STAFF PAPER:

REVIEW OF FISH PASSAGE TECHNOLOGIES AT HIGH-HEAD DAMS

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Contents

Executive Summary

This paper responds to a strategy in the Council's 2014 Columbia River Basin Fish and Wildlife Program addressing mitigation of the impacts of hydropower dams on anadromous fish in areas where dams block fish passage to historic habitat. The first phase of the three-phase approach calls for studies and evaluations to inform what is known generally about fish passage and specifically about the quality of the habitat in the blocked waters of the Upper Columbia above Chief Joseph and Grand Coulee dams. Neither dam was built with fish-passage facilities.

The habitat evaluation is being conducted for the Council by the Spokane Tribe of Indians. In this paper, which can be viewed as a corollary to that evaluation, Council staff evaluates information from passage studies at Chief Joseph and Grand Coulee, and at other dams where fish passage has been studied or completed. Included in the evaluation are dams in Washington and Oregon, on the border of Oregon and Idaho, and in California and Pennsylvania. In order to better understand each location, staff compiled standardized information into case studies, summarizing information gleaned from design documents, annual reports, and from personal communications with project staff.

The paper explores six themes that could apply in planning and providing fish passage at high-head dams such as Chief Joseph and Grand Coulee:

1. Allow adequate time for evaluations and feasibility studies
2. Do not evaluate or compare existing fish-passage projects on the basis of cost, as variations in site characteristics and the age of passage systems make cost comparisons inaccurate
3. Understand and account for differences in site characteristics
4. Stay up to date with passage technologies, as fish passage technology is evolving and improving
5. Collaborate with project owners, regulators, fish and wildlife agencies, tribes, scientists and interested parties as it can be critical to successful, large-scale anadromous fish passage projects
6. Consider developing a science-based decision framework for new projects to help organize and assess all the biological, environmental, hydraulic, technical, and economic data for a range of passage alternatives under consideration at each site

The paper addresses high-head dam passage for both adult and juvenile fish and recommends that fishery managers working on and studying passage should consider the following:

- What is the end goal or objective for fish? For example, the goal could be to achieve a natural, self-sustaining population, or it could be to gain cultural, biological and economic benefits as the result of passage.

- Where should the juvenile fish collector be located? Possible options are in the forebay near the dam, in the reservoir, at the head of the reservoir, or in tributaries upstream of the reservoir
- What types of fish passage systems should be evaluated at each project?

Introduction

Purpose

The purpose of this paper is to identify and evaluate the current methods and effectiveness of fish passage systems used at high-head dams or emerging technologies that could be applied to dams of similar or greater size and capacity, such as Grand Coulee and Chief Joseph dams.

Link to the Program

Among the recommendations that the Northwest Power and Conservation Council received for the 2014 Columbia River Basin Fish and Wildlife Program were several from federal and state fish and wildlife agencies and tribes asking for the Program to include language for anadromous fish passage into the blocked U.S. waters of the Upper Columbia River, above Chief Joseph and Grand Coulee dams. The 2014 Columbia River Basin Fish and Wildlife Program contains the *Anadromous fish mitigation in blocked areas strategy,* which includes a number of general measures. One of these is entitled *Reintroduction of anadromous fish above Chief Joseph and Grand Coulee dams to mainstem reaches and tributaries in the United States*. This measure lays out a three-phase, scientific approach to investigate the feasibility of reintroduction of anadromous fish above Chief Joseph and Grand Coulee. Phase 1 includes the task, “evaluate information from passage studies at other blockages and from previous assessments of passage at Grand Coulee and Chief Joseph dams,” to be completed no later than the end of 2016. As noted above, this staff paper aims to complete this task.

Background

Migration from natal streams to the ocean and back is an essential part of the life cycle of anadromous fish. Anadromous fish, such as salmon and steelhead, but also Pacific lamprey[1], are born in freshwater streams and spend most of their lives in the ocean before returning to their natal stream to spawn. In the Columbia River Basin, juvenile salmon and steelhead migrate from their home stream and travel the length of the Columbia River to reach the Pacific Ocean, where they spend two to seven years preying on zooplankton, forage fish, and shrimp. Once the fish has reached maturity and is ready to return to their natal stream, it will practice natal homing using olfactory clues and imprinting to lead them back to the place they were born. Once they reach

[1] Though staff understands the importance of lamprey passage, the majority of this staff paper focuses on salmon and steelhead passage.

their natal stream, the salmon or steelhead[2] will spawn and die, providing essential marine-derived nutrients to the ecosystem.

Anadromous fish runs have been blocked from historic spawning grounds in the Upper Columbia for over 80 years. When Grand Coulee Dam was constructed, beginning in 1933, "the fact that the construction of this dam would strike a serious blow to the Columbia River fishery was overlooked by the general public. … The stock of salmon spawning in some 1,100 miles of river and tributaries [above Grand Coulee Dam] was to be permanently closed" (Brennan, 1938). To mitigate for this impact, the state decided to use the Methow, Entiat, Wenatchee, and Okanogan rivers of the Upper Columbia to substitute for the lost anadromous runs above Grand Coulee, and constructed fish hatcheries near the towns of Leavenworth, Entiat and Winthrop, Washington to create the surplus needed. It is important to note that those four lower tributaries make up 677 miles of already salmon producing habitat, making it impossible to truly compensate the amount of lost fish from the 1,100 miles of habitat blocked by Grand Coulee. Grand Coulee Dam continues to fund the operation of these hatcheries, which are managed by the U.S. Fish and Wildlife Service. (Brennan, 1938)

As reported by Bill Green (date unknown), this blocked run of Chinook salmon were noted in British Columbia as reaching 50-60 pounds each. Green also reported that Kettle Falls on the Columbia River was an important cultural fishing site for the tribes in the Upper Columbia. Salmon runs reached the falls in June and continued until October, with daily catch numbers reaching 1,700 in 1826. This was a communal fishing site, directed by the chief of the Colville Tribe but shared with many neighboring tribes. It is said that 1,000-2,400 tribal members fished for salmon at Kettle Falls each year. Prior to any damming of the Columbia River, the historical average for total salmon and steelhead runs above the site of Grand Coulee Dam has been estimated to be 2.6 to 3.6 million, with nearly 3.2 million above the site of Chief Joseph. Table 1 shows the habitats of salmon and steelhead above present-day Chief Joseph prior to the construction of both Chief Joseph and Grand Coulee dams. All locations listed are lakes and/or tributaries in the blocked waters of the Upper Columbia both below and above the U.S/Canada border. (The Columbia Basin Tribes and the First Nations 2015)

[2] Steelhead may exhibit a reproductive strategy known as iteroparity, in which steelhead kelts can return to the ocean and back to the natal streams to spawn more than once before dying.

	Sockeye	Fall chinook	Spring/ summer chinook	Coho[3]	Steelhead
Upper Columbia mainstem		✓	✓		
Arrow Lakes (or tributaries)	✓		✓		
Whatshan Lake	✓				
Slocan Lake/ River	✓	✓	✓		
Pend Oreille River		✓			✓
Kootenay/ Kootenai River		✓	✓		✓
Salmo River		✓	✓		✓
Spokane River		✓		✓	✓
Little Spokane River		✓		✓	✓
Hangman (Latah) Creek		✓		✓	✓
Sanpoil River		✓		✓	✓
Colville River		✓			✓
Kettle River		✓			✓
Hall Creek				✓	

Table 1. Historic locations where anadromous fish species inhabited and/or spawned prior to the construction of Grand Coulee and Chief Joseph dams. (The Columbia Basin Tribes and First Nations 2015)

The tribes in the Upper Columbia[4] and their partners have long advocated for salmon runs to be reinstated in their blocked waters since the construction of Grand Coulee. During the Council's amendment process for the 2014 Program, recommendations were received by 13 state and federal agencies and tribes calling for the reintroduction of anadromous fish in the blocked waters of the Columbia River Basin. The Council, in keeping with its mandate to give deference to the region's fish and wildlife co-managers, included measures in the 2014 Program to investigate the feasibility of salmon and steelhead reintroduction in the blocked U.S. waters of the upper Columbia, and made it one of the emerging priorities from the program: *Investigate blocked area mitigation*

[3] There is no evidence of Coho spawning in Canada.
[4] Prior to over-harvesting practices by commercial fisheries in the late 1800s, it is estimated that the Spokane Tribe tribal members consumed 132,000 salmon annually; Coeur d'Alene Tribe tribal members consumed 124,000 salmon and steelhead annually; the Kalispel Tribe tribal members consumed about 43,000 to 54,000 salmon annually; the Kootenai Tribe of Idaho tribal members consumed 44,000 salmon annually; all Kootenai tribes members consumed 130,000 to 208,000 salmon annually; and the Colville Confederated Tribes managed the Kettle Falls Fishery which was considered the second largest fishery on the Columbia River at the time with an annual catch of 90,000 to 120,000 fish. (The Columbia Basin Tribes and First Nations 2015)

options through reintroduction, passage and habitat improvement, and implement if warranted.

Simultaneously, the regional fish and wildlife co-managers have been in discussion with their partners both in the U.S. and Canada concerning the ongoing review of the Columbia River Treaty (CRT), the 1964 agreement between the two countries on the construction and operation of hydropower dams on the Columbia River for the benefit of both countries' power development and flood control. The CRT has no end date but either party can terminate it after 2024 with at least 10-years' notice to the other party. The post-2024 obligation on the part of Canada to provide flood control operations when "called upon" by the U.S. (under the circumstances justifying the call) continues for the life of the projects even if the CRT is terminated. The fish and wildlife co-managers of the U.S. portion of the Columbia River Basin collaborated on a regional recommendation to the U.S. Department of State to assist in its development of a U.S. negotiating position with Canada to modernize the treaty. One element of the regional recommendation is "ecosystem-based function," which highlights as one of its pieces that the two countries should work together to investigate and implement, if warranted, reintroduction of anadromous fish into the blocked waters of the upper Columbia.[5]

As the mainstem Columbia and Snake river hydropower dams[6] were constructed, fish ladders and juvenile bypass systems were installed and modified or improved over time to allow for continued salmon and steelhead migration.[7] In fact, a key component of the federal government's program[8] is, "improving fish passage through the federal dams on the Columbia and Snake rivers" with surface passage installed and operational at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams (BPA 2014). Over the last half century alternative approaches to fish passage have been designed and implemented at dams around the world. This staff paper provides information on various fish passage technologies that are currently being studied or are in operation at various high-head dams in the Pacific Northwest, one location in Pennsylvania, and one location in northern California, as well as information on emerging technologies.

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[5] A major difference between the Council's program and the regional recommendation is that the Council's program pursues investigation of reintroduction feasibility in the blocked waters of the U.S. only, but it is important to note that both of these regional processes are ongoing.

[6] For purposes of this paper, mainstem Columbia and Snake river hydropower dams refer to those hydro projects downstream of Chief Joseph Dam on the Columbia River or below Dworshak and Hells Canyon dams on the Snake River.

[7] Adult ladders were installed when the dams were built. Juvenile fish bypass systems were retrofitted at the mainstem dams after passage of the Northwest Power Act and development and implementation of the Council's early Fish and Wildlife programs, and subsequently modified or improved as a result of the requirements of NOAA Fisheries' FCRPS biological opinions under the federal Endangered Species Act.

[8] The mainstem federal dams are Corps of Engineers' dams and the Corps has relied on the Columbia River Fish Mitigation (CRFM) Program funding from Congress to retrofit them with juvenile and surface bypass systems. BPA has reimbursed the federal Treasury at the power share for implementation of these fish bypass systems.

Selection Criteria

This staff paper evaluates the methods, effectiveness of fish passage systems, and emerging technologies that are used either at high-head dams or in a fashion that the passage technology could be applied to high-head dams. High-head dams are classified in various ways and there is no standard definition. For the purposes of this paper, staff chose to consider Chief Joseph's size and hydraulic head as comparable factors for a high-head dam reference point. This was done to help refine the scope of research and apply lessons that can be learned to dams of a larger size, as lift and hydraulic head can be challenging factors in fish passage. Therefore, the criteria used to determine locations for evaluation is:

1. Fish passage must have been previously or currently studied, attempted, and/or completed.
2. Dams that either
   a. have 175 feet or more of hydraulic head or at least 230 feet in height, or
   b. use emerging technologies that show promise at effectively passing adult or juvenile fish at high-head dams as alternatives to, or in combination with, existing technologies.

The first criteria was used to be consistent with the program language to, "evaluate information from passage studies…" The second criteria was used to allow the evaluation to include dams that are similar in physical size and/or hydraulic capacity to Chief Joseph (the smaller of the two dams blocking fish passage in the Upper Columbia), or similar in that the new or innovative passage technology could potentially be applied at a high-head dam such as Chief Joseph or Grand Coulee.

The high-head dams chosen for evaluation in this staff paper are Baker, Chief Joseph, Conowingo, Cougar, Detroit, Fall Creek, Grand Coulee, Hells Canyon Complex (specifically Brownlee with supporting information regarding Oxbow and Hells Canyon dams), Merwin, Pelton-Round Butte, Shasta, and Swift. Additional sites that were evaluated for their unique fish passage systems are: Chehalis, Cle Elum; Cowlitz Falls and Mossyrock dams on the Cowlitz River; Cushman; North Fork Clackamas; and two dams on the Yuba River in Northern California. These dams can be viewed geographically on this map.

Key Concepts in Planning for High-head Fish Passage

Based on research done for this staff paper, staff identified five themes that could apply in planning and providing fish passage at high-head dams:

1. **Allow adequate time for evaluations and feasibility studies:** In each case study in this staff paper, taking the necessary time to study the site prior to design and implementation and adaptively manage once construction began

likely made a difference in the success of the project. In the 1950s during the construction of Brownlee Dam, only two years and nine months were provided for the Idaho Power Company (IPC) and state fish and wildlife agencies to conduct extensive pre-design and pre-implementation studies as well as design and implement fish passage in a field that was almost brand new considering that successful high-head juvenile fish passage had not been accomplished before. This rushed timeframe resulted in only a fraction of the planned studies being executed, leaving many uncertainties prior to design and implementation. Hence, once the test facility was in place, the IPC was constantly battling issues that might have been foreseen had proper studies been conducted and a reasonable amount of time allotted for preparation. On the flip side, PacifiCorp, operating within their 50-year FERC License and Settlement Agreement, has set up a phased study approach with check-ins at the end of each phase to verify the effectiveness of the Lewis River passage facilities and adaptively manage the project post-construction. Studies are currently being conducted to determine the juvenile collection efficiency at the Lewis River projects, and it is too early to judge the projects' success; however, the check-in system in place allows for real-time learning about the project and quick response when changes are needed. Fish passage projects of this magnitude take time, and it is important to be realistic about the amount of time needed to successfully study, design, and construct juvenile fish passage facilities at a high-head dam.

2. **Learn but do not compare:** One step staff took to prepare for this staff paper was to engage the Independent Economic Analysis Board (IEAB) in an informal review of the costs associated with each passage site case study in this report. The IEAB found that a cost comparison among projects was not useful and in many cases inaccurate: "There was too much variation in the site characteristics and the vintage of the passage systems to provide a basis for predicting effectiveness or estimating cost of future projects to restore anadromous fish to currently blocked areas." However, it is important to learn from the projects that have been studied, attempted, or are in use because learning from others' past experiences can be beneficial to the success of a project, whether that means tailoring the approach, modifying objectives, or deciding not to pursue passage. Project operators are encouraged to develop fish passage performance metrics at each project site in collaboration with state and federal fish managers, tribes and other regional stakeholders. Post-construction monitoring and evaluations will help determine if the fish passage system(s) at the project site is achieving the metrics and able to support their pre-determined goals. Standardized metrics could help determine if the existing passage sites are supporting a sustainable population and then that information could be used to inform the design and implementation of future passage locations.
3. **Understand and account for differences in site characteristics:** Each passage project has its own unique site characteristics, operations, purposes, fish species and associated life histories, environmental factors, hydraulic

conditions, political and institutional restraints, and more. To be more specific, each location will have different specifications, operations, hydrology, etc.; thus the size of a project will need to be scaled for its particular site characteristics; fish species, life histories, and behavior will be different in each reservoir and dam, and these differences will likely result in different design and placement of a fish bypass system or collector at each location; adequate attraction flows and entrance velocities are crucial to draw fish to the bypass system or collector, but the attraction flow will differ based on fish species behavior and size, size of the reservoir, site-specific hydraulic conditions, project configuration and operations, capacity of the collector, etc.

4. **Stay up to date with passage technologies:** Fish passage at high-head dams has been experimented with and attempted over the last 60 years with much of the progress occurring in the last 10 years. The Independent Scientific Advisory Board and the Independent Scientific Review Panel provided an informal review of the preliminary research for this staff paper and stated that, "while a review of older studies is important, the newer technologies are critical in design of a new passage facility. It should not be constrained by the past." As with all technology, fish passage technology is evolving and improving. An example would be the recent design and use of floating surface collectors to capture fish, which take advantage of the natural tendency of juvenile fish to migrate in the upper portions of the water column. Not keeping in the past, but instead being cognizant of updated and new, emerging technologies will inform and feed the progress of high-head fish passage. Additionally, since historical attempts at fish passage, there has been a dramatic improvement in both biological research and engineering tools and methods now available to scientists and engineers evaluating fish passage opportunities; past failures of fish passage at high-head dams may have been partly due to the inability to collect sufficient information in a timely manner. Fish passage evaluations by biologists now use both active and passive fish tag and tracking technology to collect more precise data in shorter timeframes allowing decisions to be made with greater certainty. Engineers now utilize computerized hydraulic modeling and scale models to help design the most efficient, safe, and effective fish passage facility design.
5. **Collaborate with stakeholders:** Collaboration is key in successful large-scale anadromous fish passage. For example, the Pelton Round Butte complex of two dams is co-owned by Portland General Electric and the Confederated Tribes of Warm Springs. At Pelton Round Butte the co-owners have found that all interested parties must be involved, engaged, and have a voice in the decision-making process. This is crucial for all the necessary permitting, funding, and implementation at all levels of the project. Collaborators should establish site-specific goals and performance criteria early in the process. An adaptive management plan should also be developed to outline steps that will be taken if performance goals are not achieved. Goals for the fish passage project should be linked to a broader fish management or recovery plan that accounts for other

factors influencing success of the passage project leading to natural, sustainable populations of target species, or other agreed-upon goals and objectives. Entities that have interest in or regulate the fish passage project or the other factors influencing the success of establishing natural, sustainable populations or meeting other project goals and objectives need to buy into the fish passage and fish management plan goals and objectives before significant effort is made to plan and implement fish passage improvements. Collaboration is also needed on a regional level to foster scientific information sharing and learning of new and innovative fish passage technologies. Toward that end, periodic regional workshops could be held in the Pacific Northwest to share information and discuss successes and challenges of providing fish passage at high-head dams.

6. **Consider developing a decision framework:** With the complexity of providing fish passage at high-head dams, consideration should be given to developing and evaluating various passage alternatives or scenarios in several steps as shown below in a decision-support process. A science-based decision framework could be developed and applied to help organize and assess all the biological, environmental, hydraulic, technical, and economic data for a range of fish passage alternatives under consideration at each site. A decision framework, similar to the one shown in Table 2 below, which is adapted from the Corps of Engineers' Configuration/Operation Plan (COP) (2015) analysis, should aim to clearly present the tradeoffs associated with different implementation strategies to provide fish passage at a high-head hydropower project. Alternative selection criteria could also be developed to assist in determining whether or not a proposed action is: (1) biologically feasible; (2) technically feasible; and (3) cost effective. It may also be useful to document uncertainty and potential impacts (both positive and negative), that are important aspects of the framework. Finally, as new information is collected and learned, refined results need to be provided to stakeholders and decision makers, i.e., use an adaptive management approach. Each of the proposed steps in the decision-support process should have review, input, and buy-in from project stakeholders and decision makers.

STEP	Proposed Decision Support Process
Step 1	Define project goals, objectives, and constraints
Step 2	Update past study results and supplement with current data or needed studies
Step 3	Determine a range of alternatives to be assessed
Step 4	Conduct detailed biological analyses for baseline and passage alternatives under consideration
Step 5	Select several fish passage alternatives for further detailed assessment
Step 6	Conduct detailed biological, environmental, hydraulic, engineering, technical, and economic assessments
Step 7	Determine potential fish benefits and estimate costs, including uncertainty
Step 8	Determine other potential impacts, including uncertainty
Step 9	Determine significance of potential project impacts
Step 10	Compile results based on stakeholder and decision-maker input
Step 11	Present/discuss passage alternatives with stakeholders and decision makers – select a preferred alternative
Step 12	Repeat decision process as new data, information, or actions are identified

Table 2. Decision process framework executed by the Corps at their Willamette projects (COP 2015)

Possible Fish Passage Alternative Screening Criteria

Specific alternative screening criteria or assumptions can also be developed and applied to the proposed decision framework above to help assess fish passage alternatives. For example, some possible screening criteria could include the following, as modified from the Corps' COP (2015):

- Alternatives should meet dam safety requirements and not result in a reduction in flood risk management, if applicable in the project subbasin.
- At a minimum, above-dam fish reintroduction efforts should aim to reach "replacement." Fish passage improvements should provide sufficient passage survival such that the above-dam population(s) is able to replace itself on average over time, i.e., adult replacement above 1:1.
- Alternatives should try to meet Native American cultural needs and objectives.
- Develop agreed-upon biological criteria or performance standards to help design screen alternatives.
- A phased approach is preferred in order to reduce project risks and apply new information gathered during the design and implementation steps..
- Fish passage actions should be cost-effective, including consideration of both power and non-power impacts.

The Area of Inquiry

What do we know about anadromous fish passage? We know that in order for anadromous fish to achieve a) abundance levels to aid in development of natural populations, and/or b) overall abundance (natural and hatchery) to support tribal subsistence and ceremonial fisheries, recreational fisheries and ecosystem function, both upstream and downstream passage solutions must be provided where dams block fish passage. For salmon and steelhead to complete their life cycle, juveniles must have a way to safely pass through, around, or over the dam(s) as they migrate downstream on their journey to the ocean, and adults must have a way to pass through, around, or over the dam(s) as they return upstream in search of their natal stream to spawn.

Providing fish passage at high-head dams utilizes both known and relatively new technologies. At present, adult fish passage primarily relies upon a standard trap and haul system, while a number of different passage options are being implemented or evaluated to provide downstream juvenile fish passage. In trap and haul practices, adults are trapped below a project and juveniles are collected above or at a project and each are transported around the dam to continue their journey to their spawning grounds or to the ocean. The first attempts at juvenile collection at high-head dams occurred at Brownlee and Baker dams in the 1950s with the use of fish gulper systems. Brownlee's system was deemed unsuccessful and decommissioned in the early 1960s, while Baker's system remained in use with some success until being upgraded to the current style of juvenile collection facility, a floating surface collector, in 2008. In the eight years since, various fish passage solutions at high head dams have been studied, and some unique juvenile fish collection techniques have been developed and applied at dams elsewhere, particularly in the Pacific Northwest.

In the cases of trap and haul at high-head dams, trapping adults and transporting them upstream has largely been successful with relatively few problems. The more complex and vexing problem is the collection and bypass of juvenile fish. There are many considerations and variables when it comes to collecting juvenile salmonids. Fishery managers working on and studying the passage site should consider the following:

- What is the end goal or objective?
    - Achieve a natural, self-sustaining population?
        - At fish passage sites on the Lewis, Baker, and the Willamette rivers, a goal of establishing natural, self-sustaining runs have been set. To achieve recovery, NOAA relies on its Viable Salmonid Population (VSP) metrics and sets its replacement goal to be higher than 1:1 adult returns. Juvenile collection and downstream passage is often the focus given that it has proven to be the most challenging aspect of fish passage and achieving greater than the 1:1 replacement rate. Adult fish trap and haul systems and artificial propagation have been used to assist the populations until reaching a self-sustaining level. Additionally, populations supported by

artificial propagation may serve other goals for those looking to pursue passage in the blocked waters of the Columbia River Basin.

- Gain cultural, biological and economic benefits?
    - While a natural, self-sustaining population is desirable, it may not be necessary to achieve the many ecosystem, cultural, and harvest objectives of state, federal, and tribal fishery managers. For example, fish reintroductions can support tribal ceremonial and subsistence fisheries, recreational fisheries, and ecosystem-process functions without achieving self-sustaining populations. For example, adults returning into a blocked area to spawn provide to that area marine-derived nutrients and/or could supply broodstock for a hatchery that is mitigating for the blockage.
- Some key factors to consider when determining the end goal:
    - Habitat suitability above the project site;
    - Providing safe and adequate juvenile and adult fish passage around the dam or blockage;
    - Predator populations;
    - Debris load entering the system at the fish collection site; and
    - Availability of fish relative to natural or hatchery resources, and etc.

- Where should the juvenile fish collector(s) be located?
    - Possible options are: in the forebay near the dam, in the reservoir, at the head of the reservoir, or in tributaries upstream of the reservoir. Additionally, multiple collectors[9] could be used in more than one of these locations in order to achieve the managers' objective.
    - Factors to consider when determining the proper location(s) for the collector(s):
        - environmental attributes of the reservoir:
            - temperature
            - dissolved oxygen levels
            - predator populations
            - flow rates and currents in the reservoir[10]
            - debris loadings
            - reservoir travel and residence times
        - various species' life history in the reservoir and the effects of collecting and passing juvenile fish at various stages of development (i.e., fingerling, fry, smolt) to determine which passage strategy results in the highest return of adult fish;

[9] Ideally all factors would be evaluated for each possible location for each project site.

[10] According the NOAA, most reservoirs in California have much lower flow rates than in the Pacific Northwest. California reservoirs store water for longer periods than in the Pacific Northwest, which reduces currents for the fish to track as they move downstream to the dam.

- juvenile fish migration behavior and timing in the reservoir and near the dam:
    - where and when target fish species enter the reservoir and pass the dam
    - how long the target fish species reside in the reservoir
    - how deep the fish migrate in the water column
    - swimming capabilities of the target fish species
    - horizontal and vertical distribution of fish as they approach the dam (e.g., do they naturally congregate in certain key areas as they approach the dam or are they spread out along the face of the dam?)
    - juvenile fish growth in the reservoir
    - survival rates through the reservoir and various passage routes at the dam
- hydraulic (e.g., flow, velocity, depth) conditions for the area(s) where the juvenile collection system is planned to be installed and how much attraction flow is needed for fish to find the collection facility entrance (e.g., the flow depths and velocities needed to attract and accommodate various sizes of fish from juvenile salmonids and lamprey to adult steelhead kelts migrating downstream);
- flow characteristics within the passage facilities should be optimized for species survival and swimming capabilities
- where the fish enter and exit the passage facility (outfall) should not negatively impact dam operations and should be located to minimize the risk of predation and water quality issues for target fish species, debris in the fish facility should be avoided or managed, and fish entrances and exits must be operational over the range of reservoir elevations and typical river levels;
- site comparisons for additional or alternative collector locations at each particular project:
    - at-dam
    - in-reservoir
    - head-of-reservoir
    - in-tributary
- the geologic stability of the proposed site and surrounding soils should be evaluated prior to locating a fish passage facility;
- road access must be provided and maintained for construction
- any real estate issues should be addressed that could impact the cost of the final fish passage facility
- pilot, or test, releases to inform:
    - productivity

    - growth
    - spawning success
    - survival of juveniles downstream past the project
    - smolt-to-adult return rates

- What types of fish passage systems should be evaluated at each project?
  - Each dam site is unique and has conditions that will vary from other projects located elsewhere that may have implemented juvenile fish passage (e.g., configuration of the project, hydraulics, dam operations, fish species/races present, juvenile life-histories, water quality, etc.). One project might not have access to electrical power at the fish collection site and may need a system like the passive collector being implemented for Shasta[11]. Another project might be dealing with a cold-water river and a warm-water river joining together at varying currents within the same reservoir that affects behaviors of the fish entering the reservoir, similar to what has been experienced at the Pelton-Round Butte complex. And another project might need to operate under large reservoir level fluctuations, such as at Swift.
  - The type of passage system(s) considered will also depend on the fish species, the juvenile developmental stages and life history targets for collection, and the migration/emigration characteristics for that particular species and age class.

Note on Legal, Political, Social, Biological, and Institutional Considerations

Many factors play a role in the implementation of fish passage at high-head dams. In this staff paper, Council staff focused its research and evaluation on the passage technologies that allow for a comprehensive view of which technologies have been used and which are new, emerging, or innovative. The Council's 2014 Program calls for an initial evaluation of fish passage studies within Phase I to investigate the feasibility of reintroduction of anadromous fish above Chief Joseph and Grand Coulee. Should additional studies and staff papers be deemed necessary to explore the additional aspects of fish passage and/or reintroduction, this staff paper lays the foundation for that future work. Where possible, staff has provided brief information about other key considerations, such as biological, legal, social, political, and institutional factors within the case studies for each passage site, but it should be understood that these considerations are voluminous and can only be properly addressed with a more extensive review.

[11] Shasta's passive juvenile collector facility is an experimental design at this point. Efficacy has not been shown yet.

Dam Specifications Compilation

Table 3. Compilation of facts for dams studied in this paper. (BPA 1990; Bureau of Reclamation, date unknown; Corps 1985)

	Brownlee	Chief Joseph	Cougar	Detroit	Fall Creek	Grand Coulee	Hells Canyon	Merwin	Pelton	Round Butte	Swift No. 1	Baker Lower	Baker Upper	Conowingo	Shasta
River	Snake	Columbia	McKenzie (South Fork)	Santiam (North Fork)	Willamette (Fall Creek tributary)	Columbia	Snake	Lewis	Deschutes	Deschutes	Lewis	Baker	Baker	Susquehanna	Sacramento
River Mile (from the mouth of the Columbia)	609.2	545.1	337.5	271.4	307	596.6	571.2		306.9	314.7		57.3	64.3	9.9 from Chesapeake Bay	
Dam operator	Idaho Power	Corps of Engineers	Corps of Engineers	Corps of Engineers	Corps of Engineers	Bureau of Reclamation	Idaho Power	PacifiCorp	Portland General Electric & the Confederated Tribes of the Warm Spring Reservation of Oregon	Portland General Electric & the Confederated Tribes of the Warm Spring Reservation of Oregon	PacifiCorp	Puget Sound Energy	Puget Sound Energy	Susquehanna Electric Co. (Excelon)	Bureau of Reclamation
Dam licensee	FERC	N/A	N/A	N/A	N/A	N/A	FERC	FERC	FERC	FERC	FERC	FERC	FERC	FERC	N/A
Year built - dam	1958	1955	1964	1954	1966	1941	1967	1931	1964	1964	1958	1925	1959	1928	1945
Dam height (ft)	420	236	452	463	180	550	330	313	204	440	512	285	312	94	620
Dam length (ft)	1,380 ft	5962	1600	1523.5	5100	5223	910	1250	636	1382	2100	550	1200	4648	3460
Installed capacity (MW)	585.4	2620	25	100	None	6809	391	135	108	338	240	105	98	572	676
Authorized purpose	Power, flood control, power storage	Power	Flood risk management, hydropower, water quality improvement, irrigation, fish and wildlife habitat, recreation	Flood control, power, navigation, irrigation	Flood risk management, water quality improvement, irrigation, recreation, and fish and wildlife habitat	Power, navigation, flood control, power storage, and irrigation	Power	Power, power storage		Power, power storage	Power, power storage			Hydropower, flood control, recreation, water supply	Hydropower, water supply, flood control, recreation

	Brownlee	Chief Joseph	Cougar	Detroit	Fall Creek	Grand Coulee	Hells Canyon	Merwin	Pelton	Round Butte	Swift No. 1	Baker Lower	Baker Upper	Conowingo	Shasta
Type	Storage	Run-of-river	Storage	Storage	Storage	Storage	Run-of-river	Re-regulation			Storage			Run of River	
Lake name	Brownlee	Rufus Woods	Cougar	Detroit	Fall Creek	Roosevelt and Banks	Hells Canyon	Merwin	Simtustus	Billy Chinook	Swift	Shannon	Baker	Conowingo	Shasta
Lake length (miles)	58	51	6	9	6.8	151		14.5	8 miles	28	12	8	9	14	22
Storage (acre feet)	1,426,700	518,000	219,000	321,000	125,100	9.6 million	188,000	263,700	31,000			146,279	274,221	310,000	4,552,000
Flood control storage (acre feet)	1,000,000	116,000	153,500	321,000	125,100	5.2 million		422,000			755,600	29,426	124,950	75,287	
Average discharge (cfs)		108,000	860	2,100	580	100,000								41,026	267,800
Average annual inflow (acre feet)	14,952,605	511,364	626,200	1,567,800	419,600	99.3 million						2,100	1700	29,701,145	5 million
Highest inflow months		January - March	November - March	November-February	November - March	April - July						Oct- Jan	Oct- Jan	March-April	
Surface area (square miles)	23.55	13.1	2	5.5	2.8	125	3.9	6.25		6.25	7.2	3.56	7.78	13.25	46.5
Hydraulic head (ft)	272	177	447	369	N/A	343	210	188	153	365		263	285	89	330
Full pool (ft)	2077	956	1699	1569	834	1290	1688	239.6		415	1000	442.35	727.77	110.2	
Minimum pool (ft)	1976	930	1532	1450	673	1208	1678.5	165			878	373.75	677.77	101.2	
Upstream passage type	No; trap and haul in the past but no system presently	No	Yes; trap and haul	Yes; trap and haul	Yes; trap and haul system under construction	No	Yes, trap and haul	Yes; trap and haul	Yes	No; in conjunction with Pelton adult trap	No; in conjunction with Merwin adult trap	Yes; trap and haul	No; in conjunction with Baker Lower adult trap	Yes; Elevator lift, coupled with trap and haul	No; trap and haul in progress
Year installed - upstream passage	1958	N/A	2010	2012	2016	N/A	1983	2014	1958	N/A	N/A	2010	N/A	1991	N/A
Estimated capital cost of	$12.1 - 55.8 million	$9.2 - 93.5 million	$11.3 million	$28.3 million	$21.1 million	$16.8 million	$5.6 - 33.3 million	$60.1 million	$62.6 million	N/A	N/A	$20 million	N/A	$90.3 million	$29.1 million

	Brownlee	Chief Joseph	Cougar	Detroit	Fall Creek	Grand Coulee	Hells Canyon	Merwin	Pelton	Round Butte	Swift No. 1	Baker Lower	Baker Upper	Conowingo	Shasta
upstream passage (2015)															
Upstream passage objectives	N/A	N/A	minimum goal of >1:1 adult replacement	minimum goal of >1:1 adult replacement	minimum goal of >1:1 adult replacement	N/A	N/A	Upstream passage survival ≥99.5%	Upstream passage facility survival: first five years is 95%, 98% after the first five years of operation	N/A	N/A	No stated and agreed upon goals exist. Performance criteria for overall survival is 75%.	No stated and agreed upon goals exist. Performance criteria for overall survival is 75%.	Passage of 2 million adult shad and 5 million adult herring	N/A
Downstream passage type	No; collection was attempted in the past but no system presently	No	No	No	Yes; dam operations	No	No	No; in conjunction with Swift juvenile collector	No; in conjunction with Round Butte juvenile collector	Yes; collect and transport	Yes; collect and transport	Yes; collect and transport	Yes; collect and transport	No, operational methods only	No; collect and transport in progress
Year installed - downstream passage	1958	N/A	N/A	N/A	2011	N/A	N/A	N/A	N/A	2009	2012	2013	2008	N/A	N/A
Estimated capital cost of downstream passage (2015)	$33 - 61.5 million	$5.3 - 93.5 million	$127.7 million	$315.4 million	$0	N/A	$73.8 million	N/A	N/A	$62.6 million	$64 million	$53 million	$53 million	N/A	$2.7 million
Downstream O&M costs for downstream passage (2015)	$2.7 - 6.2 million	$251,600 - 1.5 million	$8.8 million	$6.8 million	$2.6 million	N/A	N/A	N/A	N/A		$309,700	$254,000 - 610,500	$254,000 - 6105000	N/A	N/A

	Brownlee	Chief Joseph	Cougar	Detroit	Fall Creek	Grand Coulee	Hells Canyon	Merwin	Pelton	Round Butte	Swift No. 1	Baker Lower	Baker Upper	Conowingo	Shasta
Downstream passage objectives	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Downstream passage facility survival: first five years is 93%, 96% after that	Overall downstream survival: 80% or greater	No stated and agreed upon goals exist. Performance Criteria: Collection - 95%; Survival within the facilities - 98%; Reservoir passage - 80%	No stated and agreed upon goals exist. Performance Criteria: Collection - 95%; Survival within the facilities - 98%; Reservoir passage - 80%	N/A	N/A
Juvenile fish passage efficiency	N/A	N/A	95%	N/A	N/A	N/A	N/A	N/A	N/A	50% for Phase I, 75% beyond that	80%	75%	75%	N/A	N/A

Footnotes for Cougar, Detroit and Fall Creek:

Capital costs are Columbia River Fish Mitigation (CRFM) appropriated funds from 2015-2033.

O&M costs are operations and maintenance appropriated funds estimated over 2015-2033 with inflation assumed at 3.5% interest rate.

Not included in table are total Willamette Basin RM&E costs of approximately $144 million (2015 dollars), which are CRFM appropriated funds from 2015-2033.

Footnotes for Pelton and Round Butte:

$125.2 million spent total for juvenile and adult passage through both projects. Council staff split the total cost in half for each project site, though that may not be accurate. The overall total is accurate.

Fish Passage Types

Upstream (Adult) Fish Passage Technologies

Trap and Haul

Trap and haul is arguably the oldest and most common form of fish passage at high-head dams being used today. Most examples given in this staff paper's case studies utilize this approach to some extent. Generally the principles for adult trap and haul are:

- Trap adult fish near or at a blockage, whether it is a natural blockage, a weir or a dam.
- Truck the adults above the blockage to a pre-determined location upstream where they will continue their journey to their natal stream to spawn or a hatchery as broodstock.

Adult trapping facilities are located below (or downstream of) the dam and are often a system of ladders, weirs, traps, and elevators to capture the adults, move them to a sorting and sampling location, and then transfer them to a truck to be transported to upstream spawning habitat or to a nearby hatchery. While trap and haul programs can be costly, labor intensive and sometimes stressful for the fish, in the short term it can help re-establish a population(s) of anadromous fish upstream of a dam or blockage.

Adult trapping facilities are routinely used to achieve fishery management or research objectives. While care in handling of sampled fish is a central tenet of fish management agencies, the effects of trapping on fish behavior are typically not quantified. Murauskas et al. (2014) conducted a five-year study on the effects of fish trapping and handling on adult sockeye salmon in the Wenatchee River in central Washington under both intensive (e.g., 7 days per week) and limited protocols (e.g., 3 days per week), by examining the passage efficiency of PIT-tagged sockeye under both trapping scenarios. Median passage delay ranged from 0.4 to 8.7 days, and 8 to 38 percent of the adult sockeye return to the Wenatchee River (2,387 to 21,090 fish) was precluded from reaching upriver spawning grounds. However, a revised protocol, which limited adult trapping to less than 24 hours per week, decreased the median passage delay to only 6 minutes, with the result being that nearly all adult sockeye were able to reach spawning habitat during the two years of limited trapping. (Murauskas et al. 2014)

Murauskas and others (2014) concluded the annual variation in delay was unrelated to run size or river flow, indicating that protocols requiring intensive trapping operations had inadvertently blocked tens of thousands of adult salmon from reaching spawning tributaries in the Wenatchee subbasin. The paper advocates for a precautionary approach where the trapping of adult migratory fishes is proposed but the effects are unknown. The passage goal should be to provide safe, timely and efficient adult fish passage with no or little increase in delay, rejection of the passage facility, or increase in injury or mortality compared to a non-trap operation.

Fish Ladders

Fish ladders, also known as fishways or fish passes, are terms used to describe methods of allowing adult fish to volitionally pass upstream at dams and natural obstructions. A fish ladder is a sloping, weired or baffled raceway, or sometimes even a more naturalistic slope with boulders, rocks and other structures, that provide hydrodynamic refuges for salmonid resting and function as “uphill stairways” for fish. Similar to stairways, fish ladders can be rather lengthy so the uphill slope should remain gradual. (Schilt 2007)

Rock Island and Bonneville dams were the first dams completed on the mainstem Columbia River, in 1933 and 1938, respectively, and both included construction of a fish ladder(s) for upstream passage. Except at Chief Joseph and Hells Canyon dams, which block upstream fish passage on the Columbia and Snake rivers, respectively, fish ladders have been installed on all Columbia and Snake river mainstem dams operated by the Corps of Engineers and mid-Columbia PUDs for adult fish passage. Mainstem fish ladders are typically made of concrete, and divert the passing fish around or over the dam over a series of low steps and pools (e.g., overflow weirs with vertical slots at the bottom to pass the fish) that are submerged in a flow of water with adequate water velocity to attract the fish into and through the ladder. (Harrison 2008) The fishways installed at dams in the Pacific Northwest, which have been developed over more than half a century, have been largely successful at passing the large, strongly swimming and highly motivated pre-spawning adult salmon and steelhead and the non-native American shad (Schilt 2007).

Fish ladders attract upstream migrants into their downstream entrances and then pass adults safely upstream above the dam by providing appropriate attraction flow to guide the adult fish. The location of the fish ladder entrance and exits are critical design parameters for successful fish passage. For adult fish to find the entrance, it must be located where the attraction flow from the entrance is perceptible to the fish as they approach the dam. Turbulent flows from adjacent spillways or powerhouses can mask or override ladder attraction flows. (EPRI 2002) Thus, at hydroelectric dams where there are fishway entrances at the ends of powerhouses and spillways, it is helpful to use turbine discharges from nearby units and tested spill patterns (e.g., such as a crown-shaped spill pattern) to improve the effectiveness of fishway attraction flows for salmonids. In addition, upstream ladder exits need to be located in calmer areas of flow in the reservoir and far enough above the dam where fish are not entrained in strong powerhouse or spillway discharges causing adult fallback. Standards for ladder entrance and exit locations, attraction flows and velocities have been established by National Marine Fisheries Service (2011).

There are many ladder designs using baffles, pools and weirs that will dissipate hydraulic energy as the water descends from the forebay above the dam to the downstream tailrace. Today there are some basic fishway types being used, including designs utilizing pool and weir, pool and orifice, vertical slots, Denil, fish elevators and locks, natural channel fishways, and the Whooshh Salmon Cannon™. Variations and combinations of these basic fishway designs also exist. To address upstream passage difficulties for adult Pacific lamprey, specialized lamprey passage structures have been developed and installed at several mainstem lower Columbia River dams. In addition, some attention has been given in recent years to developing “natural channel” fishways. (EPRI 2002) Unless otherwise noted, the brief descriptions of each of these fishway types listed below is based on information from EPRI (2002).

