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Ashlu Creek hydroelectric project
Design and optimization of hydraulic structures under construction using 2D and 3D numerical modeling

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ABSTRACT

The project site is located on Ashlu Creek, 30 km northwest of Squamish, halfway between Whistler and Vancouver, in British Columbia. The project consists of a run-of-river project that uses a short stretch of steep rapids to generate a nameplate capacity of 49.9 MW at a design flow of 29 m^3/sec, under a gross head of 224 m. .

The proposed works include a diversion spillway equipped with an Obermeyer gate, a rockfill weir, a Denil type fish ladder, a sluiceway and a side intake. This presentation will focus on the design and optimization of the hydraulic structures located at the upstream works using 2D and 3D numerical modeling. The objective was to verify the hydraulic performance of the system during construction and operations, but this validation had to be carried out on a tight schedule due to the construction in progress at the site. The time constraint made it impossible to build a physical model and an approach based on numerical modeling had to be developed to adequately simulate flow conditions.

A 2D model was first built to represent a 2 km reach of the Ashlu Creek stream that includes the upstream works site. The hydraulic behavior was simulated for natural conditions and all main construction phases. Given the general arrangement of the upstream works where the entrance of the intake structure is very close to the sluiceway channel and the oblique orientation of the intake axis with respect to the natural flow of the river, a more detailed simulation of the complex flows was required using 3D modeling to verify flow patterns under various operation conditions.

The proposed approach demonstrates an efficient alternative to small-scale physical modeling for specific applications in designing hydraulic structures.

1. INTRODUCTION

The project site is located on Ashlu Creek, 30 km northwest of Squamish, halfway between Whistler and Vancouver, in British Columbia (Figure 1). The project, developed and owned by Innergex Renewable Energy, consists of a run-of-river project that uses a short stretch of steep rapids to generate a nameplate capacity of 49.9 MW with a 29 m^3/s design flow under a gross head of 224 m. Construction of the Ashlu Creek plant, which has been granted Eco-Logo certification, began in August 2006, and the facility started commercial operation in December 2009.

The proposed works include an emergency spillway weir equipped with an Obermeyer gate, a rockfill weir, a Denil type fish ladder, a sluiceway and a side intake. Before reaching the power plant housing three 16.3 MW horizontal Francis units and six energy dissipation valves, the flow is conveyed into a 106 m high vertical shaft (3.8 m dia.), a 4.4 km long tunnel (4.08 m dia.), and a 140 m long steel penstock (2.8 m dia.). In 2007, RSW, in collaboration with Golder Associates, took over the detailed engineering of the project which was already under construction.

Due to tight schedule constraints, design and verification of the upstream works had to be carried out using numerical models instead of physical models. This unconventional approach allowed the design team to perform a rapid and efficient optimization of the spillway, intake and sluiceway structures while finding low-cost solutions to improve the design. Hydraulic conditions during construction phases were also simulated using numerical models in order to calculate the impact of various sequences of operations and validate the diversion works.

