Recommendations for improving fish passage

at the Stornorrfors Power Station on the Umeälven, Umeå, Sweden

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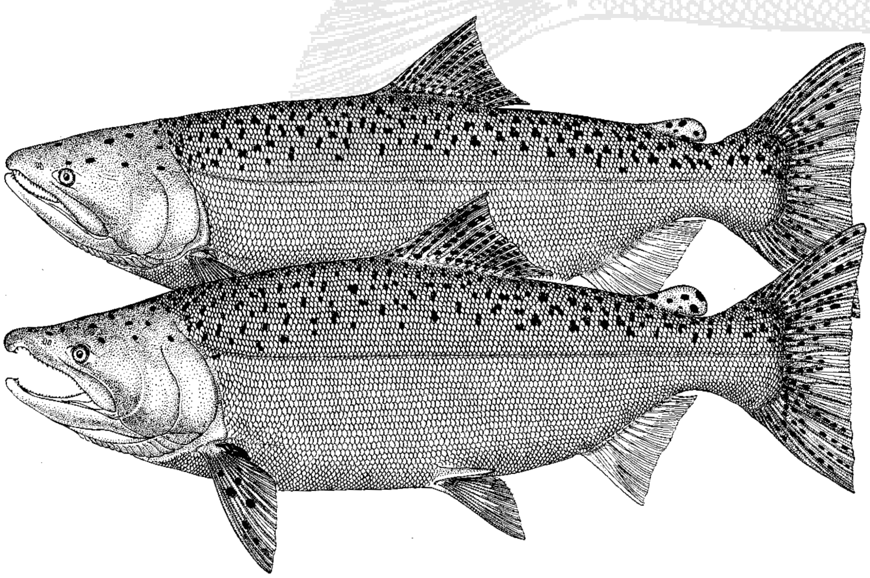

Recommendations For Improving Fish Passage at the Stornorrfors Power Station on the Umeälven
Umeå, Sweden

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BACKGROUND

Representatives from Vattenfall AB, the Vindel River Fishery Advisory Board, the Swedish University of Agricultural Sciences (SLU), and the U.S. Department of Commerce, National Marine Fisheries Service (NMFS) began a series of information exchanges in 2001. The purpose of these exchanges was to develop ways to improve passage conditions for juvenile and adult Baltic Atlantic salmon (*Salmo salar* L.) at the Stornorrfors Power Station and Norrfors Dam near Umeå, Sweden. The Swedish representatives traveled to Seattle, Washington, in May 2001 and presented information on project structures, layout, and fish passage data to fishery scientists and fish passage engineers from NMFS. The Swedish representatives toured various fish passage facilities in Washington and Oregon and observed designs and techniques implemented to solve juvenile and adult passage issues for Pacific salmon (*Oncorhynchus spp.)*.

This visit concluded with NMFS representatives providing preliminary thoughts and observations on potential solutions to the fish passage problems at the Stornorrfors Power Station and Norrfors Dam, based on information provided by the Swedish delegation. However, these powerhouse and dam structures are unique and produce complicated hydraulic conditions and channel structure, which made it difficult for NMFS representatives to provide detailed recommendations. Therefore, the Swedish delegation felt that NMFS representatives needed to tour the project in person and observe the site-specific conditions directly prior to developing final recommendations on potential solutions to fish passage problems.

NMFS representatives visited Umeå, Sweden from 19 to 23 August 2001 to view fish passage conditions on the Umeälven associated with the Stornorrfors Power Station and Norrfors Dam. The NMFS representatives were Dr. John Williams (supervisory research fishery biologist) and Mr. John Ferguson (supervisory research fishery biologist) from the Northwest Fisheries Science Center, Seattle, Washington, and Mr. Ed Meyer (fish passage engineer) from the Northwest Region, Hydropower Branch, Portland, Oregon. During this visit, discharge through the powerhouse was approximately 550 m^3/s and flow through the bypass (old river) channel was approximately 20 m^3/s. NMFS representatives observed the adult collection facility and forebay outfall pipe, spillway, adult fish ladder and entrance, and auxiliary attraction water supply system at Norrfors Dam. They also viewed the bypass channel downstream from the dam to its confluence with the turbine discharge channel, including the Laxhoppet Rapids, original powerhouse area (Klabböle Power Station), and Baggböle Rapids. Finally, NMFS representatives visited the Stornorrfors Power Station forebay, entrance tunnels, generator area, and the turbine discharge tunnel-exit site and open channel downstream to where it joins the bypass channel.

The Stornorrfors Power Station and Norrfors Dam are located on the Umeälven approximately 15 km west of the city of Umeå, Sweden. The power station was completed in 1958, has a head of 75 m, four turbine units (5.2-m runner diameter), and the capacity to discharge 1,000 m^3/s of water and produce 600 MW of power. Flow exiting the turbine draft tubes passes into a submerged tunnel that is approximately 4 km long and 11 m wide; free water surface is limited to the uppermost 1.75 km of the tunnel. The tunnel terminates downstream from the old Klabböle power station approximately 200 m upstream from a junction with the bypass channel (the old river bed), at which point the turbine discharge becomes open channel flow.

A 280-m fish ladder was constructed at the Norrfors Dam and has been in use since 1960. The ladder is a pool-weir design, with 75 weirs and 7 resting pools spaced throughout, and is located on the right bank (looking downstream) adjacent to the spillway. The ladder has a 1:10 slope and a total elevation gain of 26.5 m. Each weir has one orifice approximately 1.0 m wide by 0.82 m high. We calculate that discharge through the ladder is approximately 1.7 m^3/s. Attraction flow from the forebay of 19 m^3/s is delivered to an area below the first ladder weir via an adjacent channel. The spillway is comprised of 4 spillbays controlled by radial arm gates and has a normal discharge capacity of 3,200 m^3/s.

Existing information on migration timing, run size, migration patterns, and survival of both adult and juvenile fish through the project area is limited compared to similar sites in the United States. Montén (1985) tagged 32,000 hatchery salmon in 1967 with Carlin tags and released them at five locations throughout the project area and one near the mouth of the Umeälven to estimate survival; all turbine releases were made at full load (233 m^3/s). Results were based on adult recaptures in the salmon fishery (river, coast, and sea) through 1971. Montén estimated that mortality was 8, 19, and 25% through the turbines, discharge tunnel, and combined turbine and tunnel, respectively. Spillway mortality was estimated at 16% during 289 m^3/s spill. Mortality through the bypass channel downstream of the spillway to below the Baggböle Rapids was estimated at 23% with flow of 590 m^3/s down the channel. Overall mortality from the forebay through the spillway and bypass channel to below the Baggböle Rapids was estimated at 35%. These tests were not repeated in other years. Lundqvist et al. (1988) released ca. 41,000 Carlin-tagged smolts between 1977 and 1979. They found no difference in adult returns between fish released at the Norrfors Hatchery and those released at the lower end of the bypass channel near the Baggböle Rapids, suggesting the survival of juveniles through the bypass channel is high.

Evaluations of adult fish migrating above Norrfors Dam were conducted in 1995, 1996, 1997, 1999, and 2001. Reports covering the work in 1995 (radio-telemetry work by Carlsson, Lundqvist, and Eriksson of the County Council of Vasterbotten and SLU), 1996 (Carlin-tagged fish by Perä and Karlstrom of the Fishery Board of Sweden, Luleå), 1999 (radio-telemetry work by Rivinoja and Lundqvist of SLU), and 2001 (radio-telemetry work by Rivinoja and Lundqvist of SLU) are in Swedish. The 1997 radio-telemetry work was published in English (Rivinoja et al. 2001). A summary of the results from these studies in presented below (data from the Swedish reports, Hans Lundqvist, SLU, Pers. commun., January 2002).

	1995	1996	1997	1999	2001
Number of tagged adult fish (type of tag)	30 (radio)	574 (Carlin)	80 (radio)	60 (radio)	70 (radio)
Percentage of tagged fish passing the ladder	0	17	26	32	17
Median number of days to pass the ladder from time of tagging	52	not determined	52	44	45

These data indicate adult fish are not successfully passing the dam. For example, Rivinoja et al. (2001) tagged 55 wild and 25 hatchery salmon. Approximately 85% of the tagged fish made it to the confluence of the bypass and turbine discharge channels. However, only 26% of the wild fish and none of the hatchery fish passed the dam. The hatchery fish may not have passed because the adults may have returned to where they were released as juveniles in the pool below the ladder/hatchery. Nonetheless, the low conversion rate for wild fish was alarming and significantly influenced our approach.

Rivinoja et al. (2001) evaluated a fourth turbine added to the powerhouse in 1986 and found no apparent effect on the run timing of wild salmon migrations based on ladder counts.

The Swedish representatives also reported that radio-telemetry studies indicate adult fish tagged near the city of Umeå migrate upstream rather rapidly to the confluence of the bypass and the turbine discharge channels. However, a high percentage of the radio-tagged fish hold downstream from the bypass channel in the main river on the shore opposite from the confluence or migrate into the turbine tunnel outlet. When higher flows exist in the bypass channel as a result of increased spill many fish move into the bypass channel and hold below the Baggböle Rapids, and some fall back downstream when spill is decreased. Some fish that migrate past the Baggböle Rapids hold in the pool below the fish ladder entrance and take up to 6 days to pass the ladder. Rivinoja et al. (2001) found that more fish passed the ladder on week days than weekends, coincident with lower spill. This suggests that higher spill levels may either push fish downstream from the holding pool below the ladder or decrease the ability of fish to find the ladder entrance. Although fish consistently required nearly 2 months to pass Norrfors Dam during these studies, similar passage times were observed in the 1860s before any dams were constructed on the river (Rivinoja et al. 2001).

During the earlier tracking studies, fish exiting the adult trap at the Norrfors ladder were observed to fall back through the spillway. The exit to the ladder was subsequently modified by installing a pipe to extend the outfall release point upstream approximately 75 m. This modification has not been evaluated to determine if fallback still exists.

