DUNVEGAN HYDROELECTRIC PROJECT
RIGHT BANK SECTION MODEL

ADDENDUM No. 2 TO TECHNICAL REPORT

JULY 2004

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ACKNOWLEDGEMENTS AND AUTHENTICATION

ACKNOWLEDGEMENTS

Numerical and physical model studies were conducted as part of the Dunvegan Hydroelectric Project development joint review process with Alberta Environment, the Alberta Energy and Utilities Board, the Alberta Natural Resources Conservation Board, and Fisheries and Oceans Canada. northwest hydraulic consultants was retained by Canadian Projects Limited on behalf of Glacier Power Limited (a subsidiary to Canadian Hydro Developers, Inc.) to conduct modelling studies. The authors of this report acknowledge the key assistance and information provided by the following individuals.

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EXECUTIVE SUMMARY

northwest hydraulic consultants (nhc) was retained by Glacier Power Limited (Glacier) to construct and test a 1:25 scale physical hydraulic model of the Dunvegan Hydroelectric Project. The project is proposed for development approximately 2 km upstream of the Highway 2 Bridge at Dunvegan, Alberta. The design of the project underwent several revisions over the course of the physical model study as a result of the model study findings. The current project design consists of a forty unit powerhouse facility, a seven bay spillway, two fishway ramps (one on each bank), ten fish bypass sluices and a boat lock along the right (south) bank.

The 1:25 scale “right bank section” model encompassed an area approximately 450 m long by 130 m wide (prototype dimensions) along the right (south) bank of the river at the project site. The model included the boat lock, the right bank fishway ramp, the ten southern-most powerhouse units and three fish bypass sluices.

The present study constitutes an addendum to earlier studies conducted on the right bank section model, which have evaluated the upstream and downstream fish passage facilities and engineering-related issues such as ice accumulation in the project headpond, stage-discharge relationships for powerhouse overtopping conditions, stilling basin performance and debris passage at the project. The present report supplements the information related to upstream and downstream fish movement contained in two earlier reports: Right Bank Section Model Technical Report (May 2003); and, the Right Bank Section Model Addendum to Technical Report (December 2003). This second addendum includes refinements to the Auxiliary Water Supply (AWS) and fishway ramp entrance design, guidance on the operating scenarios for acceptable flow patterns and velocities for upstream fish movement, and an assessment of downstream fish passage through the fish bypass sluice located adjacent to the spillway.

Observation of flow patterns in the model has demonstrated that by providing AWS attraction flow within the downstream end of the fishway ramp, satisfactory attraction flow patterns for upstream
migrating fish can be achieved in the vicinity of the ramp entrance for a wide range of river discharges and powerhouse operating scenarios. Satisfactory attraction flow patterns include adequate attraction velocities at the entrance to the fish ramp, and generating a uniform transition from the lower velocity flows downstream of the fishway ramp entrance to the high velocity flows downstream of the powerhouse.

Operating scenarios that provided the best flow conditions in terms of the performance guidelines for upstream fish passage were determined in the model. In addition, operational boundaries were established to demonstrate the system’s flexibility to meet potential requirements, which may evolve from monitoring programs once the Project is constructed. These tests have demonstrated that the proposed facility has the capacity to deal with varying river discharges by using the AWS system, the adjacent fish bypass sluice and plant operation to generate flow patterns conducive to both upstream fish passage and power generation. The proposed design of the facility achieves the design criteria established for the project and provides enough flexibility in its operation to permit adaptive management techniques to be employed in the field.

An assessment of the volume of flow entrained by the fish bypass sluice adjacent to the spillway was conducted to examine the performance of the downstream fish passage facility for a range of bypass discharges, with and without the adjacent powerhouse units operating. It was demonstrated that similar entrainment volumes could be obtained by passing higher flows through the fish bypass when all the units were operating or by passing lower flows through the fish bypass with selected adjacent units shut off. These results are similar to those presented in earlier reports for fish bypass sluices located between adjacent groups of turbine units. It was also demonstrated that the entrainment volumes for a fish bypass sluice situated adjacent the (closed) spillway will be substantially greater than those previously documented for a fish bypass sluice situated between operating powerhouse units.
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I.0 INTRODUCTION

I.1 GENERAL

The information contained in this report constitutes an addendum to the main technical report entitled “Dunvegan Hydroelectric Project, Right Bank Section Model, Technical Report” (May 2003)¹ and the previous addendum report entitled “Dunvegan Hydroelectric Project, Right Bank Section Model, Addendum to Technical Report” (December 2003)², both prepared by northwest hydraulic consultants (nhc) for Glacier Power Limited c/o Canadian Project Limited. The current addendum report provides a summary of the supplemental testing for both upstream and downstream fish movement conducted on the 1:25 scale right bank section model of the Dunvegan Hydroelectric Project.

I.2 PROJECT DESCRIPTION

The Dunvegan Hydroelectric Project is a low-head, run-of-river hydroelectric development proposed for construction on the Peace River about 2 km upstream of the Highway 2 Bridge crossing at Dunvegan. A complete description of the project including the location plan, general powerhouse arrangement, the model layout drawings, the hydrology, and proposed operating rules for the project are all included in the May 2003 technical report.

Briefly, the project development will include a forty (40) unit powerhouse facility, a seven-bay spillway, two fishway ramps, ten fish- bypass sluices and a boat lock. Downstream fish passage will be accommodated primarily by the ten fish bypass sluices located along the upstream face of the powerhouse and spillway structures. The fish bypass sluices include both an upper 400 mm


diameter conduit and a lower 2.5 m wide by 2.8 m conduit with a 600 mm diameter orifice incorporated into a vertical slide gate. In addition, the two fishway ramps and fish-friendly “ECObulb™-turbines” will be capable of providing downstream passage during normal operation and the spillway will provide passage during higher river flows.

Upstream fish passage will be accommodated by the two fishway ramps and associated fishway headworks located along the north and south banks of the river. The flow patterns at the downstream end of the right bank fishway ramp were examined extensively in the present studies to assess whether the patterns will be conducive to the upstream passage of fish.

I.3 STUDY OBJECTIVES

The project developer, Glacier Power, adopted a program of physical and numerical modelling of the proposed project to evaluate the fish-related aspects of the design and hydraulic performance of the structure as a whole. The section model is the most comprehensive of the three modelling investigations, and its objectives, as defined in the May 2003 technical report, focused on the fish-related design considerations and their interaction with overall facility operation and performance.

I.4 DESIGN GUIDELINES

Specific design guidelines were established for the various fish passage facilities for the original project design and are presented in CPL’s report3 dated January 15, 2002. Design guidelines specific to the section model study are included in the May 2003 technical report. The guidelines for upstream fish passage that are associated with the current addendum report are listed below.