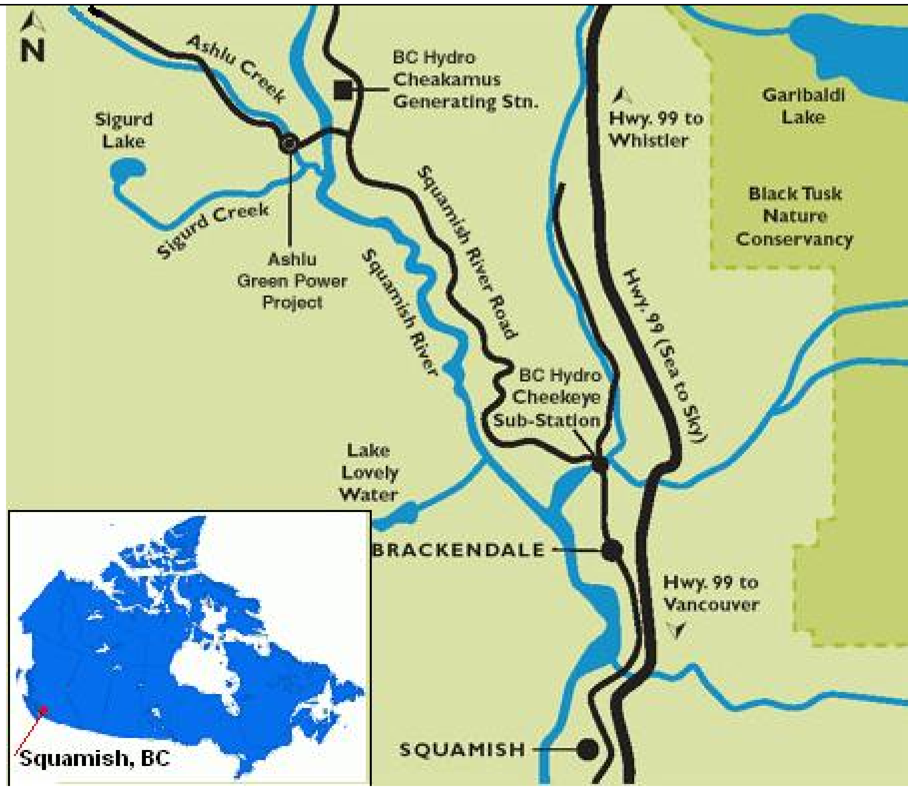

Figure 1: Ashlu Creek Hydroelectric Project Location

2. SITE DESCRIPTION AND GENERAL LAYOUT

The project is located in the extreme, steep, and rugged terrain of the narrow Ashlu Creek valley, just above the confluence with the Squamish River. The intake site is situated immediately upstream of the steep graded canyon section of Ashlu Creek at a broad U-shaped section with thick, highly permeable alluvial deposits. The general arrangement of the intake site comprises, from the left bank to the right bank, an emergency spillway weir, a rockfill weir, a sluiceway channel, and a lateral intake (Figure 2).

The emergency spillway weir consists of a 35 m long concrete sill equipped with a 4.5 m high Obermeyer gate. The spillway is designed to pass a 500-year flood with a flow capacity of 918 m^3/s when the Obermeyer gate is fully deflated.

The rockfill weir is located between the emergency spillway and the sluiceway and is 56 m long, nearly 10 m high, with a 5 m wide crest. The rockfill weir includes an upstream blanket composed of separate sections of low-permeable silt and geomembrane and a groin near the sluiceway entrance designed to improve velocity patterns.

A concrete sluiceway structure is sandwiched between the rockfill weir and the intake, and is equipped with a 6.5 m wide by 6 m high flat gate. The gate is be used to flush sediments and bed loads that accumulate in front of the intake. In the event of a flooding incident, the sluiceway can contribute to pass a 500-year flood with a flow capacity of 264 m^3/s in addition to the spillway capacity.

A concrete lateral intake completes the upstream works. The sill of the intake is set 2 m above the sluiceway sill in order to prevent sediment form entering the intake. The intake entrance is protected against floating debris by a coarse trash rack. In the converging transition, there is a fine trash rack with space bars of 42 mm, which is below the maximum size of particles that can be safely passed through the turbines, as specified to be acceptable by the turbine manufacturer (in the order of 50 mm). The intake is also equipped with flat gates used in case of an emergency shutdown. The concrete lateral intake transitions from a rectangular shape to a round one to match the diameter of the vertical shaft that connects the intake to the conveyance tunnel.

