11 ENVIRONMENTAL BACKGROUND

This section of the EIS provides a description of the environment in the vicinity of the Project. It begins with a summary of previous hydroelectric development on the Peace River. Baseline conditions on land, in the water and air are described and predicted changes in the following technical areas are presented:

- Geology, Terrain, and Soils
- Land Status, Tenure, and Project Requirements
- Surface Water Regime
- Water Quality
- Groundwater Regime
- Thermal and Ice Regime
- Fluvial Geomorphology and Sediment Transport Regime
- Methylmercury
- Microclimate
- Air Quality
- Noise and Vibration
- Electric and Magnetic Fields

The baseline information and predicted changes described in this section were used in the effects assessment on VCs, as relevant.

11.1 Previous Developments

The environmental conditions in the Peace River watershed have been influenced by a range of ongoing anthropogenic developments and environmental factors, both prior to and following the development of upstream hydroelectric facilities. Understanding environmental changes, in particular those associated with previous hydroelectric development, provides context for the environmental assessment of the Project. The following sections describe the existing hydroelectric facilities in the Peace River watershed, the environmental changes that are understood to be caused by these hydroelectric developments, and the key follow-up programs that have been initiated to manage those environmental changes due to hydroelectric development.

11.1.1 Existing Hydroelectric Generation Projects on the Peace River

BC Hydro owns and operates two hydroelectric generation facilities on the Peace River. The facilities play an important role in the BC Hydro system and together account for greater than 30% of the capacity of the electrical power generation facilities in B.C. The existing facilities are operated as part of a coordinated system to allow BC Hydro to respond to seasonal and hourly changes in electricity demand.

W.A.C. Bennett Dam was completed in 1968 and is located 168 km upstream of the Alberta border. The 183-m-high earthfill dam is located at a natural outlet of the northern portion of the Rocky Mountain trench, and impounds the Williston Reservoir. The reservoir provides capacity for the multi-year storage of seasonal runoff from tributary sources upstream of the W.A.C. Bennett Dam. The G.M. Shrum Generating Station, which is located at the W.A.C. Bennett Dam, has 10 generating units with a total installed capacity of 2,730 MW. The maximum total discharge capacity from the facility is approximately 11,200 m^3/s (1,968 m^3/s for power generation and 9,200 m^3/s for spillway).

The Peace Canyon Dam was constructed in 1976 approximately 23 km downstream of the W.A.C. Bennett Dam near the town of Hudson's Hope. The 61-m-high concrete dam impounds the Peace River to form Dinosaur Reservoir within the steep walls of the Peace Canyon, located in the eastern foothills of the Rocky Mountains. Dinosaur Reservoir is smaller than Williston Reservoir, with a width of approximately 1 km at its widest point, an operating range of approximately 3 m, and active storage of approximately 0.1% of the active storage of Williston Reservoir. Water discharged from the G.M. Shrum Generating Station or released from discharge facilities (spillways, low level outlets) at W.A.C. Bennett Dam flows directly into the Dinosaur Reservoir. The Peace Canyon Generating Station, which is integrated into the dam, has four generating units with a total installed capacity of 694 MW. Operations of the generating station are generally matched to be in balance with upstream operations such that the flow through both generating stations is approximately equal at any given time. Total maximum discharge capacity from Peace Canyon Dam is approximately 12,250 m^3/s (1,982 m^3/s for power generation, and 10,280 m^3/s for spillway releases).

11.1.2 Environmental Changes Resulting From Previous Developments

11.1.2.1 Physical Conditions

Upstream of Peace Canyon Dam

Dam construction resulted in conversion of a river valley environment upstream of Peace Canyon Dam to one composed of two separated water bodies. The construction of W.A.C. Bennett Dam resulted in the inundation of approximately 360 km of the Findlay, Parsnip, and Peace rivers, and lower portions of smaller tributaries flowing into them on the west side of the Rocky Mountains. The interconnected river valley system was transformed into a single water body with a surface area of approximately 1,773 km^2. Williston Reservoir is deep (maximum depth 166 m), with an average water surface elevation that is, on average, more than 40 m higher than river levels during pre-regulation conditions (Stockner et al. 2005). The reservoir volume and surface area extent vary on a seasonal basis. In general, reservoir levels are higher in the late summer and early fall following the capture of seasonal inflows, and lower in the early spring after water is withdrawn from storage to generate electricity through the winter. The licensed range of reservoir levels in the Williston Reservoir is 30 m; however, annual operations within this range typically vary by less than 18 m.

The construction of Peace Canyon Dam created the smaller Dinosaur Reservoir immediately downstream of the Williston Reservoir. The extent of inundation was limited by the distance between the two dams and the steepness of the canyon in which the reservoir is located. Dinosaur Reservoir levels are managed to fluctuate over a smaller range than those observed in Williston Reservoir (i.e., normal operating range of approximately 3 m).

The construction of reservoirs resulted in flooding of the valley bottom and upland areas, and increased the potential for the methylation of mercury. Inundation of the river valley bottom was more extensive in the case of the Williston Reservoir than Dinosaur Reservoir. Assessment of methylmercury concentrations in environmental receptors was first conducted in the Peace River system in 1980, following the development of existing hydroelectric facilities. Methylmercury levels in key environmental receptors (i.e., water, sediment, invertebrates, fish) were observed to be elevated above that expected in lakes in the region; and, in some species of fish, methylmercury levels exceeded some Health Canada guidelines for consumption. However, follow-up assessments have demonstrated that, as expected, the increase in methylmercury levels in environmental receptors following reservoir development was not permanent. Concentrations have declined and are expected to continue to decline to levels reflective of expected pre-regulation conditions (EVS Environment Consultants 1999). Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report provides more detailed information on the effects of previous hydroelectric developments on methylmercury in the Peace system.

As water is withdrawn from Williston Reservoir, the drawdown zone is progressively exposed around the shoreline of the reservoir. Depending on the pattern of reservoir operation, littoral zones can be exposed for periods of several weeks to several months each year. During drawdown, wind storms can pick up fine particles of silts and clays ("dust") from certain beaches in the northern end of the reservoir in the exposed drawdown zone. Reservoir water levels are typically at their lowest in April, and the majority of the drawdown zone where dust is generated is flooded again by June. The primary concern regarding dust generation is air quality and community health (BC Hydro 2003). As a result of the limited drawdown and topography of Dinosaur Reservoir, there has been no reported incidence of concerns about air quality resulting from dust generation.

Downstream of Peace Canyon Dam

Prior to development of the existing facilities, the seasonal flow pattern of the Peace was similar to that observed in other large northern rivers. Flows in the Peace River were dominated by snowmelt runoff and rainfall that produced high spring and summer flows; low flows were typical in late fall and winter. With the exception of the filling period of Williston Reservoir, long-term average flows have not been altered due to regulation; however, there have been changes on an annual basis, and more noticeable changes in the seasonal and daily pattern of flows. The nature and extent of the changes to the surface water regime due to regulation depend on: 1) time of year, and 2) distance downstream from the point of regulation (i.e., Peace Canyon Dam). Average monthly flows released from Peace Canyon Dam are between 18% (June) and 590% (February) of flows observed before regulation. In addition, generating station flow releases vary on a daily basis, generally higher flow releases during the day than at night. Changes in river flow and water levels resulting from flow regulation are most pronounced immediately downstream of Peace Canyon Dam, and attenuate with increasing distance downstream. Several unregulated tributaries (e.g., Halfway, Pine, Beatton, Kiskatinaw, Smoky, and Wabasca Rivers) join the Peace River downstream of the existing dams and dampen the changes resulting from flow regulation. However, during the fall and winter when natural tributary flows are low compared to the spring and summer, regulated releases from upstream facilities have a greater influence on downstream flows. Changes to the surface water regime of the Peace River resulting from the existing hydroelectric developments are described in greater detail in Section 11.4.2.3 below.

The Peace-Athabasca Delta (PAD) is designated a wetland of international importance under the Ramsar Convention, and it is the location of Wood Buffalo National Park, which is a UNESCO World Heritage site. Since the construction of the W.A.C. Bennett Dam, the question of whether flow regulation has caused changes to the PAD has been raised. On the basis of historical data, some authors (e.g., Peters and Buttle 2009; Beltaos et al. 2006) have concluded that there have been hydrologic changes in the PAD that are related to the operation of the existing facilities on the Peace River in British Columbia. Investigations by other authors indicate that other factors (e.g., climate change/variation, flow control weir installation, dredging, geomorphic succession of the delta) have affected the hydrology of the PAD (Timoney 2002; Wolfe et al. 2012). These other factors have acted concurrently with the hydroelectric facilities, and have confounded the assessment of hydrologic changes that have been observed on the PAD since construction of the W.A.C. Bennett Dam. The influence of flow regulation on the hydrology of the PAD has been examined for decades, yet there remains an ongoing debate amongst the scientific community about the overall contribution of hydroelectric development to observed hydrological changes in the PAD. Since flow regulation, the observed changes within the PAD lie within the range of natural variation in the system (Timoney 2006).

