APPENDIX 4.4-V

BC Hydro. 2016. Assessment of Revelstoke Unit 6 Addition Implications on Future Anadromous Fish Passage at Revelstoke Dam. Prepared by R2 Resource Consultants Inc.

- FINAL -
Assessment of Revelstoke Unit 6 Addition Implications on Future Anadromous Fish Passage at Revelstoke Dam

Prepared for:

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EXECUTIVE SUMMARY

British Columbia Hydro and Power Authority (BC Hydro) owns and operates the Revelstoke Generating Station (GS) on the Columbia River near Revelstoke, British Columbia. BC Hydro is proposing the addition of a sixth generating unit to the existing five units at the station. As part of the Unit 6 Project, BC Hydro contracted with R2 Resource Consultants (R2) to assess the potential impact of the additional unit on the technical feasibility of providing fish passage and restoration of anadromous fish into their historical range upstream of the GS in the event they are reintroduced to the upper Columbia River at some time in the future.

R2 reviewed information provided by BC Hydro concerning the existing physical, operational, and hydraulic conditions at the Revelstoke GS along with studies investigating the impacts of the Unit 6 Project on these conditions. R2 also assessed the anadromous species most likely to be introduced in the event fish are restored to Canadian waters in the upper Columbia including summer Chinook and Sockeye salmon. Basic biological and behavioural characteristics associated with these species including migration timing, swimming capabilities and general behavioural tendencies associated with each species during their migrations is presented relative to the conditions at Revelstoke.

Based on the site conditions, both existing and future conditions with the proposed Unit 6 Project, and the general characteristics of the probable fish species R2 developed two alternatives for the attraction and collection of upstream migrating anadromous fish for passage to the reservoir upstream, and similarly two alternatives for attraction and collection of anadromous downstream migrants for passage to the tailrace downstream. Two alternatives were considered for collecting fish in each direction because although there are some consistencies in general trends, specific behavioural characteristics of any group of fish vary from site to site based on local hydraulic, temporal, operational, and thermal conditions which are unique at every hydro project. Most successful existing fish passage projects were designed with the benefit of fish already being present at the project and years of study providing information on specific behavioural characteristics at that site. So in each case the two alternatives considered employ different approaches to the attraction and collection and it may not be known which would be most effective at the Revelstoke GS until the target species are present and can be evaluated in the local conditions and environment. However, for the purposes of this study considering multiple methods of collection provided for a more robust review of the potential impacts associated with the Unit 6 Project.

For each of the four alternatives considered (two upstream and two downstream) operational conditions were assessed for both the existing 5-unit powerhouse and a potential future powerhouse with the Unit 6 Project. In no case do the impacts of the proposed Unit 6 Project preclude or reduce the ability to attract and collect anadromous migrants in either direction at the project. The most significant impact would be the incremental added construction and operational costs associated with the additional collector infrastructure required to accommodate the additional powerhouse flow capacity and the additional flow paths at the Unit 6 intake trashracks and draft tube discharge.

The height of Revelstoke Dam precludes volitional upstream fish passage with any existing current technology or fish ladder design. The hydraulic head at Revelstoke is more than twice the height of the highest successful fish ladder in the world. It did not seem prudent to describe or recommend unprecedented approaches for fish passage, although there is the possibility that new technologies may exist in the future and these should be investigated during the feasibility phase of any future fish passage design at Revelstoke. The most common and efficient method of passing fish upstream around dams of this height today is by transport truck to release locations upstream. The addition of Unit 6 has no impact on this aspect of the passage. In fact, there are multiple ways to physically move the fish upstream once they have been successfully attracted and collected, albeit some more efficient and successful than others depending on characteristics such as dam height, but once the fish are collected and out of the main river channel the hydraulic capacity of the powerhouse becomes irrelevant, so the choice in this study to depict this physical movement of fish both upstream and downstream by truck transport is not relevant to the question concerning the impact of the Unit 6 Project.

R2 also considered physical and operational recommendations associated with the installation of the new Unit 6 turbine and infrastructure, and the future operation of the powerhouse over its range of operating flows. Physical recommendations include avoiding any permanent modifications to the exterior of the dam and/or shorelines that could negatively impact the ability to install one of the options presented in this report. Also, BC Hydro could request a review by the proposing turbine manufacturers concerning the feasibility of fabricating a slightly more fish-friendly turbine design (as described in the report), to see if the project efficiency and production goals could be met with a slightly modified turbine design, although survival benefits associated with this are estimated to be small. Operational recommendations involve performing studies after anadromous fish are at the site to determine if particular combinations of unit operations result in improved collection efficiencies and/or turbine passage survival, and then committing to maximizing those operating schemes, within BC Hydro's overall required powerhouse flow variations, during migration season.

1. INTRODUCTION

1.1 BACKGROUND

British Columbia Hydro and Power Authority (BC Hydro) owns and operates the Revelstoke Generating Station (GS) on the Columbia River near Revelstoke, British Columbia. BC Hydro is proposing the addition of a sixth generating unit to the existing five units at the station. Revelstoke GS is located at river kilometre 1,419, 180 kilometres upstream of Keenleyside Dam, 130 kilometres downstream of Mica Dam, and approximately 220 kilometres upstream of the border with the United States. BC Hydro has been asked to address the potential impact of the proposed Unit 6 Project on the ability to retrofit Revelstoke Dam with upstream and downstream fish passage facilities to accommodate anadromous fish restoration in the event that anadromous (sea-run) fish are reintroduced to the portion of the upper Columbia River downstream of Revelstoke Dam. Currently, anadromous fish are prevented from reaching Revelstoke Dam due to the lack of fish passage facilities at the three projects immediately downstream; Chief Joseph, Grand Coulee, and Keenleyside dams (Figure 1). Although fish passage facilities are provided at the nine lower dams on the Columbia River, no such facilities are present at the three subsequent upstream projects and the tailrace of Chief Joseph Dam is the upstream extent of anadromous fish presence on the Columbia River.

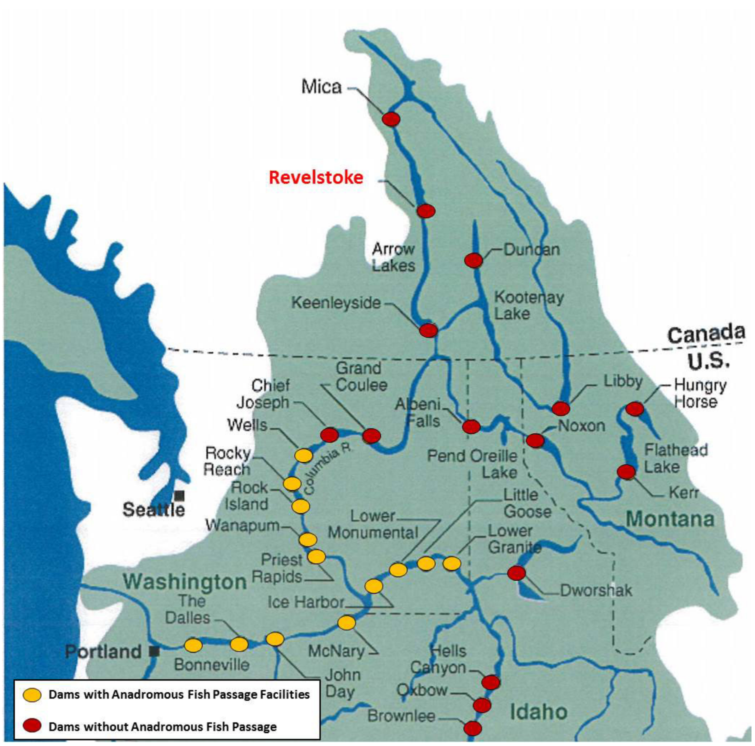

Figure 1. Columbia River Basin Map Highlighting Hydroelectric Dam Projects.

The Revelstoke GS includes a 175-metre-high dam approximately 450 metres wide across the Columbia River located 5 kilometres north of the town of Revelstoke. At normal reservoir level the project develops 133 metres of head at low tailwater (one unit running). The Revelstoke GS was originally commissioned in 1984. The Revelstoke GS was constructed with six turbine/generator bays but only four units were originally installed. The original station capacity with four units was 1,844 MW with a design maximum flow rate of 1644 m^3/s. A fifth unit was added in 2010, increasing the station capacity to 2,356 MW, at a flow rate of 2179 m^3/s. The current Unit 6 Project proposal will further increase the station capacity to approximately 2,868 MW with a design flow rate of 2632 m^3/s (93,000 cfs) (BC Hydro 2014). This will represent the full build out of the originally designed project. Figure 2 provides a plan view drawing of the Revelstoke GS. The original four units are toward the right looking downstream, and the Unit 5 and 6 bays are toward the left bank, furthest from the spillway.

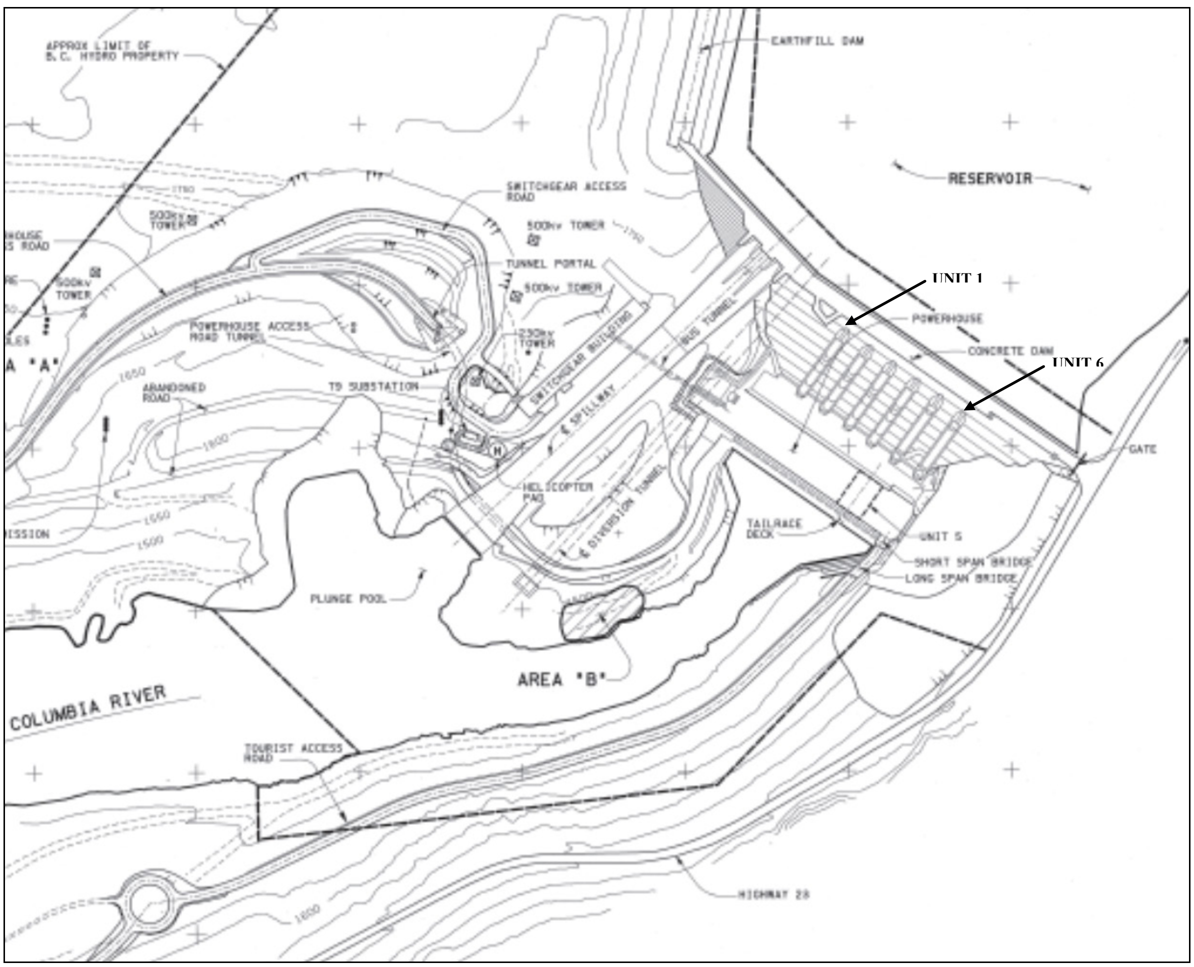

Figure 2. Site Plan Overview of Revelstoke Dam and Generating Station.

The Revelstoke turbines are large Francis turbines typical for high-head projects. The six intake trashrack structures are each 21.3 metres tall, with the invert located 39.6 metres below the normal reservoir water surface level. The trashracks consist of 19 mm thick vertical steel bars spaced at 17.8 cm on center (15.9 cm clear between bars). The water passage to the turbine is a 7.63-metre-diameter steel penstock. The penstocks can be seen passing down the downstream face of the dam to the powerhouse below. Flow discharges to the downstream tailrace through six expanding draft tubes with 23.5-metre-wide by 8.4-metre-tall exits, with the tops of the exits submerged approximately 8.6 metres at minimum normal operating tailwater level. Based on HEC-RAS modeling of the tailrace, the tailwater varies up to 5.2 metres between normal minimum operations (one-unit at approximately 75% capacity) and full operation with all five existing units, excluding extreme flow events involving added spill flows. With the addition of Unit 6 the model shows this tailwater range between normal minimum operations and 6-unit operation will increase to 6.0 metres. Figure 3 provides a profile view through the intake, penstock, turbine, and draft tube.

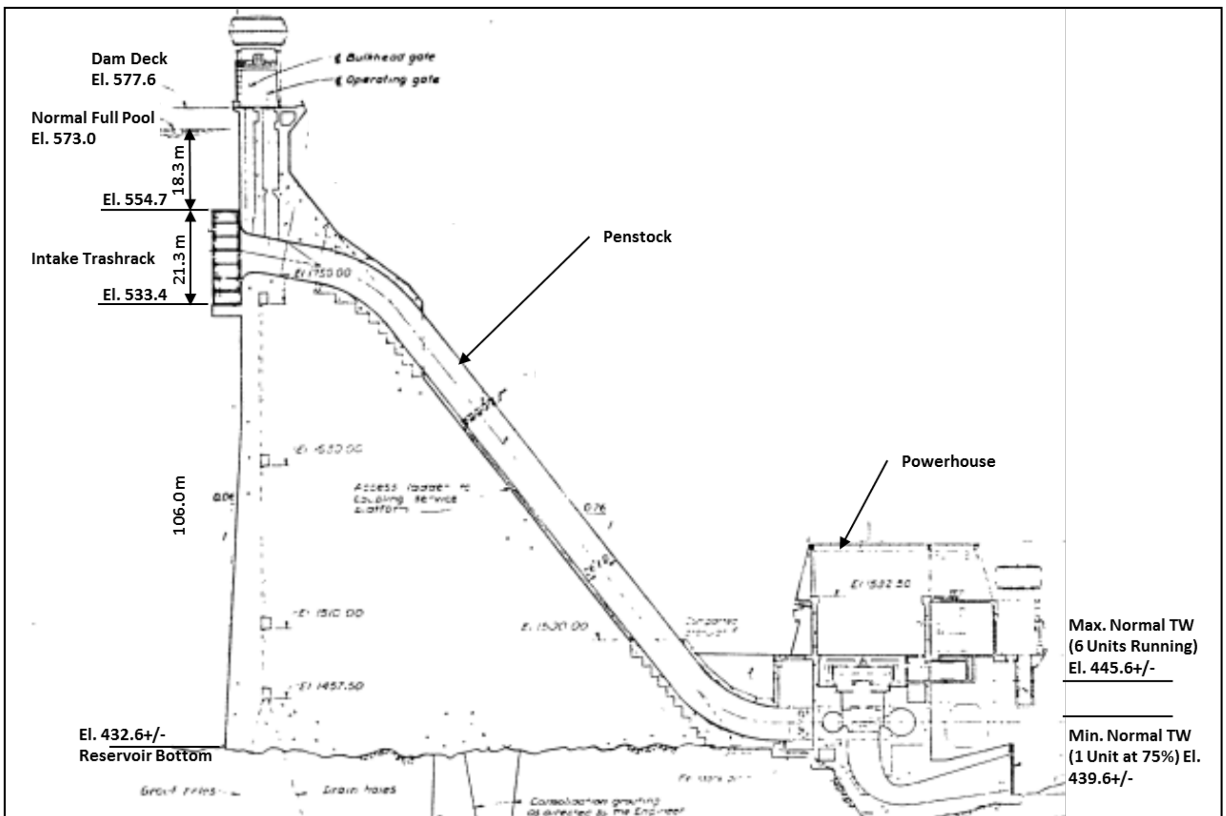

Figure 3. Profile through Revelstoke Forebay, Generating Station, and Tailrace.

The generating station operates essentially as a run-of-river project; however, the river is regulated to meet peaking demands by the operation of the Mica Generating Station upstream. In this way the two stations operate in conjunction, with daily fluctuations of the river flow to meet the Province of BC's fluctuating energy demands. The significance of this type of coordinated operation for the downstream station, in this case Revelstoke, is that it passes whatever water is coming from upstream and therefore the Revelstoke Reservoir level does not vary significantly. The Revelstoke Reservoir is generally held at or near its normal full pool elevation, and is rarely lowered more than 1.5 metres. The tailwater, on the other hand, can vary significantly within a day's operation due to the fluctuating flow rate passing through the powerhouse. Seasonal fluctuations of the operating flows also exist due to overall seasonal variation in the natural river flows and seasonal variation in the peak energy demands. Seasonally, the period of peak natural river flows extends from about May 1 to August 1.

Forced spill flows, due to extreme river flows exceeding the powerhouse capacity, are rare at Revelstoke given the hydraulic capacity of the powerhouse. The Unit 6 Project will further reduce the likelihood of forced spill events. The last time Revelstoke was forced to spill was July 2012, and prior to that the only other two forced spill events occurred on 1991 and 1997.

As part of the Unit 6 Project, this review is provided concerning potential issues associated with potential future anadromous fish passage in the upper Columbia River and possible impacts the Unit 6 Project might have on the feasibility of such passage associated with anadromous fish restoration upstream of Revelstoke Dam.

1.2 SCOPE OF WORK

R2 was contracted by BC Hydro as a third party reviewer to address the project scope items listed below:

- Identification of anadromous fish species, and their associated upstream and downstream run timing, likely to arrive at Revelstoke Dam in the event passage is provided in the future at dams downstream of Revelstoke.

- Descriptions of reasonable alternatives for providing both upstream and downstream anadromous fish passage, assuming alternatives deemed likely to be effective and feasible can be found. Conceptual level sketches of the chosen alternatives will be attached along with text descriptions of the operations of the alternatives

- An assessment of the impacts the Unit 6 Project might have on the successful operation of the described fish passage alternatives.

- Consideration of physical modifications that could be included in the Unit 6 Project design to facilitate an easier or more successful retrofit for passage.
- Consideration of operational options with Unit 6 in place that might aid in effective upstream and/or downstream fish passage.
- Preparation of a summary report detailing the fish passage alternatives chosen for evaluation, our assessment of the impacts of the Unit 6 Project on the success of the alternatives, and physical and operational considerations that could aid in the successful restoration of anadromous fish upstream of Revelstoke Dam.

Note that construction, operation, or biological evaluation cost estimates were not included in the scope of work as the time frame for implementing an anadromous restoration plan is not soon enough for the costs to be meaningful at this time.

2. ANADROMOUS SPECIES CONSIDERED FOR RESTORATION

2.1 FISH SPECIES AND TIMING

To effectively assess the potential for fish passage facilities, and the impact of the Unit 6 Project, it is first necessary to establish the species of anadromous fish, and their associated run timing, that could be expected to arrive at the Revelstoke GS assuming passage around the lower dams downstream were to be provided. The timing of the potential fish runs, and how they interact with the operating and hydrologic fluctuations at the dam, is critical to any assessment of facilities required for fish passage. To predict anadromous fish species and run timing, for fish that could potentially arrive at the Revelstoke GS, fish run data for the lower reaches of the Columbia River and historical pre-dam anecdotal information were considered. Four species of anadromous salmonids currently utilize the mid-Columbia River downstream of Chief Joseph Dam. These include Chinook, Sockeye and Coho salmon, and Steelhead Trout.