This report provides broad recommendations to improve fish passage in the lower reach of the Umeälven associated with the Stornorrfors Power Station and Norrfors Dam. These recommendations are based on observations during the site visit, the existing biological information, and our knowledge of fish passage facilities that successfully pass Pacific salmon, and they are provided with following caveats: We do not attempt to determine what overall impacts the man-made structures have had on the size of fish stocks, nor to determine absolute benefits that might accrue from making changes to existing conditions. Further, estimates of design and construction costs and potential impacts to power production and revenues are not provided. These will depend on many design, site, and labor and materials cost variables specific to the site and not available to NMFS.

RECOMMENDATIONS

1. Prioritize adult passage improvements over juvenile passage improvements.

Based on the biological information available, we believe improving adult upstream passage conditions has considerably more potential for increasing fish populations above the dam than does improving conditions for downstream juvenile migrants. Effective upstream passage facilities should pass >95% of the adult fish that migrate upstream to the site in a safe and rapid manner. Even if improved passage facilities pass only 90% of adult fish, that would still be an improvement of >300% in the number of fish ascending the ladder and continuing their migration to the spawning grounds in the upper reaches of the Vindelälven, when compared to the apparent 26% that now pass successfully. This increase is many times higher than the potential 25% increase in juvenile survival from the installation of a screen- or louver-system to guide juvenile fish away from turbines, into a bypass conduit, and back to the river below the Stornorrfors Power Station.

2. Construct a pumped or gravity-flow adult attraction system and ladder, with loading, and hauling facilities in the powerhouse tunnel outlet.

Short of a major re-direction of flow from the powerhouse to the bypass channel, the best option for improving adult fish passage problems at the Stornorrfors Power Station and Norrfors Dam is to construct a pumped- or gravity-flow fish attraction system between the turbine discharge tunnel outlet and the confluence of the bypass channel (Fig. 1). This system should include one or two entrances that allow fish to enter a ladder leading to holding and transportation facilities, or in the long term, to a ladder leading either back to the bypass channel upstream from the Baggböle Rapids or above the Norrfors Dam.

The high construction costs of a permanent ladder and the uncertainty associated with any new design for attracting fish in large rivers suggest that the most prudent first step is to construct the attraction flow system, entrance, and ladder leading to a holding facility. From the holding facility, fish are netted or lifted in water and transferred into a tanker truck for transportation to the selected release site. Also, the holding and transportation option is the most cost-efficient and effective means of verifying that the attraction system is designed and placed properly and that it passes a high percentage of fish over the dam. Numerous such facilities have operated successfully over long periods in the Pacific Northwestern U.S. Although initially less expensive than a complete fish ladder, a "trap and haul" system has the disadvantage of higher annual maintenance and operating costs to ensure the mechanical equipment and systems work properly during the entire fish passage season.

If a high percentage of fish are successfully attracted into the ladder, then replacement of the holding facilities and haul operation with a permanent fish ladder should be considered. Two ladder alignments or routes that may be feasible are discussed below:

1) Route a ladder to above the old Klabböle Power Station. Adding additional flow at the concrete wall at the upper end of the headrace would provide a flow net to lead fish through the headrace to the existing small ladder at the upstream end of the headrace. This small headrace channel ladder appears well constructed, but the shallow area at its entrance and immediately downstream may require deepening (Fig. 2). Exiting the ladder, fish would reenter the bypass channel above the Baggböle tunnel Rapids and continue upriver to the Norrfors Dam ladder.

2) Route the ladder to an exit point above Norrfors Dam or into the bottom of the existing adult ladder at the dam). A ladder to above the Norrfors Dam would place fish directly above the dam, although this would require higher construction costs. In either case, the existing grade line of the log chute is a potential alignment for a ladder. If the log chute grade is selected, it might be advantageous to place the ladder entrance(s) along the right bank of the powerhouse tunnel outlet.

We believe the primary cause of poor adult conversion over Norrfors Dam results from attraction of fish to the high flow-volume and water velocity in the Stornorrfors Power Station turbine outlet channel. Greater than 95% of the flow in the lower Umeälven comes from the powerhouse discharge during non-spill periods, providing attraction cues to adult fish that are greater than those provided by the flow in the bypass channel. We observed many adult salmon circling and milling in the turbine tunnel outlet. This observation and the behavior observed during recent radio telemetry studies, suggest that few fish choose to enter the bypass channel. Upstream-migrating fish in most cases seek out areas with higher velocities and flows. This is possibly an evolved behavior that provides high spawning success, since fish attracted to the highest flows and velocities tend to follow the main branches of rivers to the spawning grounds. Since the powerhouse outlet provides a natural source for adult attraction but no upstream passage options, it appears an excellent location for siting facilities to improve passage.

Successful adult attraction systems designed for Pacific salmon utilize entrance locations and attraction-flow volumes that complement the innate behaviors of adult salmon. It is difficult to attain successful passage rates when fish must move across rivers or into channels with low flow volume or velocity. Therefore, we believe the first and most important step to improving adult passage past the Norrfors Dam is to design solutions that utilize the animal's natural inclination to enter the channel with the highest flow. Our focus is on using the powerhouse discharge to attract fish to the tailrace channel and using auxiliary attraction flow placed in the powerhouse discharge channel to attract fish to a ladder entrance. We believe the combination of appropriate attraction flow volume, velocity, and placement will lead a higher percentage of fish to enter the ladder. The many adults presently entering the tunnel outlet likely represent a high percentage of the total number of adults migrating upstream.

Preliminary engineering analysis: Our preliminary engineering analysis is provided in Appendix A. Three options for the amount of attraction flow and overall sizing of the facilities are discussed. The first option is based on criteria we use for Pacific salmon to successfully attract fish into the ladder. We recommend a fish ladder entrance flow of 3% of the turbine discharge or 30 m^3/s and two 3.05-m-wide fish ladder entrances that produce an entrance jet velocity of 3.0 m/s when operated at a head differential of 0.458 m. One entrance should be located parallel to the shoreline and one angled at approximately 45 degrees into the tailrace.

While we are fairly confident that application of the criteria developed for Pacific salmon will work successfully, we also recognize that the Stornorrfors Power Station site is very unique. For example, all flow from any operating turbine exits the tunnel at one point, enters the tailrace from deep below, and discharges into a small and narrow area. These conditions, when combined with the milling and migration behavior of adult salmon, suggests to us that successful fish ladder entrance flow volumes may be less than those typically required in the Columbia River. In Appendix A we discuss the second and third options, which would produce entrance flows of one-half and one-quarter the 30 m^3/s we would typically recommend. We do not recommend one entrance volume option over another. Rather, we believe local representatives are best informed about the amount of benefit people are willing to forego in relation to facility construction costs.

3. Modify the hydraulic conditions at the bottom of the Norrfors Dam fish ladder where the auxiliary water is supplied to the ladder.

The current auxiliary water supply (AWS) design does not take enough energy out of the attraction water, and AWS overwhelms the lower end of the ladder, thus the attraction water is extremely turbulent and aerated.

Approximately 19 m^3/s flow is provided from the spillbay adjacent to the ladder for AWS via a small spill gate and separate channel adjacent to the ladder. The gate can release water either from the surface or at depth (top or bottom opening gate). Flow comes down a channel and enters an undersized stilling area where it is then fed into the lower 2 or 3 pools of the ladder. The weirs for these lower pools do not appear to contain orifices. AWS water is introduced into the ladder in the 3rd pool up from the base (entrance) of the ladder, however, it is not clear whether a floor or wall diffuser is used. Water velocity and turbulence in these lower weirs is quite high; too much flow appears to exit from the ladder (Fig. 3). This is a concern because good ladder passage occurs under conditions of little aeration and turbulence. Another concern is whether the elevation change in this lower area of the ladder (ca. 1 m) is larger than the 1:10 slope found in the rest of the ladder (and is typical of ladders that successfully pass Pacific salmon). We observed many fish in the large pool below the ladder, which may result from poor hydraulic conditions at the entrance to the ladder caused by the AWS to the lower weirs. However, it is also possible that some fish terminate their upstream migration in this pool because they are of hatchery origin and were released into the pool as juveniles.

Preliminary engineering analysis: Our preliminary engineering analysis is contained in Appendix B. We developed three potential solutions to the poor hydraulic conditions and potential delay problems in this area. Our preferred option is to completely rebuild the lower sections of the ladder. By this we mean that the location and manner in which the AWS is delivered to the lower portion of the ladder needs complete redesigning. A new system is needed to integrate diffuser location, sizing, and water volume and velocity, with the weirs and orifices to improve hydraulic and fish passage conditions in this area. This is our preferred option because completely redesigning and modifying the lower end of the ladder would address the poor hydraulic conditions in this area. However, this is potentially a costly alternative.

Therefore, our recommended option is to reduce AWS flow into the ladder and divert excess discharge to the spillway and to maintain bypass channel flow. This is relatively easy to test by reducing AWS flow and evaluating fish passage using radio-telemetry. We initially recommend reducing AWS flow into the ladder to approximately 4.25 m^3/s. This will require a reconfiguration of the weirs in the lower pools such that flow over the top of each weir is maintained at 0.305-0.458 m. The fish ladder entrance should also be deeper than wide, so that fish are not forced to leap into the ladder. Also, water diverted to the spillway should not create false attraction to migrating adults. The width of the spillway is potentially sufficient to create a relatively shallow, low-velocity flow that would not attract adults into the spillway area. Alternately, the diverted flow could be re-introduced adjacent to the fish ladder in such a manner as to attract adults to the fishway entrance without creating a false attraction away from the ladder. This could perhaps be accomplished by creating a velocity barrier dam across the entrance to the spillway, or a sheet flow across the spillway mouth with a 0.61- to 0.91-m drop, creating shallow conditions that fish could not leap. There are a number of other possibilities to achieve this condition, and local experts who understand the site, water sources, hydraulics, and fish passage are best qualified to come up with a final configurations to achieve the proper attraction flow if this option is implemented.

