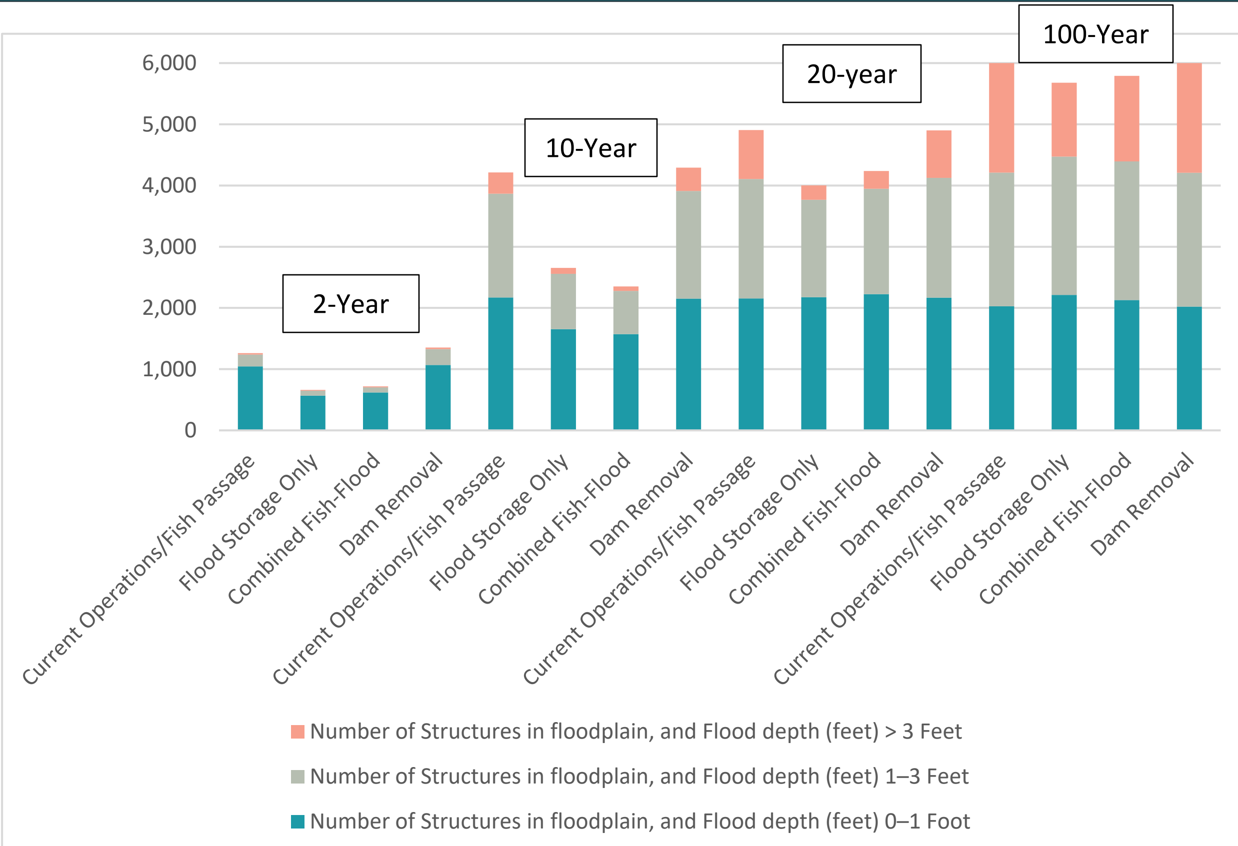


Figure 11
Modeled Existing Climate 100-Year Flood Event Inundation Extent for Four Operating Alternatives

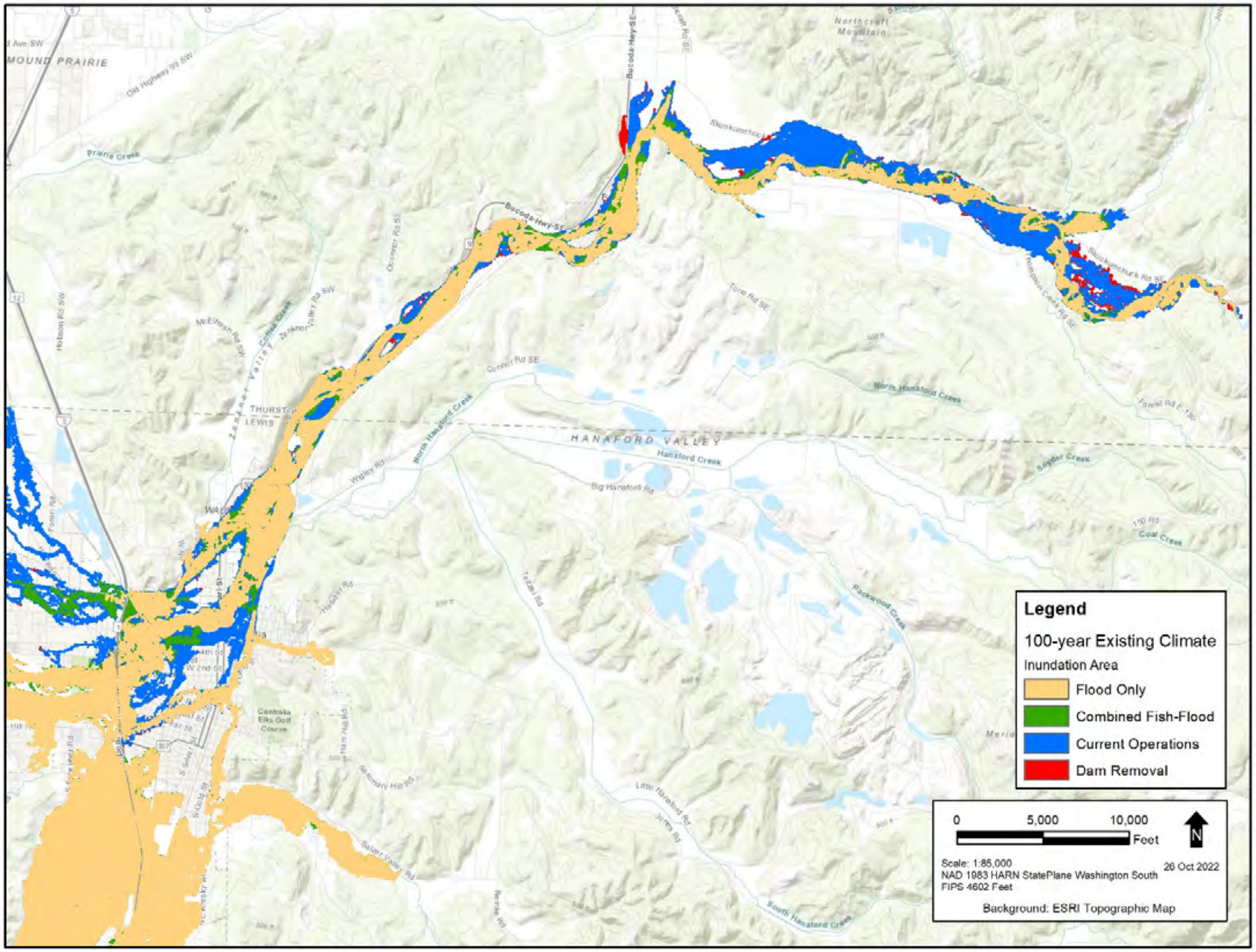


Figure 12
Modeled Change in 100-Year Flood Depth from Current Operations to the Flood Storage Only Alternative

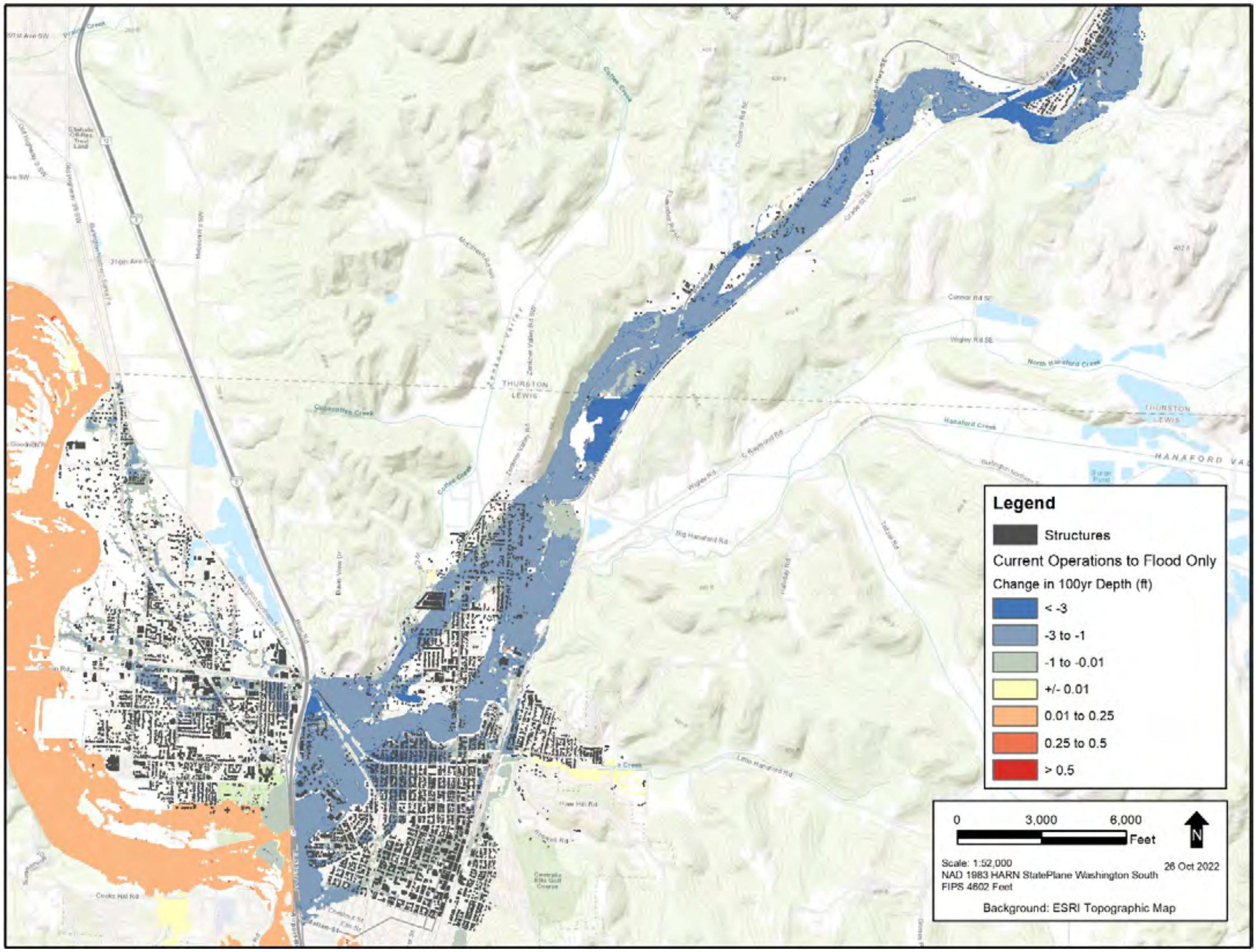


Figure 13
Modeled Change in 100-Year Flood Depth from Current Operations to the Combined Fish-Flood Alternative

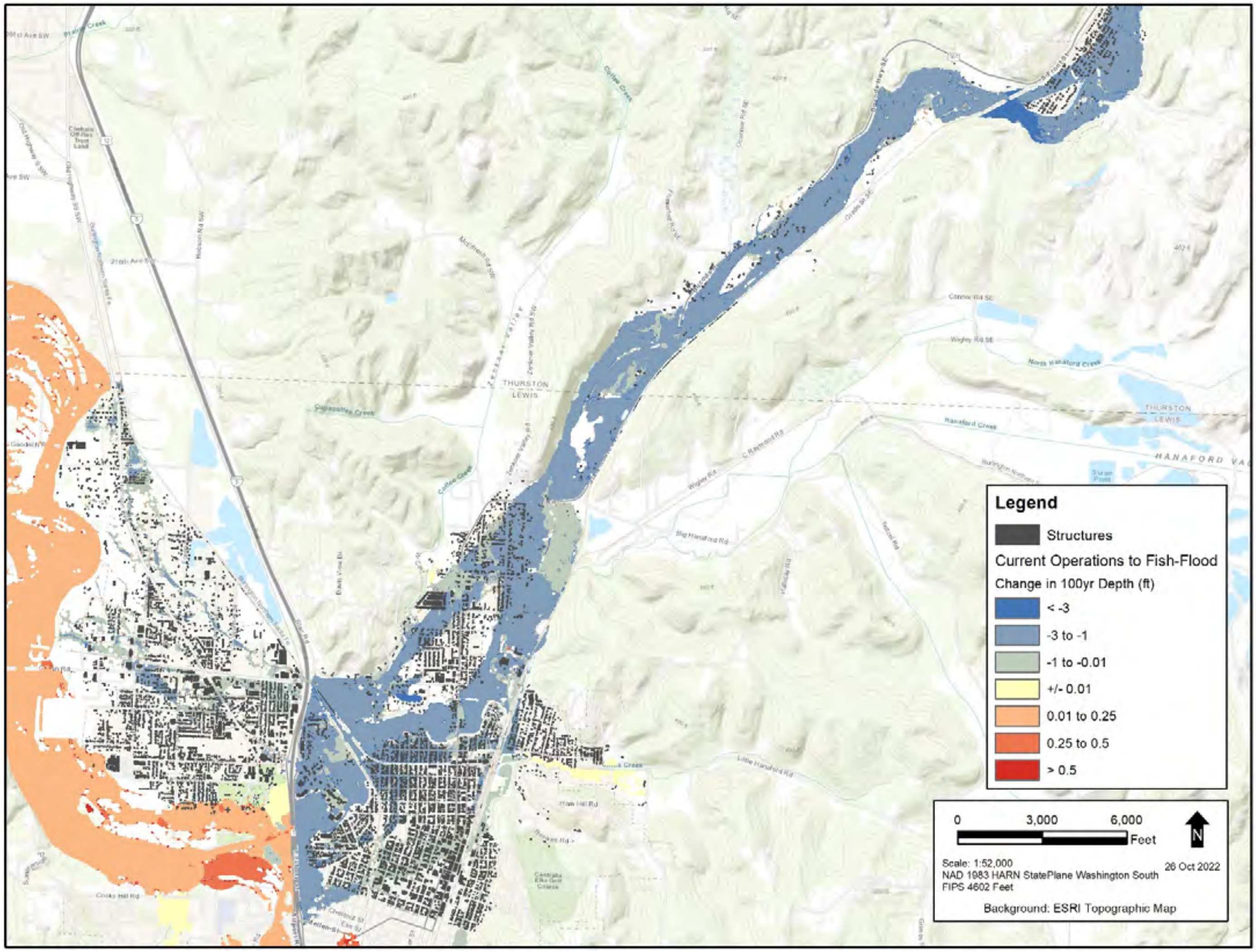


Figure 14
Modeled Change in 100-Year Flood Depth from Current Operations to the Dam Removal Alternative

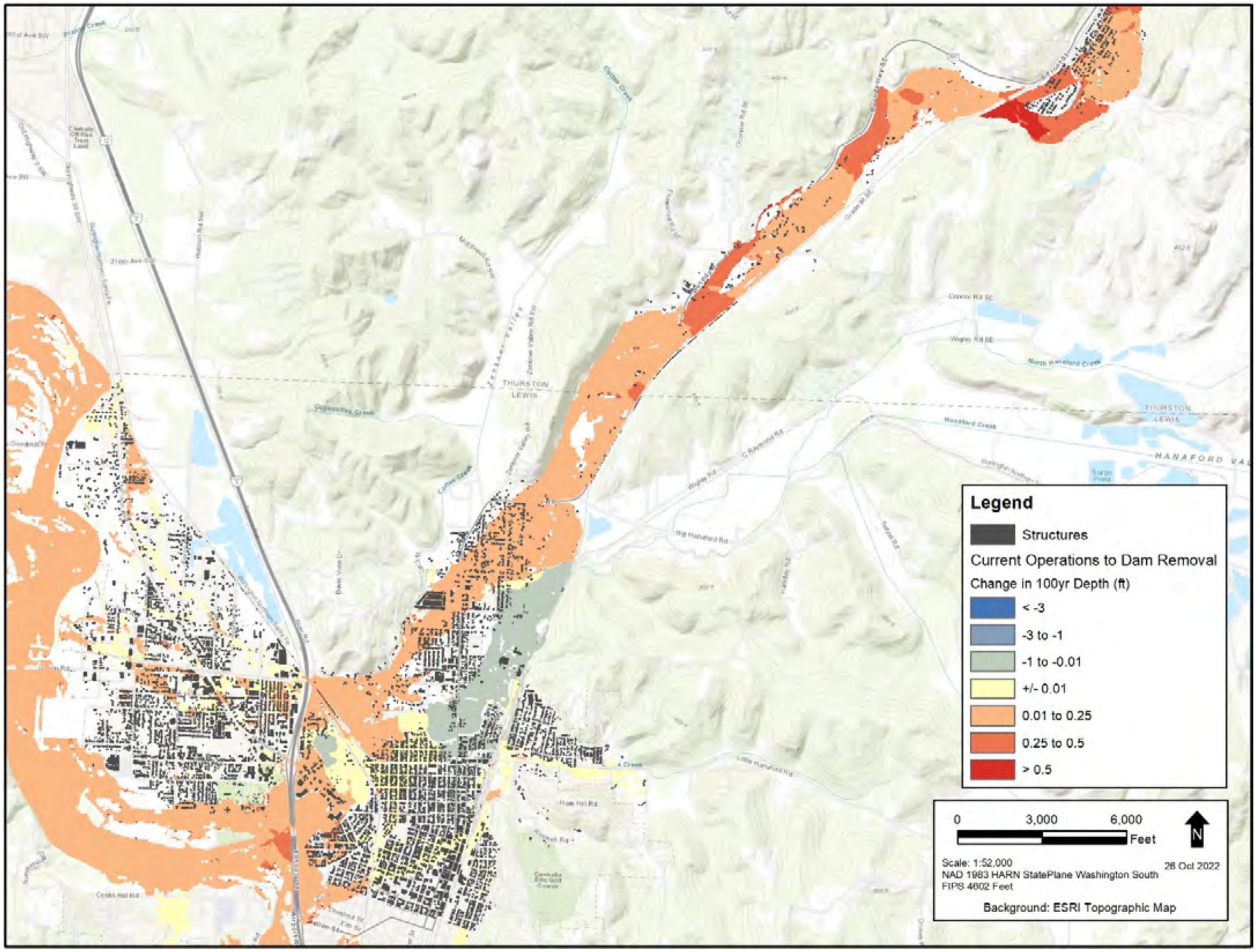
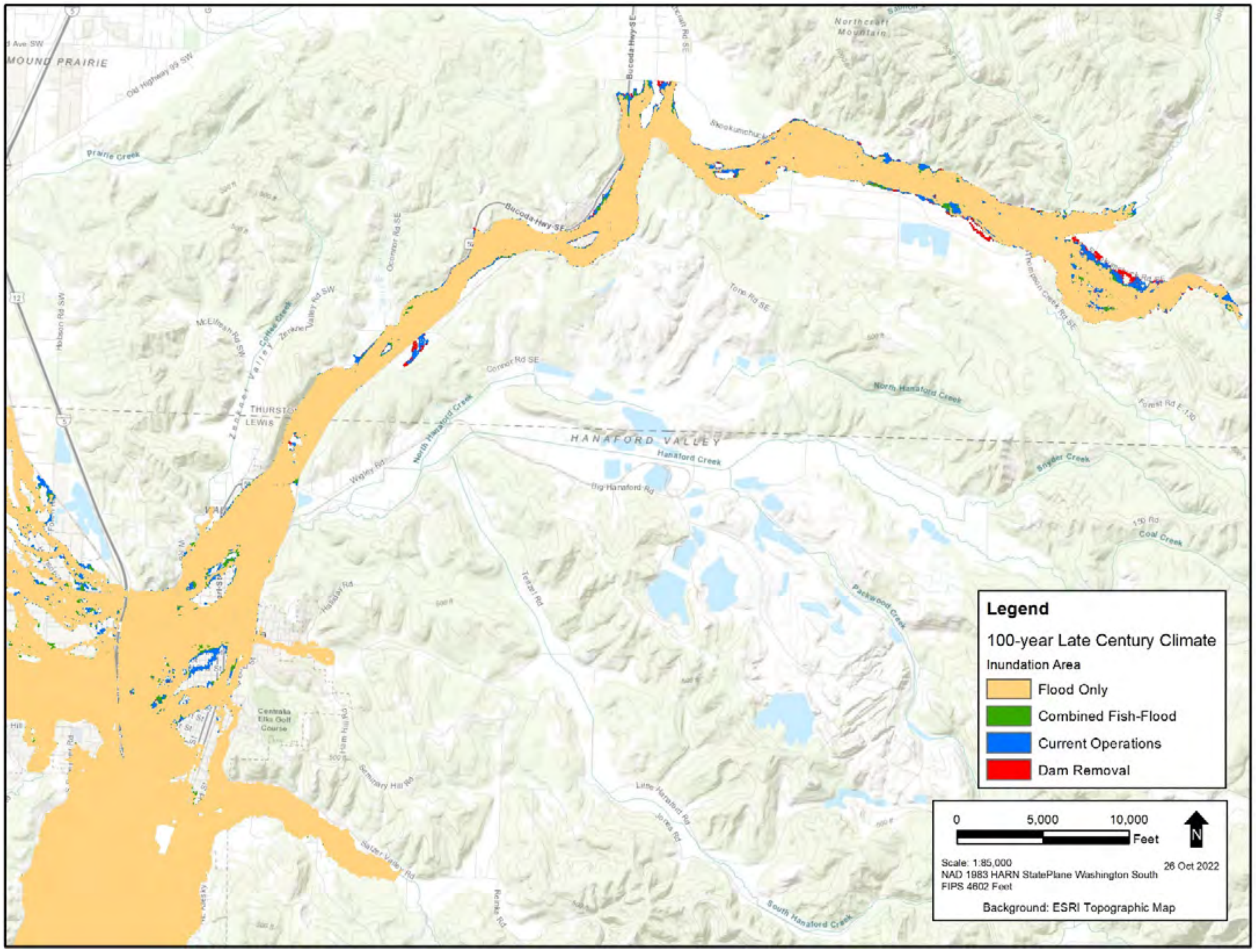


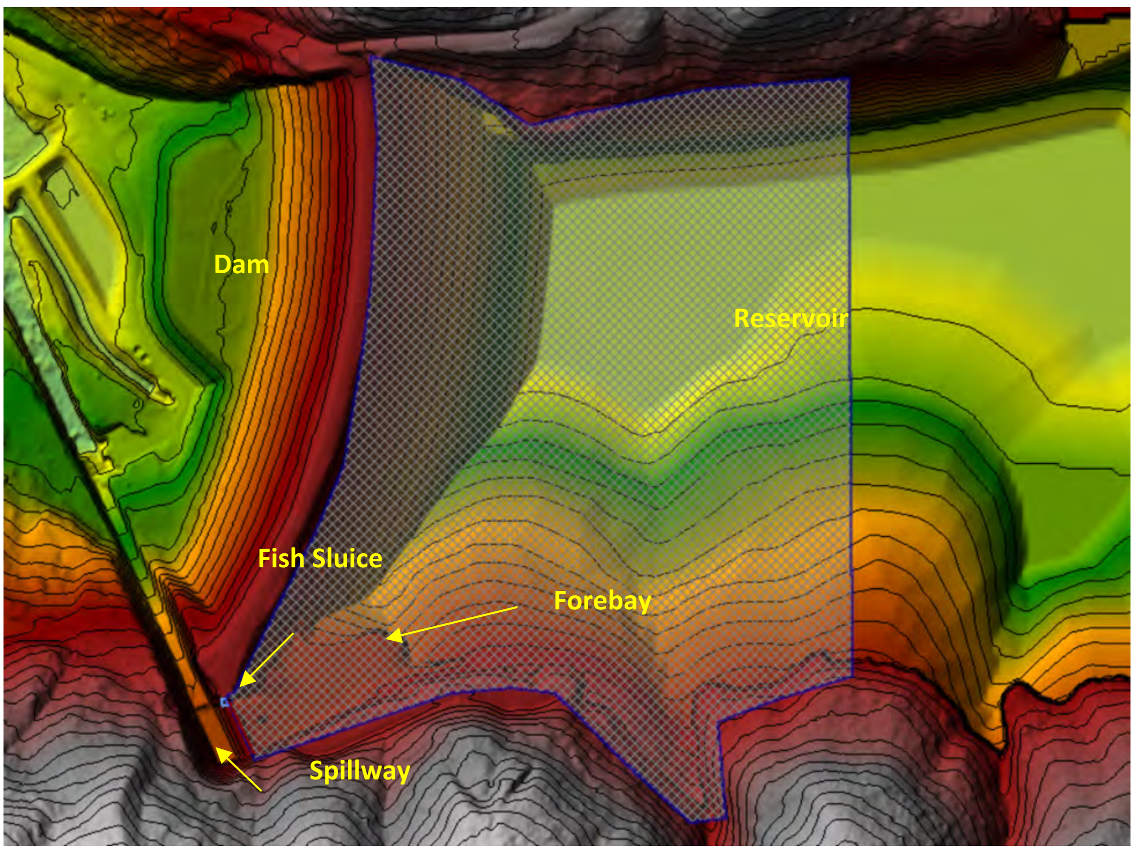
Figure 15
Modeled Late-Century Climate 100-Year Flood Event Inundation Extents for Four Operating Alternatives



3.3 CFD Modeling of Downstream Fish Passage

To support the evaluation of downstream fish passage at the fish sluice and potential alternatives, the dam and fish sluice were modeled with 2D and 3D CFD models. A HEC-RAS 2D model was used to evaluate the reservoir area extending from approximately 1,000 feet upstream of the dam to the fish sluice (Figure 16), the sluice was represented by a simple gate with a constant outflow of 65 cfs. The 2D model was used to simulate large flow patterns in the reservoir at different reservoir elevations, estimate the extents of velocities that attract fish, and evaluate potential terrain alterations for the approach to the sluice. The 2D model also informed the extents and boundary conditions used to develop the FLOW-3D CFD model.