Although Coho Salmon passage rates at Wells Dam, the most upstream dam on the Columbia River with fish passage facilities (see Figure 1), have been rebounding since 1999, these fish are generally moving up to the Methow River as a result of a hatchery and stocking program begun in the mid-1990s. Coho Salmon did not historically migrate in significant numbers as far north as the Canadian border on the mainstem Columbia River (Columbia Basin Tribes and First Nations 2014). Therefore, only the other three species are considered reasonable candidates for introduction into the upper-Columbia River watershed above Chief Joseph and Grand Coulee dams.

Chinook Salmon are differentiated into three distinct runs, defined by the time of the year in which the adults move out of the ocean and into fresh water. These runs include the spring, summer and fall Chinook. Historically, all three of these runs migrated upstream into Canadian waters in the Columbia River. However fall Chinook are not known to have migrated upstream of Arrow Lakes Reservoir (Columbia Basin Tribes and First Nations 2014), so would not be considered likely for passage at Revelstoke. Spring and summer Chinook moved upstream into the Canadian reach of the Columbia River above Arrow Lakes Reservoir. However, spring Chinook are unlikely candidates for passage upstream beyond Grand Coulee Dam, as they are listed as an endangered species in the United States and it is questionable whether this run of fish ever reached the upper Columbia River in as significant numbers as the summer Chinook did. Summer Chinook are often are often referred to as "June Hogs" because of their larger size and their first entry into the mouth of the Columbia River in June. They first reach Wells Dam (the upstream-most dam with fish passage today) during the last days of June or early-July. Therefore, they would not be expected at Revelstoke until mid to late July at the earliest.

Historically, steelhead did migrate up the Columbia River into Canada. Steelhead numbers in the mid-Columbia had also been in decline, and the U.S. National Marine Fisheries Service listed this run as 'endangered' in 1997, although their numbers have been rebounding in recent years and in 2009 the U.S. National Marine Fisheries Service (NMFS) downgraded the listing to 'threatened' based on the recovering numbers of fish. Therefore, Steelhead may be a candidate for passage upstream of Grand Coulee Dam, but Steelhead historically remained in the main river below Arrow Lakes Reservoir or moved up into the lower reaches of the Pend d'Oreille and Kootenay rivers (Columbia Basin Tribes and First Nations 2014) and did not migrate upstream of Arrow Lakes Reservoir, so they are not considered likely to arrive at Revelstoke Dam.

A large run of Sockeye salmon pass Wells Dam each year, with a majority of these migrating up the Okanagan River toward Osoyoos Lake in Canada. Sockeye salmon tend to migrate up watersheds that include significant lake habitat, as they use these lakes as juvenile rearing habitat. Historical accounts imply that sockeye utilized Arrow Lakes Reservoir (immediately downstream of Revelstoke) and upper tributary lakes to the Kootenay River as spawning and rearing habitat.

If passage is provided around the dams downstream of Revelstoke, it could be done in one of two ways. With passive passage, such as a fish ladder, any fish physically capable of traversing the passage facility can pass upstream unhindered. However, given the height of Chief Joseph and Grand Coulee dams, installation of passive passage facilities is very unlikely. On the other hand, manual transport involves trapping the fish downstream of the dam (or two dams in this case) and physically transporting them upstream and releasing them back to the river above the dam. This is typically accomplished with transport tank trucks. If passage around Chief Joseph and Grand Coulee dams is provided by manual transport and release, instead of unrestricted movement through ladders, then the species stocked would be controlled and would be the future decision of the agencies or First Nations performing the stocking. In either case, one consideration concerning run timing and population size is that many of the historic obstacles which may have slowed or blocked the upstream migration of these fish during lower-flow periods are now submerged in reservoirs, potentially making their migration upstream easier. Kettle Falls is an example of one such historic obstacle that no longer exists. Based on these considerations, Table 1 lists the estimated run timing for upstream adult and downstream juvenile migration at Revelstoke Dam.

Table 1. Estimated Salmon Migration Timing at Revelstoke Dam.

	Upstream Migration Period	Downstream Migration Period
Sockeye	July-September	April-July
Summer Chinook	July-September	April-June

2.2 RELATION OF RUN TIMING TO CONDITIONS AT REVELSTOKE DAM

Since passage facilities would need to be accessible to any or all of these species it should be assumed that the migration periods overlap and facilities need to be available for the full combined periods, which in the case of Sockeye and summer Chinook salmon significantly overlap. Therefore, upstream migration facilities should be operating and available, at a minimum, from July 1 to September 30. Downstream outmigrant facilities should be operating and available to the fish from April 1 to July 31. Figure 4 provides an annual plot of the average daily flow rates through the Revelstoke Project. These flows include a combination of the natural inflows to Revelstoke Reservoir and the peaking operation flows provided from the Mica Project upstream. Each year since initiation of operation at Revelstoke in 1984 is represented, with the peak average daily flow for each year noted.

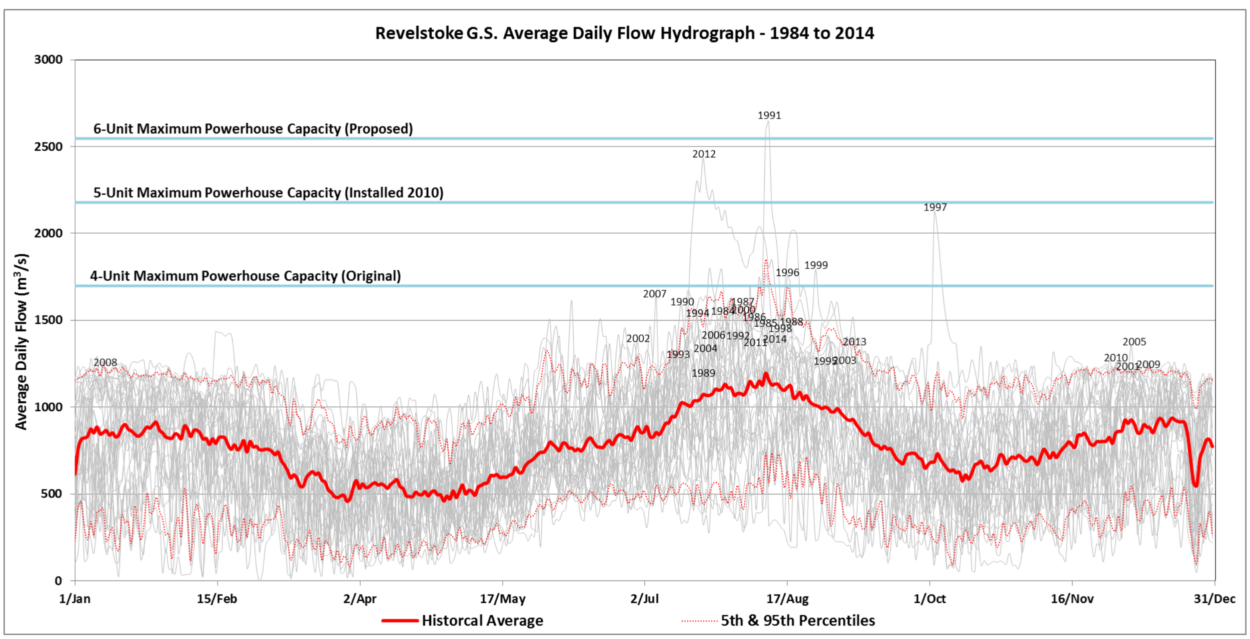

Figure 4. Daily Inflow Hydrograph for Revelstoke Dam.

During the fall and winter months there is limited natural inflow to the Revelstoke Reservoir and the majority of the flow shown in Figure 4 is provided from the Mica Project. During the months of May through July the flows at Mica are reduced to allow for refilling of Kinbasket Reservoir upstream, and the majority of the Revelstoke flow is from natural inflow to Revelstoke Reservoir. Although it is beyond the scope of this study, when planning for actual future restoration, timing of the fish migrations versus the tributary flows and seasonal variability of habitats should be considered. Relative to the anticipated passage seasons at the dam it is notable that during the upstream migration period (July to September) the flows through the project tend to be higher than at other periods, which could be beneficial for encouraging the fish to move upstream more rapidly through the Arrow Lakes Reservoir. Conversely, during the early part of the outmigration period (April through mid-May) the flows tend to be at the low end of the annual scale. Finally, Figure 4 shows how infrequently forced spill events are required (when the daily average flow rate exceeds the powerhouse capacity), which can interfere with effective fish attraction and safe passage conditions. The three major spill events that have occurred since the construction of the dam were in 1991, 1997, and 2012; although it appears that small minor spills may also have occurred in 1996 and 1999 prior to the addition of the fifth unit in 2010. It is notable that the large 1997 spill event might have been avoided if the fifth unit had been available at the time. The Unit 6 Project will further reduce the occurrence of forced spill events, and in fact may have eliminated the need to have spilled in 2012 had it already been installed.

Another consideration concerning passage is the water temperature, and most notably the differences in water temperature between the reservoir forebay and the tailrace downstream. During the summer months the reservoir tends to stratify, with warmer water on the surface and cooler water at depth. With the power intakes submerged in the forebay (as shown in Figure 3) the majority of the power flow passed downstream to the tailrace will be the cooler water from below the surface of the reservoir. BC Hydro's temperature monitoring of the reservoir and the tailrace show that the temperature of the tailrace closely matches the temperature of the reservoir at the depth of the power intakes, which are centered 29 metres below the normal reservoir level. During the months of July and August the upper four metres of the reservoir can be as much as 7 degrees Celsius warmer (Pieters 2014). To minimize the potential for thermal shock upon release, when passing fish around the dam it may be important to consider design features that minimize the difference between the temperatures of the water from which the fish are removed and the water into which they will be released. This could mean releasing upstream migrating adults into deeper parts of the reservoir, or possibly transporting them further upstream for release closer to or in the tributaries. Likewise, when removing downstream migrants from the reservoir the collector entrances should be deep enough so that a significant portion of the deeper, colder water is included in the fish flow so that the fish will be more acclimated to this temperature before being discharged into the tailrace.

3. UPSTREAM ANADROMOUS FISH PASSAGE ASSESSMENT

This assessment of potential upstream fish passage alternatives at the Revelstoke GS is focussed solely on passage of the anadromous species described in Section 2, in association with possible future restoration of these species into the watershed upstream of the dam. Although some resident species might also use, or at least attempt to use, the passage facilities, it is only anadromous species that form the design basis or consideration of the need for fish passage at Revelstoke Dam. No special design features are considered that might be considered specific to the resident species in the river. As requested by BC Hydro, the study focuses only on the feasibility of fish passage above the dam, and the effects the Unit 6 Project might have on that feasibility. No assessments are made concerning the suitability of the habitat or the survivability of the conditions in the watershed upstream of the dam, and no speculations are provided concerning the potential long-term success of any future anadromous fish restoration plans.

Anadromous fish have not been present in the Canadian waters of the Columbia River since the construction of Grand Coulee Dam in the 1930s. Since that time two additional dams have been constructed without fish passage facilities downstream of Revelstoke (Chief Joseph Dam downstream of Grand Coulee and Keenleyside Dam upstream of Grand Coulee). Although there have been discussions, and some preliminary studies performed, concerning the potential for passage at these dams, there are currently no imminent plans for developing or providing fish passage. Therefore, it is unknown how long it might be before the need for the types of facilities being assessed in this study might become a reality. It is possible that by the time facilities such as these are required that new technologies may be available that are not available today, and at that time they should be investigated; however, for the purposes of this study current fish passage technologies are reviewed relative to the existing conditions at Revelstoke Dam, and the modified conditions associated with the addition of Unit 6.

3.1 UPSTREAM PASSAGE COMPONENTS

Upstream fish passage facilities include three components that each need to function successfully for the overall passage system to be effective. If any one of these three components does not function successfully the overall passage facilities will be unsuccessful. The following three sections briefly describe these three components.

Fish Attraction and Collection

No matter how elaborate or sophisticated the passage system is, if you cannot attract fish into it the system is doomed to failure. Often, effectively attracting and collecting fish into the facility is the most difficult and site specific challenge in designing successful fish passage facilities. Ideally, the fish entrance, or entrances in the case of large rivers, should be located at or near the upstream limit of fish travel. This is typically at the downstream face of a dam either at the shoreline ends of the dam, and/or directly above the draft tube discharges. In other cases, an effective location for the entrance may be further downstream at a location where fish tracking studies show fish tend to naturally accumulate and hold, and where river flow conditions are calmer and the attractive influence of the entrance discharge flows can be more easily found by the fish. In either case, adequate flow needs to be discharged from the entrance(s), at a high enough velocity, to attract fish away from the overall river flow and toward the collector entrance. Once inside the entrance the conditions need to be such that the fish are encouraged to continue upstream toward the fish transport facilities. Further details concerning specifics associated with collector entrances will be described below in the context of feasible alternatives for Revelstoke Dam.

Fish Transport

Once fish have been attracted and collected into the facility there are numerous effective methods for transporting the fish to a location upstream of the dam. These include passive volitional systems such as fish ladders or nature-like channels; mechanical systems such as fish lifts, fish locks, or tramways; and active transport systems such as trap & haul trucking or barging. The choice of system for any given site depends on specific site conditions such as dam height and reservoir conditions, the location of suitable spawning habitat upstream and in some cases the presence on intermediate upstream dams, and the biological goals of the fish passage program.

Fish Release

The choice of the fish release location upstream of the dam can also be a critical decision. Passive and mechanical passage facilities often release fish immediately upstream of the face of the dam. At facilities with spillways that are often in use this can result in fall back over the spillway if the passage exit is located too close to the spillway. At reservoirs with thermal stratification it may be necessary to release the fish at depth to prevent thermal shock upon release into warm surface waters. In some cases it may be most productive to transport the fish and release them directly into tributaries upstream, especially if a large slow-moving reservoir may result in long delay or mortality before fish can reach the spawning grounds, or in cases where the fish need to pass multiple dams. This approach is often used early in a fish restoration program to ‘jump-start’ the restoration by maximizing spawning success.

3.2 REVELSTOKE SITE CONSIDERATIONS

Mica and Revelstoke operate jointly to meet peaking power demands throughout the day. This means that in a single given day the flows can vary dramatically from minimum flows through a single unit when power demands are low, to full powerhouse flows through all five existing available units during peak power demand hours. This maximum flow capacity will increase with the addition of Unit 6. The existing 5-Unit station capacity is 2,179 m^3/s, which will increase to 2,632 m^3/s with the Unit 6 Project.

Tailrace

With increasing powerhouse flows the tailrace deepens and the velocity increases. BC Hydro produced a HEC-RAS hydraulic model of the Columbia River from the downstream face of Revelstoke Dam to slack water in Arrow Lakes Reservoir. Model runs were performed for four lake surface levels in Arrow Lakes Reservoir and 16 Revelstoke GS discharge rates to determine the backwater effects of Arrow Lakes Reservoir on the section of the river between Arrow Lakes Reservoir and Revelstoke Dam. The limiting factor for upstream migration through the Revelstoke tailrace is the channel velocity at higher powerhouse discharge rates. These velocities are maximized when the level in Arrow Lakes Reservoir in lowest (elevation 425 m), minimizing the lake's backwater impact on the powerhouse tailrace. However, at high powerhouse discharge rates the backwater effect from Arrow Lakes Reservoir was determined to be negligible in the tailrace, which becomes entirely controlled by the powerhouse flow. Figure 5 shows the 14 upstream-most model transects, which comprise the study area of this review concerning potential locations for collecting upstream anadromous migrants.

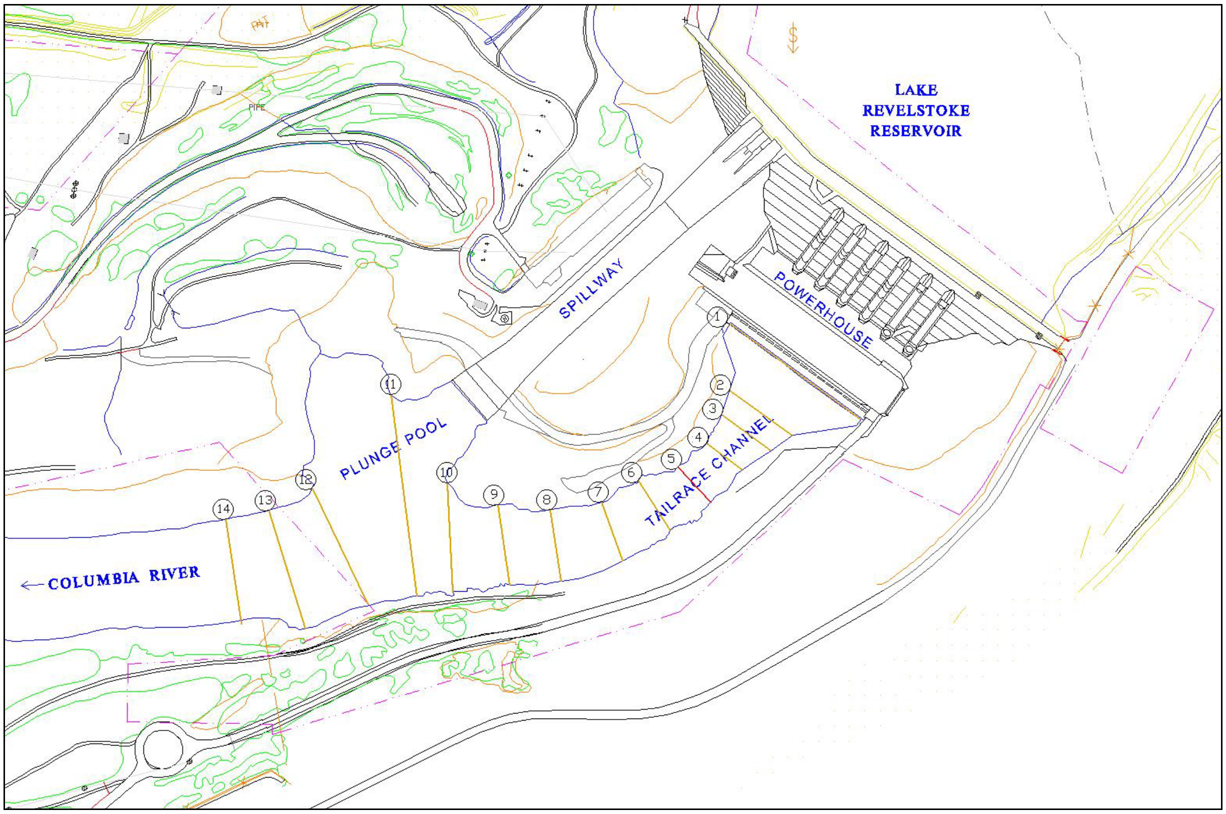

Figure 5. Revelstoke Tailrace HEC-RAS Model Transects.

BC Hydro provided R2 with the HEC-RAS model data and the output results for 16 flow rates between 5.0 and 2,124 m^3/s. These results were provided for four water levels in Arrow Lakes Reservoir between elevations 425 and 440 metres. Water levels and channel velocities were taken from these results at flows of 850, 1,274, and 1,699 m^3/s to approximately represent powerhouse flows at 2-, 3-, and 4-unit operations, respectively. R2 ran the model for the two additional flow rates of 2,179 m^3/s and 2,632 m^3/s to represent 5- and 6-unit operations. Table 2 provides the HEC-RAS model output for water levels and average channel velocities through the tailrace study area for Revelstoke GS discharges from two to six turbine unit operation. These were all calculated assuming the minimal Arrow Lakes Reservoir surface elevation of 425 metres. The maximum sustained swimming speed for adult Chinook and Sockeye salmon is approximately 3.35 metres per second (Bell 1991). At channel velocities greater than this they would have to burst against the higher current, which they can only do for short periods (5 to 10 seconds). Even so, the upper end of their burst speed capabilities is limited to slightly over 6 metres per second. Average channel velocities in excess of 3.35 metres per second are highlighted in Table 2. It can be seen that with 4-unit operation the sustained swimming speed of the salmon adults is exceeded for approximately 90 metres of channel length (from Transect 7 to Transect 5). Even if a fish were to burst upstream at their full capacity for 10 seconds, they could at best only progress upstream about 25 metres against the on-coming current before they would tire out. Operation at the existing 5-unit capacity increases the channel velocity to over 4 metres per second and extends the distance of exclusionary velocities to about 145 metres. While it is true that the Unit 6 Project will further increase the channel velocity, and extend the length of the exclusionary zone, it has little effective negative impact as compared to the existing conditions which already exceed the swimming capabilities of the adult salmon species when operating the powerhouse at or nears its capacity.