- provide downstream directed attraction flows at the fishway ramp entrance with velocities in the range of 0.3 to 1.0 m/s (target velocity of 0.5 m/s),

• provide a uniform transition to high velocity flows issuing from the powerhouse tailrace,
• provide connectivity with downstream migration corridor (shoreline zone where velocities are less than 1 m/s),
• provide flow depths greater than 0.5 m,
• minimize zones of re-circulation or areas where fish could “hold” for prolonged periods of times,
• minimize access to the powerhouse draft tubes and sluice exit through the creation of velocity barriers (areas where velocities exceed 1.0 m/s) or similar,
• provide facilities that have enough flexibility in their design and operation to accommodate changes in these guidelines that may arise from the adaptive management program following construction of the facility.
2.0 MODEL DESCRIPTION

A complete description of the right bank section model, including discussion of the model scale relationships, model controls and instrumentation, and the model layout, can be found in the May 2003 technical report. Briefly, the model was constructed at a scale of 1:25 and encompassed an area along the south (right) bank of the Peace River approximately 450 m in length and 130 m in width (all dimensions are in prototype units unless otherwise noted). The model included the right bank fishway ramp, three fish bypass sluices, and ten of the forty powerhouse units.

The fishway ramp entrance geometry used for preliminary testing in the current addendum report is similar to Geometry 8H. The description of the testing undertaken in the development of this geometry and a detailed description of its layout can be found in the May 2003 technical report. Prior to undertaking the additional model testing described herein, minor modifications, repairs, and design revisions to the model were completed. These modifications are listed below and a plan view drawing of the fishway ramp entrance area for this new geometry, referred to herein as Geometry 8I, has been included as Figure 2-1:

- The fishway ramp surface treatment was replaced with simplified pool and weir geometries, approximating the V-baffle designs as developed in the 1:10 scale ramp model;
- Flow measurement and piping facilities were installed to facilitate accurate measurement of Auxiliary Water Supply (AWS) discharges (including flows through the fishway ramp and the adjacent fish bypass sluice) and permit the introduction of flow directly into the lower end of the fishway ramp through a diffuser system;
- The AWS consists of ten diffuser chambers installed in the pool section between rows of V baffles at the downstream end of the fishway ramp to permit further increases in the magnitude of the velocities at the ramp entrance and provide more opportunities to generate a range of velocities through the selective operation of the AWS systems; and,
• The model bathymetry was modified to increase the velocities at the fishway entrance by reducing the downstream water depths. The local shoreline bathymetry was raised to El. 339 m, which reduces the amount of excavation required at the downstream end of the fishway ramp by approximately 2 m. This will provide approximately 1.5 m of water depth at the 95% exceedance discharge (tailwater level is El. 340.5 m) and 3.7 m at the 5% exceedance discharge.

Photo Plate 2-1 shows the Geometry 8I as installed in the model.
3.0 TEST PROGRAM

UPSTREAM FISH MOVEMENT
Model testing for upstream fish movement consisted of a preliminary assessment of the fish passage performance of the facilities for a wide range of operating scenarios, followed by a more detailed examination of the fish passage conditions for selected operating conditions. The operating scenarios examined herein considered the influence of the operation of the adjacent fish bypass sluice, and of various combinations of the AWS diffuser system, which supplies supplemental flow to the base of the fishway ramp. The tests were conducted at the 95%, 50%, and 5% exceedance discharges. The respective river discharges and tailwater levels (based on the proposed May Rule Curve) are listed below:

- 95% exceedance: river discharge = 954 m$^3$/s, tailwater level = El. 340.5 m
- 50% exceedance: river discharge = 1,920 m$^3$/s, tailwater level = El. 341.7 m
- 5% exceedance: river discharge = 3,000 m$^3$/s, tailwater level = El. 342.7 m

DOWNSTREAM FISH MOVEMENT
Preliminary testing was conducted in order to estimate entrainment volumes for downstream fish passage through a fish bypass sluice situated adjacent to the spillway. This was simulated by operating the model with Units 6-10 blocked off (trash racks removed) and evaluating various combinations of sluice discharge and operation of Units 1-5.
4.0 TEST RESULTS

4.1 UPSTREAM FISH PASSAGE

4.1.1 PRELIMINARY ASSESSMENT TESTS (GEOMETRY 81)
Preliminary assessments of the proposed fishway ramp entrance geometry were conducted at the 95%, 50% and 5% exceedance discharges. Preliminary testing examined a range and combination of AWS discharges and adjacent fish bypass sluice flows. These preliminary tests were similar to the “preliminary assessment tests” described in the December 2003 Addendum Report.

Testing at the 95% exceedance discharge was conducted with various combinations of five powerhouse units operating. This is representative of the anticipated operating conditions, since discharge available for power generation at the 95% exceedance condition will be sufficient to operate approximately one-half of the forty units. Testing at the 50% and 5% exceedance discharges was conducted with all powerhouse units operating as there would be sufficient power generation flows available. Documentation at each flow included injection of coloured dye, hand-written observations and sketches describing the flow patterns, and a limited quantity of velocity data collected in the vicinity of the fish bypass sluice and fishway ramp entrance.

In general, these preliminary assessment tests demonstrated that three unfavourable flow patterns could still develop:

- A low velocity zone downstream of the riverward end of the fishway ramp guidewall
- An area of stagnant flow within the entrance to the boat lock
- Diversion of water from within the fishway ramp over the left side of the fishway ramp (looking downstream), resulting in insufficient attraction velocities in the area downstream of the ramp
4.1.2 **Model Demonstration (May 6, 2004)**

Mr. Bill Johnson of CHD, and Mr. Richard Slopek of CPL observed the performance of the model during a demonstration at nhc’s hydraulics laboratory on May 6, 2004. At the meeting, conditions were demonstrated for the 95%, 50% and 5% exceedance discharges. Based on these demonstrations and the results of the preliminary assessment testing described above, it was agreed that the following refinements to the guidewall and fishway ramp geometry were required to further improve the flow patterns within the fishway ramp entrance (refer to Figure 4-1).

- Revisions to the riverward end of the fishway ramp guidewall to reduce the low flow zone downstream,
- A 40 m extension of the navigation boat lock wall to eliminate the stagnant flow area,
- Addition of a 1.6 m high wall along the left side of the fishway ramp (lined with natural rock along its edge) to reduce the diversion of fishway ramp flows, and
- Installation of an additional row of V-baffles to the downstream end of the fishway ramp to improve the uniformity of flow within the fishway ramp entrance.

The refined layout is referred to as Geometry 8J.

