April 18, 2006

CANADIAN PROJECTS LIMITED
#240 – 523 Woodpark Blvd SW
Calgary, AB T2W 4J3

Attention: Mr. Richard Slopek, P.Eng.
Via E-mail: rslopek@canprojects.com

Regarding: Dunvegan Hydroelectric Project
2-Dimensional Numerical Modelling
Additional Construction Sequence Modelling

In response to Canadian Projects Ltd.’s (CPL) request to evaluate additional construction sequence flow scenarios possible during the constructions of the Dunvegan Hydroelectric Project, northwest hydraulic consultants (nhc) has conducted additional 2-Dimensional Numerical Modelling and prepared this letter for your records.

nhc’s modelling effort is based on background information presented in two previous submittals entitled “Dunvegan Hydroelectric Project, 2-Dimensional Numerical Model Study, Technical Report” (May 2003)¹ and “Dunvegan Hydroelectric Project, 2-Dimensional Numerical Model Study, Addendum Report” (July 2004)². This letter report is intended to supplement the previous technical report, summarizing the numerical model test results as they pertain to the expanded construction sequence test program being considered by CPL.

OBJECTIVES
The objective of this analysis is to review the eight stages of the construction sequence using numerical modelling to predict water levels and velocities for the April/May 50% and 95% exceedance flows with respect to upstream fish migration.

Comprehensive rationale and criteria for upstream and downstream fish passage intended to guide, focus and facilitate development of the final design of the fish passage structures was submitted as “Dunvegan Hydroelectric Project, Fish Passage Rational” (February 2006)³.

³ Dunvegan Hydroelectric Project, Fish Passage Rational, February 2006, Northwest Hydraulic Consultants report prepared for Glacier Power Limited c/o Canadian Projects Limited
MODELLING METHODOLOGY
The 2D numerical modelling study for the Dunvegan project utilized the RMA2 hydrodynamic model to represent a 2.7 km river reach extending from a location approximately 700 m upstream of the proposed project site to a location approximately 2000 m downstream (coincides with the location of the Highway 2 Bridge). The RMA2 hydrodynamic model is a depth-averaged finite element model which computes a solution of the Reynolds form of the Navier-Stokes equations for turbulent flows.

There were four major steps taken in predicting the flow conditions using the 2D hydrodynamic model. First, the channel characteristics, including bed topography and instream structures, were defined based on contour bathymetry and project design drawings provided by CPL. Second, a computational mesh for each channel configuration (pre-project, post-project and the various construction sequencing phases) was generated. Third, using the pre-project computational mesh, the model was run and the flow conditions were calibrated to the observed and predicted water surface profiles presented in the March 2000 Dunvegan Hydro Project, Hydrology and Hydraulics Report prepared by UMA Engineering Ltd. Finally, the calibrated roughness and eddy viscosity values were incorporated into the post-project and construction sequencing meshes and steady-state flow conditions along the river channel were computed for each geometry.

Channel Geometry
The riverbed bathymetry required for numerical modelling was adopted from the information provided by CPL. As modelled previously, the channel geometry was simulated over a 2.7 km long reach of the river, beginning approximately 700 m upstream of the proposed project site. Additional drawings representing the various stages of construction were also provide by CPL. The numerical model pre-processor software, SMS, was able to incorporate information from these drawings in developing the computational meshes.

Mesh Generation
Once the channel geometry had been defined, the next step was to generate computational meshes required by the numerical model. These files, defining the spatial and hydraulic characteristics of the channel bed as a series of nodes and elements, were created using SMS as part of the previous work. The meshes adopted for this modelling effort were developed for the previous July 2004 Addendum Report.