Table 2. Tailrace Levels and Average Velocities from HEC-RAS Model for Various Operations.

Transect	Distance From Face of Dam (m)	2 Unit Flow		3 Unit Flow		4 Unit Flow		5 Unit Flow		6 Unit Flow (proposed)	
		Water Level (m)	Tailrace Velocity (m/s)	Water Level (m)	Tailrace Velocity (m/s)	Water Level (m)	Tailrace Velocity (m/s)	Water Level (m)	Tailrace Velocity (m/s)	Water Level (m)	Tailrace Velocity (m/s)
1	0	441.65	0.32	442.92	0.45	443.85	0.57	444.80	0.69	445.64	0.81
2	52.1	441.63	0.66	442.89	0.89	443.81	1.10	444.73	1.32	445.55	1.51
3	76.2	441.58	1.21	442.79	1.59	443.66	1.95	444.53	2.31	445.30	2.61
4	107.3	441.52	1.54	442.70	2.02	443.53	2.47	444.34	2.93	445.06	3.32
5	146.3	441.33	2.40	442.35	3.18	442.99	3.94	443.55	4.74	443.98	5.47
6	189.3	441.36	2.17	442.41	2.87	443.08	3.53	443.69	4.22	444.19	4.82
7	236.1	441.35	2.17	442.41	2.81	443.09	3.44	443.71	4.10	444.21	4.68
8	291.9	441.40	1.80	442.48	2.35	443.20	2.88	443.87	3.42	444.42	3.90
9	342.1	441.41	1.65	442.51	2.13	443.25	2.56	443.94	3.07	444.52	3.48
10	392.7	441.44	1.36	442.56	1.76	443.32	2.13	444.04	2.51	444.65	2.84
11	427.9	441.49	0.43	442.65	0.57	443.45	0.70	444.23	0.84	444.89	0.95
12	497.6	441.39	1.41	442.51	1.64	443.27	1.89	444.00	2.14	444.62	2.35
13	550.1	441.21	2.00	442.33	2.18	443.07	2.42	443.79	2.67	444.40	2.87
14	606.1	441.09	2.14	442.18	2.37	442.93	2.58	443.64	2.81	444.25	3.01

Highlighted velocities are in excess of adult salmon sustained swimming capabilities.

Given these tailrace conditions, and the Revelstoke daily operations, there appear to be two alternatives for effectively attracting and collecting the upstream migrants:

1. An attraction and collection facility (essentially a fish ladder entrance) could be located downstream in the tailrace at the upstream limit of migrants' swimming capability during maximum powerhouse operations. During discussions with BC Hydro environmental staff it was noted that during high powerhouse flow operations the existing resident salmonids, including adult bull trout, tend to accumulate and hold in the relatively calmer

waters in the spillway plunge pool area (see Figure 5). It is likely that anadromous salmonids would exhibit similar behaviour. It is also possible that the larger anadromous species may attempt to move up into the tailrace. Most likely they would do this along the right bank (looking downstream) because it is most directly accessible from the relatively calmer plunge pool area, and the left bank is steep and relatively smooth so velocities along the left bank are likely at least as high as the average transect velocities shown in Table 2. On the other hand, the right bank of the tailrace is more jagged, with large rock outcroppings that cause flow shadow areas, likely resulting in lower than average transect velocities along this side of the tailrace. The most significant of these outcroppings is located between Transect 4 and Transect 5, and appears to be large enough to result in downstream velocities along the shoreline that would be significantly less than the average transect velocities in Table 2. If this is the case, upstream migrants would tend to congregate along this shoreline and a strategically placed collector entrance with adequate flow to attract the fish could be very effective at capturing upstream migrants. Photo 1 shows the tailrace flow conditions in this area during a period of relatively high powerhouse flows with four units operating in August of 1999. The flow shear coming off the rock outcrop is apparent in the photo. Alternative 1 entails placing a high-flow entrance somewhere along the right bank to take advantage of these tailrace flow conditions. Two entrance locations are shown in the Alternative 1 description presented in Section 3.3 of the report. One is located near the upstream extent of the flow shear, and the other is further downstream near the downstream end of the right bank. These two locations are shown to bracket the area over which an entrance could be placed, and are not meant to imply that Alternative 1 would have more than one entrance. The optimal location for an entrance designed to take advantage of these conditions would need to be determined later based on 3-D modelling of the tailrace and observed behaviour of the anadromous migrants after reintroduction of the fish. If this approach to fish attraction and collection were to be adopted, the higher flow and velocities resulting from the Unit 6 Project could actually improve collection efficiency by further precluding fish from the main channel, while more effectively concentrating them along the right bank where they would be most likely to find the collection entrance. A potential drawback to this approach is that during the lower flow periods of the day the fish could be more evenly distributed across the tailrace and many of them may pass by the entrance without sensing it and continue upstream all the way to the dam.

Photo 1. Right Bank Tailrace Conditions at 4-Unit Operation (August 1999).

2. A second alternative approach to fish collection would be to let the fish hold downstream of the tailrace during the high powerhouse flow periods, since these are of limited duration during the peak power demand hours, and then collect them at the dam during the lower flow periods when the tailrace velocities are reduced. In this case, a collection gallery could be constructed across the dam face above the draft tube exits. A collection entrance could include as many as six entrances with one located above each of the six draft tube exits. A conceptual layout and description of this alternative is also provided in Section 3.3 of the report. Since this approach is mainly focussed on attracting and collecting fish during periods of lower powerhouse flows, when not all units are operating, the Unit 6 Project has no direct impact on effectiveness of fish collection. In fact, efficient collection of the upstream migrants may not require more than a few entrances over the lower-numbered unit draft tubes. However, if it is determined that there is benefit from having a collector entrance associated with the sixth unit there will be some added cost associated with the extension of the collection channel over the Unit 6 draft tube and on-going additional operations cost associated with the additional collector entrance.

The choice of which alternative might represent the most effective means of attracting and collecting the adult migrants would be based on the anticipated project operations at the time, the peak migration season months, and the diurnal pattern of the migration movement. Since Revelstoke is operated as a peaking plant, in conjunction with the Mica GS, the powerhouse flows peak during the day and are reduced significantly at night. BC Hydro provided R2 with the hourly flow rates through the Revelstoke GS for the months of July through October for both 2013 and 2014. To provide a graphical representation of the flow conditions throughout typical days, R2 chose one typical 7-day period (Sunday through Saturday) for each of the eight months and plotted the flow versus time. Figures 6 and 7 provide a graphical representation of the hourly flow versus time for the four chosen weeks in 2013 and 2014, respectively. The plots also highlight the maximum powerhouse flows associated with operations with 1, 2, 3, 4, or 5 turbine units.

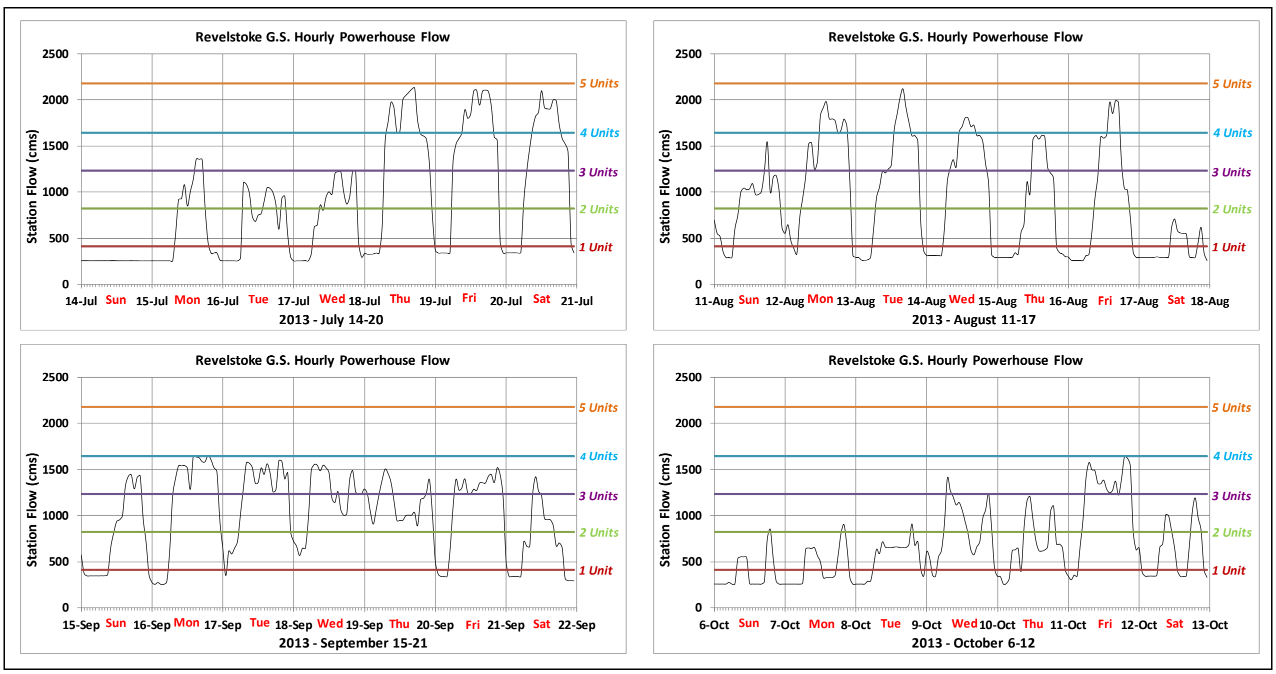

Figure 6. Hourly Powerhouse Flows for Weeks in July, August, September, and October 2013.

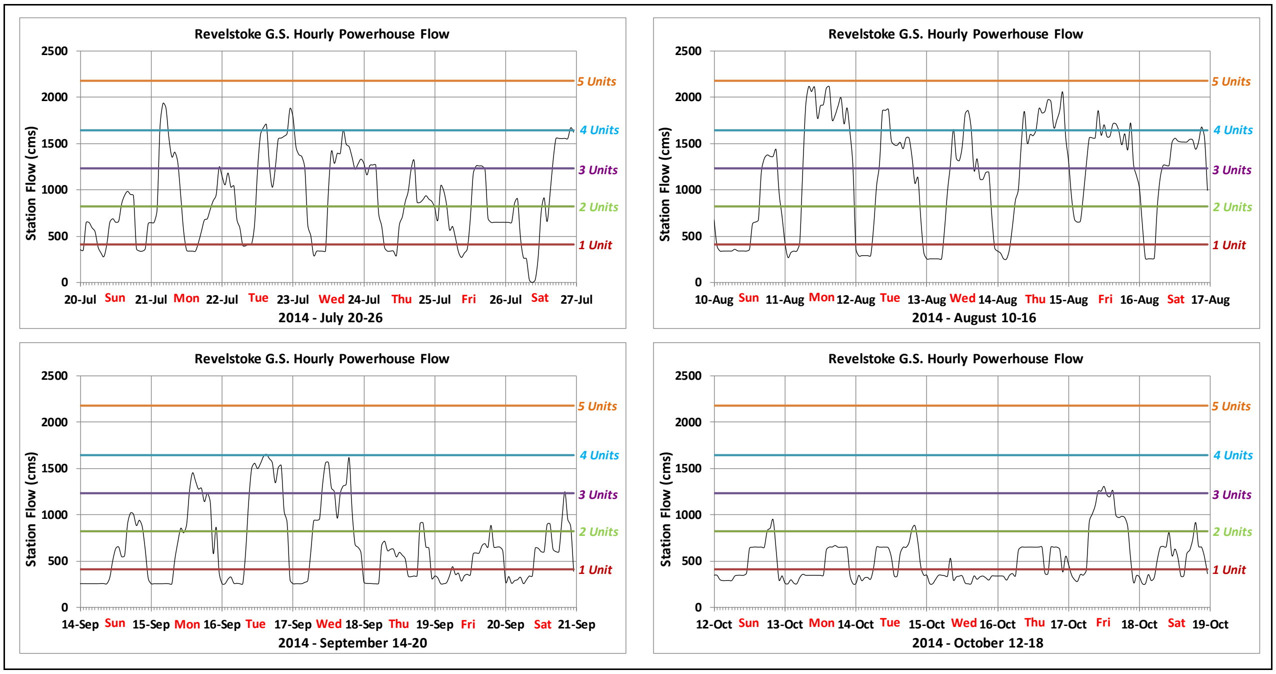

Figure 7. Hourly Powerhouse Flows for Weeks in July, August, September, and October 2014.

It can be seen from Figures 6 and 7 that overall flows are higher in July and August than they are in September and October, which agrees with the annual trends shown in Figure 4. In fact, even the peak hourly flows in September and October, for both years investigated, never exceeded flows in excess of 4-unit station capacity. Therefore, if the migration seasons of the target species tend to be focussed more heavily in these later months then a collector located with entrances at the dam would likely to be more appropriate. During the months of July and August hourly flows approaching 5-unit operation capacity do occur, and migration all the way upstream to the face of the dam would at least temporarily be precluded. However, these occurrences appear to be limited in duration to about 12 hours or less, and result in the need to operate at more extended periods of low flow (less than 1-unit operation at rated power) at night to maintain the overall daily run-of-river flow operation. Diurnal movements of the fish would therefore also play a role in the choice between collector entrance alternatives either at the dam or downstream along the right bank.

Dam

The hydraulic head at Revelstoke Dam is 133 metres at low tailwater levels. This represents an unprecedented height with regards to providing volitional upstream fish passage. The greatest vertical rise for any functional existing fish ladder providing fish with free and volitional upstream passage around a dam is 58.5 metres. This ladder is located on the Clackamas River in Oregon State in the U.S., and passes around two dams with a total ladder length of over 2.5

kilometres. Although taller ladders have been constructed they have failed to meet expectations and have been abandoned. Although in the future, by the time anadromous fish might be present in the Columbia River downstream of Revelstoke, there may be new technologies available for providing some level of volitional fish passage, at this point in time given today's technologies it would not be responsible to suggest that providing volitional fish passage around a dam as tall as Revelstoke would be feasible. An example of a current developing technology is the Whooshh fish transport system developed by Whooshh Innovations. However, to date it has only been tested on relatively small scale installations, mostly associated with fish hatcheries, and no active in-river fish passage over dams are in use. It is unknown if this technology will ever develop to the point where it could be effective at a dam as large as Revelstoke. Therefore, given todays established technologies, mechanical lifting of fish to the reservoir above the dam or active transport by truck to locations upstream would appear to be the only reasonable alternatives. The best choice between these two alternatives is a function of the reservoir conditions upstream (which are described in the following section below), the overall fish passage facilities configurations including downstream collection and passage facilities, and the short-term and long-term goals of the restoration plan. The Unit 6 Project has no impact on the methods available for passing fish upstream once they have been attracted and collected in the facilities. However, the higher total powerhouse flow could potentially result in higher fallback of upstream migrants if they are released directly into the reservoir in the near vicinity of the power intakes.

Reservoir

Since the Revelstoke GS is essentially operated as a run-of-river plant, in coordination with the peaking operations at Mica, the Revelstoke Reservoir is generally maintained at or near its normal operating elevation of 573.0 metres, although small fluctuations of up to 1.5 metres between elevation 571.5 and 573.0 do frequently occur. Figure 8 provides a historical record of the Revelstoke Reservoir water levels since the initial filling of the reservoir in 1984 (Pieters 2014). The dashed lines in the figure represent elevations 571.5 and 573.0. It is notable that in the last few years (since 2012) there have been fluctuations of the reservoir greater than the more typical 1.5 metres. The greater frequency in the last few years is due to unusually high inflows in 2012, cold snaps in 2013/2014, and a full MCA outage for GIS construction 2013 (personal communication BC Hydro). BC Hydro operations staff noted that these conditions should not be considered typical and that the 1.5-metre fluctuation will continue to be the normal operation, and that this should not be impacted by the addition of the Unit 6 Project.

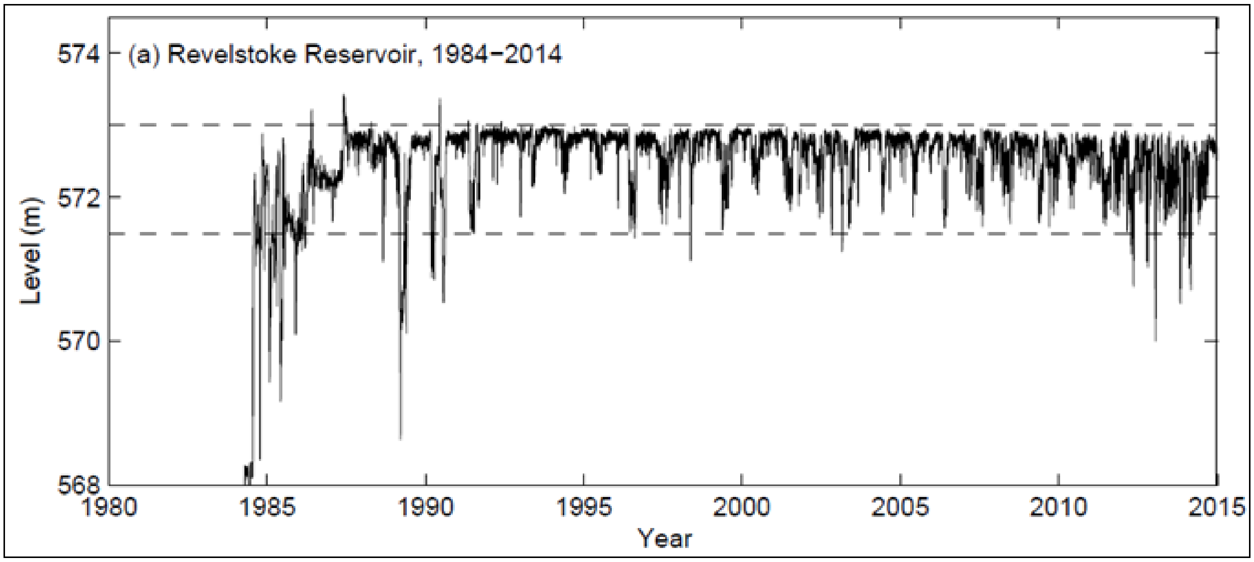

Figure 8. Revelstoke Reservoir Water Levels since Initial 1984 Filling.

The near constant reservoir elevation would simplify the design of a fish exit facility for upstream release of fish. However, factors such as water temperature, suitability of the reservoir as a migration corridor, the overall migration window of the fish, and potential for fall back through spill or turbine flows need to be considered when deciding the optimum location for releasing upstream migrants above the dam.

Temperature conditions in the reservoir, especially thermal stratification during a significant portion of the upstream migration period, were discussed previously in Section 2. This may mean that if fish are to be released at the dam they should be released at some depth in colder waters. Conversely, it may be advantageous to transport fish directly to colder upstream portions of the reservoir, or even release them directly into suitable cold-water tributaries. The Unit 6 Project has little to no effect on decisions to be made based on reservoir temperatures.

Revelstoke Reservoir is a large deep lake environment, and the peaking nature of the Mica/Revelstoke operation can result in many hours of the day with low flows through the powerhouse. These low flows result in near zero velocity in the reservoir, giving little cue to encourage the fish to actively migrate upstream. Therefore, reservoir migration to the tributaries for spawning may not be rapid. Given that these fish will have already travelled a great distance from the Pacific Ocean, past numerous dams and reservoirs, they may already be near the end of their migration windows and timely travel to the spawning grounds may be critical, especially in the early stages of the restoration program.