A third option is to extend the ladder downstream and align AWS flow adjacent to the ladder extension. This option would eliminate the lower open weirs and extend the existing ladder downstream along the rock wall on the right bank. This would move the ladder entrance downstream into the pool area, and would utilize the adjacent AWS attraction flow. This design is commonly used at spillway entrances at Columbia River dams where large volumes of spill are adjacent and parallel to the flow coming from the ladder entrance. However, since AWS flow is roughly 10 times ladder flow, hydraulic conditions would need to be evaluated and the facility carefully designed so that the AWS flow parallel to the rock wall does not hit, overpower, or occlude the ladder entrance. Currently, the small rock shelf along the right bank downstream of the ladder entrance may obscure the attraction jet into the ladder and require fish following the jet to swim up and over a shallow shelf (Fig 4). Conditions in this area under flood spill might require additional or alternative entrances to the fish ladder. Also, false attraction into the AWS would have to be considered and addressed through use of a diffuser or velocity barrier. Therefore, while potentially feasible, this option would require careful hydraulic design and possibly hydraulic modeling.

4. Reduce flow in the Norrfors Dam fish ladder.

While viewing the ladder from the top of the spillway, we noticed that hydraulic conditions in the pools were turbulent which indicated that flow volume down the ladder is too high (pools appear too small for the amount of flow).

Peter Rivinoja commented that some fish lost their radio tags in the ladder and that tagged fish took 2 to 4 days to successfully pass the ladder. The observations of high turbulence, combined with tag loss in the ladder, initially indicated to us that fish are struggling to get through the ladder and supported our observation that excess flow down the ladder is leading to turbulent conditions in each weir pool. However, later in the tour we were informed that the radio tags were attached externally to the fish, which was perhaps the cause of the tag loss. This non-hydraulic explanation for possible tag loss, combined with the apparent strong swimming capabilities of Atlantic salmon, suggests they can handle the existing hydraulic conditions in the ladder. However, based on our experience with Pacific salmon, we believe that with a total head of 26 m fish should take 12 hours or less to migrate up this kind of pool/weir ladder. Unless there is a problem with the hydraulic conditions, a blockage in the ladder, or a behavioral or physiological cause of delay, they should readily pass through the ladder. One potential problem with ladder passage times may relate to operation of the collection facility, discussed below under Additional Passage Concerns.

Preliminary engineering analysis: Our preliminary engineering analysis is contained in Appendix B; three potential solutions to the poor hydraulic conditions and delay problems in the ladder pools are presented. We recommend reducing ladder flow to approximately 1.34 m^3/s to meet the maximum energy dissipation criteria of 19.5 m-kg/s/m^3 (4 ft-lbs/s/ft^3). The depth of flow over each weir should be maintained at 0.305 m and the width of the submerged orifice should be reduced from 1.01 m to approximately 0.76 m.

5. Develop an integrated adult fish passage system and evaluate increased flow in the bypass channel.

We recommend, above, that solutions to the existing ladder and false attraction into the powerhouse discharge are needed. We believe the majority of fish migrating upstream are entering the powerhouse tunnel outlet, especially during non-spill periods. However, there are a number of reasons to not lose sight of the need to address the level of flow in the bypass channel. For example, fish will likely continue to enter the bypass channel, particularly during periods of spill. Also, there are existing problems with passage through the bypass channel at current flow levels, discussed below under Additional Passage Concerns. Further, adult hatchery fish may choose to enter the bypass channel due to olfactory cues from the hatchery. Also, if the attraction and collection entrance recommended for the turbine tunnel outlet does not perform as expected, establishing a constant flow through the bypass channel that provides good attraction and passage conditions is even more important.

Therefore, flow volume in the bypass channel should be reevaluated and possibly increased above the existing 20 m^3/s to attract fish. Such an increase may also improve passage conditions through the channel, so that fish can move effectively through the channel, rapids, and existing ladder. Experimentation and biological evaluations will be required to determine the best flows for effective fish passage.

We recommend that regardless of which passage improvements are selected for implementation, the elements be viewed as a system, not as separate components. For example, if the Norrfors Dam ladder is redesigned and performs well at the current bypass channel flow of 20 m^3/s, the ladder entrance may be impacted under higher bypass channel flows unless redesigned for these higher flows. Also, if a gravity-flow source above the old powerhouse is used for attraction flow to the powerhouse collection facility, spillway discharge will have to be increased to maintain 20 m^3/s flow down the bypass channel. In summary, the selected passage systems and flows should work together and be complementary.

6. Conduct additional research on fine-scale fish behaviors.

The behavior of fish under present conditions should be better understood before designing means to improve fish passage. For example, radio-telemetry studies of fine-scaled fish behavior in the powerhouse tunnel outlet would greatly improve knowledge of movement patterns in this area. Installation of additional underwater antennae in the turbine discharge and bypass channels would help determine where to locate entrance(s) to the fish ladder and holding facility. Antennae placed in the first weir of the Norrfors Dam ladder would provide data to determine if apparent delays in the high ladder passage are occurring in the lower weirs or in the ladder itself. This would assist in deciding whether to rebuild the entrance, the ladder weirs themselves, or both to reduce passage times to reasonable levels. Although estimating median passage time provides a good measure of overall ladder effectiveness, it is also important to look at the range of passage times, since some fish may hold for extraordinarily long periods. Reports of passage time for the 10th, 50th, and 90th percentiles for both adults and grisle under existing flow conditions may provide indications of a relationship between size of fish and passage time. If passage time is long, re-test after reducing flows in the ladder and over each weir, or set up a blocked study design of existing and reduced flow volumes, using the 10th, 50th, and 90th percentiles of time-to-pass as measures for comparison.

We suggest doubling, and preferably tripling the present plans to tag 70 adult fish for radio tracking in 2002. Given the low rates of conversion upstream, this would provide a much better sample size of fish in the area below and through the fish ladder. Furthermore, we recommend using gastric/esophageal tag implantation to reduce the potential for tag and data loss. We do not know what impact the external tagging had on results obtained to date, but we note that Rivinoja et al. (2001) found that 8 of the12 wild fish that successfully passed the ladder had lost their external tags.

We also recommend that any modification in flow regimes and facilities be evaluated for 2-3 years to evaluate performance. A number of evaluation techniques are available. In this case, we recommend use of radio telemetry and ladder counts to compare the migration timing of fish passing into the new ladder and holding facility to historic records of abundance and timing.

ADDITIONAL PASSAGE CONCERNS

During our visit a number of other areas of potential concern were noted. Here we identify and discuss these areas because solutions to these areas would likely provide additional, incremental benefits to migration passage success and adult escapement.

1. Fish ladder collection facility

The upper-most pool of the ladder is used as a holding pool where fish are collected. The floor of the pool has a sloped braille that is raised to crowd fish to the downstream end to facilitate netting (Fig. 5). According to Vattenfall AB personnel, the pool may contain as many as 300-400 fish (mostly grilse) at one time. Fish are hand-netted, weighed, and sorted. Wild fish are released from the collection facility into a pipe that outfalls approximately 75 m upstream where the adults can resume their migration. Hatchery fish are placed in a tank trailer for transportation to the Norrfors salmon breeding station. Fish in the collection facility are handled without anesthetic.

We did not observe any provisions for allowing fish to go straight through the collection facility system and into the lake upstream. The collection facility is rudimentary in that all fish are stopped by the collection facility, the fish are handled without anesthesia or water-to-water transfer, and high numbers can enter the trap at one time (Fig. 6). We are concerned that all fish are crowded, netted, and measured in air and without anesthesia. Effects of these procedures on successful migration to the spawning grounds and pre-spawning mortality are unknown. If the facility and collection process is meeting the needs of the fishery managers we would not place a high priority at this time on reconstructing the collection facility. However, if not and if funding were available in the future, we recommend considering redesigning the collection facility and installing an adult handling and sorting facility for hands-off sorting of hatchery and wild fish, and if needed, anesthetization for handling. Examples would include the facility on the Cowlitz River, Washington that we toured in May 2001, or on a smaller scale, the adult facility at 3-Mile Dam at Umatilla River, a tributary to the Columbia River near Umatilla, Oregon. If handling is required, we recommend the installation and use of anesthetic (MS 222 or clove oil) and recovery tanks to minimize stress and injury during collection and sorting. A note of caution: at Columbia River dams we have observed that any human odor in collection facilities can cause fish to delay. For example, a worker's hand in the ladder for a few minutes can stop adult migrations in the ladder for hours. Thus, the netting procedure may cause delay if human odor is passed into the ladder water from the netting and handling procedures.

Additional Information Needed: None at this time. However, if a permanent ladder is installed from the powerhouse tunnel tailrace to the top of the spillway dam, a new adult collection and handling facility could be considered at that time.

2. Potential fallback from the Norrfors Dam fish ladder collection facility outfall pipe

Fish selected from the collection facility to continue upstream are returned to the forebay via a 0.3 m gravity pipeline with flushing flow. The pipe outfall is located near a point along the right bank of the spillway inlet that divides the main flow to the powerhouse from the flow to the spillway. The outfall is located about 75 m upstream from the ladder exit (Fig. 7). The drop from the end of the pipe to the lake surface is not significant (25 to 50 cm). Based on surface water currents, it appears an eddy exists off the point of land that sweeps by the end of the outfall along the shore. This should give positive guidance to fish moving upstream from the outfall pipe. However, fish moving upstream after exiting the outfall pipe may follow the shoreline of the island and turn back downstream and follow the bulk flow toward the powerhouse. Since the powerhouse is a significant distance downstream, these fish may search the forebay and reorient to currents and resume upstream migration. When spilling, water velocity and direction past the pipe outlet should provide a positive flow net for upstream guidance, however, we did not observe the outfall conditions during spill. The primary issue regarding the pipeline outfall location is the potential for fallback over the spillway during periods of spill.

