4.6 Surface Water Hydrology and Groundwater ............................................................... 4-72
4.6.1 Boundaries .............................................................................................................. 4-72
  4.6.1.1 Spatial Boundaries .......................................................................................... 4-72
  4.6.1.2 Regional Spatial Boundary ........................................................................... 4-72
  4.6.1.3 Local Spatial Boundary ................................................................................ 4-74
  4.6.1.4 Temporal Boundaries .................................................................................. 4-74
  4.6.1.5 Administrative Boundaries ......................................................................... 4-74
  4.6.1.6 Technical Boundaries ................................................................................. 4-75

4.6.2 Description of Existing Conditions ........................................................................ 4-75
   4.6.2.1 Overview ..................................................................................................... 4-76
   4.6.2.2 Hydrology ................................................................................................... 4-76
   4.6.2.3 Diurnal Variability ..................................................................................... 4-79
   4.6.2.4 Design Floods on Tributary Creeks ............................................................ 4-80
   4.6.2.5 Sediment Transport .................................................................................. 4-80
   4.6.2.6 Channel Morphology ................................................................................. 4-82
   4.6.2.7 Hydrogeology ............................................................................................ 4-84

4.6.3 Potential Interactions, Issues and Concerns ............................................................. 4-84
   4.6.3.1 Site C at Taylor, British Columbia ............................................................... 4-85
   4.6.3.2 Naturalization of Flows and the Peace–Athabasca Delta ............................ 4-86
   4.6.3.3 Inundation .................................................................................................. 4-86
   4.6.3.4 Increases in Suspended Sediment in Peace River ..................................... 4-87
   4.6.3.5 Increased Sedimentation .......................................................................... 4-87
   4.6.3.6 Increased Erosion ...................................................................................... 4-87
   4.6.3.7 Hydrogeology ............................................................................................ 4-88

4.6.4 Residual Environmental Effects Evaluation Criteria .............................................. 4-88
4.6.5 Effects Analysis, Mitigation and Residual Effects Prediction ................................ 4-88
   4.6.5.1 Hydraulics ................................................................................................. 4-88
   4.6.5.2 Sediment Transport .................................................................................. 4-98
   4.6.5.3 Channel Morphology within the Headpond .............................................. 4-102
   4.6.5.4 Bed Material (Substrate) Size .................................................................... 4-102
   4.6.5.5 Nearshore Sediment Stability ................................................................. 4-103
   4.6.5.6 Shoreline Stability ..................................................................................... 4-103
   4.6.5.7 Channel Morphology Downstream from the Headworks ....................... 4-106
   4.6.5.8 Summary of Inundation, Sedimentation and Erosion Effects .................. 4-107
   4.6.5.9 Cumulative Environmental Effects ............................................................ 4-113
   4.6.5.10 Residual Environmental Effects .............................................................. 4-113

4.6.6 Monitoring ............................................................................................................ 4-114
4.6.7 Summary .............................................................................................................. 4-114

List of Tables

Table 4.6-1: Water Survey of Canada Streamflow Gauges used in the Hydrology
Assessment ......................................................................................................................... 4-75
Table 4.6-2: Naturalized and Post-Bennett Dam Flood Flows, Peace River at Dunvegan .... 4-79
Table 4.6-3: Naturalized and Post-Bennett Dam Low Flows, Peace River at Dunvegan .... 4-79
Table 4.6-4: Suspended Sediment Concentrations at Dunvegan Bridge, 1975-1996 ..............4-80
Table 4.6-5: Suspended Sediment Concentrations at Town of Peace River, 1973-1990 ....4-81
Table 4.6-6: Estimate of Total Suspended Sediment Load at Dunvegan ............................4-81
Table 4.6-7: Estimate of Bed Load and Bed Material Load at Dunvegan..............................4-82
Table 4.6-8: Predicted Post-Bennett Dam Hydraulic Geometry as a Percentage of the Pre- Bennett Dam Conditions .................................................................4-83
Table 4.6-9: Project Environmental Effects Interaction Matrix: Surface Water Hydrology and Groundwater .................................................................4-84
Table 4.6-10: Frequency of Powerhouse Overtopping ....................................................4-90
Table 4.6-11: Pre- and Post- Bennett Dam Flows ............................................................4-90
Table 4.6-12: Flow Velocity Summary at Dunvegan, Naturalized and Post-Bennett Dam and with the Project .................................................................4-95
Table 4.6-13: Headpond Length, Area of Inundated Shoreline and Mean Water Resident Time as a Function of Discharge ......................................................4-97
Table 4.6-14: Extent of Shoreline Types in the Dunvegan Headpond ................................4-106
Table 4.6-15: Environmental Effects Assessment Matrix: Surface Water Hydrology and Groundwater .................................................................4-108
Table 4.6-16: Residual Environmental Effects Summary Matrix: Surface Water Hydrology and Groundwater ...........................................................4-114

List of Figures

Figure 4.6-1: Spatial Boundaries for Surface Water Hydrology and Groundwater ............4-73
Figure 4.6-2: Peace River at Dunvegan Mean Daily Flows ................................................4-77
Figure 4.6-3: Peace River at Dunvegan Minimum and Maximum Daily Flows ..................4-78
Figure 4.6-4: Peace River at Dunvegan - Hydrographs for Wet, Normal and Dry Years ....4-89
Figure 4.6-5: Water Surface Profile at Project 5 Percent Exceedance Flow ......................4-92
Figure 4.6-6: Water Surface Profile at Project 50 Percent Exceedance Flow ....................4-93
Figure 4.6-7: Water Surface Profile at Project 95 Percent Exceedance Flow ....................4-94
Figure 4.6-8: Dunvegan Project General Flow Patterns, May–June .................................4-96
Figure 4.6-9: Downstream Variation in Average Headpond Water Velocity for the 50 percent Exceedance Flow in Relation to the Predicted Water Velocity at the Gravel-Sand Transition ..................................................4-99
Figure 4.6-10: Downstream Variation in Average Headpond Water Velocity for the 2-year Return Period Flood in Relation to the Predicted Water Velocity at the Gravel-Sand Transition ........................................................................4-100
Figure 4.6-11: Downstream Variation in Average Headpond Water Velocity for the 5-year Return Period Flood in Relation to the Predicted Water Velocity at the Gravel-Sand Transition ........................................................................4-101
Figure 4.6-12: Sediment Deposition in the Headpond over a 10-year Period ......................4-104
Figure 4.6-13: Sediment Deposition in the Headpond over a 50-year Period ....................4-105
4.6 Surface Water Hydrology and Groundwater

Surface water hydrology and groundwater conditions at the project site have been identified as a valued environmental component (VEC) in the AENV Terms of Reference for the EIA. This section includes descriptions of the unregulated and present hydrologic regimes (before and after the construction and operations of the Bennett Dam), and assesses the potential environmental effects of the Project on river regime, surface water hydrology and groundwater resources. The discussion of environmental effects includes flood discharges, flood stages, water levels, flow velocities, flow patterns, sediment discharge and erosion and scour. The anticipated storage volume of the headpond and mean residence time are discussed, and the location of turbulent water is identified.

The information on the surface water hydrology and groundwater VEC is taken from four technical reports prepared for the Project. Hydrology and hydraulics were examined by Mack, Slack & Associates Inc. (MSA 2006, MSA 2005) and Northwest Hydraulic Consultants. The sediment transport and channel morphology conditions were examined by M. Miles & Associates Ltd. (MMA) (2000, 2006). More detailed information on the VEC can be found in these reports.

4.6.1 Boundaries

4.6.1.1 Spatial Boundaries

The spatial boundaries for the surface water hydrology and groundwater VEC include both a regional study area (RSA) and a local study area (LSA), to allow for the assessment of potential environmental effects of the Project on the Peace River mainstem from Bennett Dam to Great Slave Lake. Figure 4.6-1 presents the spatial boundaries for the surface water hydrology and groundwater VEC.

4.6.1.2 Regional Spatial Boundary

The Peace River is a major tributary in the Mackenzie River basin. The RSA for the hydrology component of the EIA encompasses the entire Peace River drainage basin from the Rocky Mountains of northeast British Columbia across the Alberta Plateau to the confluence with the Slave River north of Lake Athabasca (Figure 4.6-1), an area of approximately 168,000 km². The Peace River basin contains four important features that have an affect on or are affected by the hydrological regime:

- the Williston Reservoir formed by the Bennett Dam at Hudson’s Hope
- the Peace Canyon Dam
- the Peace–Athabasca Delta
- the Vermilion Chutes rapids

Although outside the Peace River basin, the Slave River Delta, on the south side of Great Slave Lake, is also influenced significantly by the Peace River flow regime.

The regional study area was chosen on the basis of the need to examine the project environmental effects in a basin-wide context and the influence the Project might have on communities some distance upstream and downstream from the project site.
Regional Study Area

Local Study Area

Scale 1:2 000 000
PROPOSED LOCATION OF DUNVEGAN HYDROELECTRIC PROJECT

GLACIER POWER LTD.
DUNVEGAN PROJECT
Spatial boundaries for Surface Water Hydrology and Groundwater

DUNVEGAN
4.6-1
Given the expected local interaction of the Project with groundwater and sedimentation, the RSA for those components was the same as the LSA.

4.6.1.3 Local Spatial Boundary

The LSA includes the Peace River mainstem and tributaries potentially affected by the project components (i.e., headworks structure, headpond and access roads). The LSA extends from the Town of Peace River upstream to the Bennett Dam at Hudson’s Hope, for the hydrology component, and to the upstream end of the headpond for the groundwater and sedimentation components.

This LSA was chosen on the basis of several considerations including:

- flow regulation at Bennett Dam
- Water Survey of Canada (WSC) flow gauging stations at the Town of Peace River, Taylor and the Highway 2 Bridge crossing at Dunvegan Historic Park
- potential effect of the Project on infrastructure, nearby land owners and lease holders, recreational users, tour operators and trappers and guide outfitters

4.6.1.4 Temporal Boundaries

The temporal boundaries for the surface water hydrology and groundwater VEC extend from before the construction of the Bennett Dam—to address the hydrological conditions of Peace River before regulated flows, through construction, operations, abandonment and post-closure. This covers the period from 1915 through 2111, under the following periods:

- pre-Bennett Dam (1915 to 1967)
- post-Bennett Dam without the proposed Project (1967 to 2007)
- post-Bennett Dam during construction of the proposed Project (2008 to 2011)
- post-Bennett Dam with the proposed Project (2011 to 2111)

4.6.1.5 Administrative Boundaries

Administrative boundaries for the surface water hydrology and groundwater VEC consist of the following:

- location of WSC flow gauging stations
- the boundaries of the Northern River Basins Study, and its successor, the Northern Rivers Ecological Initiative, which were used as a source of information for the VEC
- the boundaries of the Mackenzie River Basin Board, established to protect the aquatic ecosystems and traditional lifestyles of the Mackenzie River Basin
- BC Hydro’s administration of the Bennett Dam
The locations of the Water Survey of Canada streamflow gauges and the years of operation are presented in Table 4.6-1.