4.1.3 **Preliminary Assessment Testing (Geometry 8J)**

Additional assessment testing was conducted with the refined fishway ramp entrance geometry (Geometry 8J) installed in the model at the 95%, 50% and 5% exceedance discharges. This set of tests examined a range of AWS discharges and operating combinations through both the adjacent fish bypass sluice and the AWS diffuser chambers installed within the lower end of the fishway ramp. Powerhouse operation and documentation of the flow patterns was the same as that described for the Preliminary Assessment Testing of Geometry 8I.

The results of these tests are summarized in the attached Tables 4.1 through 4.3. The following list identifies the most favourable operating conditions associated with upstream fish passage and summarizes notable trends in the results for the three discharge levels. Note that the AWS flows
to the ramp listed herein are in addition to the ramp base flow of 2 m³/s. Refer to Figure 4-1 for powerhouse unit numbers.

95% Exceedance Discharge:

- The most favourable flow conditions for upstream fish passage were observed when there was an additional 3 m³/s added to the lower end of the fishway ramp through the first two diffuser boxes and 4 m³/s was passed through the adjacent fish bypass sluice (Test 11). For this operating scenario, the mid-depth velocities at the fishway ramp entrance ranged from 0.4 m/s to 0.5 m/s and the velocities farther downstream of the fishway ramp entrance remained at 0.3 m/s to 0.4 m/s.
- The mid-depth velocities at the fishway ramp entrance ranged from 0.3 m/s to 0.5 m/s when there was 3 m³/s added to the lower end of the fishway ramp through the first two AWS diffuser chambers (Tests 11 to 17).
- If required, higher attraction velocities were achieved at the entrance to the ramp by increasing the AWS flow to the ramp. However, AWS ramp flows greater than 9 m³/s generated entrance velocities exceeding 1.0 m/s.
- The transition from the low velocity zone downstream of the fishway ramp to the high velocity zone downstream of the powerhouse was uniform when the AWS ramp flow was between 3 and 9 m³/s.
- Velocities were more uniform across the width of the ramp when the AWS flow to the ramp was supplied through the first two AWS diffuser chambers (1 and 2). Velocities were slightly higher along the right side of the ramp when flow was supplied through the first three AWS diffusers.
- For adjacent fish bypass sluice flows from 4 to 10 m³/s, adequate velocities were provided to deter fish from entering the direct vicinity of the sluice (velocities greater than 1.0 m/s).
- When powerhouse units 1 and 2 were operating, the adjacent fish bypass sluice flow was not required to maintain adequate velocities to prevent fish from entering the vicinity downstream from the fish bypass sluice.
**50% Exceedance Discharge:**

- The most favourable flow conditions for upstream fish passage occurred when there was an additional 12 m³/s added to the lower end of the fishway ramp and 15 m³/s was passed through the adjacent fish bypass sluice (Test 12). This operating scenario resulted in mid-depth velocities at the fishway ramp entrance that ranged from 0.4 to 0.8 m/s and the velocities farther downstream remained within 0.3 to 0.4 m/s.

- For an AWS ramp flow of 10 m³/s supplied through the first six diffuser chambers (Tests 4 to 6), the velocities at the fishway ramp entrance were generally within acceptable limits.

- If required, higher attraction velocities were achieved at the entrance to the ramp by increasing the AWS ramp flow. The maximum limit of AWS ramp flow was estimated at approximately 30 m³/s, above which the resulting entrance velocities exceeded 1.0 m/s.

- If lower velocities are required at the entrance to the fishway ramp, AWS ramp flows as low as 6 m³/s (Test 3) generated a uniform transition from the low velocity zone downstream of the fishway ramp to the high velocity zone downstream of the powerhouse.

- When there was AWS ramp flow from the first six diffusers (1 to 6), the flow from the ramp tended to escape over the 1.6 m high wall along the left side of the ramp, and the velocities along the right side of the ramp tended to be higher. Similar conditions were observed when only diffusers 1 through 3 were operated.

- When the AWS ramp flow was discharged through diffusers 4 to 6, the majority of the ramp flow remained within the fishway ramp and the velocities were more uniform across the width of the ramp. However, the velocities at the entrance to the ramp were less uniform through the water depth for this condition than when diffusers 1 to 3 were operated.

- When the adjacent fish bypass sluice discharge was between 12 and 20 m³/s, velocities above 1.0 m/s were achieved in the vicinity of the sluice exit. The transition from the low
velocity zone downstream of the fishway ramp to the high velocity zone downstream of the powerhouse was uniform for this range of adjacent fish bypass sluice flows.

5% Exceedance Discharge:

- The most favourable flow conditions for upstream fish passage were observed when there was an additional 20 m³/s added to the lower end of the fishway ramp through at least seven of the ten AWS diffuser chambers, and 15 m³/s was passed through the adjacent fish bypass sluice (Test 12). This operating scenario resulted in mid-depth velocities at the fishway ramp entrance that ranged from 0.3 to 0.6 m/s and velocities downstream of the sluice between 0.7 and 1.1 m/s.

- Velocities at the fishway ramp entrance were within the acceptable range with an additional 20 m³/s added to the base of the fishway ramp through the first five or more AWS diffuser chambers (Tests 4 to 6, 12, and 13).

- If required, higher attraction velocities can be achieved at the entrance to the ramp by increasing the AWS ramp flow to a maximum of approximately 40 m³/s at which point entrance velocities were found to exceed 1.0 m/s.

- If lower velocities are required at the entrance to the fishway ramp, AWS ramp flows as low as 10 m³/s (Test 2 and 3) generated a uniform transition from the low velocity zone downstream of the fishway ramp to the high velocity zone downstream of the powerhouse.

- For all operating scenarios tested, flow escaped over the 1.6 m high wall along the left side of the ramp. However, when the AWS ramp flow was restricted to the diffusers at the lower end of the ramp (diffusers 1 to 5), the majority of the flow upstream of the operating diffusers abruptly exited the ramp along its left side.

- When there was an AWS ramp flow from the first six or more diffusers, the velocities were lower along the left side of the fishway ramp than the right side of the ramp.

- When the adjacent fish bypass sluice discharge was maintained above 15 m³/s, velocities above 1.0 m/s were achieved in the vicinity of the sluice exit.
The transition from the low velocity zone downstream of the fishway ramp to the high velocity zone downstream of the powerhouse was uniform for all operating scenarios tested, excluding the case where no flow was discharged from either the AWS ramp flow system or the adjacent fish bypass sluice.

4.1.4 Agency Model Demonstration (June 22, 2004)

Mr. Chris Katopodis and Mr. Doug Lowe of Fisheries and Oceans Canada, Mr. Ross Keating and Mr. Bill Johnson of CHD, and Mr. Richard Slopek of CPL observed the performance of the model during a demonstration at nhc’s hydraulics laboratory in North Vancouver, British Columbia on June 22, 2004.