If radio-telemetry studies identify fallback through the powerhouse or spillway as a problem during spill periods, one solution might involve hauling adults trapped at the collection facility during periods of spill to a point upstream on the left bank (looking downstream) above the spillway inlet. When standing at the outfall pipe, we viewed a point of land along the main arm of the lake apparently accessible from the Road E79 that might make a good release point. Currents at this location appeared strong and positive, such that fish could orient to the left bank and proceed upstream through the impoundment to the free-flowing Vindelälven. We do not consider physically extending the ladder or running a pipe to the left bank upstream from (and across) the spillway as a viable option, due to high construction costs and limited available head.

Additional Information Needed: An evaluation of the behavior of adults exiting the existing outfall with and without spill is needed. Radio tags can be used to document whether fallback through the powerhouse or spillway is occurring, and if so, under what operational conditions. The evaluation should require small numbers of test fish because fallback will occur immediately if there is a problem. A range of river flows and spillway operations should be tested to determine whether fallback behavior is continuous or episodic. Interpreting acceptable rates of fallback is difficult. On the Columbia River we consider >5-10% fallback unacceptable, although we often see levels higher than this. The relationship between fallback and subsequent survival and pre-spawning mortality has not been rigorously defined in our region. If fallback only occurs during short periods of high spill, no action may be warranted.

3. Spillway survival

The spillway channel is rough, unfinished, and comprised of solid rock. There is no stilling basin or downstream pool for dissipating spillway jet energy. The spillway stilling basin is old river bed rock and concrete, and this may account for much of the juvenile mortality measured through the spillway by Montén (1985). The rough surface will produce high turbulence and increase the probability that juveniles will strike the substrate, causing injury and mortality. The nearest place with sufficient water depth for energy dissipation is downstream near the entrance to the fish ladder (Fig. 8). We did not observe spill during our site visit.

We do not recommend the spillway as a preferred route of passage for juveniles or adults because of the rough channel substrate immediately below the spillway, lack of energy dissipation pools or structures, and the potential for fish injury through these shallow and turbulent areas. High-energy jets meeting channel roughness will cause turbulence and increase the probability of fish striking substrate and injury. We are not aware of any adult spillway survival data. However, our concern is supported by juvenile survival data collected by Montén (1985), who reported ca. 16% smolt loss through the spillway (from the forebay to the base of the ladder).

This is extremely high mortality on juvenile fish for a spillway. For example, Muir et al. (2001) found that estimated relative survival at Columbia River dams was highest through spill bays without flow deflectors (98.4-100%), followed by spill bays with flow deflectors (92.7-100%), juvenile bypass systems (95.3-99.4%) and (Kaplan) turbines (86.5-93.4%). This concern is also supported by R2 Resource Consultants, Inc. (1998). They found that fish injury and mortality in spillway stilling basins is related to high pressure changes and shear zones in the margins of the jet, deceleration forces, and fish impact with solid objects or substrate in the stilling basin.

If significant numbers of juvenile or adult fish use the spillway as a route of passage, decreasing mortality would likely require lining the spillway channel with concrete and removing major protrusions from the pathway of the discharge. Another possible solution would involve construction of a weir or barrier dam at the downstream end of the channel to form a spillway tailrace-stilling basin. This would require hydraulic model studies to design weir or barrier placements that optimize hydraulic conditions in the basin under varying flows. Construction costs for this solution are likely very high.

While little is known about smolt outmigration timing, we presume that since most river flow passes through the powerhouse, most juveniles also pass through the powerhouse. However, juveniles will pass via the spillway during the flood events in June and July from forest and mountain snowmelt when river flows exceed powerhouse hydraulic capacity and involuntary spill occurs. Hypothetically, if juvenile mortality through the spillway was eliminated, then based on Montén's data, juvenile salmon survival through the spillway would increase from 84 to 100%. However, increases in survival for the overall juvenile population would not increase proportionately, as many juveniles likely pass through the powerhouse turbines.

4. Area below the ladder - Laxhoppet Overlook

This area of natural falls and chutes has been modified many times over the years to improve passage in the bypass reach under conditions of reduced flow. Strategically placed weirs channel the flow to create two or possibly three passage routes (Fig. 9). Further modifications to this area are best left to local passage experts who are familiar with the hydraulic conditions in the area and can observe fish behavior over long periods of time under various flow conditions.

Additional Information Needed: Visual observations of passage behavior under a variety of flow conditions are needed. Documentation of delay in the area using radio telemetry may also be advisable.

5. Bypass channel and powerhouse discharge channel junction area

During our visit total powerhouse flow was approximately 550 m^3/s while flow in the bypass channel was 20 m^3/s. The tailrace exit from the powerhouse channel is relatively narrow, and water velocity and volume in the exit are high compared to the mouth of the bypass channel (Fig. 10). Thus, it is not surprising that the majority of adult salmon are not choosing the bypass channel.

A weir placed across nearly the entire mouth of the bypass channel could potentially shape existing bypass channel flows and increase velocities, which might improve fish attraction into the bypass channel. However, this solution would likely also require construction and maintenance of a channel upstream from the weir to transport fish through the slack water to the base of the Baggböle Rapids. Unless the river channel above the weir and below the Baggböle Rapids is reconfigured, we believe low velocities upstream from the weir would affect fish movement. Fish moving from areas of high to low velocity, would sense this and move back downstream over the weir and into the main river/tailrace channel. Thus, even if a transportation channel was constructed above the weir, passage problems associated with the Baggböle Rapids would still exist. Furthermore, maintaining the channel might prove difficult and costly given the size and amount of material required to preserve a channel configuration in a river this size. A channel placed on one bank would soon fill in with substrate material, and the river would develop another channel. In addition, most fish appear to move along the right bank (looking downstream) of the main river, based on radio telemetry data.

As discussed above in Recommendation 5, one solution involves providing higher base flows through the bypass channel. The actual level of flow needed for good attraction into the bypass channel is unknown. However, it may take a substantial increase in bypass channel flow to provide attraction velocities and volumes that compete with those in the powerhouse tailrace channel. Such an increase in flow would also increase velocity in the area between the weir and the Baggböle Rapids.

In summary, after looking at the confluence between the bypass and powerhouse discharge channel and in contrast to what we recommended when the Swedish delegation visited Seattle, we believe it would be nearly impossible to design a weir across the mouth of the bypass channel to successfully attract fish into the channel under the existing conditions of 20 m^3/s flow.

6. Passage through the Baggböle Rapids

The rapids are located in the bypass channel approximately 1 km upstream from the confluence with the powerhouse tailrace channel. Based on radio-telemetry studies, the rapids may hinder fish passage at low (20 m^3/s bypass flow) and high (>200 m^3/s) flows. We discussed the possibility that passage may be optimal at 150 m^3/s. However, it is not apparent what level of flow through the bypass channel is needed to provide the best passage times and conditions. The rapids have been modified to improve passage by forming channels into stepped (ladder-like) channels to help move fish upstream past the many chutes and shallow areas. Delay or obstruction to fish passage through the Baggböle Rapids under conditions of 20 m^3/s flow through the bypass channel is likely a result of shallow, high velocity sheet flow through the lower part of the rapids. This type of flow creates adverse conditions for adult passage (Fig. 11). Under higher flows, these sheet-flow areas are likely mitigated because numerous side channels will reform, creating more passage routes and opportunities, thus improving fish passage.

We recommend that efforts to remove iron bars from the substrate/rock of the rapids continue. This will eliminate possible sources of fish injury. The Baggböle Rapids is a complicated site because of high variation in passage conditions at the rapids. Since we observed hydraulic conditions in the rapids under one flow only, we cannot make recommendations on the best flows or an optimal configuration of the area for fish passage. We suggest that further modifications to the rapids are best left to local experts. However, we offer two possibilities: 1) blast the substrate of the rapids, and terrace the lower section to decrease water velocities and create pools for velocity refuges, resting, and depth for jumping; or 2) increase base flows through the bypass channel (Fig 12).

Additional Information Needed: We fully understand the difficulty of determining the appropriate level of bypass channel flow, both from the standpoint of flow availability and determining the best level of flow for improved fish passage. We have no suggestions or perspectives *a priori* as to appropriate levels. This would require visual observations of passage conditions and radio-telemetry data on behavior and passage success through the rapids under various flow regimes. The use of video to document areas of interest at various flow levels might provide valuable observations on fish passage conditions. Outside passage experts unable to observe the site in person could view the tapes and communicate their observations on which flow levels look best for passage through the bypass channel and rapids.

7. Passage at the old powerhouse

We observed a number of possible bypass routes around the Baggböle Rapids that utilized small channels near the old powerhouse. The number, shape, and flow volumes in these channels varies with bypass channel flow. On the day we observed the area, flow of 20 m^3/sec provided a number of routes, chutes, and stepped jumps between rock formations, boulders, and areas of soil and trees (Fig. 13). These generally led to a notch in the wall of the headrace channel to (and upstream from) the old powerhouse (Fig.14). Once in the headrace channel to the old powerhouse, fish can migrate upstream and re-enter the old bypass channel above the Baggböle Rapids by using the small ladder in the concrete wall (Fig. 2). At the flow level we observed, it appeared that passage through this route was feasible. With some minor modifications to a few of the narrow chutes, these small channels would offer alternative routes around the Baggböle Rapids.

Increased flows through the bypass channel may improve conditions in this area as well, because flow volume and depth through the various chutes would increase. This could reduce the need for channel modifications at key points to eliminate blockages. However, we did not observe the channel under higher flow conditions and can only speculate as to these benefits. This site is highly complex due to the interactions between flow and the chutes and rock formations. We suggest that further modifications of this area are best left to local experts.

Additional Information Needed: Visual and radio-telemetry observations through the channel under various flow regimes are needed.

8. Juvenile salmon passage through the Stornorrfors Power Station

The headrace into the Stornorrfors Power Station is an open channel until the last approximately 75 m, where it becomes a horizontal tunnel blasted through rock. At the end of the channel, a tainter gate controls flow into each vertical-axis Francis turbine. The turbine intakes are approximately 7-8 m wide by 17 m deep, and velocity through the intakes is approximately 2-3 m/s. A total of four turbine units are located in the powerhouse, 3 with a discharge capacity of 220 m^3/s and 1 with a capacity of 340 m^3/s. Total powerhouse capacity is 1000 m^3/s.