### Table 4.6-1: Water Survey of Canada Streamflow Gauges used in the Hydrology Assessment

<table>
<thead>
<tr>
<th>Gauge Name</th>
<th>Total Years of Operation up to 2003</th>
<th>Pre-Bennett Dam Records</th>
<th>Post-Bennett Dam Records</th>
<th>Maximum Instantaneous Flows</th>
<th>Maximum Daily Flows</th>
</tr>
</thead>
</table>

#### 4.6.1.6 Technical Boundaries

Technical boundaries for the surface water hydrology and groundwater VEC consist of the following:

- limited pre-Bennett Dam flow data for the project site, necessitating hydrologic analyses to estimate the pre-Bennett Dam flows

- unavailability, at the time of report preparation, of Bennett Dam flow regulation data and flood flow routing procedures from BC Hydro to use in determining deregulated flows, necessitating the need to calculate these data using the available WSC data and conventional flood frequency analysis methods

- lack of winter flow data at the Dunvegan gauge for use in the pre- and post-Bennett Dam scenarios, necessitating extrapolation of low winter flows recorded at other Peace River gauges

The information available to the study team is sufficient to assess the environmental effects of the Project on the surface water hydrology and groundwater of the area.

#### 4.6.2 Description of Existing Conditions

The existing surface water hydrology conditions on Peace River are a result of the construction of the Bennett Dam and the regulation of flows since the late 1960s. The following description of existing conditions includes comparisons of pre- and post-Bennett Dam hydrology of the RSA.
4.6.2.1 Overview

The drainage basin of the Peace River at the Water Survey of Canada gauging station at Dunvegan is 128,500 km². Roughly half of this area lies in the Rocky Mountain Trench, which receives about 500 mm of precipitation annually. Another 20 percent of the basin lies on the eastern slopes of the Rocky Mountains where precipitation is slightly more than 500 mm annually. The remainder of the basin (39,500 km²) on the Alberta Plateau, receives slightly less precipitation than the upstream portions of the basin. A small area of the basin in the mountains at the headwaters of the Parsnip, Moberly and Pine rivers receives about triple the precipitation of the other portions of the basin.

The river channel at the proposed headworks site has a width of approximately 400 m and an average depth of 4.2 m (at average annual flows). The channel banks vary in steepness but show signs of vegetation encroachment below the original flood level trim line (tree root line formed by pre-Bennett Dam floods).

4.6.2.2 Hydrology

Construction of the Bennett Dam was completed in 1967. Filling of the Williston Reservoir from 1968 to 1972 resulted in a net storage of approximately 41 billion m³ of water. Unrestricted, the discharge of Peace River varied seasonally. The Bennett Dam has dampened the range of annual peak and low flows, but increased daily fluctuations. Also, the low-flow period has become restricted from the late summer through winter-to-early-spring period (pre-Bennett Dam) to only a few weeks in late summer (post-Bennett Dam).

Two hydrologic regimes are discussed in this section: naturalized and post-Bennett Dam. Post-Bennett Dam flow is defined as the flow that has actually occurred since Williston Reservoir was filled in 1972. Naturalized flow is defined as the flow that occurred before the reservoir filling began in 1968, and that would have occurred since then if Bennett Dam had not been constructed. Naturalized flows at Dunvegan were estimated by combining historical pre-Bennett Dam flows with derived naturalized flows for the post-Bennett Dam period (1972-2003). The naturalized flows provide a simulated flow record on the Peace River from 1915 to 1921, 1944 to 1967 and 1972 to 2003. The period of June 25 to August 19, 1996, when unusually large releases were made from Bennett Dam to lower the reservoir level in response to a sinkhole that appeared in the dam crest, was omitted from statistical analyses of post-Bennett Dam flows.

4.6.2.2.1 Naturalized and Post-Bennett Dam Flood Flows

As a result of flow regulation, mean monthly flows have generally decreased in the summer and increased in winter. This is shown in Figure 4.6-2, which compares mean daily flows, and in Figure 4.6-3 that compares minimum and maximum daily flows at Dunvegan for the naturalized and post-Bennett Dam scenarios. The Bennett Dam has significantly reduced the spring peak flows and eliminated the natural fall flow recession.

The environmental effect of regulation generally decreases with distance downstream as additional unregulated tributaries contribute flow. At Hudson’s Hope, mean monthly flows in summer have been reduced by one-half and mean winter flows have increased up to four-fold. At Peace Point, approximately 830 km downstream from Dunvegan, the regulated summer flows are two-thirds of the unregulated flows before Bennett Dam, while winter flows are 2.5 times larger.
Figure 4.6-2: Peace River at Dunvegan Mean Daily Flows
Figure 4.6-3: Peace River at Dunvegan Minimum and Maximum Daily Flows

![Graph showing daily discharges for different periods and conditions.]

- Naturalized Maximum
- Naturalized Minimum
- Post-Bennett Maximum
- Post-Bennett Minimum
Table 4.6-2 shows naturalized and post-Bennett Dam flood flow estimates for Peace River at Dunvegan. The extreme flood events are typically observed in June.

<table>
<thead>
<tr>
<th>Return Period (years)</th>
<th>Naturalized Flood Flow (m$^3$/s)</th>
<th>Post-Bennett Dam Flood Flow (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7,490</td>
<td>3,680</td>
</tr>
<tr>
<td>5</td>
<td>9,120</td>
<td>4,920</td>
</tr>
<tr>
<td>10</td>
<td>10,200</td>
<td>5,750</td>
</tr>
<tr>
<td>20</td>
<td>11,300</td>
<td>6,540</td>
</tr>
<tr>
<td>50</td>
<td>12,700</td>
<td>7,570</td>
</tr>
<tr>
<td>100</td>
<td>13,800</td>
<td>8,330</td>
</tr>
<tr>
<td>200</td>
<td>14,900</td>
<td>9,100</td>
</tr>
<tr>
<td>500</td>
<td>16,600</td>
<td>10,100</td>
</tr>
<tr>
<td>1000</td>
<td>17,800</td>
<td>10,900</td>
</tr>
</tbody>
</table>

4.6.2.2.2 Naturalized and Post-Bennett Dam Low Flows

Winter flows have generally not been recorded at the Dunvegan gauge for use in the naturalized and post-Bennett Dam scenarios. Data sets of daily flows were produced using flows recorded at other locations on the Peace River and its tributaries, as described by MSA (2006). The results of the low-flow analysis are shown in Table 4.6-3.

<table>
<thead>
<tr>
<th>Return Period (Years)</th>
<th>Naturalized Low Flow (m$^3$/s)</th>
<th>Post-Bennett Dam Low Flow (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>212</td>
<td>579</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>493</td>
</tr>
<tr>
<td>10</td>
<td>158</td>
<td>456</td>
</tr>
<tr>
<td>20</td>
<td>145</td>
<td>429</td>
</tr>
<tr>
<td>50</td>
<td>132</td>
<td>403</td>
</tr>
<tr>
<td>100</td>
<td>124</td>
<td>387</td>
</tr>
<tr>
<td>200</td>
<td>117</td>
<td>373</td>
</tr>
<tr>
<td>500</td>
<td>109</td>
<td>358</td>
</tr>
<tr>
<td>1000</td>
<td>104</td>
<td>348</td>
</tr>
</tbody>
</table>

The extreme event low flows of the post-Bennett Dam era (1972 to present) are considerably greater than what would have occurred if the dam was not constructed and flows within the Peace River regulated.

4.6.2.3 Diurnal Variability

The Peace River discharge fluctuates during the day, partially in response to variable Bennett Dam releases, and the fluctuations are noticeable at Dunvegan. The river discharge is typically highest around midnight and lowest around noon. The diurnal range, defined as the daily difference between the maximum and minimum discharge, was computed for each day of the available hourly record. The median diurnal range (i.e., the value exceeded 50 percent of the time) is 210 m$^3$/s, and the diurnal range has varied from zero to 4200 m$^3$/s. The maximum value of 4200 m$^3$/s occurred when the river discharge increased fairly rapidly on June 12, 1990, apparently in response to a major rainfall event rather than to upstream flow regulation. The diurnal range falls between 100 and 400 m$^3$/s almost...
60 percent of the time. The diurnal range is greater in summer than in winter; however, most of the hourly data obtained from WSC was collected during the open-water season; therefore, the winter estimates are based on relatively few observations and are consequently highly uncertain.

4.6.2.4 Design Floods on Tributary Creeks

As part of the Project, bridges may be constructed across two tributaries of the Peace River upstream from Dunvegan. Estimates of the 1:200 return period flood discharge are required for the design of the bridge crossings near the mouths of both of Dunvegan Creek and Hines Creek. The estimates are based on data collected by WSC at two nearby hydrometric stations, Hines Creek near Fairview and Young Drainage Project near Spirit River. The gross catchment areas of Dunvegan Creek at the mouth and Hines Creek at the mouth are 144 km² and 1,485 km², respectively.

4.6.2.5 Sediment Transport

Carson and Associates (1991) have reviewed analyses of the suspended sediment data on Peace River and calculations of annual suspended sediment loads have been presented in Carson and Associates (1992a, b), Carson and Hudson (1997) and Church et al. (1997). The data have all been collected after the construction and operation of the Bennett Dam.

4.6.2.5.1 Seasonal Variation in Suspended Sediment Transport

Table 4.6-4 illustrates the suspended sediment concentrations for Peace River at Dunvegan. The peak sediment concentration at Dunvegan occurs in the spring and early summer as a result of snowmelt- and rainfall-derived inflow from unregulated tributary streams. Various reports (Carson and Associates 1992a; Carson and Hudson 1997; Church et al. 1997) indicate that the area upstream from Bennett Dam is composed of comparatively erosion-resistant materials that limit the supply of both suspended sediment and bed material load. In contrast, the erosion-prone material comprising the Alberta Plateau produces some of the highest observed rates of sediment production per unit area in British Columbia and Alberta. The construction of the Bennett Dam is not expected to have significantly reduced the sediment availability in the downstream river, since most of the sediment comes from tributaries downstream from the dam.

Table 4.6-4: Suspended Sediment Concentrations at Dunvegan Bridge, 1975-1996

<table>
<thead>
<tr>
<th>Month</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>78</td>
<td>315</td>
<td>482</td>
<td>7</td>
</tr>
<tr>
<td>May</td>
<td>0</td>
<td>481</td>
<td>2470</td>
<td>20</td>
</tr>
<tr>
<td>June</td>
<td>79</td>
<td>439</td>
<td>4730</td>
<td>24</td>
</tr>
<tr>
<td>July</td>
<td>32</td>
<td>255</td>
<td>1390</td>
<td>16</td>
</tr>
<tr>
<td>August</td>
<td>11</td>
<td>87</td>
<td>734</td>
<td>15</td>
</tr>
<tr>
<td>September</td>
<td>5</td>
<td>46</td>
<td>221</td>
<td>15</td>
</tr>
<tr>
<td>October</td>
<td>10</td>
<td>31</td>
<td>115</td>
<td>11</td>
</tr>
</tbody>
</table>

The maximum suspended sediment concentration of 4730 mg/L was observed on June 13, 1977 during an estimated flow of 3200 m³/s, which has a return period of less than two years in the post-Bennett Dam flow regime. The associated daily suspended sediment load was estimated by WSC to be...
1.3 Mt/d (megatonnes [1000 tonnes] per day), or slightly less than ten percent of the average annual load of 15.6 Mt.