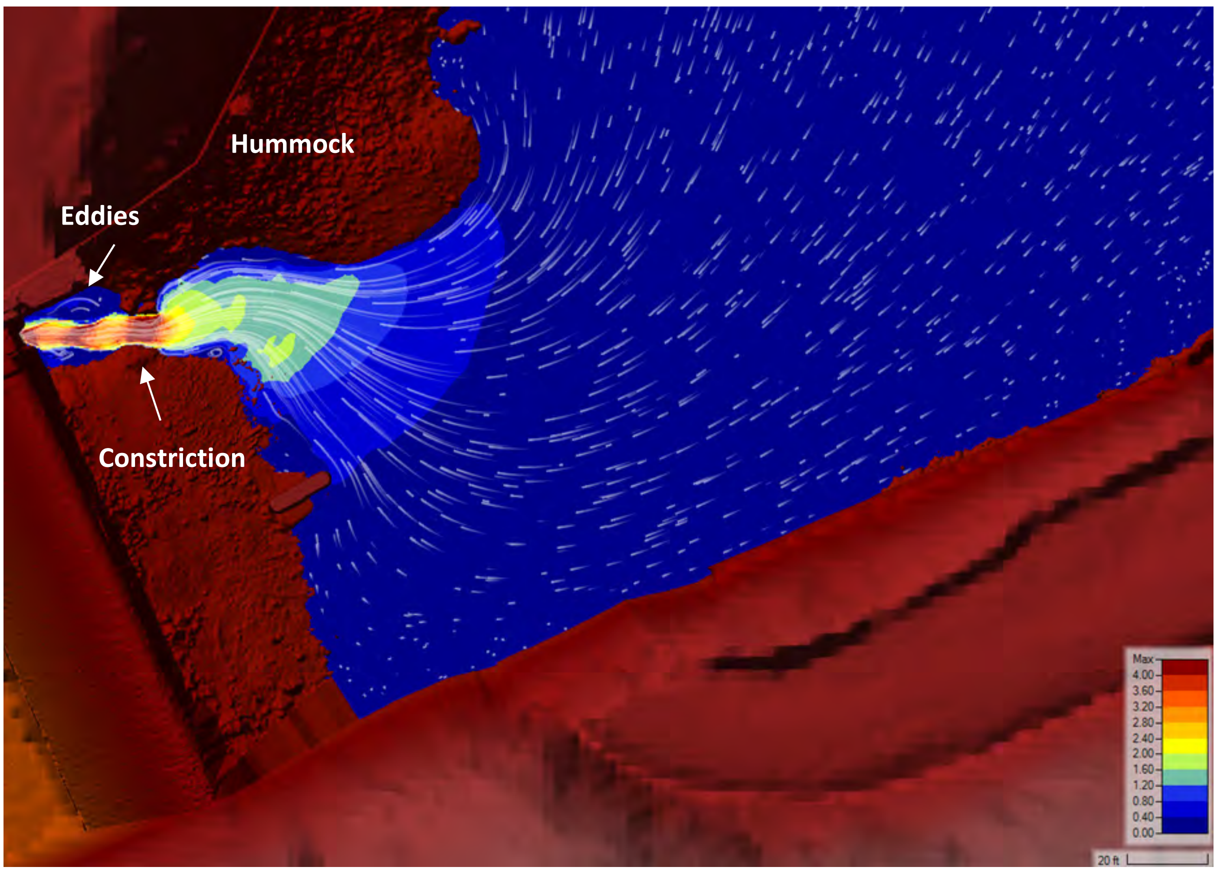
Figure 16
Model Extents (Hatched Area) for the 2D Model over the Existing Terrain



Note: Red colors are higher elevation, green colors are lower elevation.

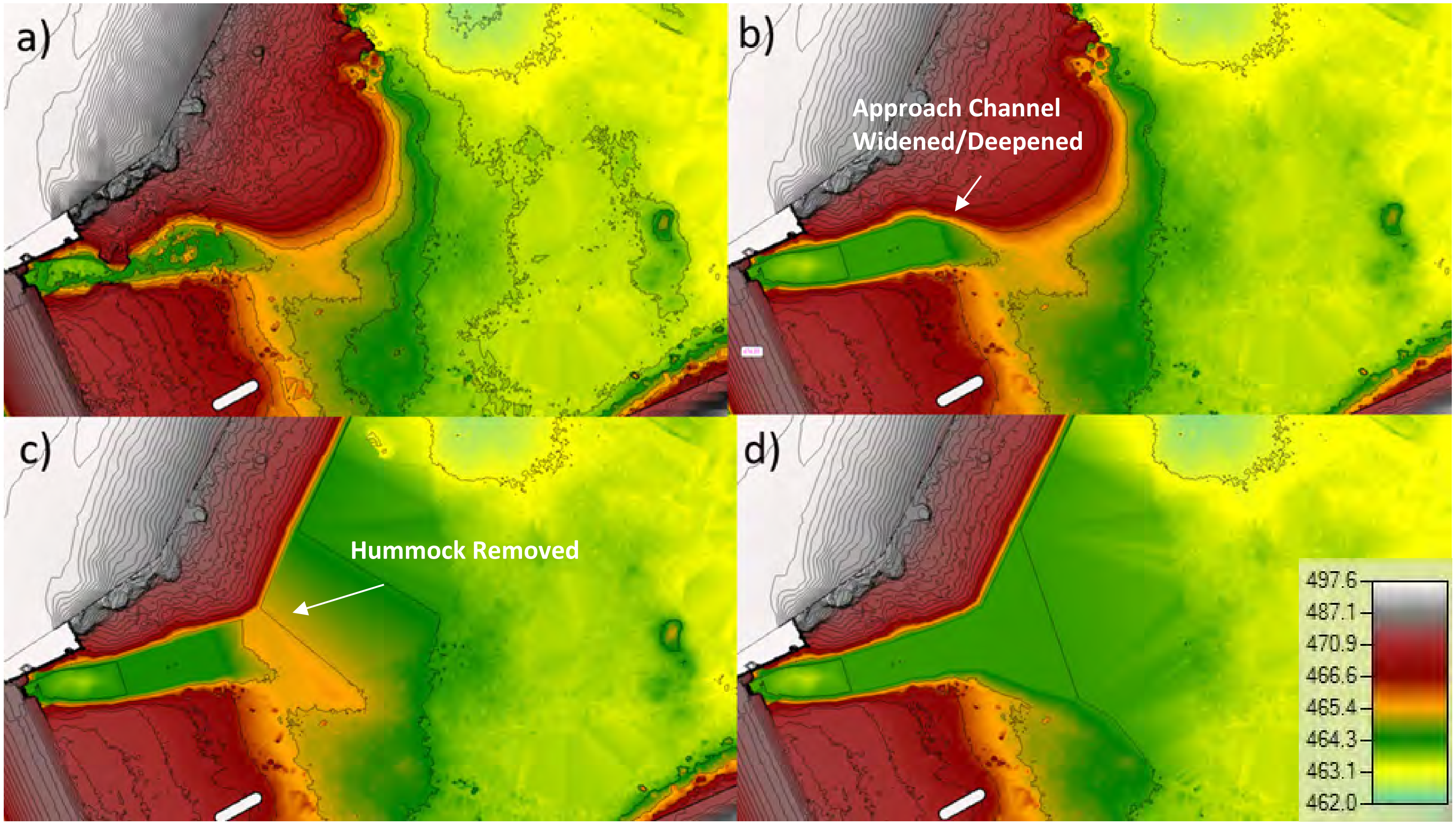
The 2D model incorporated a terrain surface developed through a combination of high-resolution drone survey obtained by the project team in the forebay approach to the sluice, 2017 LiDAR for the dam and surrounding areas, and a pre-dam topographic map for reservoir bathymetry. The 2D model demonstrated that obstructions and constrictions in the forebay and channel approaching the fish sluice caused hydraulic conditions that did not present fish with uniform approach conditions to sense and cue on due to the formation of eddies, presence of turbulence, and changes in flow direction. The results of the 2D modeling for flows entering the existing fish sluice at a 467-foot reservoir elevation are shown in Figure 17. Figure 17 depicts conditions with the existing sluice and current surface terrain. Note how flow has to go around the portion of the dam (hummock) that protrudes into the forebay, and then turns and accelerates and decelerates due to the substrate and narrow constriction, and forms eddies between the constriction and sluice entrance. Results for reservoir elevations of 470 and 477 feet are in Appendix A.

Figure 17
2D Model Results and Flow Vectors for Reservoir Elevation 467 Feet



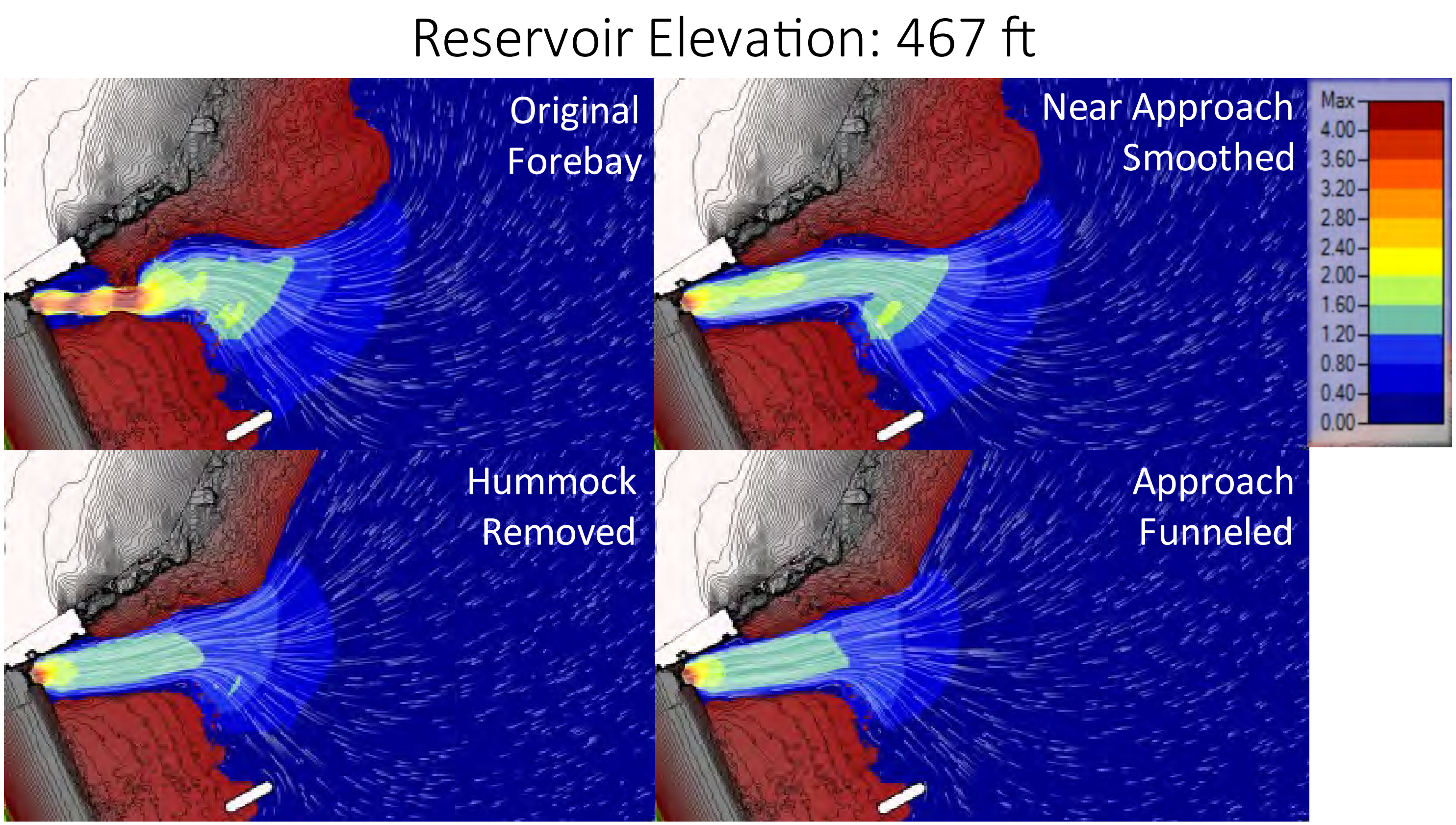
To assess potential solutions to these flow patterns, three alternative forebay terrains were developed to smooth the forebay approach to the fish sluice. The existing terrain and the three modified terrains are shown in Figure 18. The results of the 2D modeling show significant improvement to flow conditions for fish could be gained with a smoothed terrain (Figure 19), and thus this terrain was also modeled with the 3D model.

Figure 18
Terrains Developed for the 2D Model



Note: a) existing condition; b) obstructions removed from the approach channel; c) hummock near the dam removed; and d) entire approach smoothed and funneled towards the sluice.

Figure 19
Results of Water Velocity Approaching the Existing Sluice Under Current and Modified Smoothed Conditions

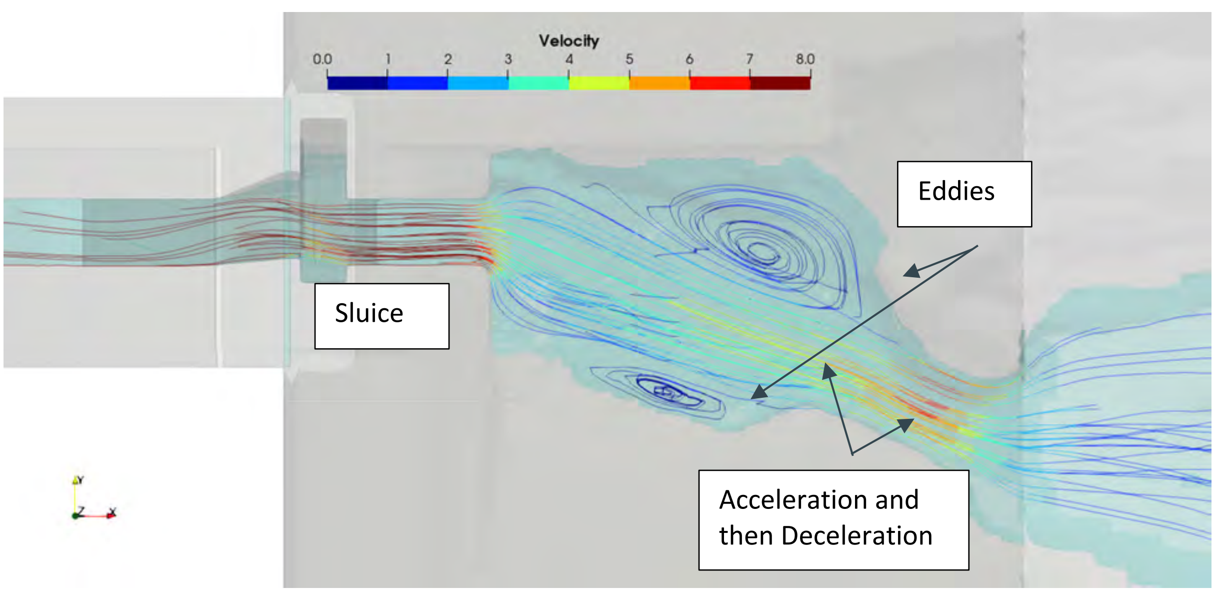


Note: Current conditions (original forebay, upper left panel) and modified conditions (upper right, lower right, and lower left panels). Reservoir elevation of 467 feet.

The FLOW-3D CFD model was used to illustrate the complex flow patterns near and through the existing fish sluice. The FLOW-3D model included the internal sluice geometry and used the existing and smoothed terrain developed for the 2D model. The FLOW-3D model included nested mesh blocks with increasingly fine computational cells approaching and entering the sluice. The model geometry and computational mesh boundaries are shown in Appendix A. Reservoir elevations of 467, 470, and 477 feet were modeled that encompass the elevation range where the existing fish sluice has sufficient flows and depths for fish attraction and with both the existing approach terrain and the smoothed approach terrain shown in Figure 18. The model includes the sluice gate, which was adjusted up or down to pass approximately 65 cfs through the sluice. However, at reservoir elevation 467, the control on flow is the sluice tunnel and the maximum flow through the sluice is 50 cfs.

The results of the CFD modeling of hydraulic conditions just upstream of the existing fish sluice are shown in Figure 20. As flow proceeds from right to left in the figure (from the reservoir to the fish sluice entrance), note how velocities increase at the point where surface terrain constricts the flow, decreases between the constriction and the sluice, accelerates sharply at the sluice entrance, and how eddies form on both edges of the approach channel downstream of the constriction. Studies of juvenile fish (smolt) behavior upstream of bypass entrances indicate that fish will sense these changes in flow velocity, acceleration, and direction, turn 180°, and move upstream and away from the entrance. For example, Haro et al. (1998) compared the behavior of Atlantic salmon (*Salmo salar*) smolts at a standard weir and a modified surface bypass weir that created uniform increases in flow velocity. They found that significantly more smolts passed the modified weir than the standard weir.

Figure 20
Results of CFD Model of Flow Streamlines of Water Approaching the Existing Sluice Under Current Conditions at Reservoir Elevation 467 Feet

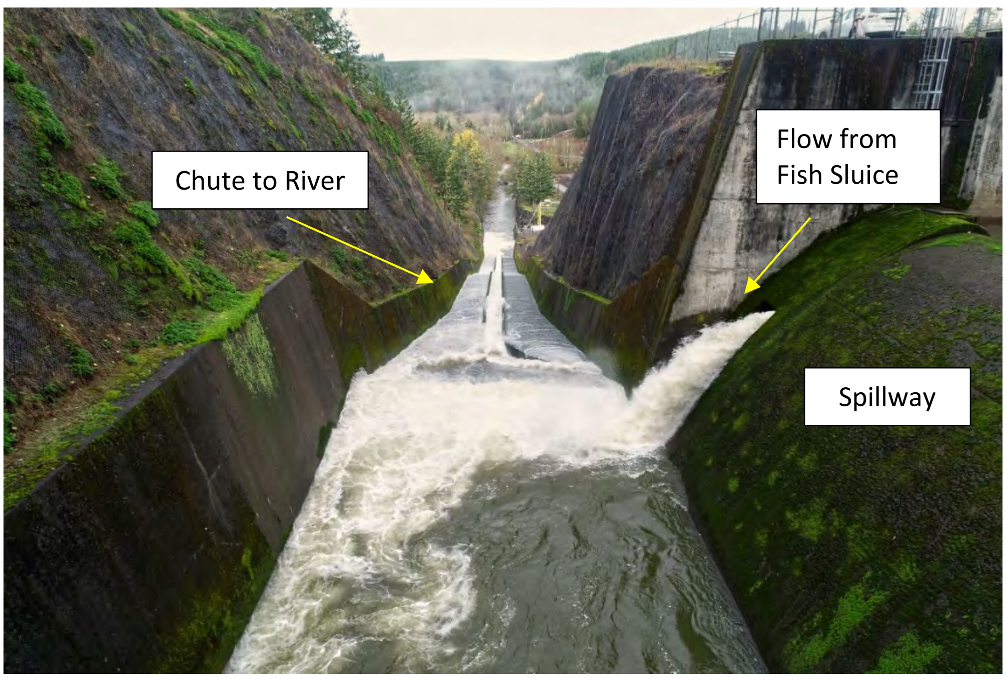


The CFD model results demonstrate that the existing sluice creates flow conditions that may not attract fish and allow their passage easily through the forebay and sluice).

3.3.1 Evaluation of Existing Downstream Fish Passage

When the reservoir elevation is above 477 feet, water flows uncontrolled over the spillway crest into an energy dissipation pool, turns 90° to the west, enters a steep (17% slope) chute with an approximately 4-foot-wide low-flow channel installed in the center of the chute, and terminates in a stilling basin near the adult fish trap (Figure 21). The low-flow channel within the chute has walls that protrude above the bottom (invert) of the main spillway chute and protrude vertically into the water and fish flow path.

Figure 21
Skookumchuck Dam Spillway, Energy Dissipation Pool and Chute on November 24, 2021



Water flows over the spillway crest when the reservoir elevation is above 477 feet, enters the energy dissipation pool in the center of the photograph, and exits the pool and flows down the chute. A low-flow channel is constructed in the center of the chute. Flow discharge from the existing fish sluice was estimated to be approximately 250 cfs. Photograph by Colin Butler, November 24, 2021.