From an engineering standpoint, two types of bypass systems to intercept juveniles prior to their entering the turbines are potentially feasible:

1) a vertical louver screening system in the open headrace channel upstream from the rock tunnels that lead to each turbine intake (Fig. 15).
2) individual screening systems placed in the rock tunnels upstream from the tainter gates for each turbine unit, such as an Eicher screen (inclined, 100% floor screen), or possibly an angled louver screen (partial, behavioral screen).

Either system will require a means to divert fish out of the powerhouse and back to the bypass channel. This may require routing diverted fish and flow through the tainter gate and bulkhead wall. Also, cleaning the screen system is a concern; Eicher screens tilt and are self cleaning, but a louver screen would require some means to keep debris from building up on the vanes or members. Additionally, ice will be a problem for any screens located in the forebay. A system for screen removal and storage or a means to handle the ice will be needed and should be addressed during the design process.

We generally consider that a juvenile collection/bypass system is successful if it intercepts >95% of the downstream migrants before they reach the turbine. Systems that rely on the behavioral response of fish are not 100% effective, and similarly, we would not expect a behavioral guidance device, such as a vertical louver, to meet this criterion. However, it is likely that an inclined screen system would be more effective in terms of guidance, because 100% of the intake area is screened. A successful guidance system should also cause little delay or injury, and should provide nearly 100% survival of fish routed to the tailrace. Thus, a successful juvenile bypass system installed at the Stornorrfors Power Station should increase juvenile survival to nearly 100% from the current survival of approximately 75% (Montén 1985). If this translates directly to adult returns and if there are no increases to survival at other life-history stages, then a 25% increase in adult returns would occur.

On the Columbia River turbines are operated within 1% of peak unit efficiency. There is some data suggesting that juvenile salmonid survival is highest within this range. However, the relationship has not been rigorously documented, and this information pertains to Kaplan turbines. We are not aware of any similar information for Francis turbines; however, a small improvement in juvenile survival may be achieved by running turbines at peak efficiency during the juvenile fish passage season.

In summary, it appears feasible to install a screen guidance system in each turbine intake, although a route to divert fish safely to the bypass channel must be planned carefully. Placement of a screen or louver guidance system in the forebay intake canal might provide a feasible alternative to an intake screen. However, such a system would require means to remove and store the system prior to winter and the ability to handle debris during the operating season.

9. Downstream passage of kelts

We did not observe kelts migrating downstream. If the Vindelälven produces significant kelts, potentially the subsequent return of large, fecund females will play an important role in rebuilding the overall population. If so, consideration of measures to ensure kelt survival is important.

The probability of striking a turbine runner is a function of fish length, the number of turbine blades or runners, the volume of flow passing the turbine, and the turbine shaft rotation speed. Estimates of adult Pacific salmon survival through Kaplan turbines are limited, but suggest mortality as high as 40%. The Stornorrfors Power Station has Francis turbines, and we would expect higher mortality through Francis than Kaplan turbines. Installation of a screen bypass system for juveniles would also provide a means to divert kelts away from turbines and route them safely back to the bypass channel.

The spillway is the other possible route of passage for kelts. Our concerns with kelt passage through the existing spillway are similar to the concerns we outlined for smolts and adults passing through this route.

CONCLUSIONS

Based on observations during our site visit and the existing biological information, we believe that improving adult upstream passage conditions has considerably more potential for increasing fish populations in the river upstream from the dam than improving conditions for downstream juvenile migrants. Effective upstream passage facilities should easily produce passage rates of 95%. Even if a new adult passage facility produced only 90% passage of adult fish, it would still provide a >300% increase in fish spawning in the upper reaches of the Vindelälven, compared to only 26% that apparently spawn there now. This increase would be many times higher than the maximum 25% increase that is possible by increasing juvenile survival.

We recommend construction of an adult collection facility in the powerhouse discharge channel. We believe such a facility has the potential to attract and pass a large percentage of adult fish moving up the lower Umeälven. This facility would include a pumped or gravity-attraction flow source; entrance(s); a ladder; and initially, an adult holding facility. In the short-term, we recommend transporting collected fish by truck to a site above Norrfors Dam, or to a site just above the old Klabböle Power Station. In the long-term, construction of a fish ladder would provide a more effective permanent solution.

Efforts to improve passage at the present fish ladder are also needed. Hydraulic conditions in the ladder and at the ladder entrance need modification to reduce air entrainment and turbulence, which may contribute to passage delay. We also suggest a review of the amount of flow provided for the bypass channel. A constant flow level that provides good attraction flow into and passage through the channel during periods of no spill might improve adult passage to above the dam. Increasing bypass channel flow above current levels may entice more fish to move upstream via this route and successfully pass the Norrfors Dam via the ladder. However, this would require evaluation of potential modifications to the ladder entrance, to the Baggböle Rapids, to the Laxhoppet area, and to the channels around the old powerhouse so that adult passage through these areas will be rapid and safe under the higher flow regime.

We stress the need to view the individual improvements as components of an integrated system, and the need for additional research prior to and after construction to finalize engineering designs and to evaluate the effectiveness of completed facilities and operations.

A number of additional concerns with adult and juvenile salmon passage past the project may merit future consideration for further improvement to fish passage. These include the adult collection facility at the top of the ladder, location of the collection facility outfall pipe, potential for injury to adults and juveniles passing through the spillway, potential for adult delay through the Laxhoppet area and Baggböle Rapids, development of the braided channels around the old powerhouse as a potential alternative route for adult passage at the Baggböle Rapids, and juvenile and kelt mortality through the existing powerhouse. Improvements in these areas should provide protection and increased adult escapement over the Norrfors Dam to augment the recommendations listed above. Alternatively, they may provide improved protection for adult and juvenile salmon migrating past the project if the recommendations listed above do not perform as expected.

ACKNOWLEDGMENTS

We thank Hans Lundqvist of the Swedish University of Agricultural Sciences for his special efforts to provide answers to our many questions and requests for additional fish passage information. We especially wish to thank members of the Vindel Fishery Advisory Board for this opportunity to review fish passage conditions at the Stornorrfors Power Station and Norrfors Dam. It has been a tremendously challenging and rewarding experience for us to develop these observations and recommendations and we sincerely hope they are helpful.

REFERENCES

Lundqvist, H., W.C. Clarke, and H. Johansson. 1988. The influence of precocious sexual maturation on survival to adulthood of river stocked Baltic salmon (*Salmo salar*) smolts. Holarctic Ecology 11:60-69.

Montén, Erik. 1985. Fish and turbines; fish injuries during passage through power station turbines. 111 p. (available from Vattenfall AB, Stockholm, Sweden).

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River dams. North American Journal of Fisheries Management 21: 135-146.

Rivinoja, P., S. McKinnell, and H. Lundqvist. 2001. Hindrances to upstream migration of Atlantic salmon (*Salmo salar*) in a northern Swedish River caused by a hydroelectric power-station. Regul. Rivers: Res. Mgmt. 17: 101-115.

R 2 Resource Consultants, Inc. 1998. Annotated bibliography of literature regarding mechanical injury with emphasis on effects from spillways and stilling basins. Contract DACW57-96-D-0007, Task Order No. 03. Report to Portland District, U. S. Army Corps of Engineers. (Available from U. S. Army Corps of Engineers, P.O. Box 2946, Portland, OR. USA. 97208)

Appendix A: Preliminary Engineering Analysis for Adult Salmon Attraction, Holding, and Transportation Facilities at the Powerhouse Tunnel Outlet

General:

These analyses are based on criteria we use for adult Pacific salmon. We have recommended a general design based on the approach we take when reviewing passage facilities. We present preliminary calculations of facility sizes and capacities we believe are needed to meet the fish passage goals, but recognize the need to address site specific issues during the design process. We stress the need to work closely with a fish passage engineer during the actual design process, especially one familiar with the local site and Atlantic salmon.

We recommend locating the entrance to the ladder on either shore of the tailrace and adjacent to, or slightly upstream of the discharge boil from the turbine tunnel outlet. For example, the Swedish team will remember how close the fishway entrances were to the powerhouses at Bonneville Dam on the Columbia River. Locating the entrances on either shore appears possible, and the selected location will depend on construction constraints and detailed information gathered on fish behavior from radio-telemetry studies. This would include whether one bank is preferred by the fish for their first approach and their milling behavior.

Space to place the pump facilities, entrance(s), ladder, and holding and loading facilities is a constraint due to the narrow, steep-banked tailrace channel. We see two possible options:

1) Center the holding pools, transport hopper, transport loading facilities, and auxiliary water pumps in the area directly above the tunnel discharge. If this is structurally feasible, it would allow for a relatively short ladder and a transport channel with long pools to move fish into the holding facility (similar to the North Fork Project on the Clackamas River, Oregon that we toured). Installation of either a gantry crane, tram, or cable-way are possible means to lift fish from a transport hopper to the truck loading facility at the top of the embankment. Although this option is likely more cost effective, it does not allow for easy conversion to a full-length ladder if that alternative is desired in the future.

2) Locate the facilities on top of the embankment above the tailrace. This will require construction of a ladder from the fishway entrance pool up the steep bank at a 10% slope to the holding, sorting, and truck/trailer loading facilities located on level ground. This option would require locating the auxiliary water pump station along the tailrace but away from the ladder entrance so that the pumps do not disturb fish entering the ladder. Based upon the drawings received, this would require a ladder that rises approximately 15.2 m. If built in one direction, it would extend for nearly 152.4 m. A possible option is to build a circular ladder that rises nearly vertically from the tailrace to the top of the embankment.