The final issue associated with releasing upstream migrants at the upstream face of a dam is the potential for fallback through the turbine or spillway flow. At Revelstoke there is little issue associated with spill flow given the highly infrequent occurrences of spill flow. The Unit 6 Project should further reduce the need for spill, which could be considered a benefit if this scenario were to be the design. On the other hand, the greater powerhouse flow during peak demand hours might potentially increase draw of fish toward the powerhouse and increase the likelihood of fallback through the turbines.

Given the considerations described above, we have chosen to present designs that would utilize trap-and-haul as the means for transporting the captured fish upstream. This would be done with fish transport trucks, with release sites defined upstream in the reservoir near the tributaries with the most promising habitat. Release sites directly into the tributaries might also be considered. This method of upstream passage is often used in the northwestern U.S. at high-head dams, and in river systems with multiple dams, to optimize the success of fish reintroduction programs. On some rivers, such as the Baker River in Washington State, it is the long-term permanent plan for both upstream and downstream passage of anadromous salmonids and has been since the 1950s. The Unit 6 Project has no impact either way of the operation or potential success of a trap-and-haul passage approach.

3.3 UPSTREAM PASSAGE ALTERNATIVES CONSIDERED

Fishway Entrance Location Alternatives

Considering the site geometry, hydraulics and operations at Revelstoke, two general entrance location alternatives are considered here for feasibility and comparison between 5-unit and 6-unit operations. Alternative 1 is a single high energy entrance on the right bank at a location that can be accessed by the target species during all powerhouse flows due to the lower velocity zones caused by the rock outcropping along the bank, as shown on Figure 9. Alternative 2 (also shown in Figure 9) is a series of entrances across the front of the downstream face of the dam. This location was chosen because during lower flows when velocities are low enough to permit fish to make it to the dam this is the furthest that a fish can travel. The choice of which alternative might be viewed as most effective should be made later based on local fish behaviour and projected project operations concerning the extent and timing of high versus low powerhouse flows at the time anadromous fish are actually present at the site.

Two extreme locations are shown for Alternative 1 (Location 1A and Location 1B) to illustrate the potential range along the right bank for an Alternative 1 entrance. Location 1A shows the furthest downstream location along the right bank of the tailrace, and would be designed to attract fish into the entrance before they get too far up the high-velocity tailrace. Photo 2 shows the existing conditions in the general vicinity of Location 1A. Location 1B represents the furthest upstream location that fish might be able to access during high powerhouse flows, because the channel velocity would likely prevent further migration upstream along the right bank. These assumptions and the precise preferred location would be determined by further study of the tailrace hydraulics and fish behavior. Photo 3 shows the existing conditions in the area shown for Location 1B, in the general vicinity of the HEC-RAS Transect 5. Although this photo was taken during low flow conditions, with only one turbine unit operating, the shear zone in the flow can still be seen peeling off the shoreline. It is possible that during high powerhouse flows a strategically located entrance along the right bank could be very efficient at capturing fish if they are concentrated along the shoreline by otherwise higher velocities in the main channel. This could result in a lower entrance flow requirement.

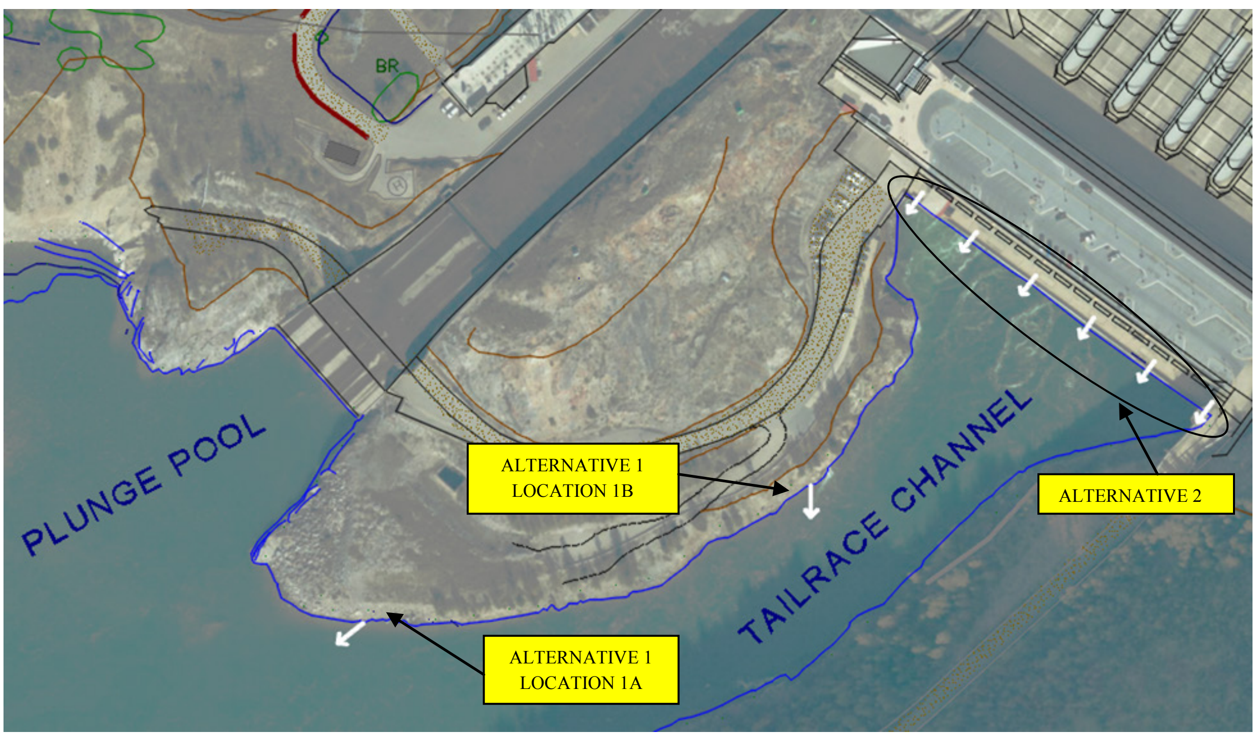

Figure 9. Potential Alternatives for Upstream Fish Passage Entrances.

Photo 2. Fishway Entrance Alternative 1 (Location 1A).

Photo 3. Fishway Entrance Alternative 1 (Location 1B).

Alternative 2 is a somewhat more traditional collection strategy for a dam on a large river. The downstream face of the dam provides a limit to upstream travel and acts as a guidance system so fish can find the entrances. Photo 4 shows the existing conditions along the downstream face of the dam where the collection channel and entrances would be installed. The concrete boxes seen in the photo above the draft tubes are storage boxes for the draft tube closure gates. This photo was taken during low-flow operations with only one unit (Unit 5) operating, which can be seen at the far end of the photo. During full powerhouse flow operation the tailrace rises to the dark line seen in the photo on the gate storage boxes. Six collector entrances are shown in Figure 9, one above each draft tube, evenly spread across the dam. This is considered to be a conservative approach and the optimum number and locations of entrances could be determined later based on tailrace flow modeling, fish behaviour, and probable future powerhouse operations. Since the premise of this approach is that the fish can only access the area during lower powerhouse flows (less than four units operating), and the fish would be forced to hold downstream during the brief periods of higher powerhouse flows, a smaller number of entrances may be required, especially if BC Hydro commits to operating specific units first based on the optimum effectiveness of the entrances present.

Photo 4. Fishway Entrance Alternative 2 (Located at Draft Tube Discharges).

Drawings 1 through 5 provide plan and section views of the two upstream attraction and collection alternative concept designs. The following sections describe the features of these upstream passage alternatives.

Fishway Entrance Flow Requirements

Adequate flow needs to be discharged from the entrance(s), at a high enough velocity to attract fish away from the overall river flow and toward the collector entrance. The amount of flow required, to successfully attract fish into an entrance varies from site to site, and depends on the entrance location, design, local hydraulics and fish behavior. Entrances on river banks where fish can continue upstream if they do not enter the fishway generally need more attraction flow and energy than entrances located where fish cannot continue upstream. However, if hydraulic conditions in the area concentrate the fish into the immediate vicinity of the entrance then less flow may be required to attract them into the entrance. Alternative 1 takes advantage of when four or more units are generating at Revelstoke. The average channel velocity is greater than the sustained swimming speed of the target fish when 4 or more units are running. Given the channel shape and rough shoreline on the right bank however, we believe fish would be able to work their way up the right bank. Fish would be concentrated along the right bank and would not be able to venture out into the main channel except for short duration bursts, such as to get around an obstacle. An entrance located along this right bank would be situated so fish would pass directly in front of the entrance allowing for effective attraction into the entrance with relatively low flow as a percentage of overall river flow. Similarly, Alternative 2 takes advantage of an area with concentrated fish, the dam face. When fish reach this upstream barrier they will search for available routes upstream and find the entrances that are distributed across the width of the downstream dam face. The Alternative 1 entrance shown in the drawings is conceptually sized for a flow of approximately 15 m^3/s. Although this is a small flow relative to the full powerhouse tailrace flow, for conceptual purposes it is considered to be adequate given that the high tailrace flow conditions would tend to force the fish into the near vicinity of the entrance. For Alternative 2 the entrances are each conceptually shown for a flow of approximately 4.0 m^3/s. Of course the actual entrance flows will be worked out later when fish passage facilities are designed. For the purposes of this report and to compare 5-unit to 6-unit operations, the attraction strategy, effectiveness and entrance flow would not be significantly different between 5-units and 6-units.

Fishway Entrance Layout

The entrance needs to be able to handle the flow required over the range of water surface elevations expected and produce the head drop and jet properties desired. For Location 1, entrances located on the right bank, the jet is aimed approximately 45 degrees out from the bank in the downstream direction. Given a total flow of 15 m^3/s and a head drop at the entrance of 0.45 m, the approximate jet velocity will be 3.1 m/s at the entrance slot and the flow area will be 4.8 square metres. A single entrance approximately 1.8 m wide by 2.7 m deep would produce the flow and velocity characteristics desired for this entrance. An automated weir would track the tailrace water surface elevation in front of the entrance to maintain a 0.45 m drop by raising or lowering the weir elevation.

For Alternative 2 the jet is aimed directly downstream, perpendicular to the dam face. Each entrance slot has a flow of 4 m^3/s, for a total flow of 24 m^3/s. The head drop and jet velocity are the same as Alternative 1. Each entrance slot would have a flow area of 1.3 square metres, so an entrance slot approximately 1 m wide by 1.3 m deep would result in the desired entrance flow characteristics. Each entrance slot would have an associated entrance pool designed to lead fish into a common channel, which would attract fish toward the trapping and crowder pool at the fish lock. Auxiliary water supply is added for each entrance independently in the floor of the associated entrance pool to allow for operation of select entrances based on the powerhouse operations at the time.

Trapping and Holding

Because of the large fluctuation in tailrace water surface elevation and the limited space available at Revelstoke we have laid out a trapping and holding design which utilizes a fish lock, rather than a ladder to lift fish into a sorting and truck loading facility. A similar facility was designed by R2 on the Baker River in Washington State and has been operating successfully since 2010. Fish enter through the entrance slot into an entrance pool where diffusers add flow, and then fish enter a holding pool through a v-trap or finger weir not allowing them to back out into the entrance pool. Two holding pools are shown in these layouts with fish crowders to move fish into the next pool if they try to hold. We have shown holding pools with the same size as those on the Baker River as a reasonable size for Revelstoke. The actual holding pools will be sized based the maximum number of fish required for holding which is a function of run size projections and sorting/loading speed. The crowder in the second holding pool is used to move the fish into the lock. After a desired number of fish have been crowded into the lock, the lock gate is closed and the lock is slowly filled with water up to the level of the sorting & handling station. A floor brail is slowly raised forcing the fish up toward the top of the lock and a weir gate is lowered allowing the fish to be sluiced down a sorting flume where the fish are identified by species and separated into specific collection tanks for sampling and/or holding for eventual transfer to transport trucks.

Truck Loading Station

After the fish have been sorted (and sampled if required) they are held in specific loading tanks based on species and upstream release locations. The tank sizes would be based on the number of fish expected between sorting crew work shifts and the size of the truck tanks. The tanks are designed with bottom openings that accommodate truck loading using water-to-water transfer, with the trucks parked directly below the tank opening. Photo 5 shows a typical truck loading bay below a sorting tank station. Photo 6 shows a fish transport truck discharging flow in a demonstration of the fish release procedure.

Photo 5. Fish Truck in Loading Position (Cowlitz River Trap-and-Haul Facility).

Photo 6. Fish Truck with Release Ramp Extended for Release Demonstration.

3.4 IMPACT OF THE UNIT 6 PROJECT ON UPSTREAM PASSAGE FEASIBILITY

As described previously, the Revelstoke GS is operated in conjunction with the Mica GS to provide peaking power as required. With this operating scenario the maximum full powerhouse flows generally only occur for a few hours during a typical day. Currently, the full powerhouse flow is five units (since the addition of the fifth unit in 2010). It is estimated that the operation of all five units already produces velocities in the tailrace that would preclude upstream passage of anadromous fish all the way to the dam. Therefore, the higher velocities associated with operation of six units would not change this condition. However, the higher velocities associated with six-unit operation could have the benefit of forcing fish attempting migration upstream in the tailrace even closer to the right bank where they would be even more likely to encounter an Alternative 1 collector entrance.

On the other hand, the Alternative 2 approach which entails allowing the fish to hold downstream during the temporary full powerhouse flow periods and then having them migrate up to the dam to encounter entrances located above the draft tubes may be a more effective approach for the full range of sizes and swimming capabilities among the target species. In fact this approach may also provide more effective collection for non-target resident species than Alternative 1.

The Unit 6 Project would have no impact either way of the recommended method of truck transport for the passage of fish upstream. On the other hand, if fish are to be released at the dam to migrate upstream through the reservoir on their own, the increase in flow associated with the sixth unit could have a slight negative impact on the potential for fallback through the turbines. However, if the fish are released on the right bank (looking downstream) the additional flow associated with the sixth unit at the far left end of the powerhouse may not be perceived by the fish at all. During the hours of low flow operations it could be beneficial to have that flow at the far left end of the powerhouse, further away from the fish release location on the right side of the dam. If fish are to be released at the dam the greatest benefit associated with the additional powerhouse flow capacity could be the reduced occurrences of forced spill, which would likely result in some fallback through the spill, which is harder for the fish to avoid in the reservoir than the more regulated and distributed turbine flows. If the spill lasted long enough, and occurred during the peak migration days, it could result in significant negative impact on an entire migration season. As an example of this benefit, if the increased powerhouse flow capacity associated with the Unit 6 Project had been available in 2012, the large spill event that occurred that year could have been avoided (see Figure 4).

3.5 PHYSICAL CONSIDERATIONS RELATIVE TO UPSTREAM PASSAGE

There are no physical considerations directly related to the installation of the sixth unit in the existing empty turbine bay that would specifically benefit upstream passage. However, features should not be added to the downstream face of the dam that might preclude the installation in the future of a collection channel over the draft tubes as described for Alternative 2. Indirect considerations would include not allowing the ancillary construction activities (mobilization and/or laydown areas, etc.) to impact the area along the right bank of the tailrace between the Alternative 1 locations 1A and 1B shown in Figure 9 in such a way as to make construction of a collector entrance and sorting/transfer station more difficult than it would be today. On the other hand, it may be possible to improve these areas for future fish passage facility installation by developing them as functional laydown areas for the Unit 6 Project construction and not restoring them to existing conditions in the end.

3.6 OPERATIONAL CONSIDERATIONS RELATIVE TO UPSTREAM PASSAGE

Operational considerations relative to upstream passage might include:

- Minimizing or eliminating operation of turbines at partial flow rates low enough to allow fish to pass upstream in the draft tubes far enough to be injured by the turbines. It would be best to limit operations to combinations of turbines operating at or near their full capacities.

- During the fish migration season, partial powerhouse flows (generally the majority of the day) should utilize combination of turbine units that maximize the collection efficiency of the fish passage entrance(s). These best combinations would be determined through experimentation after fish are present at the site.

4. DOWNSTREAM ANADROMOUS FISH PASSAGE ASSESSMENT

This assessment of potential downstream fish passage alternatives at the Revelstoke GS is focussed solely on passage of the anadromous species described in Section 2, in association with possible future restoration of these species into the watershed upstream of the dam. Although some resident species might also use, or at least attempt to use, the passage facilities, it is only anadromous species that form the design basis or consideration of the need for fish passage at Revelstoke Dam. No special design features are considered that might be considered specific to the resident species in the river. As requested by BC Hydro, the study focuses on the feasibility of safe fish passage around the dam, and specifically on the effects the Unit 6 Project might have on that feasibility.

Unlike upstream fish passage, which cannot occur at an obstacle such as a dam without some physical features provided to specifically provide fish passage across the dam, downstream fish passage can and does still occur even in the absence of any facilities specifically provided to collect and safely transport fish around the dam. In fact, hundreds of upstream fishways have been constructed over the last century at hydro projects with no consideration given at the time for downstream passage facilities, and to some extent anadromous fish did continue to survive in these rivers. This is because the downstream migrant juvenile fish will pass through the turbines and/or spillways and continue downstream toward the ocean. The more recent concern that has led to the drive to install facilities designed to lure fish away from these traditional methods of downstream passage and pass them downstream more safely is the percentage of mortality associated with turbine and spillway passage.

4.1 DOWNSTREAM PASSAGE COMPONENTS

Similar to the upstream passage discussion there are three semi-independent components of downstream passage that need to be considered. These include attraction and collection of the target fish, safe transport downstream, and release at a location downstream that will be safe for the fish to re-enter the river. The added component associated with downstream passage is an assessment of the potential for full exclusion of migrants from the traditional passage routes through the turbines or spill flows, and estimates of the survival rates through these routes if only partial exclusion is provided.

At small hydro facilities or diversions on smaller tributary rivers or streams it can sometimes be practical to screen the entire diverted flow to achieve full exclusion of fish from the facilities, and either keep them in the river or divert them to a safe bypass route downstream. However, at projects on large rivers, such as the Columbia River, including powerhouses with large hydraulic capacities it is often impractical if not impossible to provide 100% exclusion of fish from the more traditional turbine and spill flow passage. The reasons for this are discussed later in the context of potential downstream passage alternatives. On the other hand, the plus side of this is that these facilities generally include large turbine units which inherently result in higher survivability than smaller turbines, due to the larger water passage through the turbines with less potential for direct impact with components within the turbine. This issue will be considered relative to the facilities at Revelstoke in Section 4.2.

Fish Attraction and Collection

As with upstream passage, the greatest challenge associated with the design of effective downstream passage involves effectively attracting the fish to the facility entrance and safely collecting them for transport downstream. The options available for attracting fish to the collection and bypass facilities include full exclusion screening or netting of the entire river flow to exclude fish from any route downstream other than the collector entrance, or taking advantage of fish behaviour to entice the fish into the collector entrances while still leaving the less safe alternate routes through the project facilities open to them. This second approach is typical at large projects where full exclusion is not reasonable, and generally involves either entrances at the dam in near proximity to the turbine entrances but strategically located to be more attractive to the fish or a collector further upstream with guide nets in the upper portion of the water to lead surface-oriented fish toward the collector entrance. Each of these will be assessed relative to the conditions at Revelstoke.

Fish Transport

After the fish have been collected they are typically transported downstream either directly in a bypass pipeline or manually by transport truck. The latter method is typical in cases where the upstream passage is also provided by transport truck because the same issues are generally present, such as a high-head dam to pass and/or the need to get around multiple dams. Bypass pipelines need to be at very shallow slopes to limit flow velocities in the pipe so as not to injure fish.

Fish Release

Fish need to be released into the river downstream at a location that will not be inherently dangerous as they orient themselves before continuing their migration downstream. Generally, a location should be chosen where there is adequate depth so that the fish do not hit bottom upon release and they can travel deep enough to not attract avian predators, and also a location with adequate velocity that aquatic predators cannot easily hold in the river at the release site.