At the meeting, the results of testing for upstream fish passage in the refined layout, Geometry 8J, were presented and reviewed. A selection of preferred operating conditions was then demonstrated in the model for the 95%, 50% and 5% exceedance discharges. Based on these demonstrations it was agreed that the flow patterns appeared conducive to upstream fish passage and that a more detailed and quantitative assessment of the flow patterns was warranted. The following test program was agreed upon to complete the testing on the right bank section model:

- Data collection for “optimum” AWS/Fish Bypass Sluice/Turbine operation at 95%, 50% and 5% exceedance discharges. Optimum operation was based on achieving velocities of approximately 0.5 m/s in the vicinity of the fishway ramp entrance and creating a 1 m/s velocity barrier to exclude fish from the area between the guidewall and fishway ramp.

- Data collection for “2 m/s barrier” operation at 95%, 50% and 5% exceedance discharges. For these tests, the adjacent fish bypass sluice discharge was to be increased to create a velocity barrier between the guidewall and fishway ramp approaching 2 m/s. These tests were conducted to verify that barrier velocities between the guidewall and fishway ramp approaching 2 m/s could be achieved by increasing the adjacent fish bypass sluice discharge.
sluice discharge, while simultaneously ensuring that no adverse impacts occurred to the flow patterns in the vicinity of the ramp entrance.

4.1.5 Detailed Testing (Geometry B)
Detailed testing consisted of collecting mid-depth velocity data over a 100 m by 50 m wide grid to provide quantitative data for the assessment of upstream fish passage. Six detailed documentation tests were conducted. The area of measurements extended approximately 100 m downstream of the powerhouse stilling basin apron and 50 m into the river. Velocity measurements were obtained using a miniature propeller velocity probe. Velocity measurements were made at approximately 180 locations for the “optimum” operation tests, and approximately 80 locations for the “2 m/s barrier” tests. Figure 4-2 shows the measurement locations used for these tests.

95% Exceedance Discharge:
The “optimum” operating condition for upstream fish passage was achieved when an additional 5 m³/s was added to the lower end of the fishway ramp through the first three AWS diffuser chambers and 5 m³/s was passed through the adjacent fish bypass sluice. The results of this test have been organised into the upper velocity contour plot shown in Figure 4-3. The results show that this operating scenario provided a well defined migration corridor (velocities less than 1 m/s) for upstream fish movement, which converged uniformly towards the entrance to the fishway ramp. Attraction velocities of approximately 0.5 m/s were achieved at the entrance to the fishway ramp, while velocities exceeding 1 m/s were provided between the guide wall and fishway ramp to prevent fish from entering this area.

The results of the “2 m/s barrier” test are also plotted in Figure 4-2 (lower contour plot). The results show that a 2 m/s barrier was attained within the area between the guidewall and fishway ramp when the adjacent fish bypass sluice flow was increased to 15 m³/s (“optimum” conditions were achieved with an adjacent fish bypass sluice flow of 5 m³/s) and the AWS ramp flow was maintained at 5 m³/s. The 2 m/s velocity barrier was not continuous, with velocities as low as 1
m/s documented between the guide wall and the ramp; however it did obstruct access to the powerhouse draft tubes and sluice exit. There were no adverse impacts to the flow patterns in the vicinity of the ramp entrance.

**50% Exceedance Discharge:**
The results of both the “optimum” and the “2 m/s barrier” operating conditions are illustrated in Figure 4-4 (upper plot presents the results for the “optimum” conditions and the lower plot presents the results for the “2 m/s barrier” conditions). The “optimum” AWS/Fish Bypass Sluice/Turbine operation was determined to be an AWS ramp flow of 10 m³/s through the first six diffuser chambers and 14 m³/s passing through the adjacent fish bypass sluice. The resulting flow patterns demonstrated that attraction velocities of approximately 0.5 m/s were achieved at the entrance to the fishway ramp and that these velocities transitioned uniformly out into the main channel. The shoreline zone or migration corridor was bounded by a 1 m/s velocity barrier that converged towards the entrance to the fishway ramp, and acted as an obstruction to the area downstream of powerhouse draft tubes and sluice exit.

Increasing the adjacent fish bypass sluice flow to 29 m³/s, while maintaining an AWS ramp flow of 10 m³/s, provided a 2 m/s velocity barrier at the adjacent fish bypass sluice exit which extended downstream along the riverward side of the fishway ramp. Velocities between the guide wall and the fishway ramp generally ranged from 1.5 to 2.5 m/s, which are expected to be sufficiently high to restrict access to this area. There were no adverse impacts to the flow patterns in the vicinity of the ramp entrance. However, the migration corridor did narrow and the transition from the shoreline zone to the main channel was not as uniform as it was for the “optimum” operation.

**5% Exceedance Discharge:**
The results of both the “optimum” and the “2 m/s barrier” operating conditions for the 5% exceedance discharge condition are illustrated in Figure 4-5 (upper plot – “optimum” operation; lower plot – “2 m/s barrier” operation). The “optimum” operation was determined to be an AWS
ramp flow of 30 m$^3$/s through all ten diffuser chambers in combination with 30 m$^3$/s passing through the adjacent fish bypass sluice. The resulting flow patterns again demonstrated that attraction velocities of approximately 0.5 m/s were achieved at the entrance to the fishway ramp and that these velocities transitioned well out into the main channel. However, the 1 m/s barrier was not continuous due to slightly lower velocities (0.8 - 1.0 m/s) generated downstream from riverward end of the guide wall. As shown in the velocity contour plot for the “2 m/s barrier” test, this was readily corrected by increasing the adjacent fish bypass sluice flow.

A continuous 2 m/s velocity barrier was not provided even when the adjacent fish bypass sluice flow was increased to 40 m$^3$/s and the AWS ramp flow was increased to 35 m$^3$/s. The velocity contour plot (lower plot on Figure 4-5) shows that a 2 m/s barrier extends downstream from the adjacent fish bypass sluice exit, but did not fully obstruct the area downstream from the guidewall, where velocities generally ranged from 1 m/s up to 3 m/s. However, it should be noted that with the high tailwater level (El. 342.7 m) associated with the 5% exceedance discharge, velocities downstream of the powerhouse units generally ranged from 1.5 to 2 m/s. There were no adverse impacts to the flow patterns in the vicinity of the ramp entrance with the increased adjacent fish bypass sluice flow.