Run Timing, Run Size, and Average Fish Weight:

Sizing adult facilities requires information on average adult weight, the maximum number of fish expected to pass the ladder in one day, maximum facility holding capacity, and the escapement trend projected over the design period of the project. Since we do not know these specific details or sources for this information, Hans Lundqvist (Hans Lundqvist, SLU, Pers. commun., February 2002) provided information we used to develop the following design guidelines:

Maximum individual fish passing per day: 1,250

Average fish weight at peak passage times: 3 kg (large grilse component)

Maximum total fish biomass on peak day of passage: 3,750 kg

Maximum peak passage timing: late-July to mid-August

River Criteria:

River surface elevation: 0.5 m mean sea level at 600 m^3/s discharge
Elevation of the area surrounding the turbine tunnel outlet: 15 m mean sea level
Powerhouse discharge capacity: 1,000 m^3/s

Fishway Entrance Flow:

The fishway entrance (attraction) flow has to compete with the powerhouse discharge. The amount of flow required for successful attraction depends on site conditions and competition from the powerhouse discharge, and may require more entrance flow when conditions are less than ideal or there is competition from other flow sources. For example, at the Bonneville Dam Second Powerhouse on the Columbia River, the four main fishway entrances each discharge approximately 28.32 m^3/s to compete with a maximum powerhouse discharge of approximately 3,982 m^3/s or about 3 % of the powerhouse flow. When designing fish attraction systems for Pacific salmon, we recommend a fishway entrance flow of 3 to 5% of powerhouse discharge, and even higher flows are preferred (5 to 10%). Our criteria are designed to provide attraction to entrances that will cause minimal delay at a dam for adult migrants (preferably less than 24 h). For this project where maximum powerhouse discharge is 1,000 m^3/s, this criteria equates to 30 to 50 m^3/s attraction flow. Based on these criteria, it will require flows of at least 30 m^3/s for the fishway entrances and auxiliary water system.

The criteria of 3 to 5% minimum attraction flow is designed for situations where the attraction flow has to compete with a large volume of powerhouse discharge spread across a wide area. For example, at the Bonneville Dam Second Powerhouse discussed above, fish ladder attraction flow competes with discharge from 8 turbine units spread across 275 m of tailrace. However, the Stornorrfors Power Station tunnel outlet is uniquely configured compared to most power station outlets. All discharge from the 4 turbines exits a common point located deep in the tailrace, the channel is narrow and "U" shaped, no side-channels enter the area, and the majority of adult fish enter this area. These unique site conditions, when combined with the surface-oriented behavior and strong swimming capability of adult Atlantic salmon, suggest the feasibility of other designs that would require less attraction flow, if the facility is designed properly. Volume, location, and velocity are all important criteria in a properly designed and successful attraction system. We offer two possible alternatives to the facility:

1) A pump system to provide 15 m^3/s flow, and operation of one attraction entrance at full opening; or

2) A pump system to provide 7.5 m^3/s flow, and operation of one attraction entrance at a partial opening.

While there is uncertainty with these lower volumes because they are outside our normal criteria, we believe they have a high likelihood of success at considerably reduced construction costs. We believe the final decision is best left to local fish passage, power, and fishery board representatives who are better qualified than we to make judgements and trade-offs between cost, risk, and how much passage delay associated with location and size of fishway entrances is acceptable.

The volumes and dimensions for the full-flow option are provided below.

Auxiliary Water: 29.45 m^3/s assumes ladder flow is 0.57 m^3/s

Pumps:

a) For ladder flow - one primary and one backup pump capable of providing 0.57 m^3/s flow to the top of the ladder.

b) For attraction flow- a number of large pumps capable of providing 29.45 m^3/s flow for the auxiliary water supply (AWS) system.

The pumps will require an intake structure and fine trashrack (a clear opening of ca. 1.27 cm). Locate them away from the fishway entrance so the pumps do not disturb fish entering the ladder. The fine trashrack is recommended to protect the pumps but also to reduce the amount of trash entrained on the AWS diffuser panels, increasing the difficulty and cost of maintenance.

Note: Water from upstream of the old powerhouse could possibly feed the AWS, ladder and holding facility if a gravity delivery system is used. However, it is important to ensure that water quality from this area matches that of the tailrace so fish do not reject the new ladder. Also, this would reduce the amount of flow down the bypass channel, unless a volume equal to the attraction flow was spilled.

Entrance Pool:

Entrance gate(s): We recommend use of two, 3.05 m wide downward opening gates (telescoping weir gates). One gate should discharge parallel to shore facing downstream and the second should angle approximately 45 degrees downstream (so that fishway attraction flow carries across the channel). The gates are sized to carry the full AWS flow during the operation of a single gate or half the AWS flow if both gates are operated. Gate size and submergence will determine the depth of the entrance pool. When only one entrance is in use, we recommend use of the entrance angled at 45 degrees.

Table 1. Calculated submergence below tailwater for a 3.05 m wide gate based upon head differential.

Head differential Δd	Entrance velocity $V^2=\Delta d/2g$	Submergence below tailwater	
		Both gates open	One gate open
		$Q = 14.9\ m^3/s$ per gate	$Q = 29.7\ m^3/s$ per gate
0.305 m	2.44 m/s	2.62 m	4.58 m
0.458 m	3.00 m/s	2.26 m	3.88 m
0.610 m	3.46 m/s	1.99 m	3.36 m

Note: This assumes a 0.61 m high sill at the bottom of the gate. Submergence is measured from tailrace water surface level to gate crest. Head differential is defined as the water surface differential from the entrance pool to the tailrace. We suggest providing a minimum of 0.305 m of head, but 0.458 m head is preferred.

Gate discharge calculations are based upon:

$$Q=W*D*C*(2*g*\Delta d)^{1/2}$$

Where
- Q = gate discharge (m^3/s)
- W= gate width (m)
- D= Gate submergence below tailwater (m)
- C= Discharge coefficient (≈0.72 to 0.86) (depends on submergence and crest elevation above the floor)
- g = acceleration due to gravity (9.8 m/s^2)
- Δd = difference in water surface elevation between entrance pool and tailrace (m)

If the system is operated at one-quarter capacity initially, we recommend operating only one gate because operating two 3.05 m gates would create a relatively wide but shallow entrance. Under this operation, we recommend modifying the top leaves of the telescoping weir gates to create a narrower entrance. An entrance gate narrowed to 1.83 m creates a gate submergence of approximately 1.89 m at 0.46 m of head (with an entrance velocity of 2.99 m/s at a discharge of approximately 7.42 m^3/s).

Note: The design of the entrance gates should include provisions for installation of stoplogs to allow dewatering for maintenance.

Entrance Pool Depth: Based on the gate submergence calculations in Table 1, a minimum depth of 4.57 m below minimum tailwater level would allow for a submergence of 3.35 m on an entrance gate when operated alone based upon the required submergence calculated above (3.35 m submergence below the tailwater + 0.61 m of head across the entrance + 0.61 m of sill).

Entrance Gate(s) Design Head: 0.305 to 0.61 m with 0.46 m preferred.

Note: Locate staff gages in the entrance pool and tailrace to monitor the head differential across the entrance gates.

Entrance Velocity: 2.43 to 3.44 m/s; 2.99 m/s preferred

Maximum Diffuser Velocity: 0.305 m/s for wall diffusers and 0.153 m/s for floor diffusers.

Diffuser Clear Openings: Maximum of 2.54 cm

Auxiliary Water System Diffuser in Entrance Pool: Place the entrance pool diffusers on the floor, walls, or both. However, wall diffusers are easier to keep clean. A flow of 30 m^3/s requires a wall diffuser opening of 98.53 m^2 (excluding major structural members) to meet the velocity criteria if 0.305 m/s velocity through the diffuser. The top of the wall diffuser should be approximately 0.305 m below the minimum water surface level of the pool to reduce the potential for fish to leap at the surface disturbance. A 4.26 m high opening would require approximately 23.08 linear m of wall diffuser. Since the floor diffuser flow velocity criteria is 0.153 m/s area required for a floor diffuser is double that of a wall diffuser.

Note: The AWS diffusers in the entrance pool should be designed so flow from the diffuser leads fish from the entrance gates to the ladder.

Ladder:

Flow: The amount of flow depends on ladder design, but generally 0.57 to 0.85 m^3/s is used. We assumed a ladder flow of 0.57 m^3/s. Locate a staff gage in the ladder to monitor head over the weirs.

Type: Ladder types available include the "Ice Harbor" style, "Half Ice Harbor" style, and a pool-and-weir with an orifice if the tailrace water level is fairly stable during the fish passage season. If tailrace water level varies significantly, use a vertical-slot design. For the purposes of this document, we recommend and assume the use of a "Half Ice Harbor" style. The "Half Ice Harbor" style of ladder is a pool and weir/orifice ladder. The walls between the pools consist of a non-overflow section with a short wing-wall projecting upstream adjacent to the overflow weir. Locate the overflow weir along either side of the fishway. The orifice is located along the floor of the fishway and generally centered under the overflow weir. The dimensions for this style ladder are taken from Bell (1991). The various types of ladders are also described in Clay (1995).

Orifice size: 0.46 m high by 0.38 m wide

Overflow weir length: Approximately 0.85 m

Non-overflow section: 1.58 m (based upon a ladder width of 2.43 m)

Head drop between pools: 0.305 m ± 2.54 cm

Minimum pool depth: 1.83 m

Maximum energy dissipation per pool: Energy dissipation calculations in the pool are based on the following:

$Qh\gamma$/pool volume $\leq$ 19.5 m-kg/s/m^3, where

Q = flow down the ladder (m^3/s)
h = head drop between pools (m)
γ = specific gravity of water (1,000 kg/m^3)

Minimum pool size: We assume each pool is 1.83 m deep, 2.43 m wide, and 3.05 m long. This produces an energy dissipation of 12.7 m-kg/s/m^3 based on 0.57 m^3/s ladder flow.

Maximum slope of fish ladder: 10%

Transport channel velocity (if a transport channel is needed)**:** 0.61 to 1.22 m/s. Transport channels are essentially low velocity flumes that allow fish to swim easily from one area to the next with a minimum of elevation change.