Water from the reservoir flows through the fish sluice via an angled gate and into the spillway energy dissipation pool and chute when the reservoir forebay elevation is above 464 feet (only when the reservoir elevation reaches 467 feet is there sufficient head to drive at least 50 cfs of flow through the fish sluice). Flow through the fish sluice when the reservoir is not overtopping the spillway is shown in Figure 21. The upstream entrance to the fish sluice is shown in Figure 22 with a trash rack and angled slide gate. The gate is connected to a jackscrew, which runs through a gear box on top of the dam, and the opening is manually adjusted using an electric pipe wrench. Debris accumulates on the trash racks; currently TransAlta removes the debris during summer when the trash rack is accessible to personnel and the sluice is not in operation.

Figure 22
Existing Fish Sluice Entrance Showing the Concrete Entrance Walls and Apron, Debris Trash Rack, and Angled Control Gate (inside the chamber)

Photograph by Larry Karpack, November 20, 2021

The existing fish sluice and chute return to the river were evaluated to not be a desirable downstream fish passage facility. The existing fish sluice (and spillway, if any fish pass over the spillway during high flows) creates several hazardous flow and debris conditions for fish passage. These include excessive velocities and turbulence, insufficient flow depths, abrupt changes in flow direction, a lack of smooth flow transitions, and a likelihood that collisions will occur between fish and structural components of the spillway and chute. Fish could be ejected out of the main flow in the 4-foot-wide chute channel and onto the surrounding concrete of the chute where flow velocities are high, and depths are shallow due to the steep gradient of the chute. The raised channel walls likely prevent these fish from returning to the channel. In addition, the flow path for fish through the existing fish sluice is not straight and is turbulent because of the upstream topography that does not provide uniform flow towards the fish sluice and creates pockets and eddies within the fish sluice flow passageway and angled gate opening. Also, substantial debris can accumulate on the trash rack and through the small opening in the control gate that plugs up the fish sluice or causes very narrow openings of flow through the debris that can result in injury.

Juvenile salmonids undergo what is termed the parr-smolt transformation prior to migrating downstream. The transformation is a critical aspect of the juvenile life stage where their bodies change to prepare the fish to leave freshwater and enter saltwater. The transformation is needed so the fish can maintain salt and water balance within the body. One of the characteristics of the transformation is that scales are easily shed. Because of this condition, brushing against debris accumulated on trash racks dislodges, or swipes, patches of scales from the sides of juvenile fish. Passing fish through fine woody debris on trash racks under high velocity conditions causes descaling and the loss of a protective mucus layer on the surface of the scales. Loss of scales and mucus exposes fish to injury (scale loss), disease (scale and mucus loss), and the inability to control salt and water balance. If the existing fish sluice were to continue to be used for downstream passage, debris cleaning would need to occur much more frequently than what occurs currently. It would have to occur daily or more frequently via an automated, mechanical system. Adult steelhead migrating downstream through blocked trash racks are particularly vulnerable to injury due to the energetically depleted condition the fish are in following spawning. Adults may not be able to enter and safely pass through the existing sluice due to their large size, and the small openings in the current trash rack that is designed to pass juveniles or in gaps between any debris accumulated on the trash rack.

In addition, it was initially evaluated if it would be feasible to modify the existing fish sluice to reduce the clearly hazardous conditions for fish. This would require: 1) smoothing the forebay topography; 2) smoothing the sharp corners and interior side chambers within the sluice to make a smooth transition from the entrance to the control gate; 3) replacing the existing 45° angled control gate with one that operates in a fully closed or open position and incorporating a weir or other system designed to control flow downstream of this gate; and 4) providing a smooth transition from the fish sluice into a long-radius elbow turn to send fish into a pipe to a dewatering facility and holding tank rather than into the chute. This was evaluated to not be feasible because the outlet from sluice and pipe to a dewatering facility would all be located immediately below the top of the spillway crest and would be subject to high water and debris loading and potential damage when water spills over the spillway. These structures could also reduce the capacity of the spillway.

4 FISH PASSAGE CONCEPT DESIGN

Following evaluation of the likely performance of the existing fish sluice, alternative options for providing effective downstream passage for juvenile salmonids were developed, along with consideration of downstream passage of adult steelhead (steelhead can spawn more than once). The development of alternative downstream passage of salmon and steelhead was informed by the letter from the director of WDFW to the Chehalis Basin Board (WDFW 2021) stating a need to see significant improvements in Skookumchuck River spring-run Chinook salmon and steelhead populations via either removal of Skookumchuck Dam or installation of a state-of-the-art fish passage system and National Marine Fisheries Service (NMFS 2022) criteria for the design of fish passage facilities.

4.1 Key Considerations for Downstream Fish Passage

The development of a conceptual downstream fish passage facility requires that several elements be feasible to ensure unhindered passage and high survival.

Fish Species: It was determined that, at a minimum, the facility must be able to pass juvenile and post-spawn adult steelhead. Steelhead are of highest priority because currently WDFW collects adult steelhead at the adult trap and transports and releases the fish into the Skookumchuck River above the reservoir in some years, but other species are not transported. The downstream passage of juvenile spring-run Chinook salmon and coho salmon was also considered as part of concept development as desired by WDFW (2021), information on available habitat above the reservoir for these species based on Weyerhaeuser (1996) and Finn (1973), and results of EDT modeling conducted as part of this project, described in Section 5.

Safe Passage: A safe passage route prevents physical damage to fish and minimizes their energy expenditure and stress. Effective passage facilities must create flow conditions that allow fish to maintain spatial orientation and minimize the likelihood of fish colliding with structural components or hydraulic features of the facility. This includes flow paths and velocities at the sluice entrance that are high enough to attract juveniles out of the reservoir and low enough to not injure adults passing through a trash rack.

Vertical Drop to the River: Addressing the approximately 120 feet of difference in elevation between the spillway crest and the river at the base of the dam is required, including how to accommodate this differential in a relatively short horizontal distance between the spillway and base of the dam while ensuring safe conditions to return both adults and juveniles to the river. Safe elements to return fish to the river could include a low-gradient flume or trap and transport facilities.

Key assumptions about downstream fish passage and behavior of fish include the following:

- Juvenile steelhead will find and enter surface-oriented passage facilities located near the spillway of the dam based on the following factors:
  - The hydraulic signature of flow entering a sluice could be designed such that it can be sensed by fish in the reservoir and presents fish with uniform approach conditions to cue on.
  - The relatively small size of the reservoir combined with the large size (and thus swimming capabilities) of steelhead smolts. Smolts are juveniles that have transitioned from resident parr into fish that are ready to enter seawater.
  - The surface-oriented behavior of steelhead smolts based on observations of steelhead behavior at Columbia River dams and extensive information on how juvenile steelhead respond to surface-oriented outlets at dams. During the smolt stage, the fish are actively migrating and search for surface-oriented outlets such as sluices.
  - Steelhead smolts reside in the uppermost portion of the water column near the surface and sense and respond to outlets located in this reservoir zone.

These assumptions generally apply to juvenile coho salmon as well, given that their size and out-migration timing are similar to steelhead. While these assumptions may also apply to juvenile Chinook salmon, there is more uncertainty associated with the ability of juvenile Chinook salmon to find an entrance located in the corner of the dam due to their small size at emigration as fry and subyearling smolts.

The project team also assumed that post-spawn adult steelhead would find and enter surface-oriented passage facilities located near the spillway of the dam. This was based on the ability of this life stage and species to easily transit a reservoir of this size given their swimming capabilities, and observations of these fish being on the surface and actively searching for outlets to reservoirs at Columbia River dams.

4.2 Design Criteria

4.2.1 Juvenile Fish Passage Timing

It is important to understand what the timing and duration of migration is for the target fish species to ensure the design and operation of a downstream fish passage facility can accommodate all or the vast majority of this season to provide effective fish passage. Based on smolt trapping data from the Chehalis Basin[10], fish species timing is shown in Figure 23.

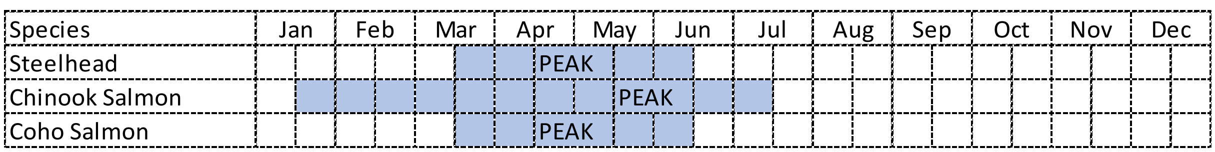
[10] Including data from smolt traps on the Chehalis River (RM 52 near Rochester, WA), Newaukum River (RM 5.8) and Bingham Creek (near Matlock, WA), as well as more recent pilot studies testing a new trap design and protocols at the Chehalis River trap site and unpublished data from the Newaukum River trap. Chinook fry data source from Quinault Indian Nation pilot study at seven locations in the upper basin, including two sites in the Skookumchuck River (Gilbertson et al. 2021).

Steelhead out-migration timing at the Chehalis and Newaukum river traps peaks in late April through the first week of May; presence occurs from mid-March through late June. Based on this information, the project team targeted operating the fish sluice at Skookumchuck Dam from mid-March through mid-June for steelhead smolt passage, and longer if water supply was available.

Chinook salmon smolt out-migration timing peaks in late May through mid-June; presence occurs from mid-March through late June but can extended into late July in some years. In addition to smolts, Chinook salmon produce a pulse of fry (≤ 45-millimeter fork length) soon after emergence from gravels (which can occur in January). For design considerations, the project team targeted operating the fish sluice from January through mid-July for juvenile Chinook salmon passage.

Juvenile coho salmon timing was not evaluated specifically but was assumed to be similar to steelhead given that coho salmon out-migrate as yearlings similar to steelhead. Timing of post-spawn adult steelhead was not evaluated specifically but occurs from mid-January through May in the upper Chehalis River (Ecology 2020) and would occur during fish sluice operations targeting juvenile steelhead and Chinook salmon passage.

Figure 23
Salmon and Steelhead Juvenile Downstream Migration Season for Skookumchuck Dam Evaluation



4.2.2 Target Attraction Flows

Juvenile salmonids migrate downstream by orienting on flows and velocities. In reservoirs, where velocities can be close to zero, it is important to provide sufficient velocity near surface bypasses so that fish can find their way to the facility. Sufficient flow volume is required to produce velocities that fish can sense. The NMFS criterion for attraction flow requires a minimum bypass flow of 5% of the total outflow (NMFS 2022, Section 8.6.3.4). However, this criterion is for juvenile fish bypass at water diversion structures and does not exactly apply to the Skookumchuck Dam situation where the facility is providing a bypass route out of a reservoir rather than around an in-river water diversion structure.

Another consideration was the multi-level intakes located upstream from the forebay and fish sluice, and vertically located at elevations 449, 420, and 378 feet. The team concluded that fish would be unlikely to be attracted to any of the three intakes that are typically well below the surface during the migration season, because juvenile salmonids are surface oriented. This is important for two reasons. First, intake flows would not help attract fish to the sluice—fish sluice flow alone would have to provide sufficient attraction cues. Second, in terms of fish attraction, the intakes would not compete with fish sluice flow.

Based on project team experience, a minimum of 25 cfs flowing through the fish sluice was considered the lowest volume likely to produce velocities that fish would cue on for migration towards the fish sluice. Thus, several flow rates were initially proposed, including 120, 65, 40, and 25 cfs discharging through the fish sluice year-round (starting on January 1). These flow rates were evaluated in the HEC-ResSim model as described in Section 3.1 to determine how long during the fish migration season each of these flows could be sustained before the reservoir elevation dropped too low for fish passage. Table 7 shows the HEC-ResSim results for the duration the reservoir can be maintained high enough for flow through the fish sluice at each of these flows. The highest flow of 120 cfs could not be maintained during the entire steelhead out-migration period in dry years, with the reservoir elevation dropping below the fish sluice by June 9. Flow rates of 40 and 25 cfs could be maintained during the entire migration period of all species, but associated 2D HEC-RAS modeling showed these flows do not provide the necessary attraction flows through the fish sluice. Therefore, the fish sluice flow rate of 65 cfs was selected as the design flow criterion to provide the largest hydraulic signature possible in the reservoir for fish to sense and cue on while also maintaining adequate reservoir elevation throughout the out-migration period.

Table 7
HEC-ResSim Results of Duration of Fish Passage Through the Fish Sluice at Evaluated Flow Rates

MAX DISCHARGE THROUGH SLUICE[1]	TOTAL DISCHARGE FROM DAM	DATE WHEN RESERVOIR DROPS BELOW OPTIMAL FOR FISH PASSAGE		
		Median	Earliest	Latest
120 cfs	140 cfs	July 21	June 9	August 14
65 cfs	85 cfs	September 19	August 5	October 26
40 cfs	60 cfs	N/A	October 3	October 3
25 cfs	45 cfs	N/A	N/A	N/A

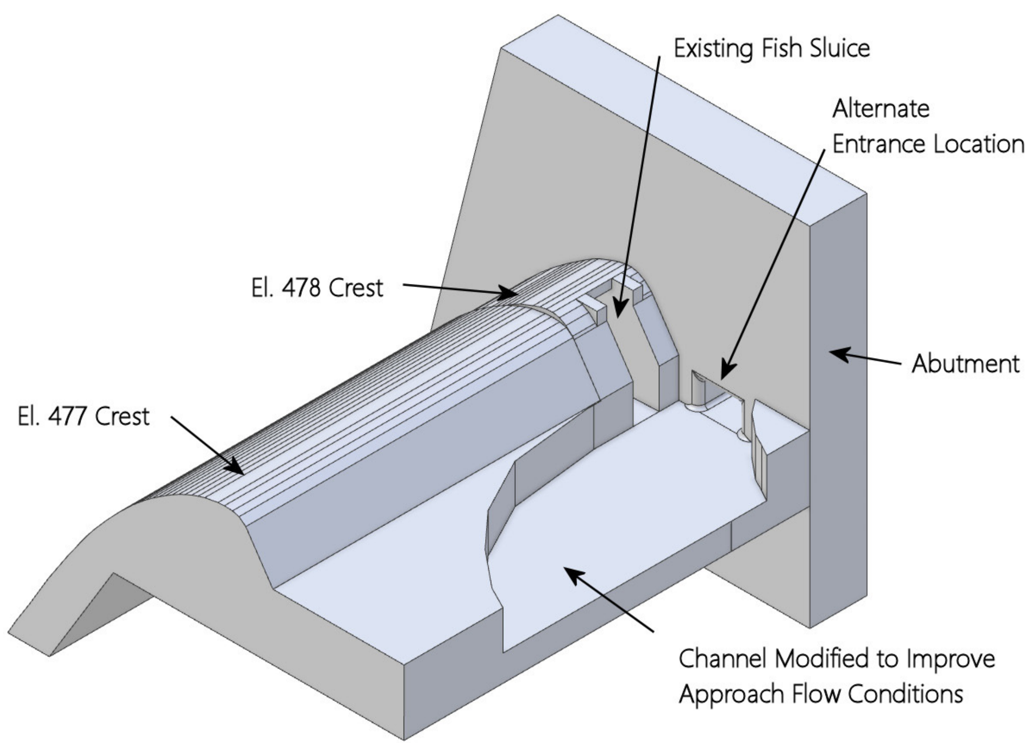
Note:
1. Assumes that no discharge occurs through the main intakes except for the 20 cfs of flow delivered to the hatchery.

4.3 Conceptual Fish Sluice Design

Based on the design criteria and considerations as well as the HEC-ResSim reservoir modeling results, a conceptual-level design of a new fish sluice was developed to achieve the desired flow conditions. This proposed fish sluice would be constructed through the left abutment and concrete wall to the right (looking downstream) of and perpendicular to the spillway to allow for a smooth angle of flow from the forebay into the sluice. The potential new fish sluice uses a rectangular entrance with filleted corners that transitions smoothly to a 48-inch-diameter pipe (Figures 24 and 25). The smoothing of the forebay described in Section 3.3 and shown in Figure 19 is also proposed. The 3D CFD model geometry for the proposed new sluice and accompanying terrain is shown in Appendix A. This proposed new fish sluice was modeled using the CFD model at reservoir elevations 467, 470, and 477 feet to encompass the reservoir elevations at which it would be operational. The 2D HEC-RAS model was not used further for the proposed fish sluice as it had informed the development of the design criteria, primarily the attraction flow needed and smoothing of the forebay topography required for any alternative.

The CFD model results for the alternative fish sluice design, including the smoothed surface topography and reshaping of the structural elements of the dam at the entrance upstream, are shown in Figure 26. The CFD model results indicate that the new design achieves the desired flow conditions described above (see Methods for Downstream Fish Passage). The design objective was to make the hydraulic signature of flow entering the fish sluice entrance project upstream into the reservoir and present fish with sufficient velocity and uniform approach conditions to sense and cue on. Flow conditions for proposed new fish sluice eliminate eddies, changes in direction and velocity, and provide uniform flow lines leading into the fish sluice entrance (Figure 26) that are expected to allow fish to enter the sluice entrance and pass directly into the transition structure between the entrance and a 4-foot-diameter pipe (Figure 25).

Figure 24
Isometric View of Alternative Fish Sluice



Note: View shows the spillway crest, existing fish sluice entrance, river left dam abutment, proposed new fish sluice entrance, and smoothed forebay upstream of the fish sluice entrance.

Figure 25
Alternative Fish Sluice Dimensions at Entrance and to a 4-Foot-Diameter Pipe

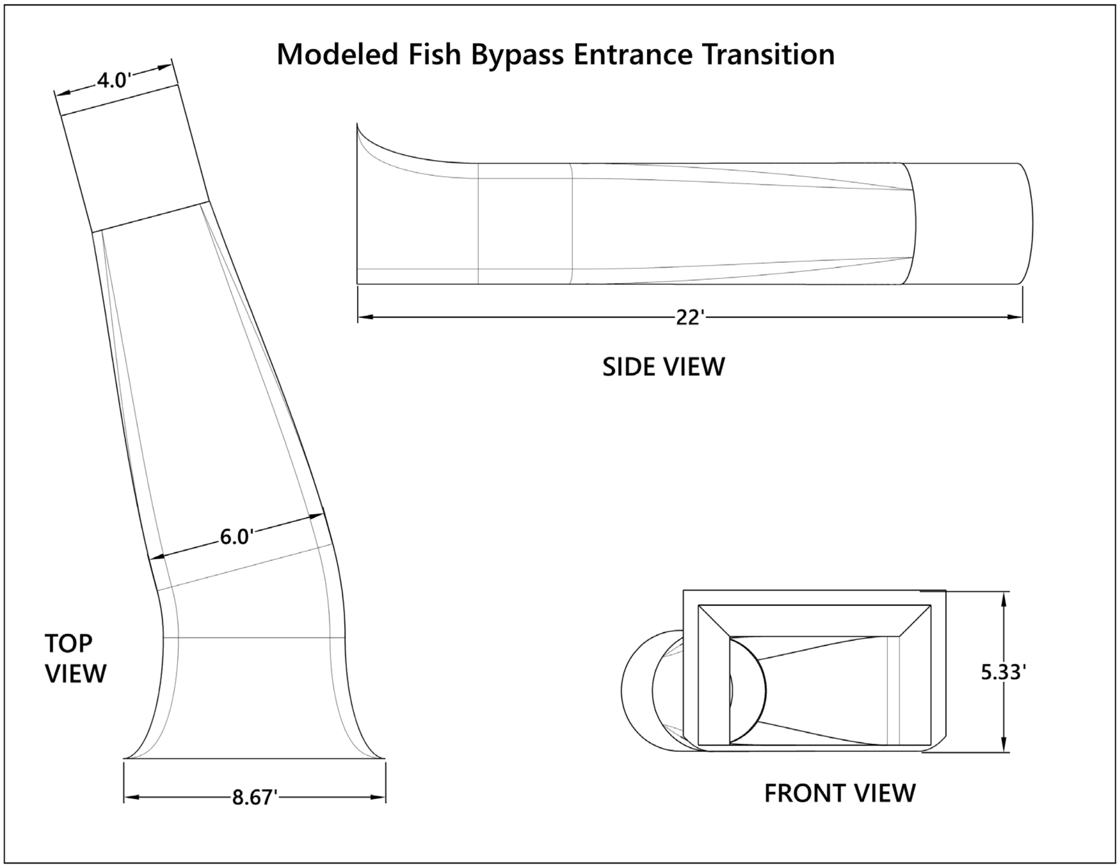
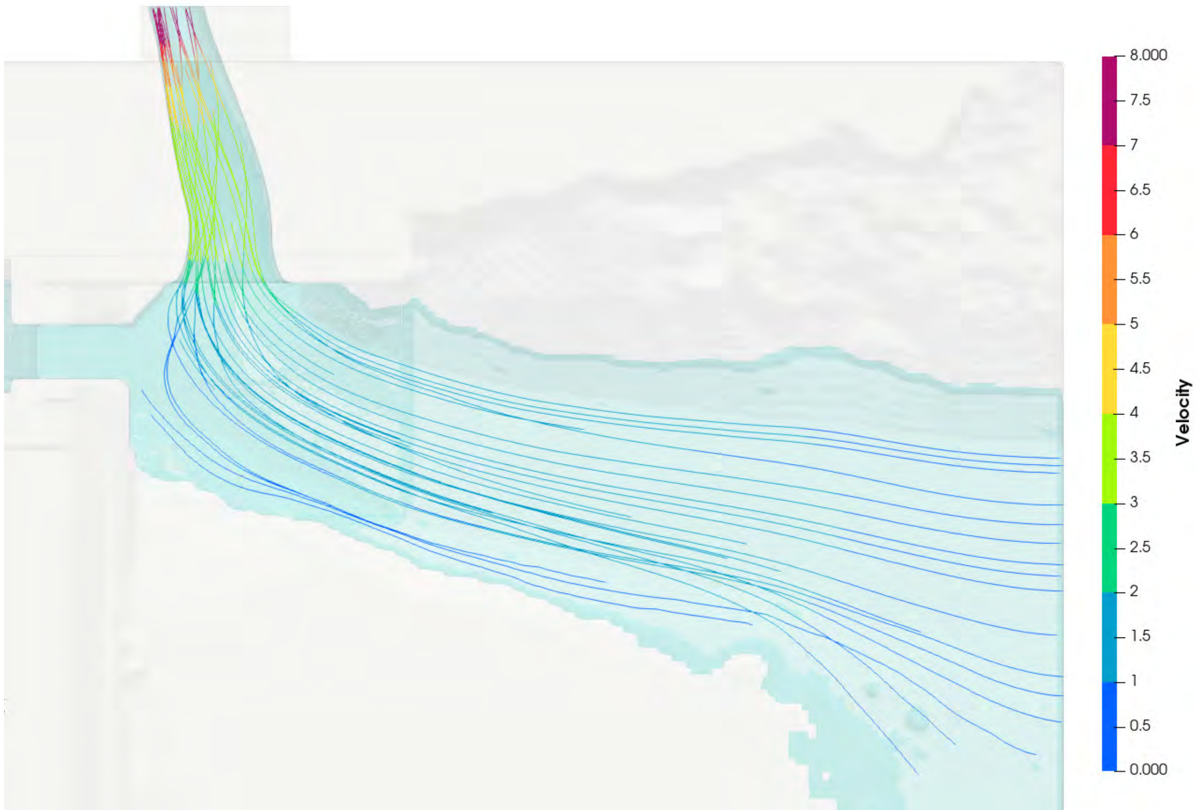


Figure 26
CFD Model Results for the Alternative Fish Sluice Entrance and Within the Fish Sluice at Reservoir Elevation 467 Feet