Table 4.6-5 exemplifies the suspended sediment data for Peace River at the Town of Peace River. This site is below the confluence with Smoky River that is known to produce large quantities of suspended sediment (Church 1995).

Table 4.6-5: Suspended Sediment Concentrations at Town of Peace River, 1973-1990

<table>
<thead>
<tr>
<th>Month</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5</td>
<td>18</td>
<td>37</td>
<td>156</td>
</tr>
<tr>
<td>February</td>
<td>6</td>
<td>20</td>
<td>56</td>
<td>143</td>
</tr>
<tr>
<td>March</td>
<td>7</td>
<td>34</td>
<td>122</td>
<td>162</td>
</tr>
<tr>
<td>April</td>
<td>10</td>
<td>934</td>
<td>6400</td>
<td>181</td>
</tr>
<tr>
<td>May</td>
<td>20</td>
<td>935</td>
<td>7410</td>
<td>514</td>
</tr>
<tr>
<td>June</td>
<td>88</td>
<td>824</td>
<td>11,400</td>
<td>510</td>
</tr>
<tr>
<td>July</td>
<td>18</td>
<td>528</td>
<td>5100</td>
<td>516</td>
</tr>
<tr>
<td>August</td>
<td>6</td>
<td>401</td>
<td>12,800</td>
<td>482</td>
</tr>
<tr>
<td>September</td>
<td>1</td>
<td>83</td>
<td>1320</td>
<td>457</td>
</tr>
<tr>
<td>October</td>
<td>4</td>
<td>52</td>
<td>425</td>
<td>465</td>
</tr>
<tr>
<td>November</td>
<td>3</td>
<td>39</td>
<td>127</td>
<td>178</td>
</tr>
<tr>
<td>December</td>
<td>5</td>
<td>23</td>
<td>47</td>
<td>156</td>
</tr>
</tbody>
</table>

The maximum observed suspended sediment concentrations of 12,800 mg/L occurred on August 3, 1987 during a flow of 11,400 m$^3$/s. The second highest value of 11,400 mg/L occurred on June 13, 1990 during a flow of 16,100 m$^3$/s. WSC has calculated that the associated sediment loads were 12.6 Mt/d and 15.9 Mt/d, respectively. These daily values represent 37 and 47 percent of the average sediment load of 33.7 Mt/d estimated by Carson and Associates (1992a).

The data from Dunvegan and the Town of Peace River indicate that very high suspended sediment concentrations occur periodically, suspended concentrations remain elevated throughout the open-water period, and that 10 to 47 percent of the average annual sediment load can occur in one day.

4.6.2.5.2 Annual Sediment Loads

Water from Bennett Dam has low suspended sediment concentration, while stream flow water from the downstream tributaries can have comparatively higher values. Thus the suspended sediment concentrations or loads at Dunvegan vary depending on the water source. Timing is also important as flows in May and June typically carry more sediment in comparison to similar flows which may occur later in the open water season. Table 4.6-6 is an estimate of seasonal and annual suspended sediment loads at Dunvegan, based on work by Carson and Associates (1992a).

Table 4.6-6: Estimate of Total Suspended Sediment Load at Dunvegan

<table>
<thead>
<tr>
<th></th>
<th>Total Suspended Sediment Load (Mt/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seasonal</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.0</td>
</tr>
<tr>
<td>Average</td>
<td>13.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>33.4</td>
</tr>
</tbody>
</table>
Estimates of bed load (gravel more than or equal to 2 mm diameter) and bed material load (sand and gravel more than or equal to 0.18 mm diameter) at Dunvegan are presented in Table 4.6-7. Bed load estimates are based on the work of McLean et al. (1999). Bed material load estimates are based on Church et al. (1997) and Komura (1963).

Table 4.6-7: Estimate of Bed Load and Bed Material Load at Dunvegan

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Average Annual Load</th>
<th>t/yr</th>
<th>m³/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed load (gravel: ≥ 2 mm)</td>
<td></td>
<td>2.3 x 10^5</td>
<td>150,000</td>
</tr>
<tr>
<td>Bed material load (sand and gravel: ≥ 0.18 mm)</td>
<td></td>
<td>7.8 x 10^5</td>
<td>500,000</td>
</tr>
</tbody>
</table>

A bed-material sampling program near the proposed headworks found the channel to have a gravel bed with a surface armour layer with an average (or D₅₀) size of approximately 80 mm and a finer, more poorly sorted subsurface materials with D₅₀ values ranging from 8 to 13 mm.

4.6.2.6 Channel Morphology

The Peace River, near Dunvegan, consists of a single-thread channel that is frequently confined by valley walls approximately 200 m high. Flat valley areas are discontinuous and consist of isolated sections of fluvial terrace and fans built up at the mouths of tributary streams. Islands are uncommon and areas of sediment accumulation are typically poorly developed and consist of small point or lateral bars. One large diagonal bar is present at a site 17 km upstream from the proposed headworks.

Three sizeable tributary streams enter the proposed headpond: Fourth Creek (basin area 254 km²), Hamelin Creek (basin area 647 km²) and Ksituan River (basin area 831 km²). Hines Creek (basin area 1610 km²) and Dunvegan Creek (basin area 146 km²) flow into Peace River immediately downstream from the proposed headworks. The tributary streams have formed sizeable fans at their confluences with Peace River. These streams appear to be the most important sediment sources within the LSA.

Following construction of the Bennett Dam, the reduced peak flows have been less competent to move the coarser textured components of the sediment load supplied by the tributaries and these materials have deposited on the fans or along the downstream bank. These deposits may be locally affecting channel slope and appear to have played a role in determining the location of bars and islands. For example, the best developed pattern of point bars, diagonal bars and islands occur near and downstream from the Fourth Creek and Hamelin Creek fans.

The environmental effects of the Bennett Dam on channel morphology have been studied using historical air photos, river regime analysis and repetitive river cross-section surveys.

4.6.2.6.1 Analysis of Historical Air Photos

Air photo analysis has shown that:

- tributary fans such as Fourth Creek, Ksituan River, Hamelin Creek and Hines Creek have enlarged and developed a vegetation cover as a result of the reduced flood velocities and water levels

- better definition of the diagonal bar at km 17 is occurring, indicating increased sediment deposition
• higher elevated bars, such as at km 18 are becoming vegetated islands
• side channels which formerly separated islands from the adjacent valley flat have been abandoned and become vegetated
• sand and silt are being locally deposited along the channel margins

These processes are resulting in a narrower and more sinuous channel, particularly in areas with a local sediment source or in multi-thread alluvial sections of channel.

4.6.2.6.2 Regime Analysis

Regime analysis relates the hydraulic geometry of the channel to flow. As shown in Table 4.6-2, the Bennett Dam has reduced the size of the two-year return period daily flood from 7840 to 3490 m³/s. The regulated flow is thus 45 percent of the unregulated value. On the basis of regime equations, the predicted post-Bennett Dam hydraulic geometry is shown in Table 4.6-8.

<table>
<thead>
<tr>
<th>Channel Parameter</th>
<th>% of Pre-Bennett Dam Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel width, alluvial sections</td>
<td>67</td>
</tr>
<tr>
<td>Channel width, non-alluvial sections</td>
<td>88</td>
</tr>
<tr>
<td>Average Depth</td>
<td>73 to 77</td>
</tr>
<tr>
<td>Average Velocity</td>
<td>87 to 92</td>
</tr>
</tbody>
</table>

Using historical air photos, Church (pers. comm.) carried out 1:20,000-scale planimetric mapping of the channel banks and vegetation boundaries for the area between the British Columbia–Alberta border and the Dunvegan Bridge. His analysis indicates that the average channel width in this area before Bennett Dam (1966 to 1969) was 449 m. By 1993, this width was reduced to 402 m or 90 percent of the pre-Bennett Dam value. The channel is still in the process of attaining equilibrium with the post-Bennett Dam conditions.

4.6.2.6.3 Repetitive River Cross-Section Surveys

Five cross sections of Peace River near the project headworks or Dunvegan Bridge have been surveyed at least twice between 1968 and 1999 and give an indication of the environmental effect of the Bennett Dam on channel morphometry. Four sections at the headworks, between the headworks and Dunvegan Bridge, and at the bridge suggest that the left bank (while looking downstream) of Peace River has been prograding, the average elevation of the river bed has been decreasing and the channel thalweg on the opposite side of the river has been deepening since the construction of Bennett Dam. Inspection of the historical air photos indicates that the enlargement of the Hines Creek fan (due to decreased flood flows since the construction of the dam) and the resulting constriction of the mainstem channel of Peace River is the most likely cause of this change in morphometry. A section 3.1 km downstream from Dunvegan Bridge suggests no significant change in channel cross section since construction of the Bennett Dam.
4.6.2.7 Hydrogeology

There is a lack of information on the hydrogeology of the RSA. Jones (1966) carried out an overview of groundwater resources in the Peace River district and Hackbarth (1976) studied the hydrogeology of the Grande Prairie area, which includes the LSA. Hackbarth reported that in the northern part of the Grande Prairie area, groundwater is not usually available and is of very poor quality. Three groundwater sources are available in the area: the buried-channel deposits of the preglacial Peace River valley, the alluvial surficial deposits and the Dunvegan Formation. As was discussed in Section 4.3, the preglacial valley is not present in the LSA. Hackbarth identified the alluvial terrace along the Peace River at Dunvegan as producing large volumes of water for vegetable farming and that high yields can probably be sustained by induced infiltration. He also noted that the Pleistocene terrace gravel deposits along the bluffs of the Peace River have been used for local water supply. Given the clay present in the Kaskapau Formation, which overlies the Dunvegan Formation and forms a cap on upward movement of groundwater from the Dunvegan, the groundwater in the alluvial terraces is likely derived from surface infiltration.

There are no water licences or groundwater wells in the headpond area.

4.6.3 Potential Interactions, Issues and Concerns

Interactions of the Project with the Surface Water Hydrology and Groundwater VEC will take place during all project phases, but primarily during the operations and decommissioning phases. Table 4.6-9 summarizes these interactions. The concerns regarding interactions of the Project with the Surface Water Hydrology and Groundwater VEC are related to increases in suspended sediment in the river, inundation, sedimentation and erosion.