Boundary Conditions
The inflow and outflow boundaries were defined for each construction stage at the same time as developing the computational meshes. The upstream boundary conditions were set as steady state inflow discharges while the downstream boundary conditions were defined as either steady state outflow discharges or fixed water surface elevations. Inflow and outflow boundary conditions were adopted from data provided by CPL. Modelled flow conditions represent April/May 50% and 95% exceedance flows of 1,920 m$^3$/s and 954 m$^3$/s, respectively. Water surface elevations of El. 340.8 m and El. 339.7 m at the downstream limit represent flows of 1,920 m$^3$/s.
and 954 m$^3$/s, respectively in accordance with the published stage-discharge curve for
the Water Survey of Canada (WSC) Gauge No. 07FD003, Peace River at Dunvegan
Bridge. Inflows from Hines Creek, which enters the Peace River approximately 900 m
downstream from the project, have not been considered in this analysis. The boundary
conditions for each stage of construction are described below and CPL drawings
defining each stage are reproduced in Appendix A.

- **Construction Stage 1** – The first construction stage involves the staging
  and preparation work. Although there is minimal instream activity prior to
  the placement of the spillway cofferdam, support structures and walkways
  are required for the staging effort. For this stage in the construction
  sequence the pre-construction mesh was adopted. The inflow boundary
  was aligned perpendicular to river centreline approximately 700 m
  upstream of the Project as a steady state river discharge. The outflow
  boundary was also set perpendicular to the river centreline, located near
  the right (south) bridge abutment at the Dunvegan Highway 2 Bridge
  crossing, approximately 2000 m downstream of the project site.

- **Construction Stage 2** – A cofferdam around the Powerhouse Units 1 to 10
  and 31 to 40 will be in place. The upstream inflow and downstream
  outflow boundaries were set along the same transects as were defined for
  the Construction Stage 1 modelling effort. A no-flow boundary
  representing the flow barrier created by the two cofferdam extends from
  both banks.

- **Construction Stage 3** – The third construction stage represents the
  construction of spillway piers and apron. A cofferdam will envelope the
  construction site protruding from Powerhouse Unit 31. Once the
  cofferdam has been removed around Units 1 to 10 and 31 to 40, the
  completed submerged fish sluices will be able to pass flow through the
  structure, if required.

  The upstream inflow and downstream outflow boundaries were set along
  the same transects as were defined for the Construction Stage 1 modelling
  effort. A no-flow boundary was defined around Powerhouse Units 1
  through 10 adjacent to the south shore representing the cofferdam
  required for this stage of construction. Additional flow boundaries were
  defined along both the upstream and downstream limits of the completed
  powerhouse units and submerged fish sluices. These boundaries
  represented flow diverted through completed fish sluices. A no-flow
  boundary representing the flow barrier created by the cofferdam was
  defined around the spillway and apron.

- **Construction Stage 4** – The cofferdams used to isolate the spillway apron
  and piers will be removed and a cofferdam isolating the construction area
  for Powerhouse Units 11 through 20 will be installed. Once the cofferdam
  has been removed from around the empty (no spillway crest) spillway
  bays and flow will be free to pass between the piers and over the apron.

  The upstream inflow and downstream outflow boundaries were set along
  the same transects as defined for the Construction Stage 1 modelling
effort. The flow boundaries representing flow diverted through completed fish sluices remain, and a no-flow boundary representing the flow barrier created by the cofferdam was defined around Powerhouse Units 11 through 20.

- Construction Stage 5 - The cofferdam used to isolate Powerhouse Units 11 to 20 will be removed and a cofferdam isolating the construction area for Powerhouse Units 21 through 30 will be installed. Once the cofferdam has been removed around Units 11 to 20, the completed fish sluices 1 to 3 will pass flow through the structure.

The upstream inflow and downstream outflow boundaries were set along the same transects as defined for the Construction Stage 1 modelling effort. Additional flow boundaries were defined along both the upstream and downstream limits of the completed powerhouse units and fish sluices to represent flow diverted through the completed fish sluices. A no-flow boundary representing the flow barrier created by the cofferdam was defined around Powerhouse Units 21 through 30.