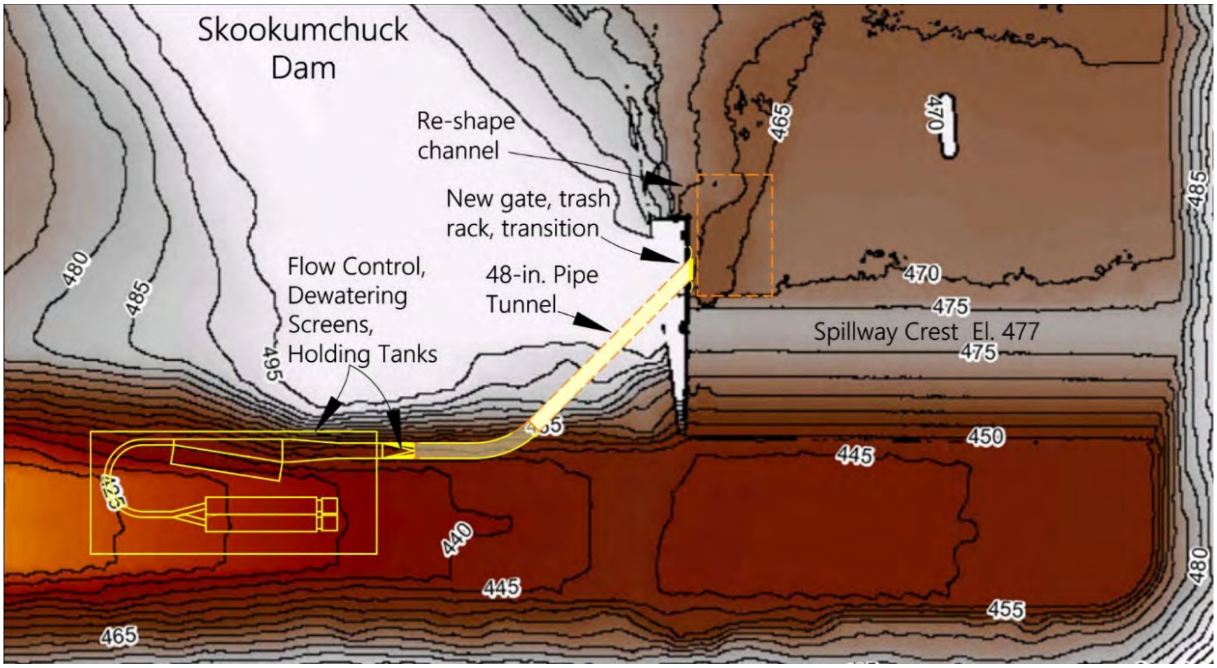
A flow of 65 cfs through the fish sluice alternative appears highly feasible based on design tradeoffs between several factors. These included providing as much attraction flow as possible so that fish in the reservoir can find the outlet, smoothing the hydraulic profile upstream of the entrance that was judged appropriate for fish attraction based on CFD modeling, maximizing the duration of sluice operation each year, and maintaining water velocities at the sluice entrance that allow adult steelhead to pass through the trash racks without injury. A trash rack and an automated trash rack cleaning system would need to be incorporated into the fish sluice design to prevent large debris from entering the sluice, conduits, and dewatering facilities or corrugated metal flume. NMFS criteria (2022) recommend velocity less than 1.5 feet per second through the gross area of a clean coarse trash rack to reduce the hydraulic pressure on the debris and thus facilitate cleaning of the racks regularly (NMFS 2022, Section 5.8.2.1). There is no evidence of fish refusing to pass through trash racks at velocities of 2 feet per second or less (Bell 1991, as cited in NMFS 2022). NMFS criteria for coarse trash racks on fish ladder exits will likely be required for downstream passage of adult steelhead. The criteria include a minimum clear space between vertical flat bars of 8 inches if adult species other than Chinook salmon are present, a lateral support bar spacing of at least 24 inches, and a design that allows trash rake tines to fully penetrate the rack for effective debris removal and the trash rack extending above the water level to allow debris raked from the trash rack to be removed (NMFS 2022, Section 5.8.2.4).

Once fish pass through the proposed new fish sluice, they will need to be returned to the river downstream, which is a vertical distance of approximately 120 feet, in an alternative to the existing chute that was determined to not provide suitable passage conditions. Two primary alternatives to return fish downstream were considered with the new fish sluice—trap and transport and a low gradient flume.

4.3.1 Bypass Routing to a Dewatering Facility for Trap and Transport

The proposed new fish sluice angles through the dam such that it exits the bedrock downstream of the spillway energy dissipation basin. This would bring the outlet pipe from the fish sluice well above the chute and allows sufficient freeboard above the water surface elevation during high spill events (Figure 27) to avoid damages from water or debris passing down the chute. Upon exiting the dam, the pipe would turn approximately 45° north and enter a dewatering facility. The dewatering facility would incorporate screens to remove most of the fish sluice flow and create hydraulic conditions for safely passing the fish to holding tanks (Figures 28 and 29). Adult and juvenile fish would be diverted to separate holding tanks. Fish in the holding tanks would be transferred into truck loading tanks (pods) and lifted from the holding facility and transferred to a tank on a transportation truck located on top of the dam. Once in the truck, fish would be transported and returned to the river downstream of the dam. Frequency of truck transport would vary with the number of fish being collected but would occur at least once each day during the migration period. Excess water from the dewatering facility would return to the spillway chute. Tunneling through this corner of the dam requires geotechnical and structural analyses to ensure it does not compromise the integrity of the dam.

Figure 27
Potential Angled Fish Sluice Through the Corner of the Dam and Routing to a Dewatering Facility Located Above the Spillway Chute



Note: The spacing between the spillway abutment and the dewatering facility is approximate.

Figure 28
Plan and Section Views of a Dewatering Facility Located Above the Spillway Chute

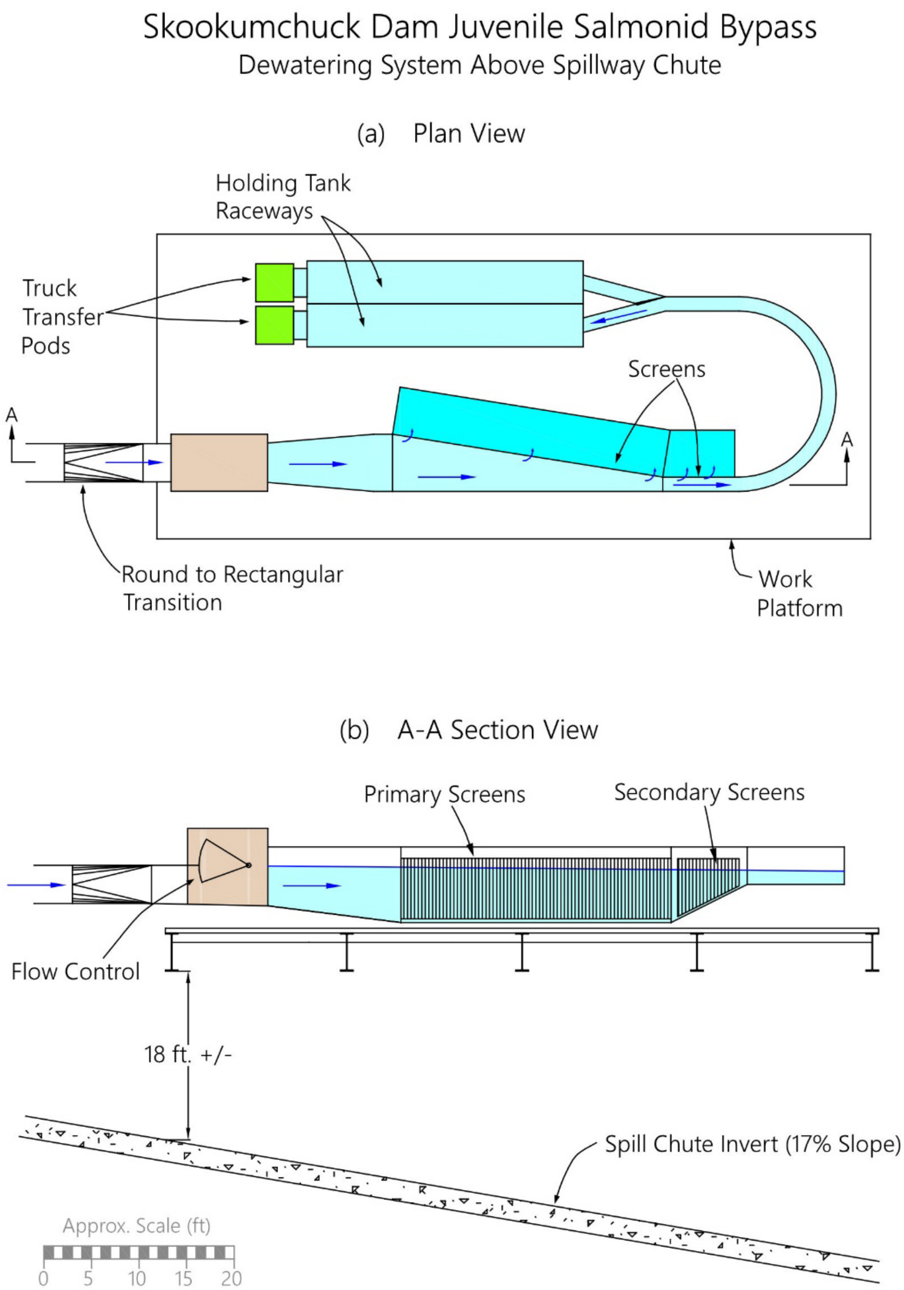
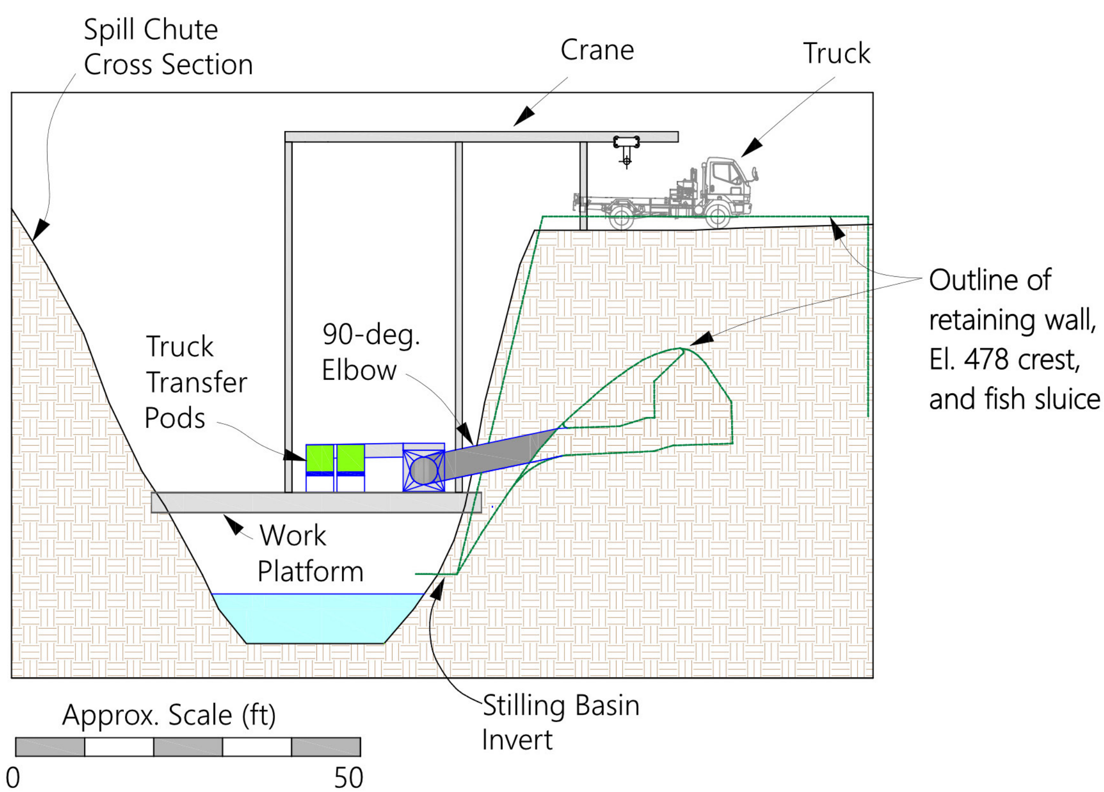


Figure 29
Schematic Diagram of How Truck Transfer Pods in the Holding Facility Would Be Lifted to the Dam Crest for Loading Juvenile Fish onto Transportation Trucks



The water flow rate required to attract migrating fish to a passage inlet can be greater than that needed to operate the fish holding and transportation facilities, or downstream return flumes. Fish screens (dewatering screens) that meet NMFS and WDFW design criteria would be used to remove the proportion of total flow that exceeds the amount needed to safely convey fish. The dewatering system would be located on the right bank above the spillway chute approximately 200 feet downstream of the spillway crest. Once past the dewatering system, fish can be routed to a corrugated metal flume that conveys the fish back to the river or holding tanks for subsequent transport. Transportation is used when a fish conveyance flume is impracticable from a design or cost standpoint. The dewatering facility would be designed such that post-dewatering, fish-bearing flows would be approximately 0.5 to 1.0 cfs to convey fish into holding tanks for subsequent truck transport. A typical "V" configuration of dewatering screens is shown in Figure 30, where the screen panels are placed vertically and cleaned of debris automatically by a mechanical brush-sweep system.

Figure 30
Typical "V" Configuration for Juvenile Fish Facility Dewatering Screens

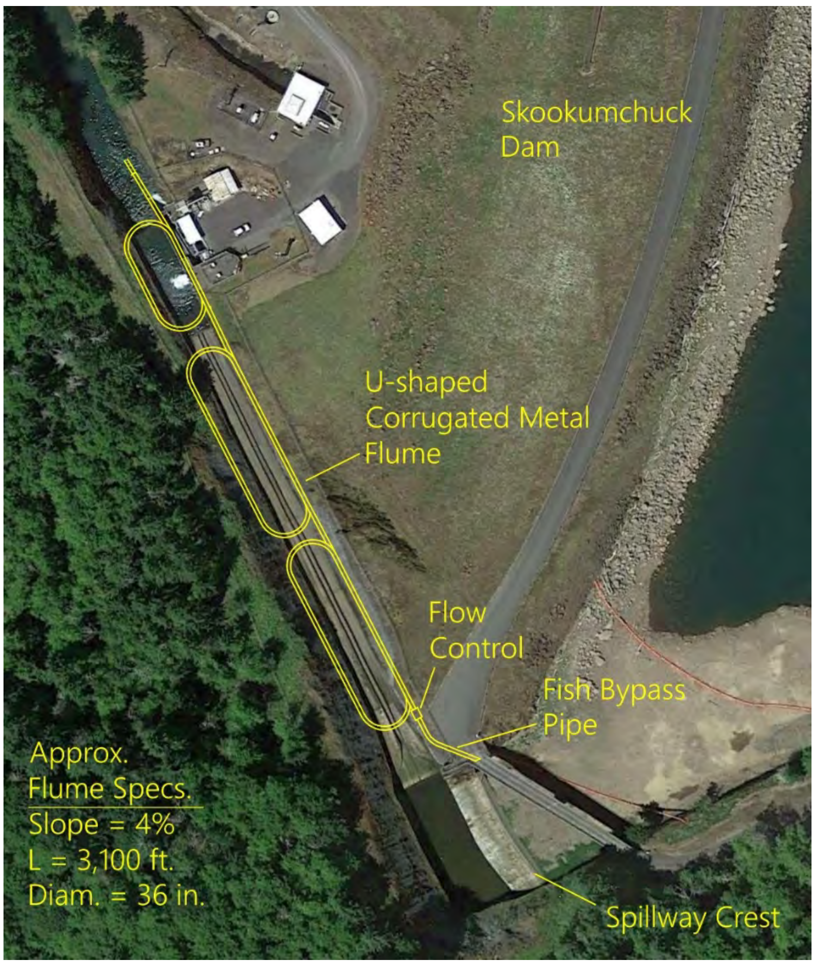
Note: Flow direction is from the foreground to the background of the photograph. Water passes through all screen panels on the right and the "V" narrows as water is removed. Screen located in Milton-Freewater, Oregon. Photograph by Larry Swenson.

4.3.2 Bypass Routing to a Low-Gradient Flume

Another alternative to return fish to the river downstream is via a low-gradient flume that passes fish over the 120 feet of vertical elevation to the river below. This would utilize a similar dewatering facility as proposed for the trap and transport option, but rather than sending fish to a holding tank, both fish and a lower volume of flow would enter a 36-inch, U-shaped corrugated metal flume. The flow capacity of corrugated metal flumes used at USACE dams on the Snake and Columbia Rivers is 25 to 40 cfs. Fish sluice flow in excess of this flow rate would be dewatered in the screening facility and the remaining 25 to 40 cfs would be conveyed down the flume. The design criteria applied to this alternative assumed a fish sluice flow of 65 cfs. Under this flow rate, 25 to 40 cfs would be dewatered in the screening facility and returned to the river via the spillway chute. Two flume routing options are possible that address the 120-foot head differential between the dewatering facility and the river below the dam:

1. *A helical, or racetrack, flume over the spillway chute*: The corrugated metal flume would be configured at a 4% slope and routed in a helix over the spillway chute. Fish would return back to the Skookumchuck River near the adult fish collection facility located at the base of the dam (Figure 31). This design could return the fish to the river either in the stilling basin associated with the dam outlet valves (the white discharge in the uppermost racetrack in Figure 31) or downstream of the adult trap. There is a vertical drop of approximately 15 feet from the stilling basin associated with the energy dissipation valves to the river. Additional assessment of the plunge pool will be needed in a future design phase to determine whether fish can safely enter the river from the stilling basin, or if the corrugated metal flume needs to be extended to the river downstream of the weir that forms the basin.

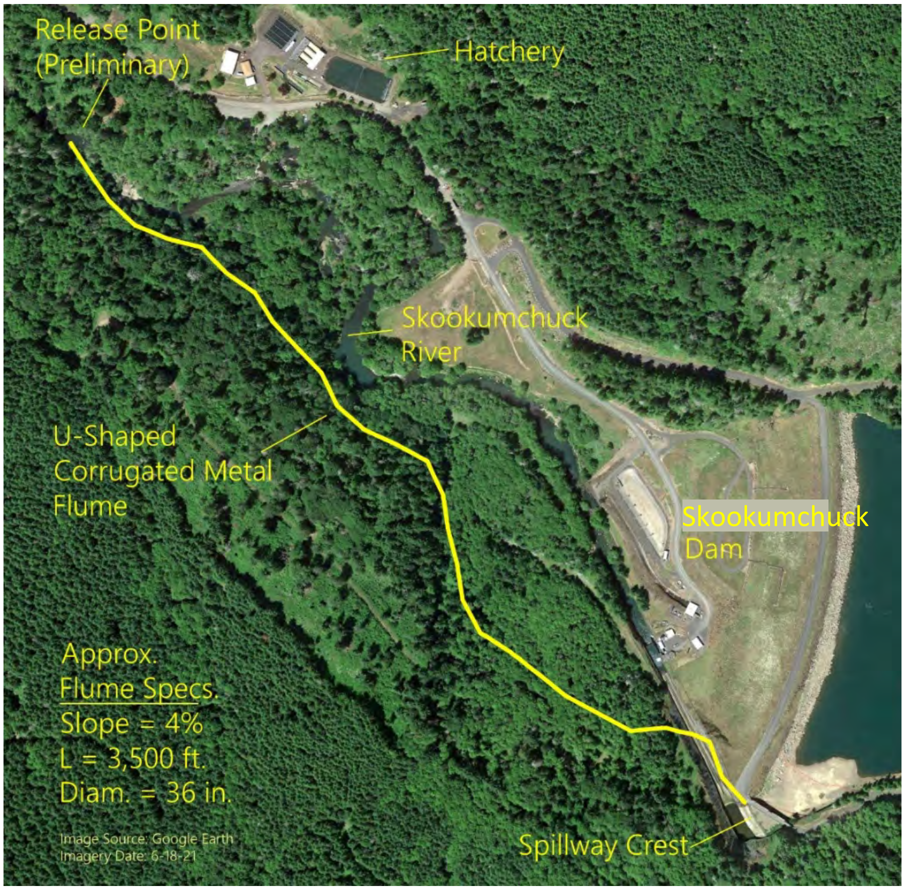
Figure 31
Conceptual Layout of Helical Low-Gradient Metal Flume Installed Above the Spillway Chute



Note: This helical, or racetrack configuration, flume is designed to convey fish from the reservoir to the river below the dam.

2. *Overland flume*: The low-gradient corrugated metal flume could alternately be aligned to cross the spillway chute and proceed downstream overland also at a 4% slope. The flume would return fish back to the river further downstream such as near the hatchery (Figure 32).

Figure 32
Conceptual Layout of Overland Low-Gradient Metal Flume



Note: This low-gradient flume is designed to travel overland to convey fish from the reservoir to the river below the dam.

2. **Full-flow volitional passage:** Another alternative could include full flow, volitional passage. In this alternative, fish sluice flow rates are limited to a maximum of 25 to 40 cfs and the entire flow is conveyed to the river via a helical or overland flume, as described above. This alternative would eliminate construction and operational costs associated with dewatering but would limit fish sluice attraction flow to 25 to 40 cfs. The alternative would allow for a longer period of operation of the fish sluice (by using less water). Tradeoffs associated between full flow and dewatering would need to be investigated further in a future design phase.

The maximum allowable water velocity in a fish bypass channel (i.e., the low-gradient flume) is 12 feet per second (NMFS 2022). This criterion rules out the use of a smooth-walled flume because the required slope of a flume needed to address the 120-foot head differential at the project site would result in water velocities exceeding this criterion. Corrugated metal flumes have a higher roughness and can be set at a steeper slope without exceeding the velocity criterion compared to a smooth flume. Corrugated metal flumes have been installed at juvenile fish bypass systems at several Snake and Columbia River dams operated by the USACE. These have been operated for years, if not decades, depending on the location. The facilities associated with the flumes are monitored continuously while operating, and samples of fish taken at facilities after passage through flumes are collected routinely and examined for injury and mortality. Based on this information, corrugated metal flumes are a proven design for conveying fish from a dam to downstream facilities or release locations. The corrugated metal flumes at USACE dams are 36 inches wide, placed at a 4% slope, configured using large radius turns, corrugated along the bottom for energy dissipation, covered for shading and temperature control, and are outfitted with an adjacent walkway for personnel access, maintenance, and inspection (Figure 33). Flow volumes in these corrugated metal flumes typically ranges from 25 to 40 cfs. Use of corrugated metal flumes results in smooth hydraulic transitions for fish, and allows for water depth, width, velocity, and turbulence to be controlled.

Figure 33
A 36-Inch, U-Shaped Corrugated Metal Flume Installed at McNary Dam on the Columbia River

Source: Advanced American 2022

At this conceptual stage, the design for the new fish sluice slightly exceeds NMFS velocity and acceleration criteria. Hydraulic conditions at the entrance were not modeled further under the scope of this analysis, but the model results showed that the width and convergence of the entrance could be adjusted to meet the acceleration and velocity criteria. Calculations conducted by the project team indicated that it is feasible to achieve these criteria by altering the configuration of the entrance. This would include enlarging the opening of the entrance and increasing the distance between the entrance and where the transition section between the entrance and the 4.0-foot-diameter bypass pipe turns slightly. Redesign of the entrance configuration to meet the criteria could be accomplished in the future in consultation with regulatory agencies and stakeholders.