Table 4.6-9: Project Environmental Effects Interaction Matrix: Surface Water Hydrology and Groundwater

<table>
<thead>
<tr>
<th>Project Activities and Physical Works</th>
<th>Inundation</th>
<th>Increase Suspended Sediment</th>
<th>Sedimentation</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access Roads, Transmission Lines, Borrow Excavation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream Crossings</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of Headworks and Headpond</td>
<td>X X X X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decommissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Removal of Facilities</td>
<td>X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malfunctions, Accidents and Unplanned Events</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure of the Headworks</td>
<td>X X X X X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.6-9: Project Environmental Effects Interaction Matrix: Surface Water Hydrology and Groundwater

<table>
<thead>
<tr>
<th>Other Past and Present Projects</th>
<th>Inundation</th>
<th>Increase Suspended Sediment</th>
<th>Sedimentation</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle Grazing</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural Land Clearing</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borrow Pits</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Dunvegan Historic Site</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water-based Recreation</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Canfor Forest Management Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devon Energy Corporation Oil and Gas Lease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bennett Dam</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Transportation and Utilities Corridors</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dunvegan Bridge</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Devon Energy Corp. and Pembina Pipeline Corp. pipeline crossing the Peace River at Dunvegan</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Water Intake Pipe at Fairview</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dunvegan West Wildland Park</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likely Future Projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New borrow sites</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Expansion of Dunvegan Historic Site</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or upgraded transportation and utility corridors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC Hydro Site C at Taylor</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The interaction between the Project and the discharge of the Peace River is expected to be minimal. The headpond volume is small relative to the river’s discharge rate such that minimal attenuation will occur. For example, at average flow rate, the headpond could be filled within five hours. With the headpond at operating level, any flow variances coming from Bennett Dam or tributary inflow upstream will simply pass through the headpond similar to the way they do presently. With the 6-m level rise at the headworks the headpond width only increases approximately 10 percent more than the present river width. Therefore for every metre of level fluctuation, the flow and level fluctuation relationship is very similar to present conditions. This is demonstrated by the fact that the headpond width and present river widths become almost identical within 15 km and are identical within 26 km. On average, for the 26-km long headpond, the river width will be within 3.5 percent of the present river width. Therefore water level fluctuations in Peace River will not be attenuated by the Project.

4.6.3.1 Site C at Taylor, British Columbia

BC Hydro is considering the development of a hydroelectric facility at Site C near Taylor, British Columbia, upstream from Dunvegan. No details are currently available. However it is understood the operation would be a run-of-river facility and would not likely affect the downstream flow regime.
Provided this is the case, Site C would not affect project operations at Dunvegan; nor would there be hydrologic interactions between the Project and Site C.

4.6.3.2 Naturalization of Flows and the Peace–Athabasca Delta

Many of the perched basins in the Peace–Athabasca Delta (PAD) are only replenished through periodic spring ice jam flooding on the Peace River. In recent years these floods have become rarer and less extensive. As a result, many of the marshy areas of the delta are being transformed into terrestrial landforms dominated by willows and sedges. The Northern River Basins Study (1996) stated "some modification of regulation of discharge from the Bennett Dam in late winter and spring, combined with high tributary flows, could be an element of major remedial plans". Accordingly, one proposal to mitigate is to restore a more "natural" flow regime to the Peace River in order to attain the ice-jams and resulting flood in the PAD. Wood Buffalo National Park (Parks Canada) and First Nations residing near the Peace–Athabasca Delta expressed concerns that their pursuit of a "naturalized" flow regime on the Peace River (one that would flood the Delta as it used to flood in previous years) would be affected by the Project. The specific concern expressed was if the Project is built and relies upon the current state of regulation from the Bennett Dam in order to remain economically viable, the presence of the Project might provide some incentive not to alter the flow regime towards a more “natural” state.

Because the Project is a run-of-river project, it has not been designed for water storage or to control downstream releases. It has been designed to make use of whatever flows may be released from the Bennett Dam. Due of the variable discharge from the dam, Glacier Power has had to develop a thorough understanding of the regulated flows in order to maximize the efficiency of the Project. Accordingly, the Project is designed to be operational under 98 percent of current flow regimes. It is not expected to be operational at the highest 2 percent of current discharges. This affords Glacier Power an enormous amount of flexibility in terms of its operations. At very low discharges the turbines may be shut off; at very high discharges the flow will simply pass over the structure. When the structure is overtopped in this manner, the head differential between the headpond and the tailwater is reduced. Depending on the extent and tailrace hydraulics the powerhouse may need to be shut down until water levels have receded.

It is unknown what might be implied by a “more naturalized” flow regime. If flows were to be returned to the completely natural regime that existed before the Bennett Dam, the Project would not be viable. If flows were to be increased periodically in late winter or spring in an attempt to emulate more “natural” patterns, it would not be expected to seriously affect the operations of the Project. Due to the operational flexibility of the Project, Glacier Power does not expect a more “natural” flow regime to significantly affect operations or the economic viability of the Project.

4.6.3.3 Inundation

The presence of the headworks and formation of the headpond will result in the inundation of portions of the present river valley and the submergence of parts of islands in the headpond area. This inundation could remove some fish and wildlife habitat from use; however, it could also potentially create new fish habitat. This is discussed in Sections 4.8 to 4.10. Slope failure, if large volumes of material are involved, could result in inundation along the headpond. Failure of the headworks could potentially result in a slight increase in water levels downstream from the structure. This unlikely event could affect vegetation and wildlife habitat in the area for a short period.
4.6.3.4 Increases in Suspended Sediment in Peace River

The construction of the project facilities, including the access roads, has the potential to cause erosion of exposed soil, resulting in an increase in suspended sediment concentrations in Peace River. This potential also exists during the operations phase if there is bank erosion along the headpond. Maintenance activities on the access roads during operations and decommissioning activities also offer the potential for increases in suspended sediment. Slope failure in the headpond would have an environmental effect similar to bank erosion but on a larger scale. The construction and operations of several past, present and likely future projects also offer the potential for bank erosion or upslope erosion, resulting in increases in the suspended sediment load in the river. The increases in suspended sediment could have harmful environmental effects on fish and fish habitat.

Information presented in the Sediment Transport and Channel Morphology Assessment technical report (MMA 2000) and update (MMA 2006) indicates that suspended solids and turbidity resulting from erosion of the Peace and Ksituan riverbanks will not significantly increase the existing values for these parameters on a yearly basis. The majority of gravel and cobble habitats in the project area (i.e., Peace River and Ksituan River) are highly embedded with small-grained particles, which reduces the quality of these habitats to the benthic communities. Over the life of the Project, the majority of the inundated section will infill with smaller-sized sediments until equilibrium is reached with the changed hydraulic regime.

The effects of increased sediment in the Peace River on the benthic population are discussed in Sections 4.5 and 4.8.

4.6.3.5 Increased Sedimentation

During the lifespan of the Project, decreased water velocities in the headpond will result in sediment deposition and changes to the riverbed. There is the potential for the sedimentation to affect walleye spawning habitat at km 17 in the headpond. Concern has been expressed by the public that sediment deposition could also affect boat navigation in the headpond. At time of decommissioning, the headworks will be removed and the sediment deposited over the life of the structure will be subject to transport and deposition. Concern has been expressed that this re-suspension and deposition of large volumes of sediment downstream from the project facilities could affect channel stability and destroy fish habitat. Effects of sediment deposition and mobilization on fish and fish habitat are addressed in Section 4.8.

Increased sedimentation in the LSA has occurred as a result of the lower flow velocities regulated by the Bennett Dam (see Section 5.2). This situation would be affected by the construction of the project at Site C and further regulation of flow.

4.6.3.6 Increased Erosion

The deposition of sediment in the headpond could increase the potential for erosion and could result in channel downcutting, scour or lateral erosion downstream from the facility. AIT has raised a concern that this increased erosion potential could affect the stability of the Dunvegan Bridge and the water supply intake at Fairview. Failure of the weir or a break in the headworks has also been identified as a potential source of downstream channel instability and erosion. Bennett Dam has significantly reduced
flood magnitudes and the ability of Peace River to transport bedload. Hydraulic calculations indicate that post-Bennett Dam flood flows are generally incapable of mobilizing the coarser sediments forming the surface of the channel. As a consequence, sediment deposition in the proposed headpond is not expected to result in significant or widespread channel degradation in the downstream channel. Sediment deposition in the headpond will however reduce the amount of sediment being transported downstream.

Past and present projects that have resulted in increased erosion of the Peace River bed include the Bennett Dam and the Dunvegan Bridge. Regulation of the river flow by Bennett Dam could result in increased erosion if flows were greater than natural ones and if sediment input has decreased. To date, post-Bennett Dam flows have been lower than pre-Bennett Dam ones, for the most part, and erosion has not increased. As discussed in Section 4.6.3.10, the sediment load in Peace River has not decreased dramatically since the construction of Bennett Dam because much of the sediment load comes from tributaries downstream from the dam. Post regulation progradation of the Hines Creek fan has likely caused local scouring around the Dunvegan Bridge abutments.

4.6.3.7 Hydrogeology

Interaction between the Project and the groundwater resources of the study area will occur due to the presence of the headpond. The water in the inundated area will become part of the water table and will infiltrate the alluvial sediments. The area of inundation is, in most areas, within the existing channel margins and the amount of infiltration is expected to be between that of the pre-Bennett Dam 95 percent and 5 percent exceedance flows. The changes to groundwater base flow are expected to be undetectable and are not discussed further.

4.6.4 Residual Environmental Effects Evaluation Criteria

A significant environmental effect on the surface water hydrology and groundwater VEC is one where inundation, increased suspended sediment, sedimentation or erosion results in a significant effect upon one of the biological, Historical Resource or human VECs.

4.6.5 Effects Analysis, Mitigation and Residual Effects Prediction

4.6.5.1 Hydraulics

The environmental effects of the Project on the Peace River flow regime were analyzed using the HEC--RAS Hydraulic Model. The model superimposed the project parameters on the flow data from Peace River to provide a picture of what would have happened during certain years of record, had the facility been in place. Details on the model are provided in MSA (2005).

4.6.5.1.1 Hydraulic Regime

The post-Bennett Dam daily flows were examined for the years of record up to and including 2003 to identify wet, normal and dry years. Figure 4.6-4 shows the mean daily flows for the years 1976 (wet year), 1994 (normal year) and 1980 (dry year). The figure also includes the mean daily flow for 1996, a
wet year where BC Hydro initiated reservoir drawdown procedures to facilitate repairs of sinkholes that had formed on the crest of the Bennett Dam.

Figure 4.6-4 also superimposes the Project on the hydrographs, showing that in the wet years there is a period of powerhouse overtopping at river flows in excess of 3380 m$^3$/s or approximately at the 1.5 percent annual exceedance flow. At this flow, the tailwater is at elevation 343.0 m and does not submerge the top of the fixed weir crest. Weir submergence occurs when the tailwater elevation reaches or rises above the weir crest elevation of 344.4 m, i.e., when flows exceed 5300 m$^3$/s. The number of days that powerhouse overtopping would have occurred for the years 1972 to 2003 is summarized in Table 4.6-10. The table shows 62 days of powerhouse overtopping in 1996 and 18 in 1997. This, however, is most likely due to higher than normal flow releases from Bennett Dam for those times.