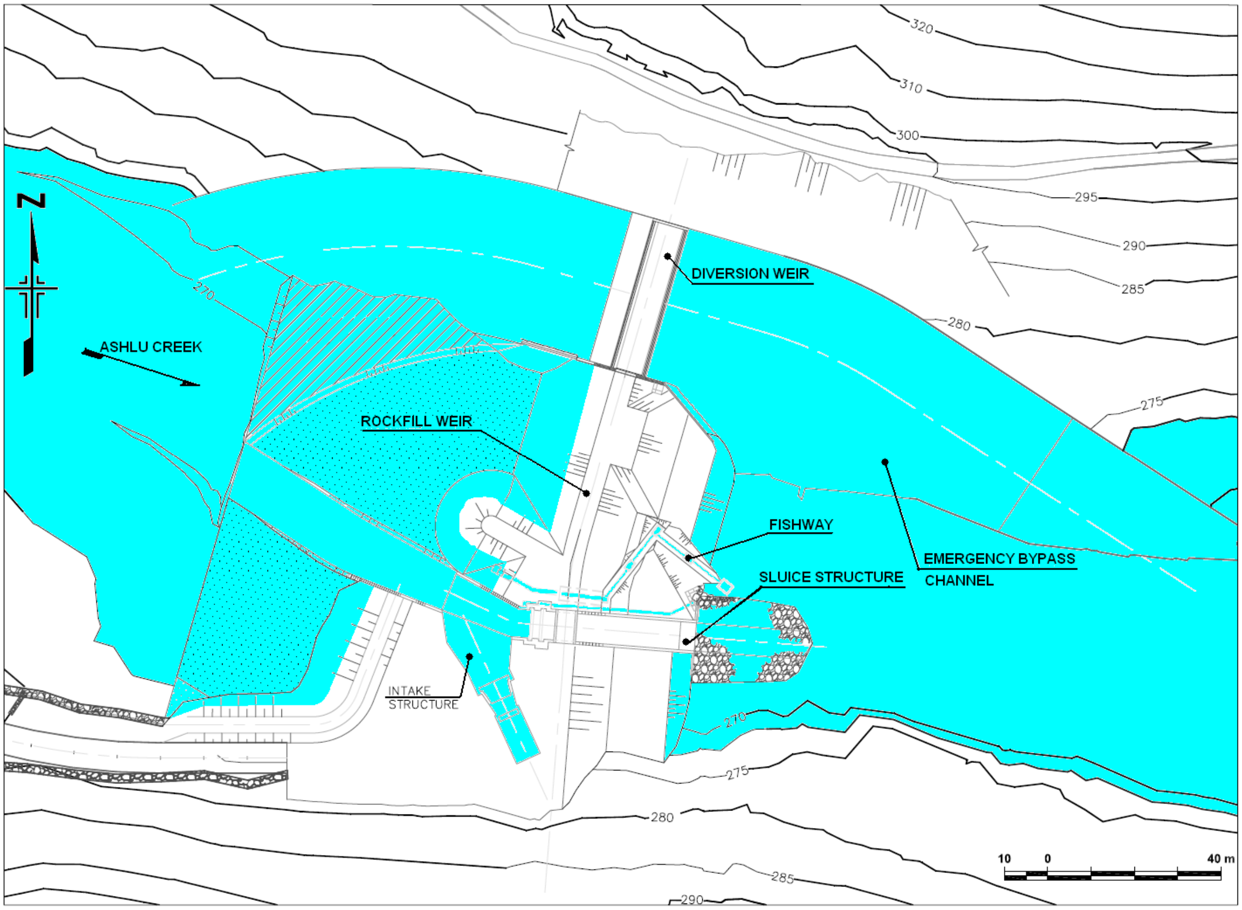

Figure 2: Ashlu Creek Project Upstream Works Layout

3. NUMERICAL MODELING STRATEGY

This paper focuses on the design and optimization of the hydraulic structures located at the upstream works using 2D and 3D numerical modeling. The objective was to verify the hydraulic performance of the system during construction and operations, but this validation had to be carried out on a tight schedule due to the construction in progress at the site. The time constraint made it impossible to build a physical model and an approach based on numerical modeling had to be developed to adequately simulate flow conditions.

A 2D model was first built to represent a 2 km reach of the Ashlu Creek stream that includes the upstream works site. The hydraulic performance was simulated for natural conditions and all main construction phases. Given the general arrangement of the upstream works with the sluiceway channel located very close to the entrance of the intake structure and the oblique orientation of the intake axis with respect to the natural flow of the river, a more detailed simulation of the complex flows was required using 3D modeling to verify flow patterns under various operation conditions.

The numerical modeling was performed in a few weeks and the design team was able to propose low-cost modifications to the structures to improve the operational conditions of the intake while providing a more efficient performance of the sluiceway.

The proposed approach demonstrates an efficient alternative to small-scale physical modeling for specific applications in designing hydraulic structures.

4. CONSTRUCTION PHASE SIMULATIONS

The construction of the upstream works was performed in three different stages:

- *Stage 1*: The first stage occurred between May 1st and July 15th 2007. The cofferdams were designed to protect the works against a 10-year flood condition (502 m^3/s). From the right bank of the river, a 64 m long upstream cofferdam and 22 m long downstream cofferdam were erected to protect the intake and sluiceway area. The diversion channel of the emergency spillway was also protected by upstream and downstream cofferdams. The flow was kept into the main river channel between the two protected zones. During this stage, the excavation of the diversion channel and the concreting of the Obermeyer sill, wing and abutment walls were completed. The excavation of the sluiceway and the intake was also performed during this phase.

- *Stage 2*: Stage 2 diversion phase took place after stage 1 was completed, from July 15th 2007 to March 2009. The cofferdams were also designed for a protection against a 10-years flood condition (502 m^3/s). The upstream cofferdam (141 m long) extended up to the spillway upstream right wingwall and the downstream cofferdam (85 m long) to the downstream wingwall, closing the river. The river flow was then diverted through the emergency spillway channel. The concreting of the spillway was then finished; leaving only the Obermeyer gate to be installed during the stage 3. During the stage 2 diversion phase, concreting of the intake and sluiceway was completed, as well as the construction of the rockfill weir and fishway.

- *Stage 3*: Stage 3 diversion phase took place during the month of March 2009, before the spring floods. The design flow for this winter period was 30 m^3/s for a 10-year flood event. The stage 2 cofferdam was dismantled and a new upstream cofferdam (122 m long) was erected from the upstream spillway channel connecting on the rockfill weir, halfway between the spillway and sluiceway. The river flow was diverted during stage 3 into the sluiceway channel. During this phase, the right upstream side of the cofferdam was completed. The Obermeyer gate was also installed.

Stage 1 and 2 construction phases were simulated using the 2D numerical model Telemac2D, developed by Électricité de France, in order to validate the sequence of operations, verify the safety of temporary construction works and optimize the cost of construction. Stage 3 diversion was simulated using the HEC-RAS 1D model.

A first series of simulations was performed to reproduce natural conditions over a 2 km stretch of the river. The upstream and downstream conditions were carefully chosen to enable a proper calibration of the model and were located sufficiently far from the construction site to avoid boundary effects. The lower section of Ashlu Creek, where the hydroelectric power project was developed, contains substrate consisting mainly of large boulders, cobbles and gravel overlying bedrock. After proper calibration, a roughness coefficient in the order of 0.07 was found to produce the best results for this substrate.

Once the model was calibrated with measured water levels and flow velocity observations, each phase of construction was represented in the model, with cofferdams used as walls to divert the flow for design conditions.

Figure 3 shows velocity patterns simulated for construction phase 1 under design flow condition (500 m^3/s) and Figure 4 presents results obtained from the simulations during the diversion (construction phase 2). The simulations allowed the identification of areas with higher velocities compared to natural conditions. Measures to prevent erosion of the natural substrate were taken before construction began to reduce the risk of damages to the site. Water levels obtained from the simulations were also used to design the required dimensions and crest level for the cofferdams.