- Construction Stage 6 – The cofferdam used to isolate Powerhouse Units 21 to 30 will be removed and two of the seven spillway bays will blocked using bulkheads located near both the upstream and downstream ends of the spillway piers. Bulkheads isolating spillway bays are necessary for the construction of the final ogee crest in these bays. During Construction Stage 6 the majority of the river flow will pass through the five remaining unfinished spillway bays. In addition, all fish sluices will be able to pass flow.

- Construction Stage 7 - The bulkheads used to isolate the construction of the ogee crests in bays 1 and 2 will be removed and two subsequent bays (3 and 4) will be blocked for construction of the final ogee crests. During Construction Stage 7 the majority of the river flow will pass through the three remaining unfinished spillway bays (5 - 7). If required flow may also pass over the two completed spillway crests and through the completed fish sluices.

- Construction Stage 8 - The bulkheads used to isolate the completed spillway bays will be removed and the remaining three spillway bays will be blocked for construction of the final ogee crests. During Construction Stage 8 the majority of the river flow will pass over the completed spillway crests (Bays 1 – 4) and through the fish sluices.

In simulating the flow conditions associated with the configurations present during Construction Stages 6 through 8 it was found that the high Froude numbers generated through the partially completed spillway bays and fish sluices impacted the stability and reliability of the 2D numerical model. For this reason flow patterns in the vicinity of the structure during Construction Stages 6 though 8 were not calculated using the model. However, tailrace water surface elevations were calculated using the 2D numerical model using the computational mesh developed for the pre-construction modelling, and are presented in Table 1. Flow distribution through the partially completed structure was calculated using the following equations:
- Forebay water surface elevation (Stages 6 to 8)

\[
WSE_{fb} = WSE_{tw} + (C_E + C_p) \cdot \frac{V_{Exit}^2}{2g} + \frac{(V_{Exit} - V_{tw})^2}{2g} - \frac{V_{fb}^2}{2g}
\]

where,  
- \(WSE_{fb}\) = forebay water surface elevation  
- \(WSE_{tw}\) = tailwater water surface elevation (calculated using the 2D numerical model)  
- \(C_E\) = entrance headloss coefficient = 0.6  
- \(C_p\) = pier headloss coefficient = 0.1  
- \(V_{Exit}\) = velocity of the jet as it enters the stilling basin  
- \(V_{tw}\) = mean channel velocity 500 m downstream of the Project (calculated using the 2D numerical model)  
- \(V_{fb}\) = mean channel velocity upstream of the Project

- Flow through the fish sluices using a standard orifice equation (Stages 6 to 8)

\[
Q_{sf} = nCA\sqrt{2g\Delta h}
\]

where,  
- \(Q_{sf}\) = fish sluice discharge  
- \(n\) = number of operational sluiceways  
- \(C\) = orifice coefficient (\(C = 0.6\))  
- \(A\) = sluiceway entrance area (2.1 m diameter)  
- \(\Delta h\) = total head drop between the forebay and tailrace

- Flow over the completed spillway crest using a standard spillway equation (Stages 7 and 8)

\[
Q_s = CLH^{1/2}
\]

where;  
- \(Q_s\) = spillway flow  
- \(C\) = spillway crest coefficient (\(C = 2.0\))  
- \(L\) = length of operational spillway crest (1 spillway bay = 14.3 m of operational spillway length)  
- \(H\) = total head over the spillway crest (gate fully down)

Equations 1) to 3) were solved iteratively resulting in the predicted flow distribution through the Project and upstream water surface elevations. The procedure involved assuming a discharge passing around the completed section of the powerhouse. Knowing the downstream water surface elevation, calculated using the 2D numerical
model, the upstream water surface elevation was then determined using Equation 1). Discharge through the completed fish sluices was then calculated and, if the water surface was above the completed spillway crests (Stage 7 and 8), discharge over the spillway was calculated. If sum of all three discharges equal the total river flow the iteration was complete. However, if the sum of the discharges was greater than the total river flow the iteration continued assuming a lower discharge around the complete section of the powerhouse. Conversely, if the sum of the discharges was less than the total river flow the iteration continued assuming a higher discharge around the completed powerhouse. The resulting flow distributions provided information from which velocities and water surface elevations were calculated using the basic principle of continuity. To verify the acceptability of these equations, they were then used to calculate flow distributions for the earlier Construction Stages and compared to the 2-D modelling results. The results are presented in Table 1.

