MEMORANDUM

Date: September 24, 2021

To: Andrea McNamara-Doyle and Nat Kale, Office of Chehalis Basin

From: John Ferguson, Merri Martz, Bob Montgomery, Bryan Nordlund, Anchor QEA, LLC; Scott Wright, River Design Group; Larry Karpack, Watershed Science and Engineering; Laura McMullen, ICF

cc: Heather Page, Anchor QEA, LLC

Re: Initial Data Compilation and Analysis for Flood Damage Reduction and Aquatic Species Benefits at Skookumchuck Dam

Executive Summary

This initial compilation and analysis of existing data for Skookumchuck Dam was undertaken at the request of the Chehalis Basin Board. The Chehalis Basin Board is interested in identifying if there are any actions that can be undertaken by TransAlta, or others, that would reduce flood damage and benefit aquatic species and associated habitats. The Board is particularly interested in near-term operational actions that can be undertaken by TransAlta.

Skookumchuck Dam is located at river mile (RM) 21.6 on the Skookumchuck River. 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 (Figure ES-1). The crest of Skookumchuck Dam is 497 feet in elevation with an uncontrolled spillway with a fixed crest elevation of 477 feet.[1] A fish sluice is located within the spillway with a bottom elevation of 470 feet. When reservoir elevations are above 477 feet, water spills over the uncontrolled spillway crest and can also discharge through the fish sluice when it is open. Water is also discharged through a multi-level intake located near the left bank abutment of the dam. Water can be routed to the Skookumchuck Hatchery, the fish trap and ladder, the small hydropower turbine, or discharged through the main outlet (Figures ES-2 and ES-3).

An analysis of hydrology was undertaken to develop a composite record and frequency of inflows to the reservoir. The hydrology analysis was based on available gage data upstream of the dam. The reservoir has approximately 33,000 acre-feet (AF) of active storage capability. Inflows from a 10-year storm event (with a duration of 7 days) or a 100-year storm event (with a duration of 3 days) would completely fill that volume of storage. A simple spreadsheet model of inflows and outflows was used to evaluate the potential for flood storage and downstream passage of juvenile steelhead.

[1] All vertical elevations in this document are referenced to the National Geodetic Vertical Datum (NGVD) 1929.

Figure ES-1
Skookumchuck River and Dam Location

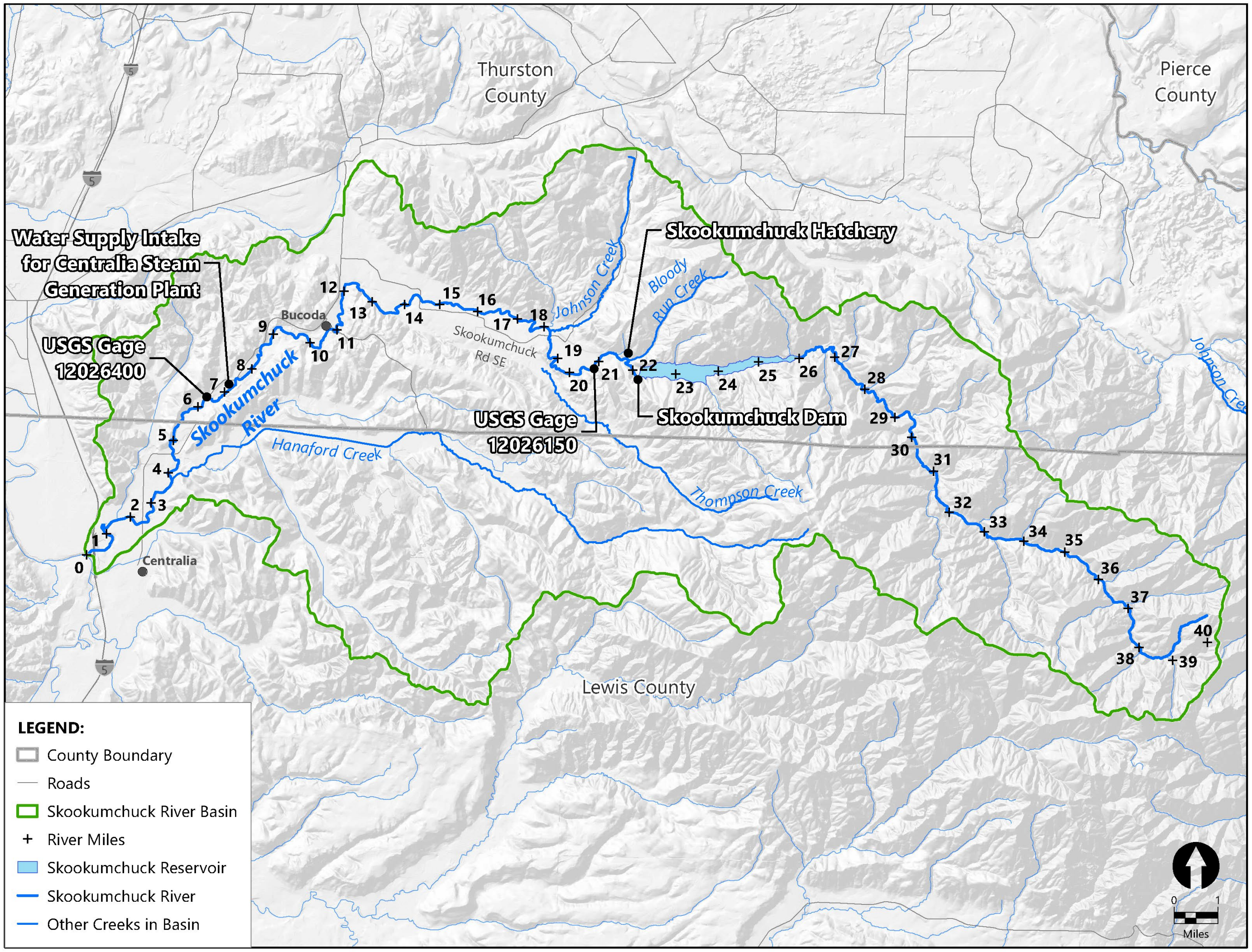


Figure ES-2
Schematic of Skookumchuck Dam Inlets and Outlets

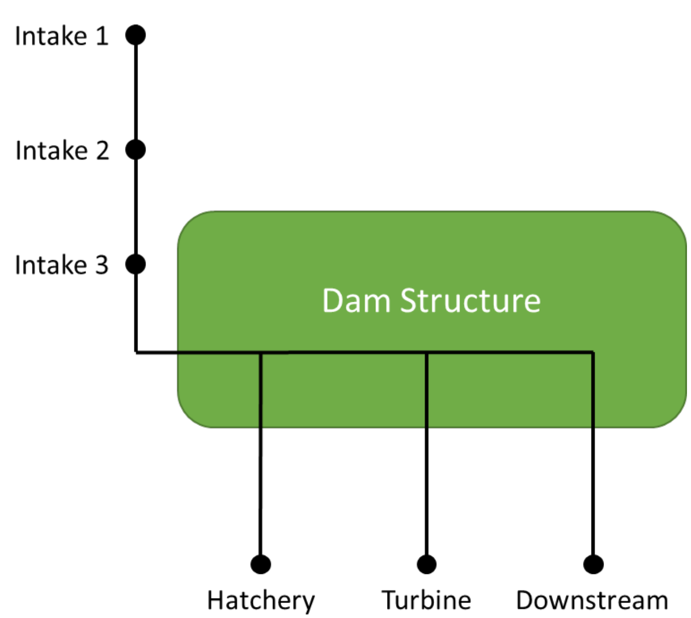
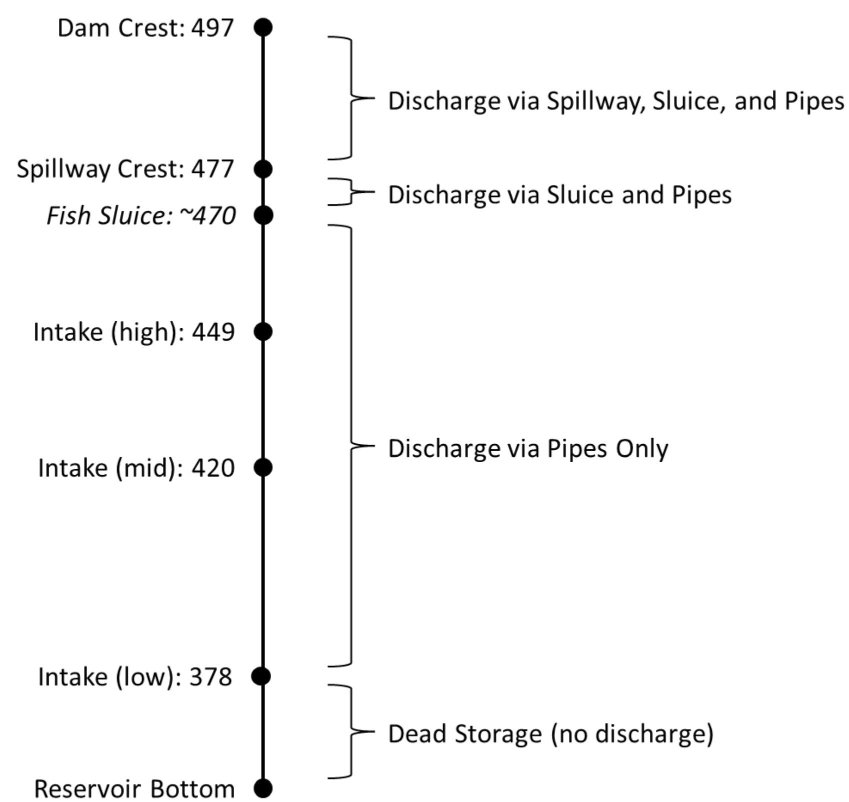


Figure ES-3
Schematic of Skookumchuck Dam Key Elevations



Flood Storage

The current dam's configuration can provide flood storage early in the rainy season (e.g., October and November). But once a larger event or multiple smaller events occur, the outlet system cannot discharge enough flow to keep the reservoir low throughout the winter and early spring to have enough space to capture flood events in the middle or later part of the rainy season in most years. Only in the driest years can the reservoir be held to a low enough elevation to be available for flood storage throughout the rainy season (November through April) while still meeting downstream minimum flows. Thus, without physical modification, the existing dam is unlikely to be able to provide reliable or substantial flood storage.

Fish Benefits

The dam has a fish trap that is used annually to collect adult steelhead broodstock for the Skookumchuck Hatchery, which is operated by the Washington Department of Fish and Wildlife (WDFW). Adult steelhead were trapped and hauled upstream until 2008. A small number were also released upstream in 2021. 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 and fish sluice function for their purpose, some modifications could be beneficial to improve performance. Overall, the dam could be operated to provide suitable downstream passage for juvenile steelhead.

Recommendations on passage upstream for Chinook salmon are not appropriate at this time. This topic needs further discussion with regional biologists regarding trade-offs between providing fish passage flows for the early Chinook salmon fry migration, steelhead smolt timing, and Chinook smolt timing that peaks after the steelhead smolt migration period and can extend into summer. The recommendations will depend on an assessment of Chinook salmon spawning and rearing habitat above the reservoir (currently information is very limited on upstream habitat conditions) and flow requirements for juvenile rearing and adult Chinook salmon spawning downstream of Skookumchuck Dam. Passage for coho salmon has not yet been evaluated.