- *Pool and Weir Ladders*
  The pool and weir ladder is the oldest of the designs and one of the more commonly used fishways. It consists of a series of pools set in steps that lead from the river below a dam to above the dam with water flowing downstream from pool to pool. The pools are separated by weirs which control the flow of water in the fishway. Fish ascend the ladder by swimming or jumping from pool to pool. (EPRI 2002) However, the operation of pool and weir ladders is limited due to its inability to operate under fluctuating operational pool levels, unless a special regulating section is provided at the upper, or discharge, end of the fishway. (Corps of Engineers Fisheries Handbook 1991)

- *Pool and Orifice Ladders*
  The pool and orifice ladder is similar to the pool and weir-type fishway except that all flow passes through submerged orifices in each weir rather than over the top.

- *Vertical Slot Ladders*
  The vertical slot fish ladder (also known as a pool and jet ladder) is similar to the pool and orifice type except that all water and fish pass through a vertical, full depth slot. This type of ladder is in common use in the Pacific Northwest and also in the Great Lakes area. This ladder type also contains a series of baffles placed at regular intervals between the walls of the fishway. The baffles are shaped and placed to provide suitable hydraulic conditions for fish passage while also dissipating energy over a wide range of water elevations and flow rates. The design of vertical slot fishways is more complex than that of the pool and weir fishway, but its advantage is that it is self-regulating.

- *Denil Ladders*
  The Denil fish ladder, first developed in 1908, consists of a flume with interior baffles placed in an upstream angle to direct the flow back on itself and reduce the velocity. Denil fishways are typically set at a steeper slope than other fish ladders making them shorter and more economical than other ladder types at a given site. Due to the excellent energy dissipation of the baffles, a Denil ladder can pass a larger volume of water than other fishways with a similar cross-sectional area. A disadvantage of the Denil ladder is that it can only operate over a relatively narrow range of flows. Thus Denil ladders have selective application for adult passage as they must be carefully engineered for width and depth relationships to provide the requisite low velocity conditions. Also, they must be

kept completely free of debris, as debris can alter the flow characteristics of the baffles. (Corps of Engineers Fisheries Handbook 1991) A variation of the Denil design is called the Alaska steep pass ladder. That ladder can be pre-fabricated in sections which can be bolted together in the field.

- *Fish Elevators and Locks*
  Water-filled fish elevators (or lifts) are similar to fish ladders in that they use attraction flow but, rather than being open passageways like fishways, passage through them is mechanized and thus more complex. Adult fish enter a downstream hopper and are held there until, triggered either by a timer, a sonar system or a human operator, the hopper is closed and lifted from the tailrace level to the forebay level. The hopper is then opened and the fish are released into the forebay on the upstream side of the dam. Fish lifts can be effective and have replaced fish ladders at many eastern U.S. dams where upstream passage for American shad is an issue. (Schilt 2007)

  An example in the Pacific Northwest of a successful fish elevator is at the Lower Baker Dam adult fish capture facility. The adult fish that are migrating upstream reach a short series of steps, somewhat resembling a fish ladder, and then enter an elevator, which fills with water until the fish rise from river level to the adult trapping facility. Once sampled and sorted, the fish are then placed on trucks and transported above Upper Baker Dam to spawn in headwater habitat.

  Fish locks[12] have lower and upper chambers connected by a sloping or vertical chamber. Using attraction flow provided by a pump or through use of bottom diffusers, fish enter the lower chamber where they accumulate. At selected times, or when adequate numbers of adult fish have congregated, the lower chamber is sealed by a gate and the sloping or vertical chamber is filled with water. Some flow is maintained through the lock to encourage upstream movement of fish. The fish are crowded toward the upper chamber, rise with the rising water level, and are free to exit the upper chamber when the lock has filled completely.

[12] The operation of a fish lock is similar to that of a navigation lock.

Figure 1. The fish elevator (the gray tower on the right) used at the Lower Baker adult fish trap. (Photo courtesy of Tony Grover)

- *Natural Channel Fishways*
  Mostly built and used in European countries such as Austria, Denmark, France and Sweden, natural channel, or nature-like, fishways are a bypass channel designed and built to act more like a natural side channel with substrate, flow, channel morphology and gradient suitable for most aquatic species. These fishways are primarily used for adult passage at low head dams, but are an interesting technology to watch as more is learned about salmon passage. (Calles 2007)

  These nature-like fishways utilize rocks, tree trunks and bioengineering materials to simulate conditions existing in a natural stream or river, e.g., mimicking the natural environment of pools, riffles or passable rapids. Thus they can provide suitable passage conditions and habitat for a wide variety of species inhabiting a particular river. Advantages of natural channel fishways include suitability for a wide variety of species, habitat enrichment, low cost for construction and operation and maintenance compared to standard concrete fishways, flexible construction allows for modifications to improve fish passage conditions, easy integration into the landscape, and aesthetic value. However, since most nature-like fishways have been designed intuitively to meet site-specific needs, it is important to develop detailed information on siting, species-specific behavior and run timing, design parameters, and hydraulic conditions. (EPRI 2002)

- *Whooshh Salmon Cannon™*
  The Whooshh Fish Transport System™, or WFTS, is an emerging technology in the field of fish passage and was originally created and used in the agricultural industry to efficiently transport produce to reduce bruising and damage. As applied to adult upstream passage, fish are moved through water lubricated

tubes via negative pressure (vacuum). Design requirements related to attraction (structure type, location, and auxiliary water needs) are consistent with traditional fish ladder designs in both scope and scale, relative to individual project/site conditions. (Whooshh website; Summerfelt 2015; Whooshh Webinar 2015)

Multiple tubes are required to facilitate passage for a single species over a typical size distribution of the stock population. Passing multiple species and life histories increases the number of tubes required. Due to the need for multiple tubes, collecting and sorting facilities (manual or mechanical) are required to ensure fish are separated and selected for the correct-sized tube. It should be noted that the WFTS design itself does not possess the structural components or engineering required for necessary attraction, collection, and sorting operations. Attraction, collection, and sorting facilities, are not inherently part of a WFTS. When these components are required, they must be individually engineered to project specific variables. Therefore, initial cost estimates of a WFTS may not include attraction, collection, and sorting facility requirements.

Currently, the size, scope, and functionality of potential in-line collection and sorting facilities are conceptual. Mechanical collecting and sorting needs of a WFTS have not been studied or attempted. More information and study are needed to address this knowledge gap. Hand-fed WFTS operations are similar in function to current trap and haul operations. Hand fed operations may decrease delay in some cases. Passage rates are a function of peak daily run size, attraction flow, total negative pressure (pump size), collecting/sorting rate, and number of available tubes/pumps.

WFTS have been used on the Washougal River by the Washington Department of Fish and Wildlife since 2013 to assist in the movement and sorting of hatchery fish as part of its fall Chinook hatchery program. In 2014, Pacific Northwest National Laboratory did a study using the WFTS at Priest Rapids Hatchery to determine the effect the tubes had on adult fish. The study took male and female adult hatchery fall Chinook nearing maturation and separated them into four groups that either traveled through a straight 12-meter WFTS tube, traveled through a 77-meter WFTS tube that followed a racetrack configuration with four corners[13], were transported via a traditional trap and haul method, or were part of a control group. The fish were studied after treatment, and no significant difference was found between the four groups in adult survival, injury or stress; immune system response; and reproductive readiness. In fact, the fish that traveled the 77-meter WFTS tube had the highest egg survival of the four groups. Overall, the results suggest that the WFTS tubes did no harm to the mature fish and may be an effective method for transportation of adult fish. The Yakama Nation has also used the WFTS at Roza Dam since 2013 to load fish from a holding facility to a hatchery-bound truck. The Yakama Nation tracked the

[13] The slope for both tubes used at the Priest Rapids Hatchery was zero.

survival of the fish that traveled via the WFTS and the success of their offspring and found no ill effects. It is believed that the WFTS is less stressful on the passed fish because the travel time through the tubes is quick. It can take hours or days for fish to travel up a fish ladder, whereas a 2016 study using an 1100-foot long and 100-foot high WFTS passed fish in about 35 seconds. Additionally, in the summer of 2016, the Columbia River Inter-Tribal Fish Commission (CRITFC) conducted a sockeye migration study using a temporary setup of a 100-foot long WFTS at the 180-foot high Priest Rapids Dam on the Columbia River. Using a sample size of 900 fish, half were sent through the WFTS over the dam and into the forebay and the other half traveled up the fish ladder. CRITFC found that the fish traveled through the WFTS in less than 10 seconds, saw no immediate signs of mortality, and based on PIT tag readings learned that the fish that were transported via the WFTS reached the next dam an average of 24 hours faster than the fish that traveled up the ladder. At this time, the WFTS has proven to be mechanically effective over distances on the scale of 100-feet for hand loading and transporting hatchery fish between trap and truck. (Whooshh website; Geist 2016; Summerfelt 2015; Whooshh Webinar 2015; Prengaman 2016; Whooshh 2016a; Whooshh 2016b)

Validation of volitional fish entry into the WFTS using a common false weir configuration has been conducted at Buckley Dam in Washington and for uniform fish sizes. The concept seems promising, although no injury or migration tests have been performed to date quantifying potential physical injury, or other potential adverse biological effects of the configuration (Whooshh website). It is unknown at this time what biological limits exist, if any, relative to the effects of tube length and ambient temperature on the general health of fish and the composition of fish slime layer. Also unknown is behavioral limitations and potential injury concerns related to WFTS and potential collection and sorting structures and configurations which may be required at high head projects. Detailed Information on the staffing, operation, and maintenance requirements are not available at this time due to a lack of prototype or full scale facilities in use. It is also unclear what failsafe, backup, or project redundancies will be required to ensure passage is provided during system failure or other emergency shut down situations.

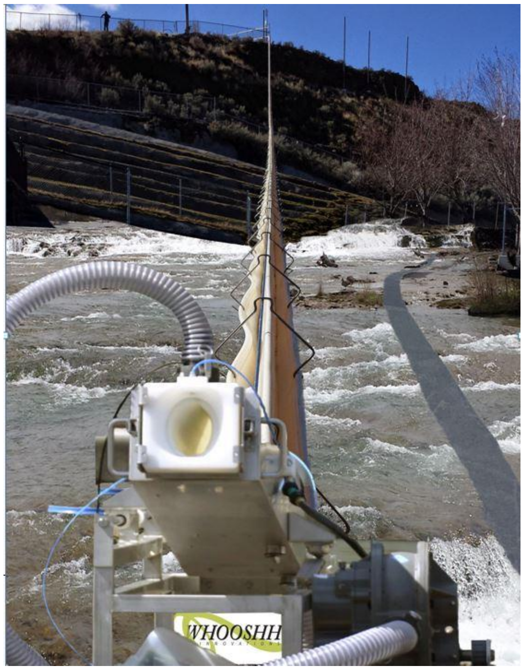


Figure 2. Whooshh Fish Transport System (photo courtesy of [Whooshh Innovations](#))

Downstream (Juvenile) Fish Passage Technologies

**Also used for steelhead kelt and adult fallback*

Downstream passage technologies can be grouped into six basic categories based on the means by which they provide fish protection or passage, including: 1) fish diversion systems; 2) physical barriers; 3) fish collection systems; 4) behavioral guidance devices; 5) turbine passage and 6) project operational changes.

The first juvenile fish bypass system used in the Columbia River Basin was at Ice Harbor dam in 1967. The Corps of Engineers created the system by allowing juvenile fish to use the ice/trash sluiceway via holes in the bulkhead slots to avoid the turbines and pass the dam. The ice and trash sluiceway is currently being used at The Dalles Dam powerhouse as a surface route for juvenile fish passage from April through November, with a bypass flow of about 4000 cfs and a discharge into the tailrace. The sluiceway is also used in early December and during March to provide passage for steelhead kelt.

Fish Diversion Systems

Fish diversion systems include various designs of pivoting, fixed, or traveling screens, louvers, and other types of bypasses associated with conventional or angled bar racks, or screens. This section discusses angled fish diversion systems leading to bypasses that are integral with the diversion device. Systems employing other types of bypasses (e.g., spillways or surface collectors), combined with barriers intended to direct fish toward them, are discussed later in this section. (EPRI 2002)

The National Marine Fisheries Service has developed design and operating criteria for fish diversion screens which can be used as a guideline in developing a system design for a given site. (NMFS 2011) However, some deviation from the standard criteria may be acceptable to fish management agencies if adequate performance of the diversion device can be demonstrated.

An important consideration in the design of all types of fish bypass systems is the potential for avian and fish predation, particularly at bypass outfalls where the fish are returned to the river in large numbers. Predatory birds and fish often target the concentration of fish at the outfall site. Care must be taken to locate the outfall site in areas of sufficient depth, which can reduce avian predation, and in high velocities with lack of shelter (e.g., in or near the river thalweg), which can discourage predatory fish. At sites with high predation potential, other means to exclude or remove[14] predators from the release site should also be considered, including the installation of avian wires, physical barriers, or behavioral deterrent systems. (EPRI 2002)

[14] The Northern Pikeminnow Sport-Reward Fishery is an example of a predator removal program on the Columbia and Snake rivers.

- *Angled Screens*

  Angled fish diversion screens leading to bypass and return channels or pipelines are commonly used for guiding salmonids in the Pacific Northwest. In addition, a variety of other fish species have been shown to guide effectively on screens given suitable hydraulic conditions. Many screens of this type use a wedge wire screen design comprised of narrowly spaced, individual bars, which can be oriented either perpendicular or parallel to the flow. Angled screens require uniform flow conditions, a fairly constant approach velocity, and low velocity through the screen to be biologically effective. (EPRI 2002) They require a head differential sufficient to pass water through the wire or mesh, while the screen openings must be small enough to prevent passage of the juvenile fish to be diverted. (Corps of Engineers Fisheries Handbook 1991)

  Screen design and operating criteria (NMFS 2011) are typically used to guide utilities and agencies when designing an angled screen bypass facility. Besides concerns with predation at a screen bypass outfall, stresses on the fish associated with diversion, dewatering and piping (with the pumping that may be required in some cases to return fish to a safe release location downstream) varies by species. Such stresses and potential injury or descaling to juvenile fish need to be evaluated and considered in determining the potential effectiveness of angled screens at a particular site. (EPRI 2002)

  Debris is a common problem with angled screens and maintaining them in a clean condition is critical to improve biological performance. Screens are subject to damage by heavy floating objects (e.g., logs, sticks and vegetation) moving downstream and must be protected with upstream trash racks or guards to collect debris loads. They can be affected by bed load movement and so must be capable of passing sands and gravels. They need to be protected against icing, where such conditions occur. McMillan and Smith (1996) have reviewed various screen cleaning systems for use with angled, flat-panel fish screen panels.

  When selecting a cleaning system, the basic criteria include debris type, flow hydraulics, screen structure location, screen type, fish protection, operations and maintenance, and economics. (McMillan and Smith 1996) For floating debris, mechanical screen cleaning systems are best. For heavier debris loads, such as algae and ice, water backwash cleaning systems are more effective. Wedge wire screens are best cleaned with brushes while wire (or nylon) mesh screens are best cleaned with backwash. For example, angled submerged traveling mesh screens at some federal mainstem Columbia and Snake river dams rotate on rollers periodically to allow flow through the screen to clean off accumulated debris. Operations and maintenance requirements vary from site to site but typically mechanical (brush) cleaning is less complex and thus less expensive than water backwash cleaning systems. (EPRI 2002)

While most angled screen facilities have been designed and installed to protect early (juvenile) life stages of salmonids, they have been known to also provide passage for steelhead kelts. However, subyearling and fry salmon life histories are more difficult to guide than the smolt (yearling) stage and are also prone to injury and descaling. Information on the potential effectiveness of angled screens in guiding non-anadromous species that can occur at many hydroelectric projects is generally lacking. However, extended-length bar screens installed at several federal mainstem Columbia and Snake rivers, while effective at guiding juvenile salmonids, have been found to impinge or injure juvenile Pacific lamprey.

- *Louver screens*
  A louver or bar rack screen system consists of an array of evenly spaced, vertical slats aligned across the stream channel at a specified angle guiding fish into a bypass pipe. Louver screens are oriented 90 degrees to the flow while rack slats are angled 90 degrees to the rack frame and their orientation to the flow is dependent on the angle of the entire rack structure. (EPRI 2002) Juvenile fish are swept along the face of the louver screen array by the flow and water velocity. The swimming effort of the fish must be sufficient to keep the fish from entering the velocity through the louver slats, but insufficient to overcome the transport velocity into the bypass channel. (Corps of Engineers Fisheries Handbook 1991)

  Results of louver screen studies have been variable by species and site. Many louver screen installations in the U.S. are in the Pacific Northwest. (EPRI 2002) A louver screen system is installed at the T.W. Sullivan Hydroelectric Project on the Willamette River near Oregon City, Oregon.

  Louver screens work on a guidance velocity principle but present operating difficulties because they require a continuous combination of ideal velocity conditions to operate effectively. Also, this type of screen accumulates debris, which may effectively alter the ideal velocity conditions as designed. Louver screens are not commonly recommended by fishery resource agencies where complete screening is required. (Corps of Engineers Fisheries Handbook 1991)

- *Eicher screens*
  The Eicher screen is a passive pressure screen designed to be used at hydroelectric facilities with penstocks. This screen concept was patented in the U.S. and Canada by George Eicher and thus is commonly referred to as the “Eicher screen.” The first Eicher screen was installed in 1980 at the T.W. Sullivan Hydroelectric Project on the Willamette River near Oregon City, Oregon. The facility incorporates a screen made of a smooth-surfaced wedge wire material which inclines upward toward a fish bypass channel. The screen is mounted on a frame and pivot axis which allows it to be rotated and backflushed for cleaning off debris. The Eicher screen at this facility has proven to be effective at bypassing spring and fall Chinook salmon and steelhead with minimal injury or scale loss. (EPRI 2002)

- *Modular inclined screens*
  A relatively new type of fish diversion screen is known as the modular inclined screen (MIS). The MIS is intended to protect both juvenile and adult life stages of fish at hydroelectric projects and water intakes. An MIS system consists of an entrance with trash racks, dewatering stop logs in operating slots, an inclined screen deployed at a shallow angle (between 10 to 20 degrees) to the flow, and a bypass for directing diverted fish into a transport pipe. The MIS module is enclosed and designed to operate at relatively high water velocities ranging from 0.6 to 3 meters per second, depending on species and life stages to be protected. (EPRI 2002)

  While the MIS has undergone extensive hydraulic evaluation in the lab and at a prototype field site, it has not been used on a permanent basis to protect fish at a project site. However, EPRI (2002) asserts the combined results of both lab and field evaluations of the MIS demonstrate this screen may be an effective fish diversion device with the potential for protecting fish at hydroelectric projects.

- *Other fish diversion systems*
  Other commonly used fish diversion systems include angled rotary drum screens, inclined plane screens and submerged traveling screens.

Physical Barriers
These barriers are designed to physically block or affect fish passage. Most are typically used under low water velocity conditions. Examples of physical barriers include barrier nets, wedge wire screens, submerged traveling screens and rotary drum screens.

- *Barrier nets*
  Under the proper hydraulic conditions, e.g., low water velocities less than 0.3 meters per second, and light debris loads, barrier nets have been shown to be effective at blocking fish passage into water intakes. (EPRI 2002) However, they are expected to be less effective in blocking fish passage at many hydroelectric projects in the Pacific Northwest due to the higher water velocities and debris loads commonly found at those projects. The Corps installed, evaluated and discarded barrier nets to help guide fish in the forebays at both Lower Granite Dam on the Snake River and at the Bonneville Second Powerhouse on the Columbia River, which are run-of-river hydroelectric projects. A thorough examination of site-specific environmental and operational conditions is recommended prior to installing barrier nets.

- *Wedge wire screens*
  Wedge wire screens have the potential to reduce both fish entrainment and impingement at water intakes and hydropower plants. EPRI (2002) states that, to accomplish those objectives the following conditions must exist: a) a sufficiently small screen slot size to physically block passage of the smallest life stage to be

protected (e.g., salmon fry); b) low water velocity through the slot; and c) relatively high ambient current velocity cross-flow to divert organisms around and away from the screen, as well as to provide continuous flushing of the screen.

While these screens have been biologically effective in preventing entrainment and impingement of juvenile fish, the clogging potential and biogrowth on these screens are major concerns. Thus, consideration of wedge wire screens with small slot dimensions for use at hydropower projects should include in situ prototype scale studies to determine both biological effectiveness and the ability to control clogging and debris fouling in a manner that does not impact project operations.

- *Submerged traveling screens*
  For submerged traveling screens to act as a fish barrier while not resulting in impingement depends on a number of site-specific factors including fish size, flow velocity, location of the screens, and the presence of escape routes. Traveling screens, as barrier devices, are not typically used at hydroelectric projects due to their high cost and their inability to protect early life stages of salmonids or organisms that have low swimming ability, such as juvenile Pacific lamprey. (EPRI 2002)

- *Rotary drum screens*
  Rotating drum screens are generally used for fish passage at tributary passage sites and at large irrigation diversions. However, since all screens tend to collect debris, a washing or cleaning mechanism must be provided. Submersible traveling screens and drum screens use a revolving backwash approach to clean off debris. Screens can also be cleaned of debris by using sprays located behind the upstream face of the screen. (Corps of Engineers Fisheries Handbook 1991

All screening devices face common problems, including debris. Screens are subject to damage by heavy floating objects (e.g., logs, sticks and vegetation) moving downstream and must be protected with upstream trash racks or guards to collect debris loads. They can be affected by bed load movement and so must be capable of passing sands and gravels. They need to be protected against icing, where such conditions occur. They require a head differential sufficient to pass water through the wire or mesh, while the screen openings must be small enough to prevent passage of the smallest juvenile fish expected to be diverted. (Corps of Engineers Fisheries Handbook 1991)

Fish Collection Systems
Fish collection systems either actively or passively collect fish for transport to a safe downstream location or to a downstream bypass system. Such systems include surface collectors, spill, fish pumps and other bypasses.

- *Rocky Reach Dam Fish Collection and Bypass System*
  The Rocky Reach Hydroelectric Project on the mainstem Columbia River is an example of an innovative juvenile fish collection and bypass system that also

uses pumps to help move juvenile salmon and steelhead quickly and safely past the dam. The project is owned and operated by Chelan County Public Utility District (Chelan PUD).

The Rocky Reach bypass system includes two main parts. The first is a collector system consisting of two channels, 22 feet wide, 60 feet deep, and 120 feet long in the forebay of the dam. The channel walls are made of fine, non-abrasive, stainless steel screen. Along the outside of the channels, 29 large submerged pumps are operated to create a strong current to help attract juvenile salmon and steelhead into the collector channels in the dam's forebay. This unique surface bypass and collection system uses the young fish's natural instinct to migrate downriver near the surface, following the water flow. This differs from conventional angled turbine intake screens, which require fish to dive deeply into the turbine intakes before they are intercepted by the screens. (Chelan PUD website 2016)

Figure 3. Rocky Reach Dam surface collector and bypass system. Photos courtesy of Chelan County PUD.

Once juvenile fish are in the collector, water moves them into the second part of the system -- a steel tube which is 9 feet in diameter for most of its length. The tube passes through the dam and extends a total of 4,600 feet along the downstream side of the powerhouse, across the face of the spillway and then about one-third mile down the east side of the Columbia River before the fish are returned to the main current of the river. The entire trip takes the fish about six to eight minutes. (Chelan PUD 2016)

After many years of prototype testing, the permanent bypass system was installed at Rocky Reach Dam in seven months between fall 2002 and the beginning of the 2003 downstream migration of juvenile salmon in April at a cost of $107 million ($138 million in 2015 dollars). Chelan PUD has conducted nine additional years of project passage and survival studies following permanent construction, confirming that the collection efficiency and survival of juvenile fish using this bypass system is very high. (Chelan PUD website 2016)

- *Spillway Weirs*

As noted above, most juvenile salmon and steelhead in the Columbia and Snake rivers tend to stay in the upper 10 to 20 feet of the water column as they migrate downstream to the ocean. Juvenile fish passage routes at the Corps of Engineers' lower Columbia and Snake river dams, because of the dams' configurations, cause the juvenile fish to dive to depths of 50 to 60 feet to find the passage routes. Over the last 15 years engineers and biologists have been implementing new technologies to provide more surface-oriented, and less stressful, passage routes for juvenile fish. Examples of surface-oriented passage routes are the installation of overflow spillway weirs and the Bonneville Dam Second Powerhouse Corner Collector. In terms of the proportion of fish passed to the proportion to total water discharged over a spillway weir, surface passage is considered a very efficient and effective route.

A spillway weir was installed at Lower Granite Dam on the lower Snake River in 2001. The weir allows juvenile salmon and steelhead to pass the dam near the water surface under lower velocities and lower pressures, providing a more efficient and less stressful dam passage route. The design of the spillway weir is different from existing spillways in that spillway gates open 50 feet below the water surface at the face of the dam and pass juvenile fish under high pressure and high velocities. The weir passes juvenile salmon and steelhead over a raised spillway crest, similar to a waterslide. Juvenile fish are safely passed over the weir more efficiently than with conventional spill, while also reducing migration delays at the dam. (Corps 2004)

The Corps has also installed spillway weirs at Ice Harbor (in 2005), Little Goose (2009), Lower Monumental (2008), McNary (2007) and John Day (2008) dams. These spillway weirs have the potential to provide not only fish benefits but also power savings to the region, since the amount of water spilled to pass similar numbers of fish is less. Biological testing has indicated that fish pass over the weirs much more efficiently than under conventional spillway gates, and can be up to 4 or 5 times more effective in fish passage per unit of flow than existing spill gates. (BPA 2013) However, some training spill at adjacent spillway bays is needed to help attract juvenile fish to a spillway weir.

- *Bonneville Dam Corner Collector*
  Another example of a unique surface collector system is at the Bonneville Dam Second Powerhouse on the Columbia River. There, a corner collector system was installed by the Corps of Engineers in 2004 to work in conjunction with the existing second powerhouse screened juvenile bypass system. The corner collector bypass facility includes a 2,800-foot long transportation channel, a 500-foot long outfall channel, a plunge pool, and modification of the ice and trash chute to ensure safe fish passage. The bypass flume begins at the southeastern corner of the powerhouse, where a gate is removed to allow about 5,000 cubic feet per second of water to spill into a chute carrying fish downstream. The fish

re-enter the river just beyond Cascades Island, over one-half mile downstream. A plunge pool was excavated into the river bottom to permit fish to re-enter the river and avoid injuries that might occur at lower river levels. (Corps 2004)

- *Surface Collectors*
  To take advantage of the near-surface orientation of downstream migrating salmonids, floating surface collector systems are increasingly being implemented to provide juvenile fish passage at hydroelectric projects with large storage reservoirs in the Pacific Northwest. Surface collectors have been installed in strategic locations in the forebays of a hydropower project where juvenile fish have been known to congregate, or where guide nets help guide the fish into the collection system. Typically surface collection systems use angled or inclined bar screens to collect juvenile fish, usually after considerable dewatering, into a holding area, where they have access to a bypass channel or are transported by truck to a safe release point downstream of the project.

  Surface collectors are designed and constructed to fit the unique characteristics at each project location; as each new facility is built, other engineers and biologists interested in juvenile fish passage can learn from the design, construction, strengths and weaknesses of each newly constructed facility and apply what was learned to their specific studies and site location, if applicable. Some collectors float in the forebay separate of the dam (such as both juvenile surface collectors at Baker), some are physically attached to the dam (such as the juvenile collector at Pelton Round Butte), some capture smolts at the head of the reservoir (such as the passive juvenile collector at the head of Shasta Reservoir), or a surface collector(s) could be used in a tributary(-ies) upstream of the reservoir.

  Some of the first attempts at juvenile fish collectors were referred to as "fish gulpers" and were tested at Brownlee Dam in Idaho in the 1950s and 1960s and used at Baker Dam in Washington starting in the late 1950s. Brownlee's attempt was considered unsuccessful while the gulper at Baker was considered the first successful floating collection system in the world at the time (PSE 2008). These gulpers were essentially smaller versions of the surface collectors used currently; they were powered by pumps that would create an attraction flow for smolts to enter a relatively small opening into the collector(14'x14' at Brownlee). In the early 2000s, the gulper at Baker was updated to the floating surface collector (FSC) style used today. An FSC is a fairly standard juvenile fish collection system and generally contains:

  - Guide nets that are anchored to shore to direct the fish toward the collector;
  - A net transition structure (NTS) that is basically a large funnel with attraction flow created by the pumps in the FSC to attract the fish into the collector;

- A screened channel to safely separate fish from water;
- A collection and handling facility where fish are sorted by species for sampling and placed in a holding tank;
- A system to move the holding tank to a truck or a bypass channel that will carry the juveniles to their release location downstream of the dam.

As stated previously, each collection facility varies according to the location's individual site-specific needs and conditions. For example, the FSC in Swift Reservoir has an access trestle that allows for truck access to the mooring tower. The mooring tower anchors the FSC but also acts as the transfer structure to move the fish from the collection container to the truck. Whereas at Baker Dam, the large, water-filled hoppers are connected to a mechanical pulley system that transfers the container of fish to a parked truck on the dam. The physical structures of the Swift and Baker systems are different to accommodate for each site's specific specifications but the concepts are the same. Additionally, both Swift and Baker placed the FSCs in the forebay near the upstream dam face, but not directly attached to it.

Guide nets are often used with surface collectors to prevent entrainment into the powerhouse and to encourage the fish to move toward the entrance of the collector. These are usually made of a strong Dyneema material (an ultra-high-molecular-weight polyethylene) with varying grades of mesh with increasing mesh size closer to the reservoir bottom. The fully exclusionary guide nets at the Baker Dam passage facilities were designed for pool fluctuations of 50-70 feet, have intermediate floats to prevent snagging during low water periods and subsequent submergence during high pool conditions, are anchored to each shore, and have pneumatic surface floats that can be submerged to during flood conditions and to accommodate operational needs. A log boom upstream of the guide net and fish collector excludes debris and prevents public access. The guide nets at Swift Dam are similar in design and use as those at Baker, and a study just completed at Pelton Round Butte showed the potential benefits of installing guide nets at that surface collector (Hill pers. comm.). Debris management and its effects on fish passage performance can be a challenge at high-head dam fish passage facilities. Labor and operation and maintenance costs for debris management can be substantial and is a factor to evaluate when considering and selecting a fish passage technology at a particular site.

Two different types of surface collectors are being studied at Shasta Dam in California; a head-of-reservoir collector and an instream collector. The head-of-reservoir collector will be located at the mouth of the McCloud River and will be passive in that no electricity will be used for attraction flows. A temperature curtain will be needed to keep the warm summer reservoir temperatures from influencing fish attraction[15], and will be paired with a guide net. The passive collector will float at the surface attached to the only open space in the guide net that spans the less than 300-foot width of the river at that location, to allow fish only one option of where to go once they enter the reservoir – into the collector.

Another innovative fish collection system is that at North Fork Dam on the Clackamas River in Oregon. Juveniles collected at the floating surface collector at North Fork immediately enter a fish transport pipeline which passes the fish through the dam and into a bypass pipeline where the fish exit below the downstream dam. This system allows for minimal handling and quicker passage.

For more information about the design and operation of each of these surface collectors described above, including the design of various types of surface collectors planned for installation at several other hydropower projects in the Northwest, see the specific case studies. Due to the large capital investment necessary to design and install such complex fish passage systems, a thorough examination of site-specific biological, environmental, hydraulic, and operational conditions is recommended prior to installing surface collectors.

Toward that end, Johnson and others (2008) conducted a study for the Corps of Engineers to evaluate fish behavioral responses to ambient flow fields to help support general design guidelines related to which hydraulic conditions will readily pass juvenile salmon at surface flow outlets, or surface-oriented collectors. This study integrated field data during 2007 on smolt movement and behavior with hydrodynamic conditions at surface flow outlets at McNary and The Dalles dams (e.g., at a spillway weir and at the sluiceway, respectively) to address the following two questions: 1) Which hydraulic variables are most strongly associated with fish behavioral responses?; and 2) Are there hydraulic threshold levels that could be used to support surface-oriented collector design guidelines? (Johnson et al. 2008)

Based on the results of this study, Johnson and others (2008) identified several management implications, including:

- The schooling behavior of fish was found to be dynamic and prevalent, which implies that a surface collector entrance area must be large enough to accommodate schools of juvenile fish;
- Juvenile fish behavior was dependent on distance from the entrance of the surface flow outlet, supporting the notion that surface flow nets need to be large expansive enough spatially to attract smolts despite competing flow fields;

[15] Water temperatures in reservoirs can have a strong influence on season and diel vertical distribution of juvenile salmonids, and therefore an important impact on the effectiveness of in-reservoir surface collectors.

- Surface collector designs cannot rely only on juvenile fish following bulk flow because passive fish behavior was observed less than 5 percent of the time in the surface flow nets that were studied;
- Since active swimming against the flow was the most common fish behavioral response, surface collector performance evaluations should include a metric for fish swimming effort in surface flow fields; and
- Fish effort variables were correlated with water velocity, acceleration and strain, so there may be some potential for this type of study approach of merging fish and flow field data leading to surface collector design guidelines in the future as more studies build the fish/flow datasets.

The conclusion of this study was that continuing efforts to analyze merged fish and flow field data from a diversity of surface collector sites over multiple years would strengthen the relationships between smolt responses and hydrodynamic conditions. Accordingly, if this is done over time at multiple surface collector sites, it could lead to surface-oriented collector design guidelines in the future as the fish/flow dataset is further populated. (Johnson et al. 2008)

Behavioral Guidance Devices

Guidance can be defined as a means of directing fish from one location to another, whether by natural or behavioral (artificial) means, or both. Fish tend to respond more readily when behavioral guidance works in concert with natural guidance. When offered a choice of stimuli causing guidance or movement, whether natural or artificial, fish may select a single stimulus which may be dominant at that place and time. Factors affecting natural guidance of fish include light and shadow (or absence of light), water velocity, channel shapes, depth, sound, odor, and temperature, among others. Some of these stimuli may also be used for behavioral guidance of fish. (Corps of Engineers Fisheries Handbook 1991)

Artificial stimuli have been used and tested to affect fish behavior and direct their movement to safe areas or to bypass channels at hydroelectric projects. The following is a brief description of various behavioral stimuli that have been used or tested to help guide or improve fish protection and passage, with particular attention to studies involving salmonids.

- *Light*
  Sources of artificial light are readily available and cheaply produced. Most fish are visually sensitive and many move up and down in the water column during the day and depending on light[16]. Turbid or discolored water, which diffuses and absorbs light, can affect fish movement by obscuring targets and other visual cues. Light, when used artificially as a behavioral guidance stimulus, repels fish at higher intensities and attracts them at lower intensities. (Corps of Engineers Fisheries Handbook 1991)

[16] Diel vertical migration behavior.

Strobe or flashing light has been evaluated as a fish protection device by repelling or guiding fish away from water intakes or toward bypasses for transport to a safe release location. This concept is supported by the results of many laboratory and cage test studies demonstrating a strong avoidance behavior by several fish species, including salmonids, to strobe light. However, taking the strobe light deterrence concept to successful field applications has proven to be difficult. Field studies have shown some species and life stages can be repelled by strobe light, but results are difficult to interpret due to confounding factors associated with environmental conditions, project design and operating parameters. However, used as a secondary guidance system, strobe lights have potential to incrementally increase fish protection effectiveness. (EPRI 2002)

There are several sites in the Pacific Northwest where strobe lights have been evaluated. At the Chittenden Locks in Seattle, Washington, strobe lights have been shown to be effective in repelling juvenile salmon from a filling culvert. Several years of testing at Dworshak Dam on the North Fork Clearwater River in west-central Idaho demonstrated that kokanee salmon could be repelled by the use of underwater strobe lights up to a distance of 120 meters from the powerhouse. While strobe lights were installed and tested at Dworshak Dam during spill events to evaluate reducing kokanee entrainment, the lights are no longer being used. More research is needed to expand a growing database on the various species, life stages and environmental conditions (e.g., flows, turbidity and diel period) under which strobe lights are found to be the most effective and applicable. (EPRI 2002)

In Grand Coulee reservoir, Simmons and others (2006) conducted studies of the physical and biological factors potentially affecting the resident kokanee population. They found that predation and entrainment into the Francis turbines had a significant impact on the fish population. To address the entrainment loss of kokanee, multiple years of study (e.g., 2002-2005) at the Grand Coulee third powerhouse were conducted to determine if fish would avoid areas illuminated by strobe lights in the forebay. Key results of the 2005 study indicated: 1) both salmonids and walleye appeared to be attracted to the strobe lights; and 2) as in previous years' studies, fish were attracted to the regions illuminated by the strobe lights both at night and during daylight hours. (Simmons et al. 2006) Based on these results, the study recommended that strobe lights should not be used at Grand Coulee Dam to deter fish from entering the third powerhouse. However, the study also identified the potential, pending further investigation, for strobe lights to help guide anadromous juvenile fish to preferred outlets at Grand Coulee. (Simmons et al. 2006)

The use of light, both constant and flashing (e.g., strobe), has shown promise for fish protection and passage. It is known more juvenile salmon pass the large, mainstem Columbia and Snake river dams by sounding to deep passage routes (e.g., spill bays, bypasses and turbines) at night and that the use of surface passage routes is generally higher during daylight hours. However, the relationship, if any, of ambient light levels to surface fish passage rates is not known. With the use of any behavioral guidance device, fish may habituate to the use of continuous or strobe lights over time. Various aspects of fish response to light stimuli remain to be investigated. (Schilt 2007)

- *Sound*
  Similar to light, sound is relatively easy to produce in water. Fishes with inner ears stimulated by sound are called "hearing generalists," which comprise most fish, including salmonids, lamprey and eels. Compared to mammals, most fish have hearing frequency sensitivities that are rather low, i.e., limited to frequencies below a few kilohertz. However, even though fish hearing is rather frequency limited, they hear well and use hearing to adjust to their environments. Very low frequency sound[17] (e.g., infrasound) has been tested on salmonids as a means for eliciting avoidance behavior for fish passage and protection. A wide variety of sounds, including impulse bangs and even recorded predator sounds have been tested on fish, but a robust and effective fish protection system based on audible sound has yet to be developed and used in the Columbia Basin. There may be many reasons for this, including the often very noisy near-dam environment, the difficulty for the fish to distinguish the sound stimulus and its direction in the noise, not fully evaluating the acoustic boundary conditions, or fish habituation to the sound stimulus. (Schilt 2007)

- *Electric Fields*
  The use of electric fields to control fish movement is quite different from the other sensory methods described above for several reasons. First, electric fields serve as a strongly aversive stimulus that can potentially be damaging to the fish. In addition, if fish are located upstream of the field, they can be stunned inadvertently, debilitated by it and drawn deeper into or through whatever passage route they were meant to be excluded from. Typically the electric field is located downstream of the passage route which is to be denied access so the disabled fish will be washed further downstream and out of the field. Other limitations include human and wildlife safety and use only within freshwater environments. For these reasons, Schilt (2007) states that electric barriers have not been a tool used by hydropower project managers or researchers to help guide fish. Primary uses of electric fields to date include stopping or slowing the spread of non-native, invasive fish into areas of native fish abundance.

- *Air Bubble Curtains*
  This type of curtain has generally been ineffective in blocking or diverting fish in a variety of field applications. Air bubble curtains have been evaluated at a number

[17] Infrasound is below the limit or lower sensitivity range of human hearing of 20 Hz.

of sites in the Great Lakes using a number of fish species. All air bubble curtains at these sites have been removed from service. (EPRI 2002) However, one evaluation of air bubble curtains, in combination with a sound device, has demonstrated some promise in diverting Atlantic salmon smolts on the River Frome in the United Kingdom. (Welton et al. 2002)

It is evident from the above examples that many sensory stimuli may be present and affecting fish behavior in various ways at a hydropower facility. However, when all environmental and artificial or behavioral factors work in concert together, the most effective fish guidance occurs. Individual fish or groups of fish may respond more readily to a particular stimulus, which can override other stimuli. For example, a fish's instinct to move from areas of sunlight to shade, or their reluctance to move from their selected migration depth or velocity gradient. There is little evidence that fish learn from a single experience; in a pond environment, with repeated applications, fish will learn to respond to painful stimuli by avoidance and to feeding rewards by attraction. (Corps of Engineers Fisheries Handbook 1991) Schilt (2007) states that little systematic empirical research has been done to decipher the motivational, sensory and behavioral systems of fish with the mechanisms facilitating juvenile fish migration through dam forebays.

Turbine Passage

Downstream passage of juvenile salmonids and lamprey through powerhouse turbines also provides a passage route. A small percentage of juvenile salmonids currently pass most mainstem Columbia and Snake river hydropower dams through Kaplan-type turbine units. The newer, second powerhouse at Rock Island Dam (operated by Chelan County PUD) has horizontal-shaft bulb turbines installed and the Wells Dam powerhouse (operated by Douglas County PUD) is a hydrocombine design. This unique hydrocombine design incorporates the powerhouse, spillway, switchyard and fish facilities into a single unit instead of separate structures. Numerous biological studies have been conducted to estimate the direct and indirect survival of different anadromous fish species passing through various types of turbines. While it is beyond the scope of this paper to review and report on the data of those studies, juvenile fish survival through conventional turbines is generally acknowledged to be much lower than survival through other passage types listed above.

However, a recent collaborative research project has been implemented and funded by the Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE), and hydropower industry partners to complete the remaining engineering necessary to develop a more "fish-friendly" hydropower turbine design, referred to as the Alden turbine. High efficiency, advanced turbine designs, including the minimum gap runners (MGRs) now installed at several Corps hydropower dams on the mainstem Columbia and Snake rivers and the Alden turbine, which has only been tested on a pilot scale, are expected to reduce fish injury and mortality and improve turbine efficiency over conventional turbines.[18] Conventional turbines have between five and eighteen fast-spinning blades, separated by gaps, which can result in rapid pressure changes, low minimum (or negative) pressures, shear forces, blade strike and gaps that can kill or injure fish. However, the Alden turbine has only three blades, no gaps, is bigger and rotates more slowly than a conventional turbine. (EPRI, 2011)

These new and improved turbine designs will continue to be installed in the future or as a retrofit option at dams where existing downstream fish passage mortality associated with conventional turbines is unacceptable to stakeholders. As dam operators continue to design, select and install new, advanced turbines with high confidence in the turbine's biological and mechanical performance, it could be useful to track advancements in turbine design and their ability to provide improved fish passage survival.

Project Operational Changes

Fish use the vestibular system in their ears and their lateral line system[19] to sense the water on their body and their spatial orientation or change in position in the water. Thus both of these systems are important for the fish's orientation in both the gravitational and flow fields, as well as for fish passage at a hydroelectric project. While evidence is growing about juvenile salmonid motivation and preferences for passage in the hydrodynamic environment, it is reasonable to assume there are physical factors which help affect fish distribution and whether they will accept or reject a particular passage route. (Schilt 2007)

Water velocity is one of the key factors affecting fish guidance. Fish can react to changes in velocity of less than 0.1 feet per second. Since swimming ability is a function of fish length, ambient temperature and dissolved oxygen levels, such factors should be measured and the guidance velocities for fish passage routes should be within allowable parameters as described in the National Marine Fisheries Service's fish passage design criteria (2011). Recently, a flow velocity enhancement system (FVES) was developed and tested in 2008 on the Cowlitz River using turbulent flow to help attract migrating juvenile salmon to a bypass entrance.