4.4 Fish Passage Alternatives Not Evaluated in this Analysis

The project team did not consider floating surface collector technology in this phase of juvenile fish passage design development. Surface collection is an evolving approach to improving the passage of juvenile and adult fish moving downstream past water storage projects, and each site and application is unique: a concept that works well at a given site may not directly transfer to another site (Appendix D in NMFS 2022). In-reservoir floating surface collectors typically use pumped attraction flow in combination with a volitional bypass or trap-and-haul bypass to pass downstream migrants out of a reservoir. These collectors take advantage of juvenile and adult fish surface-oriented behaviors and provide a surface outlet for fish to sense and pass into.

The project team did not evaluate floating surface collector alternatives for the following reasons:

- It was judged that this technology was not needed. Available flow through a new fish sluice was the primary alternative considered. This provides downstream migrants with a surface-oriented outlet where maintenance of a facility would be minimal (automated trashrack and screen cleaning systems) and personnel would primarily be required to operate trap and haul facilities if this were the selected alternative. Reservoir operations modeling confirmed that water was available for fish sluice operation during the steelhead and salmon migration period.
- The configuration of the forebay and dam do not support installation of a floating surface collector without major modification. Floating surface collectors are typically mounted onto the face of a concrete dam or at a location where fish naturally congregate due to flow patterns in the reservoir. However, at Skookumchuck Dam the area upstream of the spillway is comprised of a large, relatively flat bench at elevation 463 to 464 feet. The reservoir operates between 477 feet (spillway crest) and 378 feet (lowest intake). The floating surface collector concept is usually designed to operate throughout a forebay operating range by allowing the collector to rise and lower with forebay elevation. Such a configuration would require extensive reconstruction of the area in front of the spillway to locate a floating surface collector anywhere close to the existing sluice location.
- Kock et al. (2019) synthesized information about floating surface collectors. Conditions conducive to collecting downstream migrants using floating surface collectors include small reservoirs, small reservoir operating ranges (e.g., approximately 3 feet at North Fork Dam, Clackamas River, OR), and designs where the collector passes a high percentage of water column flow (e.g., 19.6%, North Fork Dam, Clackamas River, OR). In addition, floating surface collectors are placed where prevailing flow patterns result in juvenile fish congregating, such as near a powerhouse intake (e.g., Swift Dam, Lewis River, WA). The Skookumchuck Dam site does not have conditions that are conducive to designing effective floating surface collectors, other than the small reservoir size.
- The intake flow at Skookumchuck Dam was judged by the project team to not be in the right location or volume needed to support a floating surface collector. The intakes are located upstream of the bench upstream of the spillway and at three different elevations (449, 420, and 378 feet). Typically, floating surface collectors require both pumped attraction flow and siting the collector to take advantage of powerhouse intake flow. Siting the collector in front of a powerhouse allows powerhouse flow to draw fish to the collector location, and the pumped attraction flow on the collector guides fish into the collector. Also, pumped attraction flow has to be large to be effective. For example, attraction flow into collection

entrances at North Fork Dam is 1,236 cfs. Designing additional pumped attraction flow into a floating surface collector at Skookumchuck Dam that is placed upstream in the deep portion of the reservoir (due to the bench located upstream to spillway) would allow the floating surface collector to operate over the approximate 100-foot operating range. However, this would require a large amount of pumped attraction flow due to its location away from the spillway and lack of adjoining powerhouse flow, and access to the facility for personnel and to offload collected fish onto transportation trucks. This results in high operational and maintenance costs and a collection system that is highly dependent on mechanical systems to maintain performance objectives. As a rule, systems that are gravity flow and mechanically simple are preferred. Initial costs of the stationary floating surface collector at North Fork Dam was estimated at $54 million in 2015, and at $60 million in 2012 for a floating surface collector that operates over a 122-foot forebay range at Swift Reservoir on the Lewis River, WA.

The team also did not evaluate fixed multiport collection structures in this analysis. The USACE has estimated a cost of $220 million for implementation of a fixed multiport collection structure at Howard Hanson Dam that would allow fish collection and passage from one or two of a set of five intake ports at multiple water levels as the reservoir elevation changes. The selection of this preferred alternative is the result of a decade or more of studies of fish passage alternatives at Howard Hanson Dam. The system has not been installed and tested.

At Cle Elum Dam, the U.S. Bureau of Reclamation designed and is constructing a new facility to pass fish through an innovative multi-level intake and helix design that works even with fluctuating water levels. Washington State and federal partners including the Yakama Nation, U.S. Bureau of Reclamation, Ecology, and state and federal Fish and Wildlife departments are coordinating the $200 million project.

These large, complex, multi-intake types of systems were not considered for Skookumchuck Dam at this point of the project because they have not been constructed or tested.

4.5 Evaluation of Upstream Fish Passage Alternatives

While the focus of this study was on downstream fish passage, the existing adult fish collection facility was also evaluated to understand its general effectiveness for fish trap and transport upstream of the reservoir and Whooshh Innovations was contracted to identify concepts for their technology for lifting fish from the trap over the dam and placing them into the reservoir just upstream of the dam.

4.5.1 Existing Adult Fish Collection Facility

In February 2022, project team members toured the existing adult trap facility while steelhead broodstock collection activities were underway. The purpose of the visit was to identify any needed repairs and upgrades to the equipment and facility to improve adult fish handling and processing. The site visit summary is provided as Appendix B. The site visit and discussions with the TransAlta trap operator and WDFW staff resulted in the following takeaways:

- Overall, the trap operates well in its current configuration. Holding and loading tank capacities are somewhat limited but meet WDFW's needs for broodstock collection at this time and current steelhead run size.
- The current method of bringing multiple steelhead at a time from the holding area into a small anesthetic tank (Figure 34) for sedation using carbon dioxide and fish processing is inefficient and potentially harmful to fish. Sedating broodstock fish with electricity is a proven and commonly used method at hatcheries to anesthetize large numbers of fish quickly and inexpensively without the use of chemicals. WDFW identified this modification as a top priority.
- WDFW identified the need for a larger hopper for loading fish onto transportation trucks if the number of fish transported increases in the future. The current hopper can hold approximately 50 adult fish.
- Additional modifications identified as needed included installing a chute for returning immature fish from the anesthetic tank to the holding tank, installing a larger anesthetic tank, constructing a larger broodstock collection rack, installing a table for pathological sampling, and replacing the solid hose used to release fish from the truck with a lay-flat, flexible release hose.

Figure 34
Winter Steelhead Being Processed in the Adult Fish Trap Anesthetic Tank

4.5.2 Whoosh Innovations Alternative for Upstream Adult Passage

Whoosh Innovations was subcontracted to prepare an initial concept of adult fish passage at Skookumchuck Dam. More details are provided in the summary memorandum in Appendix C. Whooshh live fish transport technology uses pneumatic pressure differentials to transport fish in misted tubes up and over barriers such as dams. The Whoosh tube transport system requires 480-volt power, a small volume of water, and remote internet capability to monitor the tube system. Three options were identified, one that would require manual sorting and handling for fish passage and two that allow for volitional entry and passage of adult fish. The Whoosh systems could be sized and configured to accommodate adult steelhead, coho salmon, and/or Chinook salmon.

For all three options considered, the Whooshh system would be located within or adjacent to the existing fish trap facility at the base of the dam. Migrating fish would enter the facility as they do currently and volitionally enter the existing holding area within the fish facility. For the two volitional concepts, fish would enter the fish trap facility and would be transported immediately by the Whoosh system up and over the dam to the reservoir. For the third concept, operators will still be required to manually load the fish into a simpler version of the Whoosh system.

The Whoosh system uses a high-volume, low-pressure blower to provide temperature-controlled air at the entrance to facilitate movement of the fish through the transport tube(s). The tubes are lubricated by water droplets at frequent intervals along the tubes, which become mist with the air blower providing a relatively friction-free surface for the fish to glide forward in the air stream. To minimize thermal stress on the fish, the air should be chilled and the use of cold water such as that supplied to the hatchery is desirable. Additionally, shielding or shading should be used on the tubes to reflect sunlight and reduce warming. For the volitional systems, an imaging and data processing system is used to identify the fish species and appropriately sort the fish to the correct-sized tube for passage using a system of high-resolution cameras and computer. Additional data can be collected from the images such as fish size and condition. For the manually operated system, operators would manually identify and sort fish and send them to the tubes or process them for other purposes (such as hatchery broodstock or return them to the river downstream of the dam).

5 HABITAT BENEFITS MODELING RESULTS

EDT was used to model potential fish habitat for three species and four runs of fish in the Skookumchuck subbasin: steelhead, coho salmon, fall-run Chinook salmon, and spring-run Chinook salmon. Habitat potential was modeled under two time periods (existing and late-century) and five alternatives within each time period. The five alternatives included Current Operations (a baseline alternative that assumes no change to current operations), Dam Removal, Fish Passage Only, Flood Storage Only, and Combined Fish-Flood as described previously. In addition, for both the Fish Passage Only and Combined Fish-Flood alternatives, two upstream passage alternatives at the dam were modeled for steelhead: 33% passage as well as 90% passage for adults.[11]

The Skookumchuck system geometry is described in EDT by reaches of defined length and width and how they are connected. These reaches describe the physical parameters of the network of waterways that the fish species can move through. While reach lengths and connections (the network) are usually static, habitat quantity in terms of reach widths vary on a monthly basis defined by seasonal flow patterns (these were varied under the modeled alternatives). Obstructions are also part of the described system. Passage past an obstruction (both upstream and downstream) are governed by passage values for fish species moving through the system. These values are essentially the percentage of a fish species that can move through the obstruction in either the upstream or downstream direction and are life-stage specific. For this analysis, obstructions included culverts that stayed the same within a time period, with barriers on state highways removed by late-century as required for the culvert injunction (this is consistent with the ASRP EDT model), as well as passage at the Skookumchuck Dam.

Habitat attributes define the environment of the reaches, which reflect both habitat quality and quantity. Habitat attributes are described for each reach on a monthly basis. Dozens of attributes are described in EDT either by a quantitative measurement, such as percentage riffle-habitat, or a rating score based on salmonid health. Attributes that are rated are scaled from zero (best conditions) to four (worst conditions). An aggregation of each reach's monthly attribute ratings determines the survival factors of the system. For this analysis, the existing and late-century conditions that were used for the ASRP analysis were generally used as the baseline for this analysis. Specific updates to the ASRP baseline model, for all scenarios, included the following:

[11] The 33% upstream passage is for an increase in the number of adult steelhead to be passed upstream compared to an estimated 5% passage in current operations, but still within the capabilities of the current facility and staffing. The 90% upstream passage is if the majority of adult steelhead that return to the dam are passed upstream, while holding approximately 10% for hatchery broodstock. To pass 90% of the steelhead could require additional staffing or enlarged facilities for adult collection/passage.

1. Updated Thermalscape temperatures throughout the system for both existing and late-century time periods
2. Repair of the West Fork Chehalis falls barrier (though this does not affect Skookumchuck model results)
3. Updates to lower reaches in the Skookumchuck basin based on ASRP restoration projects that are completed or in-progress (additional details in Appendix D)
4. Updates to upper reaches in the Skookumchuck basin based on interpretation of recent aerial photographs and LiDAR obtained as part of this study (additional details in Appendix A)

The life history component of the model describes and defines, for each species, where the species can spawn, the timing of life stage transitions, and the rate of movement through the system per life stage (Table 8). For each species, hundreds to thousands of trajectories are run using the model. Each trajectory demonstrates a specific and realistic life history pattern that could be expressed by that species in the system. Each trajectory starts in one spawning location, has a certain number of days in the egg life stage, a certain number of days until emergence to fry, and specific locations and timings for movements and transitions to additional life stages until returning as a spawner. Collectively, all the trajectories for each species evaluated (termed a 'trajectory set') encompasses a full range of modeled spawning locations and defined life history patterns throughout the study area.

Table 8
Description of Life Cycle Components of the EDT Model Used to Define Trajectory Sets for Each Species

PARAMETER	DESCRIPTION	LIFE CYCLE APPLICATION	UNITS
Spawning Reach	Reach locations allowed for spawning trajectories start distributed among these reaches	Trajectories begin as eggs and end as spawners in these locations	EDT reach
Duration	Defines minimum and maximum amount of time trajectory may spend in a life stage	Defined specifically for each life stage	Days
Transition Time Window	Time periods during which one life stage may transition to another	Defined for spawning and for transitions between life stages (egg to fry; marine to migrant pre-spawner, and so on)	Dates
Speed	Speed at which life stage may move up or downstream	Defined for each life stage	Kilometers per day
Location Window	Locations at which one life stage may transition to another	Defined for transitions between life stages	River kilometers (relative to mouth)

Overall, system geometries (how reaches are connected) and trajectory sets remain static among scenarios. Therefore, changes in model results between scenarios are from differences in the quantity and quality of the habitat. Habitat attributes vary among scenarios, and the interaction of the components of the model for different scenarios is what drives differences in population performance. The life history trajectories for species are affected in their productivity and capacity by life stage due to habitat conditions (e.g., fish passage/access, changes in water temperatures, presence of fine sediment, conditions for benthic invertebrates) as compared to benchmark values of productivity and capacity. Survival values in the Pacific Ocean are entered as fixed survival rates to complete the species life history. Ultimately, the EDT model results in population level estimates of capacity, productivity, diversity, and equilibrium abundance by scenario.

The following components of the EDT model were varied among alternatives within the Skookumchuck subbasin in order to evaluate effects on fish habitat; further description of these model attributes and their characterization among scenarios can be found in Appendix D:

- High-flow and low-flow EDT attributes
- Reach widths
- Floodplain amounts
- Passage at Skookumchuck Dam

While flow and related attributes (widths, floodplain) were only modeled in the Skookumchuck subbasin for this study, it should be noted that changes in flow from the alternatives or due to climate change may also affect mainstem Chehalis reaches.

For the dam removal alternative, the reservoir was also changed to riverine habitat with attributes similar to neighboring reaches.

EDT model results include population level estimates of capacity, productivity, diversity, and equilibrium abundance by scenario. For the purposes of this report, equilibrium abundance is the primary result shown as well as productivity and diversity.

Equilibrium abundance is calculated based on productivities and capacities of the habitats. The estimate of potential fish performance in EDT reflects habitat conditions from spawning grounds all the way downstream to the marine environment, and back up to spawning grounds as returning adults, spanning the entire life history of the species.

Productivity in EDT is density-independent survival and represents recruits per spawner. Productivity reflects the quality of habitat in reaches and across months throughout the model, according to the life stages of the fish species being evaluated. Productivity is a function of habitat attributes such as temperature, large wood, and water quality that affect survival of life stages.

Diversity in EDT is the proportion of sustainable life history trajectories that are used to calculate equilibrium abundance. EDT diversity relates to the breadth of suitable habitat within a spatial unit and the variation in modeled life histories within the population. A lower diversity indicates that the calculated abundance relies on an increasingly narrow range of suitable habitat and life histories within the population. Populations in EDT with higher diversity are assumed to have greater resiliency to environmental perturbations compared to those with lower diversity.

The following sections provide details on each of the fish species modeled, and results for each alternative for the EDT outputs. Results are reported at the geographical spatial unit (GSU) level for the Upper Skookumchuck GSU and Lower Skookumchuck GSU. Graphs for results of the additional attributes of productivity and diversity can be found in Appendix D.

5.1 Steelhead

In the EDT model, winter-run Chehalis River steelhead are modeled to spawn from February to April, with juveniles emerging in late summer (Ashcraft et al. 2017). In the model, multiple source data have been consulted to identify that spawning occurs in most areas of the Chehalis Basin, including smaller upper-basin stream reaches. For the Skookumchuck River, steelhead trajectories include spawning in all mainstem Skookumchuck EDT reaches both downstream and upstream of the dam, as well as many tributaries, including several in the upper basin.

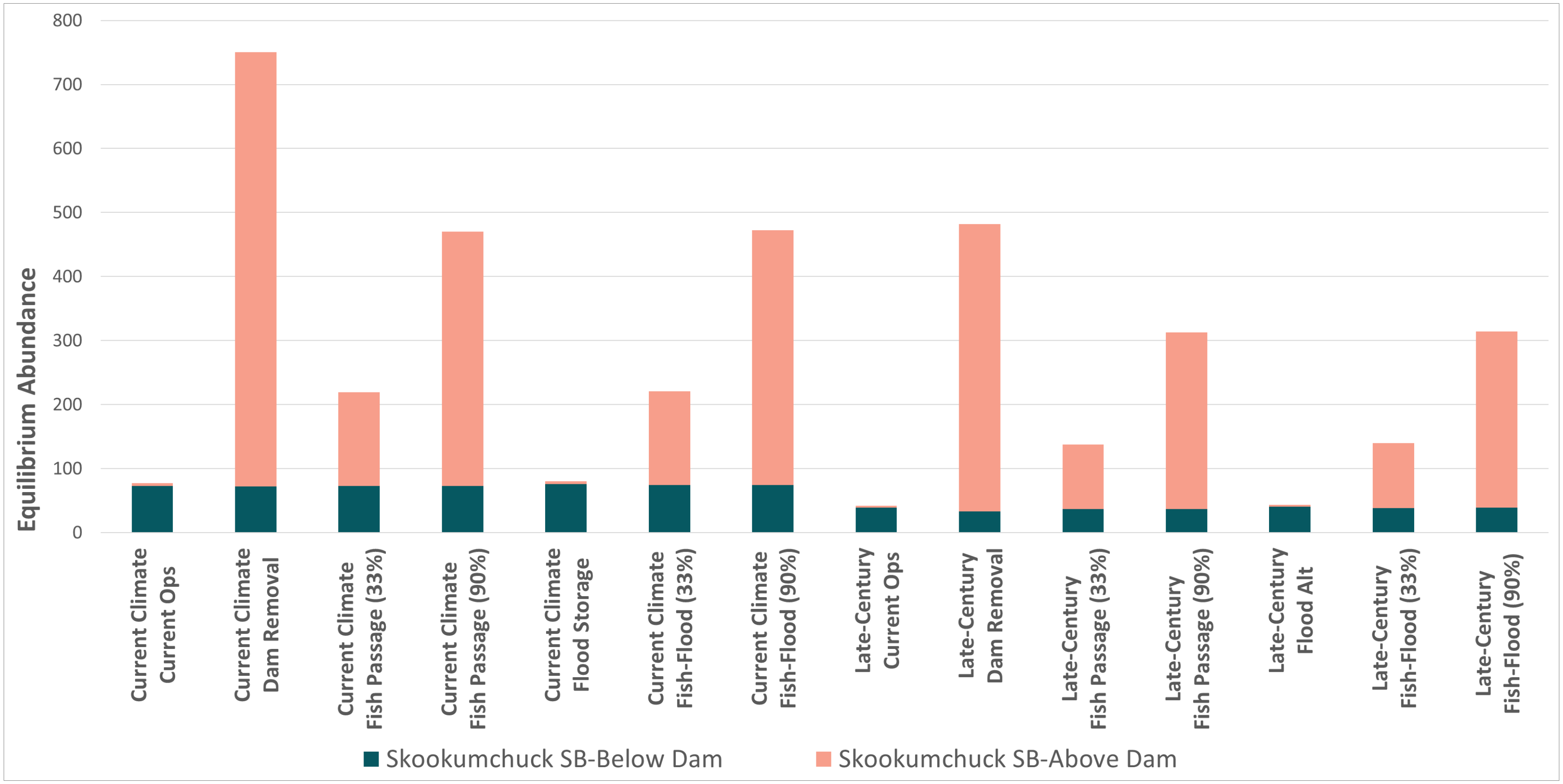
The steelhead age structure is complex; in the EDT model, individuals from the Chehalis Basin spend 1 to 3 years in freshwater and 1 to 3 years in the ocean. Steelhead life histories were parameterized the same as they were for the ASRP (2019) EDT analysis, with the following exceptions. The life history patterns used in EDT for this analysis were aligned with the most recent data regarding age structure from the Quinault Indian Nation and WDFW. The rate of smolt-to-adult return (SAR, also termed marine survival) for steelhead is uncertain, and for this analysis was set at 15%.

Under the Existing Climate Current Operations alternative, the predicted equilibrium abundance for steelhead is 73 fish in the lower watershed and 4 fish in the upper watershed (Figure 35). Among all existing climate scenarios, the equilibrium abundance stays fairly consistent in the lower watershed with the greatest differences in abundance in the upper watershed due primarily to increased passage and access to upper reaches. There is a lesser effect from changes in flow, floodplain, and channel width in the lower Skookumchuck between the alternatives. Under existing conditions, the Fish Passage Only and Combined Fish-Flood alternatives result in an overall increase in predicted equilibrium abundance of steelhead in the Skookumchuck subbasin of 183% to 186% at 33% passage and 509% to 511% at 90% passage for adult steelhead at Skookumchuck Dam. The Dam Removal alternative results in an overall 872% predicted increase in steelhead abundance in the upper watershed due to access to new high-quality habitat. The Flood Storage Only alternative has a similar equilibrium abundance prediction for steelhead as the Current Operations alternative because it does not include adult steelhead passage above Skookumchuck Dam. Steelhead diversity (the proportion of life histories that are successful under a given scenario) varies greatly under existing climate alternatives, with a high nearing 60% under the Dam Removal scenario and a low of just over 10% for the Current Operations and Flood alternatives. The higher the diversity number, the more resiliency a population may have to disturbance events.

In late-century, across all alternatives the predicted steelhead abundance decreases primarily due to climate change effects. Under the Late-Century Current Operations alternative, steelhead abundance declines a predicted 46% as compared to existing conditions. As compared to Late-Century Current Operations, the Fish Passage Only and Combined Fish-Flood alternatives in late-century increase steelhead abundance a predicted 229% to 234% at 33% passage and 646% to 651% at 90% passage for adult steelhead at Skookumchuck Dam. The Fish Passage Only and Combined Fish-Flood alternatives in late-century also predict steelhead abundance greater than that under the current time period current operations with an overall increase in abundance of 78% to 81% at 33% passage and 304% to 307% at 90% passage for adult steelhead; however, this increase is due completely to increased access to the upper watershed, while abundance numbers in the lower watershed decline by half as compared to the Existing Climate Current Operations. In late-century, the Dam Removal alternative is predicted to increase steelhead abundance in the upper watershed as compared to late-century current operations over 1,000%. This increase is due to access to the cooler upper-watershed habitat, and numbers in the lower watershed are predicted to decline similar to all other alternatives. As for existing climate, in late-century the Flood Storage Only alternative has a similar equilibrium abundance prediction for steelhead as the Late-Century Current Operations alternative.

The EDT model also predicts changes to diversity and productivity of species (see Appendix D for more details). Steelhead diversity decreases for all alternatives in the late-century time period compared to existing climate; diversity approaches 40% with dam removal in late-century and dips to around 5% for the Flood Storage Only and Current Operations alternatives. Under all time periods, abundance and diversity are highest for steelhead under the Dam Removal alternative and second highest under the Fish Passage Only and Combined Fish-Flood alternatives. Among all species evaluated, steelhead are predicted to have the greatest differences in diversity among alternatives within a time period. Productivity is lowered for all alternatives in late-century as compared to existing conditions. Dam removal remains the alternative with the highest productivity for steelhead in late-century, above 9, while all other alternatives have a productivity between 2 and 9 in late-century. This again reflects the higher quality of habitat available to steelhead above the Skookumchuck Dam, which could include cooler water habitat under climate change conditions.