Another near-term operational change that could be considered is changing the timing and volume of dam releases for fall spawning flows to provide better separation between the spawning timing of spring and fall Chinook salmon. Eliminating the currently required ramp-up in flows that occurs in September and October and instead allowing flows to naturally increase as the rainy season begins could delay fall Chinook salmon migration and spawning for a few weeks to provide greater separation from spring Chinook salmon spawning.

Relationship Between Fish Benefits and Flood Operations

The operation of the dam for flood storage would be in conflict with the intent to provide downstream juvenile steelhead passage because the reservoir would need to be held as low as possible throughout the winter and spring for flood storage, whereas for downstream juvenile steelhead passage the reservoir should be held as full as possible to allow passage through the fish sluice. A more sophisticated reservoir model would be needed to evaluate if the two purposes could be optimized to accomplish both purposes. Eliminating the increased flows in fall for spawning would not likely affect flood storage operations, but this has not been analyzed in detail.

Physical Dam Modification or Removal Options

This near-term analysis did not include a detailed evaluation of longer-term options, such as physical dam modifications to enhance flood storage or dam removal to restore upstream habitats and fish access. However, as a starting point, dam modifications proposed by the U.S. Army Corps of Engineers (USACE 2003) to provide flood storage were 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 for their proposal for 11,000 to 20,000 AF of storage, respectively. These costs should be considered preliminary and may change significantly with additional engineering analysis. In addition, it does not appear that the USACE (2003) included potential mitigation cost impacts to the shoreline, upland forest, and approximately one-half mile inundation of the Skookumchuck River upstream of the reservoir. These would have to be accounted for if further design was undertaken. Modifying the fish sluice to incorporate an automated floating weir that would allow more precise operation has been initially estimated at $500,000, based on a comparison to other floating weirs installed in the Pacific Northwest. Operational costs have not been estimated.

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. Dam removal would affect downstream water rights and current plans for a water bank, and would have to be analyzed in significantly more detail to understand the impacts and trade-offs. Additional costs to buy-out or replace water rights would be likely.

Water Rights

TransAlta operates the Centralia Steam Generation Plant with a current certificate for 51.6 cubic feet per second (cfs) and 28,033 AF/year. Water diversions are made directly from the Skookumchuck River at RM 7.2. TransAlta is currently seeking to convert approximately half of their power generation right into a water bank with the Washington Department of Ecology (Ecology). If the water bank is approved and established, there would be 24.1 cfs and 16,033 AF/year available for instream flows and other purposes until 2025. After 2025 there would be 51.6 cfs and 28,033 AF/year available, assuming the second turbine ceases operation at that point.

Downstream of Skookumchuck Dam within the Skookumchuck River watershed, there are an estimated 21.39 cfs of water rights (in addition to the Centralia Steam Generation Plant), including irrigation and municipal water supply (Ecology 2021; Smitherman 2021). The City of Centralia has agreed to purchase the rights to 8,337 gallons/minute (22.31 cfs) from TransAlta for future water supply needs.

Key Data Gaps

A number of data gaps still exist including the quantity and quality of habitat in the Skookumchuck River and tributaries upstream of the reservoir, the potential for coho or spring Chinook salmon transport and subsequent downstream passage, details on the fish sluice dimensions and elevations, and details on the hatchery water supply needs. Further analysis is warranted to determine the feasibility of the near-term options, the potential downstream benefits and impacts from flood storage, and potential long-term benefits and impacts of dam modification or removal options.

Potential Additional Analyses

A proposed sequence of additional analyses could be undertaken to evaluate the feasibility of potential operational options to address flood storage, aquatic species benefits and the combination of both purposes. To analyze flood storage, conducting more detailed reservoir modeling, hydraulic modeling downstream of the dam (which will require bathymetric surveying), and, if modeling indicates that flood storage is feasible, then conceptual design of an improved outlet structure at the dam and potential would all be beneficial to inform any decisions about flood storage. To analyze aquatic species benefits, conducting more detailed reservoir modeling, conducting a habitat survey in the upper watershed, conducting a bathymetric survey of the reservoir, conceptual design to improve fish passage, an analysis of water rights downstream that could be affected if the dam was removed or flow augmentation was substantially modified, and Ecosystem Diagnosis and Treatment (EDT) modeling of the potential benefits to fish would all be beneficial to inform decisions about fish passage and/or dam removal. To understand how both purposes may conflict or be optimized, conducting more detailed reservoir modeling would be beneficial. If one or more purposes is feasible, then further analysis of the costs and benefits is warranted. These analyses can be conducted within the funding currently allocated to evaluate Skookumchuck Dam options.

Introduction

This initial compilation and analysis of existing data for Skookumchuck Dam was undertaken at the request of the Chehalis Basin Board. The purpose of this analysis is to identify potential near-term options for operation of Skookumchuck Dam that could be undertaken to benefit flood damage reduction and aquatic species and associated habitat. In addition, as a precursor to identifying longer-term options for the dam, information on the dam modification previously proposed by the USACE (2003) and recent dam removals in the Pacific Northwest was compiled and reviewed to inform the Chehalis Basin Board on the potential costs and considerations of dam modification or removal. This memorandum summarizes the existing data that were obtained to date from TransAlta and others, identifies potential near-term options for dam operations, and identifies additional analyses that could be conducted in a second phase to further analyze near- and long-term options.

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 RM 67 in Centralia (see Figure ES-1).[2] Skookumchuck Dam is located at RM 21.9 and currently blocks access to all anadromous fish species to the upper half of the watershed. A watershed analysis prepared by Weyerhaeuser (1996) indicates 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 enables TransAlta to exercise its water right certificate S2-14966C for 51.6 cfs and 28,033 AF. The dam is exempt from a Federal Energy Regulatory Commission (FERC) license because it only has a small (1-megawatt) hydroelectric power generator (installed in 1990). However, the dam is associated with the Centralia Steam Generation Plant and is a component of the FERC license for the Steam Plant. The reservoir has a surface area of approximately 550 acres and extends 4 miles upstream of the dam.

Existing Information Summary

Description of Existing Dam

This information is summarized from USACE (2003), Ecology (2020), and design drawings for the original dam construction (Bechtel 1969). The existing dam is an earth fill dam (Figure 1) that was constructed on a bedrock foundation and extends 1,340 feet from valley wall to valley wall. The crest of the dam is at

[2] All river mile references in this document use the river miles designated by the U.S. Geological Survey.

497 feet elevation (National Geodetic Vertical Datum of 1929 [NGVD29]) and a 130-foot-wide concrete spillway (Figure 2) is located near the left abutment of the dam with a crest elevation of 477 feet. The crest of the dam is 30 feet wide and the height of the dam is 160 feet. The dam has a maximum storage capacity of 46,360 AF (at elevation 497 feet) and storage capacity of 34,790 AF at the spillway crest. Approximately 1,400 AF is dead storage below the lowest intake at 378 feet.

There is a fish sluice (Figure 3) through the spillway that is approximately 4 feet wide and 7 feet tall with its crest elevation estimated at 470 feet elevation. This allows for downstream fish passage when reservoir elevations are above 470 feet. As the reservoir fills, if the fish sluice is open, water flows through the fish sluice from 470 feet up to the spillway crest, and then over the spillway crest when above 477 feet. Flow through the fish sluice or over the spillway enters a 130-foot by 40-foot concrete trough and flows into a concrete-lined chute in the bottom of the trough that extends approximately 600 feet downstream. Water that passes through the fish sluice or over the spillway re-enters Skookumchuck River in a stilling basin just downstream of the dam next to an adult fish trap facility.

The reservoir has three intakes that feed into a combined outlet works system; the intakes are located at elevations 449, 420, and 378 feet and can be opened and closed to meet specific flow requirements and meet desired temperatures at the outlet. The maximum capacity through the outlet works is between 220 and 240 cfs. The outlet works system can send flow to multiple outlets that can be opened or closed: two Howell-Bunger valves that discharge into the spillway, the hatchery water supply pipeline, or through a small hydropower turbine. Once the reservoir elevation reaches 477 feet, water will also spill over the ungated spillway crest. At an elevation of 477.1 feet, approximately 15 cfs spills over the spillway crest. At the design maximum elevation of 492 feet, approximately 28,700 cfs would spill uncontrolled over the spillway.

Figure 1
Photograph of Skookumchuck Dam from Outlet

Figure 2
Photograph of Spillway

Figure 3
Photograph of Fish Sluice in Spillway

Current Dam Operations

Skookumchuck Dam is currently operated to provide sufficient water storage to supplement flows to the Skookumchuck River to allow year-round water withdrawals at the intake for the Centralia Steam Generation Plant at RM 7.2. Ecology has designated base flows for the Skookumchuck River (WAC 173-522-020; as measured at the U.S. Geological Survey [USGS] Skookumchuck River near Bucoda gage 12026400 at RM 6.4 downstream of the steam plant withdrawal), and TransAlta is required to release minimum discharge flows from the dam (as measured at the USGS Skookumchuck River near Bloody Run gage 12026150 at RM 20.65 downstream of the dam). TransAlta's withdrawal for the Centralia Steam Generation Plant is upstream of the Bucoda gage station. Table 1 summarizes the base and minimum flows at the two measuring points.

Table 1

Required Base and Minimum Flows for the Skookumchuck River at the Bucoda and Bloody Run Gage Stations

DATES	ECOLOGY DESIGNATED BASE FLOW (CFS) AT BUCODA	MINIMUM DISCHARGE FLOWS REQUIRED FROM THE DAM (CFS) AT BLOODY RUN	NOTES
December 1 – May 1	160	95	
By May 15	130	95	Unless drought conditions, then with WDFW approval can be reduced to 80 cfs in May
By June 1	103	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in June
By June 15	83	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in June
By July 1	67	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in July
By July 15	54	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in July
By August 1	43	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in August
By August 15	35	95	Unless drought conditions, then with WDFW approval can be reduced to 65 cfs in August
By November 1	59	100-140	Higher flows for spawning from September 1 to October 20; depending on reservoir elevation
By November 15	96	95	
By December 1	160	95	

The current operation is intended to store as much water as possible in the reservoir throughout the year to provide water supply and flow augmentation and to meet hatchery and in-river minimum flow requirements. Discharges from the dam are usually limited to what naturally spills over the spillway or through the fish sluice. The dam is not operated to keep the reservoir lower for flood storage.

Per the mitigation agreement between TransAlta and WDFW described in the Fisheries Mitigation and Passage section below, TransAlta fills the reservoir to elevation 477 feet by April 1 each year and provides flow augmentation downstream during the summer months and then higher flows during the spawning period from September 1 to October 20. Minimum flows during the egg incubation period (fall to April 1) are provided to support successful incubation.

Hydrology

The USGS maintains several streamflow gaging stations on the Skookumchuck River (Table 2). Data from these gages were used to develop a long-term time series of inflows to Skookumchuck Reservoir and to estimate flow frequency statistics for the inflows. USGS gage 12026000 was located at the site of the dam prior to dam construction; therefore, data from this gage can be used directly to represent dam inflows through 1969. To extend the dam inflow time series beyond 1969, data for the upstream gage near Vail were transposed to the dam site by scaling all flows by a factor of 1.27. This scaling factor was determined using the data for the period of overlap between the two datasets, October 1967 to September 1969. The scaled data from Vail were appended to the record for gage 12026000 to create a composite dam inflow time series extending back to 1929 with continuous data from October 1939 through present.