Hydropower operators may be able to change typical project operations to better accommodate or improve the passage of target fish species and life stages. Studies are needed to understand the run distribution timing and the typical migratory preferences (e.g., vertical and horizontal distribution and diel passage characteristics) of the species of interest as they enter the forebay of a hydropower project. Using that information, project operators may be able to provide spill or even lower reservoir elevations to increase water velocity for fish passage during the time periods when fish are migrating

[18] Pilot testing of the Alden turbine yielded some positive results. For example, the survival rate is expected be greater than 98 percent for fish less than 8 inches long, and at peak efficiency, an Alden turbine should convert about 94 percent of the water's energy into useable electricity. (EPRI, 2011)

[19] The lateral line is a system of sense organs found in aquatic vertebrates. It is used by the fish detect movements, vibration and pressure changes in the surrounding water.

past the project. Both of these operational alternatives are intended to improve fish passage survival and reduce passage delay.

- *Spill for fish passage*
  Another common form of juvenile fish passage used at dams is allowing fish to pass with water that is allowed to spill through the dam's spillway, which requires fish to sound to the depth of the spillway crest (approximately 50 feet). When the spill gates (either curved Tainter gates or flat gates) are raised slightly the water flows underneath them, down the spillway and into a "stilling basin" before continuing downstream through the tailrace. In the stilling basin, the spilled water, containing fish and air, are forced deep underwater where the increased pressure can cause the water to become supersaturated with total dissolved gas (TDG). At mainstem federal dams on the lower Columbia and Snake rivers, spill is provided for juvenile fish passage during the spring and summer migration periods, which is generally from early April through August. In the Columbia River Basin, the use of spill has gone through various legal processes involving the state, federal, and tribal fisheries agencies, as allowing water to pass over a dam rather than through the turbines can be controversial given the loss of power generation and water quality concerns.[20] TDG levels continue to be a point of contention, but under the existing NOAA Fisheries Biological Opinion and as a result of the 2005 Federal Court Opinion *National Wildlife Federation v. National Marine Fisheries Service* lawsuit, spill operations in increasing volumes can occur until either the TDG in the tailrace of the project measures 120 percent, or 115 percent saturation at the forebay of the next hydroproject downstream. (Fish Passage Center 2012)

- *Reservoir Drawdown*
  Various levels of reservoir drawdown have been implemented in the Columbia River basin to improve fish passage or reduce travel time of juvenile fish. For example, at the four federal Snake river dams and at John Day Dam on the Columbia River, which are all run-of-river hydropower projects, reservoirs are lowered several feet to near minimum operating pool (MOP) levels or to minimum irrigation pool level (MIP), respectively, each year during the spring and summer fish migrations.

  On the other hand, a unique operational change has been implemented by the Corps of Engineers since 2011 at the 180-foot high and 5,100-foot long Fall Creek Dam in the Willamette Valley for juvenile fish passage. The reservoir is drawn down to near run-of-river level each year for several weeks during November to February period to allow ESA-listed juvenile spring Chinook salmon to volitionally pass downstream through the dam's diversion tunnel. This is 45-50 feet lower than the dam's normal minimum operating pool level for flood risk

[20] That is, allowing juvenile fish to pass a dam in large volumes of spill can create elevated levels of total dissolved gas and possibly gas bubble trauma in fish which, at high levels, can cause fish injury or even death.

management. Studies have been done to understand food web impacts due to the deep drawdown, and further engineering and technical analysis is proposed while the drawdown operation continues. Given that Fall Creek Dam does not produce power, there is no cost associated with implementing the new drawdown operation. (COP 2015) See the Fall Creek case study for more information.

Figure 4. Fall Creek deep drawdown operation (Photo courtesy of Corps of Engineers)

Case Studies

In order to better understand each location, staff compiled standardized information into case studies. Each case study contains summarized information obtained from design documents, annual reports, and personal communication with technical staff working on the project. Staff organized the information to provide a quick snapshot of the project site. Provided here is the template for each case study and the purpose for each piece of information collected.

Location of Study:
*River system; State; NPCC Subbasin; whether the site is in or out of the Columbia River Basin.

Site specifications:
*Information such as dam height, length, megawatt capacity, and reservoir storage is captured for quick reference.

Species of Interest:
*The fish species that use the passage facilities are provided. This information is important when considering fish behavior and effects.

Passage Type:
*Sites evaluated by staff utilized various passage techniques mostly in conjunction with a trap and haul system: spill, fish elevators, fish ladders, drawdown operations, and bypass systems. The uses of the passage facilities are summarized to include design, implementation, and current use of the fish passage facilities.

Timeline:
*The length of time and dates of work including fish passage studies, planning and implementation of fish passage, and any O&M associated once facilities are running.

Additional Studies Needed &/or Underway:
*Many project sites required additional studies once the initial research was completed and/or after the facility was in use. The type of passage structure implemented is important with regards to specifying future research needs.

Costs:
*Staff compiled direct costs for each facility. These costs are provided as reported by staff of, or reports from, the passage sites, along with the amount converted to current dollars (2015).

Site Results:
*Results can be difficult to quantify. Staff characterized what criteria are used for each project to measure success, and what level(s) the site operators are currently observing.

Effectiveness of Upstream Fish Passage:

*Using the project's criteria of success this section illustrates the effectiveness of adult fish passage. As possible, staff lays out what is the best possible outcome for each specific project.

Effectiveness of Downstream Fish Passage:

*Using the project's criteria of success this section illustrates the effectiveness of juvenile fish passage. As possible, staff lays out what is the best possible outcome for each specific project.

Summary of results:

*A brief summary of the performance standard of facilities is provided with a summation of whether these standards are being met.

Strengths and Weaknesses:

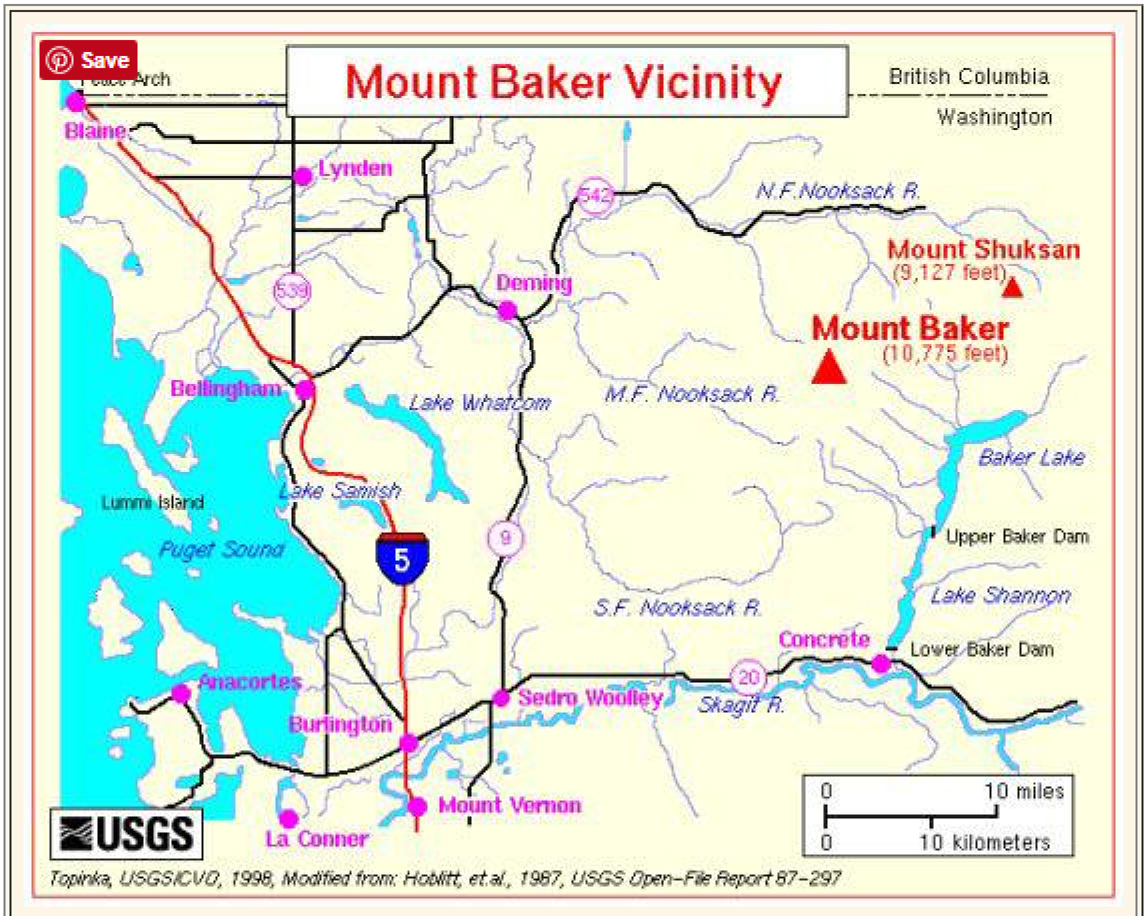
*Staff characterizes what are seen as the strengths and weaknesses of each passage project – where more work is needed and where the facility appears to have met its standards.

Other Potential Factors to Consider:

*Information provided here pertains to biological, environmental, and social impacts and effects due to fish passage.

Location of Study: Baker River Hydroelectric Project

Baker River; Skagit Basin; Northern Washington; out of the Columbia River Basin



This USGS map is modified from: Hoblitt, et.al., 1987, USGS Open-File Report 87-297, and shows the location of Mount Baker compared to the entire Whatcom and Skagit counties.

Figure 5. Map depicting the location of the Baker River Hydroelectric Project

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Site specifications:

Upper Baker Dam:

- 64.3 miles from the mouth of the Skagit River
- 312 feet in height
- 1,200 feet in length
- 98 megawatt production capacity

Baker Lake (Reservoir):

- 9 miles long
- 274,221 acre feet of storage
- Highest inflows in October – January

- 285 feet of hydraulic head
- 727.77 feet at full pool
- 677.77 feet at minimum pool

Lower Baker:

- 57.3 miles from the mouth of the Skagit River
- 285 feet in height
- 550 feet in length
- 105 megawatt production capacity

Lake Shannon (Reservoir):

- 8 miles long
- 146,279 acre feet of storage
- Highest inflows in October – January
- 263 feet of hydraulic head
- 442.35 feet at full pool
- 373.75 feet at minimum pool

Species of Interest:

Primarily sockeye and coho; also Chinook, steelhead, native char, and sea-run cutthroat trout

Passage Type:

Juvenile downstream passage: trap and haul with Floating Surface Collector (FSC) and guide nets
Adult upstream passage: trap and haul with adult capture facility and elevator

The Baker River, a major tributary to the Skagit River in Western Washington, was impounded by the construction of Lower Baker Dam in 1925, and again by Upper Baker Dam in 1959. The Skagit River is the only large river system in Washington that contains healthy populations of all five native salmon species and two species of trout. The Baker River Hydroelectric Project (Baker Project) is owned and operated by Puget Sound Energy (PSE) and is the private utility's largest hydropower operation with a total capacity of 215-megawatts of hydropower combined between the two dams. The Baker Project facilities are composed of both Lower Baker and Upper Baker dams and includes a sockeye hatchery at Upper Baker Dam operated by the Washington Department of Fish and Wildlife. Lower Baker creates Lake Shannon reservoir, and Upper Baker creates Baker Lake. (PSE 2014)

Adult fish returning to spawn in the Baker River Basin were captured and transported upstream of the Lower Baker Dam beginning with its construction in 1925. Downstream passage of outmigrating juveniles was not provided until the initiation of fish passage efforts in 1958 with a fish collection barge called the "gulper." A gulper was installed in the Lower Baker Dam forebay, with a similar system installed at the Upper Baker site in 1960, to collect juvenile salmon migrating downstream. Aside from a similar system attempted at Brownlee Dam a few years earlier, the Baker Project fish gulpers were the first of their kind and were found to be successful. The gulper in Lake Shannon at Lower Baker created 90-cfs of attraction flow and had a bypass pipeline to release the juveniles into the tailrace below the dam. The gulper in Baker Lake at Upper Baker created 162-cfs of attraction flow, and also used a bypass pipeline to allow the fish to be released into the tailrace below. (Verretto 2014)

After over 25 years of juvenile collection with the gulpers and successful adult return numbers reaching close to 27,000 coho and 11,000 sockeye in one year (1962 and 1973, respectively), adult return rates plummeted to just 99 total fish in 1985. At this time the Baker River Coordinating Committee (BRCC)[21] was formed to investigate the cause of the decline and to manage the recovery effort. Under the guidance of the BRCC, various studies on fish migration were conducted, comparisons were done of the pipeline passage technique with a trap and haul method, net pens and smolt traps were added, a new spawning beach at the hatchery was created, guide nets were deemed important for both reservoir's collection systems, and the collection location was moved for attraction benefits. (Verretto 2014)

Juvenile fish passage – floating surface collector

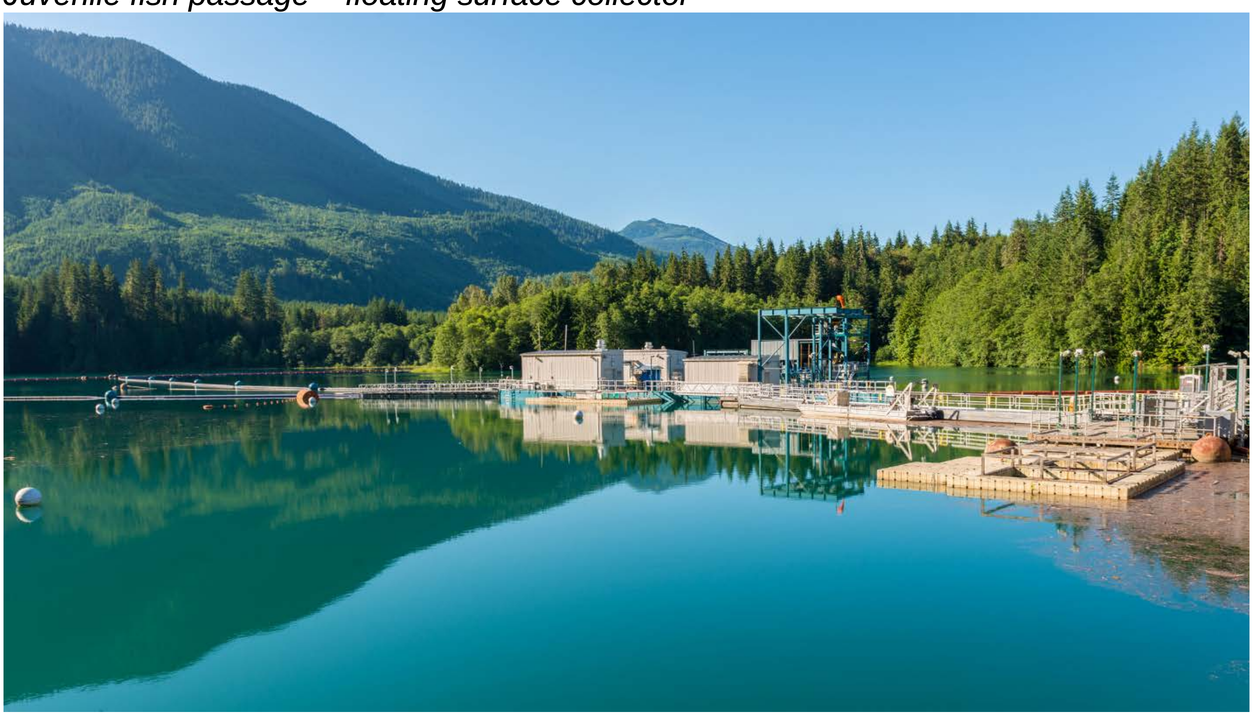


Figure 6. The floating surface collector at Upper Baker Dam. (Photo courtesy of Tony Grover)

[21] The BRCC was a collaborative effort and was composed of representatives of state, federal, and tribal resource management representatives.

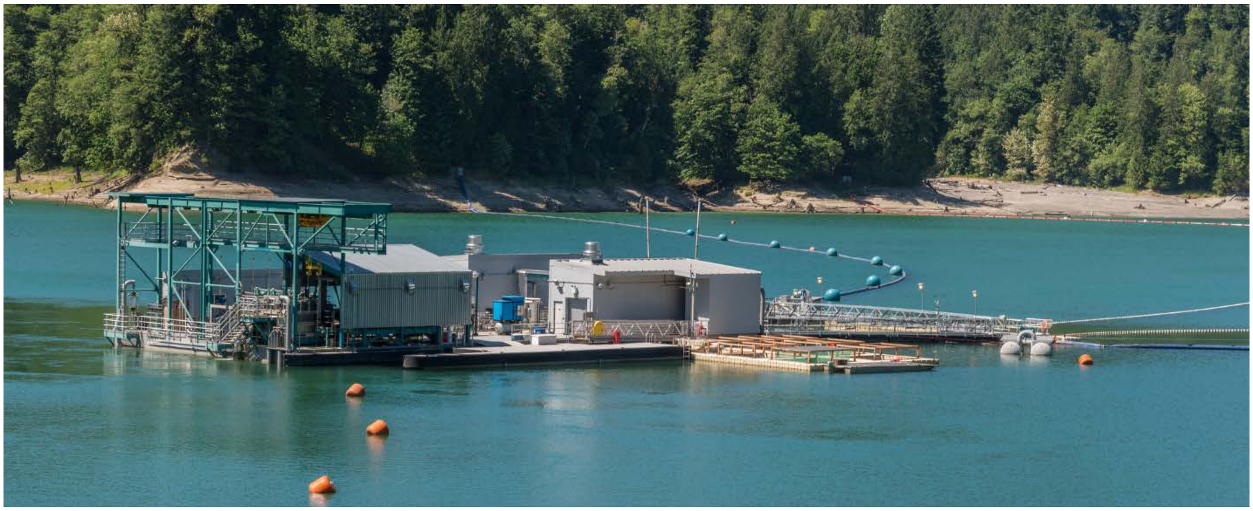


Figure 7. The floating surface collector at Lower Baker Dam. (Photo courtesy of Tony Grover)

The 2006 relicensing settlement agreement and subsequent FERC license of 2008 for the Baker Project called for improved upstream and downstream fish passage facilities. The gulpers were decommissioned and in their place floating surface collectors (FSC) were installed in the forebays of both Upper and Lower Baker dams in 2008 and 2013, respectively. The FSC was the first of its kind and received national recognition[22] once in operation. The FSC is the central feature in a juvenile fish passage facility made up of many multi-faceted parts which are laid out here in the order of moving from upstream to downstream:

- Log boom:
    - Used for exclusion of floating debris and to prevent public access to the forebay facilities, the log boom floats at the surface upstream of the guide nets
- Guide nets:
    - Prevents the juveniles from entering the turbines and instead assists in guiding them to the Net Transition Structure and collector
    - The guide nets span 5-acres of surface area, stretching shore-to-shore and surface-to-lakebed (up to 300 feet deep)
    - They are anchored on each shore and connected to the net transition structure
    - Constructed of Dyneema mesh, which is a high-strength synthetic fiber
    - The mesh size is 3/32-inch at the surface and 1/4-inch from 30' deep to the lakebed
    - "Floats" (pneumatic hose and high-density polyethylene booms) at the surface allow the net to adjust with reservoir fluctuations of up to 70 feet
- The Net Transition Structure (NTS):

[22] In 2009, the National Hydropower Association gave PSE the Outstanding Stewards of America's Waters Awards for the FSC. The Lower Baker FSC won the MWH America Gold in 2014.

    - Attached to both the downstream-end of the guide nets and the upstream end of the FSC, the NTS acts as a large funnel, with a narrowing channel and an inclined base, to direct the fish into the collector
    - Opening of the NTS is 50-feet deep and 50-feet wide to capture fish efficiently at the migration depths of most migrating fish
    - Helps control the acceleration and velocity leading up the FSC
    - Is detachable; it is removed from the FSC in the off season to allow FSC deballasting
- Floating Surface Collector (FSC):
    - It is 130-feet by 60-feet and weighs 1,000 tons
    - Provides 500 cfs of attraction flow, produced by electric pumps, that flows through a channel created by conventional vee-screens (See Figure 8)
    - Installed pumps allow an increase of entrance flow to 1,000 cfs to permit testing its impact on fish collection performance
    - Flotation tanks allow for buoyancy control, which is especially useful in the off season when the facility is raised and exposed to allow for maintenance
    - A fish trap allows for sampling, handling and transporting of the fish
    - After sampling, fish are diverted to a water-filled transport tank (See Figure 9)
    - The tank is then transferred to a truck for transport and eventual release into the Skagit River downstream of the Lower Baker Dam (see Figure 10)
- Transport and access facilities:
    - A pier, mooring docks for transport barges, and crane at Lower Baker; a cantilevered deck, stairway tower and floating walkway at Upper Baker

(PSE 2011; PSE 2014)

Figure 8. Attraction flow through the concentration flow structure guides the juvenile fish into the collector at Upper Baker. (Photo courtesy of Tony Grover)

Figure 9. The water-filled transport tank for juvenile salmon. (Photo courtesy of Tony Grover)


Figure 10. The juvenile salmon transport barge used at Upper Baker to transfer the tank of collected juveniles from the collection facility to a transportation truck via a mechanical pulley system. (Photo courtesy of Tony Grover)

Adult fish trap

The Baker Project has one upstream trap for returning adults, which is located downstream of Lower Baker Dam. In 2010, PSE installed a new trap that includes:

- A 60-foot tall and seven feet in diameter fish lock;
- A fish sorting flume;
- A control system for sorting fish by species to be placed into separate holding pools;
- A sampling area where an electronic data-management system collects a wide variety of biological information from the captured adults. (PSE 2014)

Once fish enter the fishway of the trap, they are crowded into the fish lock. The water level in the lock is raised from the level of the trap to the sorting facility. Once raised, the adult fish then exit the lock and enter a flume that passes them to the sorting area. They are then crowded into a container that is loaded onto a truck and hauled up above the dams. The adult facility can process about 3,000 adults per day. PSE can haul up to 300 adult sockeye at a time, depending on the size of the truck being used, to the relocation site about an hour drive above the capture facility and above Upper Baker Dam. (PSE 2014)

Figure 11. The fish elevator (gray tower on the right) at the adult trap downstream of Lower Baker Dam. (Photo courtesy of Tony Grover)

PSE set the following performance criteria for fish passage on the Baker River:

- Collection: 95 percent
- Survival within the facilities: 98 percent
- Reservoir passage: 80 percent
- Overall survival: 75 percent (Verretto 2014)

Timeline:

1925: Lower Baker Dam is built, blocking anadromous fish passage

1957: Construction of Upper Baker begins and artificial spawning beds are constructed at the upper end of Baker Lake to mitigate for loss of natural sockeye spawning beaches

1958: Pursuit of fish passage began with the installation of the first gulper at Lower Baker Dam

1959: Upper Baker Dam is built

1960: Installation of gulper at Upper Baker Dam

1985: Adult returns drop dramatically (only 99 adults counted)

1986: A fish hatchery[23] on Baker Lake is built and artificial enhancement begins

2008: FERC license calls for enhanced fish passage facilities at the Baker Project (adopting articles contained within the 2006 Settlement Agreement)

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[23] Run by the Washington Department of Fish and Wildlife, this hatchery produces both sockeye and coho but primarily sockeye.

2008: FSC is installed in the Upper Baker forebay

2010: New and improved adult capture facility is installed in Lower Baker tailrace and newly refurbished sockeye spawning beaches are installed at the hatchery facility.

2013: FSC is installed in the Lower Baker forebay

2015: Highest returns to date (terminal run of 50,844 adult sockeye)

Additional Studies Needed and/or Underway:

Each year PSE produces an annual report under the terms of its FERC license, and in these reports are details of monitoring and evaluation that is conducted to ensure performance evaluation of the facilities. Additionally, an annual long-term monitoring program to inform collection efficiency uses PIT-tagged juvenile sockeye and coho releases to determine release-recapture ratios for the Upper Baker FSC. This same work will be initiated at Lower Baker in 2016. (PSE 2015)

Costs:[24] [25]

Fish passage design:
- Downstream engineering design[26]: $10-12 million *($11-13.2 million in 2015 dollars)*
- Upstream engineering design: $3 million *($3.3 million in 2015 dollars)*

Original construction estimate:
- Downstream: $13-18 million *($14.3-19.8 million in 2015 dollars)*
- Upstream: $11 million *($12.1 million in 2015 dollars)*

Actual capital construction costs (including design development, overhead costs, guide nets, transition structure, land purchases, and moorage):[27]
- Downstream:
  - Upper Baker: $53 million *($53.9 million in 2015 dollars)*
  - Lower Baker: $53 million *($53.9 million in 2015 dollars)*
- Upstream: $20 million *(21.7 million in 2015 dollars)*

Operation and Maintenance:[28]
- $500-000 – $600,000 for first two years *($508,000-610,500 in 2015 dollars)*

[24] The costs provided do not include the costs of the hatchery facilities; however, the PSE biologists say that supplementation, acclimation ponds, and transportation is needed for any reintroduction effort.

[25] There are forgone revenues associated with Baker but the engineers strove to limit impacts on power operation. Since fish passage was installed Upper Baker Dam, it operates to a strict control table which has caused Lower Baker Dam to essentially operate as a re-regulation dam.

[26] Biological and other study costs are not included in the engineering design cost.

[27] Note that the actual construction cost was double the original estimate. Construction did not go as planned due to the complexity of the facilities and general lack of knowledge and experience in fish passage at high-head dams at the time. PSE biologists at the project suggest doubling the original estimate for any new surface collection facility to understand the real end cost.

[28] Operational costs change each year and include staffing for power production, maintenance and operation, periodic replacement of materials such as the guidance net, and hydraulic evaluation. Additional biological studies are at an extra cost.

Scale down to $250,000 for the long term *($254,000 in 2015 dollars)* (Verretto pers. comm.)

Site Results:

Since installing the two floating surface collectors, PSE has successfully captured and transported record numbers of juvenile sockeye and coho[29] and has seen smolt-to-adult rates that are well above average. PSE biologists for the Baker Project measure success of the project by the percent of fish recovered, as well as the uninterrupted restorations and increase in juvenile and adult fish numbers. It is important to note that juveniles entering the collector at Upper Baker can be hatchery releases from the Baker Project's associated sockeye hatchery, from the hatchery's spawning beds, or from natural production in the tributaries of Baker Lake.

Effectiveness of Upstream Fish Passage:

Four of the five highest sockeye returns to the adult-salmon trap at Lower Baker have occurred since the new trap began operating in 2010. In 2015 the trap collected 32,735 sockeye with an estimated 50,844 total sockeye returns to the entire Skagit/Baker River system, against a long-term historic average of about 3,000 fish.

Effectiveness of Downstream Fish Passage:

Upgrading the facilities from the gulpers to the FSCs and using the improved guide nets resulted in juvenile runs of outmigrants over two orders of magnitude higher than the numbers observed in the late 1980s when 8,838 juveniles were recorded in 1987. A record number of salmon smolt outmigrants were collected and transported in the Lower Baker FSC's second year of operation with over one million fish outmigrating in 2014 in total (419,518 from the Lower Baker FSC and 617,483 from the Upper Baker FSC). The juvenile fish passage efficiency goal set by PSE is 95 percent collection. Fish passage efficiency ranges from 80-95 percent depending on the year.

Summary of Results:

The Baker Project has become well-known around the world as a successful case study for fish passage at a high-head dam. While a precise number of adult returns was not established (or provided publicly) as a goal, PSE views the results as successful given the substantial increase in adult returns since the FSCs began operation. Since completion of the FSCs, PSE has won awards for their work restoring anadromous fish runs in the Baker River: the National Hydropower Association awarded the utility with the Top Environmental Award

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[29] Historically, coho had a larger run than sockeye. With the inundation of coho rearing habitat (i.e., tributaries, side channels, beaver ponds, wetlands, and other riverine areas) by the two reservoirs, Shannon and Baker, the population balance was switched due to increased sockeye habitat. Management now constitutes tacit recognition of that shift.

two years in a row in 2008 and 2009, and for Recreational, Environmental, and Historical Enhancement in 2011. It is important to note that while the Baker Project has many successful attributes important to consider when planning new downstream fish passage at similar projects, continued artificial propagation likely has contributed to the high numbers of adult returns. Continued artificial fish propagation may be indefinitely required to sustain the fish populations in the Baker River.

Other Potential Factors to Consider:

- Hatchery management practices may be attributed to higher numbers of smolt outmigrants.
- The distance that the fish have to travel from the ocean to the dams is relatively short (57.3 miles to Lower Baker and 64.3 miles to Upper Baker), and the fish do not have to pass any other dams in order to reach Lower Baker, unlike the route fish take in the Columbia River.

Location of Study: Chief Joseph

Columbia River; Columbia Upper Subbasin; Central Washington; in the Columbia River Basin

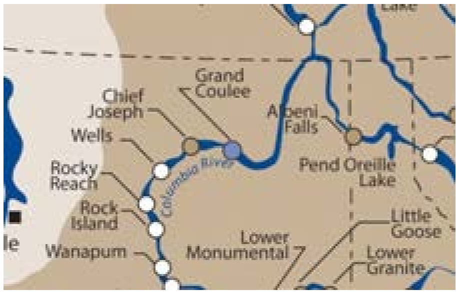

Figure 12. Map depicting location of Chief Joseph Dam

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Site specifications:

Chief Joseph Dam:

- 545.1 miles from the mouth of the Columbia
- 236 feet in height
- 5,962 feet in length
- 2,620 megawatt production capacity
- Run-of-river dam authorized for power purposes, but also used for irrigation, recreation and water quality purposes

Lake Rufus Woods (Reservoir):

- 51 miles long
- 518,000 acre feet of storage
- Highest inflows in January through March
- 177 hydraulic head
- 956 feet at full pool
- 930 feet at minimum pool

Species of Interest:

Chinook salmon (fall, spring, and summer), summer-run steelhead, sockeye

Passage Type:

Juvenile downstream passage: None
Adult upstream passage: None, but studies have been done

In 2002, the U.S. Army Corps of Engineers (the Corps) released a report detailing preliminary investigations of fish passage options at Chief Joseph Dam. Both the south and north banks were examined as sites for potential fish passage, seven passage options were examined with comparisons to similar systems elsewhere when possible, and cost estimates were provided for each site. A summary of the Corps' final report and its findings follows.

Adult upstream passage:
An existing fish ladder constructed at the Colville Tribes' Chief Joseph Fish Hatchery, below Chief Joseph Dam, collects both hatchery and natural-origin Chinook and steelhead. This fish ladder is not used for adult fish passage but for hatchery purposes. Foster Creek, which enters the Columbia River just below Chief Joseph Dam, meanders south of the dam. It is said that steelhead have been found in Foster Creek at high flows. A small, 20-foot high check dam, likely used for agriculture, is located on the creek 0.9 miles upstream from the Columbia River. This dam is a barrier to fish passage and thus marks the upper limit of open anadromous fish habitat for the Columbia River. (Corps 2002)

The Corps also examined the north bank of the dam site for adult fish passage facilities, where the bank is quite steep. Above the dam, the bank is generally unaltered, whereas below the dam revetments are needed due to the erosive power of the water over the spillway. Adult fish passage facilities implemented in this area would need to take into account the steep slopes, high velocities of water from the spillway, and the changes to water quality during spill periods. (Corps 2002)

Juvenile downstream migration:
Juvenile fish migrating downstream have passed through turbines with about a 85-90 percent survival rate in the lower-head dams of the mainstem lower Columbia River. However, the turbines operating at Chief Joseph are a different type of turbine runner and usually operate at a higher power and under 60 percent greater hydraulic head than at the lower mainstem dams. The turbines at Chief Joseph are a Francis-type whereas those used at the Corps' other lower mainstem hydropower projects are Kaplan-type. Francis turbines run at lower speeds and have different internal geometries than Kaplan-type turbines. Should fish passage through the turbines at Chief Joseph be considered, further study would be needed to estimate impacts on juvenile fish, i.e., injury and survival rates. (Corps 2002)

As a gas abatement project, spillway deflectors were installed in 2009 on all 19 spillbays at Chief Joseph Dam to dissipate excess hydraulic energy and improve water quality (e.g., lower total dissolved gas) downstream. Should fish pass through the Chief Joseph spillway in times of spill, a thorough investigation of spill passage at this project would be needed to evaluate the injury and survival rates of the fish.

Most federal hydropower dams on the mainstem lower Columbia and lower Snake rivers utilize a fish bypass system for juveniles, where angled screens block fish from entering the turbines and reroutes them to a bypass system that generally releases the passing fish into the tailrace below the dam. The Corps notes in their report that significant power production would be lost at Chief Joseph Dam if angled screens were implemented at the project. (Corps 2002)

What to consider for fish passage at Chief Joseph Dam:
According to the Corps (2002), the following information should be considered for fish passage efforts at Chief Joseph Dam:

- Fish
  - Size and Species
    - Flow depths and velocities need to accommodate various sizes of fish from juvenile salmonids to adult steelhead (kelt) migrating downstream.
    - Adult steelhead, Chinook, rainbow trout, and whitefish will need to pass upstream.
  - Direction and Location of Passage
    - There is interest in both upstream and downstream passage at Chief Joseph Dam.
    - If possible, a juvenile fish passage system should collect from both the north and south banks since fish tend to follow both banks during their downstream migration.
    - Fish behavior and hydraulic studies are needed at both the forebay and spillway to understand velocities, temperatures, and water quality in the reservoir since all of these factors affect the design of the passage facility.
    - For upstream adult fish passage, the Corps found that the following would be suitable fish passage methods for each location listed:
      - The right bank[30]: a fish ladder
      - Mid-channel: a fish lock
      - The left bank: a bypass channel, a fish ladder, or a collect and transport system
    - For downstream juvenile passage, the Corps found that the following would be suitable fish passage methods for each location listed:
      - The right bank: sluiceway passage or spillway passage
      - Mid-channel: a fish lock, a surface bypass collector or pipe, or a gatewell bypass collector or pipe
      - The left bank: a bypass channel, a collection and transport system, a surface bypass collector or pipe, a gatewell bypass collector or pipe, or turbine passage
  - Migration timing for salmon and steelhead
    - Based on the species and runs that would utilize passage at Chief Joseph, upstream passage facilities would need to be in operation year-round.
      - Fall Chinook: August – December

[30] Based on the perspective of looking upstream to downstream.

        - Spring Chinook: May – June
        - Summer Chinook: July – September
        - Summer-run steelhead: Year around[31]
  - Downstream passage for salmon and steelhead at Chief Joseph would need to be in operation from March through the end of the summer.
    - Fall Chinook: April – June
    - Spring Chinook: spring and summer
    - Summer Chinook: spring[32]
    - Summer-run steelhead: March – June
  - Swimming capabilities for anadromous fish
    - Water flow in the fish passage facilities cannot cause stress on or excessive energy use by the migrating fish.
    - The Corps provided the following swimming speed assumptions for each species most likely to use passage facilities at Chief Joseph Dam:
      - Adult Chinook at cruising: 0-3.4 ft/s; sustained: 3.4-10.8 ft/s; in a burst: 10.8-22.4
      - Adult steelhead at cruising: 0-4.6 ft/s; sustained: 4.6-13.7; in a burst: 13.7-26.5
      - 2" juvenile fish[33] at cruising: 0-0.5; sustained: 0.15-0.7; in a burst: 0.5-2.0
      - 4" juvenile fish[34] at cruising: 0-1.0; sustained: 0.3-1.4; in a burst: 1.0-4.0
  - Time in transit
    - Passage facilities should be designed to allow fish to move quickly through the system so as to minimize energy expenditure, stress and predation on the fish.
- Hydraulics
  - Attraction flows
    - Proper hydraulics must be implemented to attract the fish to the entrance of the passage facility.
    - For upstream passage the attraction flow must be strong enough that the fish will differentiate it from the main river flow.
    - For downstream passage, the flow must accelerate to attract the fish to the passage facility.

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[31] River-entry migration occurs from June to October; overwinter holding and movement occur up until spawning in April; and downstream migration of kelts is from April through the summer months.

[32] Summer Chinook in the Okanogan and other Upper Columbia tributaries have a very diverse outmigration pattern. Many fish migrate out as subyearlings in the spring, but a large proportion rear as they migrate out over a prolonged period, through July. A small percentage will overwinter in the reservoirs and migrate to the estuary in the winter or the following spring.

[33] Based on rainbow and sockeye.

[34] Based on rainbow and sockeye.

- Flow characteristics
  - Flow within the passage facilities should be optimized for survival and swimming capabilities.
  - For adult fish, entrance velocities of 4-8 feet per second are recommended, and a minimum depth of flow of 1 foot.
- Water usage
  - The amount of water needed to operate the passage facility effectively should be easily and consistently provided either through normal operations at the dam or through an additional water supply.
- Extraction and injection points
  - Where the fish enter and exit the facility should not negatively impact dam operations and should be placed in a location for the least risk of predation and water quality issues for the fish.
  - Debris in the fishway should be avoided.
  - Entrances and exits must be operational over at least the normal river and reservoir levels.
- Screening
  - Screens should be used to minimize fish injury.
  - Screens need to be easily maintained with a cleaning system to keep them from collecting debris.

- Land Use
  - Geotechnical
    - The stability of the site and its surrounding soils must be evaluated before placement of a fish passage facility.
  - Roads
    - Access must be maintained for construction.
  - Ownership
    - Real estate issues need to be addressed and could impact the cost of the final passage facility.
  - Fisheries
    - Access to tribal harvest sites could be a factor.
- Costs and Schedules
  - *See Costs section below*

Possible passage options for Chief Joseph Dam:
Seven possible passage systems were evaluated by the Corps (2002) for potential future implementation at Chief Joseph. Those were fish ladders, a surface bypass channel, fish lock or lift, a surface collector, turbine bypass, collection and transport facility, and spillway and turbine passage. Location, dimensions, attributes, issues, and costs[35] were identified for each option. That information is summarized below and the cost information:

[35] Cost information can be found in the cost section below.

- Fish ladder – pool and weir, vertical slot, or hybrid fishway
    - Location/direction: Could be used on either bank of the river but likely best on the right bank, and used for upstream adult fish migration.
    - Length and dimensions: A pool and weir ladder would be employed with the ladder(s) being 1,740 feet long on the right bank and longer if installed on the left bank. This would be 16 feet wide with two five-foot overflow weirs at the fishway floor. Flow over the weir should be between 1 to 1.2 feet deep. Ice Harbor Dam is a comparative example for this type of fish ladder; the flow rate required for the fishway at Ice Harbor is 70 cfs.
    - Attributes: As an established technology, studies needed would be minimal.
    - Issues: Supplemental flow may be needed for attraction. Some resting pools may be necessary depending on the grade and length of the ladder. Design for the foundation of the ladder will need to take into account seepage issues in the soil.
- Surface bypass channel – simulated natural channel connection to Foster Creek
    - Location/direction: For both adult and juvenile passage, a surface bypass channel on the left bank could be used in conjunction with a surface collector or with a log boom downstream of the entrance. This option would require a low-gradient channel starting at the boat ramp on the left bank and continuing along the bank into a steeper channel section made up of a series of steps and pools that eventually empties into Foster Creek.
    - Length and dimensions: The low-gradient channel portion would be 6,400 feet with a bed slope of 0.0008 ft/ft. With an inflow rate of 100 cfs, the mean channel depth would average 3 ft with a mean velocity of 1.8 feet/second; this would allow for sustained swimming speed for adult fish and slower flow near the sidewall for juvenile migration. This would only be operable with the normal range of reservoir levels, and additional attraction flow may be necessary. The steeper step-pool channel would start on a slope between 0.02 and 0.03 ft/ft as it descends into Foster Creek for about 2,440 feet. The minimum depth would be about 1.5 feet with a maximum velocity of 6.8 feet/second in the step portions and deeper depths and slower velocities in the pools.
    - Attributes: This would be a simulated natural channel, avoiding pressurization issues and should have little impact on fish.
    - Issues: An adequate attraction flow or collection mechanism would be needed for both directions of migration. Active upstream flow control could be necessary to enable operation of the facility at various reservoir operating levels.

- Fish lock or lift
  - Location/direction: Both adult and juvenile passage could use this system which could be placed at either bank or on the small island in the center of the dam.
  - Attributes: Less mechanical damage and shorter transit time than piping, collection, or trucking methods.
  - Issues: This system might need to operate in conjunction with a surface collector because attraction to the lock could be an issue. Fish can experience stress while waiting in the lock system, and a conventional lock system may not work at Chief Joseph because of the large hydraulic head.
- Surface collector at the forebay or sluiceway or other channel/pipe bypass
  - Location/direction: For juvenile passage only, placed near the upstream face of the powerhouse, either in the forebay for a deep-slot collector or near the left bank for a corner collector.
  - Attributes: Should be located to take advantage of fish migration patterns.
  - Issues: Screening and flow needs could affect water intake at the turbines. Pressurization in the piping could impact the fish. Surface collection was relatively new at the time of the 2002 Corps report and so outcomes were difficult to predict.
- Gatewell turbine bypass – submersible traveling screens
  - Location/direction: For juvenile passage only, traveling screens would be placed in each turbine intake approximately 70 feet below normal pool.
  - Attributes: The technology is well established with extensive use on the Corps' mainstem lower Snake and lower Columbia River dams.
  - Issues: Juveniles prefer to swim near the surface but would need to dive down 70 feet to be guided by the intake screens.[36] Pressurization could have effects on fish in the bypass piping from the gatewells.
- Collection and transport facility
  - Location/direction: Could be used for both juvenile and adult passage, and would likely be located on the left bank near Foster Creek. A collection and transport facility would need to be coupled with a surface collector (above) for downstream passage and a fish ladder (above) for upstream passage.
  - Attributes: Collected fish could be transported wherever necessary.
  - Issues: Attraction flow and screening issues would be the same as surface collectors and fishways. Predation on juveniles and transportation stress both at the entrance and at release locations could be issues.
- Spillway and turbine passage
  - Location/direction: For juvenile migration only.[37]

[36] While yearling smolts are surface-oriented, subyearling fall and summer run juveniles are less so.
[37] Safe passage for adults that fallback and pass downstream is also important, particularly for steelhead kelts.

- o Attributes: No additional construction needed. Operational changes would be necessary. Flow deflectors are installed on the spillway for gas abatement and should not negatively impact the fish, but spill passage would need to be evaluated for possible juvenile fish injury and mortality.

Timeline:

1949: Construction began on Chief Joseph Dam

1955: Dam completed

2002: U.S. Army Corps of Engineers Seattle District conducts preliminary investigations for fish passage at the dam

Additional Studies Needed &/or Underway:

The Corps (2002) concluded that a feasibility study would be needed for fish passage at Chief Joseph to determine both adult and juvenile fish behavior and reservoir hydraulics particular for this site.