Figure 35
Predicted Steelhead Equilibrium Abundance in Upper and Lower Skookumchuck GSUs



5.2 Coho Salmon

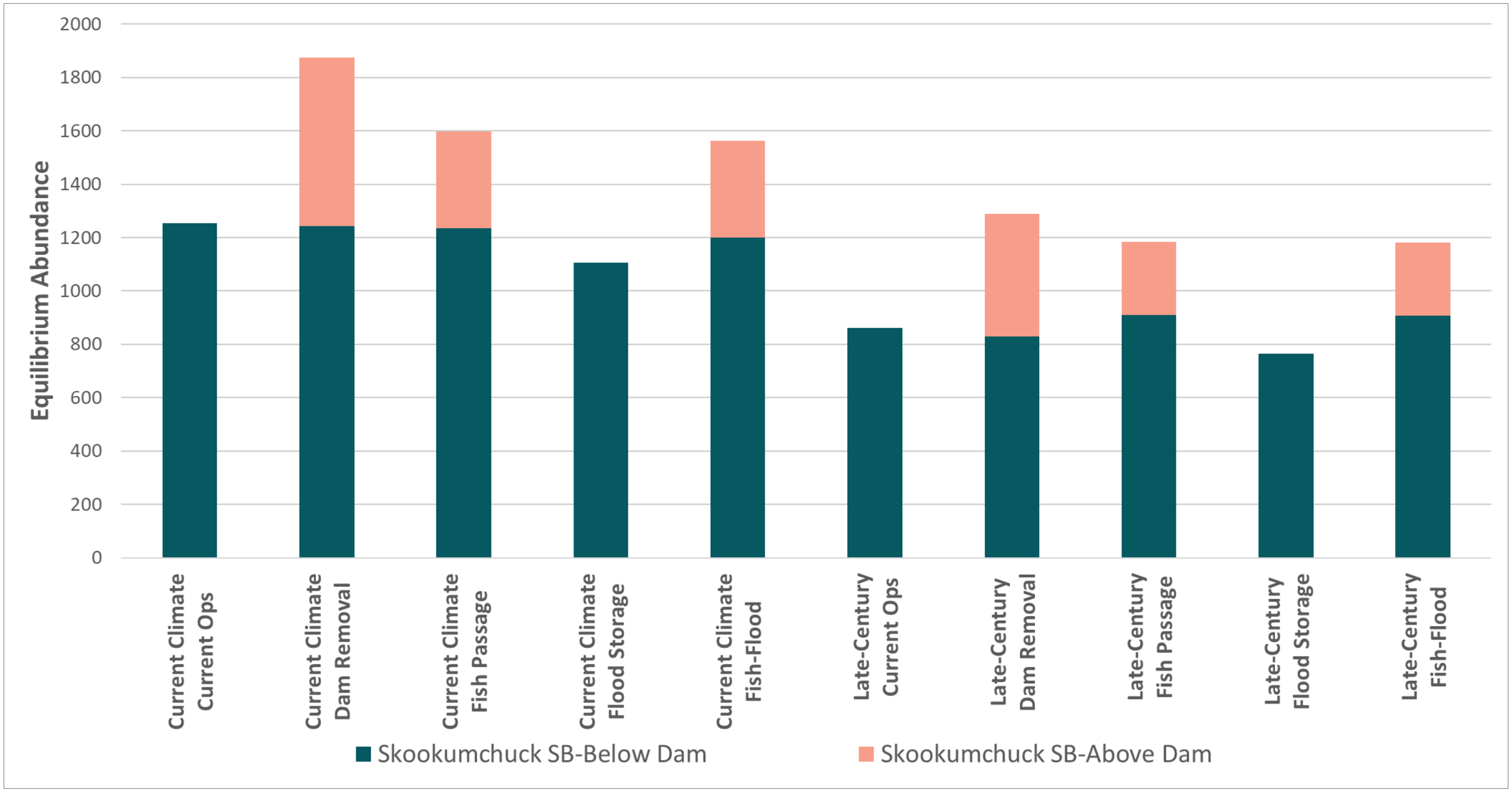
Coho salmon are the most abundant and widely distributed of the three modeled salmonid species in the Chehalis Basin. In the EDT model, coho salmon are modeled to spawn in late fall and winter, with juveniles emerging the following spring. They are modeled to rear in freshwater for 1 year and emigrate to the ocean in their second spring. The juvenile life history of coho salmon in the model included a portion that rear in the vicinity of their natal spawning reach and another portion that distributes downstream. In the EDT model, coho salmon spend about 2 years in the ocean and return to spawn as 3-year-old adults. For this analysis, coho salmon were modeled to spawn in the same reaches of the Skookumchuck subbasin as steelhead.

Under the existing climate Current Operations alternative, predicted equilibrium abundance under current operations for coho salmon is 1,255 fish in the lower watershed and 0 fish in the upper watershed. Under the Fish Passage Only alternative and Dam Removal alternative, equilibrium abundance of coho salmon in the lower watershed is predicted to decrease slightly (1,234 and 1,244 coho salmon, respectively), while abundance is predicted to increase in the watershed overall due primarily to increased access to upper watershed habitat (increases of approximately 27% for Fish Passage Only and 49% for Dam Removal). Under the Combined Fish-Flood alternative, predicted equilibrium abundance of coho salmon in the lower watershed decreases to 1,200 while overall subbasin abundance is predicted to increase by 24% due to upper watershed access. Under the Flood Storage Only alternative, coho salmon predicted equilibrium abundance declines by 12% in the overall subbasin due to changes in flow, floodplain, and in-channel habitat downstream of the dam (Figure 36). Under the current time period, diversity for coho salmon stays above 20% and below 60% among all alternatives, with the highest diversity predicted by the Dam Removal alternative (52%) followed by the Fish Passage Only alternative and Combined Fish-Flood alternative (both at 33%), and the lowest diversity predicted for the Flood Storage Only alternative (24%).

In late-century, coho salmon numbers are predicted to decline by 31% under Current Operations as compared to the current time period. The Late-Century Dam Removal alternative results in predicted equilibrium abundance only 3% higher than Existing Climate Current Operations but 50% higher than Late-Century Current Operations. The Fish Passage Only and Combined Fish-Flood alternatives in late-century are not predicted to support coho salmon at levels above Existing Climate Current Operations but do predict a 37% to 38% increase in abundance as compared to Late-Century Current Operations. The Flood Storage Only alternative in Late-Century is predicted to result in a 39% decline in coho salmon as compared to Existing Climate Current Operations and a 11% decline as compared to Late-Century Current Operations.

Coho salmon diversity in late-century is predicted to decline under all alternatives, ranging between 16% and 40%. Again, diversity is predicted to be highest under the Dam Removal scenario and lowest under the Flood Storage Only alternative. Coho salmon productivity is lowered under late-century conditions as compared to existing conditions, with existing condition values in the range of 3.2 to 3.4 and late-century condition values in the range of 2.7 to 2.8, across all alternatives.

Figure 36
Predicted Coho Salmon Equilibrium Abundance in Upper and Lower Skookumchuck GSUs



5.3 Spring-Run Chinook Salmon

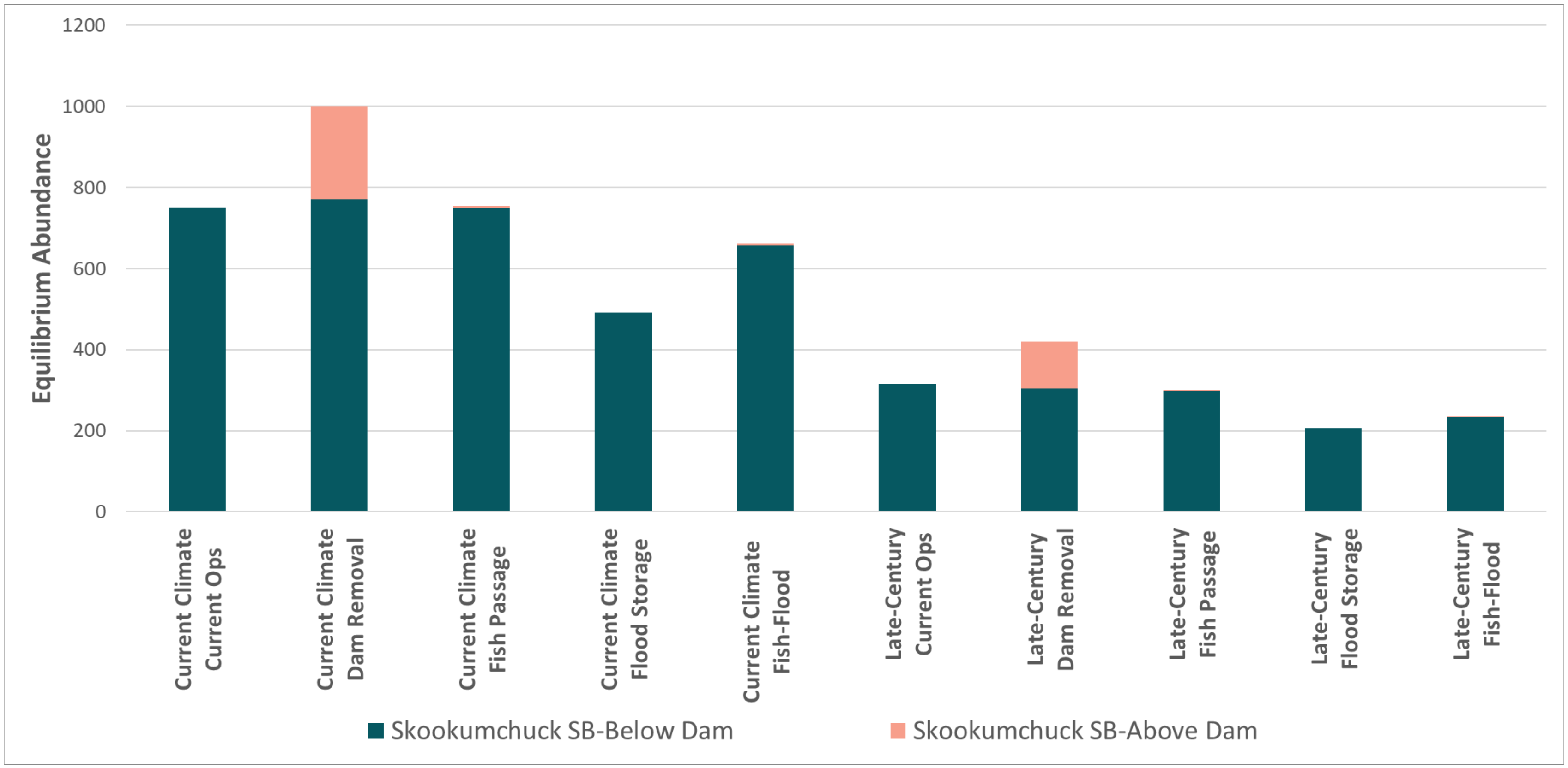
In the EDT model, spring-run Chinook salmon are modeled to spawn from late August to mid-October. Spring-run Chinook salmon in the Chehalis River system are found in the mainstem reaches of the major tributaries in the upper basin and in the mainstem Chehalis River and do not appear to migrate into upper headwater streams (Ashcraft et al. 2017). In the Skookumchuck subbasin, they were modeled to potentially spawn in mainstem reaches up past the current reservoir up to RM 30.8. In the EDT model, adult spring-run Chinook salmon enter the Chehalis River in the spring, then move upstream into the mainstem river and tributaries where they hold during summer prior to spawning. Juveniles emerge in early spring and emigrate to Grays Harbor and the ocean prior to summer in their first spring (referred to as an ocean-type life history).

Under the Existing Climate Current Operations alternative, predicted equilibrium abundance under current operations for spring-run Chinook salmon is 751 fish in the lower watershed and 0 fish in the upper watershed. These numbers remain fairly consistent under the Fish Passage Only alternative, with just 7 predicted spring-run Chinook salmon in the upper watershed. For the Dam Removal alternative, unhindered passage and access to habitat (including the area currently under the reservoir) increases predicted spring-run Chinook salmon in the basin by 33%. Under the Flood Storage Only alternative, predicted equilibrium abundance of spring-run Chinook salmon in the subbasin is reduced by 35% due to flow and habitat changes and equilibrium abundance is predicted to decline by 12% under the Combined Fish-Flood alternative (Figure 37). Under existing climate conditions, diversity for spring-run Chinook salmon does not vary much among the Current Operations, Fish Passage Only, and Flood Storage Only alternatives, staying just above 8%; however, diversity increases to just above 14% under the Dam Removal scenario.

In late-century, spring-run Chinook salmon numbers are predicted to decline by 58% under Current Operations as compared to the current time period. Spring-run Chinook salmon perform slightly worse (5%) under the Fish Passage Only alternative in late-century than under Late-Century Current operations. Dam removal in late-century still results in a 44% decline of spring-run Chinook salmon as compared to Existing Climate Current Operations due to climate change conditions, but dam removal in late-century results in a predicted 33% increase in spring-run Chinook salmon as compared to late-century Current Operations. The late-century Flood Storage Only alternative results in the lowest predicted abundance of spring-run Chinook salmon in the subbasin, at a 72% decline compared to Existing Climate Current Operations. The late-century Combined Fish-Flood alternative results in a 69% decline in predicted abundance compared to Existing Climate Current Operations.

Among all alternatives, under late-century climate conditions diversity for spring-run Chinook salmon is predicted to decrease 5% to 7%. Similar to under existing conditions, diversity values are not significantly different under most alternatives (around 3%), while for the Dam Removal scenario diversity is predicted to be 7.5%. Productivity within each alternative is lowered moving from existing conditions to late-century conditions for spring-run Chinook salmon. The highest productivity in late-century is for the Dam Removal alternative at 2.9 and it is not significantly different from productivity under Existing Conditions Current Operations.

Figure 37
Predicted Spring-Chinook Salmon Equilibrium Abundance in Upper and Lower Skookumchuck GSUs



5.4 Fall-Run Chinook Salmon

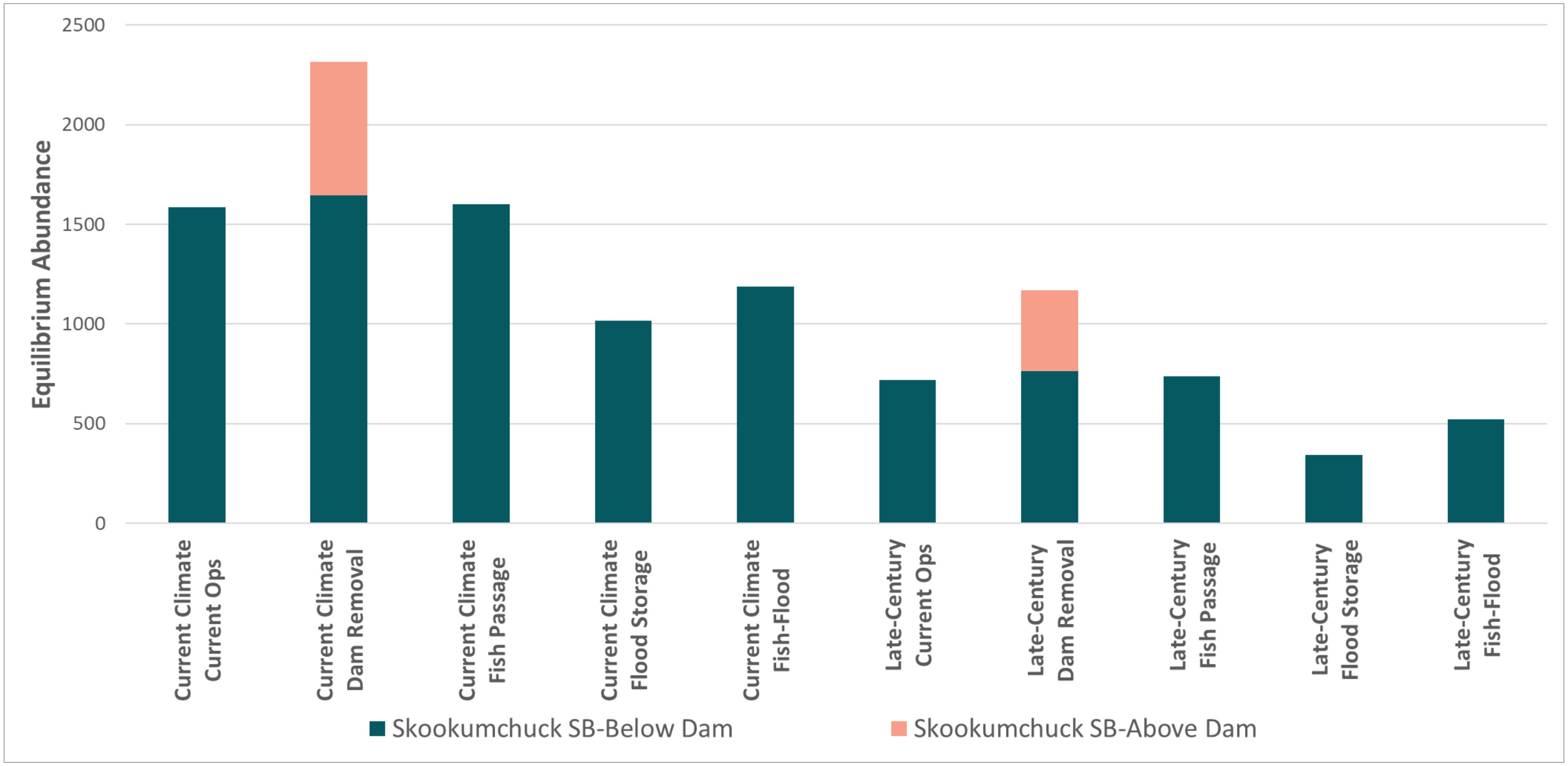
In the EDT model, fall-run Chinook salmon also have an ocean-type life history, similar to that of spring-run Chinook salmon, but do not enter the Chehalis River as adults until late summer and fall and therefore do not have the over-summer holding life stage of spring-run Chinook salmon. For this analysis, in the Skookumchuck subbasin, fall-run Chinook salmon were projected to spawn in the same areas as spring-run Chinook salmon.

Under the Existing Climate Current Operations alternative, predicted equilibrium abundance under current operations for fall-run Chinook salmon is 1,584 fish in the lower watershed and 0 fish in the upper watershed. Fall-run Chinook salmon were modeled with 0% passage at the Skookumchuck Dam for the Fish Passage Only and Combined Fish-Flood alternatives (to deliberately separate them from spring-run Chinook salmon); and under the existing climate their predicted abundance was essentially equivalent to Current Operations for the Fish Passage Only alternative and was predicted to decline by about 25% for the Combined Fish-Flood alternative. Fall-run Chinook salmon abundance is predicted to decline 36% under the Flood Storage Only alternative due to flow and habitat changes downstream of the dam. Fall-run Chinook abundance is predicted to increase 46% under the dam removal alternative due to access to upper watershed habitat (Figure 38).

In late-century, fall-run Chinook salmon numbers are predicted to decline by 55% under Current Operations as compared to the Existing Climate Current Operations. All predicted numbers in late-century are much lower than those predicted for the current time period, with predicted abundance 53% lower than current conditions under late-century Fish Passage Only alternative, 67% lower under the Combined Fish-Flood alternative, and 78% lower under the Flood Storage Only alternative. Even with dam removal, late-century predicted abundance is 26% lower than Existing Climate Current Operations. As compared to Late-Century Current Operations, dam removal in late-century is predicted to increase fall-run Chinook salmon abundance by 62%.

Diversity numbers for fall-run Chinook salmon are not significantly different among alternatives within a climate condition; diversity is predicted to decrease approximately 65% from existing conditions to late-century conditions with the exception of the dam removal scenario. Under current conditions, diversity is predicted to be 28% for most scenarios but increase to 91% under the Dam Removal scenario. In late-century, diversity is predicted to be about 5% for most scenarios and increase to 45% under the Dam Removal scenario. Productivity is predicted to be 4.7 to 5.2 under existing conditions, and 3.4 to 4.5 under late-century conditions with the highest value for the Dam Removal scenario.

Figure 38
Predicted Fall-Run Chinook Salmon Equilibrium Abundance in the Lower Skookumchuck GSU



6 WATER RIGHTS CONSIDERATIONS OF ALTERNATIVES

The further investigation of surface and groundwater rights conducted for this Phase 2 analysis was focused downstream of the dam and did not include the TransAlta water rights/water bank. The surface water rights and groundwater rights broken out by each of the 10 reaches used for the hydrologic analysis and hydraulic modeling are shown in Tables 9 and 10 and Figures 39 and 40. The surface water rights are those specifically for the Skookumchuck River and not for tributaries. The groundwater rights are those located within the valley bottom of the Skookumchuck River. The lower Skookumchuck River (below Bucoda) is considered a gaining reach that receives groundwater inputs (Thurston County unpublished data). Groundwater rights may or may not directly influence flows in the Skookumchuck River. This would require further investigation via a groundwater model that was not part of this scope of work.

Table 9
Surface Water Rights for the Skookumchuck River

SUM OF INSTANTANEOUS QUANTITY (CFS)	
Reach Name	**Total**
Dam to Bloody Run Gage	20[1]
Bloody Run Gage to Johnson Creek	1.35
Johnson Creek to Hansen Lane	2.45
Hansen Lane to Tono Road	1.14
Tono Road to RM 9 (Local Tributary)	12.29[2]
RM 9 to TransAlta Diversion	51.60
TransAlta Diversion to Bucoda Gage	0.10
Bucoda Gage to Big Hanaford Creek	1.01
Big Hanaford Creek to Centralia Gage	2.22
Centralia Gage to Coffee Creek	0.13
Coffee Creek to Mouth	0.71
Total	**93.00**

Notes:
Source: Ecology 2022
1. Does not include the 150 cfs hydropower water right (non-consumptive) at the dam.
2. Includes Town of Bucoda surface water right.

Table 10
Groundwater Rights in Close Proximity to Skookumchuck River

SUM OF INSTANTANEOUS QUANTITY		
Reach Name	**Total (GPM)**	**Total (cfs)**
Dam to Bloody Run Gage	0	0
Bloody Run Gage to Johnson Creek	400	0.9
Johnson Creek to Hansen Lane	305	0.7
Hansen Lane to Tono Road	3,035	6.8
Tono Road to Rivermile 9 (Local Tributary)	45	0.1
Rivermile 9 to TransAlta Diversion	226	0.5
TransAlta Diversion to Bucoda Gage	0	0
Bucoda Gage to Big Hanaford Creek	499	1.1
Big Hanaford Creek to Centralia Gage	1,108	2.5
Centralia Gage to Coffee Creek	1,705	3.8
Coffee Creek to Mouth	4,080	9.1
Grand Total	**11,403**	**25.5**

Notes:
Source: Ecology 2022

The following is a general comparison and impressions of potential effects. When comparing the water budget table (Table 2) to the surface water rights (Table 9) and groundwater rights (Table 10), note that Table 2 does not include the TransAlta diversion, which currently withdraws up to 27.5 cfs (which is roughly half of their 51.6 cfs water right), but would be shut down after 2025. However, their 51.6 cfs water right has now been approved for a water bank, so after 2025, some or all of that water right may be sold for other consumptive or non-consumptive uses.