Table 2
USGS Streamflow Gaging Stations on the Skookumchuck River

GAGE	PERIOD OF RECORD		BASIN AREA (MI^2)
	Peaks and Daily Data	15-Minute Data	
USGS 12025700 SKOOKUMCHUCK RIVER NEAR VAIL, WA	1967–2021	2007–2021	40.2
USGS 12026000 SKOOKUMCHUCK RIVER NEAR CENTRALIA, WA	1929–1933, 1940–1969	N/A	61.7
USGS 12026150 SKOOKUMCHUCK RIVER BL BLDY RUN CR NR CENTRALIA, WA	1969–2021	1987–2021	65.9
USGS 12026400 SKOOKUMCHUCK RIVER NEAR BUCODA, WA	1967–2021	2007–2021	112.0

Note:
mi^2: square mile

Using the continuous record of daily inflows, flow frequency analyses were conducted to determine the magnitude of potential inflows to the reservoir. Analyses were conducted for 1-day, 2-day, 3-day, 5-day, and 7-day durations. The results of this analysis are shown in Table 3. To put these inflow volumes into perspective, it is useful to recall that the reservoir has approximately 35,000 AF of storage between its lowest outlet and the crest of the overflow spillway. This corresponds to a flow event that occurs approximately once every 10 years and lasts for 7 days (inflow into the reservoir) or alternatively a 100-year event that lasts for 3 days.

Table 3
Flow Frequency Analysis of Skookumchuck Reservoir Inflow Volumes (acre-feet)

RETURN PERIOD	1-DAY	2-DAY	3-DAY	5-DAY	7-DAY
2-Year	5,700	9,700	12,400	17,400	21,500
10-Year	11,000	18,000	22,000	28,300	33,300
25-Year	13,900	22,300	26,700	33,000	39,000
100-Year	18,200	28,700	33,600	39,500	47,100

Flow frequency analyses were also conducted for the full period of available annual peak flow data at each of the gages listed in Table 2. The results of these analyses are shown in Table 4. Of particular note in Table 4 is that the 100-year flow at the Vail gage location is actually approximately 27% higher than the 100-year flow at the former gage near Centralia (at the dam site), even though the downstream location has a basin area approximately 53% larger than the upstream site. Our assumption is that this difference is primarily due to the different periods of record at the two sites, with the Vail gage including recent large flows and potentially showing the effects of climate change or other increased flow trends. Another observation is that the 100-year flow at the gage below Bloody Run is actually less than the corresponding flow at the Vail gage, even though these have essentially the same period of record and the Bloody Run gage has approximately 64% more basin area than the Vail gage. This reduction in downstream flow is attributed to incidental flood storage at Skookumchuck Dam.

Tributary inflows between Bloody Run and Bucoda can be estimated by subtracting the flow frequency results for gage 12026150 from gage 12026400 in Table 4. Making this calculation shows that a 10-year inflow between Bloody Run and Bucoda is approximately 2,260 cfs and a 100-year inflow is approximately 3,500 cfs. While there are no other USGS flow gages downstream of Bucoda on the Skookumchuck River, the increase in basin area between Bucoda and Centralia is approximately the same as the increase in area between Bloody Run and Bucoda. Thus it is reasonable to assume that the additional local inflow downstream of Bucoda is approximately equal to that calculated between Bloody Run and Bucoda.

Table 4
Flow Frequency Analysis at USGS Streamflow Gaging Stations on the Skookumchuck River

GAGE	ANNUAL PEAK FLOW (CFS)			
	2-Year	10-Year	20-Year	100-Year
USGS 12025700 SKOOKUMCHUCK RIVER NEAR VAIL, WA	2,820	5,520	6,620	9,400
USGS 12026000 SKOOKUMCHUCK RIVER NEAR CENTRALIA, WA[1]	3,600	5,390	6,020	7,380
USGS 12026150 SKOOKUMCHUCK RIVER BL BLDY RUN CR NR CENTRALIA, WA[2]	3,290	5,690	6,610	8,670
USGS 12026400 SKOOKUMCHUCK RIVER NEAR BUCODA, WA[2]	4,540	7,950	9,250	12,170

Notes:
1. The period of record for gage 12026000 ends in 1969; all other gage records extend through 2021 and therefore include higher recent flood events.
2. Gages 12026150 and 12026400 are downstream of Skookumchuck Dam and flows are therefore subject to regulation at the dam.

Existing Water Rights

TransAlta operates the Centralia Steam Generation Plant. Water Right Permit No. 14966 authorized TransAlta's predecessors to withdraw 54 cfs and 39,100 AF/year from the Skookumchuck River for "industrial use and generation of steam for electric power purposes," with a priority date of November 28, 1966. However, the full amount authorized was not used and thus, on September 1, 2009, Ecology issued certificate S2-14966C for 51.6 cfs and 28,033 AF/year.[3] Water diversions are made directly from the Skookumchuck River at RM 7.2, approximately 15 miles downstream from the reservoir.

The Skookumchuck Reservoir was constructed to ensure sufficient flow in the Skookumchuck River to operate the steam generation plant year-round. The reservoir is operated under a separate impoundment (reservoir) permit[4], which allows the right to store up to 35,000 AF of water.

TransAlta has requested approval to convert the 51.6 cfs and 28,033 AF/year power generation right into a water bank with Ecology. On June 8, 2020, TransAlta filed a change application seeking to change the purpose of use for that right to "instream flows and mitigation/water banking." On the same day, they filed a new water right application seeking 27.5 cfs and 12,000 AF/year for "industrial supply and related use," to be mitigated by the water banked per the change application.

[3] The remaining 2.4 cfs and 11,067 AF/year is considered "inchoate" and, pursuant to Permit 14966B (also issued on September 1, 2009), were authorized for use for power generation, emission control measures, operation of the Big Hanaford Plant, and carbon capture/sequestration.
[4] Permit R359; application R-19988; certificate number R11862; priority date November 28, 1966.

On January 1, 2021, TransAlta ceased operation of one of the two turbines at the steam generation plant. The 27.5 cfs and 12,000 AF/year would allow TransAlta to continue to operate the remaining turbine until 2025. If the water bank is approved, there would be 24.1 cfs (51.6 less 27.5 cfs) and 16,033 AF/year (28,033 less 12,000 AF/year) available until 2025. Through the bank there would be 51.6 cfs and 28,033 AF/year available after 2025, assuming the second turbine ceases operation at that point.

The upper Skookumchuck River (above the reservoir), under natural (non-impounded) conditions, regularly discharges fewer than 30 cfs during the summer months[5], well below the 51.6 cfs appropriation right.

Downstream of Skookumchuck Dam within the Skookumchuck River watershed, there are an estimated 21.39 cfs of water rights (in addition to TransAlta's water right), including irrigation and municipal water supply (Ecology 2021; Smitherman 2021). The City of Centralia has recently proposed to purchase the rights to 8,337 gallons/minute (22.31 cfs) from TransAlta for future water supply needs.

Current Fisheries Mitigation and Passage

The construction of Skookumchuck Dam required mitigation for adverse effects to both fish and wildlife under agreements with the originally separate Washington Department of Game and Washington Department of Fisheries. The mitigation agreements were negotiated in 1979 and 1974, respectively. When the two departments merged into the Washington Department of Fish and Wildlife, the mitigation agreements were merged into the *1998 Centralia Steam Electric Generating Project Fish and Wildlife Agreement.* The 1998 agreement includes requirements for existing the multi-level intake system for temperature control, fish handling/collection facilities at the dam, coho salmon and steelhead production via the Skookumchuck Hatchery, minimum instream flows, and the management of the 966-acre Skookumchuck Wildlife Habitat Management Area below the dam.

A small hydropower turbine was installed on Skookumchuck Dam well after the original dam construction that has a capability of generating 1 megawatt (MW) of power. This hydro turbine is small and does not require a FERC license; however, it required an Order Granting Exemption from Licensing from FERC (exemption P-004441) and some additional environmental conditions were placed on the exemption order including water temperature management, minimum flows, reservoir levels, ramping rates, water quality, revegetation after construction, erosion control, avian protection on the transmission lines, herbicide restrictions, tailrace improvements, and annual reporting. Hydropower generation first began in 1990 and PacifiCorp transferred the FERC Order Granting Exemption from Licensing to TransAlta in 2004, following TransAlta's purchase of the entire system in 2000.

[5] Measured at the USGS gage 12025700, Skookumchuck River near Vail.

Existing Fish Passage Facilities at the Dam

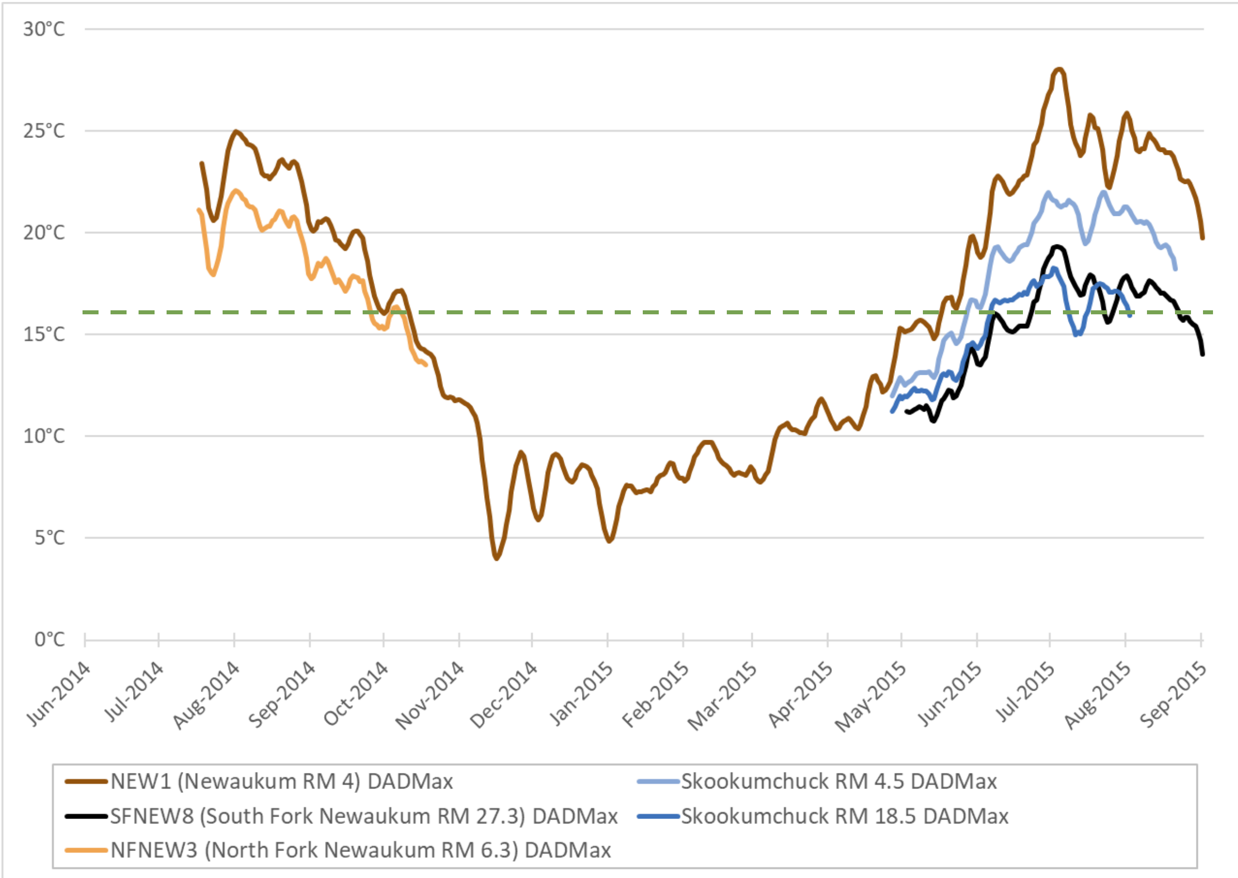
Skookumchuck Dam was constructed with adult fish collection and handling facilities (collectively called the fish trap) at the dam and protective facilities at the downstream water intake, as well as a downstream fish sluice in the spillway. These include the following: a) an adult fish ladder; b) adult holding tanks; c) a hopper for loading collected adult fish into transportation trucks; d) fish protective facilities at the Steam Plant water intake; f) an acclimation pond for juvenile steelhead reared at the hatchery to be acclimated prior to release; and g) an adult fish barrier at the outlet of the acclimation pond. The fish handling facilities were intended to be used for collection of adult fish for hatchery propagation or to transport for natural spawning, or for other purposes agreed to by the parties. The owners provide maintenance and security for the Skookumchuck Hatchery facility and provide funding to WDFW for propagation and rearing of up to 300,000 coho salmon smolts and 90,000 steelhead smolts each year.