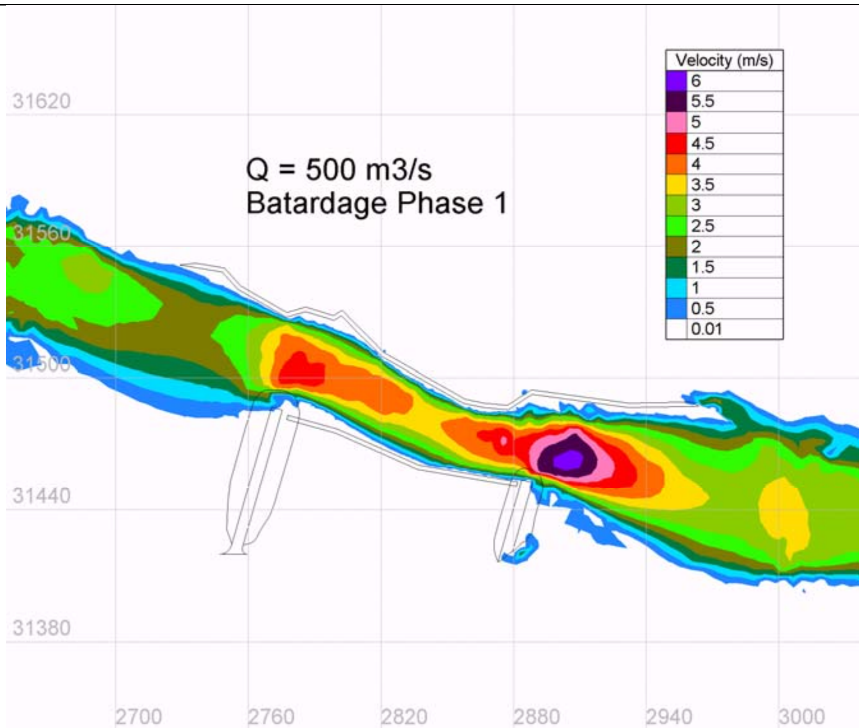

Figure 3: Simulation results for construction phase 1 at design flow conditions ($502\ m^3/s$)

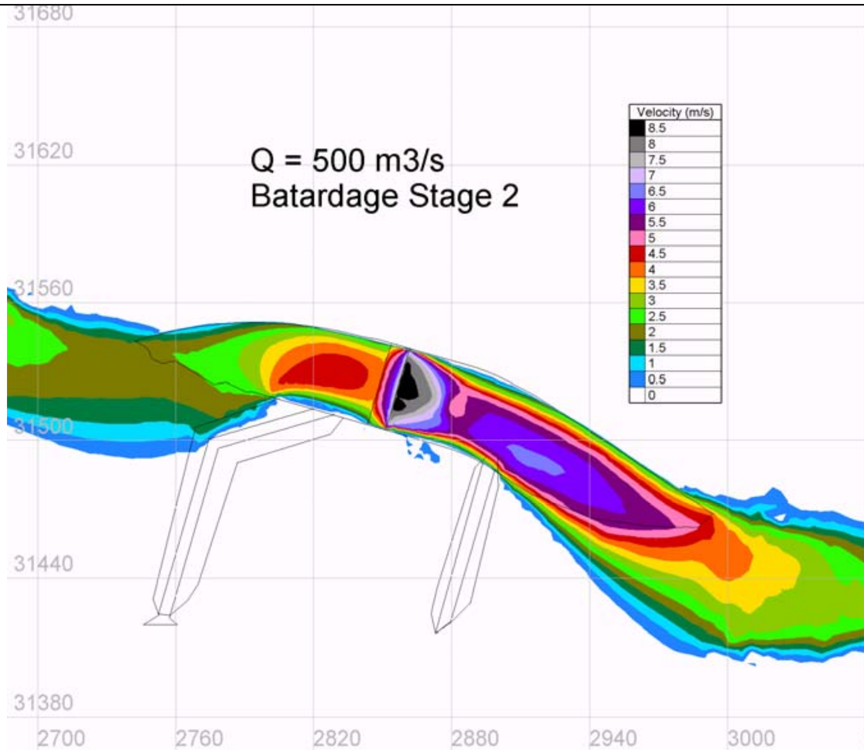

Figure 4: Simulation results for construction phase 2 at design flow conditions (502 m³/s)

5. SLUICEWAY AND INTAKE DESIGN

As seen in Figure 2, the sluiceway and the intake structure were positioned on the right side of the rockfill dam in close proximity to each other. Concerns were raised about a possible interference of flow between the two structures causing the intake's operation to be negatively impacted. The interaction of the two project components in operation was studied using the commercially available three-dimensional numerical model Flow-3D, developed by Flow Science Inc.

Flow-3D uses a rectangular structured grid to define the domain where the principle equations of fluid motion are discretized using the finite difference method. For purposes of the Ashlu Creek HEP simulations, the RNG version of the K-ε turbulent closure model was selected as it is ideally suited for solving such types of flow conditions.