The observed flows (historical conditions) from the USGS gages show that August typically has the lowest median monthly flows and is also when many of the water rights, such as for irrigation or municipal water supply, are utilized most heavily. The Current Operations can generally allow for all water rights to be exercised in all but drought years. In drought years, junior water rights (rights junior in priority date to Washington Administrative Code 173-523) may be reduced or curtailed. The TransAlta diversion is located upstream of the Bucoda gage so current diversions reduce flows particularly in the TransAlta Diversion to Bucoda Gage reach and the Bucoda Gage to Big Hanaford Creek reach. Flows coming from Big Hanaford Creek tend to increase flows in reaches downstream. With the Fish Passage Only alternative, discharges from the dam would be slightly reduced from Current Operations (on the order of 10 cfs) during the summer months to maximize the time period when fish can use the fish sluice. This would reduce the median flows and in drought years, this discharge may not meet minimum flows (e.g., 35 cfs at Bucoda). Decisions about trade-offs between water rights and downstream fish migration would have to be made in those years but could result in a greater frequency of years in which junior water rights could be reduced or curtailed. This also could extend to the mainstem Chehalis River water rights holders downstream of the Skookumchuck Dam that rely to some extent on the flows coming from the Skookumchuck River to bolster Chehalis River flows. Because the Combined Fish-Flood alternative would also result in lower summer discharges to maximize fish passage, it would have similar results as the Fish Passage Only alternative. If water rights from the water bank were transferred to water users further downstream (e.g., Centralia) from the current TransAlta diversion at RM 7.2, this could increase flow for some distance to new withdrawal locations. But, at this time it is not known from where water bank water rights might be withdrawn.

The Flood Storage Only alternative would maintain similar discharges from the dam during summer months as currently occurs except in years when it would not be possible to refill the dam due to drier spring conditions after the flood season. This alternative could cause reduced flows due to a lack of reservoir storage in drought years. This would also likely result in a greater frequency of years in which junior water rights could be reduced or curtailed and similarly could extend to the mainstem Chehalis River water rights holders downstream of the Skookumchuck River.

The Dam Removal alternative would result in lower median monthly flows in July, August, and September for all reaches from the dam downstream because there would be no flow augmentation from the reservoir and all flows would be reliant on flows from the upper Skookumchuck River and tributaries. This would likely result in a high frequency of years in which junior water rights holders in all reaches of the Skookumchuck could be required to reduce or curtail their withdrawals. Also, senior water right holders may need to receive financial or other compensation for the loss of their senior water right use(s). This would similarly also affect Chehalis River water rights holders downstream of the Skookumchuck River.

For all alternatives, further analysis of low-flow frequencies with modified operations should be conducted in a future phase of analysis or design to determine if the effects to water rights can either be mitigated or compensated while still achieving the goals of fish and/or flood benefits. It could be costly to compensate for water rights and would affect the determination of whether the cost of an alternative is worth the benefit.

Figure 39
Surface Water Rights by Reach in the Skookumchuck River

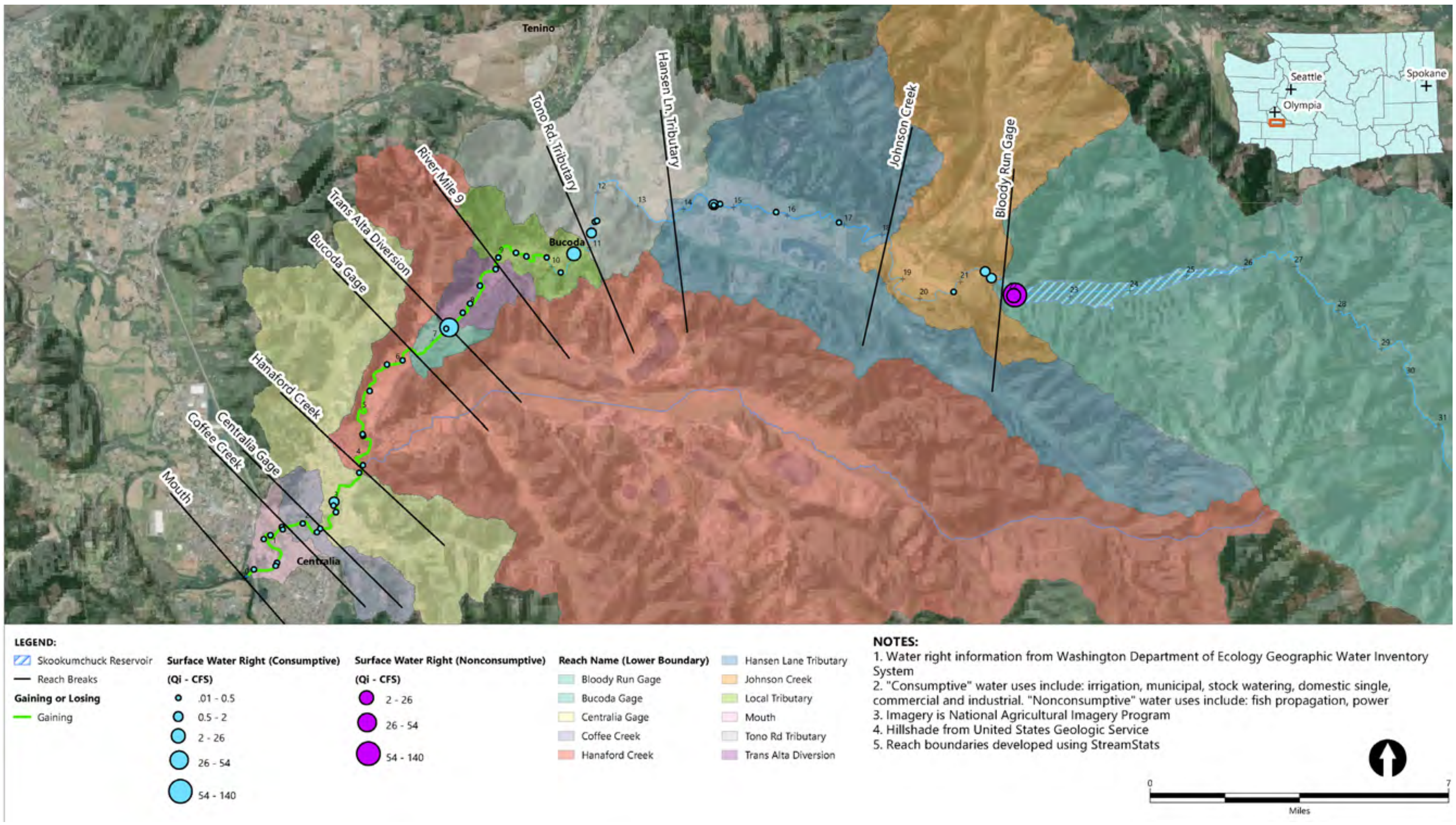
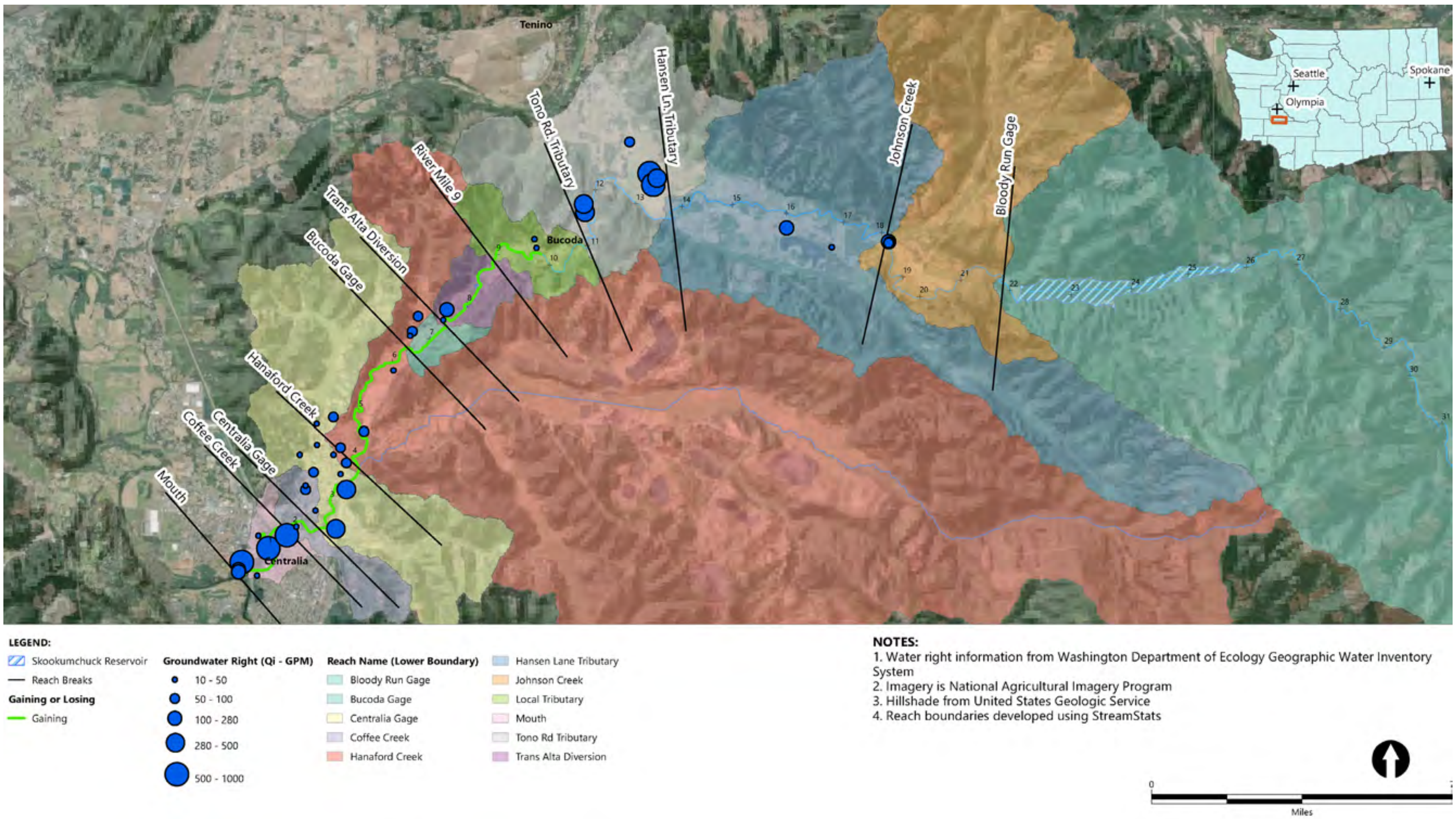


Figure 40
Groundwater Rights by Reach in the Skookumchuck River



7 COSTS OF ALTERNATIVES

Initial cost estimates were developed for the Fish Passage Only and Flood Storage Only alternatives. If both elements were desired (Combined Fish-Flood alternative), the costs at this initial level could be combined. The Dam Removal alternative initial estimate developed in the Phase 1 document (Anchor QEA et al. 2021) is carried into this memorandum so that all alternatives have a similar level of cost estimate for comparison.

All cost estimates should be considered as "concept screening" level cost estimates based on less than a 2% design, generally consistent with the Class 5 cost estimate definition of the American Association of Cost Engineers (USDOE 2018). This type of cost estimate uses analogous past projects, escalation of historical costs, and cost estimates from suppliers to create the most robust estimate feasible for this preliminary level of design. These opinions of probable cost should not be used for budgetary purposes but for comparisons of the magnitude of costs between alternatives.

7.1 Fish Passage Only Alternative

A preliminary opinion of probable implementation costs was prepared for the downstream fish passage configuration that includes potential angled fish sluice, a short tunnel that daylights above the existing spillway, 4-foot diameter conveyance pipe, a structure containing a screen to divert some of the fish bypass flow into the spillway and a long flume to convey flow to the Skookumchuck River at a suitable velocity. A summary of the preliminary opinion of costs is provided in Table 11.

Table 11
Opinion of Probable Implementation Costs, Downstream Fish Passage

COST ITEM	OPINION OF COST
New fish sluice, gate, tunnel, pipe, and screen structure	$1,189,000
Fish return flume to river	$3,268,000
Miscellaneous/unknowns (10%)	$446,000
Mobilization/demobilization (10%)	$490,000
Construction Subtotal	**$5,393,000**
Sales tax (8.1% of Subtotal)	$437,000
Engineering (20% of Subtotal)	$1,079,000
Contingency (25% of Subtotal)	$1,348,000
Total Estimated Cost	**$8,256,000**

Notes:
1. This opinion of cost was prepared in October 2022. Actual construction costs will vary based on materials and labor costs at the time of construction.
2. The subtotals and construction total are rounded to the nearest $1,000.

The opinions of probable construction costs provided in Table 11 include the following allowances and reflect the following assumptions:

- A lump sum unit cost item was included for mobilization/demobilization. An allowance of 10% was included for this item based on the subtotal of all the individual cost items.
- A lump sum unit cost item was included to reflect items not yet identified. An allowance of 10% of the subtotal of all cost items was allocated as the lump sum price for this item.
- A 25% contingency was added to the subtotal of all the individual cost items to reflect the conceptual level of design. Very little design information is available at this time on the fish return flume. It was assumed the flume would need to be elevated to meet grade requirements. If a ground-level flume is feasible, the costs could be significantly reduced.
- An allowance of 20% of the construction subtotal was included for engineering and construction management.
- Sales tax of 8.1% was applied to the construction subtotal.

The opinion of probable implementation costs is $8.26 million. This cost is appropriate to use in planning-level discussions of the project and would be refined as additional information on the alternative is obtained and designs developed.

Construction labor and materials prices have been extremely volatile since early 2020. Prices for many materials have increased dramatically and are currently very difficult to project. The costs provided are in 2022 dollars. Cost data was obtained from several sources including Washington State Department of Transportation (WSDOT) bid tabulations, bridge manufacturers and engineers for the fish return flume and other recent cost estimates for water resource and fish screening projects that Anchor QEA has designed in Western Washington for the outlet, gate, and screening structure. The 25% contingency has been provided to reflect the very preliminary nature of the design and the rapidly escalating prices.

7.2 Flood Storage Only Alternative

A preliminary opinion of probable implementation costs was prepared for a new outlet that will increase the discharge capacity from Skookumchuck Reservoir to approximately 2,000 cfs, allowing the reservoir to be drawn down more quickly than present to provide flood storage. A potential configuration is a tunnel located on the right (north) side of Skookumchuck Reservoir that would be constructed upstream of the dam in rock that forms the right abutment. The tunnel would be approximately 2,200 feet long and daylight above Skookumchuck Road SE. From that portal, flow would be conveyed in a flume to the Skookumchuck River. The components of the outlet include the tunnel, portals at the upstream and downstream ends of the tunnel, a gate to control flow into the tunnel, a gate access shaft, a 200-foot-long flume to convey flow to the Skookumchuck River, and an energy dissipator at the riverbank. An 8-foot-diameter tunnel will have adequate capacity to meet the project goal of increasing discharge from the reservoir. However, for constructability, a 10-foot or larger diameter tunnel may be constructed.

A summary of the preliminary opinion of costs is provided in Table 12.

Table 12
Opinion of Probable Implementation Costs, New Outlet

COST ITEM	OPINION OF COST
Tunnel, portals, gate, access shaft	$21,780,000
Flume, energy dissipator	$300,000
Miscellaneous/unknown (10%)	$2,208,000
Mobilization/demobilization (10%)	$2,429,000
Construction Subtotal	**$26,717,000**
Sales tax (8.1% of Subtotal)	$2,164,000
Engineering (20% of Subtotal)	$6,679,000
Contingency (25% of Subtotal)	$6,679,000
Total Estimated Cost	**$42,239,000**

Notes:
1. This opinion of cost was prepared in October 2022. Actual construction costs will vary based on materials and labor costs at the time of construction.
2. The subtotals and construction total are rounded to the nearest $1,000.

The opinions of probable construction costs provided in Table 12 include the following allowances and reflect the following assumptions:

- A lump sum unit cost item was included for mobilization/demobilization. An allowance of 10% was included for this item based on the subtotal of all the individual cost items.
- A lump sum unit cost item was included to reflect items not yet identified. An allowance of 10% of the subtotal of all cost items was allocated as the lump sum price for this item.
- A 25% contingency was added to the subtotal of all the individual cost items to reflect the conceptual level of design. No design information is available.
- An allowance of 25% of the construction subtotal was included for engineering and construction management. This is higher than the estimate for the fish return flume because of the greater difficulty in design of a tunnel.
- Sales tax of 8.1% was applied to the construction subtotal.

Cost data were obtained from several sources including WSDOT bid tabulations, and a cost estimate for the tunneling component of the dam analyzed for the Chehalis Basin Strategy (HDR 2018). The 25% contingency has been provided to reflect the very preliminary nature of the design and the rapidly escalating prices.

The opinion of probable implementation costs is $42.24 million. This cost is appropriate to use in planning-level discussions of the project and should be refined as additional information on the alternative is obtained and designs developed.

7.3 Dam Removal Alternative

The following costs for either full or partial removal of Skookumchuck Dam are carried forward from the Phase 1 analysis in late 2021 and have not been escalated to 2022 dollars. The primary difference between full and partial removal is the quantity of earth fill from the dam that would be removed and hauled to an appropriate disposal location. Either option would be designed to provide unhindered upstream and downstream fish passage and includes sufficient upstream restoration in the reservoir footprint to restore a natural river channel and riparian restoration but does not include restoration upstream of the reservoir footprint.

In addition to the construction cost of dam removal, it would likely be necessary to compensate or replace water rights that would no longer be available if the dam were removed, including the 51.6 cfs (28,000 acre-foot) water bank. At this time, it is estimated that it would cost between $1,500 and $3,000 per consumptive acre-foot, so a placeholder of $80 million for water right compensation is included (note this is a very preliminary number).

Table 13
Class 5 Cost Estimate for Full Removal of Skookumchuck Dam

DIVISION	COST
General Requirements	$1,368,000
Construction	$21,023,000
Engineering	$6,562,000
Contingency (25%)	$5,598,000
Low Probable Cost (-20%)	**$27,700,000**
Median Opinion of Probable Cost	**$34,600,000**
High Probable Cost (+35%)	**$46,800,000**
Water Rights Compensation	**$80,000,000**
Total Median Cost + Water Rights	**$114,600,000**

Table 14
Class 5 Cost Estimate for Partial Removal of Skookumchuck Dam

DIVISION	COST
General Requirements	$1,215,000
Construction	$14,904,000
Engineering	$4,704,000
Contingency (25%)	$4,030,000
Low Probable Cost (-20%)	**$20,000,000**
Median Opinion of Probable Cost	**$24,900,000**
High Probable Cost (+35%)	**$33,700,000**
Water Rights Compensation	**$80,000,000**
Total Median Cost + Water Rights	**$104,900,000**

8 SUMMARY OF ALTERNATIVES

A range of fish passage and flood reduction alternatives were conceptualized and evaluated. The primary metric used to evaluate fish passage considerations was the ability to maintain adequate discharges through the fish sluice throughout the fish passage season (from either January 1 or March 15 through the summer). The primary metrics used to evaluate flood reduction performance were flood flow frequency quantiles and number of structures flooded. Table 15 compares the fish passage performance of the alternatives investigated. This is shown as the median date in the summer that the alternative would first be unable to provide adequate fish passage flows through the existing fish sluice.

Table 15
Fish Passage Performance of Alternatives

ALTERNATIVE	MEDIAN DATE AT WHICH RESERVOIR ELEVATION/FLOW CANNOT BE MAINTAINED (FROM ALL SIMULATED YEARS)
Fish Passage: 25 cfs	Sluice flow maintained throughout summer
Fish Passage: 40 cfs	Sluice flow maintained throughout summer
Fish Passage: 65 cfs	September 19
Fish Passage: 120 cfs	July 21
Flood Storage Only: all alternatives	Sluice flows cannot be provided
Combined Fish-Flood: all alternatives	August 25
Dam Removal	Fish passage via natural channel

Table 16 compares the flood flow reduction performance of each of the alternatives for existing hydrologic conditions at Bloody Run.

Table 16
Flood Flow Quantiles at Bloody Run Gage for Each Alternative (WY 1988–2022)

ALTERNATIVE	FLOOD FLOW QUANTILE (CFS)			
	2-year	10-year	20-year	100-year
Current Operations	3,560	7,630	9,300	13,200
Fish Passage: Max 65 cfs through sluice gate	3,660	7,710	9,380	13,300
Flood Storage: 20,000 AF storage, 2,000 cfs outlet	1,480	2,540	3,120	4,930
Combined Fish-Flood: 20,000 AF storage, 50% chance of refill	2,530	3,710	4,250	5,650
Dam Removal	4,570	9,090	10,800	14,400

Table 17 compares the flood peaks for each alternative for existing hydrologic conditions at Bucoda based on the RiverFlow2D downstream flood simulations.

Table 17
Flood Peaks at Bucoda Gage for Each Alternative from RiverFlow2D Simulations

ALTERNATIVE	FLOOD FLOW QUANTILE (CFS)			
	2-year	10-year	20-year	100-year
Current Operations/Fish Passage: Max 65 cfs	5,730	11,100	13,700	18,800
Flood Storage: 20,000 AF storage, 2,000 cfs outlet	3,410	5,950	7,090	9,530
Combined Fish-Flood: 20,000 AF storage, 50% chance of refill	4,580	7,330	8,790	11,300
Dam Removal	6,270	11,900	14,500	20,000

Table 18 summarizes the number of structures that would be within the current climate 100-year floodplain, and the maximum depth of flooding at the structures, for each of the modeled alternatives. As seen in Table 18, the Flood Storage Only and Combined Fish-Flood alternatives significantly reduce the number of flooded structures and in particular the number of structures with flood depths greater than 3 feet. Table 19 summarizes the corresponding structure flood depth data for the late-century climate 100-year flood. Figure 41 shows the number of structures inundated for both the existing and late-century climate for the alternatives. In Table 19 it can be seen that the flood reduction alternatives do not remove as many of the structures from the floodplain in the late-century as they do under existing hydrologic conditions. However, there is still a large reduction (483 structures or approximately 26%) in the number of structures with flood depths greater than 3 feet when comparing the Current Operations to the Combined Fish-Flood alternative.