Limited pre-regulation information is available to precisely quantify the influence of previous hydroelectric development on the water temperature regime of the Peace

River. However, the influence of hydroelectric reservoirs on downstream water temperature can be described based on first principles. A flowing river responds more quickly to changes in atmospheric conditions than a reservoir does. This is due to the greater proportion of the total flow that is exposed (at the surface) to the meteorological conditions of the atmosphere, as well as the relatively small depths and high degree of mixing of the water in a river compared to a reservoir. Once a river reach is transformed into a reservoir with greater depths and lower velocities, water temperatures do not respond as rapidly to changes in meteorological conditions. Compared to a flowing river reach, it takes longer to warm the water in a reservoir in the spring/summer, and it takes longer to cool that water in the fall/early winter. Hence, water temperatures at the outlet of a reservoir would be expected to be cooler in the spring/summer, and warmer in the fall/winter compared to conditions prior to the creation of the reservoir. Also, the variability of water temperatures at the outlet of a reservoir would be smaller compared to a river reach, again due to the reduction in exposure to the atmospheric conditions and the larger mass of water to heat or cool. Observed temperatures of water released from the existing facilities range between approximately 0.5˚C and 14˚C.

Changes in the thermal regime resulting from construction of the existing facilities have affected the ice regime of the Peace River. The two primary changes to the ice regime are: 1) modification of the seasonal timing, duration, and location of the annual ice front progression up the river, and 2) alteration of the freeze-up and breakup conditions. Prior to hydroelectric development, ice front development progressed upstream of the location of existing hydroelectric facilities. However, after that, in all but extreme years, the ice front has not been observed in the reach of river immediately downstream of the Peace Canyon Dam (Keenhan et al. 1982). Further downstream, near the Town of Peace River in Alberta, ice cover still develops each year; however, the timing of freeze-up and ice front progression is delayed in comparison to that occurring prior to hydroelectric development. Flow regulation has not appeared to have affected timing or duration of the ice cover on the river downstream of the Town of Peace River; however, increased regulated river flows have altered the ice freeze-up levels both at the Town of Peace River and farther downstream to Peace Point, Alberta (Ashton 2003).

Prior to hydroelectric development, fluvial geomorphology and sediment transport regime in the Peace River were naturally dynamic due to the localized nature of sediment inputs from tributaries and valley-wall landslides, and due to a seasonal range in flows. The influence of hydroelectric development on fluvial geomorphology and sediment transport in the Peace River has been studied extensively (Church 1995; Church et al. 1997). The primary changes include:

- Suspended sediment generated in the Peace River watershed upstream of the two dams is trapped in the two reservoirs; this has a reduced suspended sediment load in the river downstream of the dams
- Moderation of flows in the Peace River downstream of the Peace Canyon Dam has resulted in reduced bed material mobility. This in turn has resulted in the accumulation of bedload from tributaries, which is expressed in the form of expanded alluvial fans at tributary confluences and increased bed elevation in the Peace River downstream from confluences.
- Vegetation encroachment onto gravel bars and side channels along the Peace River, and an overall reduction in active channel width of the Peace River

These changes are most pronounced in the proximal reaches downstream of the Peace Canyon Dam, and diminish in the downstream direction due to water and sediment inflows from tributaries. The largest accumulation of tributary bedload has occurred at the Halfway, Moberly, and Pine river confluences, which are the largest gravel-transporting tributaries closest to the Peace Canyon Dam. Immediately downstream from each confluence, tributary bedload inputs have accumulated in the Peace River channel, causing the bed elevation to rise over time. Vegetation encroachment and channel width reduction are most pronounced between the Peace Canyon Dam and the Smoky River confluence. Fluvial geomorphology and sediment transport regime in the Peace River have been, and will continue to be, in a state of adjustment to the regulated flow conditions for decades to come (Church 1995). For more detailed information on the effect of flow regulation on geomorphology and sediment transport on the Peace River refer to Volume 2 Section 11.8. Fluvial Geomorphology and Sediment Transport Regime.

As a result of the development of Williston and Dinosaur Reservoirs and the regulation of the flow of the Peace River, the seasonal and spatial variability of specific water quality characteristics has been dampened (Alberta/British Columbia Instream Flow Needs Sub-Committee 1991). The river now tends to have lower and more consistent concentration of dissolved components (Shaw et al. 1990). This is believed to be caused by 1) interception of dissolved constituents from tributaries flowing into the two reservoirs, and 2) reduced seasonal variability of river flow released from the two dams. Flow regulation does not appear to have affected the river's dilution capacity for the various industrial and municipal discharges currently entering the river (Shaw et al. 1990).

The operation of the existing hydroelectric power generation facilities in the Peace watershed has been observed to periodically alter dissolved gas concentrations in the Peace River. Elevated levels of total dissolved gases are directly associated with 1) operations of spillways, and 2) specific non-routine low flow operations of the generation stations (i.e., synchronous-condense cycles or air injection during turbine operations in 'rough' load zones; Millar and Wilby 1999). Tributary inflows below Peace Canyon Dam that flow into Peace River have been documented to reduce elevated gas concentration.

11.1.2.2 Biological Conditions

The construction and operation of the hydroelectric facilities have resulted in some changes to biological conditions in the Peace River relative to that which occurred prior to hydroelectric developments. Information on the current status of aquatic, vegetation, and wildlife resources is available for the geographic area affected by the existing facilities. However, there is limited information that describes biological conditions prior to the construction of the W.A.C. Bennett dam. Therefore, it is not possible to describe species composition, distribution, and productivity in biological resources that existed in the time prior to construction of W.A.C. Bennett dam from recorded observations. This makes it impossible to measure directly any change to those factors resulting from development of the hydroelectric facilities. Furthermore, other anthropogenic changes to the Peace River system have occurred that are unrelated to hydroelectric development (e.g., forestry, agriculture, oil and gas), resulting in biological changes and further confounding any effort to quantify any changes that may be attributable to the existing hydroelectric facilities. ~~Furthermore, other anthropogenic changes to the Peace River system have occurred that are unrelated to hydroelectric development (e.g., forestry, agriculture, oil and gas), resulting in biological changes and confounding understanding of changes that may be attributable to the existing hydroelectric facilities.~~ Below is a summary description of general changes to aquatic, vegetation, and wildlife resources.

Aquatic Resources

Upstream of Peace Canyon Dam

The impoundment of Williston and Dinosaur Reservoirs resulted in the transformation of flowing river sections of the Peace River, Findlay, and Parsnip rivers into two physically separated, adjacent lake-like water bodies. This conversion resulted in changes to the physical nature of the habitat conditions available for aquatic resources, and resulted in a change in the structure and productivity of aquatic communities. The major physical changes to aquatic habitats include:

- Increased habitat volume
- Reduction in diversity of the types of habitat available for fish and aquatic organisms
- Alteration of hydraulic conditions (e.g., depth, velocity) and seasonal patterns of water level
- Changes to thermal and ice regimes
- Changes to water quality

Changes in physical characteristics of habitats resulting from reservoir creation resulted in changes in the composition and productivity of aquatic communities. Replacement of flowing river habitats with the reservoirs resulted in a shift of the trophic structure of aquatic food webs from predominantly benthic to pelagic-based food webs. Similarly, replacement of riverine habitats with pelagic habitats and lower suitability littoral habitats (due to seasonal drawdown) supported a shift in the fish community to species that can exploit pelagic habitats for food resources and still meet life history requirements in unaffected portion of reservoir tributaries. In Williston Reservoir, the development of littoral trophic and fish communities is also currently limited by seasonal drawdowns.

W.A.C. Bennett and Peace Canyon dams affect survival and limit movement of fish populations that have successfully colonized the reservoirs. The dams initially interrupted established patterns of upstream and downstream movement of fish in mainstem habitats in the Peace River. Peace Canyon was believed to be a natural barrier to the upstream movement of fish; however, downstream movements would have been unimpeded to allow dispersal and genetic interchange among upstream and downstream populations of riverine species. Upstream movements are currently completely blocked, and the dams now interfere with dispersal of fish to downstream environments, which may have consequence for genetic diversity. Passage of reservoir fish through discharge structures of the dams still occurs but also causes injury or mortality to some fish and, in general, reduces the potential productivity of upstream fish populations.