The Corps notes that areas of Foster Creek have erosive slopes. If fish passage facilities were to be constructed in the Foster Creek area, the slope of the banks would need to be evaluated to determine how much of the area experiences natural erosion and how much is a result of cut and fill operations or the effects of past activities associated with building of roads. Additionally, fish behavior and use of habitat in the Foster Creek area is relatively unknown. (Corps 2002)

Costs:

When considering the costs and schedule of implementing fish passage, the Corps proposed the following:

- Design
    - o Similar passage projects should be studied and taken into account.
- Construction
    - o Both the timing and the cost of construction is dependent on dam operations and how much work is needed below the normal waterline.
    - o Fish migration timing could impact instream work.
- Monitoring and management
    - o Funding and equipment to monitor the results of the facilities is necessary.
- Benefit/cost analysis
    - o A benefit/cost analysis will not depend on the economic value (e.g., commercial or recreational fishing) of the fish.
- Costs needed to be considered in estimating fish passage facilities
    - o Capital costs for the construction of the fish passage facilities plus monitoring and evaluation facilities and real estate acquisition
    - o Operating costs

    - Operation and maintenance costs include costs for pumps used for attraction flow, facility cleaning and repair costs, and the costs for collection and transport of fish.
    - Reporting and monitoring costs include fish counting, fish behavior, studies post-construction, and salaries of biologists and personnel involved in monitoring.
  - Study costs
    - Costs for pre-construction and pre-design studies, permitting studies, and fish behavior studies.
  - Lost generation costs
    - Forgone revenue from water spilled that could have been used for power generation.
- Cost assumptions
  - Costs were estimated from fish passage facilities implemented at 16 dams ranging in size and capacity. For passage at the river banks, estimates were scaled up or down to amount for the total hydraulic head. Estimates were scaled to account for total generating capacity of the power station for passage located in or connected to the powerhouse.

Cost estimates provided by the Corps (2002) are based on an Idaho National Engineering Laboratory (1994) study that evaluated fish passage at 16 hydroelectric projects. Three of the projects in the report were high-head dams, producing over 1 million megawatt-hours of power annually: Lower Monumental, Wells, and Conowingo dams. The costs estimates from these three dams were used to help scale the potential costs for Chief Joseph Dam, and are provided both in 2002 dollars, the current year at the time of the Corps report, and 2015 dollars, converted based on inflation rates.

Cost estimates for a single fish ladder[38] for upstream passage at Chief Joseph were:

- Capital costs: $45 million in 2002 ($59.3 million in 2015 dollars)
- Annual operating costs: $191,000 ($251,600 in 2015 dollars)
- Annual generation loss: $883,000 ($1.2 million in 2015 dollars)
- Studies: $5 million ($6.6 million in 2015 dollars)

Cost estimates for a bypass channel[39] for both upstream and downstream passage were:

- Capital costs: $71 million ($93.5 million in 2015 dollars)
- Annual operating costs: $191,000 ($251,600 in 2015 dollars)
- Annual generation loss: $662,000 ($872,200 in 2015 dollars)
- Studies: $5 million ($6.6 million in 2015 dollars)

[38] Cost estimates are based on the costs of fish ladders at Wells and Lower Monumental dams which each have two ladders. These costs were scaled to account for the total head drop at each dam.

[39] No projects were available for comparison. A bypass channel at Chief Joseph would need two different sections for different gradients and each section would have individual costs. The estimate provided here assumes the costs of both sections and associated necessities such as retaining walls, slope revetments, and lining.

Cost estimates for a fish lift or lock[40] to facilitate both upstream and downstream passage were:

- Capital costs: $30 million ($39.5 million in 2015 dollars)
- Annual operating costs: $869,000 ($1.1 million in 2015 dollars)
- Annual general loss: $1.3 million (1.7 million in 2015 dollars)
- Studies: $5 million ($6.6 million in 2015 dollars)

Cost estimates for a surface bypass collector[41] that would be used for downstream passage were:

- Capital costs: $21 million ($27.7 million in 2015 dollars)
- Annual operating costs: $1.1 million ($1.5 million in 2015 dollars)
- Annual generation loss: $2.9 million ($3.9 million in 2015 dollars)
- Studies: $9 million ($11.9 million in 2015 dollars)

Cost estimates to implement traveling screens[42] for gatewell turbine bypass for downstream passage were:

- Capital costs: $51 million ($67.2 million in 2015 dollars)
- Annual operating costs: $1.1 million ($1.5 million in 2015 dollars)
- Annual generation loss: $263,000 ($346,500 in 2015 dollars)
- Studies: $4 million ($5.3 million in 2015 dollars)

Cost estimates for downstream and upstream passage collection and transportation facilities[43] was estimated to require $7 million ($9.2 million in 2015 dollars) for capital costs.

Estimated annual generation loss for a spill passageway for downstream passage was $4 million ($5.3 million in 2015 dollars)[44].
(Corps 2002)

Results:

Based on their evaluation, the Corps found that the surface collectors, fish lift, and traveling screen options would result in more forgone revenue[45] and that successful fish passage will likely be a combination of several of the options examined. (Corps 2002)

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[40] The estimates provided are based on a similar system at Conowingo Dam and are on the low-end of a lift or lock system. Costs are scaled to account for the hydraulic head of the dam and assume that flows are needed year-round.
[41] Cost estimates are based on bypass screens at Wells Dam and the collection system at Lower Monumental Dam.
[42] Cost estimates are based on a similar system at Lower Monumental Dam. Lower Monumental has six turbines, whereas Chief Joseph has 27, so the estimates are scaled according to the power generation capacity.
[43] Cost estimates are based on a similar system at Lower Monumental Dam. Costs for this facility are dependent on the expected volume of fish to be collected and not the dam specifications so estimates are not scaled.
[44] Cost estimates are based on average forgone revenue at Wells and Lower Monumental dams. Estimates do not include modifications needed for operation and turbine efficiency. Any modifications done at Chief Joseph for the gas abatement project are not included in the cost provided here.
[45] Likely spill passageway would also result in higher forgone revenue.

Other Potential Factors to Consider:

- Operational changes in conjunction with Grand Coulee Dam upstream and associated impacts to BPA power customers;
- Loss of salmon, a First Food for the tribes above Chief Joseph Dam;
- Habitat conditions in the reservoir and its tributaries since the dam has blocked and inundated the river;
- If fish passage were pursued, would fish be released and collected in Lake Rufus Woods or would the entire reservoir be bypassed with release and collection only above Grand Coulee?;
- Congressional authorization and approval should fish passage need to be directly connected to the dam.

Location of Study: Conowingo

Susquehanna River, Maryland and Pennsylvania in mid-eastern U.S. The Susquehanna drains an area of 27,500 square miles and is 444 miles long and provides more than one-half the freshwater flow to the Chesapeake Bay. Major tributaries include the 228-mile long West Branch and the 90-mile long Juniata River. (Miller 2010)

Figure 13. Map depicting location of Conowingo Dam (Pennsylvania Fish and Boat Commission 2016)

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Site specifications:

Conwingo Dam:

- 9.9 miles from Chesapeake Bay
- 94 feet high
- 4,648 feet in length
- 572 megawatt production capacity
- Run-of-river dam used for hydropower, flood control, recreation, and water supply

Conwingo Lake (Reservoir):

- 14 miles long
- 310,000 acre feet of storage
- Highest inflow month are March and April
- 89 feet of hydraulic head
- 110.2 feet at full pool
- 101.2 feet at minimum pool

Species of Interest:

American Shad[46], river herring and American eels.

Passage Type:

There are fish passage facilities at each of the four hydroelectric dams on the lower Susquehanna River. Conowingo (licensed to Excelon Corporation), Holtwood built in 1910 (licensed to Holtwood LLC) and Safe Harbor dams, the first three dams moving upriver, have fish lifts[47] or elevators. York Haven Dam (York Haven Power), the fourth dam, has a vertical slot fish ladder. All of the fishways were constructed with viewing windows where biologists count the migrating fish.[48]

Further upstream, the Fabri-Dam at Sunbury is scheduled to have a fish ladder built when state funds become available. Hepburn Street Dam in Williamsport has a ladder in place, which will be upgraded in the near future.

Fish passage operations begin at Conowingo on April 1, or when water temperature reaches 50F. Fish passage operations upstream are triggered by counts of migrating fish at the next dam downstream. Reports of fishway activity, numbers and species of fish passed are provided by the dam operators to the Pennsylvania Fish and Boat Commission on a weekly basis and are updated regularly and reported on this website (see Table 4 below). Very high flow events can disrupt normal fish passage schedules and operations, however, by following the weekly updates, observers can get a feel for the beginning, peak and end of the run. Fishway operations cease around mid-June to coincide with the apparent ending of the run. Declining numbers of fish counted, as well as water temperatures increasing to ranges above that of spawning shad, trigger the closing of the fishways. Dam operators, the U. S. Fish and Wildlife Service and the Pennsylvania Fish and Boat Commission work together to determine fish-way schedules." (Pennsylvania Fish and Boat Commission 2016)

Timeline:

The first dam on the lower Susquehanna at Conewago Falls near York Haven, PA was built in 1904. The 55-foot high Holtwood Dam, built in 1910, included a fish ladder and a sluiceway, neither worked to pass American shad and the fishery disappeared. Construction of Conowingo Dam (100 feet high) took place from 1926 through 1928 under the Philadelphia Electric Company with the dam beginning power generation in 1929. At the time, it was the second largest hydropower producing dam, behind only Niagara Falls. Safe Harbor Dam (75 feet) began operation in 1931. Both dams, downstream of Holtwood, had no fish passage facilities. (Miller 2010)

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[46] American shad are broadcast spawners that spread their spawn in several reservoirs, which accounts for much of the decline in adult passage from dam to dam moving upstream.

[47] More information on fish lifts can be found in the Upstream (Adult) Fish Passage Types section of this staff paper.

[48] Click here to watch video of gizzard and American shad moving past the viewing window at Conowingo Dam, recorded, not live.

In 1970, fish management agencies and the dam owners reached an agreement to stock the river with shad eggs and build a fish trapping facility, and the original Conowingo fish lift completed in 1972. From 1972 until 1980, only 945 shad were collected at the fish lift. In 1976, egg stocking was replaced with fish culture and release of shad fry. Construction of a shad hatchery took place on the Juniata River. (Migratory Fish Restoration and Passage on the Susquehanna River, date unknown)

Passage preparation and implementation began in earnest in 1980 with the issuance of a new license for Excelon's predecessors to operate the project. As part of the 1980 license, Excelon agreed to a second fish lift to deposit fish directly into the reservoir. (The original fish lift on the west side of the dam only went to a parking lot for truck transport operations; it is still used for research purposes.) The new east side lift was completed and went into operation in 1991. (LaRouche 2014)

A new operating agreement in 2016 (the 1980 FERC license expired in 2015) established goals for passage of 2 million shad and 5 million herring through all four dams. The fish lifts will undergo capacity expansions and the original lift will likely be used for trap and haul operations. (Dance 2016)

Additional Studies Needed &/or Underway:

New studies on fish passage will take place once the capacity and operational changes have begun. Excelon is conducting another study on sediment trapping behind Conowingo before it designs and implements expanded fish lifting configurations. (Dance 2016)

Costs:

Truck and transport operations from 1985-1994 cost $3.7 million total ($5.9 million in 2015 dollars) over the period until the new lift on Conowingo proved a workable solution. Existing passage facilities cost $12.5 million ($21.8 million in 2015) for the east side fish lift at Conowingo in 1991 and $16 million ($23.6 million in 2015) to install a fish lift at Safe Harbor Dam and $22 million ($32.5 million in 2015) at Holtwood Dam (55 feet high) in 1997. Adding a vertical slot fishway at the smaller York Haven Dam cost $9 million in 2000 ($12.4 million in 2015). (Migratory Fish Restoration and Passage on the Susquehanna River, date unknown)

Costs for the new settlement agreement were not readily available and will continue to be refined as the settlement agreement alternatives progress through the concept stage. The potential costs at the concept stage range from around $2 million for shad to over $20 million if a new fish lift for the west side of the dam is selected as an alternative. Additional costs for eel passage range from $600,000 to over $4,000,000, again at the conceptual design stage. Any configuration or operational changes will result in additional operating costs, also to be determined. (McCaffery and Sullivan, date unknown)

Site Results:

Effectiveness of Upstream Fish Passage:

As demonstrated by the numbers below, shad passage has declined since a peak[49] at the turn of the century and are now at their lowest numbers. Herring numbers, though not included below, have fallen even farther than shad, less than 1000 every year since 2003 with only 13 picked up a Conowingo in 2015. (Wheeler 2016)

Effectiveness of Downstream Fish Passage:

Downstream passage takes place only through river operations on this run-of-river project. The projects have agreed to modify operations to increase juvenile passage success, including controlled spills. (Miller 2010)

Summary of results:

YEAR	Conowingo*	Holtwood*	Safe Harbor**	York Haven**
2015	8,341	5,286	3,896	43
2014	10,425	2,528	1,336	8
2013	12,733	2,503	1,927	202
2012	22,143	4,238	3,089	224
2011	20,571	21	8	0
2010	37,757	16,472	12,706	907
2009	29,272	10,896	7,994	402
2008	19,914	2,795	1,252	21
2007	25,464	10,338	7,215	192
2006	56,899	35,968	24,929	1,913
2005	68,853	34,189	24,425	1,772
2004	109,360	3,482	2,109	219
2003	125,135	25,254	16,646	2,536
2002	108,001	17,522	11,705	1,555
2001	193,574	109,976	89,816	16,200
2000	153,546	29,421	21,079	4,675
1999	69,712	34,702	34,150	--
1998	39,904	8,235	6,054	--
1997	90,971	28,063	20,828	--

[49] Anecdotally, fisherman netted them by the millions.

* Although the Conowingo East lift began operating in 1991, fish were sorted and transported upstream by truck until 1997. ** Holtwood and Safe Harbor came online in 1997, York Haven in 2000.

Table 4. Final counts of shad passage (Pennsylvania Fish and Boat Commission 2016)

Strengths and Weaknesses:

The lift system worked to boost shad and herring passage after its start in 1991. The Susquehanna had been virtually devoid of the fish that once made runs all the way into New York State near the headwaters of Lake Otsego. However, the lifts have become crowded with non-migratory species that have kept shad and herring from entering the lifts. U.S. Fish and Wildlife Service believes that expanding capacity of the lifts will alleviate the fish crowding situation and allow shad and herring to enter the lifts. (Larouche 2014)

Other Potential Factors to Consider:

Shad landings in Pennsylvania annually averaged 63,000 fish from 1890 through 1909. Shad landings totaled 1.4 million fish in the Chesapeake Bay in 1896 and was the most important fishery in the bay. (Migratory Fish Restoration and Passage on the Susquehanna River, date unknown)

Location of Study: Grand Coulee

Columbia River; Upper Columbia Subbasin; North-central Washington; in the Columbia River Basin

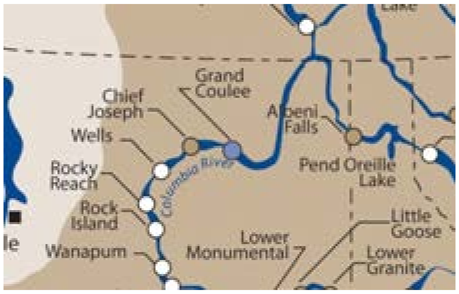

Figure 14. Map depicting location of Grand Coulee Dam

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Figure 15. The face of Grand Coulee Dam. (Photo courtesy of Tony Grover)

Site specifications:

Grand Coulee Dam:

- 596.6 miles from the mouth of the Columbia
- 550 feet in height
- 5,223 feet in length
- 6,809 megawatt production capacity
- Storage project used for power production, navigation, flood control, power storage, and irrigation and recreation

Lake Roosevelt (Reservoir):

- 151 miles long
- 9.6 million acre feet of storage
- Highest inflow between April and July
- 343 feet of hydraulic head
- 1,290 feet at full pool
- 1,208 at minimum pool

Species of Interest:

Historic: Chinook and sockeye; Current day: Chinook, sockeye, steelhead

Passage Type:

Juvenile passage: None
Adult passage: None

In 1938, the State of Washington Department of Fisheries prepared a report for the Bureau of Reclamation to provide options to preserve salmon and steelhead in the upper Columbia above Grand Coulee Dam, which was under construction at the time and which would permanently block fish passage the following year. It is important to note that investigation into fish passage design was not begun until the dam construction plans were nearly final and the construction of the foundation was almost complete; should fish passage have been installed, it was determined that costly alterations would need to have been made to the portion of the dam already constructed. Thus, planning and timing were off and not in the favor of the salmon and steelhead that were blocked, beginning that year, as the dam foundation rose. The construction of Grand Coulee Dam blocked 1,140 miles of "the San Poil, Spokane, Kettle, Colville and Clark Fork rivers, and the numerous smaller creeks in the United States as well as the vast drainage system of the Columbia in the southeastern British Columbia, including particularly Upper and Lower Arrow Lakes and Slocan Lake," according to the 1938 report prepared by the state departments of fisheries and game, and the U.S. Bureau of Fisheries and issued under the name of the fisheries department director, B.M. Brennan. The Brennan report (1938) found that passing fish over Grand Coulee via ladders, spill, or turbine passage would not be feasible for five reasons:

1. Tailrace fluctuations were large and variable;
2. Spill was scheduled to occur during the adult peak run time (June – August) which would batter the adult fish butting up against the dam;
3. In the spring when juvenile fish would be outmigrating, irrigation demands would be high and screening the intake pumps to keep the juveniles out would be difficult;
4. A spill schedule was not determined, but spill was expected throughout the year.[50] When the dam was not spilling, the juveniles could be held up behind the dam for potentially eight months, and food supply would be low. Also when spill began, the flow over the crest would be so thin that the juveniles going over the dam would be in contact with the concrete face of the dam and likely not survive;
5. It was uncertain whether fish could survive the 350-foot fall once the spill flow was abundant.

Milo Bell, who was the chief engineer of the state Department of Fisheries and who designed fish ladders and screens for the Columbia River mainstem dams, conducted experiments on a scale model of Grand Coulee to determine fish behavior once spilled

[50] Prior to construction, the practice of spill was thought to be used at Grand Coulee, but is not a regular practice at the dam now.

over the dam. Bell found that juvenile fish could get trapped in the violent backroll of spill in the tailrace, tumbling around in the current for a considerable amount of time. (Brennan 1938)

Building a salmon hatchery was also considered an option, with adult collection at the base of the dam. However, several issues arose to halt that option: 1) the adults that reach Grand Coulee are not sexually mature and so would need to be held for some time before being ready and able to spawn; 2) the same issue with providing adequate attraction flow in the violently turbulent spillway basin would be a problem; 3) a collection apparatus was estimated at no less than $1 million; and 4) due to the rugged, and inaccessible lands around Grand Coulee Dam, the State of Washington did not deem the area suitable to construct a fish hatchery both because of a lack of space and a suitable water supply. The state looked into collecting adults at Rock Island Dam, which had ladders in operation, to be held in a hatchery for Upper Columbia stocks but found that: 1) the adults reaching Rock Island would need to be held and provided for during an additional several months before reaching sexual maturity; 2) separating the fish headed for the Methow, Entiat, Wenatchee, and Okanogan rivers from those for the reach above Grand Coulee was impossible, according to the state; and 3) an experiment conducted in 1935 using water from the Columbia River near Grand Coulee to hold Chinook and sockeye resulted in 50-percent mortality, mostly due to high water temperatures in the summer, which led the state to conclude that Columbia River water was unfit to hold adult salmon in large concentrations. After conducting experiments to ensure that adults utilize a homing instinct to return to their natal stream rather than a hereditary instinct to return to the natal stream of their ancestors, the state decided to use the Methow, Entiat, Wenatchee, and Okanogan rivers of the Upper Columbia to substitute for the lost anadromous runs above Grand Coulee, and constructed fish hatcheries near the towns of Leavenworth, Entiat and Winthrop, Washington to create the surplus needed. It is important to note that those four lower tributaries make up 677 miles of already salmon producing habitat, making it impossible to truly compensate the amount of lost fish from the 1,100 miles of habitat blocked by Grand Coulee. Grand Coulee Dam continues to fund the operation of these hatcheries, which are managed by the U.S. Fish and Wildlife Service. (Brennan 1938; Brougher pers. comm.)

Timeline:

1930s: The State of Washington Department of Fisheries and Department of Game, along with The United States Bureau of Fisheries conducted studies for the Brennan report, “Report of the Preliminary Investigations into the Possible Methods of Preserving the Columbia River Salmon and Steelhead at the Grand Coulee Dam.”

1933: Grand Coulee dam construction begins; a temporary fish ladder is constructed to allow salmon and steelhead to pass while the foundation of the dam is under construction.

1938: Brennan Report is completed, concluding that downstream passage for juvenile salmon was infeasible and envisioning an effort to trap adult fish at Rock Island Dam, truck them to a holding pond at the confluence of Icicle Creek and the Wenatchee River for spawning, then release the juveniles into the Entiat, Methow, Wenatchee, and Okanogan rivers; rearing stations soon were constructed within the Entiat, Methow and Wenatchee subbasins[51] to help the effort to "reprogram" the fish.

1939: Construction of Grand Coulee Dam permanently blocks salmon and steelhead passage.

1938 - 1940: Salmon hatcheries at Leavenworth, Entiat, and Winthrop are constructed to operate in conjunction with rearing ponds in the tributaries.

1941/42: Grand Coulee dam is completed and in operation.

Additional Studies Needed &/or Underway:

In 2015, the Council, in partnership with the Bonneville Power Administration, solicited for a habitat assessment above Chief Joseph and Grand Coulee. As one element of the Council's measure to investigate the feasibility of reintroduction of anadromous fish into the blocked areas of the Upper Columbia, the Council sought proposals to, "investigate the availability, suitability, and salmon survival potential in habitats above Grand Coulee Dam (that is, between river mile 545.1 [at Chief Joseph Dam; Grand Coulee is at river mile 596.6] and river mile 745 at the Canadian Border), including in any tributaries in this area that have the potential to support anadromous fish" (NPCC 2016). The Spokane Tribe of Indians, along with several collaborators in the Upper Columbia and Washington including in-kind contributions from the Colville Confederated Tribes, submitted a proposal that was approved by the Council in April 2016. The tribe's work to identify salmon and steelhead habitat in the blocked waters will use Intrinsic Potential and Ecosystem Diagnostic Treatment (EDT) modeling of historical data and began in August 2016.

As a side note, the challenges of passing multiple species at Grand Coulee Dam would be similar to those experienced at Chief Joseph Dam. See the Chief Joseph Dam case study for more information.

Costs:

It was estimated in 1938 that an adult trap facility at the base of Grand Coulee could cost over $1 million ($16.8 million in 2015 dollars). (Brennan 1938) No other costs have been estimated and published at this time.

Site Results:

Effectiveness of Upstream Fish Passage:

[51] Artificial propagation facilities were not provided to enhance the Okanogan populations until the construction of Chief Joseph Hatchery, when the first broodstock was received in 2013.

Not applicable

Effectiveness of Downstream Fish Passage:

Not applicable

Summary of Results:

Not applicable

Strengths and weaknesses:

Not applicable

Other Potential Factors to Consider:

Many factors should be considered in respect to passage at Grand Coulee including:

- Grand Coulee[52] and Chief Joseph dams produce a significant amount of power for the Pacific Northwest.
- Upper Columbia tribes have been unable to fish for salmon and steelhead above Grand Coulee since the 1930s. The construction of the dam substantially adversely affected the Tribes' historical food supply, culture, religion and identity.
- Little has been done in this area to study passage options, the habitat condition, and fish behavior; detailed studies would need to be conducted prior to pursuing passage.
- Chief Joseph Dam, downstream of Grand Coulee Dam, also blocks salmon passage and fish passage at Chief Joseph would also need to be addressed.
- In Canada, there are contingencies in place if anadromous fish are returned upstream of Grand Coulee Dam. Should passage be opened in the U.S. and then in turn the three major facilities in Canada, the benefits of passage at the U.S. projects would greatly increase.
- Life cycle modeling would likely need to be conducted to determine the likelihood of obtaining cohort replacement rates for the target salmon species given that anadromous fish must also pass nine other mainstem Columbia River dams, both downstream and upstream, as well as passing both Chief Joseph and Grand Coulee dams.
- Predation on salmon in Lake Roosevelt by non-native, resident fish, such as bass, walleye, and northern pike, may be an issue.

[52] Grand Coulee is the largest hydropower producer in the United States, according to the Bureau of Reclamation's website.

Location of Study: Hells Canyon Complex – specifically Brownlee, but also Oxbow and Hells Canyon

Snake River, Snake Hells Canyon Subbasin, Western Idaho; in the Columbia River Basin

Figure 16. Map depicting location of the Hells Canyon Complex which is made up of Brownlee, Oxbow, and Hells Canyon dams

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Site specifications:

Hells Canyon Dam:
- 571.2 miles from the mouth of the Columbia
- a run-of-river dam used for power
- 330 feet high
- 910 in length
- 391 megawatt production capacity

Hells Canyon Reservoir:
- 188,000 acre feet of storage
- 210 feet of hydraulic head
- 1,688 feet at full pool
- 1,678.5 at minimum pool

Brownlee Dam:
- 609.2 miles from the mouth of the Columbia
- a storage dam used for power, flood control, and power storage
- 420 feet high
- 1,380 in length
- 585.4 megawatt production capacity

Brownlee Reservoir:
- 58 miles long
- 1,426,700 acre feet of storage
- 1,000,000 acre feet of flood control storage
- 272 feet of hydraulic head
- 2,077 feet at full pool
- 1,976 at minimum pool

Species of Interest:

Summer steelhead, fall- and spring-run Chinook

Passage Type:

Juvenile downstream passage: None currently; trap and haul with a surface collector ("gulper") and nets were attempted
Adult upstream passage: Trap and haul at the base of Hells Canyon Dam

Prior to the completion of Brownlee Dam, competition between public and private power interests was high. Various proposals for the Hells Canyon Complex dams were submitted by the Bureau of Reclamation, the Corps of Engineers, Idaho Power Company, Pacific Northwest Power Company, and a group of Washington public utility districts. Idaho Power Company (IPC) was granted a Federal Power Commission (FPC)[53] permit in 1955 to build all three Hells Canyon Complex dams – Brownlee, Oxbow, and Hells Canyon. Brownlee Dam was the first project to be constructed, with Oxbow and Hells Canyon, respectively, each being constructed downstream later. Brownlee was built in 1958, Oxbow in 1961, and Hells Canyon in 1967. (Chapman 2001)

An advisory committee (Committee) made up of the state fish and wildlife agencies of Washington, Oregon, and Idaho, and the U.S. Fish and Wildlife Service (USFWS) joined to evaluate alternatives for fish conservation with the development of the Hells Canyon Complex. The Committee decided that relocating salmon runs into suitable streams below the Hells Canyon Complex could possibly maintain the runs from the upper Snake. One example the Committee looked to in its evaluation was the translocation of runs to Icicle Creek for Grand Coulee Dam. (Chapman 2001)

The FPC permit was issued to the IPC in August of 1955 with Brownlee Dam slated to be complete in May 1958. That gave the IPC 33 months to fast-track biological studies, engineering design, and implementation of fish passage facilities at Brownlee, at a time when no other fish passage facilities for dams and reservoirs with the magnitude of both Brownlee Dam and Brownlee Reservoir had been attempted, and especially no known method for providing safe downstream juvenile passage. According to the IPC report written by Chapman (2001) this, "must be seen in the context of the 'power push' of the 1950s and what one can justifiably term an extension of the concept of manifest destiny… The main issues in the 1950s centered not on whether development and dams in Hells Canyon were desirable, but whether they would occur in the public or private sectors."

Significant challenges had to be considered for downstream fish passage at Brownlee, including that the reservoir draft associated with flood control operations could range up to 100 feet, and that there was also a significant debris load that entered Brownlee

[53] The Federal Power Commission, or the FPC, became the Federal Energy Regulatory Commission, or FERC, in 1977.

Reservoir. Decisions were made hastily in the limited time granted to study and pursue fish passage at Brownlee, and inadequate time was allotted to conduct all the studies that were originally envisioned. Based on results of the studies that were performed, the Committee decided that the least objectionable procedure was to provide upstream and downstream passage facilities for the fish affected by the construction of the Hells Canyon Complex. Hatcheries were not deemed feasible due to knowledge at the time, though the 2001 Chapman report notes that this seems disingenuous since several other hatcheries were already in operation.

1950s/1960s Juvenile collectors in the Brownlee Reservoir:
The penstocks (floodgates of the dam used to regulate the flow of water to the turbines) on Brownlee were constructed 16-feet below minimum pool. This did not work with the Committee's preferred approach which was to submerge the penstocks 120 feet below the minimum forebay level and pair the deep submergence of the penstocks with pumps up to a gulper system to collect fish at the surface. Therefore, this proposed method was abandoned. The next method examined was collecting smolts in the reservoir, one mile upstream from the dam in the 58-mile long Brownlee Reservoir, in a system consisting of a barrier net, gulpers, and electric pumps. Smolts captured at the gulper would be transported first downstream of Brownlee, then downstream of Oxbow and Hells Canyon, and downstream of any other Snake River dams that would be constructed in the future. (Chapman 2001)

In a 1961 document, the IPC summarized the fish passage facilities at Brownlee, which were then in operation. A skimmer/barrier method, which was used to try to capture juveniles migrating downstream, consisted of a barrier net and a fish collector called a gulper. The barrier net was made of a plastic 8-mesh/inch net measuring 2,800 feet long and 120 feet deep to prevent fish from passing the collector and continuing downstream to the dam. The skimmer/barrier had 3 gulpers with 14-foot by 14-foot entrances with attraction flow created by pumps to attract the fingerlings. As the fish entered the trap, the water velocity increased to 8 fps. The fish were pumped to a truck-loading station on the shore via a rubber pipeline, and seven custom tank trucks equipped with oxygen and aeration were used to transport the juveniles to below Oxbow Dam, which was the furthest downstream dam in the complex at the time, since Hells Canyon had not yet been constructed. (Chapman 2001)

The net barrier system encountered various complications. Clips holding panels of the net failed causing flows into the gulpers to not reach the necessary 100 cfs. Divers inspected the net and found areas that were lacking tautness, a gap between a hose on the fish transfer pipe and the bank barge site, and several breaks in the backing cloth of the net. Due to the initial construction of the net system, many of these fixes could not be made without negatively impacting other areas of the net, though divers continued to work on maintaining the net's function. The next year, bad weather caused more holes and damage to the net. Overall, the barrier net was not successful; fish swam under the net or through holes, and juvenile recovery in 1962 was only 0.85 percent for fall Chinook, 10.4 percent for spring Chinook, and 0.17 percent for steelhead. Many of the fish remained in the reservoir for an additional year, migrating out to sea a year later than normal. According to the IPC, total Chinook juveniles captured in the net were 130,559 in 1959; 49,485 in 1960; 19,767 in 1961; and 13,675 in 1962. Steelhead juveniles captured were 18,250 in 1959; 2,570 in 1960; 2,143 in 1961; and 1,531 in 1962. Although the net barrier was a problem for juvenile collection at Brownlee, water temperatures, dissolved oxygen levels, and failure of fish to migrate through the reservoir created the biggest impact on the success of the project. (Chapman 2001)

Studies were not conducted to determine the depths that the migrating juveniles swim to in the reservoir; therefore, when summer temperatures forced subyearlings to a depth lower than the barrier net, they ended up passing under the net and through the turbines where survival was low. In the summer months, the reservoir experienced high surface temperatures and low dissolved oxygen levels. This resulted in a shrinking vertical stratum of proper migratory water conditions and in some cases eliminated livable conditions entirely. Predator populations in the reservoir grew, and wastes from nearby sugar and potato processing plants and fertilization from agricultural runoff, as well as the decomposition of algae blooms, contributed to low dissolved oxygen levels. At the time, the velocity of flow through the reservoir was minimal making it difficult for juveniles to find the gulper. (Chapman 2001)

In 1962 it was decided that the net barrier system was not working and that a change was necessary. There was a push by the IPC to no longer pursue passage and to instead convert fall Chinook conservation efforts from passage to hatcheries and to translocate steelhead and spring Chinook into tributaries of the Snake River below the Complex. The fishery agencies agreed that more experience and knowledge on juvenile passage was needed. In late 1963, the FPC issued an order for IPC to abandon the net installation at Brownlee. The barrier system and gulper was removed but the fishery agencies did not preclude reestablishment of passage once more was understood about juvenile collection. In 1966, the fishery agencies requested that the FPC issue an order to discontinue fish passage at the HCC and switch efforts to a major hatchery program. (Chapman 2001; Chandler pers. comm.)

Adult traps at Oxbow and Hells Canyon dams

A temporary ladder and adult trap by the Oxbow Powerhouse next to the diversion-tunnel was used during construction of Oxbow Dam, and then a ladder and trap next to the spillway on the Oregon side of Oxbow Dam was used after construction. The adults were placed in custom-built trucks similar to those transporting the juveniles and transported 15 miles upstream to be released in Brownlee Reservoir. Scientists tagged trapped adults prior to release 0.5 miles upstream of the Brownlee juvenile collection facility, to determine which spawning grounds they went to. They found that recovery rates between the spawning sites did not differ and that the adult migration was successful. Adult spring Chinook and steelhead were successfully trapped and transported 1.5 miles upstream of Brownlee from 1956 to 1964. IPC moved to a temporary trapping facility downstream of Hells Canyon Dam in 1965. A temporary floating barge trapping facility was used in the Hells Canyon tailrace until 1984. It was anchored to a concrete wall in the immediate tailrace to trap anadromous adult returns to support the IPC hatchery broodstock needs. Later, as part of a 1980 Hells Canyon Settlement Agreement that defined hatchery mitigation requirements, IPC constructed a permanent adult fish trap slightly downstream of the tailrace. The permanent trap was constructed in 1983, and first operated in 1984. The new trapping facility continues today to meet the broodstock needs of the hatchery program. Currently, adults are transported to Oxbow Hatchery for sorting of hatchery and natural (unclipped or unmarked) adults. Natural adults are transported back downstream to below Hells Canyon Dam for release and spawning in the free-flowing reach below Hells Canyon Dam. This facility is slated for significant modification to allow for sorting and release on site at the trap facility when a new Hells Canyon Complex license is implemented. The current facility is also used to transport hatchery adults in excess of broodstock needs to areas upstream of Hells Canyon Dam to provide “put and take” harvest opportunities. (Chapman 2001; Chandler pers. comm.)

2001 Fish Passage Update:
In 2001, as a requirement for Federal Energy Regulatory Committee (FERC) relicensing, the IPC reevaluated both upstream and downstream fish passage for the entire Hells Canyon Complex. The upstream passage route was defined as beginning downstream of Hells Canyon Dam and ending in Brownlee Reservoir, and the downstream passage route as beginning at the backwater effects of Brownlee Reservoir (about 58 miles upstream of the dam) and ending downstream of Hells Canyon Dam. At the time, no successful prototype existed for downstream fish passage at high-head dams with long, slow moving reservoirs like Brownlee. On top of examining various transportation options, the passage types examined for downstream juvenile collection were gulpers, surface collectors, various screens, spillway release, and turbine passage. For upstream passage of adults, portable floating traps, fixed traps in the reservoir and in the tributary, screw traps, and a louver system were examined. Ultimately, the IPC chose not to pursue passage again because the company felt there was still not a similar hydropower project model comparable to the Brownlee Reservoir size, debris load, temperature fluctuations, and drawdown operating range (which is up to 150 feet at Brownlee). Additionally, the quality of the habitat that fish would have immediate access to is either unknown or was known to be severely degraded. (Aurdahl et al 2001; Chandler pers. comm.). In the FERC relicensing process of the Hells Canyon Complex, the National Marine Fisheries Service reserved their authority to prescribe fish passage requirements for anadromous fish, primarily based on the overall quality of the habitats upstream of Hells Canyon Dam (FERC 2007).

Before the construction of Brownlee Dam and Reservoir, Pine Creek, Eagle Creek, Weiser River, Wildhorse River, and Indian Creek were producing anadromous fish. Portions of the Malheur, Burnt and Boise rivers were also accessible to anadromous fish and differences of opinion remain on whether salmon and steelhead were still using these rivers prior to the construction of Brownlee. Earlier projects, including the 1919 construction of the Warm Springs Dam and the 1935 construction of the Agency Valley

Dam in the Malheur River basin, contributed to the decline in anadromous fish runs. As with many areas with high-head dams, the reaches above the Hells Canyon Complex contain several dams. These dams are seen as challenged to provide adequate downstream collection of juvenile outmigrants. (Chandler pers. comm; Burns Paiute Tribe 2014; Idaho Power Company 2003).

2010 to Present Fish Passage Update:
From 2010-2012, the Burns Paiute Tribe conducted a habitat suitability study as part of the tribe's effort to determine the feasibility of anadromous fish reintroductions in the Malheur River Basin, which is in the blocked waters above the Hells Canyon Complex. The tribe's work included water quality sampling from May to August (the duration needed for what could be a recreational fishery) in the Upper Malheur River with comparative modeling in areas such as the John Day and the Willamette basins that experienced water quality-related mortality. The tribe found that pH, turbidity, and dissolved oxygen levels did not exceed thresholds lethal to adult Chinook salmon. Some areas within the study area had high temperature readings that could cause mortality while some areas did not, and many small, cold tributaries were identified as cold water refuges. The study did not receive full funding and so the tribe was unable to take it further, but the tribe was able to show that while problematic sites were identified, those sites likely do not occur temporally or spatially with a recreational fishery. (Burns Paiute Tribe 2014)

As part of the ongoing FERC relicensing process, additional evaluation of a downstream passage surface collector at Hells Canyon Dam occurred in 2013 as part of a larger evaluation of reintroducing spring Chinook salmon and steelhead to Pine Creek, a tributary to Hells Canyon Reservoir. Hells Canyon Dam is a high-head dam with a height of 330 ft.[54] However, a primary difference between Hells Canyon Dam and Brownlee Dam is the size of the reservoir. Brownlee Reservoir is a large storage impoundment, whereas Hells Canyon Reservoir is operated as a run-of-the-river project and thus is much shorter in length and smaller in volume than Brownlee. (Chandler pers. comm.)

The concept of this fish collection system is similar to those in operation at the mainstem Lower Snake and Columbia dams in that submerged traveling or vertical barrier screens would be used to divert downstream migrants away from the turbine intakes, into a fish collection conduit and transported to a collection barge. Juvenile fish collected and held on the collection barge would be transported downstream of the dam for release. (Chandler pers. comm.)

As initial steps in developing a detailed conceptual design of this fish collection system, a Computational Fluid Dynamic (CFD) model was developed for the Hells Canyon reservoir approximately one mile upstream of the dam. The CFD model was used to determine the flow patterns within the reservoir and evaluate the ability of the surface

[54] More dam specs can be found here.

collector to create surface draw conditions. The flow and velocity patterns were evaluated to determine the zone of influence in which downstream fish migrants would enter and be drawn into the surface collector. Though Hells Canyon Dam has a much higher operating head at 210 feet versus 110 feet at the Lower Snake and Columbia River dams, a fish screening, collection and bypass system still appears to be feasible at Hells Canyon Dam using the same basic design principles used at the lower Snake and Columbia dams. However, the limited size and higher velocities associated with the Hells Canyon Dam penstock at the location of the bulkhead slot does not allow installation of intake gates within the bulkhead slot. The physical configuration of the dam intake also does not provide sufficient space for installation of a collection gallery type of passage system within the existing dam footprint. As a result, a new steel intake structure would be required to be installed on the upstream face of the existing dam to house the fish collection facilities. Construction of a new facility would allow the screening system design to be optimized in terms of hydraulic flow conditions as well as size and operation. The new intake could also be designed to maximize the surface attraction flow due to project operation. (Chandler pers. comm.)

Timeline:

1955: FPC[55] permit granted to the IPC to build the three dams that make up the Hells Canyon Complex; construction began for Brownlee Dam

1956: Studies were conducted to investigate fish passage alternatives at the dams and construction began on temporary passage facilities at Brownlee; Idaho Department of Fish and Game and the U.S. Department of Interior formally requested upstream and downstream fish passage facilities at the Complex

1958: Brownlee construction was completed and the dam was in operation. The net barrier system was operable as was a temporary upstream trap adjacent to the diversion tunnel at the Oxbow Dam construction site.

1961: Oxbow Dam is built and in operation. The net barrier was operable in Brownlee as was a permanent upstream trap at Oxbow Dam.

1964: The Brownlee net barrier system and gulper were decommissioned per FPC order; translocation of upper Snake River stocks of spring Chinook and steelhead to the lower river tributaries was being evaluated as were efforts to develop a hatchery program for fall Chinook salmon.

1967: Hells Canyon Dam is built and in operation, completing the IPC's Hells Canyon Complex; upstream adult trapping was conducted using a floating barge trap in the Hells Canyon tailrace to collect broodstock to support the hatchery program.

1984: New permanent fish ladder leading to a new fish trap was constructed and is still operating currently to trap and haul adults for hatchery broodstock or "put and take"

[55] In 1977, the FPC became what is now FERC.

fisheries upstream of Hells Canyon Dam, or to release unmarked fish for spawning below the dam in the free-flowing Hells Canyon reach of the Snake River.

2001: FERC[56] relicensing on the Hells Canyon Complex; the IPC conducted additional studies to evaluate fish passage options at a conceptual level for all three dams

Costs:

In 1956, $250,000 ($2.2 million in 2015 dollars) was made available within the FPC license requirements to conduct detailed studies of fishery resources within the Hells Canyon Complex area. State and federal fishery agencies investigated passage, translocation, artificial and semi-artificial propagation, and natural redistribution of fish in streams below the Complex. However, the overall costs of fish passage studies, design, and implementation at Brownlee Reservoir in the 1950s is unknown. (Chapman 2001)

In 2001, an IPC technical report (Aurdahl et al. 2001) evaluated various upstream and downstream passage options and provided high-level conceptual costs of each fish passage type evaluated (see costs in the following two paragraphs). At the time a successful high-head fish passage system had not been placed in operation that would be comparable to the Hells Canyon Complex, especially for the size and capacity of Brownlee Dam and Reservoir. The costs provided, which were provided in 2001 dollars and converted to 2015 dollars, have an added construction contingency of 50 percent to account for that uncertainty. Construction cost was the only cost estimated for the complex and it was done without hydraulic modeling or prototyping, which would need to be done if passage were to be considered. Operation and maintenance costs for mechanical and electrical systems were roughly estimated with additional construction costs for structural elements given that the design was not fully developed, so an accurate cost estimate was not available.

Downstream passage options:
At Brownlee Reservoir, final cost estimates for a collection system in the upper reservoir of Brownlee were estimated at $45.9 million ($61.5 million in 2015 dollars) capital cost and $4.6 million ($6.2 million in 2015 dollars) annually for operation and maintenance; forebay collection[57] was estimated as $24.6 million ($33 million in 2015 dollars) capital cost and $2.5 million ($3.3 million in 2015 dollars) annually for operation and maintenance; and a spillway-BGS was estimated at $39 million ($52.2 million in 2015 dollars) capital cost and $2 million ($2.7 million in 2015 dollars) annually for operation and maintenance.

At Oxbow Reservoir diversion screens were estimated at $18.5 million ($24.8 million in 2015 dollars) for capital costs and $1.8 million ($2.4 million in 2015 dollars) for annual operation and maintenance costs; and “fish-friendly” turbine passage would involve no additional costs.