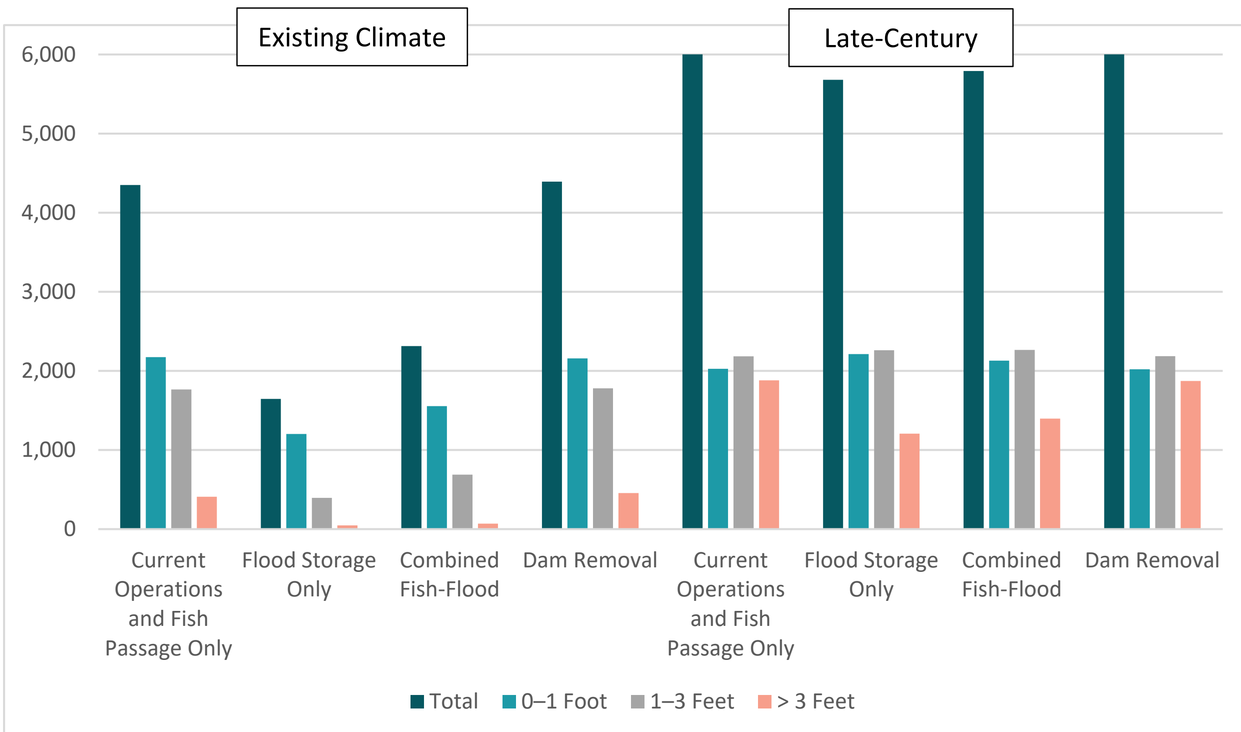
Table 18
Summary of Flooded Structures by Alternative for the Existing Climate 100-Year Flood Event

ALTERNATIVE	NUMBER OF STRUCTURES IN FLOODPLAIN, AND FLOOD DEPTH (FEET)			
	Total	0–1 Foot	1–3 Feet	> 3 Feet
Current Operations and Fish Passage Only	4,349	2,174	1,766	409
Flood Storage Only	1,646	1,203	396	47
Combined Fish-Flood	2,313	1,554	689	70
Dam Removal	4,392	2,158	1,779	455

Table 19
Summary of Flooded Structures by Alternative for the Late-Century Climate 100-Year Flood Event

ALTERNATIVE	NUMBER OF STRUCTURES IN FLOODPLAIN, AND FLOOD DEPTH (FEET)			
	Total	0–1 Foot	1–3 Feet	> 3 Feet
Current Operations and Fish Passage Only	6,091	2,027	2,184	1,880
Flood Storage Only	5,679	2,212	2,261	1,206
Combined Fish-Flood	5,792	2,129	2,266	1,397
Dam Removal	6,080	2,021	2,187	1,872

Figure 41
Number of Structures Flooded in 100-Year Recurrence Flood for Existing and Late-Century Climate for the Alternatives



The EDT modeling of salmonid effects from the alternatives indicates that both steelhead and coho salmon could see substantial increases in equilibrium abundance from both the Fish Passage Only and Dam Removal alternatives under the current climate. Spring Chinook salmon would have limited benefit from the Fish Passage Only alternative because much of their habitat is under the reservoir footprint; however, the Dam Removal alternative would result in substantial benefits. Fall Chinook salmon are not predicted to utilize habitats upstream of the dam to any great extent and would have minimal benefit from either the Fish Passage Only or Dam Removal alternatives. For steelhead, the Flood Storage Only alternative would have negligible effects, but for coho salmon, spring-run Chinook salmon, and fall-run Chinook salmon, there would be substantial declines as a result of flow reductions that reduce downstream in-channel and off-channel habitats. The potential fish effects of the alternatives under the current climate are shown in Table 20. The potential fish effects of the alternatives under late-century climate are shown in Table 21.

Table 20
Summary of EDT Modeled Fish Equilibrium Abundance by Alternative for the Current Climate Compared to Current Operations

ALTERNATIVE	EQUILIBRIUM ABUNDANCE OF FISH SPECIES IN THE SKOOKUMCHUCK RIVER BASIN			
	Steelhead	Coho Salmon	Spring-Run Chinook Salmon	Fall-Run Chinook Salmon
Current Operations	77	1,255	751	1,584
Fish Passage Only[1]	219 / 470	1,597	754	1,601
Flood Storage Only	80	1,106	491	1,015
Combined Fish-Flood[1]	221 / 472	1,562	662	1,188
Dam Removal	751	1,873	1001	2,314

Note:
1. Fish Passage Only and Combined Fish-Flood alternatives modeled with 33% and 90% upstream adult steelhead passage at the dam; results shown are for those two scenarios, respectively.

Table 21
Summary of EDT Modeled Fish Equilibrium Abundance by Alternative for the Late-Century Climate Compared to Late-Century Current Operations

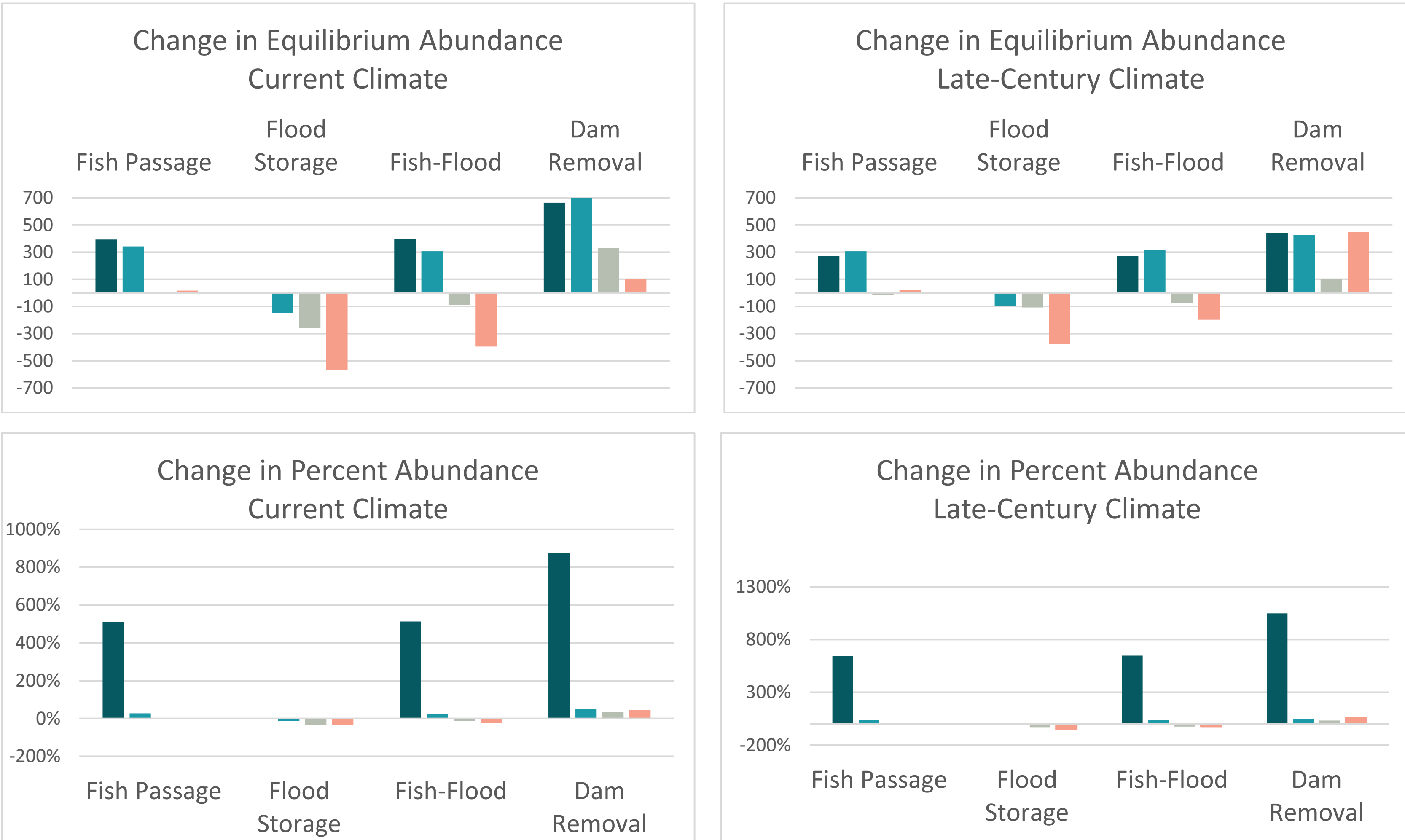
ALTERNATIVE	EQUILIBRIUM ABUNDANCE OF FISH SPECIES IN THE SKOOKUMCHUCK RIVER BASIN			
	Steelhead	Coho Salmon	Spring-Run Chinook Salmon	Fall-Run Chinook Salmon
Current Operations	42	861	315	720
Fish Passage Only[1]	138 / 312	1,185	301	739
Flood Storage Only	43	765	207	344
Combined Fish-Flood[1]	140 / 314	1,180	237	522
Dam Removal	482	1,289	420	1,170

Note:
1. Fish Passage Only and Combined Fish-Flood alternatives modeled with 33% and 90% upstream adult steelhead passage at the dam; results shown are for those two scenarios, respectively.

Under the existing climate, the Fish Passage Only and Combined Fish-Flood alternatives would substantially increase equilibrium abundance for steelhead (+184% to 510% and 187% to 513%, respectively) and coho salmon (+27% and 24%). Spring-run Chinook salmon would have limited benefit or decline (+1% and -11%) because much of their potential spawning habitat is under the reservoir footprint, with limited additional suitable habitat available upstream or potential negative effects downstream from the reduced habitat availability for the Combined Fish-Flood alternative. Fall-run Chinook salmon were modeled to not be passed upstream (to separate spring-run and fall-run Chinook salmon) so would have no benefit or decline (-25%) from negative effects downstream for the Combined Fish-Flood alternative.

The Dam Removal alternative would have substantial benefits for all species; steelhead (+875%), coho (+49%), spring-run Chinook (+33%), and fall-run Chinook salmon (+46%).

Figure 42
EDT Predicted Change in Equilibrium Abundance and Percent Change of Salmonid Species Under Existing and Late-Century Conditions



Note: Changes in equilibrium abundance and percent abundance are in comparison to current operations.

The Flood Storage Only alternative would have a slight change for steelhead (+3%), but substantial negative effects for coho (-12%), spring-run Chinook (-34%), and fall-run Chinook salmon (-36%), as a result of winter flow reductions that reduce downstream in-channel and off-channel habitats.

Very preliminary cost estimates were developed for each of the alternatives. The costs of the alternatives are shown in Table 22. These costs are intended to provide a scale of magnitude cost at this early stage (less than 2% design) and are not intended to be used for budgeting or construction bidding purposes. Of the action alternatives, the Fish Passage Only alternative is the least cost in the approximately $10 million range. The Flood Storage, Combined Fish-Flood, and Dam Removal alternatives are in the approximately $20 to $50 million range for construction. For the Dam Removal alternative, it would likely be necessary to compensate or replace water rights for senior water rights holders that lose water availability. This water rights compensation is preliminarily estimated at $80 million.

Table 22
Cost Estimates for the Alternatives

ALTERNATIVE	CLASS 5 COST ESTIMATE
Current Operations	N/A
Fish Passage Only	$8.3 million
Flood Storage Only	$42.2 million
Combined Fish-Flood	$50.5 million[1]
Partial Dam Removal[2]	$24.9 million (median) + $80 million water rights compensation
Full Dam Removal[2]	$34.6 million (median) + $80 million water rights compensation

Note:
1. Combined Fish-Flood alternative was not separately calculated; value is the sum of Fish Passage and Flood Storage alternatives.
2. Dam removal costs are carried forward from the Phase 1 analysis (Anchor QEA et al. 2021) and are the median of potential costs in 2021 dollars.

Table 23 shows a side-by-side generalized comparison of the alternatives for the effects analyzed.

Table 23
Alternatives Comparison of Analyzed Effects

ALTERNATIVE	FISH ABUNDANCE	FLOOD EFFECTS	WATER RIGHTS	COST
Current Operation	No change	No change	No change	N/A
Fish Passage Only	Steelhead **+** Coho **+** Spring Chinook **=** Fall Chinook **=**	No change	Small change, but increased risk of water rights curtailments in drought years	$8.3 million
Flood Storage Only	Steelhead **=** Coho **-** Spring Chinook **-** Fall Chinook **-**	Substantial reductions in flood extent and depth; less benefit in late-century	Small change, but increased risk of water rights curtailments in drought years	$42.2 million
Combined Fish-Flood	Steelhead **+** Coho **+** Spring Chinook **-** Fall Chinook **-**	Substantial reductions in flood extent in depth; less benefit in late-century	Small change, but increased risk of water rights curtailments in drought years	$50.5 million
Dam Removal	Steelhead **++** Coho **+** Spring Chinook **+** Fall Chinook **+**	Small increases in flood extent and depths	Higher risk of water rights curtailments in drought years	$25–$35 million (median)

9 STAKEHOLDER AND PUBLIC INPUT

As part of this Phase 2 analysis, the Office of Chehalis Basin used two methods to gather initial stakeholder and public input—a working group and two public webinars. While not a formal public input process, these two methods allowed the Office of Chehalis Basin to identify the main interests the local community has in the Skookumchuck Dam.

In April of 2021, during Phase 1 of the analysis, the Office of Chehalis Basin convened a working group representing stakeholders and key experts in fish biology and flooding/hydraulics to participate in and provide feedback for the analysis. Initially a technical working group, membership expanded over time to include a larger, less technical range of members. Work group members represented the Chehalis Basin Board, Washington Departments of Ecology and Fish and Wildlife, Quinault Indian Nation, Confederated Tribes of the Chehalis Reservation, Town of Bucoda, City of Centralia, Lewis County, Chehalis Basin Lead Entity, and Coast Salmon Partnership. Representatives from TransAlta also participated in the working group, provided invaluable information about current dam operations, and provided access to dam facilities.

Two public webinars were also held during the course of the analysis to provide information on the work conducted and preliminary results. The March 9, 2022, webinar was attended by 69 unique viewers and focused on the history of the dam and recent actions around water banking. The September 28, 2022, webinar was attended by 89 unique viewers and addressed the alternatives being developed in the Phase 2 process.

Between the working group and the webinars, the two biggest issues identified were the water bank and water rights associated with the bank, and dam removal.

Ecology approved the TransAlta water bank for the Skookumchuck River in late 2021. The cities of Centralia and Chehalis have indicated many times that acquiring a significant proportion of that water right is a top priority. The City of Centralia in particular has a long history with Skookumchuck water rights; they originally pursued a water right in the 1960s prior to the construction of the dam, which was withdrawn to support the dam project after the project proponents and the City reached an agreement about providing water to the City once the steam generation facility shut down.

The cities consider water from the TransAlta water bank as essential to meeting their projected future demand for domestic water, based on future growth estimates. They also anticipate demand for industrial water use, and see their economic future as tied to the water right.

Continuing to consider dam removal is a priority of WDFW and was raised as the preferred outcome by multiple participants in the public workshops. In a letter to the Chehalis Basin Board dated September 23, 2021, WDFW Director Kelly Susewind indicated the Department's interest in a comprehensive Chehalis Basin Strategy that includes "Significant improvements in Skookumchuck River spring-run Chinook and steelhead populations via either removal of Skookumchuck Dam or installation of a state-of-the-art fish passage system." WDFW also has expressed a preference that regardless of which alternative is further pursued that it is designed to accommodate naturally reproducing salmon and steelhead runs above the dam in all years.

TransAlta's water bank is directly tied to the year-round availability of water in the Skookumchuck River provided by the reservoir. Removing the Skookumchuck Dam would mean eliminating the TransAlta water bank and all water rights associated with it. Removal of the dam would also return the approximately 4 miles of former habitat that is currently beneath the reservoir to riverine conditions. Historical reports indicate that this habitat was historically used by spring-run Chinook salmon.

Key input during Phase 2 has included the following that could inform continued future work:

- Interest in how flow augmentation (discharges) from the dam during summer and fall months have affected spring- and fall-run Chinook salmon hybridization. This key question has already led to an in-progress study of reducing fall "spawning" releases from the dam, with the cooperation of TransAlta, to then document fish movements near Bucoda to determine spring-run vs. fall-run Chinook salmon timing of movements in the river. This study will be paired with a fry trapping effort to enumerate and collect genetic samples of Chinook fry to identify if flow modifications could help increase the proportion of spring-run Chinook salmon production from the Skookumchuck River.
- Interest in the potential for installing water quality meters in the reservoir to understand type and distribution of turbidity that is observed downstream of the dam (but not upstream of the reservoir). This could be conducted in a future design phase.
- Whether Fish Passage Only operations would increase the potential for flooding downstream. If the Fish Passage Only alternative moves into a future design phase, additional detailed modeling should be conducted.
- Interest in a more detailed investigation of upstream habitat conditions and potential fish passage barriers to better understand the quality and quantity of habitat that might be available for the multiple fish species. If fish passage is a component of a future design phase, it will be very important to conduct an on-the-ground habitat survey and identify any barriers to fish passage to understand the potential benefits to fish in detail.
- TransAlta has stated that they do not have an interest in dam removal at this time. They intend to operate the dam for the foreseeable future. The water banking agreement also binds TransAlta and any future operators of the dam to provide water for the bank.

10 NEXT STEPS

Each of the alternatives investigated in the second phase of analysis is theoretically feasible, but each alternative results in differing benefits or impacts to fish access/habitat or flood damage reduction. There is not a single alternative that can maximize both fish and flood benefits and there are trade-offs. Pros and cons for each alternative are discussed below:

Fish Passage Only:

- This alternative could provide substantial benefits for steelhead and coho salmon. However, it would only provide small benefits for spring-run Chinook salmon because much of this species' habitat is under the reservoir, and there may be some dry years when the reservoir could drop below the fish sluice in the latter part of the juvenile Chinook migration, potentially reducing survival.
- This alternative would not improve flood storage but maintains a similar level of flood damage reduction as currently occurs.
- This alternative may require slightly reducing discharges from the dam from late spring through summer to maintain the reservoir above the fish sluice elevation to allow downstream salmonid migration. This could affect water rights, although it would still allow TransAlta to operate their water bank and support other water rights in most years.
- This alternative is the least expensive but would require additional staffing and maintenance for dam operations, the fish sluice, and adult upstream passage.

Flood Storage Only:

- This alternative could provide substantial flood storage and reduced flood depths downstream. It has not yet been evaluated to determine the economic value of these benefits.
- This alternative could cause substantial negative effects to coho salmon and spring- and fall-run Chinook salmon due to degradation of habitat downstream of the dam resulting from reduced high flows and access to habitats.
- This alternative may reduce the potential refill of the reservoir during dry years, which could affect water rights, although it would still allow TransAlta to operate their water bank and support other water rights in most years.
- This alternative is more expensive because it requires substantial modifications for a new dam outlet and would also require additional staffing and maintenance for dam operations.

Combined Fish-Flood:

- This alternative could provide substantial flood storage and reduced flood depths downstream. It has not yet been evaluated to determine the economic value of these benefits.
- This alternative could have substantial benefits for both steelhead and coho salmon, although it would also have negative effects to spring- and fall-run Chinook salmon due to degradation of habitat downstream of the dam resulting from reduced high flows and access to habitats.
- This alternative may reduce the potential refill of the reservoir during dry years (although less than the Flood Storage Only alternative), which could affect water rights, although it would still allow TransAlta to operate their water bank and support other water rights in most years.
- This alternative is more expensive because it requires substantial modifications for a new dam outlet and a new fish sluice and would also require additional staffing and maintenance for dam operations, the fish sluice, and adult upstream passage.

Dam Removal:

- This alternative could provide substantial benefits for all salmonid species, including gains in late-century for steelhead and coho salmon as compared to current equilibrium abundance.
- This alternative would not improve flood storage and would somewhat increase flooding downstream, although this effect is lessened in late-century when all alternatives result in increased flooding compared to existing conditions.
- This alternative would eliminate the water bank and may curtail some other water rights downstream.
- This alternative may be the most expensive because it would likely require compensation or mitigation of water rights that are affected; however, it would eliminate the need for staffing for operations and maintenance of the dam. The water rights mitigation cost is not well understood at this time.

Many questions remain on the specific design and cost feasibility of each alternative that would need to be investigated in a future phase. For example, for any proposed dam modifications, it is necessary to determine if such modifications could be achieved without negatively affecting the geotechnical and structural integrity of the dam. Similarly, additional hydrologic/hydraulic analysis would be necessary to optimize dam operations to maximize flood and/or fish benefits. For dam removal, a detailed accounting of effects to water rights and feasible options to mitigate effects would need to be conducted.

The Chehalis Basin Board could consider a third phase of analysis that could include the following:

- Continue the Skookumchuck Dam working group and coordination with TransAlta.
- Continue the experimental flow study to assess if reducing fall flows to be more reflective of current natural inflows to the dam can help separate spring- and fall-run Chinook salmon spawning timing and minimize hybridization. This could lead to additional flow management recommendations based on the results of the study.
- Conduct a geotechnical investigation to determine if tunneling through the dam and adjacent bedrock is feasible or if there are other feasible method(s) to modify the dam for fish or flood purposes.
- Develop structure finished floor elevation data using the methods described by WSE (2016) to more accurately predict flood depths and damages (and/or avoidance of damages) downstream of the dam.
- Conduct gaging of flows on Big Hanaford Creek to more accurately predict both low and peak flows downstream of Big Hanaford Creek.
- Collect low-flow observations in multiple reaches of the Skookumchuck River to inform groundwater recharge and discharge (e.g., gaining reaches) and refine computed local inflows.
- Determine estimated water rights withdrawals and timing by month to develop detailed accounting of potential effects on water rights by alternatives or other operational changes in flows.
- Develop further detailed structural and hydraulic design of the fish sluice and low-level outlet.
- Conduct additional hydraulic modeling to optimize fish and/or flood operational rule curves and benefits.
- Conduct further analysis of downstream flood effects based on refined options and additional data collected, as identified previously.
- Conduct an economic analysis of the potential flood damage reduction benefits compared to the costs.
- Conduct an on-the-ground habitat survey upstream of the reservoir to refine fish benefit predictions.
- Install water quality gages in the reservoir to determine the source of turbidity that is discharged downstream.
- Conduct fisheries studies to assess juvenile fish passage survival under current conditions, including reservoir survival, travel time, survivability through the dam, and passage-related survivability for a relevant reach below the dam; the presence of predators/predation impacts in the reservoir (and if any impacts might be addressed); and tracking of adults to suitable spawning habitats.

- Conduct further investigation of Chinook and coho salmon juvenile out-migration timing and potential effects on feasibility of passage.
- Conduct geomorphic assessment of downstream conditions relative to reduced transport of sediment and large wood from upstream of the dam.
- Evaluate possible design refinements for downstream fish passage that could include lowering the elevation of the fish sluice.
- Develop preliminary designs to advance fish passage or flood storage elements that are feasible based on the preceding technical evaluations.

Budget options have been provided to the Chehalis Basin Board for the next phase of work that could fund some or many of these elements. At whatever funding level is provided, some of the work could move forward, with the highest priority elements including the geotechnical investigation and continued work with stakeholders and TransAlta.

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