Downstream of Peace Canyon Dam

The regulation of flow at Peace Canyon Dam has altered characteristics of aquatic habitats for fish and other aquatic organisms in the Peace River. Changes to fish habitat result mainly from changes to surface water flow regime and channel morphology. These include:

- Loss of side-channel habitat, due to river channel changes
- Reduced suitability of side channel habitats, due to reduced inundation frequency
- Reduced suitability of near-shore mainstem shallow water habitat, due to fluctuating water levels
- Increased risk of fish stranding and fish egg dewatering, due to increased daily and seasonal variation in flow levels
- Changes to the accessibility of tributaries, resulting from changes to tributary fan morphology and seasonal changes in river flow
- Reduced productivity of benthic communities, due to seasonal and daily flow fluctuations
- Periodic production of elevated levels of total dissolved gas effects

Physical changes resulting from the flow regulation and channel changes are most apparent immediately downstream of Peace Canyon Dam and diminish downstream, to where they are negligible at the Town of Peace River, AB (Hildebrand 1990). Information is available to describe the composition and relative productivity of benthic and fish communities downstream of the dams as well as certain physical changes that occurred as a result of hydroelectric development. However, there is no information about the structure and productivity of aquatic communities located in the Peace River as it existed prior to the construction of the W.A.C. Bennett Dam.

<u>Vegetation Communities</u>

Upstream of Peace Canyon Dam

Upstream of the W.A.C. Bennett Dam, the formation of the reservoir inundated river valley bottoms in portions of the Peace, Findlay and Parsnip rivers, as well as lower reaches of tributary confluences to these rivers. Flooding in the Williston Reservoir resulted in some loss of vegetation communities occupying river floodplains, and riparian features such as wetlands. To a lesser extent, upland areas within these valleys were also flooded up to the maximum reservoir elevation. Seasonal variation in storage of water and consequent variation in the reservoir surface area have created an extensive drawdown zone around the 1,770 km perimeter of Williston Reservoir. The composition and productivity of riparian communities colonizing this drawdown zone is now regulated by patterns of reservoir level variation. More limited valley bottom flooding occurred during the flooding of Peace Canyon to form Dinosaur Reservoir. Topography and physiography of the canyon, and the operational strategy of limited variation in surface water levels (3 m) limited the extent to which riparian vegetation communities were changed.

Downstream of Peace Canyon Dam

Downstream of the W.A.C. Bennett and Peace Canyon Dams, seasonal changes to the surface water regime have altered the structure of riparian vegetation communities (Church et al. 1997). Reduced annual flood flows and increased winter flows have modified the extent and seasonal timing of floodplain inundation. At upper elevations of the river floodplain, colonizing herb and shrub communities have encroached on exposed river bars due to reduced flood flows, and have progressed to early riparian forest stands. At lower floodplain elevations, successional processes have been delayed due to inundation during elevated spring and winter flows. Much farther downstream, where an annual ice cover forms, ice still plays a primary role in regulating vegetation succession by influence on water levels and through scour damage from ice jamming (Uunila 1997).

<u>Wildlife Resources</u>

Upstream of Peace Canyon Dam

The flooding of river valleys upstream of the existing hydroelectric developments transformed the terrestrial ecosystem. This transformation has resulted in loss of river valley bottom habitats used by wildlife, and displacement of wildlife to upland habitats or to adjacent unaffected river valleys. The types of changes that would have been expected due to formation of the reservoir include:

- Loss of productivity area for wildlife including semi-aquatic and riparian habitat
- Loss of wetlands
- Reduced functionality/productivity of remaining habitats located in drawdown zones surrounding the reservoir
- Loss of animals unable to escape flooding
- Fragmentation home ranges, territories, and migration corridors

Downstream of Peace Canyon Dam

Flow regulation has altered the quality and quantity of habitat conditions for wildlife resources downstream of Peace Canyon Dam. The primary change to wildlife habitat along the Peace River resulted from changes to the physical structure and vegetation communities inhabiting floodplain habitats (Blood 1979; Simpson 1991). The quality of riparian and semiaquatic habitats has been affected by 1) modification of the composition of vegetation communities in riparian habitats, and 2) alteration of the timing, extent, and frequency of floodplain inundation. Changes in the quality of riparian and semiaquatic habitats can reduce productivity of riparian or semiaquatic species groups by reduced food availability, reduced reproductive success, or reduced cover for avoiding predation, which affects local areas used for movement or migration. The quantity and distribution of riparian habitats has also been modified. Channel downsizing processes result in the modification of tributary fan areas and the abandonment of side channels and back channels, resulting in a reduction in the areal extent of river floodplain habitats. Also, changes to the river ice regime may have impeded movements of ungulates and other species groups between habitats during winter.

11.1.3 Follow-Up Programs

For all of its hydroelectric generation developments, BC Hydro undertakes a range of activities to avoid and manage the environmental effects of construction, operation, and maintenance of its facilities. The four primary activities that form the overarching strategic approach for environmental management include:

- Integration of environmental considerations into planning of maintenance and operations of hydroelectric facilities
- Development and implementation of site-specific follow-up programs to manage identified individual environmental issues arising from construction and operating of hydroelectric facilities
- Implementation of system-wide programs to develop broadly accepted and regulatory sanctioned operating regimes for each hydroelectric facility in the BC Hydro system
- Implementation of long-term programs of environmental restoration and enhancement activities to compensate where mitigation options are not available, are uncertain, or are not effective for managing environmental effects

For the existing hydroelectric facilities on the Peace River, operational management programs are undertaken to avoid and mitigate normal activities associated with the maintenance and operation of the dams, reservoir, and generating facilities. Environmental management involves the systematic integration of consideration into planning, and the application of accepted best management practices for avoidance and minimization of potential environmental effects of routine and non-routine activities. Four additional follow-up programs, which are ongoing today, have been implemented to address effects of the construction and operation of the existing hydroelectric facilities on Peace River. The primary objectives of these programs are 1) to address ongoing environmental effects of operations of the W.A.C. Bennett and Peace Canyon facilities, and 2) to address footprint effects associated with construction of the existing facilities. Brief summaries of these programs are presented below.

Alberta-British Columbia Joint Task Force on Peace River Ice

In 1975 the Alberta-British Columbia Joint Task Force on Peace River Ice was formed in to coordinate the management of effects of existing hydroelectric facilities on the Peace River ice regime in the provinces of British Columbia and Alberta. Since its inception, the Joint Task Force has conducted annual monitoring of ice front progression in the Peace River. This information has been used to inform decisions about management of flow regulation during ice front development and progression, and to develop operating procedures related to BC Hydro operations to reduce the ice jam flooding hazard at the Town of Peace River. For full details related to the mandate and mitigation efforts of the Joint Task Force, refer to Volume 2 Appendix G Downstream Ice Regime Technical Data Report.

Peace Fish and Wildlife Compensation Program

The Peace Fish and Wildlife Compensation Program was initiated in 1988 to compensate for environmental footprint effects associated with the development of the Peace River facilities. The program is a joint initiative of BC Hydro, the B.C. Ministry of

Environment and Fisheries, and Oceans Canada. The primary activities of the program are 1) planning, inventory, and research, and 2) habitat restoration and enhancement. The spatial scope of the program is limited to those areas affected upstream of Peace Canyon Dam. Additional information on the objectives, scope and programs undertaken by Peace Fish and Wildlife Compensation Program since 1988 can be found at http://www.bchydro.com/pwcp/.

Williston Reservoir Dust Management

The Williston Reservoir Dust Management Strategy was developed in 1996 in response to concerns expressed by members of the public about the potential for risk to human health from the generation of dust along the northern drawdown zone of Williston Reservoir. The strategy involved the implementation of a sequential program with the goal of controlling dust generation in Williston Reservoir. The key components of program included 1) monitoring and research to understand dust generation processes and human health effects, 2) investigate alternative means for dust control, and 3) working with the community in the development of a long-term control program and provision of employment opportunities. The implementation of the dust control program is has been ongoing since 1996, and is now managed under the auspices of the Peace Water Use Plan, which is described below. More detailed information on the Williston dust control program can be found at http://www.bchydro.com/about/sustainability/conservation/water_use_planning /northern_interior/peace_river.html.

Peace Water Use Plan

The Peace Water Use Planning process was initiated in 2001, completed May 2003, and approved by the Cabinet of the Province of British Columbia in 2007. In developing the plan, a consultative process was initiated by the Province of British Columbia, in cooperation with BC Hydro. A complete description of the consultation process, analysis of operating alternatives, and description of Information and Management Plans are found in the Consultative Committee Report: Peace Water Use Plan (BC Hydro 2003). For more detailed information on the Water Use Planning process, see http://www.env.gov.bc.ca/wsd/plan_protect_sustain/water_use_planning/index.html

To develop the Water Use Plan, information was assembled to evaluate the effects of current operating procedures over a range of non-power interests identified in the Peace River system (BC Hydro 2007). Operating constraints and procedures for the facilities were reviewed by a Consultative Committee that involved licensees, government agencies, First Nations, key stakeholders, industry representatives, and key environmental and recreation interest groups. The key interest categories identified during the process were: air quality and community health (dust); erosion and land stability; First Nations heritage and traditional use; industrial water use and effluent; power generation; public safety, flooding and ice management; recreation and tourism; transportation; water supply and quality; and fish and wildlife. Fifteen operating scenarios were developed to address power and non-power interests. In each case, detailed operational constraints on the hydroelectric facilities intended to meet certain objectives were specified. In addition, a full range of physical works alternatives to mitigate effects were developed for management of operational effects on key interests in lieu of operating changes (BC Hydro 2003).