4.2 REVELSTOKE SITE CONSIDERATIONS

Generating Station Flows

Attempting to fully exclude fish from the full powerhouse flow at Revelstoke GS with fish screens would be unprecedented in scale. Even the existing 5-unit station capacity of 2,179 m^3/s would require approximately 20,000 square metres of screen to meet criteria established to prevent impingement of the smallest fish likely to arrive in the forebay. The largest fish screens currently in use are approximately 1,500 square metres, located at the Rocky Reach Project on the Columbia River in the U.S., and those are used to screen a partial attraction flow, not the entire river, and are located in a protected environment behind entrance trashracks. Therefore, it would not be reasonable to consider installing and maintaining screens of this size in the unprotected environment of the Columbia River. With the additional flow associated with the Unit 6 Project over 22,000 square metres would be required; however either of these is equally unprecedented and the addition of the sixth unit does not change this. Full surface to bottom exclusion nets for all fish in the reservoir would need to be approximately 4 times this size and are also considered unreasonable given the near impossible task of keeping them clean and undamaged. However, some amount of guide netting could be considered as part of an overall safe passage facility so long as the mesh were large enough to keep the pressure on the net within reason. This is discussed below in the context of one of the alternatives considered.

Based on the assessment above, this study investigated two design alternatives for attracting fish to the collector and bypass entrances based on fish behaviour, while still allowing unobstructed flows into the power intakes. These include one alternative at the dam with multiple entrances located above the power intakes, and a second alternative with a floating surface collector (FSC) located upstream with partial-depth guide nets leading surface-oriented fish to the FSC entrance. Each of these alternatives is described in detail in Section 4.3.

Turbine and Spill Flow

Given that some percentage of the fish will still ultimately pass downstream through the turbine or spillway flows it is of interest to consider the potential survival rates of these fish. R2 was provided with the characteristics of the Revelstoke turbines. R2 used the turbine characteristics to develop survival estimates for juvenile salmonids passing downstream through the turbines based on the turbine survival estimating model equations developed by the U.S. Department of Energy as part of their Advanced Hydro Turbine Project fish-friendly turbine design program (Franke et al. 1997). An estimate of fish survival is a function of the type and size of the turbine, the number of internal blades, the rotational speed, the hydraulic head, the hydraulic efficiency, and the fish size (expressed as the fork length of the fish). The physiology of the fish (most critically the ability of the fish to rapidly release pressure from the swim bladder) is also a factor in turbine survival but for the purposes of this study the fish considered were limited to the anadromous salmonids listed in Table 1. With all turbine characteristics equal, which is the case when considering different individual fish passing through the same turbine, fish survival becomes a function of the fish size, with survival decreasing with larger fish sizes. Figure 10 provides the results of the survival estimates for fish lengths in the range of 100 to 500 mm passing through one of the original four turbines. A conservative band of minimum to maximum estimates around the calculated survival rate is included in the figure based on the results of actual field survival studies performed at projects with similar large Francis turbines. The estimates range from 93% (plus or minus 3%) for 100 mm fish to 74% (plus or minus 13%) for 500 mm fish. The largest Chinook and Sockeye outmigrating juveniles are likely to be approximately 250 mm in length. For a conservatively large assumed average length of 200 mm juvenile salmonid the survival rate passing through the original four turbine units is estimated to be 87% (plus or minus 6%).

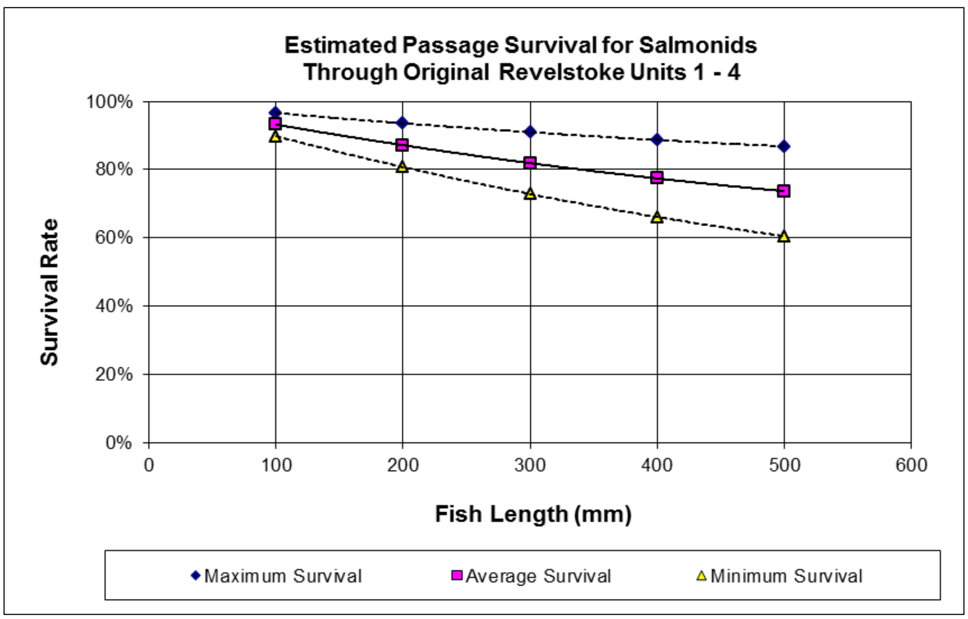

Figure 10. Turbine Survival Estimates for the Original Four Turbine Units.

The turbines at Revelstoke are quite large, with fairly big water passages, which results in fairly high survival rate estimates for the smaller fish. This makes sense since BC Hydro has found significant Kokanee entrainment through the Revelstoke turbines, but the population in the Revelstoke Reservoir remains abundant, and this is attributed to high survival of juvenile Kokanee passing through the Mica turbines replenishing the Revelstoke Reservoir population.

BC Hydro also provided the characteristics of the newer Turbine Unit 5, installed in 2010. The turbine is slightly larger than the original four turbines, and includes 13 blades; whereas the original four turbines include 14 blades. The newer turbine also has a higher hydraulic efficiency. Although each of these differences is positive for fish survival, and the estimates made reflected that, the difference was small with an estimated survival for 200 mm juvenile salmonids at 88% (plus or minus 6%).

BC Hydro has not yet requested specific turbine designs from manufacturers for the Unit 6 Project, and it is currently assumed that it will be similar to the recently installed fifth unit. However, to assess the potential impact of reducing the number of blades, an assumed turbine design with the same diameter and rotational speed as the fifth unit turbine but with 11 blades instead of 13 was entered into the survival model. The assumed hydraulic efficiency was slightly reduced based on the assumption that the choice of 13 blades in the 2010 turbine design was made to optimize the efficiency. In this case the resulting estimated survival increase over the original four units was slightly more significant, with an estimated survival rate for 200 mm salmonids at 89% (plus or minus 5%). Figure 11 provides the results of the survival estimates for fish lengths in the range of 100 to 500 mm passing through a theoretical turbine the size of the fifth unit but with 11 blades. Although knowledge of the operational characteristics of this type of change to the turbine design is beyond the expertise of the authors of this report, BC Hydro might consider requesting an assessment from the turbine manufacturers of the potential for meeting the project efficiency and production goals with a reduced number of turbine blades.

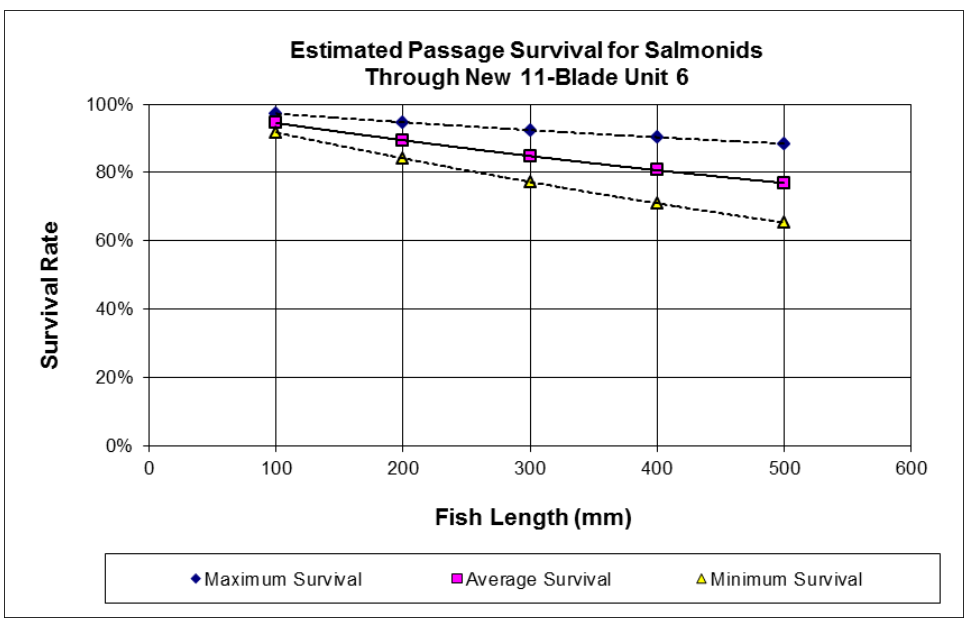

Figure 11. Turbine Survival Estimates for a Theoretical Unit 6 with 11 Blades.

The other route fish could take if they were not guided into the downstream collectors and bypass system would be the spillway. Although the spill flow conditions at Revelstoke do not appear to be very fish friendly, this is not considered to be a significant issue because spill flow is very rare at Revelstoke, and with the Unit 6 Project the spill flow occurrences should be even further reduced.

Fish Behaviour

The out-migrating juvenile Chinook tend to begin their migration in the tributaries and remain relatively surface oriented when moving downstream through the reservoir. However, Sockeye Salmon make greater use of lake environments during their rearing and therefore tend to travel through a greater range of depths during their downstream migration. This behaviour would be considered to be similar to the behaviour of the resident Kokanee in the Revelstoke Reservoir, which have been reported by BC Hydro to migrate vertically on a daily basis to depths of 40 to 80 metres below the surface (BC Hydro 2006). These differences in behaviour can be significant when designing systems to encourage fish to choose bypass systems entrances over the turbine intakes.

Turbine Intake Conditions

The turbine penstock intakes are protected by trashracks. The trashracks are half-circular towers that are 21.3 metres tall. Each of these towers has a trashrack surface area of approximately 550 square metres. This area results in an average intake velocity of about 0.75 m/s for the original Units 1-4 when operating at capacity, and closer to 1.0 m/s for the newer Unit 5 and the proposed Unit 6. Likely, the velocity is higher than the average over some areas of the trashrack and lower over others. The clear space between the vertical trashrack bars is 159 mm, which is large enough for all downstream migrating fish to easily fit through. The Unit 6 intake is already outfitted with a trashrack tower identical to the other five intakes as described above. It would not be reasonable to recommend reducing the bar spacing in an attempt to physically exclude fish from the intakes because the velocity is high enough that this could result in impingement of fish on the trashracks, which could result in greater mortality than passage through the turbine. Therefore, two alternatives are presented below for attracting fish to safer bypass routes installed at the project, especially the larger fish that are more susceptible to turbine mortality, while still leaving the turbine intakes as they are now.

Dam Height

As is the case with upstream passage, the height of the dam can impact the choice of methods for transporting the fish downstream around the dam. In the U.S. the criteria for the design of bypass pipes include limits of the slope of the pipe to maintain open-channel flow velocities of less than 3.6 m/s (NMFS 2011). To accomplish this for a height of 133 metres would require a bypass pipeline nearly 14 kilometres long. Since high-head dams generally require manual transport of fish in the upstream direction, the equipment for manual transport (most typically fish transport trucks) are already available at the project and they represent the most practical and safest means of providing downstream passage.

Release Sites

Trucking of fish around the dam also allows for a greater range of potential release sites. Given the wide range of hydraulic conditions downstream from operation at one-unit flow to peak daily flows in excess of 4-unit flow, it may be advantageous for fish survival to have the ability to choose optimum release sites based on the hydraulic conditions at the time of the release.

4.3 DOWNSTREAM FISH PASSAGE ALTERNATIVES CONSIDERED

Based on the assessment above, this study presents two alternatives for downstream fish passage. Alternative 1 is a collector at the dam consisting of multiple entrances across the face of the dam, located above the intake trashrack towers, with a sorting, sampling and loading facility located on the left bank as shown in Figure 12. Alternative 2 is a floating surface collector (FSC) located approximately 375 metres upstream of the dam with partial-depth guide nets leading surface-oriented fish to the FSC entrance. Fish would be temporarily held in holding pools on the aft end of the FSC and then barged to a facility located on the shore in batches for loading into fish transport trucks. Sorting and sampling of fish could be performed either on the FSC or at the shore-based loading facility.

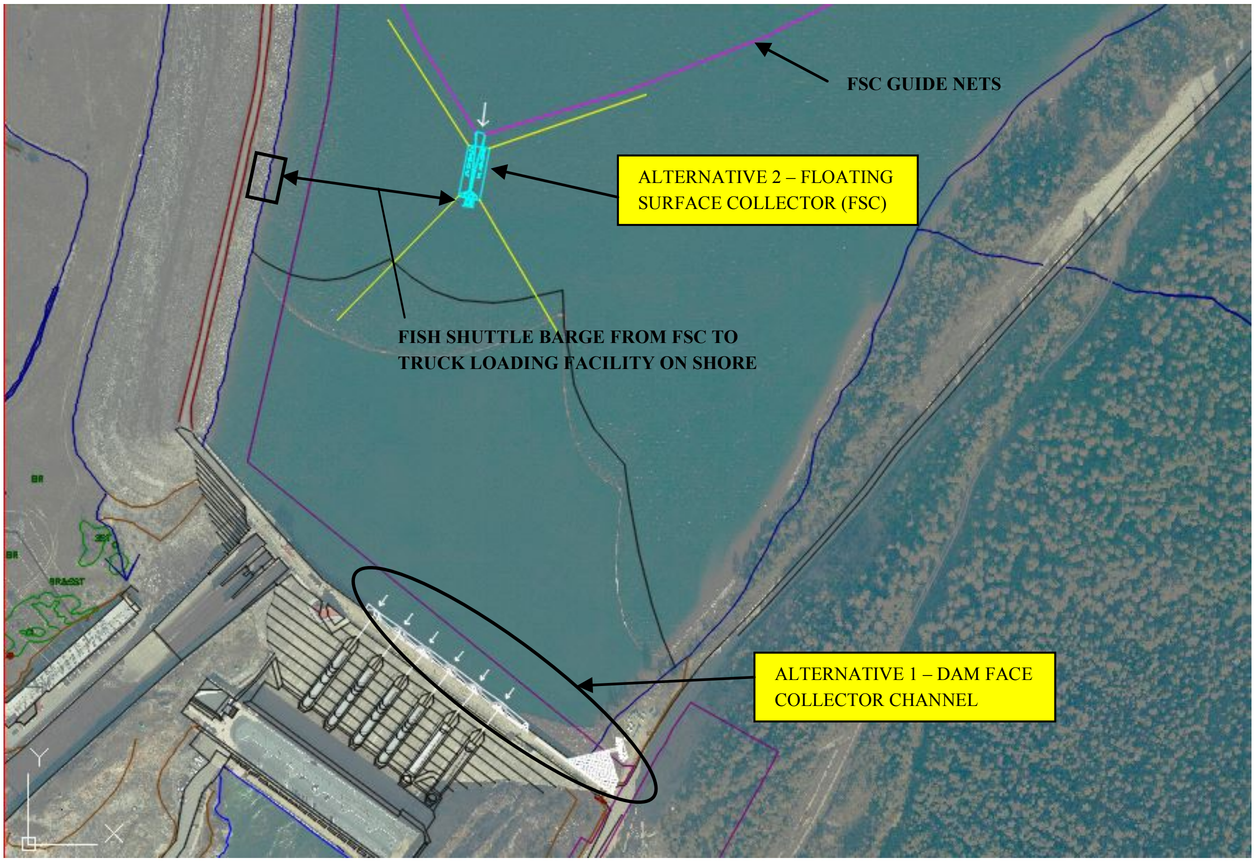

Figure 12. Potential Alternatives for Downstream Fish Passage Collectors.

Drawings 6 through 11 provide plan and section views of the two downstream alternative concept designs. The following sections describe the features of these downstream passage alternatives.

Downstream Fish Passage Alternative 1 Description

Surface collectors similar to the concept design shown for Alternative 1 are common in the U.S. for passing downstream migrating anadromous salmonids. Specific features of the system are described below.

Fishway Entrance

The fishway entrance must provide an attractive flow pattern which can compete with the ambient flow toward the turbine intakes to attract downstream migrating fish to enter the fishway. To achieve this, the entrance needs to be in an area where fish will be likely to encounter the velocity field caused by the entrance flow and the velocity should be greater than the ambient velocity in that area. Alternative 1 has six entrances, one located above each intake trashrack tower. Outmigrating Chinook Salmon generally tend to be surface oriented as they move downstream in a reservoir. However, outmigrating Sockeye Salmon tend to occupy a broader range of depths during their migration. To account for this difference each entrance has an upper and a lower entrance. The upper entrance is a deep slot with an adjustable sill elevation and free water surface designed to collect fish in the upper water column. The upper slot is nominally 2 metres wide with a maximum depth of 5 metres at a reservoir pool elevation of 573 metres. The entrance would have a maximum depth of 3.5 metres when the reservoir level is at 571.5 metres. The lower entrance is an orifice entrance with adjustable opening height located a couple of metres above the top of the trashracks. The lower entrance is provided to collect fish lower in the water column closer to the turbine intake flow. The lower entrance orifice is also 2 metres wide with a maximum open height of 4 metres. The adjustable upper and lower entrance arrangement will allow the operator to select where in the water column the majority of the flow is withdrawn based on the behavioral characteristics of the fish present at the time. The ability to selectively withdraw flow from two depths can also provide for temperature control of the water used to transport the fish during periods of reservoir stratification to reduce potential issues with thermal shock upon release of the fish downstream.

The Unit 6 Project will result in additional fish bypass construction costs associated with a sixth collector entrance located over the Unit 6 trashrack tower, and additional operational costs associated with the added screening and pumping capacity. However, the attraction strategy is the same for the entrances over each of the turbine unit intakes so the effectiveness of the collection and bypass should not be different with the addition of the sixth unit.

Dewatering

After flow enters the channel the dewatering screens begin. Dewatering continues for the entire length of the channel through both the wall and floor. As flow is taken from the channel through the dewatering screens the cross sectional area of the channel is reduced by converging walls and a rising floor with the intent of having a constant or slightly increasing velocity over the length of the channel. At the end of the channel flow passes over an adjustable weir (to adjust for changes in forebay elevation) and accelerates as it enters a 1-metre-diameter fish transport pipe flowing approximately 25 cm deep with 0.5 m^3/s flow to the sampling and sorting facility. Each entrance has an independent dewatering channel and fish transport pipeline so each entrance can be operated independently of all the other entrances to optimize collector operations in relation to varying powerhouse operations. Dewatering flow is achieved with use of a dewatering pump behind the screens with discharge through floor diffusers towards the intake trashrack structure below.

Sorting and Truck Loading Facility

A facility for holding the collected fish and ultimately loading them into the transport trucks would be located at the south end of the reservoir along the dam face. Photo 7 shows this area. The facility would be constructed behind a wall so this area could be dewatered with a permanent facility installed behind the wall. When all six entrances and fish transport pipelines are operating the total flow into the sorting facility would be 3 m^3/s (0.5 m^3/s per pipe). An additional dewatering pump located at the facility would be used to pump this flow back into the reservoir through diffusers. The facility could include features to allow for sorting and/or sampling of the fish prior to loading into the transport trucks. In some cases there may be a decision to return some non-target resident fish back upstream. After the fish have been sorted (and sampled if required) they are held in specific loading tanks based on species and/or intended release locations. The tank sizes would be based on the number of fish expected between sorting crew work shifts and the size of the truck tanks. The trucks are the same trucks that would be used for the upstream passage and are described in Section 3.3 above.

Photo 7. Location of Sorting and Loading Facility for Alternative 1.

Downstream Fish Passage Alternative 2 Description

The downstream passage Alternative 2 is a floating surface collector (FSC) located approximately 375 metres upstream of the dam, as shown on Drawing 9. FSCs have been installed in a number of deep reservoirs in the northwestern U.S., most commonly to address large reservoir fluctuations but in some instances to move the collection entrance to a location further upstream where it would not need to directly compete with the turbine intakes. FSCs have worked well to collect and safely bypass Sockeye Salmon smolt, which are harder to attract away from a deep turbine intake with a dam-mounted surface collector because they tend to travel through a deeper portion of the water column than other salmonids.