4.2 **Downstream Fish Passage**

Following the upstream fish passage testing, additional testing was conducted to estimate entrainment volumes for downstream fish passage through a fish bypass sluice situated adjacent to the control spillway. Previous testing (described in the previous Section Model reports) evaluated the entrainment volumes for downstream fish passage for a bypass sluice situated between adjacent sets of powerhouse turbine units. The current model testing simulated the presence of the spillway, in its non-operating condition, by removing the trash racks upstream of Units 6-10 and blocking off their entrances. Various combinations of fish bypass sluice discharge and operation of Units 1-5 were then evaluated in a manner similar to that described for the “preliminary testing” as presented in the December 2003 Addendum Report.
Five fish bypass sluice discharges and five powerhouse operating conditions were investigated (for a total of 25 tests). For each test, dye was injected upstream of the bypass sluice at three depths and at several sections extending to the upstream edge of the 35-degree trash racks.

Using this method, two zones of entrainment were identified: the first zone represented the boundary within which 100% of the flow (dye) was entrained into the fish bypass sluice; and the second zone represented the outer boundary of flow entrainment (i.e. no flow outside this boundary was entrained into the sluice). Between these two boundaries, a portion of the flow was entrained into the sluice and a portion was lost through the trashracks or elsewhere in the reservoir. Based on the sketched boundaries at each depth, a normalized volume of entrained flow was calculated for each operating scenario (entrainment volume was normalized by dividing the computed volume by the plan form area between two sets of trash racks).

All testing was conducted with the headwater level at El. 348.4 m, corresponding to the 50% exceedance discharge. Given the relatively small variation in the anticipated reservoir levels (ranges from El. 347.7 m for the 95% exceedance discharge to El. 348.4 m for the 5% exceedance discharge), testing at the 95% and 5% exceedance discharges was not warranted. The results obtained for the 50% exceedance discharge provide a good indication of the flow patterns that can be expected over the full range of river discharges.

Table 4.4 presents the normalized volumes for each test, and Figure 4-6 illustrates the resulting relationship between normalized entrainment volume and fish bypass sluice discharge. As expected, the entrainment volume was found to increase with increasing fish bypass sluice discharge and was found to be greater for a given fish bypass sluice discharge when the adjacent powerhouse units were shut down.

Based on these tests, it was evident that similar entrainment volumes could be obtained by either passing higher flows through the fish bypass sluice when all the units were operating, or passing a lower flow through the fish bypass sluice with selected units shut off. For example, referring to Figure 4-6, one can see that an entrainment volume of 40 m$^3$/m$^2$ can be obtained by operating the
fish bypass sluice at a discharge of approximately 5 m$^3$/s with the four adjacent powerhouse units shut down. The same entrainment volume can also be achieved by operating the fish bypass sluice at a discharge of approximately 20 m$^3$/s with only one adjacent unit shut down. This demonstrates the flexibility inherent in the design of the facility.

These test results also indicate that the entrainment volumes for a fish bypass sluice situated adjacent to the (closed) spillway were significantly greater than a fish bypass sluice situated between operating powerhouse units (Figure 4-14 from the December 2003 Addendum Report has been reproduced herein as Figure 4-7 for comparison purposes). For example, for a fish bypass sluice discharge of 20 m$^3$/s with one adjacent powerhouse unit closed, the entrainment volume for a fish bypass sluice situated adjacent to the spillway was estimated at approximately 40 m$^3$/m$^2$ (from Figure 4-6), whereas for a fish bypass sluice situated between powerhouse units with one adjacent powerhouse unit closed (on either side), the same fish bypass sluice discharge provided an entrainment volume of approximately 15 m$^3$/m$^2$ (from Figure 4-7).
5.0 SUMMARY AND CONCLUSIONS

A 1:25 scale model of the Dunvegan Hydroelectric Project was used to evaluate the designs of the upstream and downstream fish passage facilities and operating scenarios. The model encompassed an area approximately 450 m long by 130 m wide (prototype dimensions) along the right bank of the river and included the boat lock, the right bank fishway ramp, ten powerhouse units and three fish bypass sluices.

5.1 UPSTREAM FISH PASSAGE

The model test program for this second addendum to the May 2003 technical report included assessments of the downstream fish passage facilities over a wide range of operating scenarios, including detailed examination of velocities and flow patterns expected for a selected set of operating scenarios. Testing focussed on providing adequate attraction flow (volume and velocity) to the fishway ramp entrance to ensure upstream migrating fish are able to locate the fishways and avoid movement towards the powerhouse outlets or adjacent fish bypass sluice outlet.

Observation of flow patterns in the model has demonstrated that by providing AWS attraction flow within the downstream end of the fishway ramp, satisfactory attraction flow patterns for upstream migrating fish can be achieved in the vicinity of the ramp entrance for a wide range of river discharges and powerhouse operating scenarios. Satisfactory attraction flow patterns include adequate attraction velocities at the entrance to the fish ramp, and generating a uniform transition from the lower velocity flows downstream of the fishway ramp entrance to the high velocity flows downstream of the powerhouse.

Operating scenarios that provided the best flow conditions in terms of the performance guidelines for upstream fish passage were determined in the model. In addition, operational boundaries were established to demonstrate the system’s flexibility to meet potential requirements, which may evolve from monitoring programs, once the Project is constructed.
These tests have demonstrated that the proposed facility has the capacity to deal with varying river discharges by using the AWS system and plant operation to generate flow patterns conducive to both upstream fish passage and power generation. The proposed design of the facility achieves the design criteria established for the project and provides enough flexibility in its operation to permit adaptive management techniques to be employed in the field.

It is considered that sufficient information has been accumulated through the current testing and measurement program to allow for the development of the adaptive management plan and operating procedures for the project. The testing has indicated that operating procedures can be developed to provide hydraulic conditions conducive to fish migration. On the basis of this, it is recommended that these tests conclude the testing program for the right bank section model, and that the model be modified to reflect the shoreline geometry downstream of the left bank fishway ramp to confirm that a similar guide wall and fishway entrance geometry will perform satisfactorily along the left bank of the river.

5.2 Downstream Fish Passage

An assessment of the volume of flow entrained by the fish bypass sluice situated adjacent to the spillway was conducted to examine the performance of the downstream fish passage facilities for a range of fish bypass sluice discharges, with and without the adjacent powerhouse units operating. It was demonstrated that the same entrainment volume could be obtained by passing higher flows through the fish bypass sluice when all the units were operating as by passing lower flows through the fish bypass sluice with selected units shut off. This demonstrates the flexibility inherent in the design of the facility. It was also demonstrated that the entrainment volumes for a fish bypass sluice situated adjacent the (closed) spillway will be substantially greater than those previously documented for a fish bypass sluice situated between operating powerhouse units.
### TABLE 4.1
Summary of Results for Upstream Fish Movement Testing in Refined Geometry 8J at the 95% Exceedance Discharge