During the process of evaluating the operating scenarios, gaps in technical understanding that interfered with the ability to make informed decisions about water use became apparent. Key uncertainties were with respect to 1) baseline status of environmental conditions, 2) effects of operations on key non-power objectives or interests, and 3) potential effectiveness of operational or alternative physical work based mitigation programs (BC Hydro 2003; BC Hydro 2007). In response to these uncertainties, the Water Use Plan adopted an adaptive approach. Where the benefits of specific alternative operations were believed to be more certain, they were recommended for immediate implementation. These were 1) downstream minimum flow release of 283 m^3/s from Peace Canyon Dam for environmental protection, 2) continuation of special operating procedures to manage downstream flow releases for ice formation and breakup; 3) implementation of a Williston Reservoir variable minimum elevation rule to allow more effective use of reservoir storage for power generation, and 4) implementation of protocol for managing environmental effects of spillway releases into the Peace River. Where benefits were less certain, the Water Use Plan directed BC Hydro to undertake coordinated Information and Management Plans to address uncertainties and to guide further decisions about implementation of mitigation options in the future. Information Plans are detailed plans to collect sufficient information needed to assist in future decisions about mitigation measure implementation. Management Plans included studies and trial application programs to guide development of full scale non-operational mitigation measures and monitoring programs to audit their effectiveness (BC Hydro 2007).

A review of the Peace Water Use Plan was proposed to be conducted after 10 years. The review will be undertaken to interpret the results of Information and Management Plans. The results of that review can in turn be taken into account in determining effectiveness of follow-up actions, and whether there is any need to reconsider operational constraints or apply other mitigation measures in lieu of operating changes.

11.1.4 Historic Grievances regarding Existing Facilities

Since the development of the existing hydroelectric facilities on the Peace River, some Aboriginal groups have asserted claims or raised concerns, through the commencement of litigation or otherwise, that the creation and operation of the dams and associated reservoirs has created impacts to their communities, and the exercise of their Aboriginal or treaty rights. BC Hydro has a group within its Aboriginal Relations and Negotiations department that is tasked with addressing, reviewing and resolving, if appropriate, these historic grievances.

To date, BC Hydro has resolved historic grievances associated with the existing facilities with three First Nations in B.C. and Alberta. These include the Athabasca Chipewyan First Nation, the Kwadacha First Nation and Tsay Keh Dene. BC Hydro's historic grievances group is currently addressing other outstanding claims and concerns from Aboriginal groups regarding the existing hydroelectric facilities.

Issues or concerns with respect to historic grievances raised during the consultation process on the Project are set out in Volume 1 Appendix H Aboriginal Information Distribution and Consultation Supporting Documentation. During the consultations carried out to date on the Project, as grievances respecting the existing hydroelectric facilities are identified by Aboriginal groups, the Site C team advises the Aboriginal group raising the grievance of the existence of BC Hydro’s historical grievances group, and advises BC Hydro’s historical grievance group of the Aboriginal group’s grievance or concern so that it can engage directly with the Aboriginal group with respect to those concerns.

11.2 Geology, Terrain, and Soils

The geology, terrain stability, and geotechnical soil conditions within the Project activity zone are outlined in the subsections that follow. Both current conditions and potential changes as a result of the proposed project activities are described.

Details of the geology, terrain stability, and geotechnical analyses are presented in supplementary technical data reports that are contained in Volume 2 Appendix B Geology, Terrain Stability and Soil Reports. Volume 2 Appendix B, Part 1 Terrain Stability Mapping describes the results of terrain stability mapping within the Project activity zone, and the potential changes to terrain stability resulting from activities such as removal of vegetation and access road construction. Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines describes the bedrock and surficial geology within the proposed reservoir shoreline technical study area in greater detail. Predicted changes to erosion and slope stability as a result of the creation and operation of the proposed reservoir are described. Reservoir impact lines delineating zones of potential flood, erosion, landslide, and landslide-generated wave hazards are provided.

11.2.1 Physiography and Topography

The western boundary of the Project activity zone lies in the Rocky Mountain foothills, while the eastern boundary lies in the boreal plains. A shaded relief image is shown on Figure 11.2.1. The Peace River area to the east of the Rocky Mountains is characterized by forested and rolling uplands cut by deep river valleys, including the Peace River valley. The valleys and uplands are connected by benches that typically slope downward less than 2° to the east.

Within the Project activity zone, the Peace River valley is broad and flat-floored, occupying a trench approximately 3.5 km wide and 200 m deep. The river typically ranges from 0.5 to 1 km wide. Wide fluvial terraces are common between the floodplain and the broader valley walls, and are typically elevated less than 75 m above river level. At locations where the river is adjacent to such terraces, the slopes are referred to as low banks. Elsewhere, where the river is in direct contact with the deep valley walls, the slopes are referred to as high banks.

Downstream of Peace Canyon Dam, the Peace River flows to the northeast and then turns east, flowing past the city of Fort St. John. The average gradient of the river in the Project activity zone is 0.6 m/km or 0.03°. The major tributaries of Peace River within the Project activity zone are Halfway River and Moberly River, as well as Pine River, which joins Peace River about 20 km downstream of Site C.

The plains surrounding the Peace River valley are part of the Alberta Plateau. The Alberta Plateau and its subdivision, the Fort Nelson Lowland, comprise approximately 10% of the land area of British Columbia. The region is underlain by sedimentary rocks that are flat-lying and gently dipping.

The Alberta Plateau is the product of numerous cycles of broad subsidence, marine and freshwater sedimentation, and emergence and erosion cycles. The initial pattern of topography was developed during the Tertiary period by mass wasting and fluvial action. The repeated advance and wasting of glacial ice during the Pleistocene period further modified these landforms and are responsible for the majority of the unconsolidated deposits found in the area today.

11.2.2 Geology

11.2.2.1 Regional Bedrock Geology

Marine and non-marine sedimentation in northeastern British Columbia and northwestern Alberta lasted from Jurassic to Upper Cretaceous time (i.e., from approximately 200 million years ago to 70 million years ago). In the Project activity zone, the regional geology consists of flat to gently dipping sedimentary rocks of Cretaceous age. Rocks of the Lower and Upper Cretaceous Fort St. John Group are exposed along the Peace River valley and include the Moosebar, Gates, Hulcross, Boulder Creek, and Shaftesbury formations (Figure 11.2.2 and Figure 11.2.3). Upper Cretaceous rocks of the Dunvegan formation are also exposed on parts of the valley rim and in the plateau. Other rocks of importance in the Project activity zone are the limestone in the Rocky Mountains to the southwest and the Gething sandstone to the west, where potential rock quarries are located.

The Moosebar Formation is composed of marine shale and siltstone, and underlies the Gates Formation. The Gates Formation is a marine succession of near flat-lying sandstone, shale, and conglomerate. The Gates and Moosebar formations are typically found below elevation 500 m in the western part of the proposed Site C reservoir. The Hulcross Formation consists of marine shales overlying the Gates Formation, and is overlain by the Boulder Creek Formation, which comprises sandstone and conglomerate beds. The Hulcross and Boulder Creek formations are found along Peace River near Lynx Creek.

Rocks of the Shaftesbury Formation are dark grey, rusty, and fissile marine shale to mudstone with lesser sandstone. This formation dips gently northeast and appears gradationally conformable with the overlying Dunvegan Formation. The Shaftesbury formation is exposed in the river banks along Highway 29 and Peace River as far east as the Alberta border.

Rocks of the Dunvegan Formation are medium- to fine-textured, evenly bedded siltstone and carbonaceous shale with lesser interbedded ironstone, coal, coarse sandstone, and conglomerate. This formation is found primarily in the eastern part of the Project activity zone.

Past regional tectonic activity has had little effect on the rocks of the proposed reservoir area. The most easterly major thrust structures related to development of the Rocky Mountains occur immediately downstream of Peace Canyon between Hudson's Hope and Farrell Creek and consist of a series of broad northeast-trending folds and low angle thrusts.

Geologic structures near the proposed dam site, including shear zones and jointing, are described in Section 11.2.2.4.