An FSC incorporates most of the same features described for the fixed surface collector described as Alternative 1 including an entrance with velocity conditions designed to attract the fish, dewatering screens in a reducing channel to remove the majority of the attraction flow and pass fish to holding tanks in a smaller flow, and pumps to return the screened attraction flow back to the reservoir for use in power generation. Because the FSC is floating out in the reservoir, away from the shore, the collected fish need to be held for a period of time on board the FSC, and moved off in batches when it is time for transport. Although the size and number of holding tanks would need to be determined during the design, the conceptual plan view on Drawing 10 shows four tanks. Each tank can be lifted out of its holding area and placed into a floating barge docked outside the stern of the FSC. The barge is used to shuttle tanks of fish to a shore-based facility for loading the fish into transport trucks. Based on space availability, comparative costs, and/or potential need for separating fish by species or fish size prior to holding the sorting and handling of fish could either occur on board the FSC or at the shore-based facility after barging of the fish from the FSC. This system of FSC fish collection and barge movement of fish batches to loading for truck transport is used at the Upper Baker and Lower Baker Hydro Projects in Washington State as part of their extremely successful Sockeye Salmon restoration on the Baker River.

Unlike Alternative 1, the FSC alternative included guide nets to lead fish toward the FSC entrance. This is a critical component of any FSC because the fish entrance and attraction flow are very small relative to the size of the reservoir forebay, so fish need to be gently guided to the FSC entrance. The nets at Revelstoke would be somewhat unprecedented in terms of their size, flow, and environmental exposure conditions (R2 2014). To mitigate for this it is recommended that the net be a partial-depth net to guide surface-oriented migrants, with the understanding that some small percentage of these target fish may pass under it and continue downstream through the turbines, most probably this would be limited to some small percentage of the Sockeye only.

The profile view on Drawing 11 shows the net as being 60 metres deep. To provide fish guidance the nets on each side should extend upstream from the FSC entrance to locations on the shoreline that result in a 'vee-shaped' net arrangement with the FSC entrance at the downstream point of the vee (as shown on Drawing 6). To minimize loading on the net, the area of the net should be maximized within practical limits by choosing shoreline anchor points as far upstream as practical. Finally, the loading on a net varies exponentially with changes in open area resulting from different mesh sizes. Therefore, if Alternative 2 is to be considered for further design careful consideration should be given to focussing on the smolt-sized fish for guidance while allowing for passage of smaller fish through the net, given the high estimated turbine passage survival for the smallest fish (see Figures 10 and 11). Full exclusion nets in the U.S. typically use 6.4 mm (1/4-inch) square mesh net to exclude nearly all fish from passage through the net; however, very small velocities can result in large net loads with a mesh size that small, especially when debris begins to accumulate on the net. Given the large turbines at Revelstoke, and the relatively safe estimated passage for small fry-sized fish, consideration should be given to using a square mesh size between 13 and 19 mm (1/2-inch to 3/4-inch), which would allow for passage of fish approximately 100 to 150 mm in length through the net. This would greatly reduce the likelihood of catastrophic failure of the net during adverse conditions.

Although likely more costly than Alternative 1, and more complicated to operate given its more remote location, the potential advantage of Alternative 2 is the guidance and collection of fish upstream before they have gotten close enough to the dam to sense the influence of the turbine intake flows. A consideration with Alternative 2 is that the release location for adult upstream migrants would need to be upstream of the guide nets, which would preclude fixed passage facilities that release upstream migrants near the dam.

4.4 IMPACT OF UNIT 6 PROJECT ON DOWNSTREAM PASSAGE FEASIBILITY

Disadvantages associated with the Unit 6 Project are effectively limited to incremental construction and operations cost of future downstream collection and passage facilities. In the case of Alternative 1 there would need to be a sixth collection entrance with associated screening, pumping, and piping. The cost impact on Alternative 2 may be less significant, involving longer nets to mitigate for increased net loading resulting from the increased powerhouse flow.

In both cases, there is no difference between a 5-unit or 6-unit powerhouse concerning the method used for attracting, collecting, or bypassing fish; or the likely effectiveness of those methods. Therefore, it is not predicted that the Unit 6 Project would impact the overall effectiveness of systems designed to collect and bypass fish downstream around the dam.

4.5 PHYSICAL CONSIDERATIONS RELATIVE TO DOWNSTREAM PASSAGE

During the installation of the Unit 6 Project it is recommended that the upstream face of the dam not be permanently altered in any way that might preclude the future installation of collection entrances and channels above the trashrack towers as shown in Alternative 1. Also, no permanent modifications should be made at the south end of the dam and forebay area that might preclude future use of the area for the installation of a fish holding, sorting, and truck loading facility.

When having turbine manufacturers propose turbine designs for the Unit 6 Project it would be informative to have them comment on the feasibility of fabricating a turbine with 11 internal blades, instead of the 13 that are incorporated into the newer fifth unit turbine. A turbine of the same size with only 11 blades would be more fish friendly, resulting in a higher turbine passage survival rate. However, it is beyond the scope of this study to investigate or speculate on the operational feasibility of such a turbine, or whether a turbine with a reduced number of blades could meet the design efficiencies and goals of the project. A consideration here might be to evaluate the incremental cost of any efficiency decrease associated with a more fish friendly turbine against the incremental cost of other potential improvements to the overall salmon restoration solution. Marginal benefits for improved overall fish survival may be more readily realized elsewhere than from changes to the turbine in the context of the overall salmon restoration solution.

4.6 OPERATIONAL CONSIDERATIONS RELATIVE TO DOWNSTREAM PASSAGE

As with upstream collection facilities there may be particular units, or combinations of units, that result in better collection efficiencies during powerhouse operation at reduced flows. This could be determined through live fish testing in the forebay with various combinations of turbine operations. For example, it may be found that operating every other unit results in better collection efficiencies than operating adjacent units, or visa-versa. These types of subtle differences are generally site specific and impossible to estimate or predict in advance. If differences are found, a procedure of turbine operations (i.e., which turbine comes on first, then second, etc.) could be established to maximize collection and bypass efficiency. If there is no significant difference found in collection efficiency relative to which units are operating, then the newer Units 5 and 6 will result in higher survival rates than the four original units and should be considered for first-on/last-off operation.

5. SUMMARY

R2 Resource Consultants was contracted by BC Hydro to review the Revelstoke Unit 6 Project relative to the existing conditions and assess the implications of the project on the future ability to collect and pass anadromous salmon in the event they are introduced to the upper Columbia River above Keenleyside Dam. Based on historic pre-dam records and the current status of species in the lower Columbia River, we concluded the species of anadromous fish that might potentially migrate to Revelstoke in the event passage is provided downstream might include summer Chinook and Sockeye salmon. Four alternatives were developed for attracting and collecting these migrating fish into safe passage facilities (two for adult upstream migrants and two for juvenile downstream migrants). We concluded that the Unit 6 Project will not preclude or reduce the ability to attract, collect, and pass these species. The greatest potential impact of the project on these alternatives is the added cost of attraction and collection infrastructure to accommodate the additional flow capacity and the Unit 6 intake and draft tube areas. A benefit of the project is a reduction in the occurrence of forced spill events when high river flow events exceed the hydraulic capacity of the powerhouse, as these events would reduce the effectiveness of the passage facilities.

BC Hydro also requested that R2 provide considerations regarding physical modifications that could be included in the Unit 6 Project design to facilitate an easier or more successful retrofit for passage, and operational options with Unit 6 in place that might aid in effective upstream and/or downstream fish passage. Table 3 provides a summary of R2's conclusions regarding physical and operational considerations associated with the Revelstoke Unit 6 Project relative to future anadromous salmon passage.

A draft of this report was provided to the First Nations involved in the project and a conference call with BC Hydro, the First Nations, and R2 was held on February 22, 2016 to discuss the report and conclusions. Subsequently, comments were received and a compilation of these comments and the responses from BC Hydro are included in Appendix A.

Table 3. Physical and Operational Considerations Relative to Future Anadromous Fish Passage.

Physical Considerations During Design and Construction of the Unit 6 Project:
• Avoid permanent alterations to the upstream and downstream faces of the dam that would interfere with the installation of fish attraction and collection facilities as described in this report.
• Avoid permanent alterations to the right bank of the tailrace and forebay in areas shown for potential fish attraction and collection facilities as described in this report.
• Although the potential benefit to overall downstream migrant survival through the project may be small, BC Hydro may consider investigating whether a turbine design potentially exists that meets the project efficiency and design goals with a minimum number of internal blades.
Considerations During the Design of Future Bypass Facilities:
• Identify optimal locations for upstream and downstream fish release sites and investigate site upgrades required to provide access for fish transport trucks.
• After anadromous fish are present in the tailrace, perform field studies to determine predominant fish behaviour relative to various flow conditions to form basis of upstream passage collector location and design.
• Utilize three-dimensional physical or computer modeling of the tailrace area to optimize the design of upstream attraction and collector facilities relative to the fish behaviour.
• After successful upstream passage and spawning perform field studies to determine predominant behaviour of the juvenile downstream migrants to form basis of downstream passage collector location and design.
• Investigate new passage technologies that may have developed between the writing of this report and the time anadromous fish become present at Revelstoke to determine potential applicability.
Operational Considerations After Installation of Passage Facilities:
• Schedule planned maintenance and Mica/Revelstoke flows so as to avoid volitional spills during the upstream and downstream passage seasons (April through September)
• Limit reservoir fluctuations to 1.5 metres during the downstream anadromous migration season (April through July) if possible.
• After installation of upstream passage collector facilities, determine through field studies the optimal turbine choices (i.e., first-on, second-on, third-on, etc.) and flow rates for attraction efficiency and commit to these operation procedures during the upstream migration season (July through September).
• After installation of downstream passage collector facilities, determine through field studies the optimal turbine choices and flow rates for attraction efficiency and overall survival and commit to these operation procedures during the downstream migration season (April through July).
• During the upstream migration season avoid operation of turbines at partial flow rates low enough to allow fish to pass upstream in the draft tubes far enough to be injured by the turbines or distracted from the collector entrances. It may be best to limit operations to combinations of turbines operating at or near their full capacities.

6. REFERENCES

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DRAWINGS

Drawing 1 – Upstream Fish Passage Alternatives Overall Plan View

Drawing 2 – Upstream Fish Passage Alternatives Plan View

Drawing 3 – Upstream Fish Passage Alt. 1 – Right-Bank Entrance Profile

Drawing 4 – Upstream Fish Passage Alt. 2 – Dam Face Entrances Elevation

Drawing 5 – Upstream Fish Passage Alt. 2 – Dam Face Entrances Section

Drawing 6 – Downstream Fish Passage Alternatives Overall Plan View

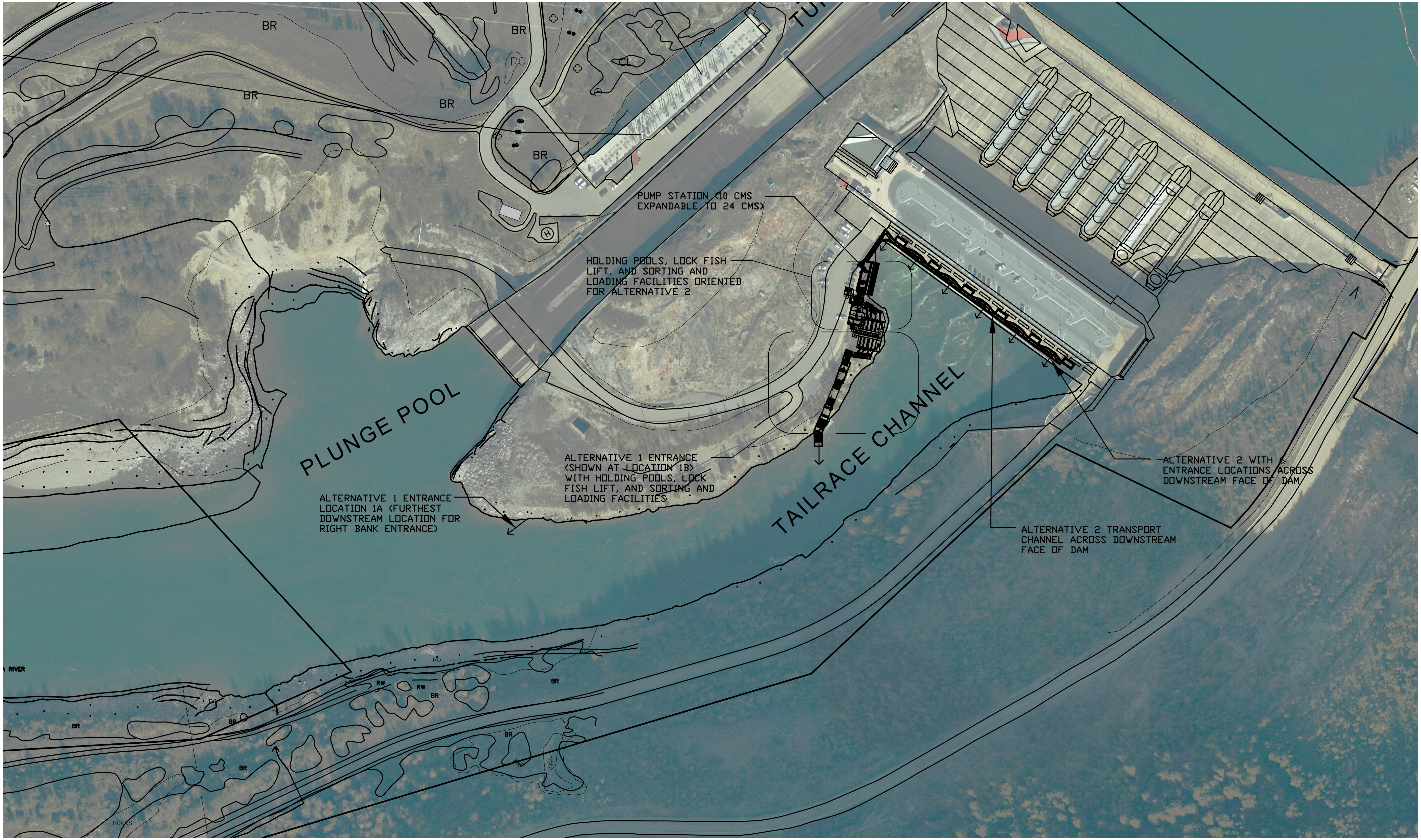
Drawing 7 – Downstream Fish Passage Alt. 1 – Dam Face Collector Plan View

Drawing 8 – Downstream Fish Passage Alt. 1 – Dam Face Collector Elevation

Drawing 9 – Downstream Fish Passage Alt. 1 – Dam Face Collector Sections

Drawing 10 – Downstream Fish Passage Alt. 2 – Floating Surface Collector Plan View

Drawing 11 – Downstream Fish Passage Alt. 2 – Floating Surface Collector Profile



NOTES:
1. LOCATINOS 1A AND 1B SHOWN REPRESENT THE UPSTREAM AND DOWNSTREAM EXTREMES OF A POTENTIAL RANGE IN WHICH A SINGLE HIGH-FLOW ALTERNATIVE 1 ENTRANCE WOULD BE LOCATED. (SEE REPORT TEXT FOR A DETAILED EXPLANATION OF ENTRANCE LOCATION)

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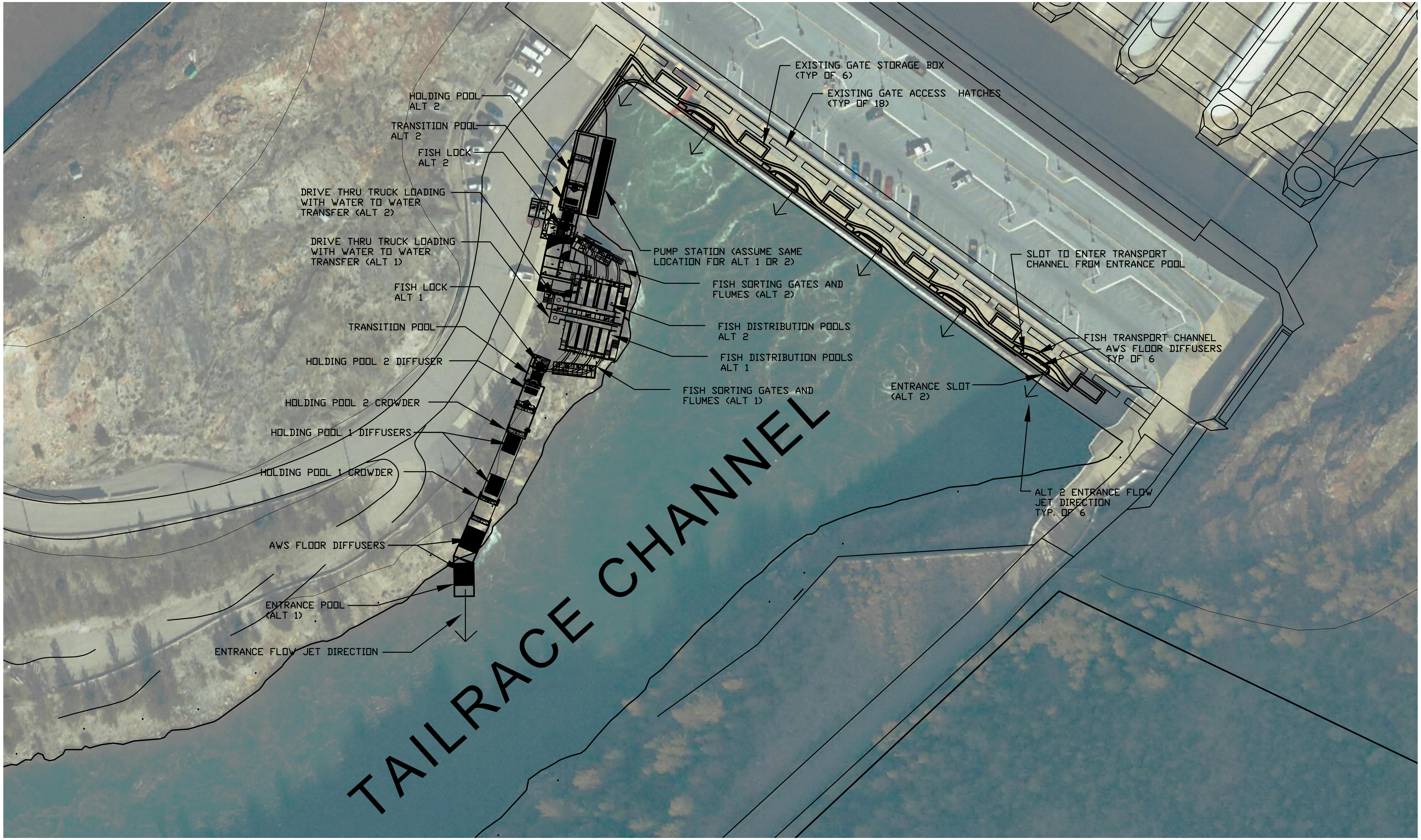
SCALE 1:2500

Resource Consultants, Inc.
REDMOND, WA.

BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

UPSTREAM FISH PASSAGE
ALTERNATIVES OVERALL PLAN VIEW
DRAWING 1



NOTES:
1. BOTH ALTERNATIVES SHOWN ON DRAWING. EITHER ONE OR BOTH OF THESE ALTERNATIVES COULD BE CONSTRUCTED INDEPENDENTLY. THIS DRAWING SHOWS A LAYOUT THAT WILL ACCOMMODATE BOTH ALTERNATIVES TOGETHER OR SEPARATE.
2. THE PUMP STATION WOULD SUPPLY WATER TO BOTH ALTERNATIVES

-10 0 10 20 30 40 METRES
SCALE 1:1000

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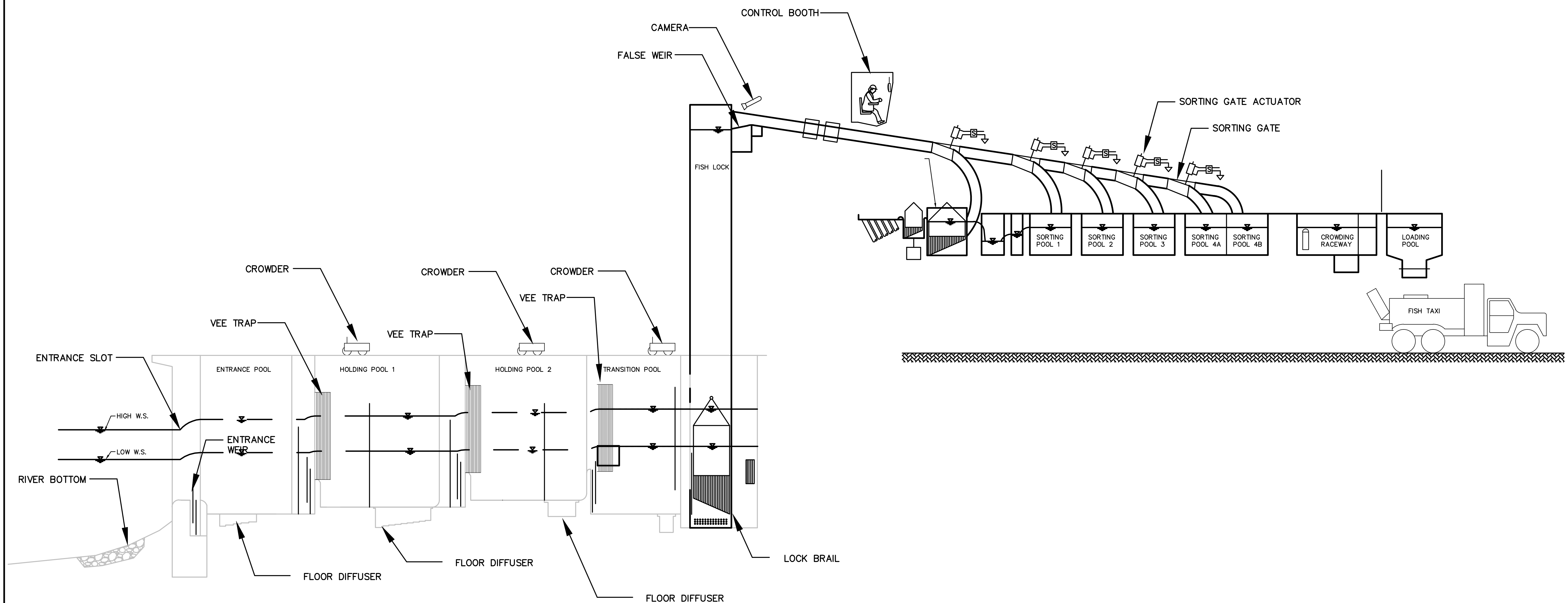
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

UPSTREAM FISH PASSAGE
ALTERNATIVES PLAN VIEW
DRAWING 2



SCHEMATIC PROFILE – UPSTREAM PASSAGE FACILITY AT BAKER RIVER

ALTERNATIVE 1 – RIGHT BANK ENTRANCE (NTS)

NOTES:

1. THIS SCHEMATIC IS SHOWN AS AN EXAMPLE OF A SIMILAR SIZED EXISTING UPSTREAM PASSAGE FACILITY WITH HOLDING, SORTING, SAMPLING, TRUCK LOADING AND A LOCK TO LIFT FISH, SIMILAR TO THE PROPOSED FACILITY FOR REVELSTOKE.

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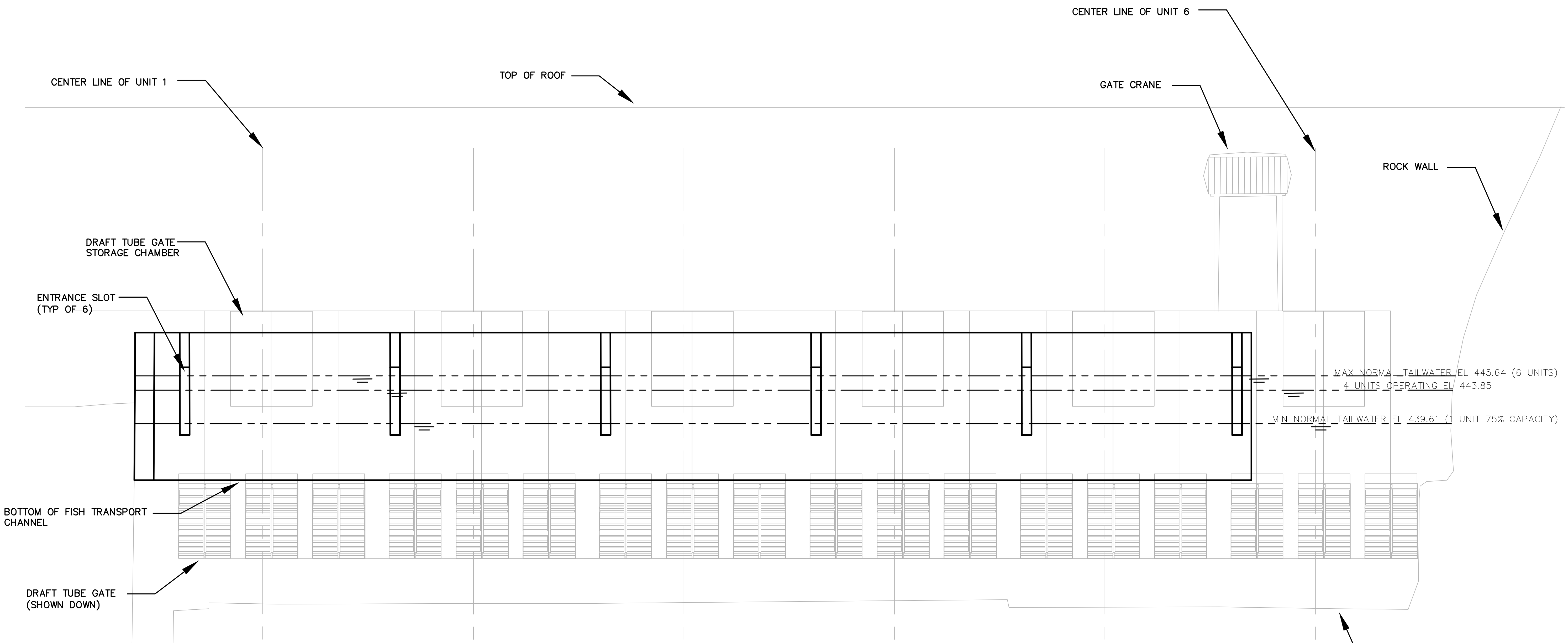
	UPSTREAM FISH PASSAGE ALT. 1 – RIGHT BANK ENTRANCE PROFILE DRAWING 3



ELEVATION – DOWNSTREAM FACE OF DAM
ALTERNATIVE 2 – DAM FACE ENTRANCES

SCALE 1:500

NOTES:
1. THIS DRAWING SHOWS THE FULL BUILD-OUT OF SIX (6) ENTRANCES ACROSS THE DOWNSTREAM FACE OF THE DAM. INITIAL CONSTRUCTION COULD START WITH A FEW ENTRANCES OVER THE LOWER NUMBERED UNITS WITH SUBSEQUENT BIOLOGICAL MONITORING TO DETERMINE IF MORE ENTRANCES ARE REQUIRED.

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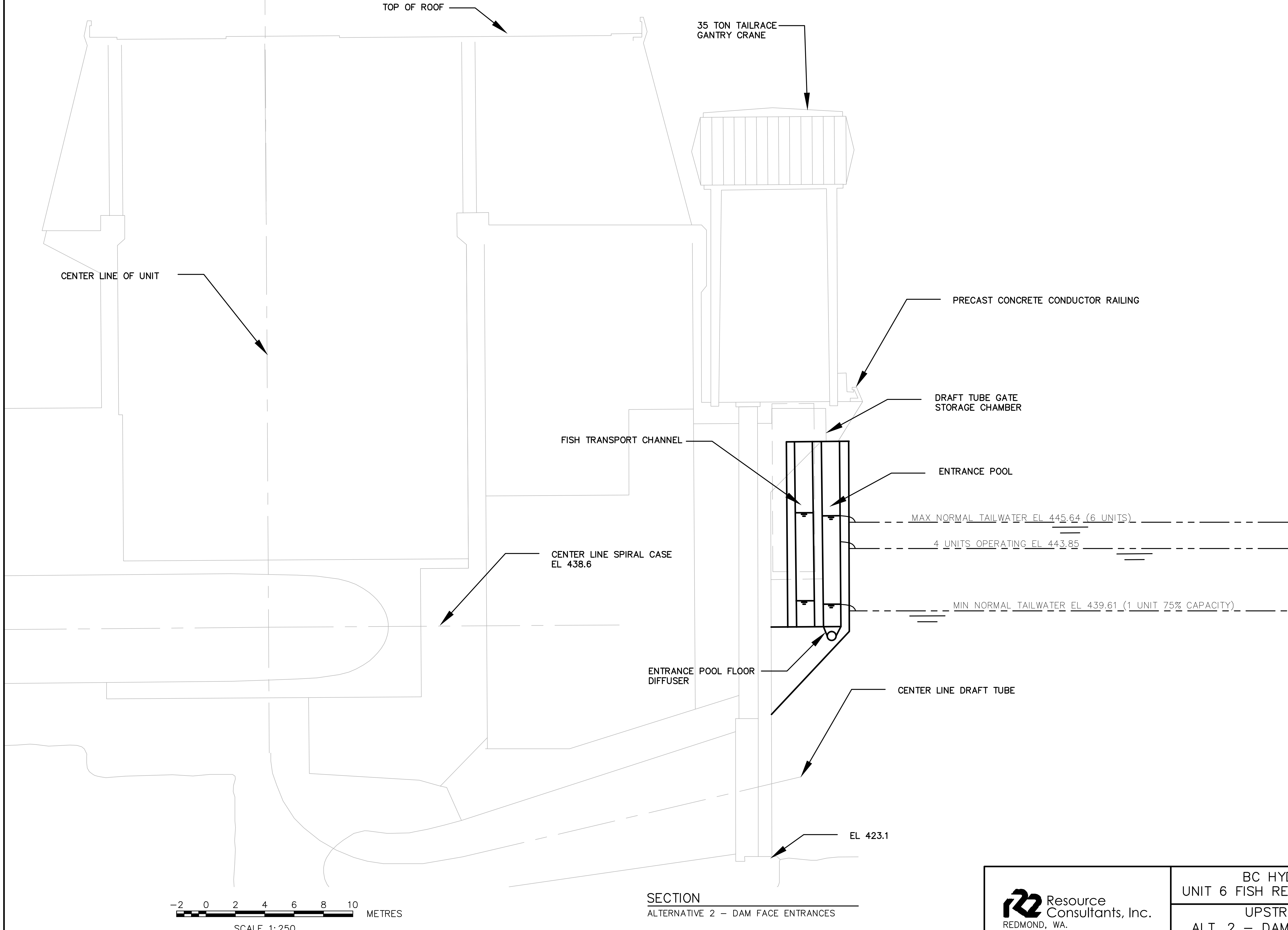
UNIT 6 FISH RESTORATION IMPACTS REPORT

UPSTREAM FISH PASSAGE
ALT. 2 – DAM FACE ENTRANCES ELEVATION
DRAWING 4



SECTION

ALTERNATIVE 2 – DAM FACE ENTRANCES

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UNIT 6 FISH RESTORATION IMPACTS REPORT

UPSTREAM FISH PASSAGE
ALT. 2 – DAM FACE ENTRANCES SECTION
DRAWING 5

ALTERNATIVES KEY
PLAN VIEW

-40 0 40 80 120 160 200 METRES
SCALE 1:5000

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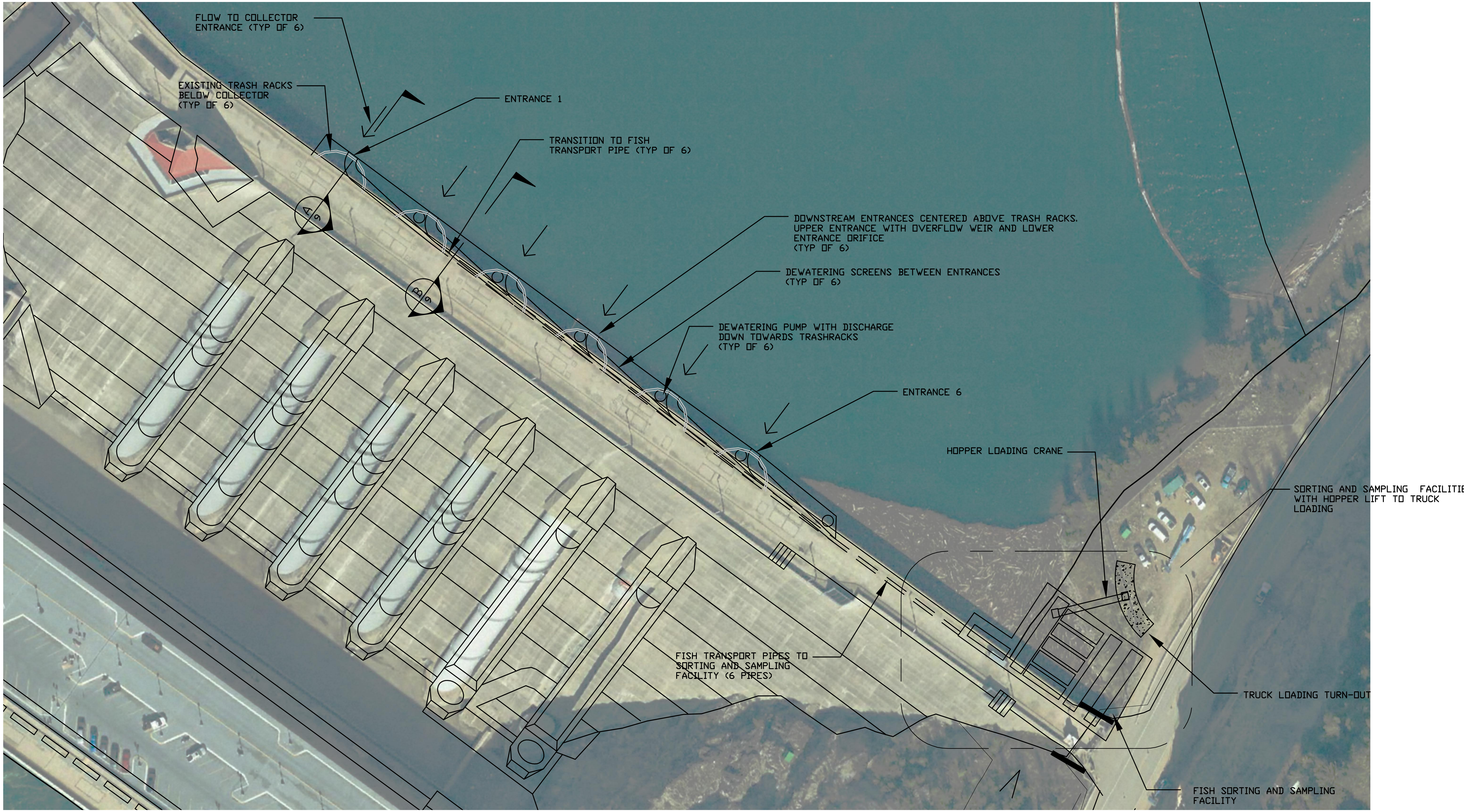
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALTERNATIVES OVERALL PLAN VIEW
DRAWING 6



-10 0 10 20 30 40 METRES

SCALE 1:1000

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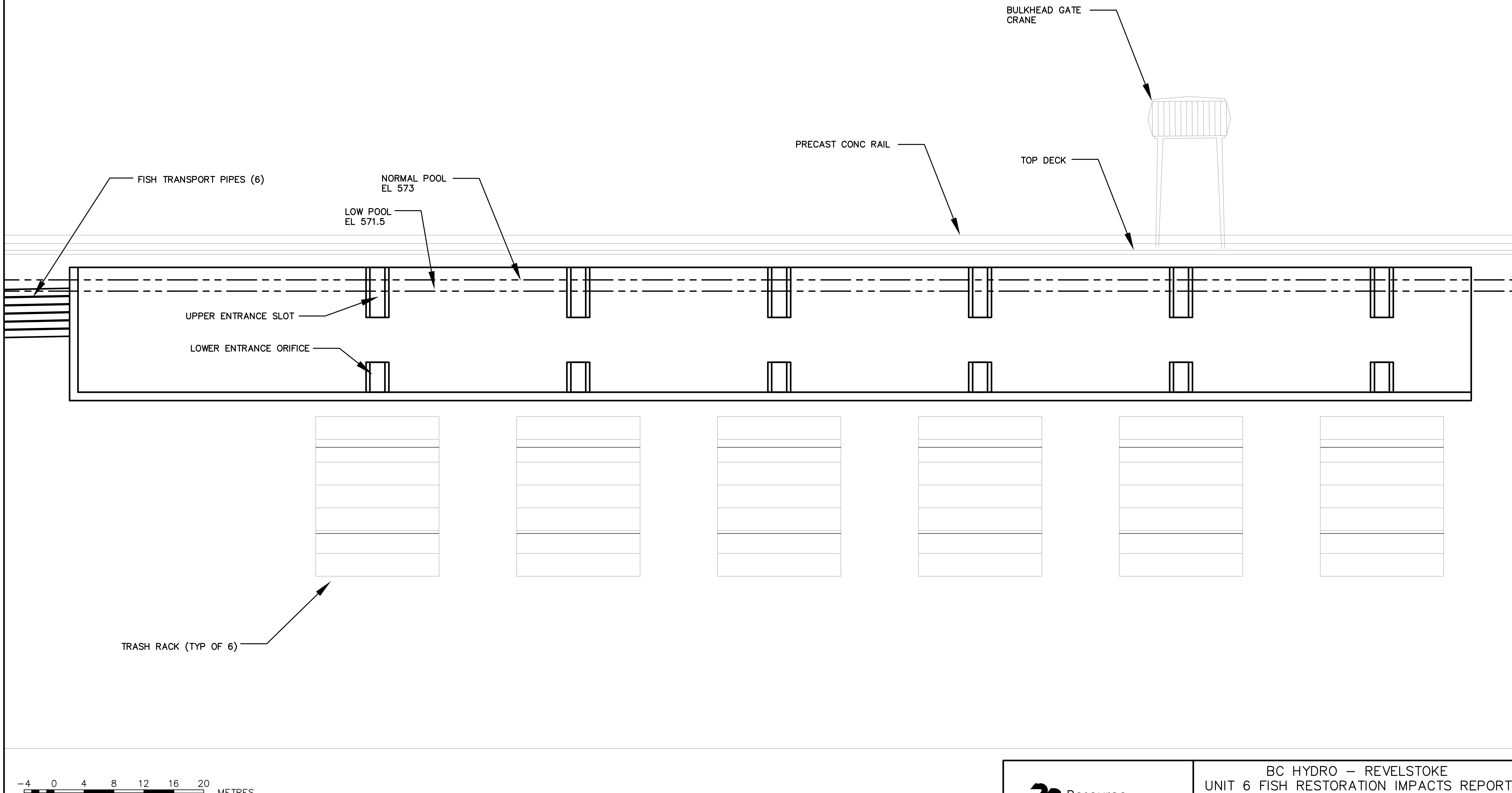
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALT. 1 – DAM FACE COLLECTOR PLAN VIEW
DRAWING 7