Trap and Haul Facilities (potentially for interim use only):

Holding pool at top of ladder: Fish should swim into the holding pool. The entrance to the holding pool should have a V-picketed lead with 2.54 cm maximum clear opening on the legs of the picket lead and a maximum opening at the apex of 12.7 cm so fish cannot back out of holding pool. Provide a means to block the V-picket so fish cannot enter the holding pool during crowding. Locate the entrance to the holding pool on the sidewall and upstream from the crowder, which is parked along the back wall. Make the upstream apex of the V-picket flush with the wall of the holding pool so it will not interfere with crowding operations and also not create a sanctuary where fish can avoid the crowder.

Holding pool volume: In the Pacific Northwest we assume the average holding volume required for an adult chinook salmon is 0.23 m^3, which may compare favorably to the early run of Atlantic Salmon in the Umeälven. We assume steelhead have an average required holding volume of 0.07 m^3, which may compare well with the later run of grilse salmon. Based on the maximum number of 1250 fish per day, a holding pool 2.4 m deep by 2.6 m wide by 9.1 m long could hold about 1440 smaller-sized fish (assuming 0.07 m^3 is required/fish) or 450 larger-sized fish (assuming 0.23 m^3 required/fish). These pool dimensions assume the facility is operated once per day. A smaller holding pool is needed if the trap is operated more than once per day, and a larger pool is needed if operated less than once per day.

Flow through the holding pool: Size the flow through the holding and braille pool at 0.57 m^3/s, the same as the ladder. We base this recommendation on experience with holding facilities for hatcheries. Use a diffuser so that flow into the head of the holding pool has a maximum velocity of 0.15 m/s. Limit diffuser openings to a maximum of 2.54 cm.

Crowder: Ensure that the crowder is smooth and free of any projections that might injure fish. Limit screen mesh or bar openings to 2.54 cm. Size them to resist deformation by large fish when crowding them into the braille/sorting pool. When not in use, the crowder should retract to the back wall and have seals that prevent fish from swimming behind it.

Braille/sorting pool: Provide a means to close the braille pool from the holding pool. Recess the braille into the floor and provide seals so that fish cannot get behind or under it. Ensure the braille is smooth and free of any projections that might injure fish. Construct the braille of aluminum bars spaced with clear openings of 2.54 cm and sides that slope to a floor that in turn slopes to the transport hopper. Installation of a removable work platform would provide personnel the ability to easily reach fish during manual sorting. Use water-to-water transfer (for example, a sanctuary dip net) to transfer fish into the transport hopper, return them to the holding pool, or place them in a second hopper or smaller holding pool for later transport. We recommend a braille pool with dimensions of approximately 3.7 m by 3.7 m.

Additional: Size the ladder pool just downstream from the holding pool to hold the number of fish expected to pass the ladder in 60 to 90 minutes, the time required to operate the crowder and trap. Assuming a maximum of 1250 fish/day and 90 minutes to complete one operation, we would expect approximately 160 fish to accumulate in this area during operation of the trap. Based upon the holding volume required for grilse-sized fish (0.07 m^3/fish), a pool approximately 1.8 m deep by 2.4 m wide by 4.6 m long should provide an adequate holding volume. Note: The 4.6 m length includes the V-picket at the entrance to the holding pool.

Operation: Prior to operation of the trap, the V-picket is closed so no additional fish enter the holding pool. The entrance to the braille pool is opened (so fish have access to this area) and the crowder is slowly moved forward from the back wall of the holding pool to crowd fish up to the braille area through another V-picket. When the braille pool has sufficient fish for sorting, the crowder is stopped, the gate to the braille pool is closed, and the crowder is backed up slightly to reduce stress to fish still in the holding pool. The braille is then raised slowly so fish are gently crowded. When not sorting, monitor the number of fish entering the hopper and close it when fish capacity is reached. Transfer fish from the hopper to the truck or trailer via a water-to-water transfer. After fish are loaded into the truck or trailer tank, return the hopper and repeat the cycle until all fish in the braille pool are safely loaded. The gate to the braille pool is then opened again and the crowder used to move more fish into the braille pool. The cycle is repeated until all fish are removed from the holding pool. The hopper, braille, and crowder are then returned to their parked position and the V-picket opened to allow fish to again enter the holding pool.

Sorting: Once the fishery management requirements for sorting have been identified, a comprehensive design for the facilities needed can be developed. Here we describe the basic options and associated facilities. If fish sorting is done manually, we recommend the use of anesthetic, particularly if tagging, sampling, measuring, and weighing occurs. This requires the installation of an anesthetic tank and a recovery tank to revive fish prior to release. Alternatively, sorting of fish could occur automatically if hatchery fish were coded-wire-tagged. In this case, install a false weir that all fish leap. The fish would then enter a transport flume or pipe, pass through a coded-wire-tag detector, and the detector would trigger a gate, diverting tagged (hatchery) fish to a separate holding pool. This would require construction of two holding pools and separate transportation of hatchery and wild fish.

Transport hopper: Transport hoppers typically hold approximately 3.785 m^3. The bottom is solid, and the walls are partially solid and slotted above a point to allow excess water to drain off when lifted until the minimum amount of water and all fish remain. The bottom typically has a special gate and seal that mates to the transport truck or trailer so fish transfers from the hopper to the truck or trailer tank are made water-to-water. The size of hopper selected will depend on the density of fish typically used by local experts, the number of fish moved per transfer, average fish size, and how many times per day fish are transported. In the Pacific Northwest we typically use hoppers that are 2.44 m long by 2.44

m wide by 0.91 m deep and place about 120 smaller-sized individual fish in the hopper at one time. This number would probably work well later in the season when fish are mostly grisle; earlier in the season when large females are migrating the number in each hopper transfer would involve fewer fish.

Transport truck or trailer: Designs for truck or trailer tanks that safely haul fish are commonly available and we can provide documents describing these design details when needed.

Release location: For wild fish collected in the holding facility, we recommend transporting them above the slack water in the reservoir. This would limit the likelihood that they would swim back downstream and pass through turbines or spill.

References:

Bell, Milo. 1991. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Northwestern Division, P.O. Box 2870, Portland, Oregon, U.S.A., 97208-2870.

Clay, Charles H. 1995. Design of fishways and other fish facilities. CRC Press, Inc., 2000 Corporate Blvd., N. W., Boca Raton, Florida, U.S.A. 33431. 248 p.

Appendix B: Preliminary Engineering Analysis of the Adult Salmon Ladder and Auxiliary Attraction Water System at Norrfors Dam

THE UPPER LADDER

Physical Characteristics of the Upper Ladder:

The ladder is a standard pool/weir/orifice design with bottom deflectors downstream of each orifice. All dimensions and volumes are approximate.

Reported flow down the ladder:	1 to 1.5 m^3/s
Elevation drop between each pool:	0.3 m
Fishway slope:	10%
Pool width:	3.5 m
Pool length:	3.0 m
Pool depth:	2.0 m
(This assumes 0.3 m over the weir)	
Pool volume:	21 m^3

Note: Pool size varies. Every 8 to 10 pools a larger pool was constructed that was probably designed as a fish resting pool and to meet energy dissipation guidelines.

Weir

Width:	1.0 m
Depth:	0.5 m

Orifice

Width:	1.0 m
Height:	0.82 m

A floor-mounted deflector is located downstream of each orifice, the top of which is approximately 25.8 cm above the invert of the orifice.

Calculated Flow Down the Ladder:

Assuming a depth over the weir of 0.305 m (this is typical of the design depth of flow in these types of ladders) and a 0.305 m drop between pools (also typical), flows through the ladder are calculated as follows:

Weir flow	0.30 m^3/s
Orifice flow	1.37 m^3/s
Total flow	1.68 m^3/s

If the reported ladder flow of 1.5 m^3/s is correct, then flow depth over the weir is less than the 0.305 m assumed in the calculations. Field measurements of the water surface differential between pools and depth of flow over the weirs would enable better estimates. Also, dimensions of the pools (length, width and normal depth) and weir orifices we developed from the drawings should be verified.

<u>Calculation of Ladder Pool Energy Dissipation:</u>

Assuming ladder flow is 1.68 m^3/s, the energy dissipated in each pool is based on the following formula:

$$Qh\gamma/\text{pool volume} \leq 19.5 \text{ m-kg/s/m}^3\text{, where}$$

Q = flow down the ladder (m^3/s)
h = head drop between pools (m)
γ = specific weight of water (1,000 kg/m^3)

The existing ladder has an energy dissipation value of 24.4 m-kg/s/m^3 which is approximately 5.0 m-kg/s/m^3 the maximum criteria for the design of fish ladders we use. This means there is too much flow down the ladder (or the ladder is too small for the given flow) given current fishway design criteria. The result is excessive turbulence in the ladder that can potentially delay fish. This excessive energy is probably what we observed during our site visit in some pools that seemed excessively turbulent. For a totally new ladder of similar length and height, we would set the energy dissipation level at 18.0 to 18.3 m-kg/s/m^3. However, a new ladder is much more costly than reconfiguration of the existing ladder to meet the maximum energy dissipation criteria of 19.5 m-kg/s/m^3. Therefore, we developed three options for reducing the amount of energy dissipated per pool to meet the criteria: 1) reduce the flow in the ladder; 2) reduce the water surface drop between the pools; or 3) increase the volume of the individual pools.

Energy Dissipation Option 1: Reduce ladder flow to meet criteria

Given the current ladder configuration, and assuming a 0.305 m drop between pools and the depth of the pools remains about the same, a reduction of flow by approximately 20% to 1.34 m^3/s is required. This is approximately the amount of flow that presently passes through the orifices. However, weir flow tends to disperse the orifice flow so that excessive energy does not carry down the ladder from one pool to the next. Without water flowing over the weir, it is not clear that the existing floor deflector alone could accomplish this same dispersion of energy. If the deflector alone was not sufficient (the weir component of flow was required to aid in the dissipation of the orifice jet) then reduction of the width of the orifice from 1.01 m to approximately 0.76 m would provide approximately 0.305 m of flow over the weir.