11.2.2.2 Regional Glacial History

In the latter part of the Quaternary, the Project activity zone experienced at least three major advances of Laurentide and Cordilleran ice. The Laurentide (or Continental) ice sheets dominated the plains region during the Pleistocene. The greatest extent of Cordilleran ice occurred about 15,000 years ago, when it overrode the foothills and, extending eastward, probably abutted the Laurentide ice sheet occupying the plains region. Much of the plains region experienced cyclical glacial and interglacial deposition sequences: fluvial gravels during interglacial periods; glaciolacustrine sands, silts and clays resulting from aggradation and ponding of Peace River by advancing Laurentide ice; till deposition by the ice itself; and then sands, silts and clays deposited in a series of ice dammed lakes during the retreat stages of Laurentide glaciation.

As the eastern front of the Cordilleran ice retreated from the plains, back to the foothills and the Rocky Mountains, it was responsible for the deposition of tills, glacial fluvial sands and gravels, and glaciolacustrine sediments in numerous localities throughout the plains/foothills region.

Throughout the area, many glacial deposits were removed by the fluvial action of modern streams and rivers. With a few exceptions, the courses of streams and rivers fall within the boundaries of older river valleys that formed during interglacial periods.

The formation of the modern Peace River valley began 14,000 years before present (BP), with the retreat of the Laurentide ice sheet and the formation of glacial lakes behind it. By 10,500 BP, the glacial lakes had drained and Peace River had begun incising the modern valley. The formation of the modern Peace River valley is shown schematically on Figure 11.2.4 and Figure 11.2.5.

11.2.2.3 Regional Surficial Geology and Terrain Stability

Terrain stability mapping involves the subdivision of landscape into geomorphic units (i.e., terrain polygons), based on criteria established for a particular study. Terrain mapping, and the various standards that are involved in it, form a British Columbia-wide standard practice requested by regulators for proposed resource road construction and other development activity. Where activity is proposed within unstable or potentially unstable terrain polygons, additional field investigation is usually undertaken and, if required, measures to reduce the potential for landslides are prescribed.

Standard terrain mapping techniques were used to delineate areas with distinct surficial geology and terrain stability for the Project activity zone. The terrain mapping results are presented in drawings contained in Volume 2 Appendix B, Part 1 Terrain Stability Mapping.

Much of the proposed reservoir shoreline is flanked by steep valley walls underlain by fine-textured material composed of glaciolacustrine sands, silts and clays, silty colluvium, or shale bedrock. Most of these slopes have been mapped as unstable (Class V) or potentially unstable (Class IV). Large flood plains are common at river level and large glaciofluvial terraces are common above the riverside scarps. The terrace surface is mapped as stable (Class I), while the steep scarp slopes are usually mapped as Class III to V. Thick colluvial deposits are present on gentle to moderate slopes where they have been deposited by slumps or slides from higher elevations. These deposits are usually mapped as moderately stable (Class II or III).

The proposed transmission line and many of the proposed construction access roads cross a gentle plateau underlain by glaciolacustrine sands, silts and clays, or glacial till. Bogs are scattered throughout this area. Much of the plateau area is very gently sloping, and no landslides are present. These areas are mapped as stable (Class I). Steeper slopes are present where the transmission line or access roads cross streams. These slopes have been mapped as Class III to V based on their steepness and the presence of landslides.

Proposed quarry development sites at Portage Mountain and West Pine are located in rocky areas to the west and southwest of the proposed reservoir. In both areas, rock ridges are partially covered by till or colluvial material. Based largely on slope steepness and morphology, most polygons in these areas have been mapped as Class II to III. A few steeper slopes overlain by shallow colluvium have been assigned Class IV.

The results of the terrain stability mapping are intended to support planning for activities such as access road construction and reservoir clearing. In some locations, such as at the proposed dam site and reservoir, the results of the terrain stability mapping have been superseded by more detailed geotechnical investigation and analysis.

11.2.2.4 Dam Site Geology

The dam site is located in a section of the valley where the postglacial Peace River has cut down from the general level of the Alberta Plateau near Fort St. John, at about elevation 630 m, through the overburden filling the interglacial valley and into bedrock.

The north (left) bank of Peace River at the proposed dam site is about 180 m high, slopes at about 1.8H:1V and consists of glacial and interglacial deposits of clay, silt, sand, and gravel between about elevation 580 m and bedrock at about elevation 470 m. Colluvial deposits, derived from sliding and sloughing of overburden and shale slopes above, skirt the toe of the bank and in places extend for a considerable distance from the toe of the slope.

The present-day river flows in a wide channel mainly infilled with up to 10 m of medium dense to dense alluvial sands and gravels overlying bedrock. In some areas adjacent to the north bank, clayey colluvium occurs above bedrock and is interlayered with the granular materials. The overburden bedrock interface is smooth in some areas and irregular in others. The bedrock at the interface is slightly weathered, very weak rock to a depth of 1 to 3 m, below which it is fresh, weak to medium strong rock.

The south (right) bank of Peace River at the proposed dam site is composed of broad terraces at about elevation 415 m and elevation 470 m. Bedrock is near elevation 405 m beneath the lowest terrace and near elevation 455 m beneath the upper terrace. Alluvial silts, sands and gravels overlie bedrock in the terraces. Behind the second terrace, the slope rises to the plateau at about elevation 630 m, with bedrock generally at about elevation 455 m. A thick deposit of clay, silt, and sand overlies a layer of sand and gravel about 10 m thick on top of the bedrock.

A buried valley is located to the south and west of the dam site that passes from a point about 2 km upstream of the mouth of the Moberly River to the Pine River. The base of the buried valley is between elevation 440 m and elevation 460 m but is at about elevation 455 m near the dam site.

Rock exposed at the site is part of the Shaftesbury Formation and consists of weak to medium strong, flaky to fissile, silty shale interbedded with siltstone, sandstone, and shale. The “Fish Scale Marker Bed”, commonly used to define the boundary between the Upper and Lower Cretaceous in northwestern B.C., is found in the rock of the upper north abutment. Thus, most of the rock at the site is Lower Cretaceous in age. The rock is of marine origin and is in an intermediate stage of diagenesis. The stratigraphy is uniform throughout the site. Numerous marker beds, as little as a few millimetres in thickness, can be traced throughout the site. The bedding has a regional dip of about 1° northeast, although local variations of 1° to 2° from this regional dip are common. As a result, the beds on the south bank are about 10 m higher than equivalent beds on the north bank. The bedrock has been divided into a number of units based on lithology, as shown in Figure 11.2.6. For example, the lowest bedrock unit that has been designated is a silty shale designated Unit 1 and shown on Figure 11.2.6 as SSH 1.

The bedrock is cut by three sets of fractures (Figure 11.2.7), which are characteristic of valleys eroded in flat-lying, weak, sedimentary rocks, namely:

- Fractures or softened zones parallel to bedding
- Steep relaxation fractures parallel to valley slopes
- Low angle shear zones of limited displacement

These structural features are explained by general rebound effects of valley erosion in reducing the horizontal and vertical stresses. These stress changes have resulted in:

- Inward movements of the valley walls
- Sprung bedding planes
- Shear zones formed due to displacements along the weaker beds
- Local thrust faults in the abutments

Although many discontinuities along the bedding have been recognized, only seven bedding planes are considered in design. Four of these – Bedding Plane 8 (the white clay), Bedding Plane 12 (the Marl), Bedding Plane 18, and Bedding Plane 25 – are important because of their low frictional resistance and because they are considered to be continuous throughout the site, although they are located above the rock surface in the valley floor. The fifth, Bedding Plane 28, is important because it might be continuous beneath the earthfill dam. The remaining two, Bedding Plane 31 and Bedding Plane 33, are important because they will be present in the deeper excavations for the buttress on the south bank.

Bedding Planes 8, 12, and 18 are continuous, but will not influence the structures. They are, however, important to the stability of the upper north bank and to the stability of excavations on the south bank. Bedding Plane 8 is continuous on the north bank, but not continuous on the south bank. It comprises 0.5 to 10 mm of light grey clay and shale breccia. Bedding Plane 12 underlies the Marl marker bed, and is continuous within the north and south banks. It comprises 1 to 4 mm of grey clay. Bedding Plane 18 is continuous on the north and south banks. In some areas, it is a tight discontinuity with rock-to-rock contact, and in others, comprises up to 50 mm of broken shale.

Bedding Plane 25 underlies the area of the proposed concrete structures on the south bank and occurs about 10 m below river level on the north bank. It is notable because of its relatively low peak and residual shear strength and its continuity throughout the site. Where exposed in exploratory Adits 3 and 5, this bedding plane is a discrete but tight discontinuity, very planar and apparently continuous. Clay-size material is almost always found at Bedding Plane 25, formed either as gouge from shearing movements or from softening of the shale by groundwater circulation. Although this clay material is generally observed, there are locations where it is not present and rock-to-rock contact occurs.

Under the riverbed, sprung (rebound) bedding planes exist in the upper 6 to 8 m of rock. Because of the difficulties of drilling in the river, it has not been possible to confirm the absence or presence of continuous open bedding planes beneath the river. There is some evidence to suggest that Bedding Plane 28 is reasonably continuous about 2 m below bedrock surface in the river channel.