ELEVATION

ALTERNATIVE 1 – DAM FACE COLLECTOR

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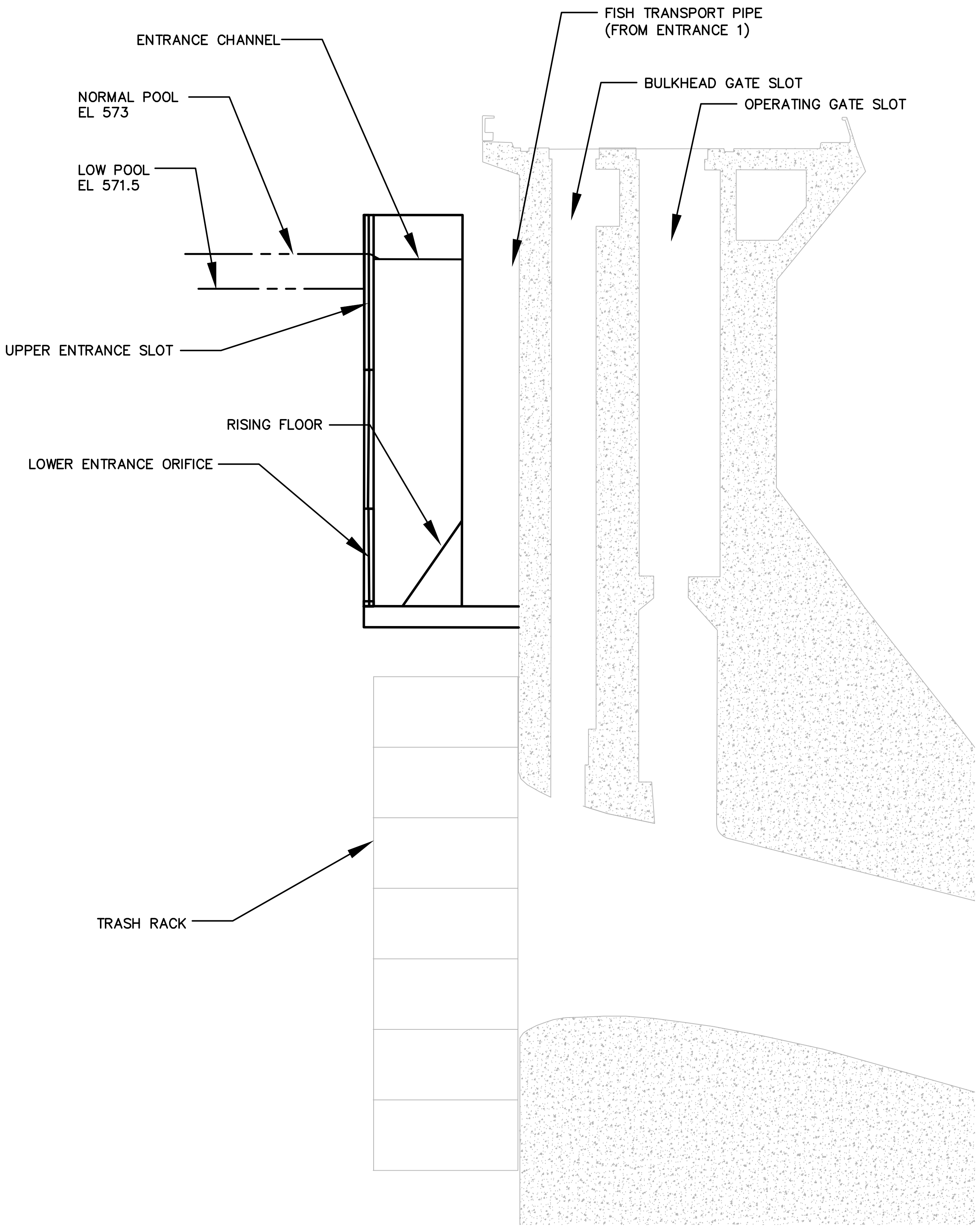
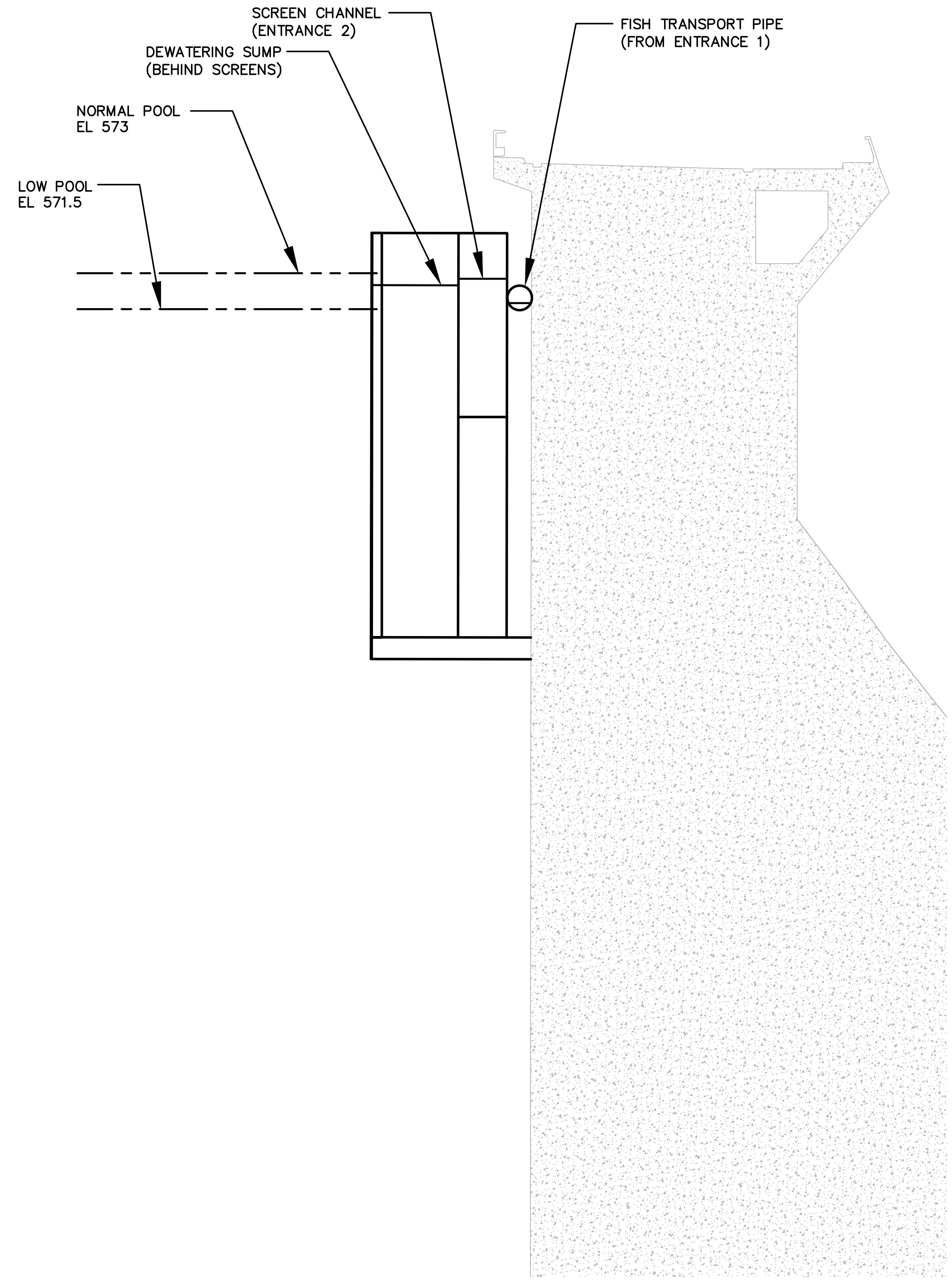
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALT. 1 – DAM FACE COLLECTOR ELEVATION
DRAWING 8



SECTION THROUGH ENTRANCE 1 (A/7)
ALTERNATIVE 1 – DAM FACE COLLECTOR



SECTION BETWEEN ENTRANCE 2 AND 3 (B/7)
ALTERNATIVE 1 – DAM FACE COLLECTOR

−2 0 2 4 6 8 10 METRES
SCALE 1:250

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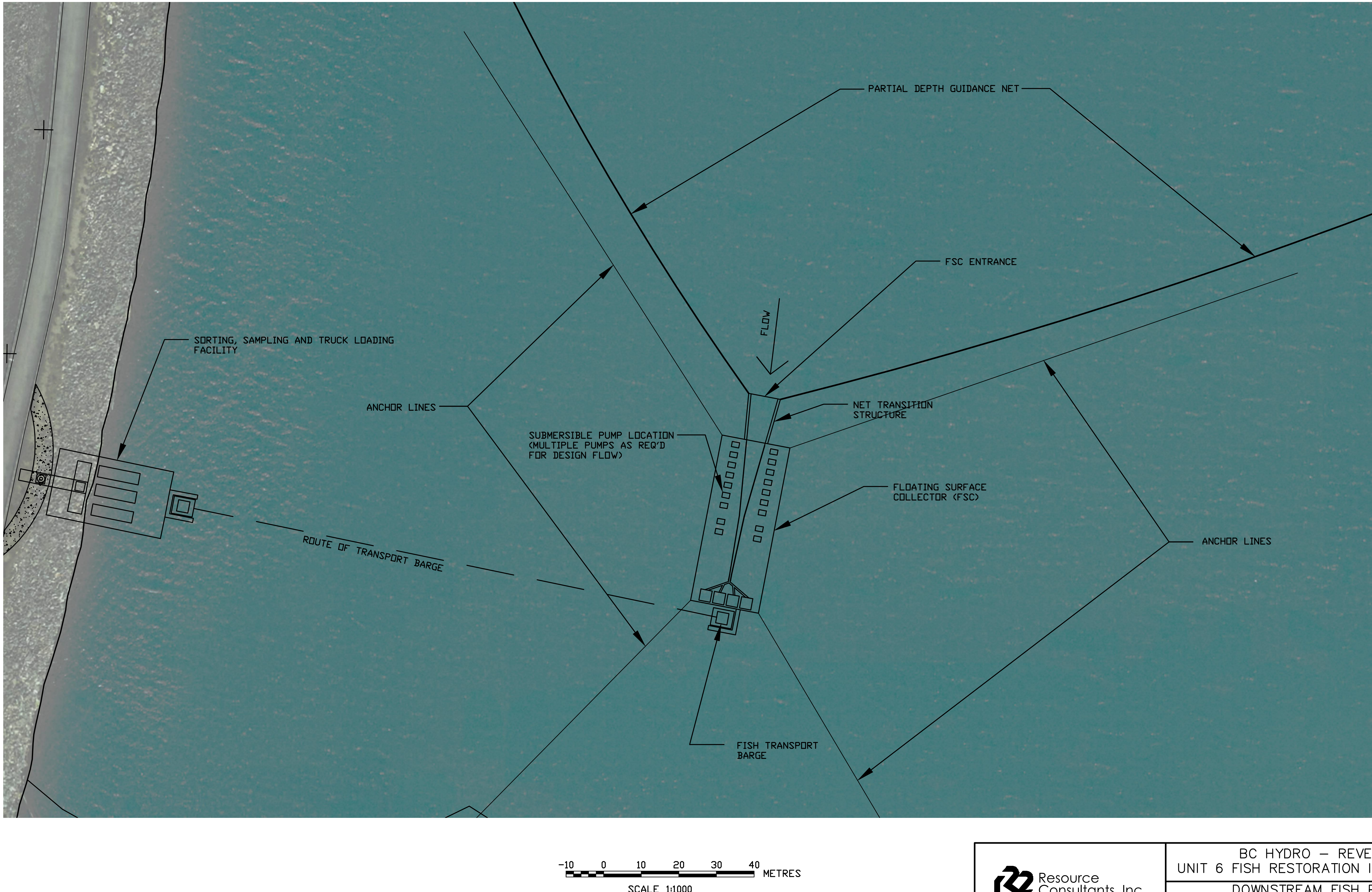
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALT. 1 – DAM FACE COLLECTOR SECTIONS
DRAWING 9



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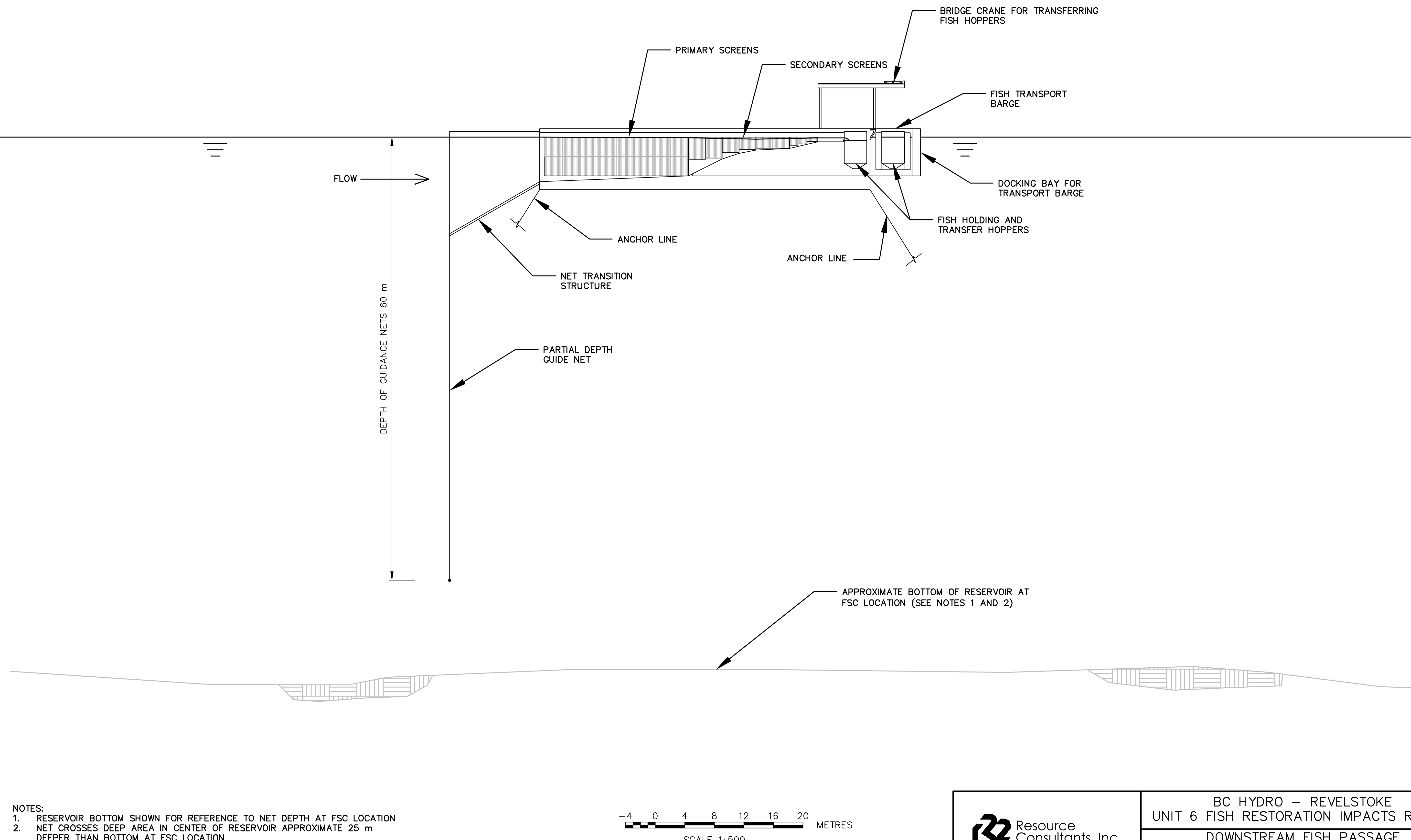
BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALT. 2 – FLOATING SURFACE COL. PLAN VIEW
DRAWING 10



NOTES:
1. RESERVOIR BOTTOM SHOWN FOR REFERENCE TO NET DEPTH AT FSC LOCATION
2. NET CROSSES DEEP AREA IN CENTER OF RESERVOIR APPROXIMATE 25 m DEEPER THAN BOTTOM AT FSC LOCATION.

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BC HYDRO – REVELSTOKE
UNIT 6 FISH RESTORATION IMPACTS REPORT

DOWNSTREAM FISH PASSAGE
ALT. 2 – FLOATING SURFACE COL. PROFILE
DRAWING 11

APPENDIX A

Record of BC Hydro and First Nations Review

APPENDIX A
Record of BC Hydro and First Nations Review

A review of the draft report was completed by BC Hydro and First Nations involved in the project. A conference call was hosted by BC Hydro to gather feedback and provide a venue for discussions on the draft.

A summary of the verbal feedback and other comments received in writing by BC Hydro is provided below. In some cases, feedback was incorporated into the current version of this report. In other cases, the feedback is documented below to be used for any subsequent design reports regarding Salmon Restoration. Subsequent design reports for Salmon Restoration are outside of the current approved Definition phase scope of the Revelstoke Unit 6 project but may be approved as the project continues through its project lifecycle.

Item #	Comment Received	Action Item
1	Expand potential species and migration window.	Will be addressed in subsequent design reports.
2	Add a statement in executive summary referring to reintroducing salmon into their "historical range"	Edit made to current version of report.
3	Better modeling suggested to understand the velocities (Average velocity used in report).	Subsequent design reports will incorporate the most recent modeling available and perform additional modelling as needed to assess and describe velocity/flow characteristics.
4	Reference other downstream by-pass systems that need to be reviewed for subsequent feasibility evaluations	As technology for this purpose is evolving, subsequent design reports will review additional options available at that time.
5	Reference dam safety concerns regarding the use of nets for fish guidance.	To be addressed in subsequent design reports.
6	Reference other fish guidance technology that could be considered for subsequent feasibility evaluations	As technology for this purpose is evolving, subsequent design reports will review additional options available at that time.
7	The report comments about forced spills due to extreme river levels. What are the environmental impacts (short and long term) on the Columbia River downstream from the dam when emergency spills occur?	Addressed as part of the EA process for Revelstoke Unit 6.

Item #	Comment Received	Action Item
8	These spills are relatively short in duration but they do happen; has a study been conducted from past occurrences such as in 1991 and 1997? Is there any modelling that shows negative effects on environment??	Addressed as part of the EA process for Revelstoke Unit 6.
9	OKIB supports all historical salmon species that were resident in the Columbia prior to the hydroelectric dams for reintroduction	Noted – Species and timing will be reviewed as per Item #1
10	Require more information on the proposed truck and transfer of salmon. Would like to know location for release above the dam.	Will be addressed in subsequent design reports.
11	See discussion of Waknitz et al. 1995. There is little evidence that June hogs existed as a discreet stock that used the Canadian reaches of the upper river. In fact, there is conflicting reports that the large sized fish were from spring or summer runs. What we do know for sure is that out-migrating smolt chinook collected at Revelstoke and Golden, (i.e., would have spawned above Revelstoke Dam) were of the stream type life history, as all were yearlings (Eigenmann 1895). All remaining stocks of this life history in the US upper Columbia migrate much earlier, around April. It is hard to imagine that the ones destined the furthest would migrate later but I suppose it is possible. Also, in the Fraser River, all chinook destined for spawning locations >800km are stream type and spring run. So we don't know for sure, but I would say two things: 1) The life history of chinook spawning above the location of Revelstoke dam would have unquestionably been stream type. It is simply too far from the ocean for sub-yearling emigrants to persist. 2) Migration timing for this life history is most likely to be earlier in ~April, but could possibly encompass ~June summer timings at the latest (e.g., the latest migrating snake river stream type stocks typically reach Bonneville dam from late May to early June). I have developed a run timing model that would allow us to look at specific dates that salmon might arrive at Revelstoke Dam, given a river entry timing range. But without going into details, I think we can broaden the timing window to include May and June dates.	Noted – reference report was reviewed and is included in the reference list. Species and timing will be reviewed as per Item #1.
12	If 2D hydraulic model results are available, I think it is worthwhile to examine how velocity changes throughout the tailrace (i.e., not just average velocity). For example, by installing Rev6, does this eliminate a velocity shadow that may currently be present on the left bank that fish would use to access the dam face? Does preferential, increased flow from REV6 result in deflection of velocities across the channel, making the downstream collection alternative nonviable?	Noted – see Item #3

Item #	Comment Received	Action Item
13	Mortality might be overestimated based on assumption of average smolt size ~200 mm. Smolts are likely to be smaller; ~90-150 mm for yearling chinook.	Edit made to current version of report.
14	At a tour of the pelton-round butte fish passage facility, a Floating surface collector was being used to trap downstream migrating smolts (sockeye and chinook), and bypass them downstream via truck, as is recommended here; however, they also had future phase plans to install a bypass tube so that passage became more passive, and did not require a truck. The round butte dam is quite high (~130m), so might a smolt bypass tube be possible if it is being attempted in other high head dams?	Noted – see Item #4