The adult fish collection and handling facilities are operated annually from early January to mid-March to collect adult steelhead for hatchery broodstock. Adult fish that enter the spillway stilling basin can ascend the ladder, be sorted to a holding pond, and guided into the fish hopper for loading into transportation trucks. Fish collected at the trap that are in excess of hatchery broodstock requirements can be transported and released upstream of the reservoir (this was conducted up until 2008 and then stopped due to a disease outbreak at the hatchery; limited transport above the reservoir once again occurred in 2021; M. Scharpf, WDFW, pers. comm. 2021) or provided to the Chehalis Tribe or local food banks. As hatchery-produced juvenile steelhead are released from the acclimation pond downstream of the dam, the adult steelhead return to the dam. Hatchery-produced juvenile coho salmon are released directly from the hatchery and adult coho salmon return to the hatchery.

Water Temperatures

Water released from Skookumchuck Dam can be taken from upper, middle, and lower elevations within the reservoir to optimize temperatures for the hatchery and maintain cool water downstream in the river. Temperature recorders installed by WDFW in the Skookumchuck and Newaukum rivers in 2014 and 2015 (Figure 4; WDFW unpublished data) show that water temperatures near the dam (RM 18.5) are several degrees Celsius cooler than water temperatures downstream (RM 4.5) after solar heating in reaches with limited riparian cover and downstream of the various water withdrawals. The Newaukum River shows a similar trend of cooler temperatures in the North and South Forks than in the mainstem. However, the North Fork Newaukum River is more similar in temperature to the lower Skookumchuck River site. The South Fork Newaukum River is known to have several springs near the gage location (RM 27.3) that would keep it cool. The volume of flow released from Skookumchuck Dam during summer (minimum flows of 95 cfs except in drought years) is also higher than the flow volume in the Newaukum River in summer, which may also help to maintain cooler water for a longer distance downstream than in the Newaukum River.

Figure 4
Water Temperatures (7-Day Average of the Daily Maximum) in the Skookumchuck and Newaukum Rivers (2014 to 2015)



Note: Dashed line shown at 16°C water quality standard for Core Summer Salmonid Habitat (June 15 to September 15; Ecology 2019).

Upper Watershed Habitat Conditions

Conditions in the Skookumchuck watershed prior to dam construction were evaluated by Finn (1973) and are summarized here. Three dams present on the Skookumchuck River had substantially limited anadromous fish access into the watershed from the early 1900s until the removal of the final dam (Agnew Dam at RM 3.7) in 1969. At Agnew Dam, reports of numerous gaffers taking salmonids had been reported as early as 1914. The dams present at RM 11.5 and 23.8 were removed in the late 1930s and mid-1940s. The extensive coal mining that occurred in the Hanaford Creek drainage, starting as early as 1878, also significantly affected the quality and quantity of habitat in this key tributary to the Skookumchuck River. Finn (1973) identified the falls at RM 30.6 as impassable to salmon (although they may be passable to steelhead), with limited habitat upstream, although both Eleven and Twelve Creek were noted as supporting resident and anadromous trout.

The area between the falls and the proposed reservoir was noted as having 3.5 miles accessible to anadromous salmon and represented approximately 16% of the total spawning habitat available in the river. No Chinook salmon were observed in this survey within this reach and it was speculated that the canyon present just upstream of the proposed reservoir may present a low-flow blockage to Chinook salmon. The reach within the proposed reservoir represented approximately 4.3 miles of habitat and 34% of the total spawning habitat available in the river. Coho, spring Chinook, and fall Chinook salmon were noted as spawning within this reach. Adult spawner surveys in 1967 and 1969 found spring Chinook and coho salmon spawning in the reservoir reach. Fall Chinook salmon were observed spawning from the dam site to the mouth of the river. It was noted that no chum salmon were observed spawning in the Skookumchuck River but had historically been present. The estimated loss in spawning habitat upstream of the dam was based on available habitat area rather than actual spawners due to the significantly reduced numbers of fish due to dams and harvest. It was estimated that 1,800 coho, 500 spring Chinook, 371 fall Chinook, and 2,100 chum salmon would have spawned upstream of the dam (Finn 1973). There was also concern expressed about fall Chinook and coho salmon spawning on top of spring Chinook redds below the dam once it was constructed, and it was recommended that a temporary fish weir be used to segregate the Chinook salmon runs.

Data on the existing habitat conditions upstream of the reservoir are also limited. Weyerhaeuser (1996) conducted a watershed assessment and the results of the fish habitat assessment are summarized here. It was estimated that 38.6 miles of habitat are potentially fish-bearing and the entire Skookumchuck River up to the headwaters is potentially accessible to steelhead (22.4 stream miles). Resident cutthroat trout were sampled in the mainstem and all accessible tributaries. The results of the field surveys of habitat indicated that most of the tributaries are high gradient (>8%) with the mainstem generally less than 8% gradient, large wood is limited, and spawning gravel may also be limited because of the lack of wood or other structural elements to hold the gravel and redd scour is likely. Approximately one-third of the fish-bearing reaches had low riparian shading and cover.

While the upper Skookumchuck River is incorporated into the EDT model being used for the Aquatic Species Restoration Program (ASRP), the data on habitat conditions were older and limited and updating the model with new habitat condition data would help in future analyses of the potential benefit to fish from fish passage or dam removal.

Potential Operational Scenarios to Benefit Flood Storage or Aquatic Species and Associated Habitat

A simple reservoir operations model was developed in Excel and used to evaluate potential operations scenarios for Skookumchuck Dam. The model used the time series of daily inflows, developed from the USGS data as described previously, for inflow. Outflows from the dam were configured in the model as follows:

- 20 cfs was delivered to the hatchery at all times via the intake.

- A minimum instream flow requirement of 95 cfs was delivered to the downstream Skookumchuck River whenever feasible, using inflows and stored water. The minimum instream flow requirement was achieved with the sum of all outflows including the 20 cfs hatchery flow, fish sluice flows, spillway flows, and discharges via the intake.
- Spill via the overflow spillway was based on the hydraulic capacity of the spillway.
- The volume of water retained in storage, and corresponding reservoir water surface elevations, were updated daily.

Using the reservoir operations model, the following operating alternatives were simulated:

1. Fish Operation 1: Discharges via the sluiceway at the full hydraulic capacity of the sluiceway based on the assumed existing configuration of the sluice outlet
2. Fish Operation 2: A constant discharge of 65 cfs via the sluiceway whenever water levels exceed elevation 470 feet (i.e., the crest of the sluiceway). Note that this option would require modification of the sluiceway, for example, using stop logs or a controllable floating weir.
3. Flood Operation: A constant discharge of 220 cfs (maximum capacity) via the intake/outlet at all times unless the reservoir elevation drops below the lowest intake inlet at elevation 378 feet. This option also includes maximum discharges via the fish sluice and overflow spillway at all times.

Figure 5 shows the simulated median (50% exceedance) water level in the reservoir under the three different operation scenarios. As seen in Figure 5, the median reservoir water level under either fish scenario is above elevation 470 feet from early November until late July, meaning that the sluiceway will be operational during that period. The median water level under the flood operation shows that the pool can be held below the level of the overflow spillway throughout the year but that the water levels are generally high starting in early December and thus the flood pocket (i.e., the flood volume that could be captured and stored) would not typically be very large.

Figure 6 shows the same information as in Figure 5 except at the 90% exceedance level (meaning the stage that is exceeded 10% of the time). This shows that at least 90% of the time flow can be discharged via the fish sluice between December and June. It also shows that in at least 10% of the years the flood pocket can be maintained below elevation 450 feet through January and below elevation 460 feet throughout the year. Finally, Figure 7 shows the simulated water surface elevations at the 99% exceedance level. This shows that even in the most extreme case the fish operation scenarios can discharge via the sluiceway between January and May and that Fish Operation 2, with a constant discharge of 65 cfs, can operate the sluice through the end of June.

Overall, the reservoir simulations show that there is generally always sufficient water to meet fish sluice requirements during the target April to May time period for steelhead passage. This is particularly true if the sluiceway is modified to provide greater control on outflows (in all three plots shown below the Fish

Operation 2 performed better, provided a broader range in days of operation, than Fish Operation 1). Conversely, the simulations indicate that the hydraulic capacity of the existing intake outlet severely limits the potential for providing significant flood control storage. Even with the intake kept fully open it is not possible to create a significant flood pocket in the reservoir in most years. Finally, the simulations show that the operations for fish and flood are generally contradictory in that the fish operations scenario targets maintaining high reservoir levels in the winter and spring and the flood operations scenario targets maintaining low reservoir levels during fall and winter. As such, any operating scenario that seeks to meet both fish and flood needs will require a much more nuanced approach than the simple scenarios evaluated here.