The domain of the model is presented in Figure 4 and was selected in such a way so as to properly simulate the expected flow conditions caused by the operation of the sluiceway and intake structure in tandem. Given the limited time period of three weeks to perform the simulations, only one flow case was studied. The model was set up for a fully open sluiceway condition with the project operating at maximum capacity and with the headpond at full supply level. The domain selected for the study precludes the simulation of the operation of the spillway.

The upstream boundary condition, positioned perpendicularly to the river's natural flow direction and defined by the full supply level of 276.3 m, was placed approximately 110 m upstream of the main dam axis in order to limit the effects caused by the high velocities encountered near the entrance of the sluiceway. The downstream boundary was placed approximately 15 m downstream of the dam axis and was defined with a continuative condition, which allowed the supercritical flow in the sluiceway to exit the model domain without affecting upstream flow conditions. This boundary also allowed for the simulation of the fully open gate condition when the flow capacity of the channel is controlled by the geometry of the structure

The lateral boundaries of the domain were defined with a symmetrical condition and were positioned in order to allow a lateral flow component to develop along the embankments of the dam.

Due to the design of the intake structure, which plunges from the horizontal towards the powerhouse via a sharp 90° bend, the final boundary condition is located on the bottom of the domain and is defined with the project's design discharge of 29 m^3/s. The boundary condition was placed in such a way so as to enable only the orifice of the penstock to draw the specified flow from the domain.

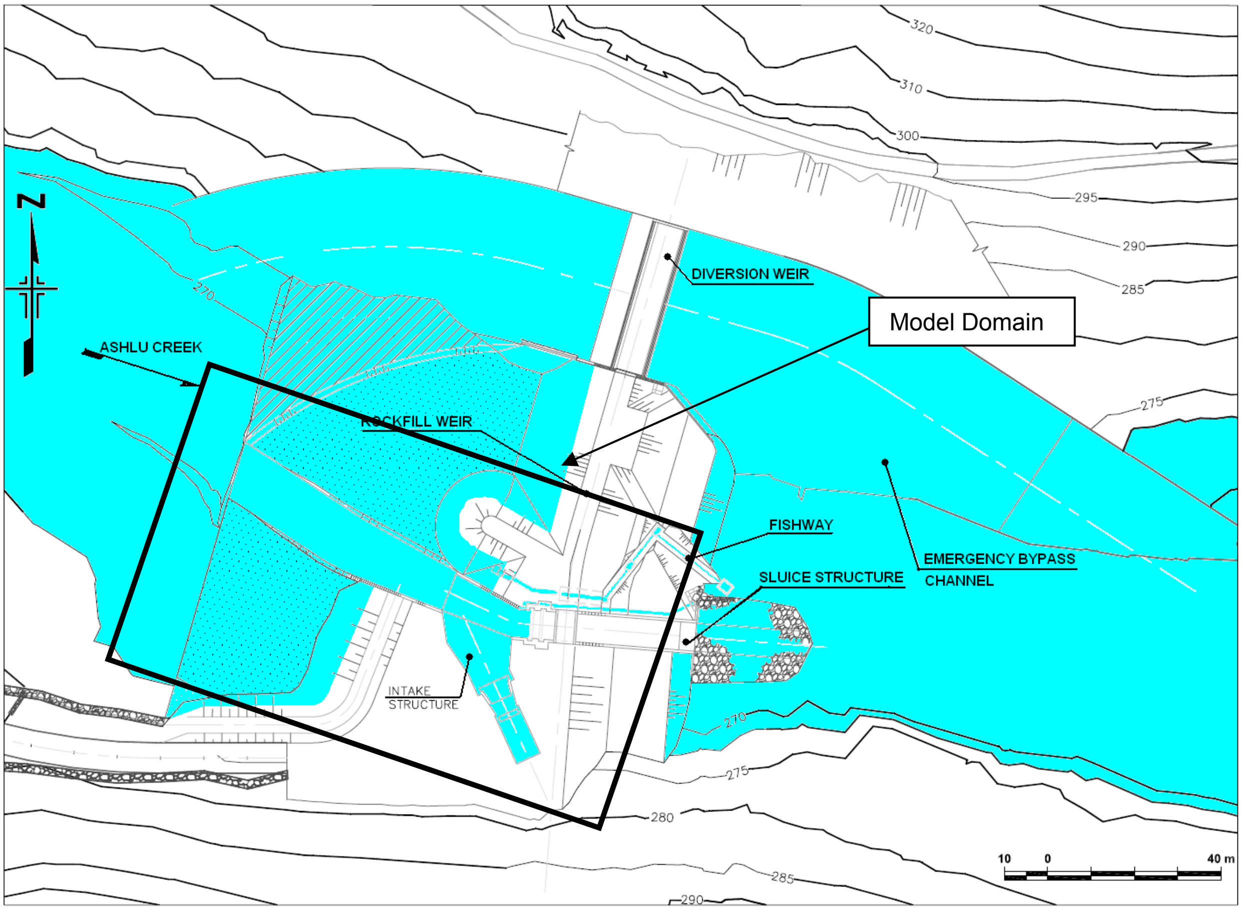

Figure 4: Domain of the Ashlu Creek HEP Flow-3D Model

Figure 5 presents a three dimensional rendering of the simulated flow conditions for the original design of the Ashlu Creek headworks. Note that at this stage, as compared with Figures 2 and 4, the design of the headworks does not yet include the groin located to the left of the sluiceway channel.