Energy Dissipation Option 2: Reduce head drop between pools

It is probably not practical to reduce the water surface drop between pools since this would require the addition of a number of pools in the ladder. Based on a ladder flow of 1.68 m^3/s, the water surface drop between each pool needs reduction to 0.24 m to achieve the criteria. This 20% reduction in head would require approximately 20% more pools in the ladder.

Energy Dissipation Option 3: Increase pool volume

Pool volume could be adjusted by raising the water surface level of each pool to meet the criteria. Based on ladder flow of 1.68 m^3/s and a 0.305 m drop between pools, pool volume would have to be increased to approximately 26.05 m^3. Since the width and depth of each pool is basically fixed and only the depth can be varied, the pool depth would have to increase by 0.49 m to a total depth of 2.50 m. This would overtop the weirs and most likely the walls of each pool. This option is not practical unless the weirs and walls heights are also raised.

Upper Ladder Recommendation:

We recommend reduction in flow down the ladder to approximately 1.34 m^3/s to meet the maximum energy dissipation criteria of 19.5 $m\text{-}kg/s/m^3$. Also, we recommend maintaining the depth of flow over each weir at 0.305 m. This will require reducing the width of the submerged orifice by 1.01 m to approximately 0.76 m.

THE LOWER LADDER AND FISHWAY ENTRANCE AREA

Physical Characteristics of the Lower Ladder:

(Note: All dimensions and volumes are approximate)

Ladder flow: (From the analysis of the upper ladder)	assume 1.68 m^3/s
Auxiliary water supply (AWS) (Reported information)	19 m^3/s
AWS channel width	3.5 m
AWS channel slope	1:23 (4.34 %)
Calculated depth	0.56 m
Calculated velocity of AWS flow	9.6 m/s

Note: The energy in this flow is probably dissipated to some extent through a hydraulic jump in the AWS chamber. We cannot calculate the amount of energy reduction that occurs here and whether this is sufficient to provide uniform flow through the diffuser system and into the ladder.

Physical Characteristics of the Pools Just Upstream of the AWS Diffuser:

Length	3.0 m
Width	3.5 m

Little information is provided in the drawings we reviewed on the weirs in this section of the ladder. They are apparently constructed of stop logs inserted in the guide slots between the fishway pools. Depending on the pool, the weirs are either 2.0 or 3.0 m wide. The height of the weir depends on the number of stop logs inserted to raise the water surface level. This section of the fish ladder apparently does not contain orifices. Based upon our analysis of the upper portion of the ladder, these pools are undersized by approximately 20 to 25%.

AWS Diffuser Pool:

The diffuser pool is apparently located between the 3rd and 4th weir from the bottom of the ladder in an irregularly shaped trapezoidal pool. The AWS water enters the pool via orifices or vertical slots, the dimensions of which are unclear. A small orifice opening from the AWS to the ladder would create relatively high velocities into the fish ladder, false attraction of fish to the AWS system, and passage delay. It is not clear from the drawings whether diffuser gratings are provided to prevent adults from entering the AWS system. No diffusers are apparent in the rock (or possibly concrete) floor. This pool is 14.6 m long and approximately 4.35 m wide.

Diffuser Requirements:

Based upon our current design guidelines, the present amount of flow in the AWS would require approximately 62.3 m^2 of wall diffuser (excluding major structural members) to meet a maximum velocity through the diffuser of 0.305 m/s (excluding major structural members). Assuming a depth of 4.5 m in this area, it would require approximately 13.87 linear meters of wall diffuser to meet the guidelines. A floor diffuser in this area would have to have approximately 124.4 m^2 of area based upon a maximum diffuser velocity guideline of 0.152 m/s. In either case, the diffuser grating should have a maximum clear opening of 2.54 cm to prevent smaller salmon and grilse from becoming gilled in the diffuser. Given the velocity of the AWS flow into the diffusion chamber, we also recommend installation of baffling in the AWS system to reduce the amount of energy transferred to the fish ladder.

Pools located just downstream of the AWS diffuser:

Length	6.0 m
Width	5.5 m
Depth	3.13 m (assumed)
Volume	90.4 m^3

The weirs between the pools have a 4.0 m wide by 2.30 m high opening, the height of which is adjusted by the installation of stop logs. Flow in this section of ladder is approximately 20.7 m^3/s (a combination of ladder plus AWS flow). Assuming a 0.305 m drop in water surface level between pools and no stoplogs in the weir opening, approximately 20.1 m^3/s flows through the opening. The flow level over the weir adjacent to the opening is approximately 0.38 m. Currently, due to the amount of flow, limited pool size, and arraignment of the overflow weirs, there is a significant amount of energy carried from the upper to the lower pools, creating turbulent conditions that may adversely affect fish passage.

Discussion:

Three options exist for resolving the design of the bottom weirs and entrance area to the existing ladder:

Option 1: Completely rebuild the lower end of the ladder

This is our preferred option. It involves completely redesigning and reconstructing the lower portion of the ladder (including the AWS system, diffuser pool, lower three pools of the ladder, and the entrance pool and gates) to accommodate the current level of flow. This design would be very similar to the design for the new trap and haul facility for the tunnel outfall described in Appendix A. However, this is most likely the most expensive option.

Option 2: Reduce AWS flow into the ladder and discharge excess into spillway

This is our recommended option since it is the easiest to implement and test. If it doesn't work as well as desired, little costs are incurred and the other options are still available. This option reduces the amount of AWS flow into the ladder to approximately 4.25 m^3/s and puts the remaining 15.0 m^3/s flow into the spillway to maintain bypass channel flows. This will require reconfiguration of the weirs in the lower pools to accommodate the reduced flow. Design the fish ladder so that its entrance is deeper than wide so that fish are not forced to leap into the ladder. We recommend using radio-tagged fish to evaluate changes in ladder passage time and success. If the changes improve fish passage, we recommend introducing the 15.0 m^3/s spill back into the river channel without creating a false attraction to migrating adults. Potentially, the width of the spillway is sufficient to create a relatively shallow, low velocity flow that would not attract adults into the spillway area. Alternately, this flow could be introduced adjacent to the fish ladder in such a manner as to attract adults to the fishway entrance without creating a false attraction away from the ladder. There are a number of other possibilities to achieve this condition. Local experts who understand the site, water sources, hydraulics, and fish passage are best qualified to come up with a configuration to achieve the proper attraction flow conditions to the ladder under this test condition.

Option 3: Extend the ladder downstream and align AWS flow adjacent to it

This option has potential but would require careful hydraulic design and possibly hydraulic modeling. It involves removing the lower open weirs and extending the existing ladder with additional pools and weirs, as necessary, downstream to a point adjacent to the rock wall on the right bank. It would also require extending downstream the existing channel for the AWS flow to a discharge point adjacent (and parallel) to the ladder entrance which is now located in the pool area. It might also require deepening the bottom of the pool immediately downstream of the ladder entrance. This type of design is commonly used at spillway entrances at Columbia River dams, where large volumes of spill are adjacent and parallel to the flow coming from the ladder entrance. The local hydraulic conditions would need evaluation and the facility designed so the AWS flow does not occlude the ladder entrance, and prevent fish from entering. Also, the AWS flow might require a diffuser or velocity barrier to avoid false attraction of adults.

And finally, if bypass channel flows are increased above the current level of 20 m^3/s, then all options will need reconsideration to determine how they work under the higher flows. Additional design changes in the ladder and spillway area may be required so the ladder entrance performs well under the flow volume selected for the bypass channel.

Figure 1. Stornorrfors Powerhouse tunnel tailrace, looking downstream (east).

Figure 2. Small dam and ladder at the upper end of the old powerhouse headrace.

Figure 3. Norrfors Dam fish ladder entrance in upper left of photo and auxiliary water supplied to weirs downstream of the ladder entrance showing aerated, turbulent flow.

Figure 4. Pool and rock ledge downstream from the Norrfors Dam fish ladder entrance.

Figure 5. The adult collection facility is located in the top pool of the fish ladder. The pool is used to collect and hold fish, and the floor has a sloped brail that is raised to crowd adults for netting.

Figure 6. All adult salmon are held, netted, and sorted in the adult collection facility without pre-anesthesia.

Figure 7. Fish from the adult collection facility return to the forebay via a gravity-flow, 0.3 m pipeline with flushing flow, located an estimated 75 m upstream from the Norrfors Dam. The pipe outfall is located in the area shown along the right bank of the peninsula that divides the powerhouse and spillway forebays.

Figure 8. Spillway channel is comprised of rough, unfinished bedrock. The first energy-dissipating basin is downstream by the fish ladder entrance.

Figure 9. Laxhoppet area of natural falls and chutes has been modified to improve passage in the bypass reach under reduced flow conditions. Strategically placed weirs create 2 or 3 routes for fish passage.

Figure 10. Confluence of the bypass channel (right) and powerhouse outflow channel (left). Water velocities and flow volume at the mouth of the bypass channel are low compared to the powerhouse outflow channel.

Figure 11. Baggböle Rapids with 20 m^3/s flow. Adult delay may result from shallow, high velocity sheet flow over the bedrock substrate in portions of the rapids.

Figure 12. Lower end of the Baggböle Rapids (foreground) and bypass channel (background) under 20 m^3/s flow. Increasing base flows through the bypass channel might improve passage conditions in the rapids and channel. The confluence of the bypass channel and powerhouse outflow channel is in the far background.

Figure 13. Approximately 20 m^3/sec flow down the bypass channel provides a number of routes, chutes, and stepped jumps between rock formations, boulders, and potential areas of passage around the Baggböle Rapids near the old powerhouse.

Figure 14. Notch in the wall of the headrace channel just upstream of the old powerhouse that provides an alternative route around the Baggböle Rapids.

Figure 15. Stornorrfors Power Station intake channel where a juvenile salmon louver bypass system could potentially be installed. Flow between the rocks leads to each turbine.