Figure 5
Fish Flows and Flood Storage Capabilities: 50% Exceedance Levels

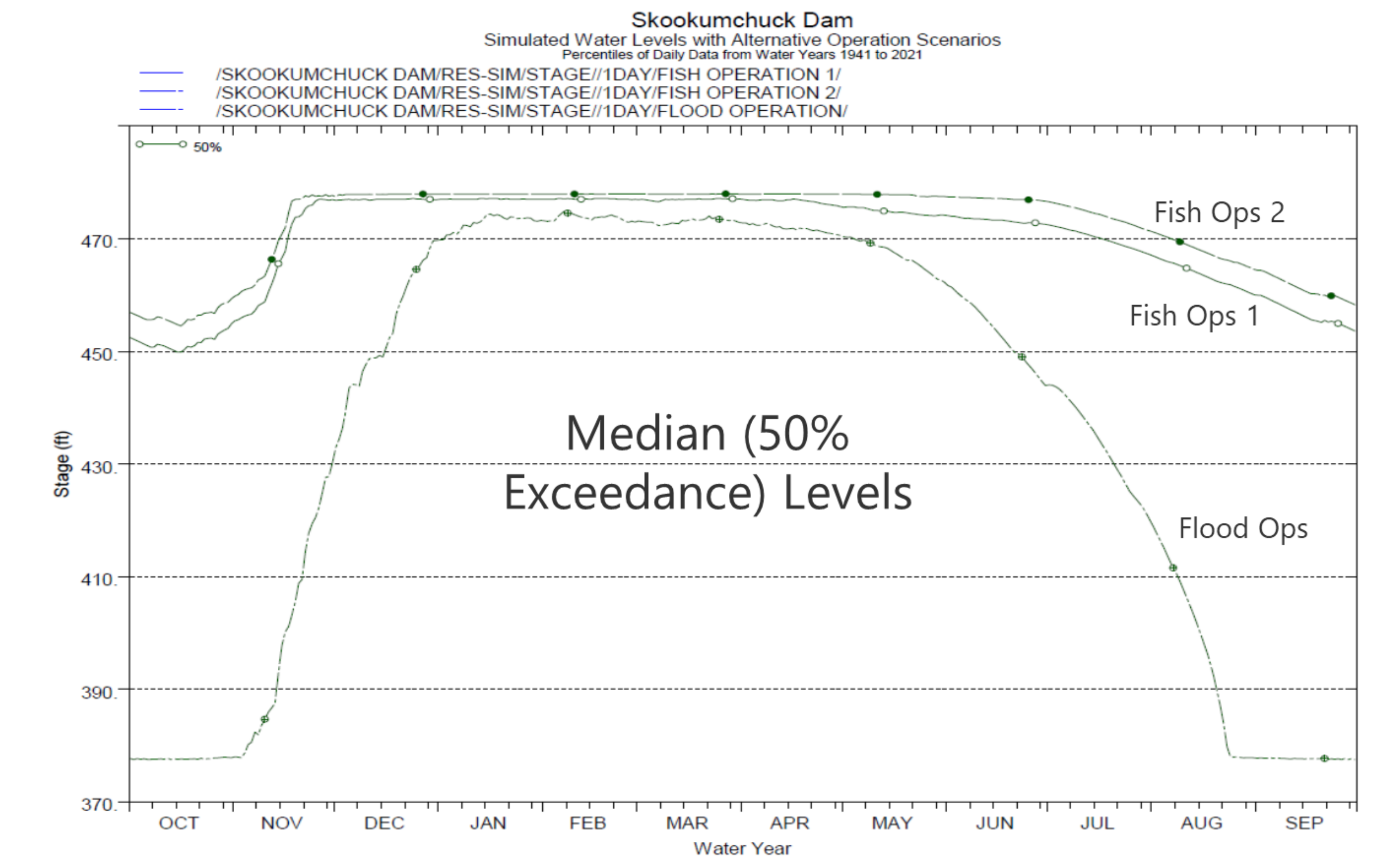


Figure 6
Fish Flows and Flood Storage Capabilities: 90% Exceedance Levels

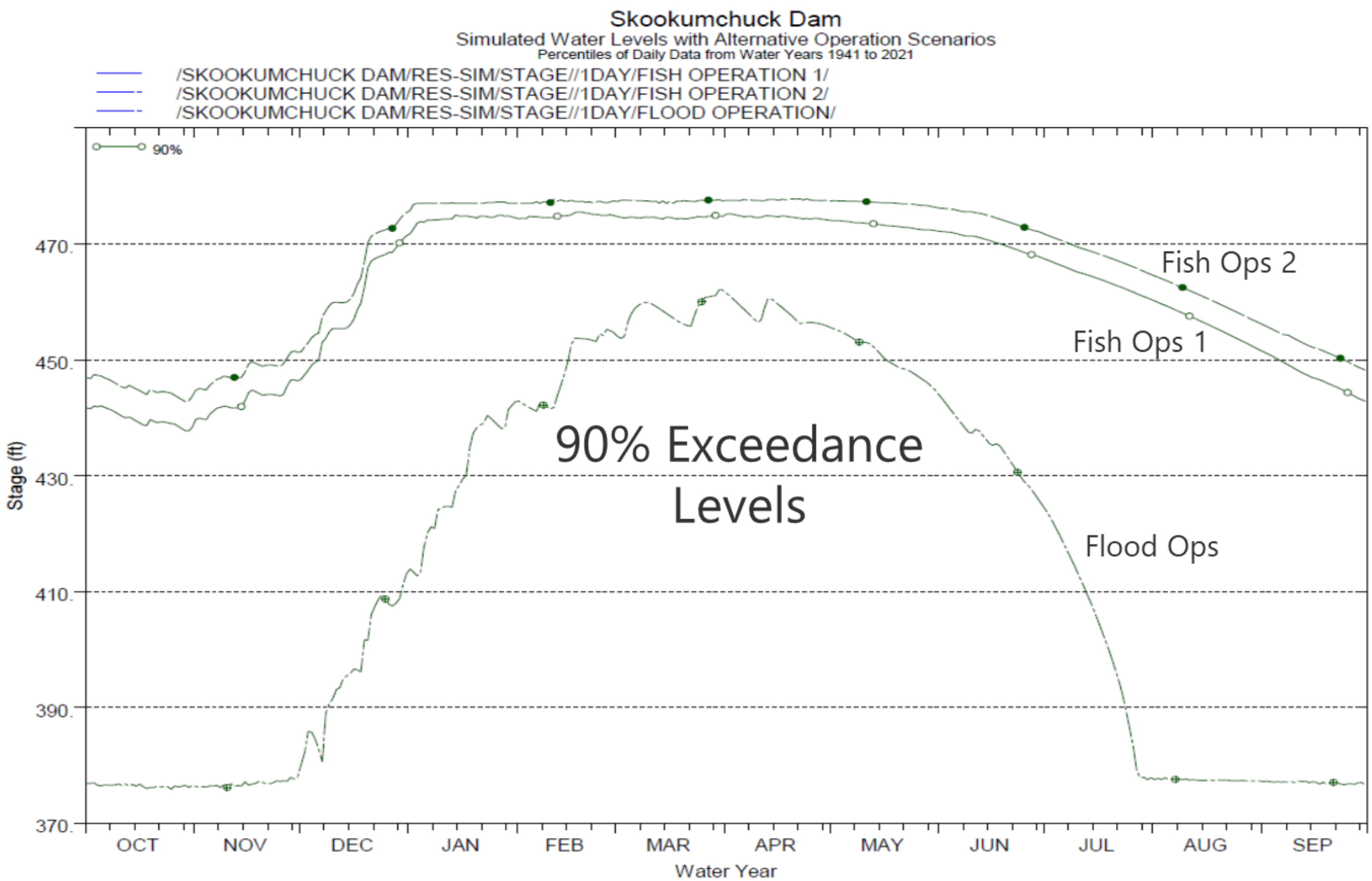
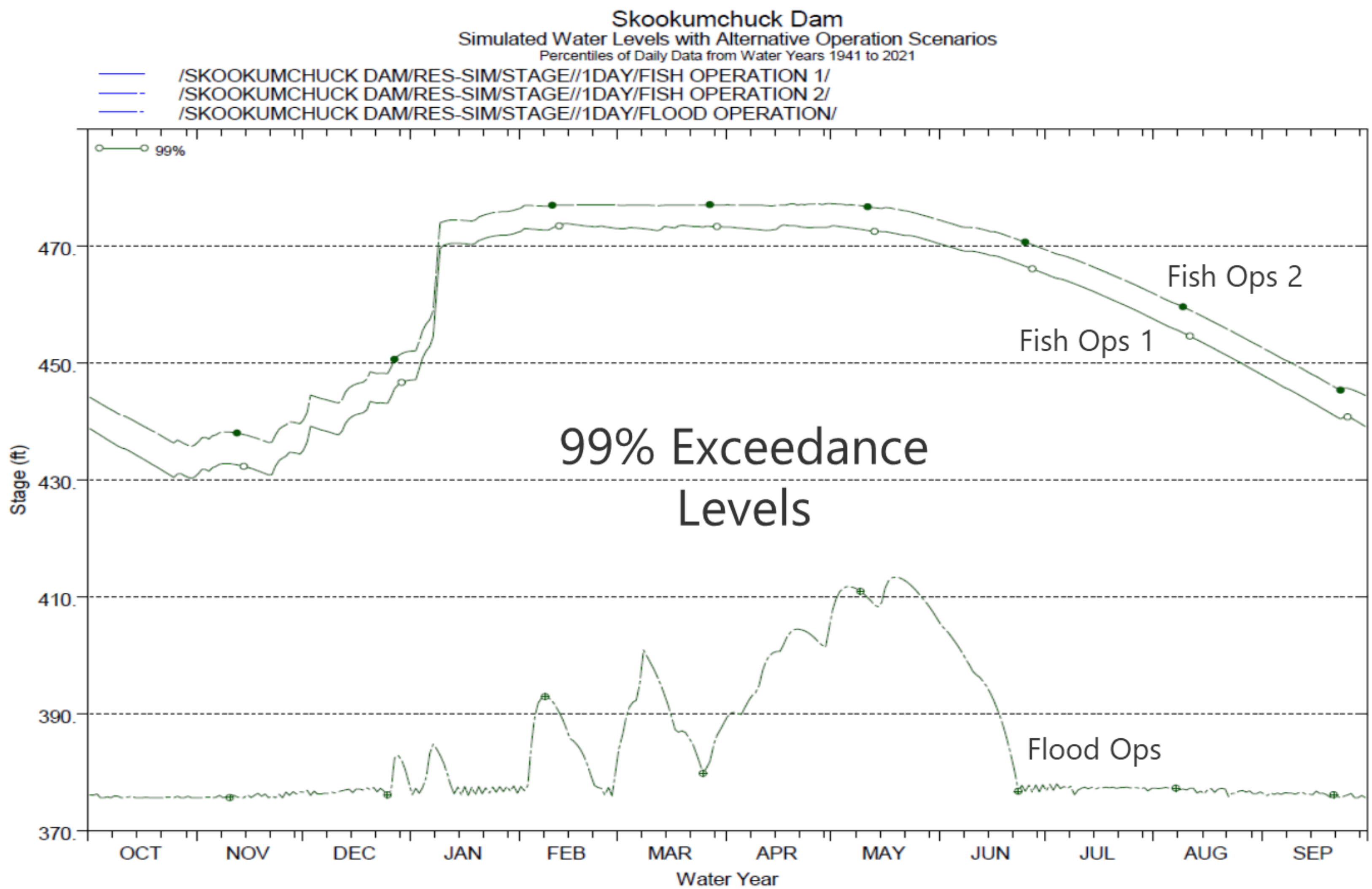


Figure 7
Fish Flows and Flood Storage Capabilities: 99% Exceedance Levels



Potential for Near-Term Fish Passage

Juvenile steelhead produced by adults collected at the dam and transported above the reservoir will enter the reservoir during their downstream migration. These fish need to exit the reservoir and pass through or over Skookumchuck Dam to continue their downstream migration to the ocean. Juvenile steelhead are large in size because they reside in their natal river and freshwater habitats for extended periods as parr prior to smolting to migrate to the ocean. Extensive information is available on steelhead smolt behavior in reservoirs at mainstem Snake and Columbia River dams. Juvenile steelhead reside in the very upper portion of the water column (<3 feet), are strong swimmers, and actively search for a surface-oriented outlet. Estimated efficiency of screens used to guide steelhead out of turbine intakes at these dams ranged as high as 97% (Ferguson et al. 2005); the vertical distribution of juvenile steelhead in the water column resulted in high guidance efficiency estimates. Juvenile steelhead passage at Skookumchuck Dam was assessed based on this behavioral information.