[56] In 1977, the FPC became what is now FERC.

[57] Assumes full draft of Brownlee Reservoir; lost revenue from reduced power generation is not included in cost estimate.

Passage costs for Hells Canyon Reservoir were estimated as $27 million ($36.2 in 2015 dollars) capital costs for diversion screens with $2.7 million ($3.6 million in 2015 dollars) in annual operation and maintenance costs; and $7.5 million ($10 million in 2015 dollars) for spillway release capital costs and $400,000 ($536,000 in 2015 dollars) annual operation and maintenance costs. (Aurdahl et al 2001)

Upstream passage options:
Both trap and transport and fish ladders were evaluated as upstream fish passage options around the three projects in the Hells Canyon Complex: Brownlee, Oxbow, and Hells Canyon. The trap and transport option for Brownlee was estimated to be $9 million ($12.1 million in 2015 dollars) in capital cost with $900,000 ($1.2 million in 2015 dollars) in annual operation and maintenance needs; and the fish ladder was estimated at $41.7 million ($55.8 million in 2015) in capital cost with $4.2 million ($5.6 million in 2015) in annual operation and maintenance costs.

At Oxbow, the trap and transport option was estimated to be $6.8 million ($9.1 million in 2015) for capital cost with $700,000 ($937,000 in 2015) for operation and maintenance; and the fish ladder was estimated as $11.1 million ($14.8 million in 2015 dollars) in capital cost with $600,000 ($803,000 in 2015 dollars) for operation and maintenance.

For the Hells Canyon Reservoir, a trap and transport system was estimated to be $4.2 million ($5.6 million in 2015 dollars) in capital cost with $400,000 ($536,000 in 2015 dollars) for operation and maintenance; and a fish ladder was estimated to be $24.9 million ($33.3 million in 2015 dollars) with $1.2 million ($1.6 million in 2015 dollars) for operation and maintenance.

In 2013, IPC evaluated the cost of a downstream surface collector constructed on the face of Hells Canyon Dam. The structure was estimated at $72.5 million ($73.8 million in 2015 dollars) ± 30 percent (Chandler pers. comm).

Results:

Effectiveness of Upstream Fish Passage:

The upstream adult trap below Oxbow appeared to work relatively well. The trap proved to be effective and the tagging studies showed that the adults successfully spawned above Brownlee.

Effectiveness of Downstream Fish Passage:

The juvenile net collection system in the Brownlee Reservoir failed to function adequately due to many factors including a lack of knowledge and time, and environmental factors.

Lack of knowledge in:
- Juvenile passage systems
- Fish migration behavior in Brownlee Reservoir

- Water quality issues of the reservoir
- Proper netting material and design

Time:

- The condensed timeframe made available to the IPC and fishery agencies to conduct studies, and design and implement fish passage was two years and nine months and was considered too little time to understand and complete the full scope of the project
- Many biological studies that were planned were not executed due to lack of time

Environmental factors:

- Agricultural, industrial, and municipal waste entered the reservoir, influencing the levels of dissolved oxygen
- High summer surface temperatures
- Increase in reservoir predators
- Length and size of the reservoir

Summary of Results:

In the rush to establish the Hells Canyon Complex (given the timeframe of permit issuance from the FPC) and benefit from new hydropower production, adequate time was not properly allotted to conduct the studies and experiments necessary for successful fish passage. Additionally, new dam construction was being considered at sites on the Snake River downstream of Hells Canyon Dam, so uncertainty was prevalent at the time, especially in what type of fish passage would be needed in the future and if any fish passage implemented at the time would suffice for any future construction. The inadequate amount of time to conduct the necessary studies was the biggest problem in successful passage at Brownlee and in the Hells Canyon Complex as a whole. Had the time and resources been allotted to examine the environmental factors, the fish behavior in the reservoir, and the reservoir conditions and operations, passage either could have been implemented differently or not at all, which could have saved the money and time invested in the passage systems.

Other Potential Factors to Consider:

- Specific to the attempt in the mid-1900s:
    - FPC relicensing timeframes and limitations
    - The number of other mainstem Snake River dams planned for construction downstream and uncertainty about their fish passage capabilities.
- Relative to the history described above and the questions of pursuing fish passage at the HCC today:
    - Federal and state fish management authorities to prescribe or mandate passage
    - Differing positions regarding reintroduction by those working in the area

- Habitat suitability and availability above Hells Canyon Dam
- Fish behavior and predation in Brownlee Reservoir
- The impact to the tribes from the loss of anadromous fish in historic habitats
- Availability of fish and hatchery resources necessary to support reintroduction

Location of Study: Lewis River Hydroelectric Project – Merwin and Swift

Lewis River; Lewis Subbasin; Southwest Washington; in the Columbia River Basin

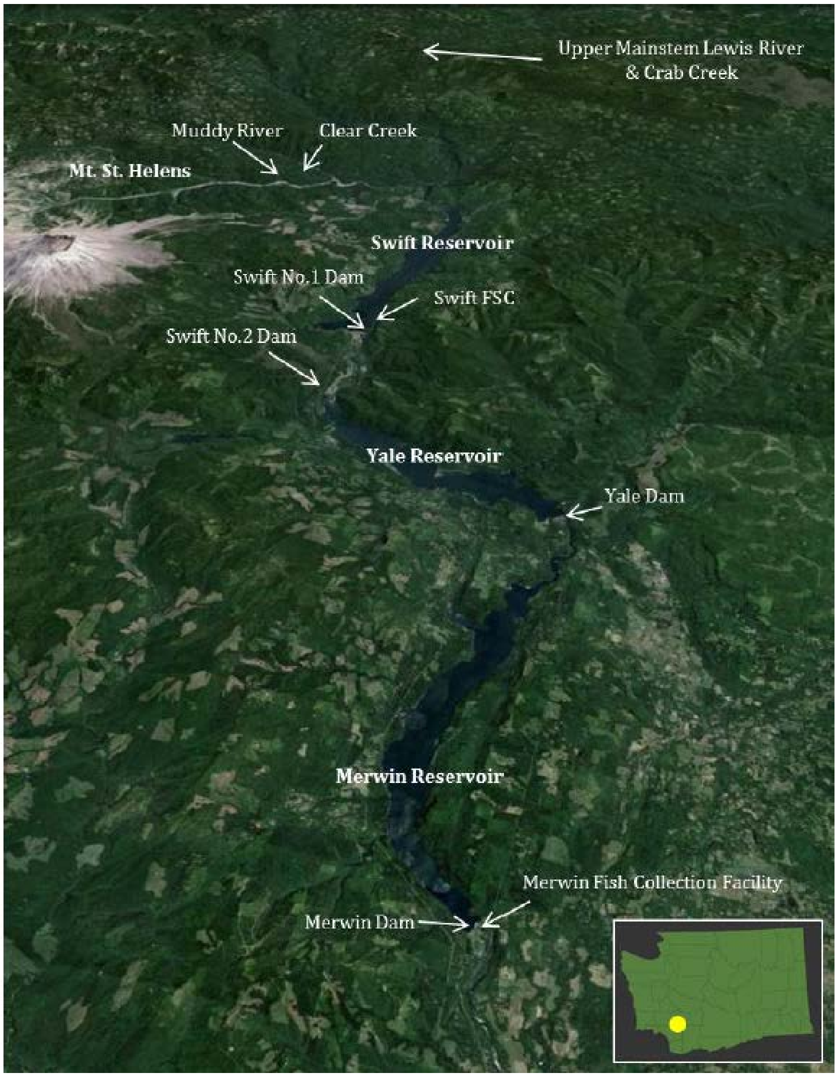

Figure 17. Map depicting location of the Lewis River Hydroelectric Project including Merwin and Swift

To view this passage location in relation to the others evaluated in this staff paper, please view [this map].

Site specifications:

Merwin Dam:

- 313 feet high
- 1,250 feet in length
- 135 megawatt production capacity
- Re-regulation dam used for power and power storage

Merwin Lake (Reservoir):

- 14.5 miles long
- 263,700 acre feet of storage

- 188 feet of hydraulic head
- 239.6 feet at full pool
- 165 feet at minimum pool

Swift Dam:

- 512 feet high
- 2,100 feet in length
- 240 megawatt production capacity
- Storage dam used for power and power storage

Swift Lake (Reservoir):

- 12 miles long
- 1,000 feet above sea level at full pool
- 878 feet above sea level at minimum pool

Species of Interest:

Spring Chinook, early-run Coho, winter steelhead

Passage Type:

Juvenile downstream passage: trap and haul with Floating Surface Collector (FSC) and guide nets in the Swift Reservoir
Adult upstream passage: trap and haul with an adult collection facility at the base of Merwin Dam

2004 Settlement Agreement and the Reintroduction Program:
In 2004, in preparation for the 2008 FERC relicensing of the Lewis River Hydroelectric Projects, a Settlement Agreement was signed between the Settlement Parties[58] and the Lewis River Hydroelectric Projects (Lewis River Projects) owners and operators, PacifiCorp and Cowlitz PUD. This Settlement Agreement was sent to FERC along with proposed license articles. The centerpiece of the 2004 agreement was a reintroduction program, a component of which focuses on providing fish passage and connectivity for anadromous salmonids. The overarching goal of the reintroduction program is to, "achieve genetically viable, self-sustaining, naturally reproducing, harvestable populations of anadromous salmonids upstream of Merwin Dam" (PacifCorp 2004). Reintroduction of anadromous fish will:

- "Assist in the recovery of natural runs of Chinook, steelhead, and Coho;
- Reconnect fish habitat and fish populations in the basin,
- Support interconnected and spatially distributed populations of anadromous fish; and

[58] National Marine Fisheries Service; National Park Service; U.S.Bureau of Land Management; U.S.Fish and Wildlife Service; USDA Forest Service; Confederated Tribes and Bands of the Yakama Nation; Washington Department of Fish and Wildlife; Washington Interagency Committee for Outdoor Recreation; Cowlitz County; Cowlitz-Skamania Fire District No. 7; North Country Emergency Medical Service; the City of Woodland; Woodland Chamber of Commerce; Lewis River Community Council; Lewis River Citizens At-Large; American Rivers; Fish First; Rocky Mountain Elk Foundation, Inc.; Trout Unlimited; and The Native Fish Society.

- Provide marine-derived nutrients and trace elements to support reintroduction and to benefit riparian habitats and riparian-dependent wildlife" (PacifCorp 2004).

The agreement makes it clear that full benefits from the program will not be seen for many years. The Services[59] shall determine whether the "reintroduction outcome goal" that was set forth in the Settlement Agreement has been achieved for each North Fork Lewis River anadromous fish population that is being transported. It was noted that it would likely take several life cycles to determine whether the program was succeeding and how out-of-basin effects were impacting the initiative. It was anticipated that lessons learned from reintroduction above Swift No. 1 could be applied later to reintroduction in Yale Lake and Merwin Lake, the two reservoirs between Merwin and Swift dams.

Passage is an important component of the reintroduction program. The following performance standards are used annually to evaluate and adaptively manage passage facilities:

- 98% adult trap efficiency[60]
- 95% juvenile collection efficiency[61]
- 99.5% smolt collection survival[62]
- Less than or equal to 2% injury
- 80% overall downstream survival[63]
- 99.5% upstream passage survival[64] (PacifiCorp 2011)

Currently Merwin upstream and Swift 1 downstream collectors are in place. Additional passage at Merwin, Yale and Swift 1 dams are scheduled for years 13 and 17 unless the Services determine that reintroduction or fish passage for anadromous fish is inappropriate. In addition to annual evaluations, time was planned following the construction of the fish passage facilities should structural modifications be needed to meet the fish passage performance standards as part of the re-introduction program. Built into the reintroduction program are status checks at 27 years and 37 years to ensure that reintroduction outcome goals for each species are met or are on target to be met. If the progress is not sufficient at the check-ins, there are detailed processes in place to get the program on track. (PacifiCorp 2004)

The settlement agreement lays out a phased approach to reintroduction and passage at the Lewis River Projects. This allows the parties involved to learn and adaptively manage along the way, and spread the cost of new fish passage over a reasonable amount of time. The long-term goal of the reintroduction program is to "achieve genetically viable, self-sustaining, naturally-reproducing, harvestable populations of

[59] National Marine Fisheries Service; National Park Service; U.S. Fish and Wildlife Service; USDA Forest Service.
[60] Adults actively migrating past and trapped by the trap.
[61] Juveniles available and collected by the collection facility.
[62] Juveniles that leave release ponds and are successfully collected at the collection facility.
[63] Juveniles that have entered the reservoirs and survive passage through to below Merwin Dam.
[64] Adults that survive the trap and transport process.

anadromous salmonids upstream of Merwin Dam" of which passage is an important component. (PacifiCorp 2004)

As of the 2014 Annual Report, whether work moves beyond the first phase of fish passage will be discussed in 2017 (PacifiCorp 2015).

The Swift Dam downstream juvenile collection facility:

Figure 18. View of the Swift surface collector. (Photo courtesy of Jim Ruff)

A floating surface collector (FSC) near the turbine intake at Swift No. 1 was constructed and began operating in December 2012. It consists of: a fish collection barge, truck access trestle and mooring tower, and barrier net and net transition structure (NTS). Swift's juvenile collection system is similar in design to the FSC and NTS in operation at the Upper Baker Dam. The FSC is 170 feet long, 60 feet wide, and 53 feet tall and provides attraction flow for the juvenile salmonids to enter the NTS. The NTS has a funnel design and electric pumps, both of which keep the flow moving quickly into the collector and create a stream channel with a capture velocity of about 7 feet per second with 600 cubic feet per second attraction flow during normal operations. The fish are attracted and "captured" within the stream channel, which guides them into the collection facility where they are sorted by life stage and into holding tanks for sampling and transport.

The access trestle, which is 660 feet long, allows for truck access to the mooring tower. The mooring tower, which is 280 feet in height, also acts as the transfer structure to move the fish from the collection container to the truck, which can be done at any level within the 120-foot operating range of reservoir elevations at Swift. The exclusion net, which attaches to the NTS and is anchored on each shore, is similar to that used at

Baker Dam: with a forward-facing exclusion net made of a Dyneema nylon, a high-strength synthetic fiber, with the upper section being solid, the middle being a fine net with 1/8” mesh opening, and the lower part having 3/8” mesh opening. The two side nets attach from either end of the exclusion net to the shore and are made up of Dyneema nylon with 1/8” mesh opening in the upper section and the lower part 3/8” mesh opening. After installation the area experienced severe weather and debris and the net was damaged in the two spots where the exclusion net meets the side nets, which proved to negatively impact the collection during the 2013 migration season before the damage could be repaired. (PacifiCorp 2015).

The FSC operates continuously 24 hours a day year-round except during power loss or when facility modifications or maintenance is needed. In 2014 this occurred six times, mostly for scheduled repairs. (PacifiCorp 2015)

Figure 19. Entrance to the Swift surface collector. (Photo courtesy of Jim Ruff)

The Merwin Dam upstream adult trap facility:

An adult capture facility already existed at the base of Merwin Dam but was in need of upgrades. A phased approach was put in place to design and construct modifications that were needed at the existing trap. In 2013 it was decommissioned for renovations and the facility was considered substantially completed in 2014. Four major features were the focus of the renovations: an auxiliary water supply (AWS) pump station and conveyance pipe, upgrades to the fishway entrance, a lift and conveyance system, and a sorting facility. (PacifiCorp 2016)

The AWS pumps water from the tailrace into the fishway entrance pools, via the 108-inch conveyance pipe, to attract the adult fish arriving into the tailrace. The fishway entrance is adjacent to discharge from a turbine unit and is followed by a series of pools and vertical-slot style fish ladders with 30 cfs attraction flow. This style of fish ladder allows the water surface elevations to be self-regulated by the pool levels. The last pool, the loading pool, contains a fish crowder that loads fish into the water-filled hopper that is part of the lift and conveyance system that transports fish from the ladder to the sorting facilities. (PacifiCorp 2016)

Fish are manually sorted by biologists daily. First an electro-anesthesia (EA) system temporarily anesthetizes the fish to reduce the stress that can occur for the fish during sorting. After sorting, fish are placed in holding tanks for transport to their release location upstream, to the hatchery, or returned to the lower Lewis River for Washington Department of Fish and Wildlife's Fish Recycling Program. (PacifiCorp 2016)

The Merwin adult collection facility operated 24-hours a day during 2015, except when the facility needed modification, scheduled maintenance, or repairs. (PacifiCorp 2016)

Timeline:

2004: Settlement Agreement with Reintroduction Plan

2008: FERC license issued

2012: Juvenile passage facilities begin operation

2013: Existing adult trap at Merwin Dam was decommissioned for renovations

2014: Renovations of adult trap is complete and trap begins operation

Additional Studies Needed or Underway:

In 2015, the Swift FSC collected 47,832 juvenile salmonids, with 39,483 transported and released below Merwin Dam with Coho salmon making up most of the juveniles (Coho 81 percent; spring Chinook 14 percent, steelhead 3 percent, and coastal cutthroat trout 2 percent). A biotelemetry study to measure the collection efficiency of the FSC has been conducted since the pilot study in 2013, first using radio-telemetry, and then switching to acoustic telemetry in 2015. For this study, the zone of influence is the 150-foot radius immediately outside of the NTS; it is influenced by the attraction flow of the FSC. If a juvenile is detected within the zone of influence, then it is considered available for collection. The 2015 study not only provided information on collection efficiency but also on approach behavior of smolts and the potential thermal effects on passage success rates. Over 75 percent of the tagged smolts passed at water temperatures less than 15°C, but overall no significant effect from temperature was observed. (PacifiCorp 2016)

In 2015, a total of 200 smolts were tagged with an acoustic transmitter and a PIT tag and released at the head of Swift reservoir. Nearly all of the 200 fish were detected within 650 feet of the FSC, and 159 of the 200 tagged fish were detected in the zone of influence. This and other studies in the reservoir show that fish move easily and widely in the forebay and have been found to be spread throughout the forebay and cross the length of the reservoir multiple times. Collection efficiency was significantly low in the

2015 study with an overall collection efficiency of 13.2 percent.[65] Steelhead collection efficiency was 18.6 percent, and coho was 11.8 percent. Conclusions drawn from this study are that smolts of all species enter the forebay evenly between the north and south shorelines; once they are in the forebay, over two-thirds of the tagged smolts approach the FSC from the south; approximately 90 percent of the smolts pass within 650 feet of the entrance of the FSC. Researchers plan to continue this study to evaluate operational and structural options for the FSC. (PacifiCorp 2016)

Costs:

Capital cost:

Downstream juvenile collection: $62 million ($64 million in 2015 dollars)
Upstream adult trap: $60 million ($60.1 million in 2015 dollars)

Annual O&M:[66]

Downstream juvenile collection: $300,000 ($309,700 in 2015 dollars)
Upstream adult trap: $200,000 ($200,200 in 2015 dollars)

Results:

Effectiveness of Upstream Fish Passage:

In 2014, the first year of use for the renovated Merwin Trap, 31,944 adult fish were captured including hatchery summer steelhead (12,994 total), early-run Coho (12,136), late-run Coho (3,221), winter steelhead (1,601), spring Chinook (934), various resident fish (692), and fall Chinook (366). Of those fish, 1,033 winter steelhead, 9,179 early Coho, and 42 cutthroat trout were trapped, transported, and released upstream above Swift Dam for reintroduction with the remainder taken to the hatchery. In 2015, 15,597 fish were captured at the trap, with the majority being summer steelhead again. The full analysis for the adult collection efficiency of the renovated facility for 2015 was not complete at the time of this staff paper, but 2015 was a drought year with low flows and high water temperatures throughout the Northwest. (PacifiCorp 2015; PacifiCorp 2016)

The Settlement Agreement requires that upstream passage survival (UPS), which is defined as survival from the entrance to the adult trap to the release above Swift Dam, of adult salmonids and bull trout should be greater than or equal to 99.5 percent. In 2014, the project had 99.96 percent UPS. In 2015, all 5,008 adult salmonids that were trapped, transported, and released above Swift survived, resulting in a UPS of 100 percent. (PacifiCorp 2015; PacifiCorp 2016)

[65] Juvenile collection efficiency criteria for Swift is 95%.

[66] O&M requirements of juvenile passage facilities at high-head dams can be a substantial investment and technically challenging given the size and complexity of the facilities and since many are located in reservoirs with large fluctuations in water surface elevation and with large debris loads.

Effectiveness of Downstream Fish Passage:

The Swift FSC began operating in 2012 and has experienced some problems in the first few years of operation. First the damage to the net made for inefficient collection in 2013, and then the screw trap used in 2014 to collect the fish for PIT tagging only collected a fraction of what the biologists expected to collect. An overall downstream survival (ODS) of 80 percent or greater is required in the Settlement Agreement and is based on a goal of having 996 tagged fish per species in the M&E Plan. ODS is measured as the percent of PIT-tagged juvenile salmon coming from the head of Swift Reservoir to enter the Lewis River below Merwin Dam via either the juvenile collection system or passage via turbines.

In the 2014 migrating season, the sample size was much smaller than the goal due to limited screw trap collections (while 996 fish per species was the goal, only 140 Coho, 201 Chinook, and 57 steelhead were able to be captured, tagged, and released at the head of the reservoir). With these small sample sizes, the weekly ODS reached 66.7 percent with an annual average of 31 percent for Coho, 12.3 percent for steelhead, and 0 for Chinook. At this early point in the collection and operation of the FSC, it is too early to determine accurate success metrics. (PacifiCorp 2015)

In 2015, the goal of 996 tagged fish per species was not met again because of a lack of fish being captured by the screw trap. Instead only 382 Coho, 37 Chinook, and 117 steelhead were tagged and released; hence, the ODS estimates are uncertain and low. Coho had 6.5 percent ODS, 0 percent for spring Chinook, and 12.8 percent for steelhead. PacifiCorp will continue to conduct this study in 2016, but in order to reach the necessary amount of tagged fish will use fish that have already been collected at the FSC if not enough fish are captured in the screw trap. (PacifiCorp 2016)

Survival rates at the FSC in 2015 ranged from 89.4 percent to 99.6 percent with steelhead having the highest survival rate (99.6 percent), then Coho (98.9 percent), cutthroat (98.7 percent), spring Chinook (97.6 percent), bull trout (95 percent), and adult steelhead (89.4 percent). Overall, the survival rates appear to be high, but a more rigorous statistical analysis is needed. Almost all mortality was caused by debris accumulation on the fish sorting bars in the holding tanks. PacifiCorp is considering modifications to help alleviate this debris problem. Additionally, as noted above, the biotelemetry study conducted since 2013 found that there was no significant effect from temperature on the juvenile's ability to find the collection facility. The study also found that once the smolts are in the forebay, they approach the FSC from the south regardless of which side of the forebay they entered. (PacifiCorp 2016)

Summary of Results:

The fish passage facilities at the Lewis River Projects have been recently constructed and placed into operation, being in operation from 2012 for the FSC and 2014 for the adult trap. Major actions identified to improve collection efficiency have been implemented and are being tested (i.e., improving fish guidance with nets and booms), but it is premature to expect definitive results. However, PacifiCorp appears to be learning and adaptively managing with the unexpected impacts occurring at the FSC facility and the low juvenile collection at the screw trap affecting the monitoring results.

Location of Study: Pelton Round Butte Complex

Deschutes River; Deschutes Subbasin; Central Oregon; in the Columbia River Basin

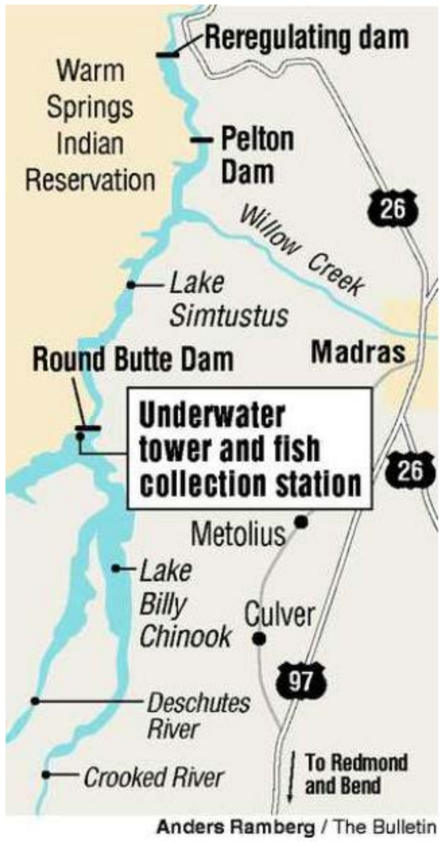

Figure 20. Map depicting location of the Pelton Round Butte Complex

To view this passage location in relation to the others evaluated in this staff paper, please view [this map].

Figure 21. Overview of the Pelton Round Butte surface collector and selective water withdrawal tower. (Photo courtesy of Portland General Electric)

Site specifications:

Pelton Dam:
- 306.9 miles from the mouth of the Columbia
- 204 feet high
- 636 feet in length
- 108 megawatt production capacity

Lake Simtustus (Reservoir):
- 8 miles in length
- 31,000 acre feet of storage
- 153 feet of hydraulic head

Round Butte Dam:
- 314.7 miles from the mouth of the Columbia
- 440 feet high
- 1,382 feet in length
- 338 megawatt production capacity
- Used for power and power storage

Lake Billy Chinook (Reservoir):
- 28 miles in length
- 365 feet of hydraulic head
- 415 feet at full pool

Passage Type:

Juvenile downstream passage: Floating juvenile surface collector with selective water withdrawal tower used in a trap and haul system
Adult upstream passage: Adult trap used in trap and haul system

Fish passage began at Pelton Round Butte in 1964 with a downstream surface collector, fish ladder, and transport hopper system for upstream and downstream migration of Chinook, steelhead, and sockeye. It was soon determined that confounding surface currents and water temperatures in Lake Billy Chinook were making it difficult for the juveniles to find the surface collector. In 1966, PGE abandoned the fish passage system and later began funding a hatchery program for the Oregon Department of Fish and Wildlife to mitigate for the loss of anadromous fish in the upper Deschutes River. In the mid-1990s, PGE revisited fish passage and began a design to accommodate passage and water temperature issues in anticipation of the FERC relicensing process that was approaching. (Corson 2012)

Pelton Round Butte is co-owned and operated by the Confederated Tribes of the Warm Springs (CTWS) and Portland General Electric (PGE). Pelton Round Butte is a hydroelectric complex made up of three hydropower facilities (listed here from upstream to downstream): Round Butte, Pelton, and a re-regulating dam. As part of the 2005 FERC license, the co-owners produced a Fish Passage Plan, whose goals and objectives are:

- “Establish self-sustaining, harvestable populations of steelhead, spring Chinook, and sockeye in the Deschutes River Basin to fully utilize the available habitat and production capability
- Provide access to habitat to support a self-sustaining fishery
- Support the contribution of salmon, steelhead, and other native species to a healthy ecosystem
- Provide access to and through project waters for Pacific lamprey, summer/fall Chinook, rainbow trout, bull trout and other native fish species
- To contribute to recovery efforts for Middle Columbia steelhead” (Gauvin 2012)

Pelton Round Butte’s fish passage system consists of an adult trap below the re-regulation dam and a floating juvenile collector above Round Butte. The juvenile collector is at the dam in Lake Billy Chinook, the reservoir created by Round Butte Dam. The collector is located at the top of a Selective Water Withdrawal tower (SWW), which was built and operates to regulate water temperatures below the dam to be similar to pre-project temperatures, modify surface currents to support fish collection, and stimulate water flows for power generation. After careful study by the co-managers, a blend of nutrient-rich surface water and cooler bottom water was created to be flushed downstream to remove the project’s influence on water temperature. Pre-SWW, the lower Deschutes was artificially cool in the spring and artificially warm in the late summer and fall. Modeling indicated this was not beneficial to native fall Chinook salmon and trout populations immediately downstream of the project. On August 12, 2016, the Deschutes River Alliance filed a lawsuit against PGE in the U.S. District Court of Oregon. The lawsuit cites violations of the Oregon Department of Environmental Quality’s water quality requirements of the project, specifically the temperature of water released downstream from the complex and the associated violations of pH levels and dissolved oxygen levels. More recently, PGE filed a motion with the District Court to dismiss the lawsuit with prejudice. The court has not yet ruled on this motion. (Corson 2012; DRA 2016; Columbia Basin Bulletin 2016)

Juvenile downstream passage and the SWW:
The SWW was constructed in pieces on barges in the forebay and then anchored directly in front of the intake for the powerhouse of Round Butte Dam. It is 273-feet tall, with widths ranging from 60 feet to 90 feet. At the top of the structure is the surface collector (40 feet deep) where fish are collected into two V-screens and then sorted by size with larger fish (bull trout and kokanee) returned to the lake, and the smaller juvenile salmon and steelhead are tagged in the floating fish transfer facility that is next to the collector and then loaded into a truck to be transported and released downstream of the re-regulating dam below both Round Butte and Pelton dams. All fish that enter the collector are handled and marked to indicate that they originated upstream of the project. The smolt transfer trucks are 650 gallons, can carry 3,500 smolts at one time, and maintain temperature for the 10-mile, 35-minute drive to the lower Deschutes River below the complex. (Corson 2012; Madden 2016)

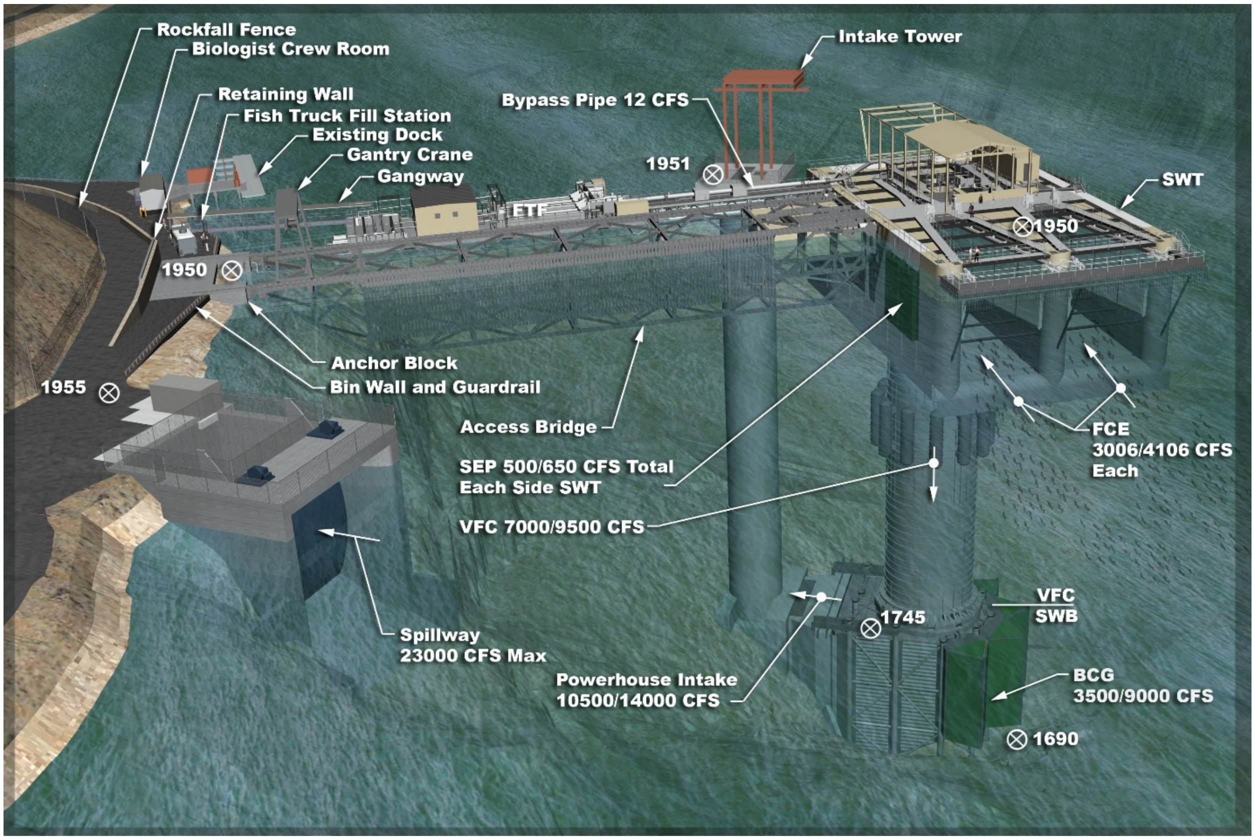

Figure 22. Schematic of the selective water withdrawal tower and surface collector at Pelton Round Butte. (Image courtesy of Portland General Electric)

Adult upstream passage:
Upstream adult fish passage occurs through trap and haul operations. The Pelton trap sits below the re-regulating dam and began operation in 1956. Since 2010, a varying proportion of upstream-origin fish returning to the Pelton trap have been either transported above the project and allowed to spawn, or used as broodstock for the Round Butte Hatchery reintroduction program. Those released in the reservoir are tagged for PGE and CTWS biologists to track their movement and success in spawning upstream. Only fish with marks indicating they originated upstream of the project are allowed to be passed back upstream. (PGE and CTWS 2015)

Species of Interest:

Spring Chinook, summer steelhead, sockeye

Timeline:

1958: Pelton and the Re-Regulating dams are completed; a permanent adult trap facility is constructed

1964: Round Butte dam is completed; upstream and downstream fish passage implemented (a gulper, ladder, and transportation system)

1966: Fish passage system is proven ineffective and decommissioned

1968: PGE begins funding a hatchery for Oregon Department of Fish and Wildlife

2002: CTWS acquire partial ownership of Pelton Round Butte

2005: FERC license is issued; the co-owners agreed to spend $130 million on fish-related projects in the Deschutes Basin over the 50-year operating period of the new license

2007: Construction of the Selective Water Withdrawal tower (SWW) began

2009: SWW and juvenile surface collector begin operation

2010: Juvenile release facilities construction completed

2011: First adults return from fry/smolt releases

2012: First adults passed above project

2013/2014: Guidance net studies conducted

Additional Studies Needed &/or Underway:

A study was recently completed to evaluate flows near the fish entrances and determine if the installation of guide nets could improve fish collection; the co-owners are seriously considering it. The co-owners are currently conducting studies to learn more about survival in the Deschutes River such as migration timing, predation, and disease. Like all dams with fish passage facilities, one factor they cannot account for is ocean conditions, and that could play a major role in the number of adults returning.

PGE is currently conducting studies on juvenile fish migration that focus on determining: 1) the number of smolts entering the reservoir from each tributary (specifically the Metolius River, Whychus Creek, and the Crooked River)[67]; 2) the timing and number of salmon and steelhead emigrating from the reservoir; and 3) the percentage of fish that enter the reservoir and successfully enter the SWW. As part of this study, increased flow at night (8pm-5am) was experimented for 18 days because the biologists observed that the salmonids were attracted to more flow and tended to pass more in the evening and early morning. 100 juvenile Chinook were released in the forebay each evening prior to the increase in generation. A complete analysis will be released in the summer of 2016, but at this time Hill (2016) says that the highest Chinook passage for 2016 was seen under these conditions. PGE plans on producing more night generation for longer in the 2017 season to see if numbers continue to improve. PGE is also examining juvenile migration downstream as they migrate toward the Columbia on their journey to the ocean. For this study, biologists used radio-telemetry to determine where delays in migration and mortality might be occurring, as well as the estimated travel time to the mouth of the Deschutes River. Adult salmon and steelhead migration, spawning, and

[67] The historical barrier to anadromy on the Deschutes is at Big Falls, essentially blocking the upper Deschutes. Therefore, the upper Deschutes was not a location chosen for this study since very little habitat is available. Most of the habitat is in Whychus Creek, a tributary to the Deschutes.

competition, and overall fish health is also being studied by the utility. (Hill 2016; Quesada 2016; Bennett 2016; Stocking 2016)

The Confederated Tribes of the Warm Springs (Warm Springs) and the Columbia River Inter-Tribal Fish Commission (Fish Commission) are conducting a sockeye study to examine if a local and historical gene pool for anadromous sockeye is present in the kokanee population in Lake Billy Chinook and its tributaries. Prior to the construction of Round Butte, sockeye populations existed in the upper Deschutes and Metolius rivers. Through the inundation of the river and the creation of Lake Billy Chinook, the sockeye population was landlocked and continued on as kokanee. Via tissue samples, the Warms Springs Tribe and Fish Commission have found that the kokanee population of Lake Billy Chinook is more consistent with the genes of kokanee than with the genes of sockeye, meaning that they likely will not pass through the fish passage system and return to their spawning grounds as a sockeye population would. This work is ongoing and final results have not been released at the time of this staff paper. (Matala and others 2015).

Costs:

$115.14 million ($125.2 million in 2015 dollars) has been spent in total; PGE’s share is $76.8 million ($83.5 million in 2015 dollars) with the remainder coming from the CTWS (PUC 2010).

Site Results:

Effectiveness of Upstream Fish Passage:

Survival criteria for upstream (adult) passage was set at 95 percent during the first five years of operation and 98 percent for all years following (ODFW 2008). These goals have been met each year of operation. The co-owners do not have a numerical goal for smolt-to-adult return rates, although they remain too low to reach the goal of sustainable runs. (Hill pers. comm.)

Effectiveness of Downstream Fish Passage:

The project co-owners aimed for 50 percent reservoir passage efficiency in Phase I, and since the tower began operating in 2009 they have seen 20-60 percent of the smolts in the reservoir enter the facility. The 50 percent goal was reached in 2011, at which time a goal of 75 percent reservoir passage efficiency was set; the co-owners are working toward that goal now. The project co-owners also set smolt survival criteria at 93 percent for the first five years of downstream passage operations, increasing to 96 percent for all later years. This criteria applies to the collection, transport, and release of smolts below the reregulating dam (i.e., it does not apply to passage through the reservoir). This criteria has been exceeded (≥98 percent) since passage operations began. (ODFW 2008; Madden 2016)

Summary of results:

For the first time in 40 years, salmon and steelhead are migrating and spawning in the Metolius and Crooked rivers and once-blocked areas of the Deschutes River. However, the project has not met its goals as laid out in their 2005 Fish Passage Plan, particularly the goal of establishing self-sustaining populations for steelhead, spring Chinook, and sockeye. Adaptive management, additional studies, and more time are needed to meet survival and adult escapement goals for all species.

Location of Study: Shasta

Sacramento River; Sacramento Basin; Northern California; out of the Columbia River Basin

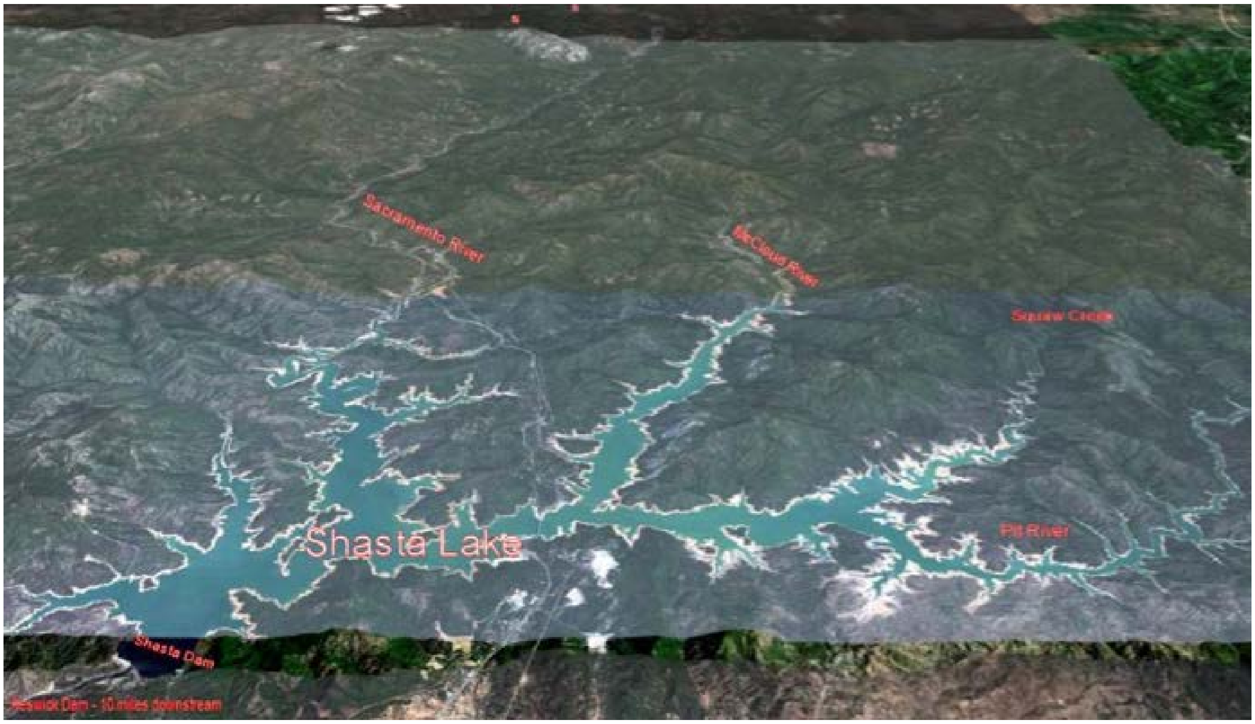

Figure 23. Map depicting location of Shasta Lake

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

Site specifications:

Shasta Dam:

- 620 feet high
- 3,460 feet in length
- 676 megawatt production capacity
- Used for hydropower, water supply, flood control, and recreation

Lake Shasta (Reservoir):

- 22 miles in length
- 4,552,000 acre feet of storage
- 330 feet of hydraulic head

Species of Interest:

Winter-run, spring-run, fall-run, and late fall-run Chinook, and steelhead

Passage Type:

Juvenile downstream passage: Currently none; implementing a passive juvenile collector at the head of the reservoir for use in a trap and haul system

Adult upstream passage: Already existing adult trap for trap and haul system

The Bureau of Reclamation, in response to the 2009 Central Valley Project Biological Opinion, is currently implementing a pilot juvenile collection system at the head of Lake Shasta. The Shasta Dam Fish Passage Evaluation (SDFPE) is an effort to investigate the feasibility of reintroduction above Shasta Dam, particularly into the tributaries above Lake Shasta. Several federal and state agencies are collaborating on a Fish Passage Pilot Implementation Plan. The pilot juvenile collection system is part of this implementation plan. The trap is not yet built and the information provided in this case study is based on biological studies and conceptual design plans to date. (IFPSC 2014)

Given the long length of the reservoir (22 miles), Reclamation decided to locate the collector in the upper portion of the reservoir near the mouth of the McCloud River. The reservoir temperature stratifies in the summer with surface temperatures reaching 80 degrees in the top 30 feet. Following a joint study done by the University of Nevada-Reno and the Bureau of Reclamation on the reservoir temperatures, run timing, and the effects of the use of a temperature curtain, Reclamation decided to incorporate a temperature curtain at the fish trap to keep the cool tributary waters at the trap which should help ensure survival. The fish trap is a passive inclined plane collector, in that it does not require electricity, and uses guide nets to encourage the fish coming into the reservoir up the inclined plane and straight into the trap that floats at the surface at the only hole in the net. The floating trap will be eight feet wide and five feet deep. It will have a debris deflector, a vertically-adjustable inclined plane entrance, live boxes with juvenile refuge baskets, a removable back panel for easy cleaning, and a large platform with hatches for easy access to all areas of the trap. The live box feature is made up of two stacking boxes with a horizontal separator at the entrance of the two. The lower live box will exclude predators by allowing space at the horizontal separator only for juvenile salmon to fit through, and not the larger predators. Predators and debris will be caught in the upper live box that has a 6-inch opening, whereas the lower live box will have openings smaller than one inch. Each live box will be 18-inches deep, four feet long, and three feet wide. (Clancey et al 2016; U.S.Department of Interior 2015)

The trap will be in the middle of the arm of the reservoir at a location less than 300 feet wide, with the guide nets anchored to each shore to create a “V” shape and completely block any passage past the nets. Debris booms are planned upstream at the head of the reservoir and in the McCloud River. The design of the passive collection facility was completed in 2016. Testing is slated to occur later in the year with fish set to release at the end of 2017 during the initial collection season, which is expected to be August through December. One potential issue is debris coming downriver and being trapped by the collection facility. Given the high level of recreation at Lake Shasta, the collection facility will need to be removed when not in use to allow for boating and other water equipment. (U.S. Department of Interior 2015)

Upstream passage is already in place and used in conjunction with the hatchery. A small fish ladder leads into an adult trap at Keswick Dam, the reregulation dam below Shasta Dam. (IFPSC 2014)

Timeline:

1945: Shasta Dam is constructed

2009: The Biological Opinion on the Long-Term Operation of the Central Valley Project (CVP) is released with a Reasonable and Prudent Alternative to evaluate reintroduction of winter-run and spring-run Chinook salmon and steelhead in order to continue operations at the CVP

2015: Preliminary design for juvenile fish passage facility completed

2016: Final design for juvenile fish passage facility completed

2016: Start of the pilot implementation study;

2017: Initial testing of juvenile fish collection facility; juvenile Chinook are expected to be released

2020: Results of the implementation study should be released

Additional Studies Needed &/or Underway:

The California Department of Water Resources (DWR) has been conducting studies in the delta between the ocean and Shasta Dam (which is 250 miles from the ocean) to evaluate fish survival and habitat needs. It is also working on life-cycle models to determine what trapping success rate will be needed. Once the trap is in operation, the juvenile collection efficiency will need to be determined as well as whether any injuries to fish are occurring from the temperature curtain/guide net.