**Figure 4.6-4: Peace River at Dunvegan - Hydrographs for Wet, Normal and Dry Years**
Table 4.6-10: Frequency of Powerhouse Overtopping

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Days Powerhouse is Overtopped</th>
<th>Year</th>
<th>Number of Days Powerhouse is Overtopped</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>29</td>
<td>1989</td>
<td>0</td>
</tr>
<tr>
<td>1973</td>
<td>0</td>
<td>1990</td>
<td>8</td>
</tr>
<tr>
<td>1974</td>
<td>7</td>
<td>1991</td>
<td>0</td>
</tr>
<tr>
<td>1975</td>
<td>0</td>
<td>1992</td>
<td>0</td>
</tr>
<tr>
<td>1976</td>
<td>20</td>
<td>1993</td>
<td>0</td>
</tr>
<tr>
<td>1977</td>
<td>3</td>
<td>1994</td>
<td>1</td>
</tr>
<tr>
<td>1978</td>
<td>0</td>
<td>1995</td>
<td>0</td>
</tr>
<tr>
<td>1979</td>
<td>1</td>
<td>1996</td>
<td>62</td>
</tr>
<tr>
<td>1980</td>
<td>0</td>
<td>1996 (revised)</td>
<td>12</td>
</tr>
<tr>
<td>1981</td>
<td>0</td>
<td>1997</td>
<td>18</td>
</tr>
<tr>
<td>1982</td>
<td>0</td>
<td>1998</td>
<td>0</td>
</tr>
<tr>
<td>1983</td>
<td>14</td>
<td>1999</td>
<td>0</td>
</tr>
<tr>
<td>1984</td>
<td>11</td>
<td>2000</td>
<td>0</td>
</tr>
<tr>
<td>1985</td>
<td>0</td>
<td>2001</td>
<td>8</td>
</tr>
<tr>
<td>1986</td>
<td>0</td>
<td>2002</td>
<td>3</td>
</tr>
<tr>
<td>1987</td>
<td>5</td>
<td>2003</td>
<td>0</td>
</tr>
<tr>
<td>1988</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Number of Days Including 1996: 190
Average Number of Days/Year: 5.9
Total Number of Days Revised for 1996: 140
Average Number of Days/Year Revised for 1996: 4.4

4.6.5.1.2 Water Surface Elevations

The HEC-RAS Model was used to calculate water surface elevations at 38 locations starting at the WSC Station at -2+270 (2270 m downstream from the proposed headworks) and ending at Station 26+360 (26.36 km upstream from the proposed headworks).

Naturalized and post-Bennett Dam flow scenarios without the proposed Project, as well as post-Bennett Dam flows with the Project in place were used to investigate changes in the water levels in the river. The flows used are summarized in Table 4.6-11.

Table 4.6-11: Pre- and Post- Bennett Dam Flows

<table>
<thead>
<tr>
<th>Exceedance</th>
<th>Naturalized Flow</th>
<th>Post-Bennett Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>5,450 m³/s</td>
<td>2,500 m³/s</td>
</tr>
<tr>
<td>50%</td>
<td>Naturalized Flow</td>
<td>822 m³/s</td>
</tr>
<tr>
<td></td>
<td>Post-Bennett Dam</td>
<td>1,540 m³/s</td>
</tr>
<tr>
<td>95%</td>
<td>Naturalized Flow</td>
<td>218 m³/s</td>
</tr>
<tr>
<td></td>
<td>Post-Bennett Dam</td>
<td>753 m³/s</td>
</tr>
</tbody>
</table>
Figures 4.6-5, 4.6-6 and 4.6-7 compare the changes from pre- to post-Bennett Dam water levels with and without the proposed Project. The changes in water surface elevation are most notable at the structure and diminish towards the upstream end of the headpond. For flow events greater than the 50 percent exceedance, the additional increase in flow produces minimal additional changes due to the width of the river. At 50 percent exceedance flow, the water level increases 7.6 m at the structure compared to naturalized levels and 6.6 m compared to post-Bennett Dam levels. At five percent exceedance, the water level increases 2.15 m at the structure compared to naturalized levels and 6.07 m compared to post-Bennett Dam levels.

### 4.6.5.1.3 Flow Velocities and Patterns

Table 4.6-12 summarizes the calculated average cross section total flow velocity at four sections (26+000, 15+985, 0+000 [proposed headworks] and –2+270 [downstream from the headworks]) for selected percent exceedance flows and flood flows.

Post-Bennett Dam flow velocities show minimal change with the addition of the Project at the upstream end of the headpond. The most significant change is near the upstream side of the headworks where flow velocities decrease by approximately 40 to 75 percent up to the 1:5 year flood event. There are no changes in velocities between the post-Bennett Dam and post-Project scenarios downstream from the headworks.

Figure 4.6-8 shows the modelled flow patterns for May and June. As shown in the figure, the velocity is in the order of 0.3 to 1.75 m/s 120 m downstream from the structure. Further downstream the velocities are higher on the right side of the river compared to the left, due to flow concentration along the thalweg in this area. Upstream from the structure the velocity has been reduced by approximately 50 percent.

The results of the analysis of flow velocity and patterns show that the structure has minimal effect on these parameters and does not increase average velocity beyond the immediate vicinity of the structure. Existing downstream flow regimes are established within 1000 m of the structure. Turbulent flows will occur between 38 and 55 m downstream from the powerhouse and spillway, respectively. An armoured apron will extend 38 m downstream from the powerhouse and 55 m downstream from the spillway to prevent erosion and scour. Extensive numerical and physical modeling was done to assess downstream flow patterns for structure design and fish passage; see the modeling summaries by Northwest Hydraulic Consultants (2002 through 2006) for further detail on upstream and downstream micro-flow patterns, and areas of turbulence.
Figure 4.6-5: Water Surface Profile at Project 5 Percent Exceedance Flow
Figure 4.6-6: Water Surface Profile at Project 50 Percent Exceedance Flow
Figure 4.6-7: Water Surface Profile at Project 95 Percent Exceedance Flow

- 95% Exceedance Flow 218 cms Naturalized Flow
- 95% Exceedance Flow 753 cms Post Bennett Dam
- 95% Exceedance Flow 753 cms With Dunvegan Project
- Invert Elevation (m)
Table 4.6-12: Flow Velocity Summary at Dunvegan, Naturalized and Post-Bennett Dam and with the Project

<table>
<thead>
<tr>
<th>Flow Event</th>
<th>Pre-Bennett Dam Discharge (m³/s)</th>
<th>Post-Bennett Dam Discharge (m³/s)</th>
<th>Station 26+000</th>
<th>Station 15+985</th>
<th>Station 0+000</th>
<th>Station –2+270</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Naturalized (m/s)</td>
<td>Post-Bennett Dam (m/s)</td>
<td>With Project (m/s)</td>
<td>Naturalized (m/s)</td>
<td>Post-Bennett Dam (m/s)</td>
<td>With Project (m/s)</td>
</tr>
<tr>
<td>95%</td>
<td>218</td>
<td>753</td>
<td>0.6</td>
<td>1.0</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>50%</td>
<td>822</td>
<td>1,543</td>
<td>1.1</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>5%</td>
<td>5,450</td>
<td>2,500</td>
<td>2.2</td>
<td>1.7</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>1:2 yr.</td>
<td>7,490</td>
<td>3,680</td>
<td>2.6</td>
<td>1.9</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td>1:5 yr.</td>
<td>9,120</td>
<td>4,920</td>
<td>2.8</td>
<td>2.1</td>
<td>1.9</td>
<td>2.7</td>
</tr>
<tr>
<td>1:10 yr.</td>
<td>10,200</td>
<td>5,750</td>
<td>2.9</td>
<td>2.3</td>
<td>2.1</td>
<td>2.9</td>
</tr>
<tr>
<td>1:50 yr.</td>
<td>12,700</td>
<td>7,570</td>
<td>3.2</td>
<td>2.6</td>
<td>2.3</td>
<td>3.1</td>
</tr>
<tr>
<td>1:100 yr.</td>
<td>13,800</td>
<td>8,330</td>
<td>3.3</td>
<td>2.7</td>
<td>2.4</td>
<td>3.2</td>
</tr>
<tr>
<td>1:500 yr.</td>
<td>16,600</td>
<td>10,000</td>
<td>3.5</td>
<td>2.9</td>
<td>2.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>
4.6.5.1.4 Headpond Characteristics

Table 4.6-13 summarizes the environmental effects of the headpond area with and without the Project. The project headworks will form a headpond that extends approximately 26 km upstream. The new area inundated by the headpond will be 106 to 215 ha.

Table 4.6-13: Headpond Length, Area of Inundated Shoreline and Mean Water Resident Time as a Function of Discharge

<table>
<thead>
<tr>
<th>Flow</th>
<th>Water Level Difference at Headworks (m)</th>
<th>Distance over which Post-Project Water Levels Exceed (km)</th>
<th>Mean Resident Time (hr)</th>
<th>Change (increase) (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>Naturalized minus Pre-Bennett Dam</td>
<td>Post-Project minus Naturalized</td>
<td>Post – Project minus Post-Bennett Dam</td>
<td>Naturalized Water Levels</td>
</tr>
<tr>
<td>95%</td>
<td>-1.321</td>
<td>8.89</td>
<td>7.57</td>
<td>&gt;26.3</td>
</tr>
<tr>
<td>50%</td>
<td>-1.02</td>
<td>7.67</td>
<td>6.65</td>
<td>&gt;26.3</td>
</tr>
<tr>
<td>5%</td>
<td>2.15</td>
<td>3.92</td>
<td>6.07</td>
<td>16.0</td>
</tr>
<tr>
<td>1:2 yr.</td>
<td>2.25</td>
<td>4.26</td>
<td>6.50</td>
<td>16.0</td>
</tr>
<tr>
<td>1:5 yr.</td>
<td>2.27</td>
<td>4.15</td>
<td>6.40</td>
<td>17.0</td>
</tr>
<tr>
<td>1:10 yr.</td>
<td>2.32</td>
<td>3.96</td>
<td>6.33</td>
<td>16.0</td>
</tr>
<tr>
<td>1:50 yr.</td>
<td>2.37</td>
<td>3.83</td>
<td>6.20</td>
<td>16.0</td>
</tr>
<tr>
<td>1:100 yr.</td>
<td>2.44</td>
<td>3.71</td>
<td>6.15</td>
<td>16.0</td>
</tr>
<tr>
<td>1:500 yr.</td>
<td>2.67</td>
<td>3.37</td>
<td>6.04</td>
<td>11.7</td>
</tr>
</tbody>
</table>

The table illustrates that the post-Bennett Dam water levels are higher than naturalized ones for the 95 percent and 50 percent exceedance flows. This reflects the increased low flows which result from Bennett Dam (see Figure 4.6-2). In contrast the naturalized water levels are higher than those which occur following regulation for five percent exceedance flows or flood flows having a return period of more than two years. This occurs as a result of a reduction in flood size due to river regulation.

As the magnitude of the discharge increases, the environmental effect of the headworks at Dunvegan is diminished due to the low profile of the structure. The height of the structure in relation to the depth of flow decreases and the width of the river will accommodate a large portion of the flow without a large increase in depth. The steep banks of the river moderate any increase in water surface area.

Table 4.6-13 illustrates how the length and elevation of the headpond upstream from the proposed Project will vary with discharge. During the 95 percent exceedance flow, the proposed Project will increase water levels at the headworks by 7.57 m in comparison to present conditions and by 8.89 m in comparison to the naturalized flow regime. During conditions of the 1:2 year flood, the water surface will be 6.5 and 4.26 m above the present and naturalized elevations, respectively. The headpond elevation will exceed naturalized water levels for a distance of more than 26 km under low flow conditions and by 16 km under conditions of a 1:2 year flood.