The figure illustrates that flow separation occurs at the discontinuity caused by the junction of the main dam's embankment and the entrance to the sluiceway, resulting in the formation of a large, deep, high-velocity vortex. Such hydraulic conditions are not acceptable for a sluiceway designed mainly to flush out gravel and debris that will accumulate in front of the intake structure. In order to enable the proper functioning of the sluiceway and avoid unwanted interferences with the intake flow, two groin alternatives were conceptually developed and modeled in order to better channel the flow in this location.

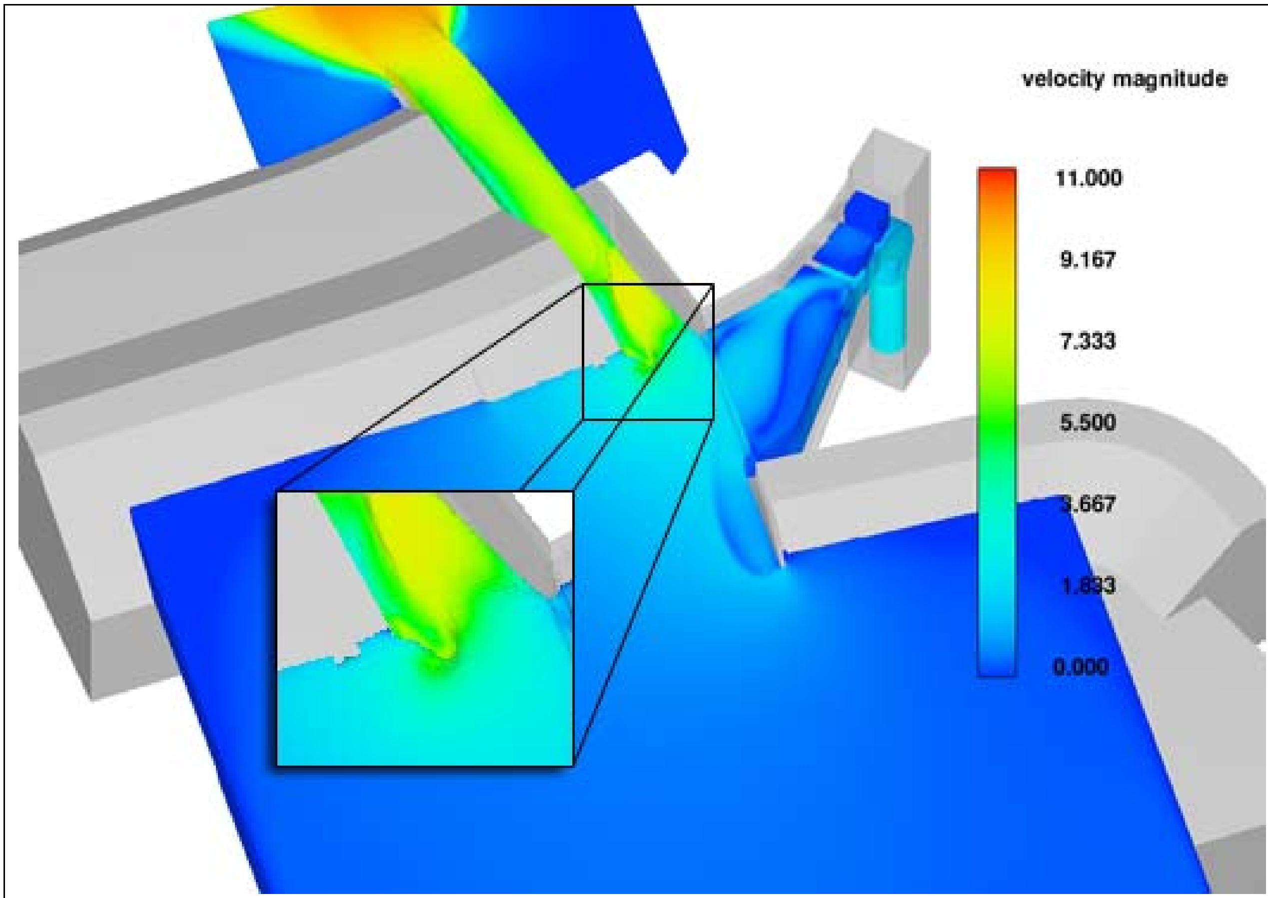

Figure 5: Three-Dimensional Rendering of Flow Conditions during the Operation of the Sluiceway and Intake Structure for the Original Design of the Ashlu Creek Headworks

Figure 6 presents the three-dimensional rendering of the results for the first proposed modification to the headworks design which includes a groin shaped in such a way so as to guide the flow more uniformly towards the sluiceway entrance.

As it is observed, results indicate that the flow conditions were not improved much by this design modification. It was inferred from the results of this simulation that the observed vortex is not only caused by the inherent discontinuity of the dam/sluiceway interface, but also by a submerged concrete retaining wall located to the left of the sluiceway's channel. The final groin design took this fact into account by following the length of this wall.