The release of Chinook salmon in late 2017 will mark the start of the pilot study that is slated to finish in March 2020 to provide three years of experimentation. The steering committee anticipates a comprehensive fish passage feasibility report to be released in May 2020. (IFPSC 2015)

Costs:

The total cost for the hatchery and Keswick Dam adult fish trap in 1942 was $2 million ($29.1 million in 2015 dollars). Biological studies currently being conducted are approximately $1.5 million each year, and the passive downstream juvenile fish collection trap costs $2.7 million and includes both the temperature curtain and the trap. (Hannon pers. comm.)

Site Results:

At this point it is too early to provide results for collection and trap and haul of both adults and juveniles at Shasta Dam. Reclamation is currently using models to determine various collection efficiencies and has not yet narrowed down or selected what the success rate of the juvenile collector should be.

Other Potential Factors to Consider:

- U.S. Bureau of Reclamation and tribal agreement on the species of anadromous fish to pass above Lake Shasta.

Location of Study: Willamette Basin Project – Cougar, Detroit, and Fall Creek

Background

The Corps of Engineers' (the Corps) Willamette Project (WP) consists of 13 multipurpose dams and reservoirs, as well as about 92 miles of riverbank protection project (e.g., revetments) in the Willamette River Basin in western Oregon. The Corps operates each project to contribute to overall water resources management in the basin, and for multiple authorized purposes including flood risk management, hydropower, irrigation, navigation, recreation, fish and wildlife, and improved water quality in the basin.

Several fish species have been listed under the Endangered Species Act (ESA) in the Willamette Basin and have been adversely affected by the construction and operation of the Corps' WP dams and reservoirs. Large declines in abundance of the listed salmonid species in the Willamette Basin were noted prior to construction of the WP dams due to commercial and sport fisheries, hatchery practices, poor water quality (domestic and industrial) and habitat degradation (including logging). However, the dams and revetments constructed by the Corps, primarily on eastside tributaries of the Willamette River Basin during the 1950s and 1960s, also contributed to the declines in salmon and steelhead abundance. (COP 2015)

Several fish species were listed as threatened in 1999 under the ESA, including Upper Willamette River (UWR) spring Chinook salmon, UWR winter steelhead[68] and bull trout (*Salvelinus confluentus*).[69] Four of the seven UWR spring Chinook salmon populations, which are located in the North and South Santiam, McKenzie and Middle Fork subbasins, as well as two of the four winter steelhead populations located in the North and South Santiam subbasins, have been affected by WP dams and system operations. The Corps' WP dams have blocked access to a majority of good spawning habitat for spring Chinook and winter steelhead, as well as impacted their production by channelizing the mainstem Willamette River and its major tributaries with revetments, altering flows and sediment dynamics, and impacting water temperatures. (COP 2015)

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[68] UWR spring Chinook salmon and UWR winter steelhead were originally listed as threatened under the ESA in March 1999; the listings were revised in 2005 and 2006, respectively.

[69] Oregon chub (*Oregonichthys crameri*) are also affected by the WP but were officially delisted from the ESA by the USFWS in early 2015.

Figure 24. Map depicting location of the Willamette Basin and its hydroelectric projects

To view this passage location in relation to the others evaluated in this staff paper, please view this map.

In response to the ESA listings, the Corps prepared a Biological Assessment (BA) in 2000 to meet its requirements under Section 7 of ESA for continued operation and maintenance of the WP. A supplemental BA[70] was prepared in 2007 by the three federal action agencies (the Corps, Bonneville Power Administration and the Bureau of Reclamation). NOAA Fisheries subsequently prepared a Willamette Biological Opinion under ESA (2008), which concluded that UWR spring Chinook and winter steelhead would be jeopardized by the continued operation and maintenance of the WP and it included a Reasonable and Prudent Alternative (RPA) to avoid jeopardy. The U.S. Fish and Wildlife Service completed a biological opinion for bull trout (2008), concluding that

[70] The Supplemental BA provided an update on the biological information for ESA-listed species, developed the environmental baseline condition, and an analysis of the effects of a revised proposed action on UWR spring Chinook and UWR winter steelhead.

bull trout would not be jeopardized by continued WP operations if the federal action agencies implemented the NOAA Fisheries biological opinion RPA.

A major objective of the NOAA Fisheries biological opinion RPA is to provide effective fish passage for both UWR spring Chinook and winter steelhead at various WP dams to reintroduce access to historic upstream spawning grounds and increase fish production.[71] To provide an effective fish passage program for spring Chinook and steelhead at select WP dams, the Corps developed a Willamette Valley Projects Configuration and Operation Plan, Phase II Report (called COP) in late 2015. The COP analysis was focused on biological modeling and evaluating the feasibility of several downstream passage alternatives at various WP dams. The analysis provides a timeline for installing fish passage facilities or making operational changes at the dams to attract, collect and safely pass downstream-migrating juvenile fish.[72] (COP 2015)

The Corps' COP (2015) notes the 2007 BA and 2008 RPA call for the following specific priority actions to be implemented, "unless the COP analysis indicated they were infeasible or identified more cost-effective actions:

- Upstream passage improvements (complete Cougar adult trap facility, replace/improve Minto, Foster, Dexter, and Fall Creek adult fish collection facilities;
- Provide downstream fish passage (Cougar, Detroit and Lookout Point); and
- Provide temperature control (Detroit)."

To date, various fish passage actions have already been completed under the 2007 BA and 2008 biological opinion RPA. These actions include construction of two new adult fish facilities (one at the Minto trap downstream of Detroit and Big Cliff dams and another below Foster Dam) for collection and transportation of adults to upstream habitats above these projects; interim operations for downstream fish passage and temperature improvement at several dams; research and improvements to adult fish release sites near spawning grounds above the dams; and research to close data gaps related to alternative selection and design of juvenile fish passage facilities. The Corps also notes, however, that improving downstream juvenile fish passage at WP high-head dams will be challenging and site-specific. (COP 2015)

Corps' COP Criteria and Approach to Evaluating Passage Alternatives

NOAA Fisheries' 2008 biological opinion RPA called for the Action Agencies to evaluate a variety of potential actions intended to benefit ESA-listed fish to avoid jeopardy, and that the biological criteria would be defined during the COP process. The Action Agencies would then present specific implementation plans to NOAA Fisheries and regional parties based on the COP analysis. NOAA would then evaluate whether the

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[71] The NOAA Fisheries biological opinion also includes a variety of measures to minimize take associated with the continued operation of the WP, including minimum flows, reduced project ramping rates, improved adult fish collection and release facilities, water quality improvements, and habitat restoration.

[72] Adult bull trout and steelhead kelt will also pass downstream at some of these juvenile passage facilities.

actions proposed were likely to have the biological results that NOAA relied on in their 2008 BiOp to avoid jeopardy. Thus, the Corps' biological evaluations in the COP were intended to incorporate the biological criteria and an analysis approach similar to what was used in the NOAA Fisheries biological opinion. (COP 2015)

In the COP (2015), subbasin alternatives and systemwide scenarios were evaluated in several steps as shown below in the decision support process table. A science-based decision framework was developed and applied to organize and assess biological, technical and economic data for the wide range of subbasin passage alternatives under consideration in the Willamette Basin. This decision framework aimed to clearly present the tradeoffs associated with different implementation strategies. The criteria applied by the federal Action Agencies determined whether or not the action was: (1) biologically feasible; (2) technically feasible; and (3) cost effective. Documenting uncertainty and impacts (both positive and negative) were important aspects of the framework. In addition, as new information is collected and learned, refined results will be provided to decision makers, i.e., an adaptive management approach. (COP 2015)

COP Phase II Steps

STEP	Corps' Decision Support Process
Step 1	Define project goals, objectives, and constraints
Step 2	Update COP Phase I results and supplement with current data
Step 3	Determine range of alternatives to be assessed
Step 4	Conduct detailed biological analyses for baseline and alternatives (review with WATER[73])
Step 5	Establish subbasin alternatives and system-wide scenarios for assessment (review with WATER)
Step 6	Conduct detailed technical and economic assessments
Step 7	Determine benefits and costs, including uncertainty
Step 8	Determine other potential impacts, including uncertainty
Step 9	Determine significance of impacts (work with WATER)
Step 10	Compile results based on decision-maker input
Step 11	Presentation/discussion with decision makers – Action Agencies select Preferred Plan
Step 12	Repeat decision process (as new data, new measures, etc. are identified)

Table 5. Decision process framework executed by the Corps at their Willamette projects (COP 2015)

The Corps' decision framework, identified above in Table 5, applied a range of specific screening criteria and assumptions to help assess alternative actions in the COP (2015) analysis, which are briefly summarized below:

[73] WATER is the Willamette Action Team for Ecosystem Restoration.

1. *Actions will meet dam safety requirements, and not result in a reduction to the Corps flood risk management mission*.
2. *Any above-dam fish reintroduction efforts must reach "replacement."* Upstream fish passage, and in some cases downstream fish passage, were expected to be via trap and haul, (i.e., not volitional fish passage). Fish passage improvements must allow sufficient passage survival so that the above dam sub-population is able to replace itself on average over time (i.e., enough adult progeny must successfully return and be transported above the dam to seed production of the next generation).
3. *Drainages with both Chinook salmon and steelhead are a priority.* Actions which provide benefits for both Chinook salmon and steelhead species are understood to be of greater value than actions that address only one species.
4. *Improvements for more than one population per species needed.* Improvements for at least two populations per species (Chinook or steelhead) are necessary to spread risks for the species relating to environmental variability and catastrophic events.
5. *Biological Criteria required a System Viable Salmonid Population (VSP) score ≥1.6 above 95 percent confidence interval and two subbasin populations above 2.0.*
6. *A phased approach is preferred.* This approach is intended to reduce risks and apply information gained during the design and implementation steps.
7. *Middle Fork investments are most risky (technically and biologically).* Of the subbasins within the Willamette system, the Middle Fork Willamette (with the exception of Fall Creek) poses the most challenges for reintroducing and establishing a stable population of spring Chinook salmon above the dams. Although Fall Creek is a tributary to the Middle Fork, improvements there were also considered since wild Chinook are established above Fall Creek Dam.
8. *Actions should be cost-effective, including consideration of hydropower impacts*.

The Viable Salmonid Population (VSP) Analysis Framework was used in the COP (2015) process to assess the biological benefit of individual and combinations of actions for achieving population-level goals. The VSP principles were used by the Corps to help form an explicit science-based framework to evaluate population extinction risk. The VSP assessment approach provides a comparable framework to what was used in the NOAA Fisheries 2008 Biological Opinion and 2011 UWR Recovery Plan. Two biological modeling tools, the Species Lifecycle Analysis Module (SLAM) and the Fish Benefits Workbook (FBW), were developed and used to prepare the VSP scores. These tools were parameterized with regional input through the Willamette Action Team for Ecosystem Restoration (WATER). (COP 2015)

The Species Lifecycle Analysis Module (SLAM) was developed by the Northwest Fisheries Science Center (NWFSC). Several workshops (eight) were conducted with WATER in 2014 to develop model input assumptions and provide guidance on model results. Model documentation products and results authored by NWFSC (Appendix C) were reviewed by WATER and the Council's Independent Scientific Advisory Board (ISAB).[74] (COP 2015).

The Fish Benefits Workbook (FBW) methodology and input parameters were developed collaboratively at WATER Fish Passage Team meetings and multiple regional workshops. The workbook documentation was reviewed by regional parties and the model framework, parameters and results were reviewed by the ISAB and WATER (Appendix K). Additionally, model parameter assumptions were provided by WATER and used to test the Fish Benefits Workbook tool.

Cost estimates for design; construction, supervisory, and administration costs during construction; and operation and maintenance costs were also developed by the Corps. All costs were derived using corollary data from similar passage projects completed recently and scaled up or down to the projected design. Cost information was reviewed by the Corps' Cost Engineering Mandatory Center of Expertise (Cost MCX) located in the Walla Walla District. (COP 2015)

Multiple non-monetized impacts were identified for a range of alternatives through the technical assessments. Each impact category was considered for how it would impact decision making. To help simplify the analysis, only the critical impact components were captured for decision makers. Forgone hydropower revenue was also monetized and used for some cost-effectiveness calculations. (COP 2015)

Cougar Dam

Figure 25. Aerial photo of Cougar Dam. (Photo courtesy of the Corps of Engineers)

[74] The executive summary and full report from the ISAB are available at www.nwcouncil.org/fw/isab/.

Location of Study:

The McKenzie River is a 90-mile-long tributary of the Willamette River located in the Willamette subbasin in western Oregon. It drains an area of 1,340 square miles from the Cascade Mountain Range east of Eugene and flows westward into the Willamette River north of Eugene at the southernmost end of the Willamette Valley. Figure 26 shows a map of the McKenzie River watershed, including streams, dams and barriers, current distribution of spring Chinook salmon, and land use.

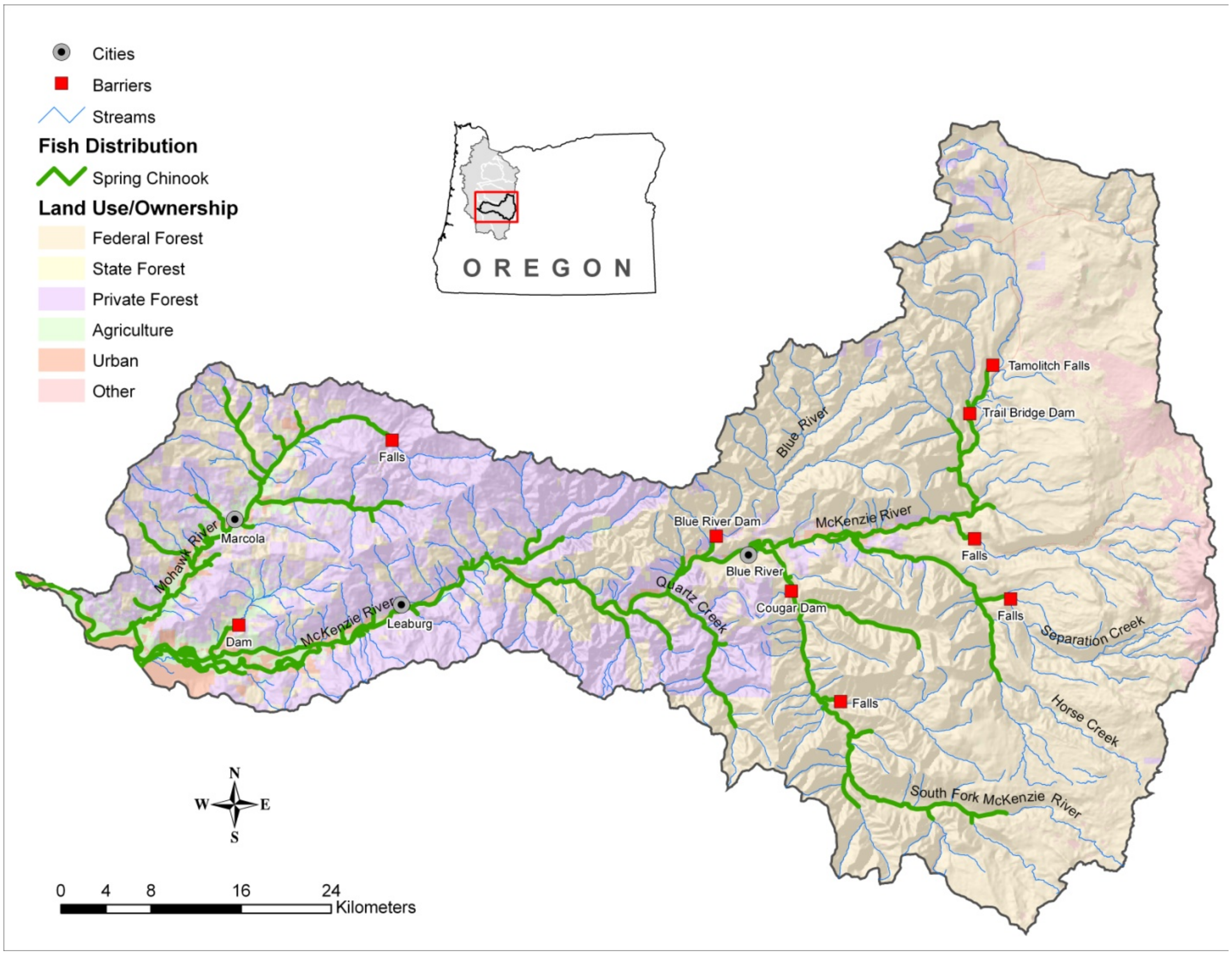

Figure 26. McKenzie River Watershed. (Map courtesy of ODFW)

Site specifications:

Cougar Dam:

- 337.5 miles from the mouth of the Columbia
- 452 feet high
- 1,600 feet in length
- 25 megawatt production capacity
- Storage dam used for flood risk management, hydropower, water quality improvement, irrigation, fish and wildlife habitat, and recreation

Cougar Lake (Reservoir):

- 6 miles in length
- 219,000 acre feet of storage
- 447 feet of hydraulic head
- 1,699 feet at full pool
- 1,532 feet at minimum pool

Physical Features:
Cougar Dam is a 452 foot high, 1,600-foot-long rockfill embankment and has 153,500 acre-feet of flood control storage in its six-mile long reservoir, with a total storage capacity of 219,000 acre-feet. The dam has a penstock to power two Kaplan turbines with a 25-megawatt generating capacity, an emergency spillway with a capacity of 76,140 cfs, a flow-regulating outlet (RO) and a diversion tunnel. The diversion tunnel was built to divert the South Fork McKenzie River during the construction of Cougar Dam; the tunnel was later closed with a concrete plug once the construction of the dam was complete. From 2003 to 2005, new state-of-the-art runners were installed in the turbine-generator units at the Cougar powerhouse, which were designed to resist cavitation and operate more efficiently over the project's 167-foot operating range in head. (Corps 2016a)

Cougar Reservoir is primarily used for flood risk management for population centers downstream in the Willamette Valley, and as such, the forebay elevation is maintained at high elevations during summer months and at low elevations during winter months. The reservoir's maximum pool elevation is 1,699 feet, and while the maximum conservation pool level of 1,690 feet is typically reached in May, the normal minimum flood-control pool elevation of 1,532 feet is usually reached in December.

Two dams were constructed by the Corps in the McKenzie River subbasin. Cougar Dam was completed in 1963 and is located at river mile 4.4 on the South Fork of the McKenzie River and is about 338 miles from the mouth of the Columbia River. Blue River Dam was constructed in 1968 and is located at river mile 1.8 on the Blue River, a tributary to the McKenzie.[75] (Corps 2016)

Passage Improvements Implemented:
In 2005, the Corps constructed a temperature control tower at Cougar Dam to help regulate the water temperature released to the river below the dam to help reduce the negative effects on salmon migration and provide improved attraction of adult salmon to the project. The temperature control tower passes water to the RO and to a powerhouse penstock through a common wet well. In addition, a new adult fish collection and sorting facility was completed at Cougar in 2010 that provides for safe and improved collection,

[75] Various small diversions and canals are also located on the McKenzie River, as well as other hydropower dams, including Leaburg Dam (located at river mile 29 and part of the Leaburg-Walterville Hydroelectric Project) and the Carmen-Smith Hydroelectric Project (at river mile 82), both of which are owned and operated by Eugene Water & Electric Board (EWEB). In 2005-2006, EWEB outfitted Leaburg Dam with new adult fish ladders, improved its existing screened diversion intake at Leaburg and fully screened its Walterville diversion intake.

sorting, and transport of adult fish (both Chinook salmon and bull trout) above the dam. (COP 2015)

Currently, there are no facilities actively providing downstream fish passage at Cougar Dam. Downstream-migrating juvenile fish exit the project via either the RO or the turbines at the dam, as both outlets are located within the existing temperature control tower. As noted above, the Corps' baseline operation at Cougar Dam is to draw down the reservoir to elevation 1,532 feet during December and January each year for flood risk management. Based on radio-telemetry data collected at Cougar Dam during 2012, the dam passage efficiency[76] for spring Chinook salmon ranges from about 11 percent (SE[77]=1.5 percent) at the highest reservoir elevations (elevation range between 1,690 to 1571 feet) in the spring to about 58 percent (SE=2.4 percent) for hatchery Chinook and roughly 65 percent (SE=7.0 percent) for wild Chinook at lower pool levels (elevation ranges from 1690 to 1500 feet) in the fall. (Beeman et al. 2014b) Juvenile fish survival[78] rates in late 2012 ranged from nearly 46 percent (SE=5.4 percent) under a small RO gate opening (e.g., low RO flow) to nearly 74 percent (SE=11.6 percent) under a large gate opening (e.g., high RO flow).[79] Based on radio telemetry data in November 2011, Beeman and others (2012) estimated that dam passage single-release survival of radio-tagged subyearling Chinook salmon from entry into the temperature control tower to a detection site 3 km downstream was 0.386 for fish passing through the turbines and 0.425 for fish passing through the RO at Cougar Dam.

The results from these studies indicate that entrainment and survival of juvenile salmonids passing Cougar Dam varies with dam operating conditions. The condition that appears most conducive to dam passage was the higher discharge, low pool elevation condition tested during December 2012, including large RO gate openings, which was the condition with the highest dam passage survival. (Beeman et al. 2014a)

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[76] Dam passage efficiency (DPE) values are based on radio-telemetry (acoustic) tag studies conducted at Cougar Dam. DPE values vary by season and the amount of time the reservoir is operated at a selected elevation, e.g., the shorter the reservoir is operated at a given elevation, the less time a tagged juvenile fish has to pass the dam. Also, since acoustic tag life is relatively short (weeks), and some fish may take months to migrate out of the system, some tagged fish may have passed the dam when tags were not functioning. These two factors likely resulted in lower estimates of DPE than would have occurred if the reservoir was operated at a specific level over the entire migration period

[77] The standard error (SE) is a measure of the statistical accuracy of an observation or estimate.

[78] Survival estimates of juvenile fish passing through the turbines and ROs at Cougar were based on the results of mark-recapture studies using HI-Z balloon tags, radio-telemetry (acoustic tag), PIT tags, marked fish, etc. Each tagging technology measures mortality over various time periods and distances. Thus, the amount of direct and indirect mortality included in the survival estimate varies by technology. For example, HI-Z balloon tag studies measure survival rates over 48-hours and the estimate is to the tailrace. The acoustic tag studies at Cougar measured survival rates to points upwards of 100 km downstream of the release site based on detections over many days, which may include expression of both direct and indirect passage effects.

[79] RO survival as a function of gate opening based on Beeman et al., 2014a.

Species of Interest:

It is estimated Cougar Dam blocked between 16 and 25 percent of the historic spawning habitat for spring Chinook salmon in the McKenzie subbasin; the fish management agencies assert this habitat is some of the best quality habitat in the basin (ODFW and NMFS 2011, NOAA Fisheries 2008). The McKenzie River supports the most abundant population of natural origin Chinook salmon in the upper Willamette Basin. McLaughlin et al. (2008) estimate the average abundance of natural origin Chinook passing Leaburg Dam from 2002-2006 to be 3,509 adults, although adult abundance in recent years has declined. For example, from 2007-2015 an average of 1,606 natural origin Chinook salmon have passed Leaburg Dam. (C. Sharpe, pers. comm.) The McKenzie subbasin does not support a population of winter steelhead.

The 2008 USFWS biological opinion identified three populations of listed bull trout within the McKenzie subbasin. Based on survey data from 2005-2007, ODFW (2007) estimated the current spawning population of bull trout to be between 250-300 adults. Oregon chub can be found currently at three sites in the McKenzie subbasin (Scheerer et al. 2007).

Studies Completed, Ongoing or Needed:

Subsequent to release of the NOAA Fisheries and USFWS' biological opinions in 2008, biological and hydraulic studies were undertaken at the Cougar project to assist resource agencies in providing improved juvenile and adult fish passage at the project. Several years of studies have been completed, including spawning surveys of adult Chinook salmon above and below the project; screw trapping of juvenile salmon both above and below the dam to obtain migration timing; trapping of juvenile salmon in the reservoir to determine migration and rearing behavior; active tag and PIT tag studies of juveniles to determine migration behavior above and below the dam; and survival studies of fish passage through the turbines and RO at Cougar.

A computational fluid dynamics (CFD) model[80] was developed by the Corps for the Cougar reservoir to evaluate flow vectors and velocities in the near forebay area of the dam to assist managers in locating the most preferable site(s) to locate a surface bypass structure. In addition, a prototype pilot-scale, portable floating fish collector (PFFC) was constructed and operated by the Corps at Cougar Dam at two different locations in the forebay during recent years to evaluate the efficacy of a small, pilot-scale surface collector. The PFFC was designed to use internal pumps to draw attraction flow over an inclined plane at a depth of about 3 meters, through a flume at a design velocity of up to 6 feet per second, and to empty a small volume of water with

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[80] Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems involving fluid flows. Computer software is used to perform the calculations required to simulate the interaction of fluid flows with surfaces defined by boundary conditions.

any entrained fish into a collection box. It was tested under two inflow rates; a low inflow of 64 cubic feet per second (cfs) and a high inflow of 109 cfs.

Beeman et al. (2016) evaluated the biological and hydraulic performance of the PFFC over the last seven months of 2014 and found it collected a total of only 156 juvenile Chinook salmon and 280 individuals of other species, primarily dace and largemouth bass. Fish collection efficiency was very low under both the low and high flow treatments. Specifically, the proportion of acoustic plus PIT-tagged fish collected in the PFFC of those detected in the reservoir cul-de-sac was 0.5 percent and none were detected during the low and high flow treatments, respectively. Very few of the active tag fish were collected in the PFFC, although they were detected in the proximity of the PFFC entrance in the forebay. (Beeman et al. 2016)

The researchers concluded the hydraulic performance of the PFFC did not achieve the design goals of providing a smooth acceleration of inflow or a peak water velocity of six feet per second and, as a result, the lackluster hydraulic performance of the PFFC likely contributed to its low biological performance. The greatest water velocity measured in the throat of the PFFC was less than two feet per second, much lower than designed, due in part to the PFFC being lower in the water column than expected. The Corps also experienced difficulties during anchor deployment, which prevented placing the PFFC closer to the reservoir outlet as planned, which resulted in a PFFC position outside the prevailing flow field and known areas of high fish densities. The researchers concluded "the results indicate that [PFFC] location, hydraulic conditions, water temperature, and shallow depth of the entrance were among the factors contributing to the low biological performance of the PFFC in 2014." (Beeman et al. 2016)

Passage Alternatives under Evaluation:
Based on the CFD modeling and research studies, several promising juvenile fish passage alternatives at Cougar Dam have been identified by the Corps, working with regional fish managers and others, in the 2015 COP. In addition to a baseline, or no action, alternative, two other design alternatives were identified in the COP, which are currently under regional consideration for improved juvenile fish passage at Cougar Dam and proposed for further engineering and technical analysis.[81]

One design alternative is construction of a floating screen structure (FSS) which would be attached to the existing water temperature control tower, with a modification to the tower to allow operation at lower reservoir levels. This alternative is unique to Cougar Dam because it would involve attaching a guide rail or track to the upstream face of the WTC tower to enable the floating screen structure to move up and down with large changes in forebay elevation. It is anticipated the FSS would use up to 1,000 cfs of project outflow as attraction flow for juvenile fish.[82] Based on a description of this

[81] Other ideas considered include a wide range of operational alternatives that the Corps' COP report did not recommend for further feasibility analysis.
[82] However, a critical design component includes operation of the FSS down to low gravity flow conditions, which may affect the entrance velocities and the internal functioning of the collector.

alternative in the COP (2015), up to 1,000 cfs of project outflow would be drawn as surface flow into the FSS entrance, dewatered using v-screens, passed over a penstock-side weir gate into the WTC tower, and then released through either the RO or penstock and turbines. Juvenile fish collected in the FSS and a small percentage of flow would enter a bypass channel located at the downstream end of the screens. The bypass flow and juvenile fish would either be routed around the dam to the tailrace or transported via truck downstream.

Based on research and CFD modeling, juvenile fish have been shown to be attracted to a narrow portion of the Cougar forebay known as the “cul-de-sac.” In this more confined area of the forebay, the Corps expects the zone of influence of a FSS should be enhanced relative to placement elsewhere in the forebay. A similar confined forebay condition at upper Baker Dam resulted in relatively high passage efficiency observed for juvenile sockeye salmon into the FSC at Baker (see Baker Dam case study). (COP 2015)

The COP (2015) states the risks of construction and timing of implementation impacts would likely be high due to the complexity of designing and constructing downstream fish passage structures. Multiple engineering disciplines will be required for design and construction. The design of the FSS will be complicated by high debris loading on the intake screens and the large annual reservoir fluctuations. However, since the FSS would have no impact on reservoir elevations or outflows, no impacts on downstream water quality are expected (e.g., temperatures or TDG).

The second design alternative at Cougar Dam also involves attaching an FSS to the WTC tower via rails or guides installed on the upstream face of the tower, without modification of the tower. This alternative allows a FSS to float up and down along the upstream face of the tower with reservoir level fluctuations, with floating anchorage above elevation 1571. The FSS would provide active screening of fish and flows above elevation 1571, but would be inactive below that elevation while tethered to the tower. Under this alternative, up to 1,000 cfs of project outflow would be attraction flow drawn from the surface into the FSS entrance, dewatered using angled v-screens, passed over a penstock-side weir gate into the WTC tower, and then released through either the RO or penstock and turbines. Juvenile fish collected in the FSS and a small percentage of flow would enter a bypass channel located at the downstream end of the screens and then would be sent to a separation and holding barge where the fish would be lifted to the top of the tower for truck transport downstream.

Below elevation 1,571 feet, fish would be preferentially bypassed through the RO.[83] Except in the driest quartile of water years, Cougar Reservoir is at or below elevation 1,571 only during the late November through early February time period during the winter flood risk management operations. This alternative would prioritize flow through

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[83] Direct survival studies by Monzyk and others (2011) during December 2010 indicated higher survival rates through the RO than for the turbine under lower project head conditions.

the RO at Cougar without considering the potentially higher TDG levels that would be produced by higher RO flows. The COP (2015) states the minimum conservation flow would be 400 cfs, with 100 cfs through the turbine for station service and the remaining outflow through the RO at its minimum gate opening of 1.3 feet.

Based on the Corps' modeling, flow through the RO would more than double relative to the baseline from November through January and sometimes into early February. The increased flow through the RO will likely increase the TDG immediately below Cougar. While the gas levels are expected to dissipate a short distance downstream, there could be "slight impact on newly hatched salmon that may be present within the affected reach."[84] (COP 2015) However, as noted above, the higher RO flows would occur primarily during the winter salmon incubation period, so the effects on fish are expected to be minimal. Since this alternative should not impact total project outflows or reservoir elevations, it is not expected to impact downstream temperature management operations.

The risks of construction and timing of implementation impacts for this alternative would likely be high due to the complexity of constructing downstream fish passage structures. Multiple engineering disciplines will be required for design and construction. Again, the design of the FSS will be complicated by high debris loading on the intake screens and the large reservoir fluctuations.

Timeline:

An improved adult fish facility at Cougar was completed in 2010. Engineering design of a FSS for improved juvenile fish passage at Cougar (e.g., alternative one above) is underway and is expected to be completed by the end of 2019, with construction expected to be complete by the end of 2021. Then juvenile fish passage performance testing and any needed juvenile bypass facility modifications would occur from 2022 through 2024.

Cost Estimates:

The cost of constructing the new adult fish facility below Cougar Dam was $10.4 million in 2010 ($11.3 million in 2015 dollars). The Corps estimates the life cycle cost[85] of constructing the first juvenile fish passage alternative will be $140.2 million (PV in 2015 dollars). The Corps estimates the life cycle cost of building the second hybrid fish passage alternative would be $124.1 million (PV in 2015 dollars). (COP 2015) Although the hybrid alternative appears to be more cost-effective than the other FSS passage alternative when considering only life cycle costs, the first alternative becomes more

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[84] Since newly emerged alevin could be present in the reach below Cougar Dam, it would be useful to evaluate where salmon redds are located below the dam and how far elevated TDG levels extend downstream of the dam.

[85] Life cycle costs include project design and construction costs, the present value of expected O&M costs, plus a contingency factor up to 50 percent, as well as a cost for Corps staff time during planning, design, construction and operation.

cost-effective when forgone hydropower revenues are also considered in the economic analysis.

Objectives and Site Results:

The Corps' COP (2015) states a minimum goal of providing improved juvenile and adult fish passage is to achieve better than 1:1 sustainable adult replacement via natural production above Cougar Dam. In addition, Viable Salmonid Population (VSP) scenarios identified in the Upper Willamette Conservation and Recovery Plan for Chinook Salmon and Steelhead (Recovery Plan) (ODFW and NMFS 2011) indicates the desired VSP Chinook salmon abundance targets for delisting and broad sense recovery in the McKenzie River are 10,918 and 13,613 adult Chinook salmon, respectively. The Upper Willamette recovery plan also indicates the VSP extinction risk for delisting and recovery of spring Chinook in the McKenzie River should be very low for both abundance and productivity, and low for both diversity and spatial structure (ODFW and NMFS 2011).

In June 2016, the Corps and NMFS agreed to performance criteria for juvenile fish passage for the Cougar Dam FSS, including adaptive management steps necessary if the criteria are not achieved after testing. Specifically, the juvenile fish design criteria should achieve at least 95 percent fish collection efficiency (SE=2.5 percent) based on a series of adaptive management steps, with different measures required depending on monitoring and evaluation results of the FSS (COP 2015, pp. 4-5 to 4-11). In addition, the design criteria for the Cougar juvenile fish facility is expected to comply with the current NMFS anadromous fish passage design guidelines (NMFS 2011).

Effectiveness of Upstream Passage:

To date, the collection of returning adult Chinook salmon at the Cougar adult facility and trap and haul operation above the project has resulted in increasing numbers of returning adults. However, it has had limited success in establishing a viable, sustainable population of natural-origin fish due to the lack of safe and effective downstream fish passage at Cougar Dam.

Effectiveness of Downstream Passage (Expected):

Under the first juvenile fish passage alternative, the Corps estimates that downstream fish passage survival for Chinook salmon would improve from the current 11 percent (baseline) up to 64 percent. It is also estimated this FSS alternative would result in self-sustaining populations of spring Chinook above Cougar Dam.[86]

[86] The fish passage expectations are tempered by the uncertainty in the biological modeling assumptions used for downstream passage, including those for juvenile fish reservoir survival, collection efficiency and dam passage survival.

Under the second fish passage alternative (e.g., hybrid FSS), the Corps estimates that downstream fish passage survival for Chinook salmon would improve from the current 11 percent (baseline) to 56 percent. It is estimated this hybrid alternative would also result in self-sustaining populations of spring Chinook above Cougar Dam.

COP-Phase II Recommendation:
The Corps' COP (2015) recommends that both of the FSS surface bypass facility alternatives identified above should be carried forward for engineering design and additional analysis. Based on analysis in the COP (2015), construction of either of these juvenile fish passage alternatives, or a variation thereof should, together with the existing Cougar adult fish facility trap and haul operation, result in the highest likelihood of achieving self-sustaining populations of spring Chinook salmon above Cougar Dam.

Other Potential Factors to Consider:

The fish passage alternatives identified above are expected to have a beneficial effect on ESA-listed bull trout and have no impact on Oregon chub in the McKenzie subbasin, as well as no impact on flood risk management and little or no impact on water quality conditions (TDG or water temperature) downstream. In addition, low to no impacts are expected on the following uses by implementing the preferred alternative: achieving downstream tributary flows, meeting mainstem Willamette flow targets, reservoir or river recreation, or current or future water supplies (either for irrigation or municipal/industrial uses).

Detroit Dam

Figure 27. Aerial photo of Detroit Dam, courtesy of the Corps of Engineers.

Location of Study:

The North Santiam River is a 92-mile long tributary of the Willamette River located in the Willamette subbasin in western Oregon. It drains an area of over 760 square miles from the Cascade Mountain Range east of Salem. It emerges from the foothills of the

Cascades into the Willamette Valley near Stayton, Oregon, then flows 15 miles southwest through the valley where it joins the South Santiam River to form the Santiam River. The Santiam River flows for approximately 10 miles west to its confluence with the Willamette River near Salem in the central portion of the Willamette Valley. Figure 28 shows a map of the North Santiam River watershed, including streams, dams and barriers, the current distribution of spring Chinook salmon and winter steelhead, and land use.

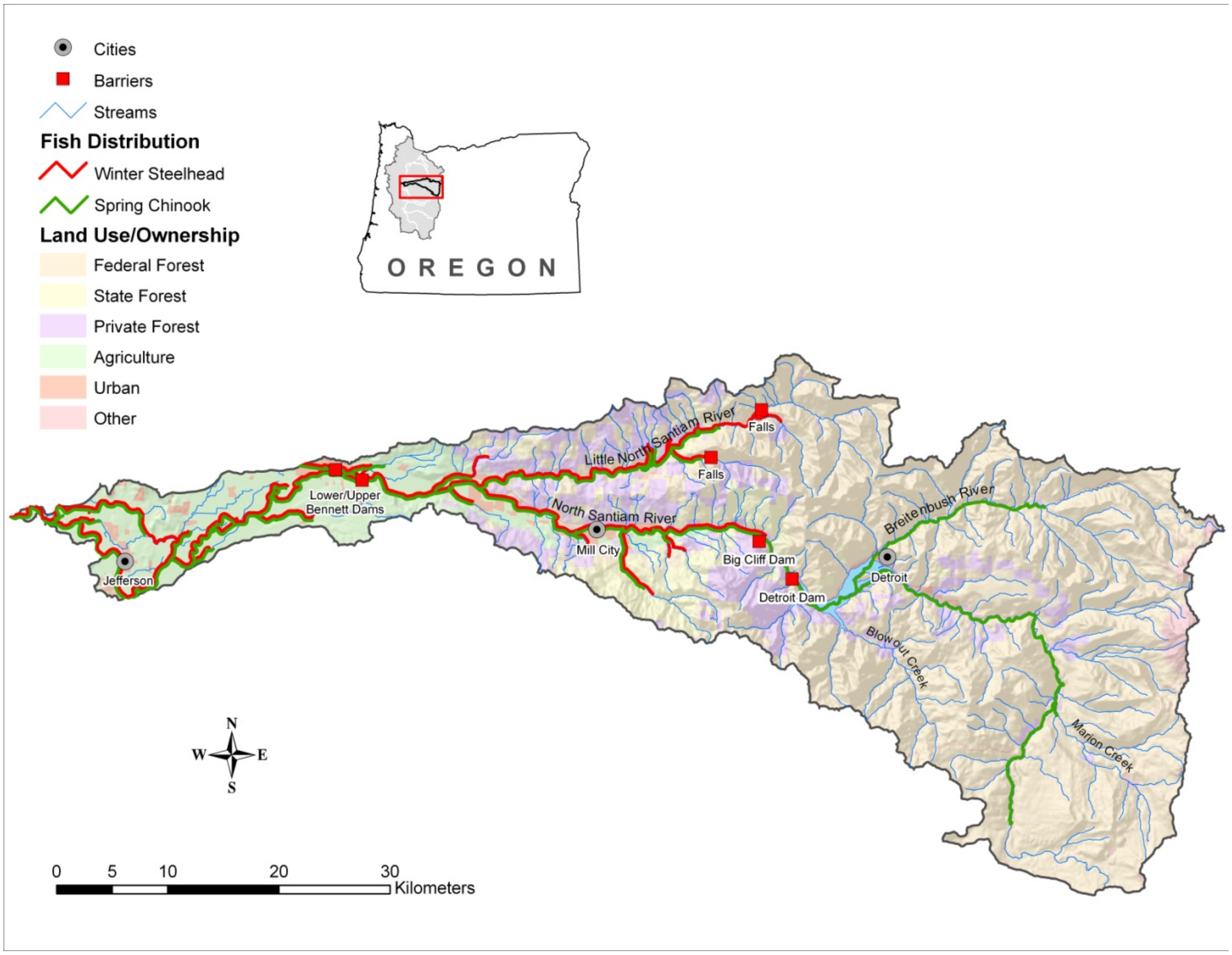

Figure 28. North Santiam Watershed (map courtesy of ODFW)

Site specifications:

Detroit Dam:

- 271.4 miles from the mouth of the Columbia
- 463 feet high
- 1,523.5 feet in length
- 100 megawatt production capacity
- Storage dam used for flood control, power, navigation, and irrigation

Detroit Lake (Reservoir):

- 9 miles in length

- 321,000 acre feet of storage
- Highest inflow months between May and August
- 369 feet of hydraulic head
- 1,569 feet at full pool
- 1,450 feet at minimum pool

Physical Features:
The North Santiam River is impounded by two hydropower projects operated by the Corps of Engineers; Detroit Dam, which is a multipurpose storage project located at river mile 49, and Big Cliff Dam, which is the re-regulating project for Detroit Dam. Detroit Dam is 463 feet high, 1,524 feet long and has 321,000 acre-feet of flood control storage in its nine-mile long reservoir. Detroit Dam has two hydropower generating units capable of producing 50 megawatts each.[87] The Corps operates Detroit Dam together with Big Cliff Dam to provide flood risk management. Other authorized primary purposes for Detroit Dam include hydropower, water quality improvement, irrigation, fish and wildlife habitat, and recreation. (Corps 2016b)

Detroit Reservoir is primarily used for flood risk management for downstream population centers in the Willamette Valley, and as such, the forebay elevation is maintained at high elevations during the summer months and at low elevations during winter months. The reservoir's maximum pool elevation is 1,574 ft, and while the maximum conservation pool level of 1,569 ft is typically reached in May, the normal minimum flood-control pool elevation of 1,450 ft is usually reached in December.