MODEL RESULTS

Velocities and Water Surface Elevations

Velocities and water depths were calculated for the specified construction sequences to illustrate the predicted flow patterns for the various stages of construction. Figures 1 to 10 present the calculated velocities for the first five construction sequences and ten test conditions simulated using the RMA2 numerical model, and Table 1 presents the calculated water surface elevations immediately upstream and downstream of Project for all eight construction stages. Each figure includes a highlighted contour of indicating the location of the 1 m/s velocity contour. The 1 m/s velocity contour along each bank of the river defines the zone of the river where upstream migrating fish are expected to concentrate.
### Table 1

**Construction Sequence Model Results**

**Velocities and Water Surface Elevation**

<table>
<thead>
<tr>
<th>Construction Sequence</th>
<th>April/May % Exceedance</th>
<th>Reach Boundaries m³/s</th>
<th>Flow Boundaries Flow Boundaries</th>
<th>Water Surface Elevation at the Project (m)</th>
<th>Flow Required to Pass Through Turbine Bays During Construction to Maintain a Water Level Below 348.4 m</th>
<th>Maximum Predicted Velocities m/s</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upstream Discharge</td>
<td>Downstream Water Surface Elevation (m)</td>
<td>Open Channel Sluices Spillway</td>
<td>Upstream</td>
<td>Downstream</td>
</tr>
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<td>- 59 863</td>
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</table>

Note: 1) Water surface elevations estimated using standard open channel flow equations.
DISCUSSION OF RESULTS

In general, the predicted flow patterns and water depths appear to agree well with hydraulic engineering principles. As construction progress through the eight stages, the constriction to the river channel increases generating increased water surface elevations and decreased velocities upstream of the Project and accelerated velocities immediately downstream of the Project. These trends are evident in velocity contour plots and the tabulated values. Velocities approach 8.7 to 10.4 m/s immediately downstream of the spillway piers during Construction Stage 7, the final stage that experiences uncontrolled flow as the final empty (no ogee crest) spillway bays are capable of passing flow. These high velocities may affect the stability of the riprap apron placed downstream of the partially-completed spillway stilling basin.

Following Stage 2, the civil work for a number of powerhouse units will have been completed. These units will be able to pass flow if the Peace River passes an extreme flood event. Flow passing through the completed powerhouse units was not considered in these modelled simulations. Based on the 1,920 m³/s flow results it is not expected that the powerhouse will be required to pass flow during Construction Stages 3 to 7. However, the powerhouse units will be required to pass up to 951 m³/s, a significant percent of the maximum 50% weekly exceedance flow condition, during Stage 8 to maintain a forebay water surface elevation below 348.4 m.

Fish Migration

The construction sequence results demonstrate that the impacts on river currents are most pronounced upstream of the Project. In this reach of the river, there is an overall decrease in the magnitude of the river currents and increase in the flow depth. This translates to a substantial increase in the width of the 1 m/s migration corridor, thus upstream fish migration above the Project will be unhindered.

Flow velocities across the structure and immediately downstream increase as flow accelerates through the constricted channel. However, these high velocities are limited between and immediately downstream from the constriction. A migration corridor (velocities below 1 m/s) downstream of the construction site remains along both banks. The model results demonstrate that during Construction Stages 2 to 5 areas of low velocity extending up to the entrances to the ramp fishway structures exist on both banks, therefore the migration corridor connectivity to the project is retained.

Although it was not possible to use the RMA2 model to compute the expected flow patterns for Construction Stage 6 to 8, it is expected that the high velocity jets predicted for Stages 6 to 8 will dissipate in a manner similar to that illustrated for Stages 3, 4 and 5 (Figures 5 through 10). This should provide an uninterrupted migration corridor along the left (north) bank, while the relatively small discharge volume passing through the completed fish sluices will ensure a wide corridor along the right (south) bank.