**Head Pond Level = El. 347.7 m, Tailwater Level = 340.5 m**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Base Fishway Ramp Flow (m³/s)</th>
<th>AWS Ramp Flow (m³/s)</th>
<th>Operating AWS Valves</th>
<th>AWS Adjacent Sluice Flow (m³/s)</th>
<th>Units Operating</th>
<th>Flow Pattern at Entrance to Fishway Ramp</th>
<th>Velocity at Fishway Ramp Entrance (m/s)</th>
<th>Velocity D/S of Fish Sluice (m/s)</th>
<th>Transition from zone d/s of fishway ramp to zone d/s of powerhouse</th>
<th>Comments / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>6</td>
<td>1, 3, 5, 7, 9</td>
<td>The flow along the right half of the fishway ramp (looking d/s) was stagnant</td>
<td>&lt; 0.3 to 0.6</td>
<td>1.2</td>
<td>non-uniform</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1 to 3</td>
<td>6</td>
<td>-</td>
<td>Slightly higher velocities resulted along right side (looking downstream) of fishway ramp.</td>
<td>0.4 to 0.7</td>
<td>1.2</td>
<td>predominantly uniform</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>Velocities significantly higher along right side of ramp entrance</td>
<td>0.6 to 0.95</td>
<td>1.2</td>
<td>predominantly uniform</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>9</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Upper limit for AWS flow at base of ramp</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>9</td>
<td>1, 2 (1/2 open), 3 (1/4 open)</td>
<td>6</td>
<td>-</td>
<td>Inflow from diffuser 1 created visible disturbance at water surface</td>
<td>1.2</td>
<td>uniform</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>9</td>
<td>1 &amp; 2, 3 (1/2 open)</td>
<td>6</td>
<td>-</td>
<td>Slightly higher velocities resulted along right side (looking downstream) of fishway ramp.</td>
<td>0.7 to 0.95</td>
<td>1.2</td>
<td>predominantly uniform</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>6</td>
<td>1 &amp; 2</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>1.3 - 1.8</td>
<td>uniform</td>
<td>predominantly uniform</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>Velocities more uniform across ramp width when diffusers 1 and 2 operate rather than diffusers 1 to 3</td>
<td>1.2</td>
<td>predominantly uniform</td>
<td>Velocities in area downstream of fish sluice are less than 1.0 m/s</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
<td>uniform</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>0.6 to 0.7</td>
<td>0.9</td>
<td>uniform</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>Velocities uniform across ramp width and within acceptable limits of attraction velocity range</td>
<td>0.3 - 0.5</td>
<td>1.0</td>
<td>uniform</td>
<td>Minimum required sluice flow to result in velocities d/s of sluice higher than 1.0 m/s. Considered optimum operating scenario.</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>5</td>
<td>1, 6 to 9</td>
<td>Velocities uniform across ramp width</td>
<td>0.8 to 1.0</td>
<td>uniform</td>
<td>predominantly uniform</td>
<td>When PH Units 1and 2 operate, velocities in area d/s of fish sluice exceed 1 m/s even without operation of fish sluice</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>0</td>
<td>1, 2, 3, 7, 9</td>
<td>Velocities uniform across ramp width and within acceptable limits of attraction velocity range</td>
<td>0.4 to 0.5</td>
<td>0.7 to 1.7</td>
<td>uniform</td>
<td>Velocities up to 2.8 m/s beyond tip of guidewall, d/s of PH Units</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>0</td>
<td>1 to 5</td>
<td>-</td>
<td>0.9 to 1.7</td>
<td>predominantly uniform</td>
<td>predominantly uniform</td>
<td>Upstream directed flow near tip of guidewall</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>6 to 10</td>
<td>-</td>
<td>0.9</td>
<td>predominantly uniform</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>5</td>
<td>6 to 10</td>
<td>-</td>
<td>1.3</td>
<td>predominantly uniform</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>5</td>
<td>1,2, 6, 7, 8</td>
<td>Velocities uniform across ramp width</td>
<td>0.7 - 1.3</td>
<td>predominantly uniform</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 4.2
Summary of Results for Upstream Fish Movement Testing in Refined Geometry 8J at the 50% Exceedance Discharge
Head Pond Level = El. 347.7 m, Tailwater Level = 341.7 m

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Base Fishway Ramp Flow (m³/s)</th>
<th>AWS Ramp Flow (m³/s)</th>
<th>Operating AWS Valves</th>
<th>AWS Adjacent Sluice Flow (m³/s)</th>
<th>Units Operating</th>
<th>Flow Pattern at Entrance to Fishway Ramp</th>
<th>Velocity at Fishway Ramp Entrance (m/s)</th>
<th>Velocity D/S of Fish Sluice Flow (m/s)</th>
<th>Transition from zone d/s of the fishway ramp to zone d/s of powerhouse</th>
<th>Comments / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>1 to 10</td>
<td>Velocities at entrance to ramp were &lt; 0.3 m/s</td>
<td>&lt;0.3</td>
<td>non-uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>10</td>
<td>*</td>
<td>Flow nearly stagnant at entrance to fishway ramp</td>
<td>&lt;0.3</td>
<td>non-uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>6</td>
<td>1 to 6</td>
<td>10</td>
<td>*</td>
<td>Velocities slower along centerline of ramp entrance. Velocities in area downstream of ramp &lt; 0.3 m/s</td>
<td>&lt;0.3 to 0.5</td>
<td>0.9</td>
<td>uniform</td>
<td>Velocities in area downstream of fish sluice &lt; 1.0 m/s</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>10</td>
<td>*</td>
<td>5</td>
<td>*</td>
<td>Velocities significantly higher along right side (looking downstream) of fishway ramp entrance</td>
<td>0.6</td>
<td>uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>10</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>0.3 to 0.6</td>
<td>uniform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>10</td>
<td>*</td>
<td>15</td>
<td>*</td>
<td>0.3 to 0.5</td>
<td>1.2</td>
<td>uniform</td>
<td>Optimum flow scenario</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>12</td>
<td>*</td>
<td>0</td>
<td>*</td>
<td>Velocities at entrance to ramp were &lt; 0.3 m/s</td>
<td>&lt; 0.3</td>
<td>0.6</td>
<td>uniform</td>
<td>Velocities in area downstream of fish sluice &lt; 1.0 m/s</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>12</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>Slightly higher velocities resulted along right side (looking downstream) of fishway ramp</td>
<td>0.4 to 0.8</td>
<td>0.8</td>
<td>uniform</td>
<td>Minimum required sluice flow to result in velocities d/s of sluice higher than 1.0 m/s</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>18</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>0.5</td>
<td>uniform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>24</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>0.4 to 1.2</td>
<td>0.9</td>
<td>uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>30</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>Upper limit for velocities &gt; 0.8 m/s was reached along RHS of ramp. Rest of ramp width velocities were between 0.6 and 0.8 m/s</td>
<td>0.6 to 1.5</td>
<td>0.9</td>
<td>uniform</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>12</td>
<td>*</td>
<td>15</td>
<td>*</td>
<td>Flow exits over wall along LHS of fishway ramp. Velocities higher than RHS of ramp entrance than other points across width of ramp</td>
<td>uniform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>12</td>
<td>*</td>
<td>20</td>
<td>*</td>
<td>0.4</td>
<td>1.2 to 2.0</td>
<td>uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>12</td>
<td>4 to 6</td>
<td>20</td>
<td>*</td>
<td>Less flow exits over wall along LHS of ramp. Flow across ramp width is relatively uniform. However, velocities at water surface were higher than at floor.</td>
<td>uniform</td>
<td></td>
<td></td>
<td>Inflow from diffusers created visible disturbances at water surface</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>12</td>
<td>1 to 3</td>
<td>20</td>
<td>*</td>
<td>Flow exits over wall along left side (looking downstream) of fishway ramp. Velocities higher along right side of ramp entrance</td>
<td>uniform</td>
<td></td>
<td></td>
<td>Velocities appeared small in areas where ramp V-baffles were submerged (u/s of diffuser 6)</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>12</td>
<td>1 to 3, 4 to 6 (1/2 open)</td>
<td>20</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>uniform</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>12</td>
<td>1, 3, 5</td>
<td>20</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>uniform</td>
</tr>
</tbody>
</table>
### Summary of Results for Upstream Fish Movement Testing in Refined Geometry 8J at the 5% Exceedance Discharge