From review of the design and location (vertical and horizontal) of the three existing intakes to the combined outlet works, it appears these intakes will not pass juvenile steelhead due to their location (the intakes are too deep, and steelhead will not find them). Nor would it be desirable for juvenile steelhead to enter the intakes because the configuration of the outlets works system was judged by the project team to be lethal to juvenile fish passing through the outlet works system. Therefore, analysis of downstream juvenile fish passage out of the reservoir and over the dam focused on the spillway as a preferred fish passage route. To assess this route, further evaluation was conducted of the structure of the spillway, juvenile fish migration timing, and the inflow needed to provide a flow volume that is large enough to attract and pass fish over the spillway.

The spillway has a fish sluice, stilling basin, and chute that can pass flow and juvenile salmon and steelhead downstream when reservoir elevations allow. As described previously, for the spillway to pass juvenile fish downstream, the reservoir elevation must exceed 477 feet. Additionally, juvenile passage is provided by a fish sluice that can pass flow above elevation 470 feet.

To assess juvenile fish migration timing at Skookumchuck Dam, smolt trapping data were reviewed for Chehalis mainstem (RM 52 near Rochester, Washington), Newaukum River (RM 5.8), and Bingham Creek (near Matlock, Washington) smolt traps provided by Devon West (WDFW). The focus of the review was to estimate steelhead smolt timing because adult steelhead have been transported above the dam by WDFW in some years. Chinook salmon out-migration timing was also considered because habitat above the dam that could support Chinook salmon production may be present and transporting adult Chinook salmon above the dam is a potential future consideration.

The Bingham Creek trap has the longest dataset (1982 to 2015) and provides catch data for steelhead and coho salmon, but not Chinook salmon. The mainstem Chehalis trap has been operated for a long time to measure coho salmon production. In 2017, WDFW conducted a pilot study that tested a new trap design and multi-species trapping protocols to develop a more comprehensive understanding of freshwater production among multiple species of salmonids in the Chehalis River basin. Data collected from 2018 to 2020 from the mainstem trap were reviewed. The mainstem trap represents a location downstream from the Skookumchuck River and smolts trapped at this location include out-migrants from the Skookumchuck River. The Newaukum River trap has been operated since 2019. WDFW shared Newaukum trap data on steelhead from 2019 (complete), 2020 (presence only, no abundance estimates), and 2021 (preliminary data). Although Bingham Creek represents the longest dataset, the Chehalis mainstem and Newaukum River traps are more representative for this assessment than Bingham Creek due to their proximity to Skookumchuck Dam and more similar environmental conditions and temperatures than spring-fed Bingham Creek.

Based on the available information it was estimated that steelhead out-migration timing at Skookumchuck Dam would peak in late April through the first week of May, and that juvenile steelhead are expected to be present each year from mid-to-late March through mid-to-late June. Based on this information, the following recommendations have been determined for operating the fish sluice and spillway at Skookumchuck Dam to pass juvenile steelhead:

- At a minimum, operate the sluice and spillway for 4 weeks from April 15 to May 15.
- If supported by inflow, operate the sluice and spillway for 8 weeks from April 1 to May 31.
- If further supported by inflow, operate the sluice and spillway from late March through mid-June.

WDFW has collected steelhead in excess of hatchery broodstock needs at the Skookumchuck Dam adult trap and transported fish to release locations above the dam in the past. This occurred regularly up through 2008 and again in 2021. Fish released above the dam in the winter of 2021 will produce age-1, age-2, and age-3 parr that will smolt, move from stream to the ocean, and be intercepted by the Skookumchuck Dam and reservoir. Modeling of steelhead responses to the ASRP and effects of flood retention structures located in the upper basin has been conducted. These model studies require that assumptions be made regarding the proportion of juveniles in each age class. For the Programmatic Environmental Impact Statement issued by Ecology for proposed dam options near Pe Ell, Washington, it was assumed that 85% of the juvenile steelhead spend 2 years in freshwater (age-2 fish) and 15% spend 3 years in freshwater (age-3 fish) (McConnaha et al. 2017). For ASRP modeling conducted by the National Oceanic and Atmospheric Administration (NOAA), based on review comments from Quinault Indian Nation representatives, NOAA assumed that 2% of the juvenile steelhead that migrate are age-1 fish (Tim Beechie, personal communication, August 23, 2021). These estimates were based on analysis of scales of adult steelhead returning to the Chehalis River basin from 1981 to 2019 (Quinault Department of Fisheries, unpublished data). West et al. (2021) reported results of smolt trapping activities in 2020 at a mainstem Chehalis River trap located downstream of the Skookumchuck River near RM 52, and that the age composition of juveniles was 45.3%, 50.3%, and 4.3% for age-1, -2, and -3, respectively. Although the age composition values discussed vary among sources, they suggest that decision-makers should consider starting operations for passing juvenile steelhead at the dam in spring 2022 to pass age-1 smolts. Continuing those operations in spring 2023 and later to pass older-aged smolts produced from adults transported upstream in 2021 and in the future should also be considered.

Based on a review of the WDFW smolt trap data, Chinook salmon smolt out-migration timing peaks in late May through mid-June. As the smolt traps do not begin operation each year until March, Chinook fry may emigrate from as early as January, with fry and then smolts continuing through late June, and presence can extend into mid-to-late July in some years. In addition to smolts, Chinook salmon produce an initial pulse of fry (≤45-millimeter fork length) following emergence from gravels. In 2020, the Quinault Indian Nation conducted a pilot study on fry trapping at seven locations in the upper basin including two sites in the Skookumchuck River (RM 6.2 and 19) and three in the Newaukum River. In general, Chinook fry were present as soon as trapping began in early February, increased gradually to peak abundance in mid-to-late March, and declined to relatively low abundance in early May (Gilbertson et al. 2021). Based on fry being caught during the initial weeks sampled that year, fry migrations likely begin in January.

Recommendations on Skookumchuck Dam operations for juvenile Chinook salmon are not appropriate at this time. These need further discussion with regional biologists regarding trade-offs between providing fish passage flows for the early Chinook salmon fry migration, steelhead smolt timing, and Chinook smolt timing that peaks near the end or after the steelhead smolt migration period and can extend into July. The recommendations will depend on results of assessments of Chinook salmon spawning and rearing habitat above the reservoir and flow requirements for juvenile rearing and adult Chinook salmon spawning downstream of Skookumchuck Dam. Passage for coho salmon has not yet been evaluated.

As previously described, a fish sluice is installed in the spillway. The sluice is in a good location for attracting juvenile steelhead. Downstream migrating steelhead will typically reside in the upper water column (<3 feet) in an area that passes the bulk of the project flow. The location of the sluiceway is near the intakes to the outlet works, and because these flow outlets (for power production, hatchery water supply, and instream flow) are lower in the water column, it is highly unlikely the three intakes will be accessible to juvenile steelhead migrants. Because these outlets pass all of the river flow that does not pass over the spillway or sluiceway, steelhead migrants are likely to eventually encounter the sluiceway (or spillway) and pass the dam through this route if flow is being provided. If flow over the spillway and through the sluice is not available, steelhead migrants will remain in the reservoir and will likely lose their desire to migrate and residualize (i.e., become resident trout).

A trashrack with approximately 6-inch bar spacing is located on the upstream face of the sluice opening. Access for removing collected debris is limited when the sluiceway is operating, and likely impossible if flow passes over the spillway crest. Debris accumulations can adversely impact juvenile fish passage because of injury potential (scraping, impingement, and grinding when passing through debris on a trashrack under high-velocity flow conditions), behavioral reaction (avoidance), and by occluding the sluice and limiting the amount of attraction flow for fish passing through it.

Based on a review of the original spillway designs, the sluice sill (i.e., the floor of the opening) elevation is estimated to be at 470 feet, 7 feet below the crest of the 130-foot-long spillway. The downstream end of the spillway crest includes the sluiceway opening, which is shown as having an opening (width) of 4 feet. The design drawings indicate that originally the sluice included stoplogs that could be inserted horizontally to control and reduce outflow through the sluice. Controlling the amount of flow through the sluice could be used to extend the duration of the operation of the sluice as a fish passage route. However, no stoplogs were apparent at the site during the site visit in May 2021.

The flow from the sluice and spillway passes into a 40-foot-wide stilling basin that runs the length of the spillway. A control structure is located on the downstream end of the stilling basin that routes spillway flows into the spillway channel that descends from the sluice (i.e., the top of the dam) to the Skookumchuck River channel immediately downstream of the dam. The stilling basin, control structure, and spillway channel all appear to be viable and safe routes for downstream fish passage.

Frequency of Reservoir Elevations that Allow Downstream Passage

Generally, best practices used for initial downstream passage design include providing a minimum of 10% of the river flow for attraction of downstream fish passage through a reservoir. This range is project specific, and what may work at one project may not work as well at another. In general, providing a higher percentage of flow for downstream fish passage increases the potential for successful fish passage. Because the total capacity of the outlet works at Skookumchuck Dam is approximately 220 to 240 cfs, a fishway attraction flow of 65 cfs was chosen for frequency analysis based on the sluice gate geometry and assumed operating head of 3 feet. A flow of 65 cfs would provide approximately 30% of the maximum outlet flow capacity for Skookumchuck Dam for attraction flow to the sluice for fish passage.

As previously described, a spreadsheet model was used to evaluate the potential for downstream fish passage. Fish Option No. 1 (shown in Figures 5 to 7) represents the sluice being operated in its current configuration with no flow control other than head produced by reservoir elevation. Fish Option No. 2 represents the sluice being operated but under the assumption that flow through the sluiceway is controlled via the installation of a floating weir. A floating weir allows control to maintain a constant flow of 65 cfs through the sluice and increases the number of days flow can be supplied to the sluice for fish passage. In lieu of an automated floating weir, stoplogs could be used to provide some sluice flow regulation depending on how they can be operated. From this exercise, it was determined that 65 cfs flow for downstream fish passage through the sluiceway could be provided by Option No. 2 in a below-average water year (example 99% exceedance) from mid-January to mid-May. In a normal water year (50% exceedance), 65 cfs could be provided by Option No. 2 for sluice flow from mid-November through July. In summary, Option No. 2 would provide a good route for juvenile steelhead for the out-migration time period.

It is important to note that while Option No. 1 would provide some fish passage, because flow through the sluice under this option cannot be controlled, ideal hydraulic conditions for fish passage at the sluice would not be provided during portions of the out-migration. Ideal hydraulic conditions include a steady or gradually increasing flow velocity gradient from the forebay to the sluice that fish can sense as being within acceptable limits and thus would follow (enter the sluice). Because with Option No. 1 sluice head is dependent on reservoir elevation, this velocity gradient will change as the reservoir elevation changes. Some reservoir elevations will likely provide good passage conditions, but some elevations may not. For example, maximum sluice flow occurs (without spillway flow) when the reservoir elevation is just at the spillway crest, likely providing a velocity gradient that is greater than the accepted maximum level of acceleration (0.5 foot per second per foot of travel) conducive to attracting juvenile fish. If the velocity gradient is too high, fish will sense this and may avoid this condition and remain upstream of the sluice in the reservoir. Conversely, with minimal flow into the sluice, the net flow may not be detectable to some fish. The smaller this outflow and velocity are, the less likely juvenile steelhead swimming in the reservoir in search of a surface-oriented outlet will find it. Lastly, Option No. 1 uses up reservoir storage more rapidly than Option No. 2 due to uncontrolled releases through the sluice.