Passage Improvements Implemented:
Detroit and Big Cliff projects were completed in 1953 and created a complete barrier to upstream anadromous fish passage in the upper North Santiam River. The Marion Forks Hatchery and Minto Adult Fish Collection Facility were constructed to help mitigate for the natural spawning and rearing habitat blocked or inundated by the construction of these two dams. The Minto adult facility was originally designed to collect broodstock for the hatchery. A new and upgraded Minto adult fish collection facility was completed by the Corps over a period of two years in 2012. It is located about 4 miles downstream from Big Cliff Dam. The Minto Adult Fish Collection Facility provides for safe and improved collection and sorting of adult spring Chinook salmon, winter steelhead and hatchery summer steelhead for a variety of purposes. Such purposes include transport and release, or outplanting, above Minto Dam, Detroit Dam and in the Little North Fork Santiam River for natural spawning, as well as broodstock collection. The Minto facility also serves as a holding and acclimation site for juvenile summer steelhead and spring Chinook prior to their release. The operation of the new Minto adult fish facility is also expected to reduce pre-spawning mortality for transported adult Chinook and steelhead. (COP 2015)

[87] The Detroit generating units use Francis type turbine runners, which have more blades operating at higher hydraulic heads and at lower efficiency than Kaplan turbines. Francis units are considered less "fish friendly" than the Kaplan-style turbines installed at the Corps' mainstem lower Columbia and Snake river hydropower dams.

Currently, there are no facilities actively providing downstream fish passage at Detroit Dam. The juvenile fish that migrate downstream exit the project either through the spillway, the regulating outlets (ROs) located at multiple heights on the dam face, or the turbines at Detroit Dam. The Corps' baseline operation at Detroit Dam is to draw down the reservoir to elevation 1450 feet during December and January each year for flood risk management. For juvenile spring Chinook, the highest dam passage efficiency (DPE) is found when surface spill occurs in spring and summer at full pool. DPE is lowest when the reservoir is drafted below spillway crest, and surface spill is not available but the pool elevation is still relatively high. DPE increases somewhat in fall as the pool is drafted deeply for flood risk management, and the head over the regulating outlets and turbine intakes declines. Based on radio-telemetry data collected at Detroit Dam during 2012 and 2013 with the spillway operating during higher reservoir elevations, the dam passage efficiency (DPE) for spring Chinook salmon ranged from about 78 percent in the spring refill period at the higher pool levels down to only about 23 percent during the fall drawdown months at middle reservoir operating elevations. The DPE for juvenile steelhead in the spring refill period was between 58-60 percent. (Beeman et al. 2014) Data indicate the DPE decreases as the reservoir elevation decreases, with lowest DPE values observed in the fall months at the middle reservoir elevations when turbine fish passage efficiency is high and there is no spill available for fish passage. The data imply that DPE is higher at higher reservoir elevations when fish are able to pass the project via the spill gates.

Route-specific juvenile fish survival data for spring Chinook and steelhead are not available at Detroit Dam. Instead, survival rates for large (>185 mm) juvenile rainbow trout at Detroit have been used to estimate survival for juvenile spring Chinook and steelhead. It is estimated that juvenile Chinook direct survival through the RO will range from 72 percent under a small RO gate opening (e.g., low flow) to about 94 percent under a large gate opening (e.g., high flow).[88] Based on a balloon tag study (Hi-Z tag data of malady-free fish[89]) of the survival of juvenile rainbow trout, it is estimated that juvenile Chinook direct survival through the turbines at Detroit Dam is about 52 percent and would be slightly higher (60 percent) for fry. (Normandeau 2010) survival rates of malady-free rainbow trout passing through the Detroit Dam spillway varied with gate opening and spill flow. Based on this data, it is estimated that juvenile Chinook direct survival through the spillway will range from 43 percent at a high spill gate opening, high-flow condition to 53 percent under a low spill gate opening, or lower flow condition. (Normandeau 2010)

Species of Interest:

It is estimated that between 43 and 71 percent of the historic spring Chinook production in the North Santiam subbasin originated in habitat above Detroit Dam. (ODFW and NMFS 2011, Mattson 1948) It is also estimated about 48 percent of the historic

[88] RO survival as a function of RO gate opening based on Normandeau 2010.

[89] Malady-free fish show no signs of injury or descaling.

steelhead habitat above Big Cliff Dam was lost due to construction of Big Cliff and Detroit dams (ODFW and NMFS 2011). The COP (2015) states the current spawner capacity is estimated at 11,500 adults, with over 70 percent of that capacity available above Detroit Reservoir. Hatchery-origin spring Chinook are currently outplanted above Detroit Dam in both the North Santiam and Breitenbush rivers.

Adult counts at the Minto adult trap from 2002-2007 indicated that fewer than 500 naturally produced Chinook adults returned each year to the North Santiam. In recent years, however, the abundance of naturally-produced returning Chinook adults has increased. Spill operations at Detroit since 2009 may have increased the number of juveniles passing the Detroit-Big Cliff dams, resulting in increased adult returns.[90] Genetic pedigree analysis of returning unmarked adult spring Chinook salmon indicates a cohort replacement rate of > 1.0 for the progeny of 2009 female spawners. (O'Malley et al. 2015)

Additionally, recent spill operations at Detroit Dam have improved water temperatures in the reaches below Big Cliff Dam, and adult Chinook may be responding to this change by migrating upstream earlier in the summer to enter the Minto fish facility or to spawn naturally. However, due to the high elevation of the spillway crest, surface spill can only be provided at Detroit in average to wet water year conditions. Thus, in dry years such as 2015, no spill can be provided for fish passage or for interim temperature control operations. (COP 2015)

Below the Detroit-Big Cliff dam complex, Chinook salmon spawning and productivity are affected by flow management, elevated TDG and water temperature effects due to dam operations, effects of Chinook mitigation hatchery releases,[91] fishing impacts, and agricultural and other land use impacts, among other effects. Since 2007, changes in dam operations have reduced some of the adverse temperature effects caused by very cold water being released through the turbines from deep in the reservoir, followed by accelerated egg incubation due to warm water being evacuated from the reservoir during the fall and winter drawdown period. Since 2007, interim temperature control operations have improved water temperature conditions downstream due to warmer water being released through spill, increasing summer temperatures, with cooler water being released in the fall, reducing fall temperatures, resulting in improved adult migration timing in summer and better incubation conditions in the fall below Big Cliff Dam. However, there are limits to the effectiveness of the interim temperature control operations because: a) a warm water pulse is still present in the fall months, which accelerates incubation below the dams; and b) in drier water conditions or with equipment failure, the ability to operationally manage water temperatures effectively below Detroit and Big Cliff dams will be impacted. (COP 2015)

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[90] Recent improvements made at the adult fishways at both Upper and Lower Bennett Dams on the North Santiam River may have also contributed to the increase in adult returns.

[91] Hatchery fish effects include both competition and genetic effects on wild fish populations.

Currently, no production of ESA-listed winter steelhead occurs above Detroit Dam. McElhany et al. (2007) provided a current short-term geometric mean abundance estimate of 2,109 adults based on 1990-2005 data for the North Santiam. However, the COP (2015) states that adult abundance trends for winter steelhead in the Willamette Basin in general have been declining based on fish ladder counts at Willamette Falls, with the majority of winter steelhead passing above Willamette Falls originating from the North Santiam subbasin.

Bull trout were historically distributed in the North Santiam subbasin but are no longer present. Oregon chub can be found currently at five sites on the North Santiam River and at two sites on the mainstem Santiam River. (Scheerer et al. 2007)

Studies Completed, Ongoing or Needed:

Several years of biological studies have been completed at Detroit Dam, including spawning surveys of adult Chinook salmon above and below the project; screw trapping of juvenile salmon both above and below the dam to obtain migration timing; trapping of juvenile salmon in the reservoir to determine migration and rearing behavior; active and PIT tag studies of juveniles to determine migration behavior and adult return rates above and below the dam; and survival studies of fish passage through the spillway, turbines and RO at Detroit Dam using rainbow trout as a surrogate species for spring Chinook and steelhead.

Passage Alternatives under Evaluation:
A wide range of juvenile fish passage alternatives, including both structural and operational alternatives, were identified and analyzed by the Corps in the COP (2015). In addition to a baseline, or no action, alternative, two alternatives were identified in the COP, which are currently under regional consideration for improved juvenile fish passage at Detroit Dam and proposed for further engineering and technical analysis.

One design alternative provides a hybrid solution for downstream fish passage and water temperature management at Detroit Dam. In this alternative, a floating surface outlet (FSO) similar to a "glory hole" spillway structure[92] would be constructed to provide a surface outlet for juvenile fish whenever the reservoir is lowered below the spillway crest (elevation 1,541 feet). Detroit Dam would be operated to provide water temperature management, with the spillway being used until the reservoir is drawn down below spillway crest. At that point, the FSO would be used to continue to release surface water for improved juvenile fish passage and downstream temperature management. (COP 2015)

In this alternative, if the FSO is unsuccessful in attracting and passing adequate numbers of juvenile fish, a floating surface collector (FSC) would be added. The current conceptual design includes installation of a FSC with guide nets to fully exclude fish movement below the structure that would operate all year and over the entire forebay

[92] Hungry Horse Dam in Montana uses a glory hole spillway outlet structure.

operating range. Collected fish would be kept in an attached live box before being either truck transported around the dam(s) to a downstream release point, or diverted into a bypass channel (pipeline) for release below the dam(s). (COP 2015)

A second design alternative also provides fish passage and temperature improvements in the North Santiam River. It involves the construction of a selective withdrawal structure (SWS) for temperature control and installing a guide or track to allow a floating screen structure (FSS) to travel up and down along the upstream face of the SWS as the reservoir elevation changes, similar to the conceptual design at Cougar Dam. Current design plans call for the SWS to be designed and constructed initially with a downstream passage structure similar to the FSS. It would be added to the SWS later in Phase II using information collected during biological testing. (COP 2015)

For both design alternatives, the risks of construction and timing of implementation impacts will likely be high due to the complexity of constructing downstream fish passage structures. Multiple engineering disciplines will be required for design and construction. Operation of these temperature control and fish passage structures would not impact Detroit Reservoir elevations or outflows. They would, however, replace the current temperature operations at the project by allowing more water through the powerhouse than through the ROs, resulting in lower TDG levels downstream. These structural improvements proposed by the Corps of Engineers at Detroit Dam would provide the most operational flexibility compared to the other alternatives evaluated, e.g., they would be less dependent on the limits and functionality of the existing dam outlets, so they are expected to greatly improve downstream water temperatures in the North Santiam River.

Timeline:

An improved adult fish facility at Minto was completed in 2013, with additional modifications implemented since completion. Both alternatives identified above met the minimum 1:1 adult replacement criteria and are being carried forward for further analysis. However, the second SWS-FSS fish passage design alternative appears to be more cost effective and has the highest likelihood of achieving both the fish passage and temperature control criteria. Engineering design of a SWS-FSS for improved juvenile fish passage at Detroit (e.g., alternative two above) would occur in a two-phased approach. In Phase One, initial design would begin in 2017 and is expected to be completed by the end of 2019, with construction expected to be complete by the end of 2022. Then juvenile fish passage performance testing and any needed juvenile bypass facility modifications would occur from 2023 through 2025.

With the SWS-FSS alternative, a Phase II design process would be initiated for a floating screen structure to be attached to the SWS. The Phase II design would occur from 2020 through 2022, with construction of the FSS taking place in 2023 and 2024. Then juvenile fish passage performance testing and any needed juvenile bypass facility modifications would occur from 2025 through 2028. Implementation of the SWS-FSS fish passage alternative at Detroit Dam will be informed by the Corps' experience with the design, construction and testing of the selected fish passage alternative at Cougar Dam, which is expected to be constructed first.

Costs:

The cost of constructing the new Minto adult fish facility below Detroit and Big Cliff dams was $27.4 million in 2012 ($28.3 million in 2015 dollars). The Corps estimates the life cycle cost[93] of constructing the first juvenile fish passage FSO-FSC alternative will be $187.2 million (PV in 2015 dollars). (COP 2015) The Corps estimates the life cycle cost of building the second SWS-FSS fish passage alternative will be $263.3 million (PV in 2015 dollars). (COP 2015) Although the first FSO-FSC alternative appears to be more cost-effective than the other SWS-FSS passage alternative when considering just life cycle costs, the second alternative becomes more cost-effective when forgone hydropower revenues are also included in the economic analysis.

Objectives and Site Results:

The Corps' COP (2015) states a minimum goal of providing improved juvenile and adult fish passage is to achieve better than 1:1 sustainable adult replacement via natural production above Detroit Dam. In addition, Viable Salmonid Population (VSP) scenarios identified in the Upper Willamette Conservation and Recovery Plan for Chinook Salmon and Steelhead (Recovery Plan) (ODFW and NMFS 2011) indicates the desired VSP Chinook salmon and steelhead abundance targets for delisting in the North Santiam River are 5,428 adult Chinook salmon and 8,362 adult winter steelhead, respectively. The Upper Willamette recovery plan also indicates the broad sense recovery target for winter steelhead in the North Santiam River is 10,013 adult steelhead. In addition, the recovery plan indicates the VSP extinction risk for delisting of spring Chinook and steelhead should be low (very low for steelhead) for both abundance and productivity, and low for both diversity and spatial structure. (ODFW and NMFS 2011)

Effectiveness of Upstream Passage:

So far, the collection of returning adult Chinook salmon at the Minto adult fish facility and trap and haul operation above the project has coincided with increasing numbers of returning adults, with arrival timing at the trap of adult Chinook salmon more consistent with pre-project run timing. Also, pre-spawning mortality of adults transported above Detroit Dam from the Minto adult fish facility is relatively low compared to other drainages in the Willamette subbasin, e.g., at 12 percent or less above Detroit Dam during 2012-2015. (Sharpe 2016). Fishery managers are not currently transporting unmarked, natural origin Chinook or steelhead above Detroit Dam due to the poor downstream passage conditions at

[93] Life cycle costs include project design and construction costs, the present value of expected O&M costs, plus a contingency factor up to 50 percent, as well as a cost for Corps staff time during planning, design, construction and operation.

the project. Thus, the Minto adult trap and haul operation will likely have limited success in establishing a viable, sustainable population of natural-origin fish above Detroit Dam as long as: a) there is not a safe and effective downstream fish passage alternative implemented at Detroit and Big Cliff dams; and b) hatchery-origin fish continue to be outplanted above Detroit Dam.

Effectiveness of Downstream Passage (Expected):

No agreed upon juvenile fish performance criteria have been identified for a Detroit Dam passage structure to date. NMFS anticipates the performance of downstream passage facilities at Detroit Dam will be comparable to that achieved by facilities designed and constructed to the NMFS Salmonid Passage Facility Design guidelines (NMFS 2011). Under the first juvenile fish passage FSO-FSC alternative, the Corps estimates downstream juvenile fish passage survival is expected to improve from 29 percent in the baseline, or current, condition to 62 percent for spring Chinook salmon, and from 21 percent to 41 percent for steelhead. Population viability is also expected to be improved. Fish production below the dam(s) is expected to be as good or better as the current level of production provided by the ongoing interim temperature control operation. (COP 2015)

Under the second fish passage SWS-FSS alternative, downstream fish passage survival is expected to improve from 29 percent in the baseline, or current, condition to 66 percent for spring Chinook salmon, and from 21 percent to 57 percent for steelhead. Population viability is also expected to be improved. Again, fish production below the dam(s) is expected to be as good or better as the current level of production provided by the ongoing interim temperature control operation.[94] (COP 2015)

COP-Phase II Recommendation:
The Corps' COP (2015) recommends that both of the FSO-FSC and SWS-FSS surface bypass alternatives identified above should be carried forward for engineering design and additional analysis. Based on analysis in the COP (2015), construction of either of these juvenile fish passage alternatives should, together with the existing adult fish facility trap and haul operation, result in the highest likelihood of achieving self-sustaining populations of spring Chinook salmon above Detroit Dam.

However, there are several benefits associated with the SWS-FSS alternative. The Corps assumes the SWS-FSS alternative will result in improved DPE values similar to spillway operations, over both the baseline (current) condition and the FSO-FSC option. A key uncertainty is whether DPE will remain fairly constant with the FSS alternative regardless of reservoir elevation, water temperature, or seasonal timing, as the floating

[94] The fish passage expectations should be tempered by the uncertainty in the biological modeling assumptions used for downstream passage, including those for juvenile fish reservoir survival, collection efficiency and dam passage survival.

structure will fluctuate with the pool levels and continue to operate as a surface outlet. The FSS is also expected to have a larger zone of hydraulic influence with its larger flow capacity than the FSO. The FSS also provides a single point of water discharge, which should help attract fish to the facility, similar to the Round Butte surface collector.[95]

Other Potential Factors to Consider:

In the FSO-FSC alternative, operation and maintenance of the large nets used to help guide juvenile fish to the collector entrance could be complicated by Detroit Dam's annual winter flood risk reduction operations, which require water levels in the forebay to fluctuate over 75 feet. Such large water level fluctuations, along with harsh environmental conditions and potential debris loads during the winter drawdown period, will increase the risk associated with damage to the guide net and debris loadings at the FSO-FSC fish facility.

The two alternatives identified above are expected to have a positive impact on Oregon chub in the North Santiam subbasin, as well as no impact on flood risk management, with a slight improvement to TDG levels and a positive impact on water temperature downstream. In addition, low to no impacts are expected on the following uses by implementing the preferred alternative: achieving downstream tributary flows, meeting mainstem Willamette flow targets, reservoir or river recreation, or current or future water supplies (either for irrigation or municipal/industrial supplies).

[95] The Corps expects the DPE for the Detroit FSS could be better than what has been observed at Round Butte since the forebay conditions at Detroit will not be complicated by the large temperature differences entering from the two arms of Lake Billy Chinook.

<u>Fall Creek Dam</u>

Figure 29. Aerial photo of Fall Creek Dam. (Photo courtesy of the Corps of Engineers)

Location of Study:

Fall Creek is a 34-mile tributary of the Middle Fork Willamette River in the Willamette subbasin in Lane County Oregon. Rising from the western Cascade Mountains, Fall Creek is a relatively smaller stream compared to other Willamette tributaries discussed above. It drains a predominantly forested area and flows generally west through the Willamette National Forest to enter the Middle Fork upstream of Jasper, about 20 miles southeast of the cities of Springfield and Eugene. (Corps 2016c) Figure 30 shows a map of the Middle Fork Willamette River watershed, including Fall Creek, with streams, dams and barriers, the current distribution of spring Chinook salmon, and land use.

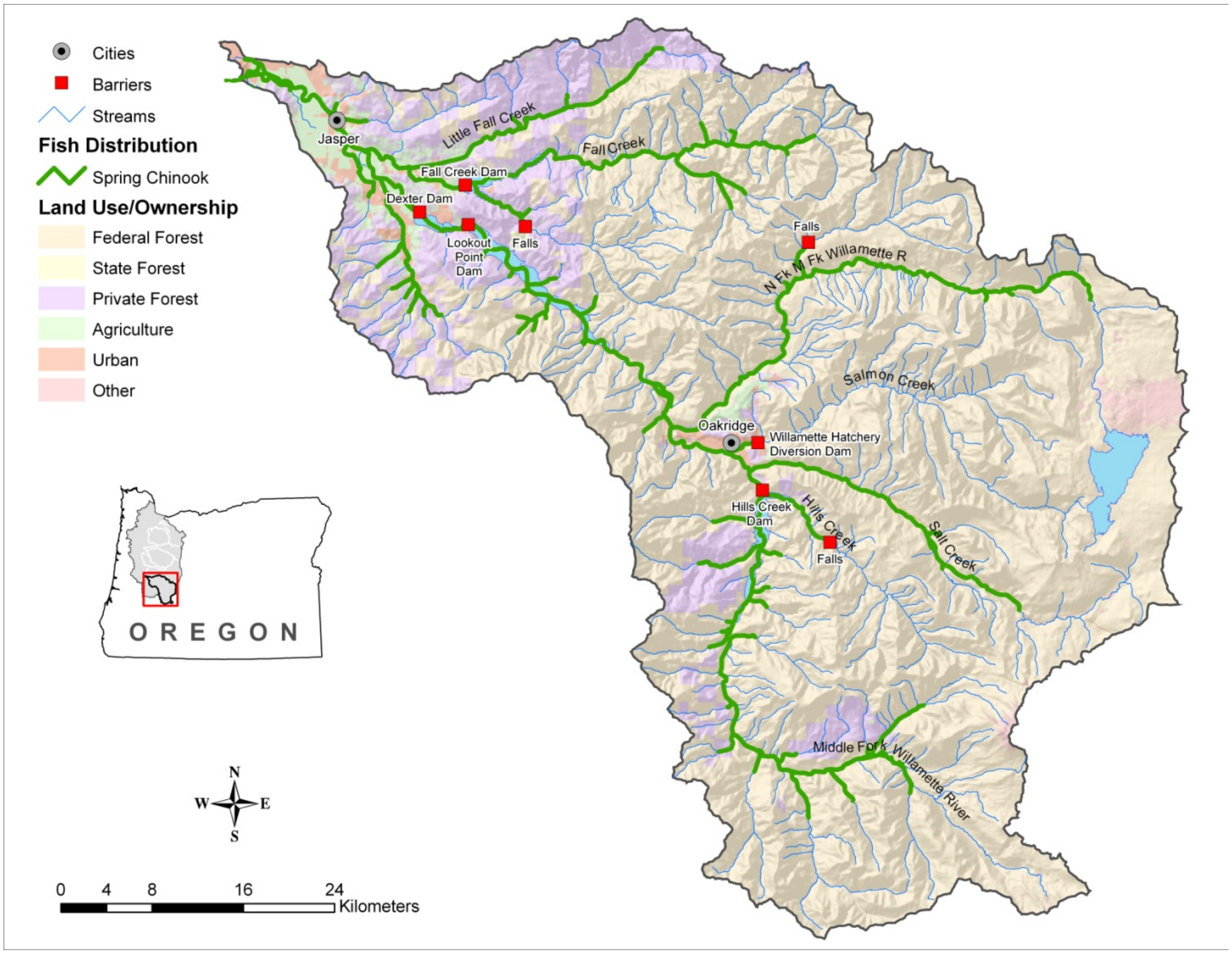

Figure 30. Middle Fork Willamette River Watershed. Fall Creek drainage is located in the northern portion of the Middle Fork watershed. (Map courtesy of ODFW)

Site specifications:

Fall Creek Dam:

- 307 miles from the mouth of the Columbia
- 180 feet high
- 5,100 feet in length
- No megawatt production
- Used for flood risk management, water quality improvement, irrigation, recreation, and fish and wildlife habitat

Fall Creek (Reservoir):

- 6.8 miles in length
- 125,100 acre feet storage
- 834 feet at full pool
- 673 feet at minimum pool

Physical Features:

Fall Creek Dam is operated by the Corps and is located at river mile 7.2 on Fall Creek. Fall Creek Dam is a rockfill structure with a gated concrete spillway and outlet works for regulating lake levels. When the dam was completed in 1966, it formed a complete barrier to upstream fish passage. During flood season, the dam holds back water to help regulate downstream flows. The rock-fill dam is 180 feet high and 5,100 feet long. The authorized purposes of the Fall Creek project include flood risk management, water quality improvement, irrigation, recreation and fish and wildlife habitat. There is no power generating capability at this project. A gated concrete spillway and regulating outlet (RO) are operated to regulate the reservoir elevation.[96] (Corps 2016c)

Fall Creek Lake provides 125,100 acre-feet of flood control storage and controls runoff from a 184 square mile watershed. Fall Creek Lake is primarily used for flood risk management for downstream population centers in the Willamette Valley, and as such, the forebay elevation is typically maintained at higher elevations during the summer months and at low elevations during winter months. The reservoir's maximum pool elevation is 834 ft and the minimum flood-control pool elevation is 673 ft, which is usually reached in December.

Passage Improvements Implemented:
An older adult fish passage facility, located on the north bank of the RO channel below the dam, has been operated at Fall Creek Dam to collect hatchery broodstock and to transport adult Chinook upstream to habitat above the project. The Corps currently transports only unmarked Chinook salmon upstream of the dam with few, if any, hatchery Chinook returning to the trap in recent years since hatchery fish outplanting has been discontinued. There are also some winter steelhead returning to the trap, although they are not considered an historical population and thus are not included in NOAA's UWR steelhead ESA listing. (ODFW and NMFS 2011)

Fall Creek's construction in the mid-1960s included provision for downstream juvenile fish passage through a series of fish horns,[97] but low collection efficiencies and high injury or mortality of juvenile fish led to their closure for fish passage. The fish horns, however, are presently being used to provide some operational water temperature control below the project. Although Fall Creek Dam currently has no structural juvenile passage facility in operation, it was selected for a case study in this paper because the Corps is implementing an operational approach at Fall Creek to help pass juvenile fish. Downstream fish passage is provided at this project by drawing the storage reservoir down to run-of-river conditions each year for a few weeks in late fall, thus allowing juvenile fish to pass downstream through the dam's diversion tunnel. (COP 2015)

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[96] The regulating outlet is used throughout the year to provide downstream flows to Fall Creek and the spillway gates are used in emergencies to evacuate flows from the reservoir during extreme flood events.
[97] The fish horns at Fall Creek Dam are a series of three small openings on the upstream face of the dam located at specific elevations.

Species of Interest:

Currently, ESA-listed spring Chinook salmon, Oregon chub (which were delisted in 2015), and bull trout are present in the Middle Fork Willamette subbasin. Nearly all the historic spawning habitat for spring Chinook in the Fall Creek watershed is located upstream of the Corps' dam. Production of natural-origin Chinook salmon remains at very low levels in the Middle Fork Willamette River watershed compared to pre-Corps dam estimates. However, in Fall Creek, Chinook abundance has increased slightly in conjunction with the downstream passage operation being provided via reservoir drawdown and the ongoing trap and haul program for unmarked adult Chinook. (COP 2015) For example, Figure 31 below illustrates, since the drawdown operation began in 2011, the return of unmarked Chinook salmon to the Fall Creek trap has ranged from 338 to 451 adults in 2012-2014. (Taylor et al. 2015).

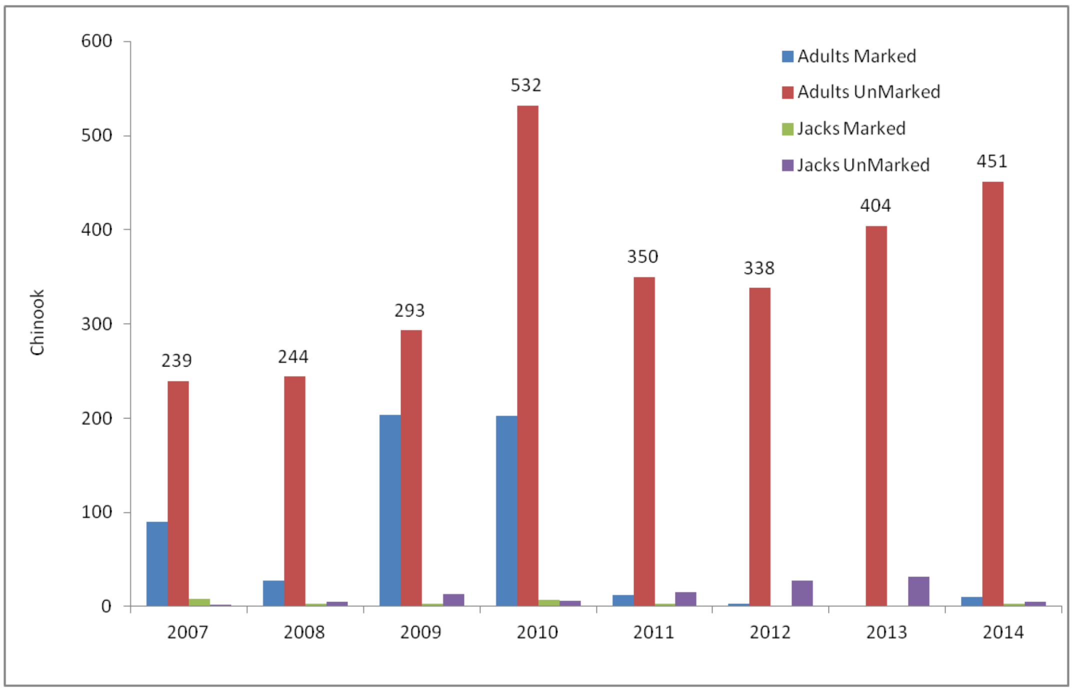

Figure 31. Number of adult Chinook salmon trapped below Fall Creek Dam, then transported and released above the dam by year (Graph from Taylor et al. 2015)

For comparison, the USFWS (1962) estimated a population of about 600 Chinook adults in the Fall Creek drainage before the dam was constructed, with about 450 of those fish located in the watershed above Fall Creek Dam. The Middle Fork Willamette River watershed, including Fall Creek, does not support independent populations of winter steelhead; however, some winter steelhead are present. (ODFW 2016)

Bangs and others (2015) estimated the population abundance of Oregon chub at 21 locations in the Middle Fork Willamette Recovery Area, with 12 populations in the Middle Fork drainage having more than 500 Oregon chub. The largest population of Oregon chub in the Middle Fork Willamette Recovery Area is found in the Fall Creek spillway ponds. (Bangs et al. 2015) ODFW has identified one of the 12 populations of

Oregon chub found in the Middle Fork subbasin in the Fall Creek spillway ponds. (Scheerer et al. 2007)

Pacific lamprey are also found in the Middle Fork Willamette watershed. Clemens and others (2012) used radio tracking of Pacific lamprey to detect adults in the vicinity of both Fall Creek and Dexter dams, and ammocoetes are present in the Middle Fork below Fall Creek Dam. In 2013 and 2014, the Confederated Tribes of the Grande Ronde initiated a Pacific lamprey translocation pilot project whereby adults were captured at Willamette Falls and transported (e.g., relocated) by truck to high quality habitat above Fall Creek Dam and reservoir. (Fendall 2015)

The goal of the tribe's translocation study was to determine if: a) Pacific lamprey would successfully reproduce above the dam; and b) juvenile pheromone presence would cause adult lamprey to approach and attempt passage at Fall Creek Dam. Fendall (2015) indicated Fall Creek Dam was used as a case study for translocating Pacific lamprey for several reasons: 1) it has high quality, historic habitat; 2) the ongoing drawdown operation would make it easier for juvenile lamprey to migrate downstream and exit the dam; and 3) adult lamprey likely already use the reach below the dam for spawning. In addition, passage modifications for juvenile and adult lamprey at Fall Creek Dam are potentially low cost and may require minimal modifications. (Fendall 2015) For example, juvenile lamprey could utilize the ongoing drawdown operation to migrate downstream and a lamprey passage structure could be installed at the adult salmon collection facility to collect adults and transport them upstream above Fall Creek reservoir.

Studies Completed, Ongoing or Needed:

Various biological studies have been undertaken at Fall Creek Dam to assist resource agencies in providing improved juvenile and adult fish passage at the project. Several years of studies have been completed, including spawning surveys of adult Chinook salmon above and below the project; screw trapping of juvenile salmon both above and below the dam to obtain migration timing; and a food web study of Fall Creek Lake was conducted under the deep drawdown operation. Food web conditions in Fall Creek Lake were then compared to other (control) reservoirs in the Willamette subbasin with other operations to determine potential impacts on the food web and carrying capacity of the lake due to the change in operation.

Passage Alternatives under Evaluation:

Figure 32. Fall Creek drawdown conditions. (Photo courtesy of the Corps of Engineers)

In addition to a baseline, or no action, alternative, one alternative has been identified in the COP (2015), which is currently under regional consideration for improved juvenile fish passage at Fall Creek Dam and proposed for further engineering and technical analysis. That alternative includes continuing the deep drawdown operation to help improve the downstream migration of juvenile Chinook in Fall Creek with design and construction of a new adult fish passage facility below the project. This alternative would continue to draft Fall Creek Reservoir to a deeper elevation than it would in the normal project operations.

Historically, the Corps drafted Fall Creek Reservoir down to a minimum elevation of 728 feet for flood damage reduction downstream during the winter flood season. However, since juvenile salmon prefer to swim near the surface, at that elevation it was difficult for them to find a route through the dam due to the depth they had to dive – over 50 feet - to reach the dam's regulating outlets. In addition, when the fish did find the outlet, many were injured due to the harsh passage conditions through the dam structure since there is greater hydraulic pressure under higher reservoir levels. Presently, the reservoir is proposed to be held at the deeper elevation of 685 feet for approximately two weeks within November or December, except during flood events, to improve juvenile fish passage and survival during outmigration. (COP 2015) This deeper reservoir elevation is only 10 feet above the regulating outlet at the dam and much nearer the historic streambed. Data has shown that lowering the reservoir to a deeper elevation during juvenile migration results in assisting outmigration of juvenile salmon and, with the exception of one year, has generally shown an increase in the adult salmon that later return to Fall Creek compared to holding the pool at a higher elevation of 728 feet.

However, under this operation there is no safe reservoir outlet available to migrating fish between March 15 and October 15. While some juvenile salmon are flushed from the reservoir during the short deep drawdown period in winter, other juvenile fish entering the reservoir after the drawdown operation are unable to exit the reservoir during their natural migration timeframe. As a result, salmon managers have recommended additional studies for the Corps to evaluate the potential impacts (both positive or negative) of allowing juvenile salmon to pass the dam under a deep drawdown or delayed refill operation during natural migration periods, including allowing outmigration from the reservoir during the spring and summer months.[98] (ODFW 2016)

A new adult fish collection facility has been designed and is under construction at Fall Creek in compliance with NMFS Salmonid Fish Facility Design criteria (2011) for upstream passage and collection facilities. The new adult fish collection facility will provide improvements for upstream passage in the Fall Creek watershed. The existing, older adult fish facility was not designed to handle ESA-listed fish and needs to be upgraded to improve collection and handling conditions for these fish and allow safe sorting and transport, while also managing for other species. For example, the existing facility does not have suitable facilities or space for holding adult fish following sorting. Also, the existing truck loading system does not provide a water-to-water transfer of adults from the hopper to the transport truck. All of the existing conditions described above at the older adult fish facility could contribute to pre-spawning mortality. The new adult facility, however, should minimize stress on returning adults, provide adequate holding and sorting areas and safe transport of fish, provide a safe and reliable water supply, and provide safe working conditions for employees. The new adult fish passage facility is not expected to impact reservoir elevation or project outflows. It should also help reduce pre-spawning mortality of adult fish reintroduced upstream of the project. (COP 2015)

Timeline:

The operational alternative of a deeper drawdown of Fall Creek Reservoir for a short period during November or December of each year is an ongoing operation and it should continue to be implemented to improve juvenile fish passage and survival, as it has been since 2011. As noted above, an extended drawdown with a delayed refill

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[98] It is possible that juvenile spring Chinook salmon might move out of the reservoir quickly in late spring rather than rear in the reservoir if the typical Fall Creek project operations could be modified to continue the drawdown operation and delay refill until June.

operation could also be tested to evaluate the potential impacts (both positive or negative) of allowing juvenile Chinook salmon to volitionally pass the dam during the late spring months. The Corps expects that some additional post-implementation monitoring may continue with evaluation of dam safety requirements, sedimentation analysis and other engineering monitoring at the project.

The new Fall Creek adult fish facility will be the next construction project to be completed under the 2008 NOAA Fisheries biological opinion implementation. Engineering design work was completed in 2015 with construction of the new adult facility scheduled during 2016, with post-construction evaluation and monitoring and any facility modifications, if necessary, occurring during 2017 through 2019. (COP 2015)

Costs:

Since there is no structural alternative proposed and no hydropower production at Fall Creek Dam, there is no cost associated with implementing the deep drawdown operation. According to the COP (2015), the fully funded capital costs of constructing the new Fall Creek adult fish facility is expected to be $21.1 million (2015 dollars), with $2.6 million in O&M costs over 2015-2033 period.

Site Results:

The Corps' COP (2015) states the overall goal of providing improved juvenile and adult fish passage is to achieve better than 1:1 sustainable adult replacement via natural production above Fall Creek Dam. In addition, Viable Salmonid Population (VSP) scenarios identified in the Upper Willamette Recovery Plan (ODFW and NMFS 2011) indicate the desired VSP Chinook salmon abundance target for delisting in the Middle Fork Willamette River is 5,820 adult Chinook salmon. The Upper Willamette recovery plan also indicates the VSP extinction risk for delisting spring Chinook in the Middle Fork Willamette River should be low for both abundance and productivity, and low for both diversity and spatial structure (ODFW and NMFS 2011). NMFS anticipates the performance of downstream passage at Fall Creek Dam will be comparable to that achieved by facilities designed and constructed to the NMFS Salmonid Passage Facility Design guidelines (NMFS 2011).

Effectiveness of Upstream Passage:

To date, the collection of returning adult Chinook salmon at the Fall Creek adult facility and trap and haul operation above the project has resulted in increasing numbers of returning adult Chinook, although more years of data are needed to confirm that transporting only unmarked naturally produced adults above the dam will establish a viable, sustainable population. While the number of returning adult salmon has increased under the deep drawdown operation at Fall Creek, the number of redds above the project in recent years has been an order of magnitude lower than the number of outplanted adults. Additional evaluation of the factors influencing the success of outplanted adults may be prudent. (ODFW

2016) Further analysis is planned, including genetic studies, to summarize Fall Creek Chinook salmon demographics during recent years to confirm if the population is meeting replacement. (COP 2015)

Effectiveness of Downstream Passage:

Under the deep drawdown operational alternative at Fall Creek Dam, downstream fish passage and survival is expected to improve but it was not estimated or modeled in the Corps' COP analysis (2015). In 2012, NOAA Fisheries (Nesbit et al. 2014) evaluated passage behavior and survival of juvenile spring Chinook salmon at Fall Creek Dam at two different reservoir elevations (e.g., near elevations 728 feet and 703 feet). Both fish passage efficiency and survival of radio-tagged juvenile Chinook passing through the Fall Creek Dam diversion tunnel (RO) at the lower, drawn down reservoir elevation in this study were greater than at the higher reservoir elevation. For example, fish passage efficiency through the RO increased from about 87 percent at the higher elevation to 98.6 percent at the lower elevation, while project survival probabilities (from forebay to tailrace) ranged from over 79 percent at the higher elevation to 98 percent at the lower elevation.[99] The researchers stated the most important factor to improve survival may be to operate Fall Creek Dam with larger RO gate openings when juvenile salmon are passing the project (Nesbit et al. 2014).

COP-Phase II Recommendation:

The Corps' COP (2015) recommends that the operational alternative of a deeper drawdown of Fall Creek Reservoir from November through February should continue, as it has since 2011. Specifically, the reservoir would continue to be lowered from the normal minimum winter operating level of 728 feet down to elevation 680 to 690 feet beginning in November or December for approximately two weeks. This operation draws the reservoir down to within 10 feet of the regulating outlet entrance near the historic streambed, which should continue to provide improved downstream migration conditions. In addition, design and construction of a new, improved adult fish facility at Fall Creek Dam is expected to be completed in the near term. (COP 2015)

Other Potential Factors to Consider:

Under the deep drawdown operation, a lack of winter storage could result in missing the salmon incubation flow targets in some years below Fall Creek Dam,[100] and water stored in Fall Creek is also used to meet mainstem Willamette River flow targets. While current flows should not be affected by this operation, there could be future impacts if the project does not refill in low water years; the Corps indicates the degree of impact will depend upon the extent of future municipal and irrigation demands for stored water.

[99] It is recommended the results of this study be validated using juvenile fish of a similar size to the naturally-produced smolts passing Fall Creek Dam.

[100] However, only a few successful salmon redds have been found below Fall Creek Dam in recent years.

Downstream water temperatures and TDG levels should not be negatively impacted by this operation. While there could be impacts to reservoir recreation under the drawdown operation, there should be no changes from baseline conditions for downstream river recreational uses. (COP 2015) In addition, due to large releases of sediment associated with the drawdown operation, some potentially negative effects on Oregon chub habitat downstream of Fall Creek have been documented and will need to be monitored. (ODFW 2016)

Additional Short Case Studies

Location of Study: Chehalis River

Background

The Chehalis River Basin is the second largest river basin in Washington and is located in the southwestern part of the state. The Chehalis River originates at the confluence of the West Fork Chehalis River and East Fork Chehalis River in southwestern Lewis County. From there, the river flows north and east, collecting tributary streams that drain the Willapa Hills and other low mountains of southwestern Washington. The South Fork Chehalis River joins the mainstem a few miles west of the city of Chehalis. The Chehalis River is 115 miles in length and drains an area of 2,660 square miles. Major tributaries to the Chehalis include the Newaukum, Skookumchuk, the Black, the Satsop and the Wynoochee rivers. The Chehalis River empties into the Grays Harbor estuary at the city of Aberdeen, near where the Wishkah, Humptulips and Hoquiam rivers also join. Streamflows vary significantly in the Chehalis River at Satsop and can range from a low of only 400 cfs up to a peak flow of 47,000 cfs, with an average flow of 6,425 cfs. With such widely fluctuating flows, the Chehalis River has had a history of flooding.

Frequent Flood Events

The five largest floods in the Chehalis Basin have occurred during the past 30 years, causing massive damage to private property, livestock, farms, public buildings, roads and bridges. More recent floods occurred in early December 2007 and January 2009 due to severe winter storm events. Each of these recent floods closed the I-5 freeway near Chehalis for days. Climate change models predict significant increases in peak flood levels over the next 100 years, with costs expected to exceed $3.5 billion if no action is taken. (Chehalis Basin Strategy 2015)

Status of Salmon Populations

The Chehalis Basin supports five species of salmon and numerous other aquatic species, including the most diverse collection of amphibians in the State of Washington. However, all these species are significantly degraded, with salmon populations at only 15-25 percent of their historic levels. (Chehalis Basin Strategy 2015) The Chehalis Basin Strategy (2015) states it is possible that, with the current trajectory of the salmon populations, coupled with the potential impacts of climate change, it could lead to Endangered Species Act listings and economic and cultural losses for tribal, commercial and recreational fishers, including the complete loss of spring Chinook salmon from the basin.