Bedding Plane 28 has been observed in five out of seven large diameter drill holes in the riverbed and in two large-diameter drill holes on the south bank of the Peace River. On the south bank, it is a tight to slightly separated bedding plane within a 20 to 50 mm thick fracture zone with 1 mm of clay gouge seen in one of the holes. Beneath the riverbed, this bedding plane is similar, except that the fracture zone is up to 100 mm thick and sometimes contains shale fragments and silty alluvial infill.

Bedding Planes 31 and 33 have not been shown to be continuous and have only been observed in a few large diameter drill holes in the riverbed and south bank. They are typically hairline discontinuities with little to no infill.

Steep relaxation fractures in the bedrock striking approximately parallel to the valley have been observed in exploratory trenches and in the exploratory adits. On the north bank, the steeply dipping fractures are open greater than 1 mm for a horizontal distance of about 20 m into the bedrock and, on the south bank, for a horizontal distance of about 35 m (Figure 11.2.7). These fractures are typically truncated by bedding surface discontinuities, particularly Bedding Plane 8, Bedding Plane 12, and Bedding Plane 25.

A zone of open relaxation fractures is also found within the top 8 m of rock in the riverbed. These fractures are along the bedding as well as across it.

Cross-cutting shears have been observed in most areas of the proposed dam site. These shears are characterized by distorted bedding and a few centimeters to a few metres of gouge and breccia. The major shears can consist of over 3 m of gouge and breccia with pods of intact rock and distorted bedding. Shearing on the north bank is not as intense as on the south bank. Offsets are less and shears do not appear to be as continuous as on the south bank. The orientations of the shears are such that they are not critical to the stability of the planned excavations on the south bank.

The shears are generally more permeable than the bedding plane fractures and are thought to be one of the main features controlling groundwater movement within the rock mass. In the adits or large-diameter drill holes, shears were often observed to be moist or dripping water.

Mapping of the large-diameter drill holes revealed that two sets of joints occur on the south bank; these are more commonly found above the Marl layer near elevation 435 m. On the south bank above elevation 430 m, more relaxation of the bedrock has occurred. Evidence for this is relatively closely spaced joints seen in large-diameter holes and seismic survey results. Similarly, on the north bank, joints are more closely spaced at higher elevations, especially above Bedding Plane 8, which is near elevation 432 m.

The permeability of the rock mass, based on extensive packer tests and response tests of piezometers, ranges from more than 10^{-6} m/s in the relaxed surface rock to less than

10^{-9} m/s in the relatively undisturbed bedrock (i.e., deeper than 30 m below the bedrock surface).

On the north bank, the piezometers (mainly standpipes) indicate that the elevation of the piezometric surface on individual bedding planes decreases with depth. The piezometric pressure seldom exceeds 10 m above any given bedding plane discontinuity. However, the piezometric pressures have not been found to be higher than the top surface of the bedrock.

On the south bank, the piezometric surfaces have a gradient toward the river of about 25H:1V. Since the horizontal permeability is probably several orders of magnitude greater than the vertical permeability, the water probably flows near horizontally. An exception is near the valley walls, where steeply dipping relaxation joints are present.

Piezometric levels existing in the rock immediately below the river are generally near river level. At depth in the rock, piezometric levels are lower than river level.

11.2.3 Reservoir Impact Lines

11.2.3.1 Background

The proposed Site C reservoir will result in changes to erosion and slope stability at some locations within the reservoir shoreline technical study area. The location and nature of these changes have been predicted through a detailed characterization of the reservoir shoreline geology, inventory and characterization of existing slopes and landslides, groundwater monitoring and modelling, shoreline erosion modelling, and slope stability analyses. Preliminary reservoir impact lines have been prepared to characterize the following hazards around the proposed reservoir:

- Potential floods – the Flood Impact Line
- Potential erosion – the Erosion Impact Line
- Potential landslides – the Stability Impact Line
- Potential landslide-generated waves – the Landslide Generated Wave Impact Line

11.2.3.2 Simplified Geological Mapping Units

The geology of the proposed reservoir shoreline is described in detail in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines and was summarized in Section 11.2.2.

The proposed reservoir area is underlain by gently northeast-dipping Upper and Lower Cretaceous sedimentary rocks. Due to the regional northeasterly dip of the beds, younger rocks are progressively exposed at river level along Peace River between Hudson's Hope and the proposed dam site.

For the purposes of groundwater, erosion, and stability analyses, bedrock exposed at the maximum normal reservoir level has been divided into three main groups on the basis of general decreasing grain size and age, and increasing susceptibility to erosion and landslides with distance downstream:

- Siltstone upstream of Gates Island

- Silty shale between Gates Island and Cache Creek
- Shale downstream of Cache Creek

Sandstone bedrock exposed in the Dunvegan Escarpment above the proposed reservoir level between Cache Creek and Wilder Creek has been grouped as a separate sandstone unit.

The Cretaceous bedrock in the technical study area is overlain by a Quaternary sequence of overburden comprising fluvial, glacial, and interglacial deposits up to 400 m thick.

For the purposes of groundwater, erosion, and stability analyses, the overburden units have been grouped based on dominant grain size, age, and susceptibility to erosion and landslides. The simplified overburden mapping groups include:

- Interbedded sand, silt and clay
- Overburden colluvium
- Bedrock colluvium
- Sand and gravel
- Till
- Tufa

All glaciolacustrine units in the technical study area, including Glacial Lake Peace, Glacial Lake Mathews and Cordilleran Basin glaciolacustrine deposits, have been grouped together as interbedded sand, silt, and clay, while all fluvial and glaciofluvial units have been grouped together as sand and gravel. Man-made fills and the large diamicton exposure across from Lynx Creek have also been included in the sand and gravel group.

Sand, silt and clay materials are interpreted to be most susceptible to shoreline erosion and potential changes in slope stability caused by reservoir operations. The Cordilleran Basin glaciolacustrine deposit (interbedded sand, silt, and clay) is present along approximately 8% of the proposed reservoir shoreline at the maximum normal reservoir level. An additional 15% of the shoreline comprises sand, silt, and clay landslide debris (overburden colluvium), which, in most locations, is of limited thickness and overlies sand and gravel or bedrock. The remainder of the proposed reservoir shoreline comprises sand and gravel and fill (37%), bedrock colluvium (10%), and bedrock (30%). The approximate distribution of the materials present at the proposed maximum normal reservoir level is shown on Figure 11.2.8.

Around the majority of the proposed reservoir, one or more sand and gravel units separate the materials present at maximum normal reservoir level from overlying interbedded sand, silt, and clay units. As discussed further below, the presence of the sand and gravel limits the potential for the proposed reservoir to influence groundwater flow and slope stability in the overlying Glacial Lake Mathews and Glacial Lake Peace interbedded sand, silt and clay units.

Interpreted geological conditions along the proposed reservoir shoreline are presented in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines by way of geological fence diagrams (which illustrate the position of the main geological units in profile along the river valley) and cross-sections located approximately every kilometer along the north and south bank of the river valley. Figure 11.2.8 shows the locations of the geological cross-sections.

11.2.3.3 Landslide Inventory

Post-glacial downcutting of the modern Peace River during the Late Pleistocene and Holocene formed steep slopes in Cretaceous bedrock and Quaternary fluvial, glacial, and interglacial deposits. The bedrock topography and the occurrence of Quaternary soils in the area are controlled by the presence of buried interglacial valleys (paleovalleys), which have been re-excavated by the modern valley. Landslides most commonly occur within the Cretaceous Shaftesbury Formation, and within glaciolacustrine deposits of laminated silt and clay. In some cases, the modern river valley intersects paleovalleys in which landslides were present, potentially facilitating the reactivation of paleo-landslide surfaces.

Landslides in shale bedrock and glaciolacustrine overburden share some similarities. Most have the character of compound slides, exploiting weak near-horizontal clay layers found at multiple levels in both materials. Typically, a basal sliding surface first develops along a bedding plane pre-sheared to a residual friction angle and then connects to a steep main scarp by cross-cutting the layers of soil or bedrock. Frequently, this mechanism repeats successively at multiple levels if multiple weak bedding planes are present.

Bedrock landslides from low bank slopes typically comprise rock falls, toppling, and shallow slumping along steep valley relaxation joints. Overburden landslides from low bank slopes typically comprise shallow translational and rotational landslides and earth flows.