Recirculating currents are present downstream from the Project for each of the modelled stages. Figures 3 through 10 illustrate that size of the recirculating zone, or eddy, increases as construction extends farther into the river. It is difficult to determine the influence these flow patterns may have on fish migration behaviour and efficiency of passage due to the relatively short time that they persist during the construction period. However, operation of the fish ramp and potential operation of fish sluices should provide adequate opportunity for passage around the site.
SUMMARY AND CONCLUSION
The RMA2 two-dimensional numerical model was utilized to study the potential impacts construction of the proposed Dunvegan Hydroelectric Project could have on water levels and river currents upstream and downstream of the Project site. Of particular importance was the prediction of the alignment of the fish migration corridors along each bank of the river, which based on previous studies, are defined as the zone of the river where velocities are less than 1 m/s where migrating fish are expected to concentrate.

The model was used to predict flow velocities and water depths along a 2.7 km reach of the river through eight stages of Project construction. The construction sequence results demonstrate that the impacts on river currents and flow depths are most pronounced upstream of the Project where there will be an overall decrease in the magnitude of the river currents and increase in the flow depth. This translates to a substantial increase in the width of the 1 m/s migration corridor.

The model also indicates that flow velocities across the partially-completed structure and immediately downstream of the structure increase as flow accelerates through the constricted channel opening. These high velocities are limited to an area downstream from the construction and are restricted to the centre of the channel. Although the migration corridors (velocities below 1 m/s) disappear at the narrowest section and migration corridor widths are reduced in close proximity to the project site, access to fishway ramps on both banks and the operating fish sluices in the completed powerhouse units should remain unimpeded.

Finally, it was noted that the high velocities predicted during the later stages of construction (up to 10.4 m/s) may affect the stability of the rock riprap placed downstream of the partially-completed spillway stilling basin. Consideration should be given to design the rock protection to withstand these velocities.

I trust the above information is sufficient for your present needs. If you have any questions or require additional information, please feel free to give me a call at 604 980-6011 or send me an e-mail at KChristison@nhc-van.com.

Sincerely,

northwest hydraulic consultants

original signed by

Ken J. Christison, P.Eng.
Associate
Velocity (m/s)

1 m/s contour

Construction Stage 2
April/May 50% Exceedance Conditions
River Discharge = 1,920 cms
3.7
3.4
3.1
2.8
2.5
2.2
1.9
1.6
1.3
1.0
0.7
0.4
0.1

Velocity (m/s)

1 m/s contour

GLACIER POWER LIMITED
DUNVEGAN HYDROELECTRIC PROJECT
NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
2D NUMERICAL MODEL

Construction Stage 3
April/May 50% Exceedance Conditions
River Discharge = 1,920 cms

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FIGURE 5
GLACIER POWER LIMITED
DUNVEGAN HYDROELECTRIC PROJECT
NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
2D NUMERICAL MODEL

Construction Stage 3
April/May 95% Exceedance Conditions
River Discharge = 954 cms

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FIGURE 6
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DUNVEGAN HYDROELECTRIC PROJECT
NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
2D NUMERICAL MODEL

Construction Stage 4
April/May 50% Exceedance Conditions
River Discharge = 1,920 cms

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FIGURE 7
Construction Stage 4
April/May 95% Exceedance Conditions
River Discharge = 954 cms

GLACIER POWER LIMITED
DUNVEGAN HYDROELECTRIC PROJECT
NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
2D NUMERICAL MODEL

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NUMERICAL AND PHYSICAL HYDRAULIC MODEL STUDIES
2D NUMERICAL MODEL

Construction Stage 5
April/May 50% Exceedance Conditions
River Discharge = 1,920 cms

FIGURE 9
1. Maximum upstream 10% exceedence flow - August 17,000 cfs.