The flushing action will not decrease significantly. At the 1:2 year flood event, it takes only 2.8 more hours for a particle of water to travel 26.3 km down the river. During a 1:100 year flood the time is only 1.2 hours longer.

Once the construction of the headpond has been completed, it will be filled at a rate of about 0.15 m per hour over a 40-hour period. The variation in water level downstream from the headworks during
headpond filling will be within the normal daily fluctuations presently experienced. There will be no change in the flow regime of the tributaries downstream. The filling of the headpond is scheduled for fall 2011.

4.6.5.2 Sediment Transport

The expected reductions in water velocity, as discussed above, and the associated reductions in shear stress, will affect sediment transport in the LSA. Unlike a large conventional reservoir, water velocities through the headpond will vary significantly with discharge. Sediment deposition will occur during periods of low velocity, while transport or re-entrainment could occur during periods of high flow.

Work done on Peace River by Kellerhals et al. (1972) indicate that the transition between the deposition of gravel and sand occurs at water velocities of 0.9 m/s for mean annual flow, 1.6 m/s for a 1:2 year flood and 1.8 m/s for a 1:5 year flood. These values, which reflect the hydraulic capacity of the river to move material of varying size, provide an initial basis for assessing the effects of the Project. The above velocity criteria are shown in Figures 4.6-9 to 4.6-11, along with the predicted post-project velocities in the headpond. This analysis suggests that the reduced water velocities will cause much of the headpond to become sand bedded, with the gravel to sand transition zone being near the upper end of the headpond between km 20 and 23.

MMA (2006) presents results on sediment transport modeling of the Project using the Generalized Stream Tube model for Alluvial River Simulation (GSTARS) (Yang and Simoes 2002). The GSTARS analysis indicates that 22 percent of the total incoming sediment load will be trapped over the initial 10 years of project operations. This corresponds to a volume of 21.2 x 106m3 which is 33 percent of the proposed headpond volume of 64.9 x 106m3 at the 50 percent exceedance flow. The headpond trap efficiency will decrease over time as sediment deposits constrict the channel and increase water velocities. GSTARS predicts the total trap efficiency over 50 years will be 11.1 to 11.6 percent (assuming a transmissive and impermeable lower boundary, respectively). This corresponds to a volume of 33.6 to 35.0 x 106 m3 which is 52 to 54 percent of the initial headpond volume at the 50 percent exceedance flow.

Based on the GSTARS model, the volume of sediment deposited along the headpond over 10 and 50 years is indicated on Figures 4.6-12 and 4.6-13, respectively. These graphs show deposition in each of four size classes:

- coarse clay and silt (0.002 to 0.0625 mm)
- sand (0.0625 to 2.0 mm)
- very fine to medium gravel (2.0 to 16 mm)
- coarse to very coarse gravel (16 to 64 mm)

This analysis illustrates how the size of the deposited sediments decreases downstream through the headpond and the limited distribution of greater than sand-sized materials. Some gravel deposition will occur in the upstream end of the headpond during the initial 10 years of the Project (i.e., upstream from km 18.2 for fine to medium gravel). Very fine to medium gravel does also begin to be deposited upstream from km 16 over a period of 50 years. Coarse to very coarse gravels are limited to the area upstream from km 21.5 over the first 50 years of project operations. All other areas will develop a sand-sized or finer bed material.
50% EXCEEDANCE WATER VELOCITY

- Pre-Bennett
- Post-Bennett Pre-Dunvegan
- Post-Bennett Post-Dunvegan

0.9 m/s - Proposed Criterion for Gravel to Sand Bed Transition
2-YEAR FLOOD WATER VELOCITY

- Pre-Bennett
- Post-Bennett Pre-Dunvegan
- Post-Bennett Post-Dunvegan

1.6 m/s - Proposed Criterion for Gravel to Sand Bed Transition
GLACIER POWER LTD.

DUNVEGAN PROJECT
Downstream Variation in Average Headpond Water Velocity for the 5-year Return Period
Flood in Relation to the Predicted Water Velocity at the Gravel-Sand Transition

5-YEAR FLOOD WATER VELOCITY

1.8 m/s - Proposed Criterion for Gravel to Sand Bed Transition

KILOMETERS

VELOCITY (m/s)
Coarse-textured sediment deposition will modify the geometry of the headpond over the life of the Project, but these changes will not significantly affect the engineering performance of the structure. Coarse textured materials consisting of gravels will deposit in the upstream end of the headpond. Sand will deposit in deeper water areas, while finer textured sediments are expected to deposit along the channel margin, in slack water areas and upstream from the control weir. The location of coarse textured sediment deposits will progress downstream over the life of the structure.

### 4.6.5.3 Channel Morphology within the Headpond

The preceding analyses indicate that substantial sediment deposition will occur within the proposed headpond. Coarser, gravel-sized sediments will be deposited at the upstream end and the texture of deposited material will generally decrease in a downstream direction. Bennett Dam has significantly reduced the frequency with which the coarser fraction of the river bed materials is transported. As a consequence, a lengthy period of time could be required for significant coarse gravel accumulations to occur at the upstream end of the headpond. The most likely area for initial sediment deposition is upstream from km 24. This will likely be associated with the enlargement of the point bar at km 27 and the development of a transverse bar, or possibly more distributed deltaic like sediment accumulation, between approximately km 28 and 24.

Historical air photo studies indicate that tributary fans have prograded following construction of Bennett Dam. This trend will continue although headpond formation will further reduce Peace River's ability to redistribute the coarser fractions of the incoming tributary sediment load. Continued enlargement is expected on the fans formed at Fourth Creek, Hamelin Creek and Ksituan River. However, increased headpond levels for flows of less than 2500 m³/s could further shift the preferred areas for coarse textured sediment deposition toward the fan apex. The incoming coarse silt or larger sized sediments will be deposited in the headpond. The GSTARS model indicates that the elevation of the channel bed will increase by an average of 3 to 5 m (at the upstream and downstream ends of the headpond, respectively) over a 50-year period. Water velocities on the margins of the channel will be less than those in the centre of the channel. As a consequence, fine-textured sediment deposition in the nearshore areas could be somewhat greater than the average values of 3 to 5 m.

### 4.6.5.4 Bed Material (Substrate) Size

Modeling results indicate that water velocities within the proposed headpond are generally insufficient to maintain the present gravel bed. Sand or finer textured sediments will therefore be deposited in all areas except near the upstream end of the headpond where gravel deposition is expected. The GSTARS analyses suggest that the gravel to sand transition will occur near km 18; however, other (possibly less reliable) analytical procedures indicate the transition could occur further upstream between km 20 and 23 (see Section 4.6.5.2). Gravel deposition will gradually extend downstream over time. However, the small volumes and infrequent occurrence of gravel transport under the post-Bennett Dam discharge conditions indicates that this will be a slow process.

The walleye spawning area associated with the transverse bar at km 17 is expected to undergo a gravel to sand evolution. However, the depth of sediment accumulation in this area may be reduced (in comparison to other parts of the headpond) as the height of the existing bar will locally increase water velocities. These elevated water velocities may periodically allow some localized sand mobilization during large floods. The GSTARS analyses indicate that the total depth of sediment deposition will be
2 m or less at 10 years and 3 m or less at 50 years. It is therefore unlikely that sediment re-mobilization will expose or maintain the underlying gravelly materials.

Figures 4.6-12 and 4.6-13 illustrate how the deposited volume of coarser materials will increase over a 10-year period and a 50-year period near km 17 and 18. The surface texture of the sediments forming the bed of the channel will be initially composed of sand-sized or finer sediments soon after empondment. These materials will gradually be replaced with very fine to medium gravel over the longer term. However, sand or silt-sized material will continue to be deposited during periods of low flow and any deposited gravels are therefore expected to be intermixed or periodically covered with these finer sediments over the longer term.

### 4.6.5.5 Nearshore Sediment Stability

Substantial quantities of fine-textured sediments will be deposited within the lower velocity areas along the headpond margin. Portions of these deposits will be exposed during periods of reduced headpond water levels. Wave actions during periods of low water could locally re-entrain some of these materials. Exposed materials may also be periodically entrained by wind. However, the limited variation in headpond water levels under the proposed operating regime and nearshore ice or frozen ground during the winter will restrict these processes.

### 4.6.5.6 Shoreline Stability

The effects of increased water levels in the headpond on valley wall stability were discussed in Sections 4.3.3 and 4.3.5. Additional mapping and analyses were undertaken to assess the possible effects of raised water levels on shoreline stability. Details of these analyses are presented in MMA (2006) and summarized here.

MMA mapped shoreline characteristics along the headpond and the distribution of materials is summarized in Table 4.6-14. Post-project water levels will be below the pre-Bennett Dam 2-year return period flood elevations upstream from about km 17. Within this upper area, raised water levels will cause some inundation of low-lying areas. However, the inundated channel banks or valley walls were exposed to river flow before river regulation by Bennett Dam. As a consequence, areas where previous river reworking has formed lag deposits on the surface should be relatively resistant to erosion. Areas composed of fluvial terraces, fluvial fans and colluvial slopes overlying bedrock are generally expected to fall into this category. The effects of increased water levels in areas composed of colluvial fans or aprons are more difficult to assess reliably. Post-Bennett Dam slope movement could have formed surfaces which have not been previously reworked by river processes. Wave or possibly river-ice action might have a greater likelihood of causing localized sediment production in these materials. However, the potential for project-related sediment production from these areas is minimized by the limited increase in water levels which will occur.
GLACIER POWER LTD.

DUNVEGAN PROJECT

Sediment Deposition in the Headpond over a 10-Year Period

DISTANCE UPSTREAM OF WEIR (m)

VOLUME OF SEDIMENT DEPOSITION (m³)

Coarse to V. Coarse Gravel
V. Fine to Medium Gravel
Fine Sand to Coarse Sand
Coarse Clay to Coarse Silt
GLACIER POWER LTD.

DUNVEGAN PROJECT

Sediment Deposition in the Headpond over a 50-Year Period

VOLUME OF SEDIMENT DEPOSITION (m³)

DISTANCE UPSTREAM OF WEIR (m)

Coarse to V. Coarse Gravel
V. Fine to Medium Gravel
Fine Sand to Coarse Sand
Coarse Clay to Coarse Silt
### Table 4.6-14: Extent of Shoreline Types in the Dunvegan Headpond

<table>
<thead>
<tr>
<th>Shoreline Type</th>
<th>Length (km)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Bank</td>
<td>Right Bank</td>
</tr>
<tr>
<td>Colluvial veneer over rock</td>
<td>9.4</td>
<td>17.7</td>
</tr>
<tr>
<td>Colluvial fan or colluvial apron</td>
<td>10.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Fluvial fan</td>
<td>1.6</td>
<td>5.0</td>
</tr>
<tr>
<td>Fluvial terrace</td>
<td>6.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>28.0</td>
<td>28.7</td>
</tr>
</tbody>
</table>

Downstream from km 17, post-project water levels associated with 2-year (or more) return period flood flows will exceed 2-year return period pre-Bennett Dam flood levels. The newly inundated areas range up to approximately 4 m in height at the project headworks. Wave, or possibly ice action, is most likely to result in localized shoreline erosion in sites composed of colluvial fans or aprons. These materials comprise approximately 29 percent of the headpond shoreline and are preferentially on the left bank. Extensive colluvial fan or apron deposits occur on both channel banks downstream from km 8. Fluvial terrace deposits are also potentially subject to accelerated erosion as they are composed of unconsolidated materials and are likely to have less coarse textured rock inclusions than most colluvial deposits. These materials form 5 percent of the shoreline downstream from km 17 and are generally between km 7 and 12. The predicted water level increase in this area will range up to approximately 2 m above pre-Bennett Dam levels.