Designing a sluice weir configuration to provide ideal hydraulic conditions for downstream fish passage is readily feasible but is beyond the scope of work for this initial assessment of juvenile fish passage. Hydraulic modeling (physical and numerical) is a typical design exercise needed to provide hydraulic conditions for optimal downstream passage. In any case, if good fish passage is expected through the sluice, a trashrack maintenance plan must be developed and implemented. However, the important outcome of this current analysis is that, if juvenile fish passage is proposed, sufficient flows can be provided to provide decent passage potential.

Fish Trap Configuration/Operation

The fish trap was examined by the project team and found to be in good working condition. It consists of an approach ladder, a trap entrance pool, a steep-pass ladder, a brail-type trap, and a hoist to lift the trap pool to position over the fish transport vehicle. There was also a fish barrier located at the acclimation pond release site to prevent adult salmon or steelhead from swimming upstream into the acclimation pond or to the powerhouse and dam. This pond is used by WDFW to acclimate steelhead reared at the hatchery prior to their release into the Skookumchuck River.

To trap fish in the adult trap, flow is provided from the outlet works and routed into the steep-pass ladder. Fish holding in the trap entrance pool are then attracted to the steep-pass flow and ascend the steep-pass into the brail-trap. Once in the trap, fish are lifted by a fixed hoist and deposited into a tanker truck designed for fish transport. Once fish are in the transport vehicle, they can be transported to any release site with road access.

This is a common style of trap, which has been used successfully at multiple sites throughout Washington State for hatchery operations or for fish transport. During the site visit in May 2021, trap operators were not present so trap operation could not be witnessed.

A few minor corrections might be necessary to improve fish trapping and fish safety such as tightening up gaps to prevent unwanted fish entry or exit. For example, while on site, an adult steelhead was observed above the fish barrier rack at the outlet to the acclimation pond and turbine tailrace, likely having passed through the fish barrier into the outlet channel.

Potential Operational Changes to Spawning Flows

Another near-term operational change that could be considered is changing the volume of dam releases for fall spawning flows to provide better separation between the spawning timing of spring and fall Chinook salmon. As shown in Table 1 (see page 12 of this memorandum), flows are ramped up from the 95 cfs minimum flows in summer to 100 to 140 cfs from September 1 to October 20 each year to attract fish upstream to spawn. Eliminating the current ramp-up in flows and instead allowing flows to naturally increase as the rainy season begins could delay fall Chinook salmon migration and spawning for a few weeks to provide greater separation from spring Chinook salmon spawning that occurs in September and early October. This could reduce the hybridization that appears to be occurring between spring and fall Chinook salmon in the Skookumchuck River (Brown et al. 2017; Gilbertson et al. 2021). WDFW has been actively working with TransAlta in 2021 to reduce the spawning flows as an experimental measure to identify if this could separate spring Chinook salmon spawning timing from fall Chinook salmon spawning.

Initial Costs to Modify Dam to Increase Flood Storage or Fish Passage

These preliminary costs are entirely based on an escalation of previous costs developed by the USACE (2003, 2012) or a very rough comparison to similar fishway modifications. No additional design development has been undertaken for this memorandum. The USACE (2003) evaluated alternatives to provide flood storage of 11,000 and 20,000 AF. Storing 11,000 AF does not require raising the spillway crest but would require increasing the discharge capacity of the reservoir to convey the probable maximum flood (PMF), which was calculated by the USACE as 32,500 cfs. The current spillway discharge capacity is 28,000 cfs, which was the calculated PMF at the time of dam design. The outlet system for discharging water when the reservoir is below 477 feet or to augment passive discharge over the spillway only has an existing capacity of 220 to 240 cfs, which would not drain the reservoir down quickly enough to maintain flood storage capacity during the winter. Storing 20,000 AF would require modifications of the spillway to raise the crest elevation (such as with a rubber weir) and operable gates that would allow additional storage in the reservoir up to 492 feet elevation. To convey the PMF and to provide significantly greater discharge to maintain storage area for flood management, the USACE evaluated several outlet alternatives using an intake tower and discharging through a tunnel to the chute below the spillway to allow for discharging up to 8,000 cfs for the PMF and up to 3,000 cfs when the reservoir is a low pool elevation (455 feet). The estimated total cost for the 11,000 AF storage option in 2002 dollars was $9.9 million and the estimated total cost for the 20,000 AF storage option in 2002 dollars was $12.2 million. Annual operation and maintenance costs for either option were approximately $500,000.

The USACE re-evaluated and updated costs in 2012 and identified that some elements of construction overhead and profit had not been included in the 2003 cost estimate and that the contingency should be considerably higher (63% compared to 35% contingency). The 2012 report does not state the estimated total cost, but rather provides the unburdened cost (not including contingency, construction management, or profit) escalated to 2011 dollars, which was $12.1 million for the 11,000 AF storage option.

Construction costs were escalated using USACE cost indices described in Engineer Manual 1110-2-1304, Civil Works Construction Cost Index System. A yearly composite index was used to escalate from 2002 to 2021 (USACE 2021). The estimated total cost for the 11,000 AF storage option in 2021 dollars, including an additional 25% allowance, is $22.3 million, and the estimated total cost for the 20,000 AF storage option, including an additional 25% allowance, is $27.5 million. These costs should be considered preliminary and may change significantly with additional engineering analysis. In addition, it does not appear that the USACE (2003) included potential mitigation costs for the spillway/reservoir raise relative to impacts to the shoreline, upland forest, and approximately one-half mile inundation of the Skookumchuck River upstream of the reservoir. These would have to be accounted for in a further design phase. Modifying the fish sluice to incorporate an automated floating weir has been ballpark estimated at $500,000, based on a comparison to other floating weirs installed in the Pacific Northwest. Operational costs have not been estimated.

Information from Other Recent Dam Removals to Identify Initial Conceptual Costs and Considerations for Dam Removal

Dam removal and reservoir restoration has become more commonplace as a technique to restore fish passage and reinstate natural river functions and processes. Past dam removal monitoring efforts and research have documented results from dozens of projects and provide a wealth of knowledge for predicting likely outcomes and river response due to dam removal (e.g., Major et al. 2017; Tullos et al. 2014). Table 5 provides a summary of several Pacific Northwest dam removals from the past 15 years and highlights the fact that most dam removal projects are fully removed from the river and most dams are concrete structures.

Table 5
Recent Pacific Northwest Dam Removals

DAM	STATE	DAM TYPE	REMOVAL	YEAR	DAM HEIGHT (FEET)
Elk Creek	OR	Concrete	Partial	2008	80
Gold Ray	OR	Concrete	Full	2010	38
Condit	WA	Concrete	Full	2011	125
Elwha	WA	Concrete	Full	2012	105
Glines Canyon	WA	Concrete	Full	2014	210
Skookum	OR	Earthen	Partial	2016	37
Mill Pond	WA	Concrete	Full	2017	55

Two partial dam removals in Oregon, Elk Creek Dam and Skookum Dam, created volitional fish passage channels through large-scale dam structures. Figure 8 provides a view of the roller compacted concrete Elk Creek Dam, with a notch through the dam to allow the river to flow through the dam and create a natural river condition with volitional fish passage. Figure 9 shows the Skookum Dam, an earthen structure, and the construction of a volitional fish passage channel through the dam. Approximately 20,000 cubic yards of material was removed from the Skookum Dam to create the volitional fish passage channel. The Elk Creek Dam partial removal allows for more natural river processes by removing a larger portion of the dam than Skookum Dam, which primarily created a fish passage channel as illustrated in Figure 10.

Figure 8
Looking Upstream at Elk Creek Dam
(*View shows partial removal to allow Elk Creek to freely flow through the roller compacted concrete structure*.)

Figure 9
Looking Downstream at Skookum Dam
(*View shows volitional fish passage channel being constructed through the earthen dam embankment*.)

Figure 10
Looking Downstream 2 Years after Partial Removal of Skookum Dam
(*View shows volitional fish passage channel through earthen dam*.)

In addition to these past projects, several dam removal projects are currently planned. Most notable is the Klamath River dam removal project in Northern California and Southern Oregon that consists of removing four dams from the mainstem Klamath River. Methods and costs for removal of these dams are available and provide another resource when looking at concepts for the Skookumchuck Dam.

Full Removal Option

Based on the information provided by TransAlta on pre-project geologic conditions and proposed dam construction embankment sections, the dam is approximately ±170 feet high with the crest at an elevation of 497 feet (NGVD29 with 1947 adjustment), overflow spillway at 477 feet, and base of dam approximately ±330 feet. Using this information, a cursory estimate of dam embankment material yields a volume of ±2,000,000 cubic yards for the earthen structure.

Methods

The existing dam is readily accessible on each side of the embankment and the water level in the reservoir can be controlled using the existing outlet works. The outlet works consist of two 24-inch Howell-Bunger valves with reservoir water intakes at 378 feet, 420 feet, and 449 feet. The general strategy for dam removal assumes natural release of sediment stored in the reservoir, consistent with most dam removals in the Pacific Northwest. The following sequence to remove the entire dam would likely be used based on past dam removal projects:

1. Mobilize equipment and remove existing fish collection facilities, hydropower facilities, and buildings.
2. Lower reservoir storage water surface through the outlet works as low as possible, approximately ±100 feet below the crest of the dam to an elevation of ±380 feet.
3. Remove dam embankment material down to an elevation of ±400 feet and potentially lower where pilot channel breach will occur.
4. Excavate pilot channel through embankment starting at downstream end of dam and working in an upstream direction. Pilot channel would be excavated in the approximate footprint of the historical river channel. Assumes all flow into reservoir area can be passed through outlet works/bypass. Temporary sheet piling may be required in select areas of the embankment for stability and safety.
5. Breach embankment by connecting pilot channel to reservoir and drain reservoir down to historical river channel elevation, approximately ±330 feet.
6. Excavate remaining southern portion of dam embankment and deposit into spillway area. Remove outlet works, piping, and ancillary structures, recycle and/or dispose of off site.
7. Excavate remaining northern portion of dam embankment and deposit in upstream reservoir area; leave a portion in place and blend into existing landscape features.
8. Restore Skookumchuck River through dam reach primarily with the use of large wood and revegetation techniques.

9. Restore reservoir area primarily through revegetation techniques while allowing for natural river processes to be reinstigated and natural channel evolution.
10. Stabilize construction staging areas and demobilize equipment and facilities from project area.

Class 5 Opinion of Probable Cost

An opinion of probable costs for construction was developed in accordance with the American Association of Cost Engineers (AACE) recommendations. AACE guidance for studies like this where the definition of the alternatives is at the "concept screening" level or less than 2% maturity level, recommends a Class 5 cost estimate (DOE 2018). Our Class 5 estimate uses a combination of parametric (statistical relationships from historical data), analogous (past projects), and cost estimates from suppliers to create a robust opinion of probable cost at this preliminary stage in the project. Furthermore, our estimate is based on extremely limited information and quantities were estimated from original dam construction drawings (paper copy). This opinion of probable costs should only be used to gain an idea of the cost magnitude and should not be used for budgetary limits or guaranteed maximum prices. All estimates are rounded up to the nearest $1,000.