The four dominant types of landslides from high bank slopes in the Peace River valley are:

- Compound bedrock slides (typically associated with failures in Shaftesbury shale)
- Compound soil slides (typically associated with failures in Glacial Lake Mathews, Cordilleran Basin glaciolacustrine and Upper Paleovalley glaciolacustrine sediments)
- Flow slides (typically associated with failures in Glacial Lake Peace sediments)
- Earth flows (typically associated with remobilization of bedrock and overburden colluvium)

A comprehensive inventory of landslides that have occurred in the modern Peace River valley was completed for the proposed reservoir area based primarily on identification and interpretation of geomorphological features evident in a high-resolution digital elevation model generated from light detection and ranging (LiDAR) imagery. The LiDAR analysis was supplemented by an examination of 1:20,000 and 1:40,000 scale orthorectified aerial photographs (orthophotos) that were taken in 2007. Additional historical airphotos dating back to 1945 were also examined, and extensive reference was made to an existing regional airphoto-based landslide inventory. Additional ground-truthing was carried out during site investigation work in 2010 and 2011 (see Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines). Historical and recent drilling and test pitting results were also studied, including laboratory tests on samples taken from the 1973 Attachie Slide and adjacent slopes.

Two of the most significant landslide complexes in the landslide inventory are the Cache Creek Slide and the Attachie Slide.

The Cache Creek Slide is a bedrock landslide located on the north bank of Peace River downstream of the confluence with Cache Creek. The landslide complex is defined by a prominent head scarp approximately 1500 m long and 150 m high. It is the largest known landslide complex in the Peace River valley with an estimated volume of 82 million m^3. The age of the landslide complex is unknown; however, anecdotal evidence suggests that reactivation of a part of the landslide may have occurred in the late 1700s. Geotechnical investigations indicate that sliding occurred along a weak, pre-sheared, sub-horizontal bedding plane within the Shaftesbury shale approximately 100 m below the shale-sandstone contact and approximately 140 m above the proposed maximum normal reservoir level. While future movement of the Cache Creek Slide is possible, movement rates within flat-lying shale bedrock landslides like the Cache Creek Slide are expected to be slow to moderate.

The Attachie Slide is located on the south bank of Peace River opposite the Halfway River confluence. The slide occurred on May 26, 1973, and has an estimated volume of 14.7 million m^3. Debris traveled across the river and up the opposite bank, damming the river for approximately 12 hours. Geotechnical investigations suggest that the basal failure surface was coincident with a pre-sheared layer located near the base of the Glacial Lake Mathews interbedded sand, silt and clay deposits. The Attachie Slide exhibited two main phases of movement: an initial phase of slope deformation over a period of several decades resulting in a slope marked by scarps and open tension cracks, followed by a rapid to extremely rapid compound slide that transitioned to an extremely rapid flow slide. The Attachie Slide was unusual in that it is the only confirmed extremely rapid landslide of this size that has occurred within over-consolidated glaciolacustrine sediments in the Peace River valley.

A total of 1,834 landslide complexes comprising 4,010 individual landslides were identified. Of the individual landslides in the inventory:

- 6% were classified as compound rock slides in Shaftesbury shale; 40% were classified as compound earth slides in Glacial Lake Mathews, Cordilleran Basin glaciolacustrine, and Upper Paleovalley glaciolacustrine sediments; 52% were classified as flow slides in Glacial Lake Peace sediments; and 2% were classified as earth flows in overburden and/or bedrock colluvium
- 19% were classified as having experienced a significant episode of movement affecting all or part of the landslide within the last 100 years, while 81% of the landslides were classified as greater than 100 years old
- The debris from 71% of the landslides did not extend to the proposed maximum normal reservoir level elevation of 461.8 m, while debris from 29% of the landslides did
- Estimated deposit volumes ranged between 1,100 m^3 and 44 million m^3, with a mean value of 320,000 m^3 and a median value of 90,000 m^3

Of particular interest is the number and percentage of existing landslides with a basal failure surface situated below the maximum normal reservoir level, as these landslides have a greater likelihood of being affected by reservoir operations. Eighty-nine (approximately 2%) of the landslides identified around the perimeter of the proposed reservoir appear to have a basal failure surface elevation that would be below the proposed maximum normal reservoir level. Fifty-eight of these landslides are in shale bedrock slopes situated downstream of Cache Creek, where potential landslide movement rates are expected to be low.

Further details on the landslide inventory, along with more detailed descriptions of the Cache Creek, Attachie, and other large landslides are provided in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines.

11.2.3.4 Slope Angle Inventory

Representative cross-sections were generated to create an inventory of the slope angles that have formed in the different geological materials around the proposed reservoir.

Within each geological unit, the steepest slopes observed are typically slopes that are subject to active river or gully erosion at the base of the slope. The steepest slopes provide an indication of the range of slope angles likely to form over the short term as a result of wind-generated shoreline erosion, and are referred to as ‘eroded slope angles’.

The flattest slopes observed within each geological unit are typically not subject to active toe erosion. In most cases, these slopes have been modified by surface erosion and landslides that have contributed to the gradual flattening of the slopes over the past several hundred to several thousand years. The flattest slopes provide an indication of ultimately stable slope angles within each of the geological units, and are referred to as ‘ultimate slope angles’.

The results of the slope angle inventory, combined with results from the geotechnical site investigations and slope stability analyses, were used to establish predicted eroded and ultimate slope angles for each of the geological units around the proposed reservoir. These values are summarized in Table 11.2.1.

Table 11.2.1 Predicted Slope Angles by Geological Unit

Geological Unit	Eroded Slope Angle	Ultimate Slope Angle
Sandstone	N/A	1H:1V (45 degrees)
Siltstone	vertical	1H:1V (45 degrees)
Silty Shale	1H:1V (45 degrees)	1.5H:1V (34 degrees)
Shale (low bank)	1H:1V (45 degrees)	1.5H:1V (34 degrees)
Shale (high bank)	1H:1V (45 degrees)	3H:1V (18 degrees)
Bedrock Colluvium	1.3H:1V (38 degrees)	3H:1V (18 degrees)
Sand and Gravel	1.3H:1V (38 degrees)	2H:1V (27 degrees)
Interbedded Sand, Silt, and Clay (low bank)	1.3H:1V (38 degrees)	2H:1V (27 degrees)
Interbedded Sand, Silt, and Clay (high bank)	1.3H:1V (38 degrees)	4H:1V (14 degrees)
Overburden Colluvium	1.3H:1V (38 degrees)	4H:1V (14 degrees)

NOTE:
N/A = not applicable

11.2.3.5 Groundwater Flow

Predicted changes in groundwater flow that might affect slope stability as a result of proposed reservoir operations were characterized using a series of two-dimensional geological cross-sections located at key locations perpendicular to the river valley (Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines). The cross-sections illustrate the subsurface geology, hydrostratigraphy, and water table positions for unconfined and confined aquifers. Two-dimensional numerical groundwater flow models (seepage models) were developed to simulate baseline groundwater flow under current conditions and to predict potential changes to groundwater flow as a result of reservoir operations at the locations of the key cross-sections. The reservoir shoreline geological models were used to extend the results of the groundwater monitoring and seepage analyses to the other slopes around the proposed reservoir. Results of the analyses of current and predicted conditions are presented in contained in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines.

The groundwater regime within the slopes adjacent to the proposed reservoir typically consists of water tables perched on lower permeability silt and clay or bedrock units, with the sandier interbeds providing drainage to the slope face, resulting in groundwater exiting as springs. Springs from some of these groundwater bearing zones form a calcium carbonate (tufa) deposit at the ground surface. Deeper lying bedrock aquifers consist of sandstone, siltstone, and shale bedrock units that generally dip at less than 3° to the northeast.

Recharge to the system is typically from percolation into and through gravel aquifers present at either the ground surface and/or at depths corresponding to relict fluvial drainage systems. Locally, this may be supplemented by groundwater from a deeper buried, glacially-carved basin that passes beneath the project area in the vicinity of Hudson’s Hope, Lynx Creek, and Farrell Creek.

In the uppermost unconfined aquifer in the unconsolidated sediments, the water levels fluctuate with seasons and climatic variability, as the recharge areas tend to be dependent on precipitation and snow melt. The regional recharge area is located upland and groundwater flow is generally towards the Peace River.

Predicted average and above-average groundwater recharge rates were estimated by applying a baseflow separation technique to historical streamflow data collected from two hydrometric stations located on the Halfway River near Attachie, B.C. The groundwater seepage modelling and subsequent slope stability analyses considered both average and above-average recharge rates and explored the potential changes of up to a 67% increase in long-term groundwater recharge rates over average conditions on groundwater levels. The above-average recharge conditions used in the seepage analyses are expected to be greater than those predicted by BC Hydro (2012a) under a range of potential long-term climate change scenarios.

The widespread presence of sand and gravel units within the valley slopes limits the potential for the proposed reservoir to influence groundwater flow and slope stability in the upper Glacial Lake Peace and Glacial Lake Mathews interbedded sand, silt, and clay units. Groundwater flow and slope stability within these upper units are dominated by seasonal and annual variability in recharge rates and by the presence of sub-horizontal clay layers that tend to control stability and promote the formation of perched water tables.