There are 8.6 km of island or bar deposits downstream from km 17. Sediment re-mobilization on these surfaces is expected to be generally limited to finer-textured ‘overbank’ deposits. Shorelines composed of colluvial veneers over rock (which comprise 50 percent of the total shoreline downstream from km 17) may be the least susceptible to long-term shoreline erosion. This reflects the shallow depth to bedrock and the potential for coarse textured fragments within the colluvium to form an erosion resistant surface.

Post-project shoreline stability is expected to reflect material characteristics, water level increase and supplementary factors such as fetch and wind direction, vegetation cover, ancillary water supply, upslope land use (such as grazing) and climatic variation. As a consequence the response is likely to be variable and will evolve over time.

### 4.6.5.7 Channel Morphology Downstream from the Headworks

Construction of the Dunvegan headpond will reduce the supply of coarse textured sediments to the downstream channel, potentially causing degradation of the stream bed as the river re-entains sediment from this stretch of the channel. However, as previously indicated, the Bennett Dam has significantly reduced flood magnitudes and the ability of Peace River to transport bed load. Hydraulic calculations indicate that post-Bennett Dam flood flows are generally incapable of mobilizing the coarser sediments forming the surface of the channel. As a consequence, sediment deposition in the proposed headpond is not expected to result in significant or widespread degradation in the downstream channel. Any potential channel downcutting is therefore expected to be minor and of limited extent.
The channel bed in the area between the Hines Creek Fan and the Dunvegan Bridge is currently downcutting as a result of post-Bennett Dam enlargement of the Hines Creek Fan. This process is likely to have formed a coarse-textured armour on the river bed which may be immobile under all but extreme flood conditions.

The Hines Creek Fan will continue to aggrade, constricting the river channel and possibly cause further downcutting near the Highway 2 bridge. The Project is not expected to alter this ongoing process.

The headpond is expected to trap 22 percent of the incoming sediment load over 10 years and 11 to 12 percent over 50 years. The majority of these materials will be greater than 0.2 mm in diameter. The deposition of these materials will decrease the downstream sediment load and could reduce rates of overbank sediment deposition in the downstream channel. This effect will be less noticeable downstream from the Smoky River confluence due to the large sediment load which is transported by this tributary.

4.6.5.8 Summary of Inundation, Sedimentation and Erosion Effects

Table 4.6-15 is an environmental effects assessment matrix for the Surface Water Hydrology and Groundwater VEC. The potential environmental effects of the Project on the VEC and proposed mitigative measures are summarized below.

4.6.5.8.1 Inundation by the Headpond

Inundation of 106 to 215 ha of mostly existing riverbanks by the formation of the headpond will result in adverse environmental effects due to the loss of land. Merchantable timber will be removed from the inundated area before project construction. Neither of these environmental effects however is significant and the environmental effect of inundation by the headpond is, therefore, rated as not significant.

4.6.5.8.2 Sediment Production During Construction

The major instream works associated with construction of the Project will be undertaken during the period between April and October. Background suspended sediment concentrations typically begin to increase in late-March, have elevated levels throughout the period between April and September and decrease to comparatively low levels by mid- to late-September. The timing of the proposed construction work therefore more or less corresponds to the period with high naturally occurring background levels.
## Table 4.6-15: Environmental Effects Assessment Matrix: Surface Water Hydrology and Groundwater

<table>
<thead>
<tr>
<th>Project Activity</th>
<th>Potential Positive (P) or Adverse (A) Environmental Effect</th>
<th>Mitigation</th>
<th>Evaluation Criteria for Assessing Environmental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Magnitude</td>
</tr>
<tr>
<td>Construction</td>
<td>Increased suspended sediment (A)</td>
<td>Dredging&lt;br&gt;Use of sheet piling instead of coffer dams&lt;br&gt;Implementation of specific erosion protection measures, as developed for the Environmental Protection Plan</td>
<td>1</td>
</tr>
<tr>
<td>Operations (Formation of Headpond)</td>
<td>Inundation of former riverbanks (A) and (P)</td>
<td>Removal of merchantable timber</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sedimentation affecting boat navigation (A)</td>
<td>Installation of buoys marking the main channel, if required</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Changes in the characteristics of the gravel bar at km 17 (A)</td>
<td>None proposed</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Increased suspended sediment (A)</td>
<td>None proposed</td>
<td>1</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>Downstream sedimentation following decommissioning (A) and (P)</td>
<td>To be determined at the time of decommissioning and detailed in a Decommissioning Plan</td>
<td>2</td>
</tr>
<tr>
<td>Accidents</td>
<td>Headworks failure (A)</td>
<td>Development of an Emergency Response Plan</td>
<td>2</td>
</tr>
</tbody>
</table>

**KEY:**

- **Magnitude:**
  - 1 = Low: e.g., a few persons, species and/or habitats affected.
  - 2 = Medium: e.g., a moderate percentage/number of persons, species and/or habitats affected within the study area.
  - 3 = High: e.g., a large percentage/number of persons, species and/or habitats within the study area affected.

- **Geographic Extent:**
  - 1 = <1 km²
  - 2 = 1-10 km²
  - 3 = 11-100 km²
  - 4 = 101-1000 km²
  - 5 = 1001-10,000 km²
  - 6 = >10,000 km²

- **Frequency:**
  - 1 = <11 events/year
  - 2 = 11-50 events/year
  - 3 = 51-100 events/year
  - 4 = 101-200 events/year
  - 5 = >200 events/year
  - 6 = continuous

- **Reversibility:**
  - R = Reversible
  - I = Irreversible

- **Ecological/Socio-cultural and Economic Context:**
  - 1 = Relatively pristine area or area not adversely affected by human activity.
  - 2 = Evidence of adverse environmental effects.
  - N/A = Not Applicable
The initial stages of construction will consist of localized controlled dredging to prepare a foundation for pre-cast concrete barges that will be floated into position and sunk to provide a working platform for sheet pile installation. The barges will form a permanent part of the structure. All excavation work within the sheet piling will be undertaken in contained cells that will again limit the potential for sediment production. If required, the water within the cells could be allowed to settle before its removal and sediment laden seepage water could be pumped to a settling pond for treatment. Similar procedures will be undertaken during construction of the proposed weir. The construction of the fishways and boat lock will take place in the riparian zone but on dry land. Erosion control measures will be in place to prevent sedimentation of the river.

There is a potential for local channel bed scour to occur during the final stages of construction when portions of the spillway and power house have been completed on either side of the river, but the structure has not been closed in the middle. Similarly there is a potential for erosion downstream from the structure once the turbines housings or sluice gates in the weir are opened. The potential for downstream erosion will be mitigated by aprons and rip rap to be installed in the turbulent zone of the tailrace.

The environmental effect of sediment production during construction is rated as not significant.

4.6.5.8.3 Potential Environmental Effects of Sediment Deposition in the Headpond on Boat Navigation

Church (1995) has reported that post-Bennett Dam sediment deposition near Carcajou has resulted in the formation of mobile gravel bars which adversely affect the ability of small boats to navigate this section of Peace River. Historical air photographs documenting the post-Bennett Dam development of a diagonal bar in the channel downstream from Carcajou suggest that the Bennett Dam has caused a pre-existing diagonal bar to increase in size such that much of its surface is exposed during late-summer conditions.

Coarse textured sediments (consisting of cobbles, gravel and sands) are expected to deposit at the upstream end of the headpond and, over time, these materials will prograde downstream. It is likely that the existing pattern of point and diagonal bars in the upstream end of the headpond will enlarge in more or less the present position. These structures could affect river navigation by locally restricting water depth. Given the small draft of recreational boats that presently use the river, this problem is not expected to be consequential, except possibly under conditions of unusually low discharge. If necessary, buoys indicating the position of the main channel could be installed to mitigate this environmental effect. The environmental effect of sediment deposition in the headpond on boat navigation is rated as not significant.

4.6.5.8.4 Potential Environmental Effects of Sediment Deposition on the Gravel Bar at km 17 of the Headpond

The large diagonal bar at km 17 is a unique feature in this section of river and is used for spawning by walleye. The sediment stored in this structure appears to have been derived from both upstream bed material transport and from sediment being delivered by Hamelin Creek. The bar at km 17 is within the upper portion of the headpond. Development of the Project is predicted to reduce water velocities in this area to 84 and 53 percent of their pre-project value for average flow conditions and the 1:2 year
return period flood, respectively. Modelling suggests that the post-project velocities will not be able to mobilize and clean the existing gravels except possibly during large flood flows. A decrease in grain size on this bar and increase in the percentage of fines is therefore expected.

The environmental effect of sediment deposition on the gravel bar at km 17 on the VEC surface water hydrology and groundwater is rated as not significant. This effect as it relates to fish habitat is discussed in more detail in Section 4.8.

4.6.5.8.5 Environmental Effect of Bank Erosion on Suspended Sediment Concentrations

The Project will inundate portions of riverbank above the elevation of commonly occurring pre-Bennett Dam water levels. Current or wave action therefore has the potential to elevate the present rates of suspended sediment production if these inundated materials are erosion susceptible. Similarly, AGRA (2000) indicates that the proposed headpond could locally increase rates of sediment production from the valley walls. Given the limited extent of valley flat areas and the generally bedrock confined character of the proposed headpond area, it is expected that the actual increase in sediment production will not be dramatic and could be difficult to detect, given the very large suspended sediment loads which are being naturally transported by Peace River during the open water season (spring and summer). Studies by Northwest Hydraulic Consultants (2006a) indicate that the Project will result in an earlier ice cover within the Dunvegan headpond in comparison to present conditions and will reduce the potential for ice jams to disturb the channel banks in the headpond area. Post-project channel shifting on tributary streams is also expected to follow the annual discharge hydrograph and the timing of sediment production is therefore not expected to be significantly affected. These factors suggest that sediment production from within the headpond is likely to follow the pre-project seasonal regime.

The environmental effect of bank erosion on suspended sediment concentrations is rated as not significant.

4.6.5.8.6 Downstream Environmental Effects of Sediment Production Following Project Decommissioning

By the time of decommissioning the Project, 100 years following construction, the downstream channel should have more or less reached equilibrium with both the post-Bennett Dam discharge regime and the reduction in coarse textured sediment load which would occur as a result of the Project. The channel would therefore be narrower than at present, many side- or backchannel areas would likely be abandoned and mature vegetation would have established on the pre-Bennett Dam channel banks. These changes would be due principally to regulation by Bennett Dam.