Accordingly, thorough evaluations of the potential benefits, technical feasibility, and estimated costs of numerous flood damage reduction alternatives were conducted. In November 2014, the Chehalis Basin Work Group, with the support of Governor Inslee, state agencies, and the Chehalis River Basin Flood Authority, created a shared vision and set of recommendations for an integrated package of flood damage reduction and aquatic species restoration. (Chehalis Basin Strategy 2015)

The main recommendations of the Chehalis Basin Work Group included: 1) a concrete flood retention dam on the upper Chehalis River; 2) restoration of over 100 miles of spring Chinook spawning and rearing habitat, removal of priority fish passage barriers, restoration of off-channel habitat for aquatic species, and a comprehensive strategy to address bank erosion; 3) investment in high priority, small-scale flood damage reduction projects in the basin; and 4) local government land use management actions to protect the remaining floodplain function. The Washington Department of Ecology (WDOE), in consultation with the Chehalis Basin Work Group, Governor's office, and other agencies and stakeholders, is evaluating the timing and cost of the recommended package of flood damage reduction and aquatic species restoration actions through preparation of a Programmatic State Environmental Policy Act (SEPA) Environmental Impact Statement (EIS). The programmatic EIS will analyze the potential environmental, social and economic impacts associated with the recommended package of actions, as well as a "no action" alternative. (Chehalis Basin Strategy 2015) A draft EIS has been prepared by WDOE and is now available for public review and comment. chehalisbasinstrategy.com/eis-library/

In addition to the actions to restore and improve salmon habitat in the basin, one of the large scale actions to reduce the basin's exposure to flood damage is construction of a Flood Retention Facility (i.e., a dam with associated reservoir) coupled with fish passage systems. Two storage options are under consideration. One option is referred to as a Flood Reduction Only dam (FRO) and the second alternative is called a Flood Retention and Flow Augmentation dam (FRFA). The FRO dam would be constructed to retain water temporarily during major floods only, and the river would flow normally during normal conditions or smaller floods. The FRFA dam would be constructed to retain water permanently instead of only during major floods. In addition to reducing flood damage during the winter, summer, and early fall, water stored in the reservoir would be released to provide both flow augmentation and cooler water temperatures downstream to benefit anadromous fish. (Chehalis Basin Strategy 2015)

For the FRO option, adult fish passage will be provided via a conduit through the dam and it is expected the various life histories of juvenile salmon, resident fish and Pacific lamprey could also be accommodated. For the FRFA alternative, fish passage would be provided for both juvenile and adult salmon, resident fish and Pacific lamprey. Under this alternative, a fish Collection, Handling and Transfer (CHTR) Facility would be designed and constructed at the dam, which would include a fish ladder for adult salmon, an adult lamprey passage structure, a fish elevator, a fish sorting and work-up facility, and adult fish holding ponds for truck transfer upstream. (Chehalis Basin Strategy Fish Passage Update 2016)

Under the FRFA option, two alternatives are under consideration to provide downstream juvenile fish passage. The first alternative is a floating surface collector (FSC), with a design similar to the FSCs installed at upper and lower Baker Dam, Swift Dam and North Fork Clackamas River. The primary design elements of the FSC option include, guide nets, a lead net, a net transition structure leading to primary and secondary dewatering screens, a fish collection barge, mooring and guide systems, an access tower with a gangway, and a hopper gantry system which would lift juvenile fish to the land-based monitoring and evaluation station at the CHTR facility. (Chehalis Basin Strategy Fish Passage Update 2016)

A second fish passage alternative under the FRFA option is a passive, multi-port outlet structure to provide fish passage for juvenile salmon and steelhead, post-spawn adult steelhead kelt, and resident fish. The design elements of the multi-port outlet structure include four fixed V-screen collectors with a 10-foot reservoir fluctuation per screen, 500 cfs attraction flow into the V-screens, a 25 cfs pressurized fish bypass conduit through the dam leading to an open channel return of fish to the Chehalis River below the dam. (Chehalis Basin Strategy Fish Passage Update 2016)

More details about the design of each of these fish passage alternatives under the FRFA option will be available in an upcoming conceptual engineering design report, which was not available at the time this paper was prepared. Both of these downstream fish passage alternatives are expected to be designed in accordance with NMFS' Anadromous Salmonid Passage Facility Design guidelines (2011).

Location of Study: Clackamas River Complex – specifically North Fork Dam

Background

Portland General Electric's (PGE) North Fork Dam sits on the Clackamas River in Oregon, above River Mill Dam, the Faraday Powerhouse, and Faraday Dam. The three dams make up the Clackamas River complex. The North Fork Dam was built in 1958, is 206 feet high and 676 feet long, and backs up the North Fork Reservoir which has a 2-foot normal reservoir fluctuation. Two turbine generators make up the powerhouse, with intake depths of 125 feet. The spillway has three 50-foot wide spill gates. The dams downstream of the North Fork support adult fish passage with fish ladders but do not have downstream passage facilities. (PGE website, Christensen 2013)

Adult sorting facility

Enhancing the already existing 1.9-mile long adult fish ladder from the tailwater of Faraday Dam to the North Fork Dam is now an adult sorting facility. Adults enter the facility from the ladder, where they are sorted via a mechanical sorter operated by staff, which provides sorting free of human contact and handling. A cool, 16-foot deep holding tank sits at the top of the fish ladder. The staff biologist operating the sorter opens a gate, with a push of a button, to bring a fish into an observation tank. Once in the observation tank, the staff person looks for signs of the species type and the presence or absence of an adipose fin. Fish with the fin (wild fish), are immediately released back into the Clackamas to continue their journey to their natal spawning ground. Those deemed as hatchery fish (without an adipose fin), are sent to one of three holding tanks at the facility. The average time the fish remains in the observation tank is 2 seconds. In its first year of operation the facility sorted 5,166 wild fish from 2,248 hatchery fish, with 15 different species types recorded, passed six adult lamprey upstream, and decreased temperatures in the fish ladder by 1.5°C. In one day, the facility sorted 1,100 fish, marking a record for the PGE site. The budgeted cost of the facility was $4.1 million in 2013 ($4.2 million in 2015 dollars) and the actual cost was $5.1 million ($5.2 million in 2015 dollars). (Shibahara 2014, Gautschi 2013)

Juvenile downstream fish passage – River Mill Dam
In the early 2000s, a surface collector was designed and constructed for juvenile salmon and steelhead downstream passage at River Mill Dam. Studies were conducted from 2001-2004, the design phase lasted from 2010-2011, construction occurred in 2011-2012, and the surface collector was officially in operation in November of 2012. The collection system at River Mill passes juveniles through a transport channel and a fish bypass pipeline to be released in the dam's tailrace. The design and construction costs of the collector was $12 million in 2012 ($12.4 million in 2015 dollars). (Shibahara 2014)

The smolt survival standard for the Clackamas project is set at 97 percent. PIT tag evaluation found that the fish guidance efficiency into the surface collector at River Mill was 98.3 percent for Chinook, 99.8 percent for coho, and 95.8 percent for steelhead, with overall survival rates of 98.6 percent for Chinook, 99.0 percent for coho, and 95.2 percent for steelhead. (Shibahara 2014)

In the first year of operation, PGE found that the facility performance for guidance and fish condition were excellent, and that benefits of fish collection should result in increased adult returns of about 3-6 percent. (Shibahara 2014)

Juvenile downstream fish passage – North Fork Dam
Pit-tag studies showed that juvenile fish congregated near the center of the forebay along the dam, which told scientists and engineers working on the project that a floating surface collector (FSC) in the forebay of the dam would likely be ideal for attracting juveniles. Both the FSC and attached fish guide nets of the North Fork Dam are similar in design as those used at Swift and Baker dams. This FSC does not use a net transition structure but instead the guide nets attach directly to the FSC[101]. Once a fish enters the facility, the flow rapidly increases to a speed too fast for a juvenile to exit the facility. A major difference with juvenile passage at North Fork Dam compared to similar sites is the transportation of the juveniles once collected: a 1,500-foot long fish transport pipeline, passes the fish through the dam and into a bypass pipeline downstream to River Mill Dam. To accommodate for transport pipeline, a large hole was drilled into the dam. Juvenile fish are attracted to the collector from simulated flows at the entrance. A transition channel and debris trap assist in debris management of the FSC utilizing grizzly debris racks, traveling screens with debris pegs, and a deflector gate at the fish exit. (Christensen 2013, Gautschi 2015)

[101] Guide nets can detach when FSC need to be raised.

The goal of the project is 97 percent passage through the whole Clackamas complex. Construction began in December 2013 and the FSC was scheduled to be launched in spring or summer of 2016. In 2015, the North Fork FSC was estimated to cost $54 million. (Gautschi 2015)

In summary, fish passage in the Clackamas complex, specifically at the North Fork Dam, is using innovative technology to sort, handle, and pass both juvenile and adult fish efficiently and without human handling. As of the release of this staff paper, the juvenile passage system is brand new; staff thinks this is a location to keep watch on for its successes and challenges as it begins operating and once adults that were passed through the system as juveniles begin returning.

Location of Study: Cle Elum

Background

Cle Elum Dam, located on the Cle Elum River 10 miles northwest of the city of Cle Elum in southeastern Washington, is an earthfill dam constructed in 1933 by the Bureau of Reclamation. The dam is situated at the end of a 7-mile long natural lake (at full pool) with an active reservoir capacity of 436,900 acre-feet and draining an area of 260 square miles. Both the dam and lake are managed for irrigation and fish purposes by the Bureau of Reclamation as part of the Yakima Project. The dam is 165 feet high and experiences seasonal swings in reservoir elevation of about 100 feet. (Bureau of Reclamation 2016 web page)

The Cle Elum River is a 28-mile long tributary to the Yakima River, which enters the Columbia River near Richland, Washington. The Cle Elum River originates off the eastern slopes of the Cascade Range near Mount Daniel and flows generally south, through Hyas Lake. The river is joined by many tributary streams, including the Waptus River and Cooper River, after which it enters Cle Elum Lake.

Historically, Cle Elum Lake and its upper tributaries supported sockeye, spring Chinook, coho, steelhead and bull trout. However, once Cle Elum Dam was constructed, aquatic habitat was altered and the upstream and downstream migrations of salmonids were blocked. The Cle Elum watershed has the largest reservoir and second largest river network[102] in the Yakima subbasin blocked to anadromous fish migration. (Horn and Monk 2015)

[102] Reclamation's "Yakima Dams Fish Passage, Phase I Assessment Report -- February 2003," states that new anadromous stream miles made accessible by providing fish passage at the dams would be 29.4 river miles opened above Cle Elum Dam (2nd highest) and 36.8 river miles opened above Tieton Dam (highest).

Yakima River Basin Water Enhancement Project

In 1994, the U.S. Congress passed Public Law 103-434, the Yakima River Basin Water Enhancement Project (YRBWEP). The act had the goals of protecting and enhancing fish and wildlife resources through improved water management, while also improving the reliability of irrigation water supplies. Section 1206 of the act authorized Reclamation to modify Cle Elum Dam to increase the amount of reservoir storage and to construct fish passage facilities. (Horn and Monk 2015)

Since passage of YRBWEP, Reclamation has been collaborating with partners, including the Yakama Nation Fisheries and WDFW, to explore whether fish passage facilities could be implemented at Cle Elum Dam to help reintroduce sockeye salmon to the upper watersheds. Fish passage at Cle Elum would also benefit many other native species and would enhance ecosystem health of the Cle Elum watershed. Non-native species would not be allowed to pass the dam based on the Yakama Nation's proposed salmon reintroduction plan. The Yakima Basin Integrated Plan is funding biological studies evaluating fish passage and permanent passage facilities at Cle Elum Dam. (Horn and Monk 2015)

Interim Fish Passage

In 2005, Reclamation constructed an interim fish passage facility at Cle Elum Dam. A narrow wooden flume was constructed to provide a surface passage route over the spillway. Flow into the temporary flume is controlled by adjusting a series of weir, or flash, boards, which allow it to operate from reservoir elevation of 2,224 feet up to the full pool level of 2,240 feet. Flows through the flume during fish passage operations can range from less than 100 cfs to about 500 cfs, with 1-5 feet of head flowing over the weir. (Horn and Monk 2015)

From 2006 to 2009, studies were conducted by the Yakama Nation, Reclamation and USFWS to explore juvenile fish timing and use of the temporary flume passage system. For these studies, groups of PIT-tagged hatchery coho smolts were either released in early April into the reservoir directly from a transport truck or held and released from a net pen. The flume, which had PIT tag detection, was typically operated during the April through early July period. The median dates of smolt passage at Cle Elum and Prosser[103] dams from the 2009 juvenile coho releases were June 14 and June 20, respectively. While fish were able to migrate throughout May, most migration for the 2009 releases occurred during June. Juvenile fish released in 2008 that migrated downstream in 2009 were found to have an earlier overall migration. (Lind et al. 2010)

Multiple years of evaluation determined that juvenile salmon would locate the passage entrance on the spillway with little delay at flows ranging from 100-300 cfs and volitionally move downstream. However, the interim flume was only able to be operated when the reservoir was within a narrow range near full pool condition. Observations suggest a potentially significant but unknown proportion of sockeye smolts have been

[103] Prosser Dam is located downstream of Cle Elum Dam at river mile 47.1 on the Yakima River.

injured while exiting the interim fish passage flume.[104] Further biological evaluation of fish survival and injury in the flume may be necessary. (Horn and Monk 2015)

Figure 33. The interim bypass flume on the Cle Elum spillway. (Source: USBR)

Sockeye Reintroduction

In 2009, 1,000 adult sockeye salmon, using stocks from the Wenatchee and Okanogan subbasins, were collected and transported from Priest Rapids Dam on the Columbia River and released directly into Cle Elum Reservoir, which allowed the fish to migrate into the upper river and tributaries for spawning. Progeny from these sockeye spawners rear in the reservoir for 1+ years. Once the fish smolted, they migrated through Cle Elum Reservoir and used the temporary spillway flume to exit the reservoir. Outmigrating sockeye smolts have been observed at both Roza and Prosser dams downstream, indicating successful passage out of Cle Elum Reservoir. (Horn and Monk 2015)

The numbers of adult sockeye released into Cle Elum each year have varied based on the availability of adults, but in 2010, 2,500 sockeye were transported and released into the reservoir; in 2011, 4,100 fish were released; 10,000 fish in 2012; 4,000 fish in 2013; 10,179 fish in 2014; and roughly 10,000 fish in 2015 and 2016. A hydroacoustics array at the dam was used to better understand the outmigration timing and abundance of

[104] It is hypothesized the injuries most likely occurred when fish entered the Cle Elum River at water velocities in the flume reaching 40 feet per second.

juvenile sockeye salmon, as well as to describe juvenile fish behavior and movement patterns as they approach the interim passage facility. Hydroacoustics data was supplemented with visual observations of smolts in the Cle Elum River and smolt counts from the Chandler Juvenile Fish Facility from 2011-2014. (Horn and Monk 2015)

Biologists state that sockeye smolts readily find the entrance to the interim spillway flume. Smolts have been observed travelling down the flume within 15 minutes of its opening in the early spring. Sockeye smolts are also seen migrating along the shoreline of the lake to the spillway. It is hypothesized the lake configuration is a contributing factor for several reasons: 1) at low pool in the spring the lake tapers to the face of the dam, thus guiding fish toward the spillway; and 2) the wind fetch blows down the lake toward the spillway, increasing the current to the spillway. (Hubble pers. communication 2016)

In addition, the Yakama Nation is currently placing a few hundred surplus hatchery spring Chinook salmon into Cle Elum Reservoir, primarily for their nutrient contribution. A Reclamation biologist says these fish are spawning successfully and likely are producing viable smolts. (Hubble, pers. communication 2016)

Helix Design for Downstream Fish Passage

Reclamation has recently completed developing an innovative downstream passage design for Cle Elum Dam. It consists of a series of surface structures allowing juvenile fish to volitionally enter an entrance to a structure that carries them safely around the dam and downstream to the river. Several fish passage options underwent numeric and physical hydraulic modeling by Reclamation's Hydraulic Investigations and Laboratory Services group in Denver. Based on these modeling analyses, a new juvenile fish passage concept using a helix-configured design was developed for Cle Elum Dam. (Hanna et al. 2015) The purpose of this project was to construct juvenile fish passage facilities and maximize ecosystem integrity by restoring connectivity, biodiversity and natural production of anadromous salmonids.

The fish passage facility design, expected to be consistent with the guidelines in NMFS' Salmonid Passage Facility Design (2011), consists of an intake structure attached to a helix structure, a tunnel and an outfall. An important design consideration for local biologists was that the downstream passage facility should be a passive system. The innovative helix design dissipates energy and allows downstream juvenile fish transport from Cle Elum Reservoir under a wide range of reservoir elevations, ranging from a maximum of 2,243 feet to a minimum of about 2,180 feet. The inlet structure has six levels operating over a 60-foot pool elevation range coinciding with the smolt passage timing in the spring of most years.[105] The inlet structure was intentionally designed to remain in contact with the shoreline as the reservoir fills to take advantage of the shoreline migration pattern of sockeye smolts. The inlets were also designed for surface

[105] Except in extreme drought years when Cle Elum Reservoir may not fill or fills after the desired smolt outmigration period.

fish passage, i.e., no “sounding” of fish is required to find the inlet entrance. Operationally, once the lower inlet is underwater it will be closed and the next inlet above will be opened for fish passage, etc. as the pool fills. Based on the observed fish passage at the temporary fish passage flume on the spillway, Reclamation expects to obtain nearly 100 percent fish passage efficiency with this new structure. (Hubble, pers. communication 2016)

The helix is designed to pass all juvenile fish species, but also steelhead kelts and other large adult species. The design has between 200-400 cfs of water and fish exit the helix structure near elevation 2,137 feet into a tunnel, or conduit, extending over 1,200 feet through the right abutment of the spillway to the Cle Elum River. Flow and fish can be introduced into the helix at six different elevations, each one separated vertically by almost 12 feet, with a 3-foot overlap between the inlets. A key design objective was to ensure that any transitions within the passage system, i.e., from the intake structure into the helix or from the helix into the bypass conduit, should have extremely smooth hydraulic flow. (Hanna et al. 2015) If the helix design proves to be effective for fish passage at Cle Elum Dam, a similar design could be scaled up or down to meet different pool fluctuation and fish passage needs, including potentially at Grand Coulee Dam. (Hubble, pers. communication 2016)

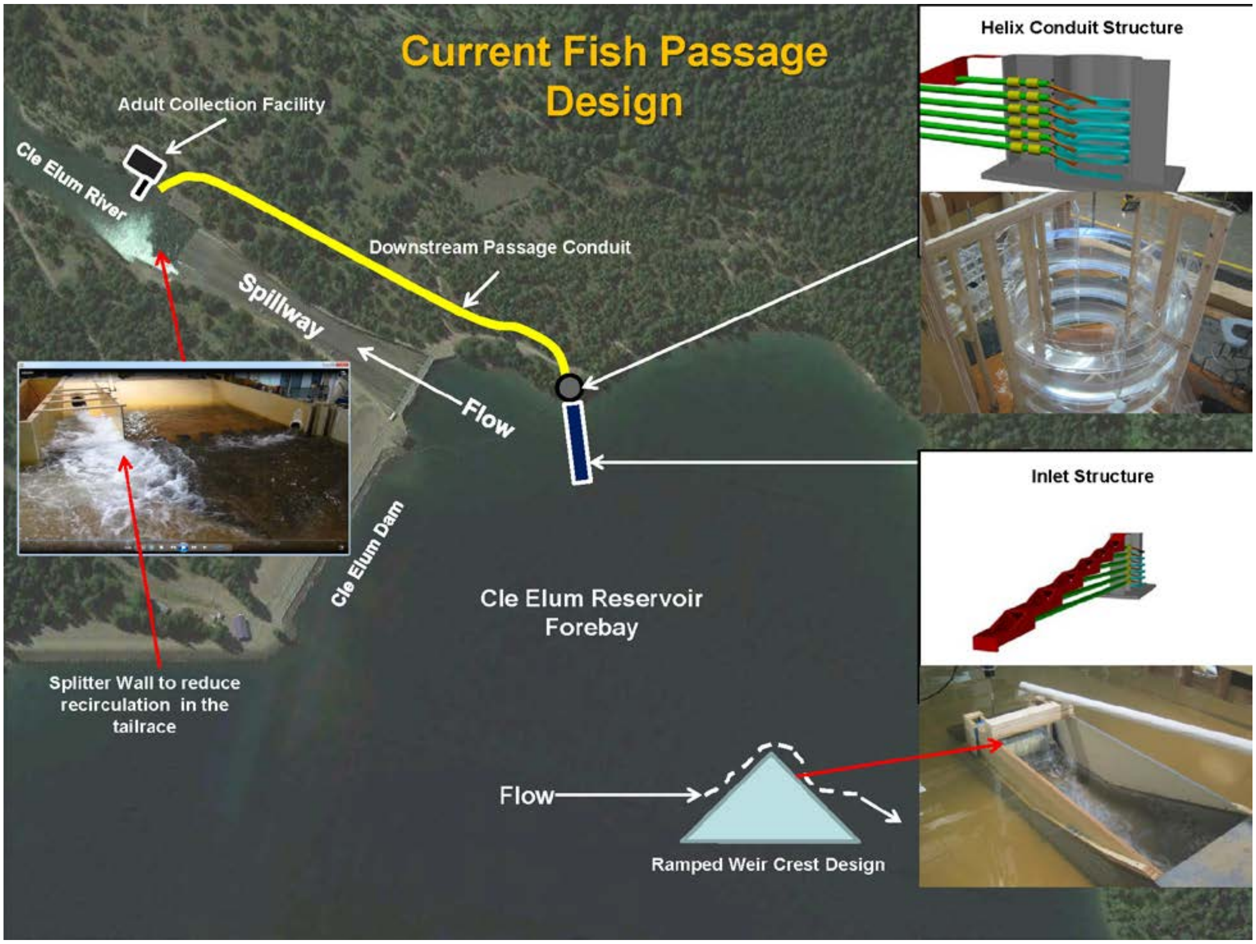

Figure 34. The Bureau of Reclamation's proposed helix bypass design for juvenile fish passage at Cle Elum. (Source: USBR)

<u>Upstream Fish Passage</u>

Presently Reclamation is using a conventional trap and transport system below Cle Elum Dam to collect and move adult salmonids around the project. However, Reclamation is presently working with Whooshh Innovations to prototype test a long Whooshh tube to move adult fish volitionally. (Hanna et al. 2015) If successful, it would eliminate the need and ongoing expense to truck the fish from a holding facility. Further testing of a Whooshh tube is planned in the fall of 2016 at the Yakama Nation's Prosser fish hatchery facility using fall Chinook and coho salmon, and in the summer of 2017 at Cle Elum Dam (Hubble, pers. communication 2016).

<u>Construction Period and Cost</u>

It is expected the period needed to construct the helix fish passage structure will be 5-7 years, based on a steady and continuous appropriations. Initial work on roads and bridges is nearly completed; construction on the helix vault will begin in spring 2017, followed in sequence by the tunnel (conduit), the helix and inlet structures. The estimated construction cost is roughly $100 million (2015 dollars). (Hubble, pers. communication 2016)

Location of Study: Cowlitz River – Cowlitz Falls and Mossyrock

Background

The Cowlitz Falls Project is a 70 megawatt hydroelectric dam constructed in the early 1990s. The dam and power generation facility were completed in 1994. While the project is owned and operated by Public Utility District #1 of Lewis County (Lewis PUD), it was cooperatively developed with the Bonneville Power Administration (BPA), which purchases the annual energy output of the project under a long-term contract. In exchange for receiving the output of the Project, BPA pays all costs associated with its operation and maintenance.[106] The dam is 140 feet high and spans approximately 700 feet across the Cowlitz River. The reservoir behind the dam has a surface area of approximately 700 acres. (Lewis PUD 2016)

The Cowlitz Falls Project is built in a narrow constricted portion of the Cowlitz River immediately upstream from Tacoma Power's Riffe Reservoir in eastern Lewis County. Located a short distance below the confluence with the Cispus River, the dam operates in a "run-of-the-river" mode, using water from both the Cowlitz and Cispus rivers. (Lewis PUD 2016)

BPA, in cooperation with Lewis PUD, state and federal agencies, and Tacoma Power, has constructed a downstream anadromous fish collection facility at Cowlitz Falls Dam. The fish facility has permitted the reintroduction of salmon and steelhead in the upper Cowlitz River basin. The upper Cowlitz and Cispus River basins were blocked from migrating salmon and steelhead by Tacoma Power's construction of the Mossyrock and Mayfield Dams in the 1960s. Lewis PUD, BPA, and Tacoma Power are involved in efforts to improve the anadromous fish reintroduction program for the upper Cowlitz River. (Lewis PUD 2016)

Mossyrock Dam, completed in 1968, is owned and operated by Tacoma Power Company. It is a concrete arch-gravity dam located on the Cowlitz River near Mossyrock in Lewis County, Washington. Mossyrock is the tallest dam in Washington State at 606 feet above bedrock[107] and it is 1,648 feet long. The primary purpose of the dam is hydroelectric production, with flood control and recreation as secondary purposes. The reservoir created by the dam is called Riffe Lake, which at full pool is a 23 mile long reservoir on the Cowliz River with a surface area of about 11,800 acres. The reservoir elevation at full pool is 778.5 feet and it drops to 600 feet at minimum conservation pool. (Tacoma Public Utilities 2016)

The Mossyrock Dam's power plant contains two 150 MW Francis turbine hydroelectric generators for a total generating capacity of 300 MW. Hydroelectric power from

[106] Lewis County PUD buys its power from BPA so the power generated by the Cowlitz Falls Project helps supply the needs of Lewis County residents and businesses.
[107] Mossyrock Dam rises 365 feet above the Cowlitz River bed.

Mossyrock Dam supplies about 40 percent of Tacoma Power's electricity needs. (Tacoma Public Utilities 2016)

Flow Velocity Enhancement System

Since it is well known that downstream migrating juvenile salmonids have evolved to follow mildly turbulent river currents to assist in their downstream migration, NATURAL SOLUTIONS - A Dam Site Better LLC designed and developed a Flow Velocity Enhancement System® (FVES). The FVES is an innovative behavioral guidance device that uses hydraulic turbulence as a means of guiding migrating juvenile or adult fish into a bypass channel or fish ladder, thereby allowing fish passage at dams or other barriers. The FVES design and construction process is patented. (Natural Solutions 2016)

Natural Solutions (2016) describes the FVES® as a simple steel hollow tube with a unique, patented "log" for inducing moving water. The FVES uses low volumes of high-pressure water to induce a high volume content of water through a venturi pump, or educator, to create a turbulent velocity plume in a water body. The FVES generates turbulent boils and eddies typical of a natural river.[108] Higher pressure motive water and/or larger diameter eductors can be used to create larger plumes (e.g., wider and longer), so plume sizes can be tailored to meet a specific need. The conversion of motive water to discharge water can be as high as 5 to 1, or for 1,000 gallons in, a FVES can produce 5,000 gallons out. (Natural Solutions 2016) See www.fishpassage.com for more information.

The "natural" current induced by a FVES is attractive to both juvenile and adult fish, providing migrational cues to help guide fish toward bypass structures, adult fishways, or traps. Natural Solutions (2016) claims use of a FVES can:

- Increase attraction of adults to fish ladder entrances;
- Help prevent fall-back of adult fish;
- Break-up conflicting currents at the dam face; conversely, the induced current can enhance fish guidance away from hazardous turbine intakes and into fish bypasses or surface collectors;
- Enhance fish egress; and
- Reduce predation at surface collector and bypass system outfalls.

The FVES was one of the Council's recommended Innovative Technology projects in 2007 that was funded by BPA for field testing. Burns and others (2010) conducted studies in the Cowlitz River over a several year period under BPA and self-funding. The focus of these studies using the FVES was smolt collection at the head of Tacoma Power's Riffe Lake reservoir, where fish guidance to potential collection site was demonstrated.

The efficacy of the FVES for guiding juvenile fish was evaluated in detail in 2008 through use of a two-dimensional acoustic tracking study of juvenile Chinook salmon

[108] Natural Solutions claims the turbulent water doesn't spiral as it would if it were spun by propellers.

smolts. The objectives of this acoustic telemetry study were to determine if operation of a FVES: (1) affected the migratory paths of individual acoustic-tagged juvenile Chinook salmon in the upper Cowlitz River near the FVES, and (2) affected the distribution and timing of smolts in that reach of river, both compared to fish migration and distribution without the FVES operating. A secondary objective was to test the ability to capture smolts in a net placed in the path of the FVES plume. A total of 90 juvenile Chinook salmon were collected at Cowlitz Falls Fish Facility where they were acoustic tagged and then released in upper Riffe Lake during August 2008. (Burns et al. 2010)

Evaluation of the 2008 acoustic tracking results showed that tagged juvenile salmon were highly attracted to areas located in and on the periphery of the primary FVES plume throughout their residence time within the array. The FVES did not, however, have a statistically significant effect on the migratory path of downstream migrants when initially exposed to the induced flow based on passage through a grid of river transects. (Burns et al. 2010)

However, Burns and others' (2010) comparative analysis of all fish locations in grid spaces aligned to the physical structure of the FVES plume showed highly significant differences between on and off FVES test conditions. Researchers stated it appeared that fish needed some time to respond to the hydraulic conditions of the FVES plume. The turbulent plume enticed smolts to remain in the area, often moving in and out of the plume and sometimes returning to the head of the plume to be entrained again. From a qualitative observation of the acoustic fish tracks, it appeared that a location about 100 feet from the FVES discharge was the point where most juvenile fish passed through (often multiple times) and thus would be subject to being collected or diverted. (Burns et al. 2010)

In summary, fish guidance was demonstrated using acoustic telemetry to track tagged juvenile fish and statistical analyses of fish locations and behavior in relation to the FVES velocity plume. Acoustic-tagged juvenile Chinook salmon smolts were found to be attracted to (e.g., respond to) and be successfully guided by locally induced turbulent flows using a FVES at the upper end of Riffe Lake in the Cowlitz River in 2008. (Burns et al. 2010)

Location of Study: Cushman Hydroelectric Project

<u>Background</u>

The 134.6-megawatt producing Cushman Hydroelectric Project is located on the North Fork Skokomish River near the Hood Canal on the Olympic Peninsula in Washington state and is owned and operated by Tacoma Power. The hydroelectric project, which produces 11 percent of Tacoma Power's electric supply, consists of two dams, two powerhouses, Lake Kokanee and Lake Cushman. Cushman No. 1 Dam was completed in 1926, is 235-feet tall and 1,100-feet long, and creates Lake Cushman, a 10-mile long reservoir. Cushman No. 1 powerhouse has two 22-megawatt turbine generators.

Cushman No. 2 Dam was completed in 1930, is 175-feet tall and 575-feet long, and creates Lake Kokanee, a 2-mile long reservoir. Cushman No. 2 powerhouse has three 27-megawatt turbine generators. The first FERC license for the project was in 1924, with the newest license issued in 2010 with an expiration of 2048. Included in the new license was a new powerhouse at Cushman No. 2 Dam, called the North Fork Powerhouse. Additionally, key license articles addressed in the new FERC license include a fish habitat enhancement and restoration plan, downstream fish passage, upstream fish passage, and a fish supplementation program. The species of interest for fish passage are coho, spring chinook, steelhead, and sockeye salmon. (McCarty 2013; McCarty 2014)

Adult upstream fish passage

The new powerhouse, the North Fork Powerhouse that is located at Cushman Dam No. 2, incorporates a new upstream fish passage system and adult fish sorting facility, all of which began operating in 2013. This unique facility attracts adults into the collector using water discharged from the two 1.8-megawatt Francis-style turbine generators. A holding pond sits above the turbines' draft tubes, which is a design that had never been done before. In fact, the turbine manufacturers were wary of this idea and did not think it would work. The final design, which was based on scaled physical models, included protection for both the turbines and their draft tubes and the adult fish being collected. Another unique piece to the adult trap at Cushman is the tram. Once the adults are trapped, they are placed in a hopper and a fish tram transports the hopper up the face of the 175-foot tall dam. A jib crane at the top of the dam moves the hopper to the fish sorting facility, also at the top of the dam. At the fish sorting facility, the fish are separated, counted, and marked (as necessary) and then transported upstream of the two dams. The cost of the adult trap facility was $28 million in 2014 ($28.03 million in 2015 dollars). (McCarty 2013; Tacoma Public Utilities website; McCarty 2014)

Juvenile downstream fish passage

A floating surface collector used to collect juvenile salmon, was installed in Lake Cushman and began operating in 2015. Full exclusionary nets are used with the FSC to keep fish from entering the turbines of Cushman No. 1 Dam. Similar to the juvenile collector at Baker Dam, Cushman's FSC is attached to a net transition structure[109], a sorting station on the FSC, and a hopper system to transfer the collected juveniles from the collector to the transport truck. (McCarty 2013)

Further upstream of the FSC, a debris barrier allows for year-round recreational traffic flow and summer boat passage. Challenges to the debris barrier are the bathymetry survey and investigation, sizing of mooring anchors, and public notification and safety. (McLaughlin 2015)

In 2015, the costs for the FSC and its additional parts were:

- Debris barrier:

[109] 250 cfs of flow attract the juveniles into the entrance of the FSC.

    - Expected cost: $606,000
    - Actual cost: $686,000[110]
- Netting:
    - Expected cost: $1,995,000
    - Actual cost: $1,746,000[111]
- FSC/NTS materials:
    - Expected cost: $14,867,000
    - Final cost: $14,866,000[112]
- FSC/NTS install:
    - Expected cost: $9,580,000
    - Final cost: $9,678,000[113]
- *Total costs:*
    - *Expected cost: $27,048,000*
    - *Final cost: $26,976,000*[114]

Performance standards

Performance standards for the FSC will be measured by system survival and fish collection efficiency. Marked fish will be released at the upstream end of Lake Cushman, the percentage of those fish who are successfully collected at the FSC is the system survival. Fish collection efficiency will be measured with an annual mark-recapture study to determine the efficiency of outmigrating juvenile coho in finding the FSC once they are in close proximity to it. The percent of coho that are recaptured at the FSC after being released 360 feet upstream of Cushman Dam No. 1 and survive passage to the release location downstream of Cushman Dam No. 2 will provide the fish collection efficiency. The fish collection efficiency will be measured each year within Phase One (years 9-13) of the FSC development or until the performance standard is met for 3 consecutively averaged years and then every five years after the performance standard is met. (Tacoma Power 2014)

[110] $80,000 more than expected.
[111] $249,000 less than expected.
[112] $1,000 less than expected.
[113] $98,000 more than expected.
[114] $72,000 less than expected.

Smolt evaluation study
At the end of 2014, Tacoma Power released a Request for Proposals for a smolt evaluation study of downstream migrant fish in Lake Cushman with a purpose to establish performance measures for the FSC. The study will determine the fish collection efficiency of coho, and examine the difference in hatchery-origin and natural-origin smolts used in the fish collection efficiency study, and implement a statistical review to ensure that the sample sizes and study approach laid out is sufficient to achieve the study precision goals of +/- five percent (of 90 percent confidence level). Calendar year 2016 was the first study year; results from this work have not been published as of the release of this staff paper. (Tacoma Power 2014)

In summary, this fish passage location has tried some new techniques, especially for adult fish passage, while increasing power production. The new powerhouse generates 3.6 megawatts of hydropower energy while also working efficiently to pass adult fish into the blocked Skokomish waters above Cushman. Additionally the cost for the juvenile collection facility is reduced compared to other similar facilities such as the Baker Dam floating surface collectors. Staff thinks the progress of this location would be good to track as fish return numbers and results of studies are released for Cushman.

Location of Study: Yuba River – Englebright and New Bullards Bar

Background
Englebright, a concrete arch dam that is primarily used for hydropower generation, was built in 1941 in response to the relegalization of hydraulic mining in the 1930s and was needed at the time to trap mining debris on the Upper Yuba River. Englebright is 260-feet high and provides hydraulic head for two hydropower plants downstream: Narrows 1 and Narrows 2. Englebright backs up a 12-mile reservoir (Englebright Lake) that is popular for water recreation, and provides 45,000 acre-feet of storage. The dam currently has no fish passage facilities. Below Englebright is 24-foot tall Daguerre Point Dam, which has fish ladders in need of an update. Daguerre Point's ladders accommodate salmon and steelhead but not the ESA-listed green sturgeon. (R2 Resource Consultants 2014; NOAA Fisheries 2016)

Further upstream North Yuba River in 1969, the New Bullards Bar Dam was built for flood control and provides the primary water storage for the Yuba River Basin. This concrete arch dam is 2,323-feet long and 645-feet high, making it one of the tallest dams in the country. New Bullards Bar has 1 million acre-feet storage capacity in the reservoir, and no fish passage facilities. Water from New Bullards Bar generates power downstream through the New Colgate Powerhouse, the capacity of which is 340 megawatts. (R2 Resource Consultants 2014; NOAA Fisheries 2016)

California's Central Valley recovery planning
Three ESA-listed species of anadromous fish inhabit the Yuba River: steelhead, spring-run Chinook, Green Sturgeon. As part of the recovery planning process for California's

Central Valley, the Yuba River was identified by the National Marine Fisheries Service (NMFS) as a high-priority watershed for recovery actions, particularly for reintroduction of salmon and steelhead above Englebright Dam in an effort to delist the three anadromous species. (R2 Resource Consultants 2014)

From 2009 – 2014, NMFS funded various studies on the Upper Yuba River to evaluate the feasibility of fish passage. The Upper Yuba River was split into four subbasins upstream of Englebright: North, Middle, South, and mainstem Yuba River. For the area of focus for purposes of this staff paper is what NMFS refers to as the Yuba mainstem which is between New Bullards Bar and Daguerre Point dams, and the North Yuba which is the area above New Bullards Bar. Field surveys were conducted in each subbasin to collect hydraulic geometry data, habitat characterization, and temperature data. Habitat modeling, sediment transport modeling, and engineering studies were completed. (NOAA Fisheries 2016)

<u>Adult upstream fish passage</u>
Various options were considered for further exploration for adult fish passage at Englebright such as full or partial dam removal, operational changes, a volitional-entry fish ladder, a semi-volitional tramway, or a full trap and haul system from Daguerre Point Dam to available upstream habitats. Taken into consideration was flood risk and biological impact. (NOAA Fisheries 2016)

<u>Juvenile downstream fish passage</u>
Three options were considered for further exploration for juvenile fish passage in the mainstem Yuba River: fish screens at the hydropower intakes; a floating surface collector at Englebright Dam; and tributary collectors with downstream transport. Ultimately work was conducted for a preliminary design for a floating surface collector. (NOAA Fisheries 2016)

<u>Reintroduction potential & RIPPLE and Life-cycle modeling</u>
Like most areas where anadromous fish have been extirpated for a significant period of time, the habitat quality above the block will be a determining factor in the success of reintroducing salmon and steelhead. One existing known habitat condition in the New Bullards Bar stream reaches is reduced wetted areas and increasing water temperature due to flow regulations. (R2 Resource Consultants 2014)

A habitat and juvenile production potential model called RIPLLE was used to test the biological production potential in the Upper Yuba River. With a moderate smolt-to-adult survival parameter value used in the model, predicted adult escapement was adequate to fully seed the available habitat for most model runs. Additionally, results from the RIPPLE model provided an estimate of the proportion of each juvenile life stage such as fry that were estuary-bound, subyearling smolt migrants, and yearling migrants. RIPPLE model results suggest that significant numbers of spring Chinook juveniles and smolts could be produced in the North Yuba, above New Bullards Bar Dam, under all scenarios (i.e., dry conditions scenario and two alternative water scenarios). Estimates of steelhead habitat capacity showed that the North Yuba subbasin has more production potential than the other Yuba subbasins.[115] During modeling, it was not investigated whether the reservoirs could be used as summer holding and rearing habitat; in the pilot phase of the reintroduction program, this potential behavior should be tested as it could increase the productivity and survival for both salmon and steelhead in the area, especially during drought years. (R2 Resource Consultants 2014)

Given the lack of anadromous fish in the blocked waters of the Upper Yuba River, NMFS was required to collect biological information elsewhere for the model inputs. NMFS used data from populations in the lower, un-blocked waters of the Yuba or elsewhere in the Sacramento River Basin, information based on historical accounts and compiled from previous habitat studies in the Upper Yuba, and any information from native Sacramento River or hatchery stocks that was found to be relevant. (R2 Resource Consultants 2014)

Similar to the migration of juveniles through the Columbia River, juveniles produced in the Upper Yuba will need to emigrate downstream through dams and reservoirs and again on their migration back as adults. A life-cycle model was used to evaluate both a collection and transport program for the North Yuba subbasin as well as construction of a fish ladder and juvenile passage facilities at Englebright. Each alternative included several hydro scenarios and juvenile production estimates from the RIPPLE model, and accounted for uncertainty in survival and fish passage. These factors were combined with estuary and ocean survival to comprehend the full life-cycle dynamics and potential in order to better predict outcomes associated with the reintroduction alternatives. R2 Resource Consultants (2014) noted that these two alternatives are not the only options for safe fish passage and that variations and combinations of these options are also possibilities. The Life-cycle model results suggest that a collection and transport system to the upper North Yuba (above New Bullard Bar Dam) could support a self-sustaining population of spring-run Chinook during dry, wet, and average flow conditions, but is the subbasin that is most difficult to access for fish passage. (R2 Resource Consultants 2014)

Reintroduction Plan

The Upper Yuba River Anadromous Salmonid Reintroduction Plan contains the RIPPLE habitat assessment model results, the Life-cycle model results, the fish passage alternatives and a phased adaptive management program. The overall goal for the Reintroduction Plan is to delist the three listed species; the short-term goal is to open up habitat above Englebright to increase geographic distribution and abundance of the listed species; and the long-term goal is to increase abundance, productivity, and distribution, and improve the life history and genetic diversity of the listed salmon and steelhead. (NOAA Fisheries 2016, R2 Resource Consultants 2014)

The phased, adaptive management program consists of three phases: a pilot experimentation phase, a short-term reintroduction phase, and a long-term

[115] Data limitations resulted in the population production portion of the RIPPLE model to not be run for steelhead.

reintroduction phase. The pilot experimentation phase will consist of 2-3 years of field studies to test the key assumptions that were recognized based on the RIPPLE and Life-cycle model results, and to identify critical factors that could impact reintroduction. The short-term reintroduction phase will consist of science and engineering evaluations of survival, reproduction, and migration rates and fish passage performance. This second phase will take 9-12 years to allow for 3-4 fish generations, and will include design, construction, and operation of interim fish passage facilities. The last phase, the long-term reintroduction phase, will focus on improving the fish passage system, understanding evolutionary and genetic factors, and assessing the sustainability of the reintroduced population. Managers plan to use the adaptive management framework to ensure the resources are allocated to provide the best benefits for overall cost and performance.

In summary, fish passage for the Yuba River has begun and is in the research and design phase. As of May 2016, discussions were continuing on the possibility of a trap and haul system to bypass Daguerre Point, Englebright, and New Bullards Bar dams. (NOAA Fisheries 2016)

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