Table 6
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**
Opinion of Probable Cost	**$34,600,000**
High Probable Cost (+35%)	**$46,800,000**

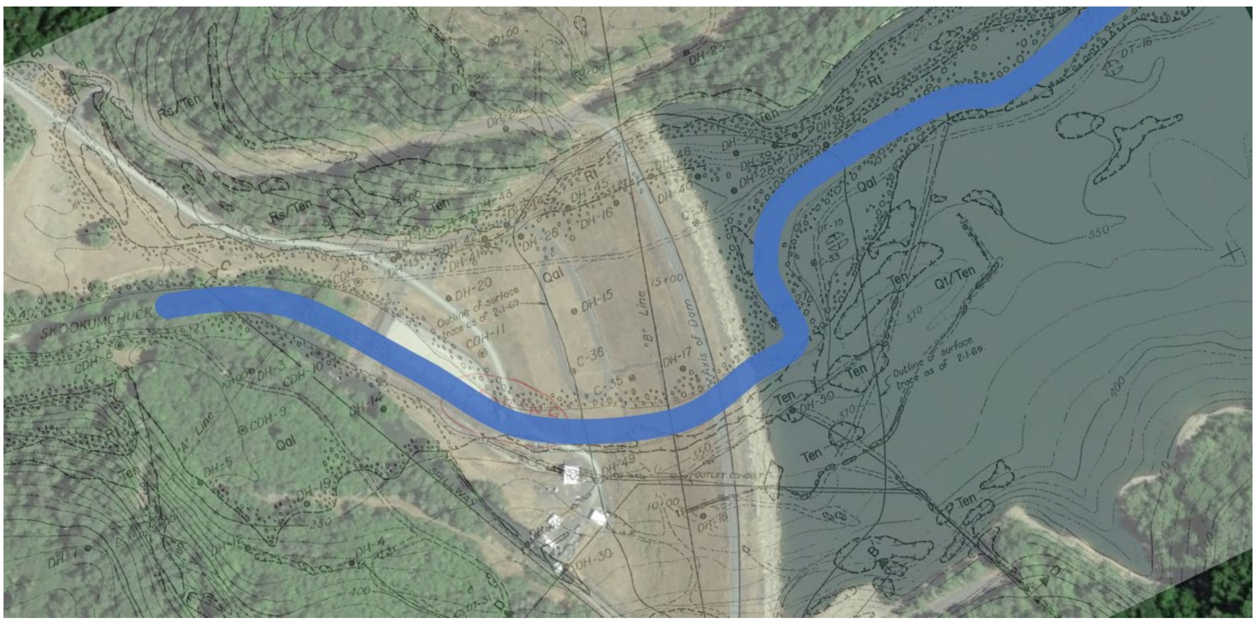
Partial Removal Option

The Skookumchuck Dam layout is configured in a manner that is conducive for developing a partial dam removal option like the Skookum Dam (Oregon) example where a fish passage channel was constructed through the earthen embankment. A partial dam removal allows for volitional fish passage and restores many natural river functions and processes. Figure 11 shows the historical river channel alignment overlain on an aerial image of the current Skookumchuck Dam.

Methods

For this alternative it is assumed that a river channel width of 100 feet would be excavated through the embankment and follow the alignment of the historical channel. For grading and excavation quantities, the 100-foot-wide river channel was assumed to be graded through the embankment at a constant longitudinal elevation of 340 feet with side slopes at 3H:1V that extend through the embankment and daylight. The volume of excavated material for the river channel template is approximately ±1,200,000 cubic yards, roughly 800,000 cubic yards less than full dam removal. Partial dam removal would use similar construction sequencing and methods as full dam removal with the major difference being the reduced volume of excavation.

Figure 11
Historical Alignment of Skookumchuck River in Relationship to Current Dam Configuration
(*View shows Google Earth aerial image overlain with geologic map (drawing C-5110) from original dam construction*.)



Class 5 Opinion of Probable Cost

The opinion of probable cost for partial dam removal is similar to the full dam removal; however, the embankment excavation quantity is reduced by approximately ±800,000 cubic yards. Embankment slope stabilization is warranted with this alternative to ensure a stable structure remains after partial removal. The excavated embankment would likely be deposited in the overflow spillway area and southern area of the remaining dam and reservoir. This opinion of probable costs should only be used to gain an idea of the cost magnitude and should not be used for budgetary limits or guaranteed maximum prices.

Table 7
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**
Opinion of Probable Cost	**$24,900,000**
High Probable Cost (+35%)	**$33,700,000**

Full Dam Removal Compared to Partial Removal

Construction staging and disposal areas for excavated material exist on the upstream and downstream side of the embankment making the site favorable for full removal or partial removal. Likewise, the existing site configuration is conducive to partial dam removal with adequate working areas on each side of the embankment and vast areas to build stable slopes through the embankment.

The primary difference between the full dam removal option and partial dam removal option is project cost. A net excavation reduction of approximately ±800,000 cubic yards of material from the embankment saves more than ±$6 million. Both options would allow for volitional fish passage, restore natural sediment transport, and allow for natural river processes. The partial removal would have a more constricted floodplain and would leave significant portions of the dam embankment in place; however, the Skookumchuck River corridor upstream of the dam consists of similar geologic features that constrict the floodplain within a narrow valley so this configuration would be similar to natural conditions.

Data Gaps

The following data gaps will require further information gathering and analysis:

- Details on all hydraulic outlets, in particular the fish sluice elevation and dimensions
- Details on the hatchery hydraulic characteristics (hydraulic demand, other sources of water, flow records for Bloody Run Creek, etc.)
- Quantity and quality of habitat upstream of the reservoir and potential steelhead, coho, and spring Chinook salmon capacity.

Potential Additional Analyses

The following additional analyses are options to further inform the feasibility of potential solutions that could benefit fish or flooding, or both objectives simultaneously. These additional analyses are provided in general order of priority because it will be important to understand to evaluate the feasibility of flood storage, aquatic species benefits, and the explicit trade-offs or optimization that can be achieved, prior to designing modifications. In addition, an evaluation of conditions upstream of the dam will primarily inform the scale of benefits that could be achieved with fish passage or dam removal.

- **Detailed Reservoir Modeling.** The reservoir simulations completed for this memorandum used a simple spreadsheet model of daily inflows and outflows and evaluated simple, single purpose operating plans for flood storage and then independently, downstream fish passage. To provide a realistic evaluation of the potential benefits of either flood storage or fish-focused operations, additional detail should be added to the hydraulic model (for example hydraulic characteristics of the intake and sluiceway and a change to hourly simulations to accurately assess spillway flood discharges). The reservoir operations analysis will also need to evaluate multi-objective operating plans that consider both fish and flood needs. Reservoir operations modeling should consider current hydrologic conditions as well as future climate change hydrology. An initial estimate to conduct detailed reservoir modeling is $55,000 and will address flood storage, fish passage, and combined options.
- **Hydraulic Modeling and Analysis Downstream of the Dam.** In order to determine if flood storage can effectively reduce downstream flood flows and flood damages, hydraulic modeling of flood events as routed through the dam will need to be conducted. An existing RiverFlow2D model of the river (part of the Chehalis River model) exists and could be updated and refined to better account for levees and other features downstream as well as including more recent channel and floodplain topographic data. The model would be run with discharges from the dam based on the detailed reservoir modeling. Comparisons of inundated area, flood depths, and numbers of structures affected for each modeled condition will be prepared. Climate change should be incorporated into this modeling as well because the intent is to consider whether effective options for flood storage exist that could be beneficial over the next 50 years. An initial estimate to conduct downstream hydraulic modeling and analysis is $80,000, and will primarily be beneficial to understand the benefits of flood storage.
- **Cross-Section Survey of Lower Skookumchuck River**. The existing model and recent modeling has not included the update of any channel cross-sections on the Skookumchuck River downstream of Bucoda in at least 20 years, with some cross-sections having never been surveyed and others more than 30 years old. We recommend conducting cross-section surveys for the lower 9.8 miles of the river, downstream of the Bucoda railroad bridge, with spacing of approximately 1,000 feet between sections resulting in about 50 new channel cross-section surveys. These will be compared with the existing channel surface (interpolated from the old cross-sections), re-interpolated as appropriate, and incorporated into the RiverFlow2D model. An initial estimate to conduct cross-section surveys of the lower Skookumchuck River is $35,000 and is important for the accuracy of the hydraulic model.
- **Concept Designs for Sluice.** Options to install stop logs, a floating weir, or other type of control mechanisms on the sluice need to be initially designed to identify costs and operational needs. Design alternatives considered for the sluice should also include consideration of effective debris management. An initial estimate to develop a concept design for the fish sluice is $30,000

and could be conducted once more refined modeling identifies key elements to address in the design for fish passage.

- **Conduct Habitat Survey Upstream of the Reservoir.** No recent habitat information has been obtained for the area upstream of the reservoir. A survey would identify the quantity and quality of habitat for anadromous salmon and steelhead if passage was provided or if the dam was removed. A proposed index reach survey and overall reconnaissance of habitat conditions for the mainstem upper Skookumchuck River from the reservoir to RM 38 and the lower ends of accessible tributaries is initially estimated at $50,000 and would greatly inform the benefits of fish passage and/or dam removal.
- **Bathymetric Survey of the Reservoir.** It is not known how much sediment may have deposited behind the dam since it was constructed; thus, a bathymetric survey would be very useful to understand the existing storage capacity of the dam and to identify considerations for dam removal and restoration upstream. An initial estimate for this task is $35,000 and would primarily inform flood storage and dam removal considerations.
- **CFD Modeling of Existing Sluice.** Effective use of the existing fish sluice may or may not be feasible, depending upon hydraulic conditions upstream of the sluice over the range of potential water levels and flows. The existing sluice is tucked into a narrow corner of the existing spillway and has sediment and debris deposition, which can affect hydraulics (flow rates and velocities) of the sluice. Detailed hydraulic analysis of the sluice requires a Computational Fluid Dynamics (CFD) model. In addition to analysis of the existing conditions, CFD modeling could also be used to configure and evaluate design alternatives for the sluice to optimize hydraulic conditions for fish passage. An initial estimate to conduct CFD modeling of the existing sluice is $35,000. Analysis of alternative designs to improve fish passage would be in addition to this.
- **Concept Designs for New Outlet.** Flood storage does not appear feasible with the existing dam configuration. Conceptual designs for a new outlet structure based on ideas developed by the USACE (2003) should be developed sufficiently to develop concept level costs. An initial estimate for this task is $50,000 and would only make sense to conduct if modeling shows substantial flood damage reduction benefit from flood storage.
- **EDT Modeling of Benefits of Fish Passage and Restoration.** The existing EDT model in use for the ASRP could be updated with habitat data from a survey upstream of the reservoir and then run for options to provide fish passage past the dam or from dam removal and reservoir and stream restoration. An initial estimate of this task is $50,000 and would further refine the potential benefits of fish passage and dam removal to salmonids.
- **Detailed Inventory of Water Rights Downstream of the Dam.** In order to understand the potential costs and impacts of a dam removal option, a detailed inventory is required of water rights, including on the Chehalis River downstream of the Skookumchuck River, that could be affected by the elimination of flow augmentation. This analysis would only be conducted if there is interest in continuing to evaluate dam removal. An initial estimate for this analysis is $20,000.

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