Removal of the Dunvegan headworks would increase water velocities through the former headpond, allow the mobilization of deposited sediments and result in river-bed degradation within the headpond and aggradation in the downstream channel. This process would be expected to increase suspended sediment concentrations and loads until such time as an erosion-resistant surface formed within the headpond and sediment delivered to the downstream channel was either moved onto the flood plain or carried into other depositional areas. Elevated rates of sediment transport would be expected to increase the percentage of fine-textured materials on or within the downstream river bed. The
maximum increases in suspended sediment concentrations would likely occur in the first few years after
decommissioning and occur over the longer term in association with large flood events.

Sediment deposition within the channel downstream from the structure could result in lateral channel
instability in areas with low-lying alluvial channel banks. The magnitude of the predicted morphological
changes would generally decrease with distance downstream from the former project site, except that
comparatively low-gradient sections of river channel could act as preferred areas for sediment
deposition.

It is difficult to reliably predict the time scale over which a new equilibrium channel would become
established following weir removal. Experience from Bennett Dam suggests that 43 percent of the
predicted change in river width has occurred in approximately 30 years. Erosion of material entrained
from the former Dunvegan headpond could occur comparatively faster than the post-Bennett Dam
adjustments in river width as sediment availability and rates of vegetation growth are controlling the
present rate of channel narrowing. If this hypothesis is correct, over half of the environmental effect of
Project removal within or adjacent to the headpond might occur within the first 10 to 20 years following
deactivation. The speed could be increased if a number of large floods occurred soon after
deactivation; similarly the rate could be retarded if no large flood flows occurred. Morphologic changes
in the downstream channel would generally be delayed with distance downstream from the former dam
site. It is presently expected that most post-decommissioning channel changes would be complete
within 30 to 50 years.

Downstream environmental effects of sediment production following project decommissioning on fish
are rated as positive, based on the expected increase in habitat complexity and quality (see
Section 4.8). The effects of decommissioning on water quality are rated as not significant (see
Section 4.5). Therefore, the environmental effects of the Project on downstream sediment production
following project decommissioning are rated as positive or not significant.

4.6.5.8.7  Environmental Effect of Post-Project Channel Adjustments on the Stability
of the Dunvegan Bridge

The design of the Dunvegan Bridge, which was opened in 1960, is described in reports by McCune
(1960) and Lamb and McManus (1960). This information indicates that the southern of the two
in-channel piers is founded in a spread footing keyed 5 m into shale bedrock and 12 m below the
stream bed. The north pier is founded in a concrete caisson sunk 21 m below the stream bed.

At least two surveys have been undertaken to assess the effect of local scour on the Dunvegan Bridge
piers (Alberta Department of Highways 1964; Hydroconsult EN3 Services Ltd. 1996). The 1996 surveys
indicate that minimum depths of cover were 18 m and 8 m for the north and south piers, respectively.
The Hydroconsult report concludes that the “sustained high discharges through the 1996 summer
season have not resulted in significant scour at piers” and that there are “no bed scour or river
engineering concerns”.

In a review of the Alberta Hydro Committee Project at Dunvegan, previously studied in 1975,
G.M. Mazurek (1980), Chief Bridge Planning Engineer, Alberta Transportation and Utilities expressed
concern that “channel degradation and resulting bank erosion could adversely affect the stability of the
anchors for the suspension bridge”.

Jacques Whitford © 2006  PROJECT ABC50541  October 2006  4-111
The information presented in MMA (2000 and 2006) suggests that enlargement of the Hines Creek fan is resulting in a narrower and deeper river cross section at the bridge site. The documented trend towards a narrower, deeper river may be resulting in the apparent decrease in the depth of cover on the north pier from 21 m (design) to 18 m (1996 survey) and on the south bank from 12 m (design) to 8 m (survey). It is expected that post-project the Hines Creek fan will continue to aggrade, constrict the river channel and possibly cause further channel downcutting near the bridge. This process has been occurring under the present regulated flow regime, and bedload deposition in the proposed headpond is expected to result in limited acceleration.

Existing conditions are resulting in scour of the Dunvegan Bridge piers and, as suggested by Mazurek (1980), the bridge suspension anchors could be adversely affected by channel shifts. It is assumed that AIT will be studying the situation. Sediment trapping in the proposed headpond will reduce the coarse textured sediment load to the downstream channel, which has the potential to exacerbate channel downcutting. However, the post-Bennett Dam flow regime is generally incapable of mobilizing the channel bed. As a consequence, a significant acceleration in channel downcutting or degradation is not expected (MMA 2006).

The comments by Mazurek (1980) suggest that the stability of the bridge suspension anchors could be adversely affected by future channel shifting. The anchors were not inspected as part of the present study. The design specifications discussed in McCune (1960) and Lamb and McManus (1960) indicate that the north and south anchors are set back approximately 30 and 75 m, respectively, from the channel edge. The north bank is in an area of sediment deposition and future bank instability is not presently expected to be an issue. The south bank is within an old slide deposit. This area is potentially more susceptible to bank erosion as a result of progradation of the Hines Creek fan. Flow patterns and velocities 1000 m downstream from the project headworks will be unaltered from present conditions (Northwest Hydraulic Consultants, 2004); therefore, the Project is not expected to have a significant effect on downstream erosion patterns or channel shifting.

The environmental effect of the Project on the stability of the Dunvegan Bridge is rated as not significant.

4.6.5.8.8 Environmental Effect of Post-Project Channel Adjustments on the Fairview Water Intake and Pipeline Crossings

The town of Fairview obtains their water supply from Peace River at a site 16 km downstream of the proposed project site. The intake is in a deep scour hole on the outside of a bend. This site is unlikely to be affected by post-Bennett Dam sediment deposition or scour. Similarly, the Project is unlikely to cause changes in channel morphometry at this site, nor to contribute significantly to channel scour. Future channel scour is unlikely to affect the stability of the intake as it has likely been designed to withstand the environmental effects of large flood flows.

The two natural gas pipelines cross Peace River at the location of the Fairview water intake. The amount of scour at this location is not expected to affect the pipelines.

The environmental effect of the Project on the Fairview water intake and two pipelines at that location is rated as not significant.
Environmental Effect of Failure of the Spillway or a Breach in the Headworks on Downstream Channel Morphology

Although unlikely to occur, a structural failure of the Dunvegan headworks structure is predicted to produce a flood level having a maximum crest height of about 3 m at Dunvegan and this would be reduced to around 1.4 m at the Town of Peace River. Failure of the spillway crest gates would release a much smaller flood wave that would decrease in height from 0.4 m at the structure to less than 0.2 m at the Town of Peace River.

If these failures occurred at low or intermediate flows, the resulting flood waves would be more or less confined within the pre-Bennett Dam high-water levels.

The hydrologic analyses undertaken by MSA (2006) indicates that the post-Bennett Dam flood flows are 60 percent of the natural values for a return period of 100 years and flood magnitudes are 61 percent of the natural values for the 1 in 500 year event. Structural failure is most likely to occur during an extreme event. In this circumstance, the resulting flood discharge would exceed those that occurred before Bennett Dam for the same return interval flood. This would result in the substantial erosion of post-Bennett Dam sediment deposits, removal of post-Bennett Dam riparian vegetation, bank erosion in susceptible materials, reconfiguration of fans at stream confluences, and the reactivation of side channels. These types of events would be expected to occur during an exceptional flood and the incremental environmental effect of a failure of the Project might be difficult to quantify in a reliable manner.

Because the failure of the crest gates or breach of the headworks, while unlikely to occur, would be associated with a large flood event, the incremental increase in the environmental effect from a headworks failure is rated as not significant.

Cumulative Environmental Effects

Potential developments identified for the cumulative effects assessment case include probable borrow pits, the proposed expansion of the Dunvegan Historic Site, the proposed development of BC Hydro’s Site C at Taylor and potential expansion of existing transportation and utility corridors. Details on the development of Site C are not available and its potential effects on surface water hydrology and groundwater cannot be assessed. The other potential developments may contribute to increased sedimentation of Peace River. It is assumed that these projects will be required to have erosion control measures in place and that erosion will be controlled or minimized. Given this assumption, the contribution of the Project to cumulative effects on surface water hydrology and groundwater is rated as not significant.

Residual Environmental Effects

Table 4.6-16 is a residual environmental effects summary matrix for the Surface Water Hydrology and Groundwater VEC. Residual adverse environmental effects are predicted to be not significant.
Table 4.6-16: Residual Environmental Effects Summary Matrix: Surface Water Hydrology and Groundwater

<table>
<thead>
<tr>
<th>Phase</th>
<th>Residual Environmental Effects Rating, Including Cumulative Environmental Effects*</th>
<th>Level of Confidence</th>
<th>Likelihood of Significant Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability of Occurrence</td>
</tr>
<tr>
<td>Construction</td>
<td>NS</td>
<td>3</td>
<td>N/A</td>
</tr>
<tr>
<td>Operations</td>
<td>NS/P</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>NS/P</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Malfunctions, Accidents and Unplanned Events</td>
<td>NS</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Project Overall</td>
<td>NS</td>
<td>2</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Key:
- Residual Environmental Effect Rating:
  - S = Significant Adverse Environmental Effect
  - NS = Not significant Adverse Environmental Effect
  - P = Positive Environmental Effect

- Level of Confidence:
  - 1 = Low Level of Confidence
  - 2 = Medium Level of Confidence
  - 3 = High Level of Confidence

- Probability of Occurrence: based on professional judgement
  - 1 = Low Probability of Occurrence
  - 2 = Medium Probability of Occurrence
  - 3 = High Probability of Occurrence

- Scientific Certainty: based on scientific information and statistical analysis or professional judgement
  - 1 = Low Level of Confidence
  - 2 = Medium Level of Confidence
  - 3 = High Level of Confidence
  - N/A = Not Applicable

*As determined in consideration of established residual environmental effects rating criteria.

4.6.6 Monitoring

Glacier Power is not proposing to monitor environmental effects related to the surface water hydrology and groundwater VEC.

4.6.7 Summary

The Project will result in the inundation of 106 to 215 ha of existing shoreline. Project operation is expected to result in sedimentation in the headpond. The presence of the headworks and formation of the headpond will alter river flow velocities in the headpond. Downstream from the headworks the flow regime returns to pre-project conditions within 1000 m. The change in flow velocities in the headpond will be accompanied by changes in the sedimentation regime and result in the deposition of fine material in the gravel bar at km 17. Over time sedimentation in the headpond may affect navigation; however, the effects are not expected to be consequential and have been rated as not significant. Downstream from the structure, the potential for increased scour erosion by the river due to the lower sediment load being carried is expected to be not significant.

At the decommissioning phase, the removal of the headworks will re-mobilize the sediment deposited in the headpond and result in redeposition downstream. The river may take decades to reach equilibrium following decommissioning.
The construction and operations of several previous and existing projects along the portion of Peace River have resulted in minor amounts of sedimentation. The major project affecting the river regime on this section of Peace River is the Bennett Dam. The dam has regulated flows and affected flood levels. The Project will bring some of these levels back to their pre-Bennett Dam elevations.

The inundation of existing riverbank along the headpond will have a positive environmental effect, through the creation of new fish habitat, and an adverse environmental effect, through the loss of land. Inundation, increased sedimentation and increased erosion resulting from the Project are not predicted to cause significant effects on biological, historical resource or human VECs. The environmental effect of the Project on the surface water hydrology and groundwater VEC is rated as not significant.