**Head Pond Level** = El. 347.7 m, **Tailwater Level** = 342.7 m

**TABLE 4.3**

**DUNVEGAN HYDROELECTRIC PROJECT**  
**NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES**  
**RIGHT BANK SECTION MODEL**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Base Fishway Ramp Flow (m³/s)</th>
<th>AWS Ramp Flow (m³/s)</th>
<th>Operating AWS Valves</th>
<th>AWS Adjacent Sluice Flow (m³/s)</th>
<th>Units Operating</th>
<th>Flow Pattern at Entrance to Fishway Ramp</th>
<th>Velocity at Fishway Ramp Entrance (m/s)</th>
<th>Velocity d/s of Fish Sluice (m/s)</th>
<th>Transition from zone d/s of the fishway ramp to zone d/s of powerhouse</th>
<th>Comments / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>1 to 10</td>
<td>Some of the flow near the entrance to ramp was upstream directed</td>
<td>-</td>
<td>-</td>
<td>non-uniform</td>
<td>Velocities in area downstream of fish sluice less than 1.0 m/s</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>10</td>
<td>1 to 10</td>
<td>0</td>
<td>*</td>
<td>Velocities at entrance to ramp were &lt; 0.3 m/s</td>
<td>&lt;0.3</td>
<td>0.4 to 0.8</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>10</td>
<td>*</td>
<td>5</td>
<td>*</td>
<td>Minimum limit for attraction flow velocities reached. Flow exits over wall along LHS of fishway ramp. Velocities higher along RHS of ramp.</td>
<td>&lt;0.3</td>
<td>0.4 to 0.6</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>20</td>
<td>*</td>
<td>5</td>
<td>*</td>
<td>Flow exits over wall along LHS of fishway ramp. Velocities higher along RHS of ramp; entrance than other points across width of ramp.</td>
<td>&lt;0.3</td>
<td>0.5 to 0.7</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>20</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td>Flow exits over wall along LHS of fishway ramp. Velocities higher along RHS of ramp entrance. Velocities across ramp. Velocities less than 1.0 m/s.</td>
<td>&lt;0.3</td>
<td>0.6 to 0.7</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>20</td>
<td>1 to 5</td>
<td>10</td>
<td>*</td>
<td>Minimum limit for attraction flow velocities reached. Flow exits over wall along LHS of fishway ramp. Velocities less than 1.0 m/s.</td>
<td>0.3 to 0.6</td>
<td>0.6 to 0.7</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>30</td>
<td>1 to 10</td>
<td>15</td>
<td>*</td>
<td>Flow exits over wall along LHS of fishway ramp. Velocities low along LHS of ramp entrance.</td>
<td>0.5 to 0.9</td>
<td>0.6 to 1.0</td>
<td>uniform</td>
<td>Minimum required sluice flow to result in velocities d/s of sluice higher than 1.0 m/s.</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>30</td>
<td>1 to 6</td>
<td>15</td>
<td>*</td>
<td>A small re-circulation pattern formed near the LHS of the entrance to the fishway ramp</td>
<td>0.4 to 0.7</td>
<td>0.7 to 1.0</td>
<td>uniform</td>
<td>Flow exits ramp abruptly prior to reaching the furthest upstream, operating diffuser box (diffuser 6)</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>30</td>
<td>1 to 6</td>
<td>20</td>
<td>*</td>
<td>Flow exits over wall along LHS of fishway ramp. Velocities low along LHS of ramp entrance.</td>
<td>0.3 to 0.6</td>
<td>0.8 to 1.3</td>
<td>uniform</td>
<td>** ** ** ** ** ** **</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>30</td>
<td>1 to 10</td>
<td>20</td>
<td>*</td>
<td>Upper limit for velocities at ramp entrance. Flow exits over wall along LHS of fishway ramp. Velocities low along LHS of ramp entrance.</td>
<td>0.3 to 0.9</td>
<td>0.8 to 1.1</td>
<td>uniform</td>
<td>Velocities from 0.6 to 0.7 m/s within ramp directly downstream of diffuser 3</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>40</td>
<td>1 to 10</td>
<td>20</td>
<td>*</td>
<td>Upper limit for velocities at ramp entrance. Flow exits over wall along LHS of fishway ramp. Velocities low along LHS of ramp entrance.</td>
<td>0.4 to 1.0</td>
<td>0.8 to 1.0</td>
<td>uniform</td>
<td>Velocities from 0.8 to 0.9 m/s within ramp directly downstream of diffuser 3</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>20</td>
<td>1 to 7</td>
<td>15</td>
<td>*</td>
<td>Attraction velocities and flow patterns adequate when at least AWS ramp diffuser boxes 1 to 7 are operated.</td>
<td>0.3 to 0.6</td>
<td>0.7 to 1.1</td>
<td>uniform</td>
<td>The acceptability of flow patterns was marginal when only AWS ramp diffuser boxes 1 to 6 operated at this flow.</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>20</td>
<td>1 to 5</td>
<td>15</td>
<td>*</td>
<td>Majority of fishway ramp flow was re-directed out and over the wall on the LHS of the ramp.</td>
<td>0.3 to 0.7</td>
<td>0.7 to 1.2</td>
<td>uniform</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>20</td>
<td>1 to 4</td>
<td>15</td>
<td>*</td>
<td>Upstream directed flow observed near LHS of entrance to ramp.</td>
<td>0.3 to 0.8</td>
<td>0.7 to 1.3</td>
<td>uniform</td>
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</table>
### Summary of Entrainment Volumes
Downstream Fish Movement Through Fish Bypass Sluice Adjacent to Spillway