Figure 7 presents the three-dimensional rendering of the results for the second and final proposed modification to the Ashlu Creek headworks design.

The upstream and downstream views of Figure 7 show that the velocities at the sluice way entrance are greatly reduced and conditions promoting the formation of a large vortex are considerably diminished.

Despite the continual presence of a recirculating region opposite to the intake structure, the design proposed in Figure 7 was retained for construction as it presented a low-cost solution which greatly improved the initial design conditions.

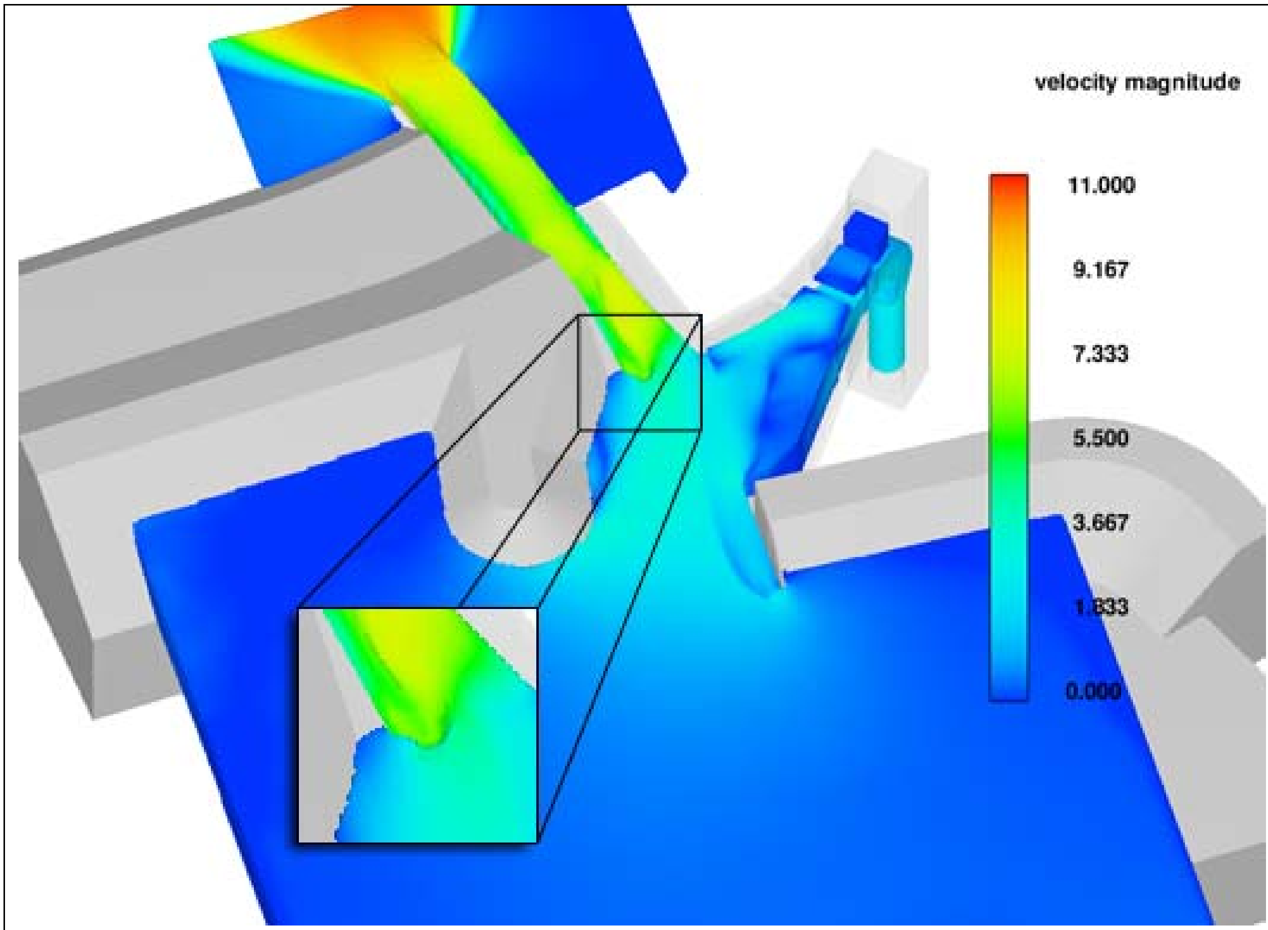

Figure 6: Three-Dimensional Rendering of Flow Conditions during the Operation of the Sluiceway and Intake Structure for the Ashlu Creek Headworks with the 1st Groin