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Fish Sluice Discharge</th>
<th>Powerhouse Units Shut Down</th>
<th>Normalized Entrainment Volume</th>
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<tr>
<td></td>
<td>m³/s</td>
<td></td>
<td>m³/m²</td>
</tr>
<tr>
<td>1</td>
<td>6.2</td>
<td>none</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>4 – 5</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>3 – 5</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>2 – 5</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>9.8</td>
<td>none</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>&quot;</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>&quot;</td>
<td>4 – 5</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>&quot;</td>
<td>3 – 5</td>
<td>27</td>
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<tr>
<td>10</td>
<td>&quot;</td>
<td>2 – 5</td>
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<tr>
<td>11</td>
<td>23.7</td>
<td>none</td>
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<td>12</td>
<td>&quot;</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>13</td>
<td>&quot;</td>
<td>4 – 5</td>
<td>48</td>
</tr>
<tr>
<td>14</td>
<td>&quot;</td>
<td>3 – 5</td>
<td>60</td>
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<td>15</td>
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<td>2 – 5</td>
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<tr>
<td>16</td>
<td>32.4</td>
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<td>17</td>
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<td>5</td>
<td>64</td>
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<td>4 – 5</td>
<td>61</td>
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<td>2 – 5</td>
<td>102</td>
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<tr>
<td>21</td>
<td>57.6</td>
<td>none</td>
<td>87</td>
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<td>22</td>
<td>&quot;</td>
<td>5</td>
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<td>3 – 5</td>
<td>101</td>
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<tr>
<td>25</td>
<td>&quot;</td>
<td>2 – 5</td>
<td>109</td>
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</tbody>
</table>
FIGURES
NOTES:
1) ALL UNITS GIVEN IN PROTOTYPE METRES.
NOTES:
1) ALL UNITS GIVEN IN PROTOTYPE METRES.
NOTES:
1) TESTS WERE CONDUCTED AT THREE OPERATING CONDITIONS: 5% EXCEEDANCE, 50% EXCEEDANCE, AND 95% EXCEEDANCE.
2) 180 SAMPLE LOCATIONS WERE USED FOR DATA COLLECTION.
3) VELOCITY DATA WAS COLLECTED AT EACH SAMPLE LOCATION AT MID-DEPTH USING A MINIATURE PROPELLER PROBE.
TEST A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Test Number</td>
<td>A-95</td>
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<tr>
<td>Operating Rule, Max. Project Head</td>
<td>May</td>
</tr>
<tr>
<td>River Discharge (m³/s)</td>
<td>3000</td>
</tr>
<tr>
<td>Reservoir Level</td>
<td>342.7</td>
</tr>
<tr>
<td>Tailwater Level</td>
<td>342.7</td>
</tr>
<tr>
<td>powerhouse Units Operating</td>
<td>1:10</td>
</tr>
<tr>
<td>fish sluice Flow (m³/s)</td>
<td>30</td>
</tr>
<tr>
<td>fish sluice Flow (m³/s)</td>
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TEST B

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<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Test Number</td>
<td>B-65</td>
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<tr>
<td>Operating Rule, Max. Project Head</td>
<td>May</td>
</tr>
<tr>
<td>River Discharge (m³/s)</td>
<td>3000</td>
</tr>
<tr>
<td>Reservoir Level</td>
<td>347.7</td>
</tr>
<tr>
<td>Tailwater Level</td>
<td>347.7</td>
</tr>
<tr>
<td>powerhouse Units Operating</td>
<td>1:10</td>
</tr>
<tr>
<td>fish sluice Flow (m³/s)</td>
<td>36</td>
</tr>
<tr>
<td>fish sluice Flow (m³/s)</td>
<td>36</td>
</tr>
</tbody>
</table>

VELOCITY (m/s)
- 3 - 5.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0.4 - 0.6
- 0.3 - 0.4
- < 0.3

NOTES:
1) MODEL SCALE: 1m = 25 m PROTOTYPE
2) VELOCITY MEASUREMENTS WERE MADE USING A MINIATURE PROPELLER PROBE
3) ISOLINES PRODUCED USING QUICKSURF SURFACE MODELLING FOR AUTOCAD 14 AND ARCVIEW 3.X WITH 3G-ANALYST

GLACIER POWER LIMITED
DUNVEGAN HYDROELECTRIC PROJECT
NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
RIGHT BANK SECTION MODEL
TAILRACE VELOCITY CONTOURS
GEOMETRY 8J
5% EXCEEDANCE DISCHARGE

northwest hydraulic consultants
Entrainment Volume vs. Sluice Discharge
Sluice Adjacent to Spillway

NOTES:
1) ENTRAINMENT VOLUMES NORMALIZED BY DIVIDING
BY THE PLAN AREA BETWEEN THE TWO TRASH RACKS.
2) BEST-FIT LINES BASED ON LOGARITHMIC RELATIONSHIP.
NOTES:
1) ENTRAINMENT VOLUMES NORMALIZED BY DIVIDING BY THE PLAN AREA BETWEEN THE TWO TRASH RACKS.
2) BEST-FIT LINES BASED ON LOGARITHMIC RELATIONSHIP.
PHOTO PLATES
(1) View looking upstream at fishway ramp Geometry 8I. Note the installation of V-baffles, and the AWS diffuser chambers. (IMG_0838)

(2) View looking downstream at fishway ramp Geometry 8I. Note the local shoreline bathymetry was raised to El. 339 m. (IMG_0840)
(1) View looking upstream at fishway ramp Geometry 8J. Note the addition of a 1.6 m high wall along the side of the fishway ramp, and the additional row of V-baffles to the downstream end of the fishway ramp. (IMG_1004)

(2) View looking downstream at fishway ramp Geometry 8J. Note the revisions to the riverward end of the fishway ramp guidewall, and the 40 m (prototype) extension of the navigation lock wall. (IMG_991)
1) 5% Exceedance Discharge
Fishway Ramp Flow = 2 m³/s
AWS Flow to Ramp = 30 m³/s
Fish Sluice Flow = 20 m³/s

2) 50% Exceedance Discharge
Fishway Ramp Flow = 2 m³/s
AWS Flow to Ramp = 10 m³/s
Fish Sluice Flow = 15 m³/s

3) 95% Exceedance Discharge
Fishway Ramp Flow = 2 m³/s
AWS Flow to Ramp = 3 m³/s
Fish Sluice Flow = 5 m³/s