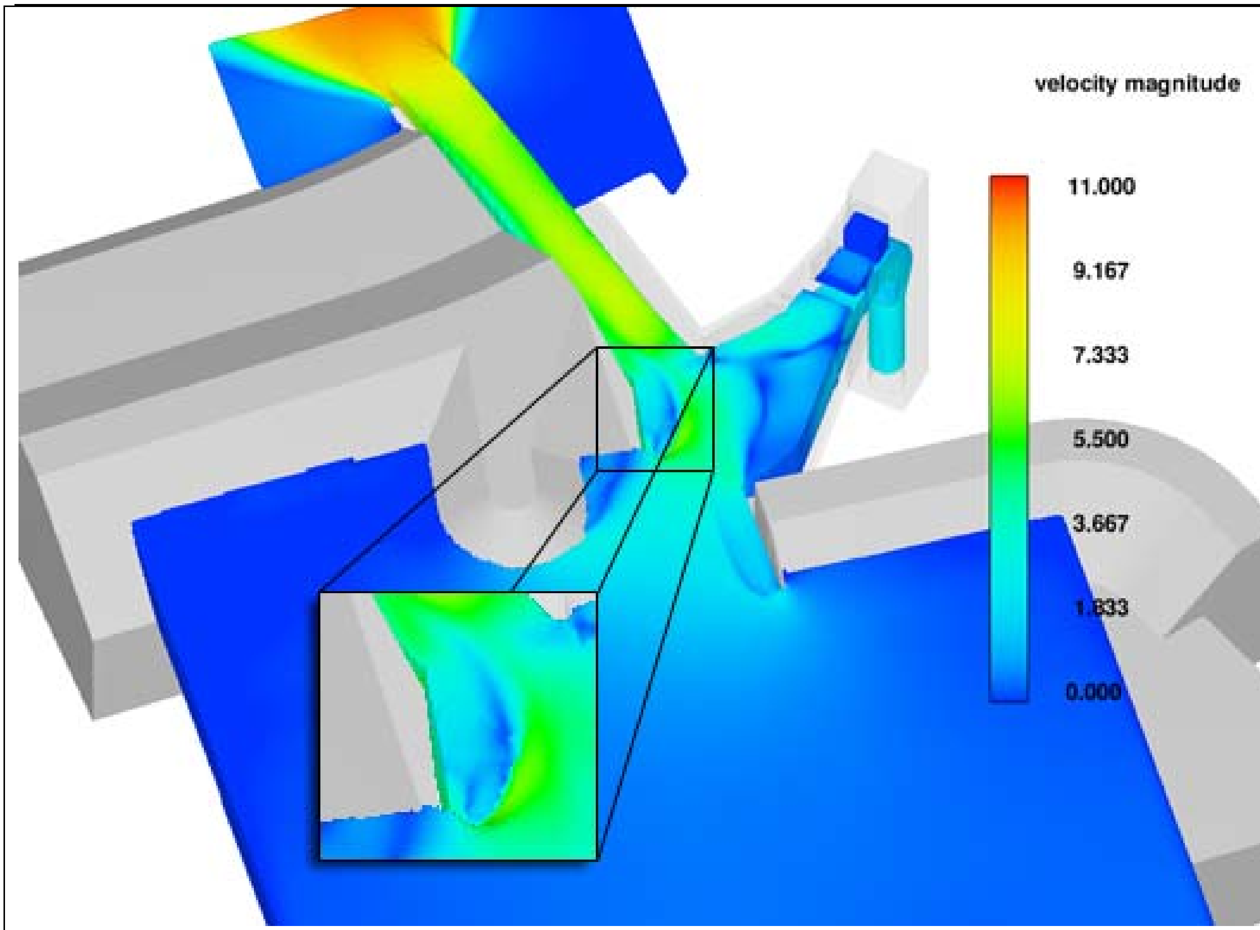

Figure 7: Three-Dimensional Rendering of Flow Conditions during the Operation of the Sluiceway and Intake Structure for the Ashlu Creek Headworks with the 2nd Groin

6. POST-COMMISSIONING OPERATIONS

The project is now in commercial operation and can produce, at full load, up to 54.9 MW as allowed by the contract with BC Hydro (maximum output of 110% of the nominal capacity of 49.9 MW). The flow velocity patterns in the headpond, at the intake and tailrace, are consistent with the design objectives and ensure optimal efficiency of the Ashlu Creek powerhouse.

The velocities observed at the intake entrance while the sluiceway is in operation are in agreement with the numerical models and ensure a smooth operation at all times.

Indeed, figure 9 shows the calm water surface at the intake entrance while the sluiceway is evacuating 50 m^3/s.

Figure 9: Ashlu Creek Sluiceway in operation (50 m^3/s)
Entrance of the structure (left) and gate opening (right)

7. CONCLUSION

The proposed approach demonstrates an efficient alternative to small-scale physical modeling for specific applications in designing hydraulic structures. Using the right numerical models (1D, 2D or 3D), depending on the nature of the flow, to validate the design and arrangement of structures, their proper operation under normal and exceptional conditions, as well as to verify the feasibility of construction phases was found to add significant value to this fast track project. The results were available rapidly to enable an efficient response from the designers and the constructor at the site.

The model was also able to provide to the Owner optimal operating conditions at the intake and sluiceway (maximum flow conditions at sluiceway before diverting flow through the emergency spillway).

The Ashlu Powerhouse can produce at full capacity since the commercial operation on November 29th 2009 - only 39 months after construction began and was built for a total cost of $138 M. The project won two engineering awards in the provinces of Quebec (Leonard Award, AICQ) and British Columbia (Award of Merit, CEBC) in recognition of its innovative approach and design, among others for the numerical modeling developed for the project.