The largest changes in groundwater flow potentially affecting slope stability, as predicted by seepage modelling, occur within the glacially-carved buried valley that extends below the riverbed in the Hudson's Hope to Farrell Creek stretch of the Peace River. At these locations, the amount of groundwater rise is directly correlated to the proposed increase in water levels associated with reservoir filling, and the lateral extent of predicted changes in groundwater levels are based on the predicted widths of the glacially-carved buried valley.

Groundwater levels are also expected to increase near the valley bottom as a result of reservoir operations at most other slopes around the proposed reservoir. At these locations, however, current regional groundwater levels are typically higher than the proposed maximum normal reservoir level. Consequently, the predicted lateral extent of changes in groundwater flow is less than for the glacially-carved buried valley sections.

11.2.3.6 Floods and Wind-Generated Waves

Flood discharges from Peace Canyon Dam upstream of the proposed reservoir, and from tributary valleys within the proposed reservoir, combined with wind-generated waves, have the potential to temporarily inundate lands above the maximum normal reservoir level. Conditions that result in operation of the auxiliary spillway could also surcharge the reservoir.

As described in Section 4 Project Description, the Project would be designed for the probable maximum flood. As described in effects of the environment on the Project in Volume 5 Section 37 Requirements for the Federal Environmental Assessment, the methodology used to determine the probable maximum flood does not define an annual exceedance frequency; however, the governing storm combination has an annual exceedance frequency of less than 1/10,000. More likely events with higher annual exceedance frequencies were analyzed for determining the reservoir impact line for potential floods and wind generated waves.

An analysis of the potential floods on the proposed reservoir is summarized in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines, along with an analysis of potential wind-generated wave runup at selected locations along the proposed reservoir shoreline.

Three flood and wind-generated wave scenarios were analyzed to help understand the potential range of reservoir levels. The events analyzed included:

- 1000-year release from Peace Canyon Dam (7,000 m^3/s) combined with waves from the 200-year wind storm
- 1000-year return period flood from Halfway River (4,250 m^3/s) and powerhouse flows from Peace Canyon Dam (2,000 m^3/s), combined with waves from the 200-year wind storm
- Passage of upstream powerhouse flows from Peace Canyon Dam (2,000 m^3/s) with the Site C generating facilities offline and all spillway gates inoperable and in the closed position

MIKE-11 and HEC-RAS flood modelling were carried out to estimate potential reservoir water levels for each of the flood scenarios. Wave runup estimates were combined with wind setup (storm surge) estimates to determine total wind effects.

For the 1000-year Peace Canyon Dam release (7,000 m^3/s), the modelled reservoir surface profile was higher than elevation 465 m near Peace Canyon Dam; but declined exponentially downstream (to below elevation 462 m downstream of Farrell Creek). Similarly, for the 1000-year Halfway River flood (4,250 m^3/s), the modelled reservoir surface profile was higher than elevation 465 m near the upstream end of the Halfway River arm of the proposed reservoir, but declined exponentially downstream (to below elevation 462 m at the confluence of the Halfway River arm and the main Peace River reach).

As described in Volume 5 Section 37 Requirements for the Federal Environmental Assessment, in the unlikely event that the powerhouse was inoperative and all spillway gates failed to open, the auxiliary spillway could pass 2,000 m^3/s powerhouse flows from Peace Canyon Dam, with the reservoir at elevation of 465 m.

The estimated wave runups for the 200-year return period wind storm vary around the proposed reservoir and ranged from 0.5 m to 4.2 m.

11.2.3.7 Reservoir Shoreline Erosion

Wind-generated waves would have the potential to cause shoreline erosion around the proposed Site C reservoir. The potential erosion volumes are a function of the potential wave energy and the erodibility of the geological materials present at the reservoir shoreline. The amount of bank recession for a given erosion volume is a function of the bank height and the inclination of the eroded slopes that are predicted to form above the shoreline.

The shoreline materials were classified based on field mapping, drilling, and interpretation of the LiDAR digital elevation model (Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines). Erodibility coefficients assigned to each of the classified material types were established based on a review of case studies and on historical erosion observed along the shores of Williston Reservoir and Dinosaur Reservoir.

Average shoreline recession distances were predicted for vertical ~~banks~~ bluffs at five and 100 years after reservoir filling, as described in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines. The results are shown in Table 11.2.2.

Table 11.2.2 Summary of Average Predicted Shoreline Erosion Distances

Years of Operation	Predicted Erosion Distance (in metres) by Shoreline Material Type (percentage of shoreline length is shown in brackets)						
	ISC (8%)	OC (15%)	BC (10%)	SG (36%)	SST (11%)	SSH (11%)	SH (8%)
5	24	18-43	2-5	1-6	<1	<1	1
100	47	30-80	5-23	4-18	<1	2	3

NOTES:

ISC = interbedded sand, silt, and clay; OC = overburden colluvium; BC = bedrock colluvium; SG = sand and gravel; SST = siltstone bedrock; SSH = silty shale bedrock; SH = shale bedrock

An additional 1% of the reservoir shoreline would comprise fill that would be designed to prevent erosion.

As shown in Table 11.2.2, the shoreline materials with the greatest predicted recession distances are the interbedded sand, silt, and clay materials and overburden colluvium.

Within these material types, approximately half of the predicted shoreline erosion would be expected to occur during the first five years of reservoir operation.

11.2.3.8 Slope Stability

Potential groundwater changes and shoreline erosion would affect the stability of slopes around the proposed Site C reservoir.

Two-dimensional limit equilibrium slope stability analyses were carried out to refine an understanding of the mechanisms controlling slope stability, and to help quantify the potential changes of the proposed Site C reservoir on the stability of the reservoir slopes (Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines). The purposes of the analyses were to: calibrate shear strength parameter values; analyze the relative change in slope stability upon reservoir filling; analyze the relative change in slope stability due to predicted shoreline erosion over time; analyze the sensitivity of the slopes to potential earthquakes, rapid drawdown scenarios, and ranges in groundwater recharge rates; and to confirm that the ultimate slope angles used to determine the location of the preliminary Stability Impact Line are appropriate.

Twenty-one representative cross-sections along the proposed reservoir shoreline were analyzed, including 12 low bank and 9 high bank cross-sections where subsurface information was available nearby. In addition, a back-analysis of the pre-failure conditions at the 1973 Attachie Slide was carried out. All of the low bank cross-sections were located where existing residences may be impacted by the proposed reservoir or in the vicinity of propose shoreline protection measures at Hudson's Hope. The high bank cross-sections were located at well-documented landslides and/or where there is a possibility of landslides that could generate waves that could impact low-lying properties or sections of Highway 29.

Each cross-section was assessed at three stages: existing conditions, Year 1 conditions during operations, and Year 100 conditions during operations. Reservoir Year 1 analyses were conducted using the present slope geometry and a reservoir at maximum normal reservoir level. For reservoir Year 100 analyses, slope geometry was adjusted to account for a conservative prediction of 100 years of shoreline erosion.

The analyses indicate that the creation of the proposed reservoir would have limited impact on the overall stability of the high bank slopes. This is because the critical failure surface for most potential landslides typically daylights above maximum normal reservoir level, and because sand and gravel units within the high bank slopes generally prevent a rise in the groundwater table, as a result of reservoir impoundment, into overlying Glacial Lake Mathews sediments, which tend to be more prone to landslides. Exceptions include the slopes opposite Lynx Creek and Farrell Creek, where interbedded sand, silt, and clay sediments extend below current river level, and where current groundwater levels are low. At these locations, the seepage and stability analyses, combined with predictions of shoreline erosion, indicate a decrease in stability. Shoreline erosion could also reduce the stability of high bank slopes where the maximum normal reservoir level would be located in the sand and gravel units. A decrease in stability is also predicted in the high bank bedrock slopes downstream of Wilder Creek (including Moberly River), where weak bedding planes would be located below maximum normal reservoir level. Some remobilization of overburden and bedrock colluvium at the toe of high bank slopes throughout the proposed reservoir area could also be expected.

Very small changes in stability are predicted for the low bank slopes in bedrock located upstream of Hudson's Hope, with predicted changes in stability ranging from a 5% decrease to a 2% increase.

In general, creation of the reservoir would have a higher impact on the low bank slopes in overburden. The results of the analyses indicate up to a 7% decrease in stability at some of these locations. However, shoreline erosion would likely dominate the observed changes.

The seepage and slope stability analyses indicate that potential rapid drawdown of the proposed reservoir would have limited impact on the overall stability of most high bank and low bank slopes. The slopes that potentially benefit from a buttressing effect from the proposed reservoir under normal operating conditions would experience the greatest decrease in stability under rapid drawdown conditions.

The computed static factor of safety at the position of the preliminary Stability Impact Line was equal to or greater than 1.5 in every case. Under 2,475 year earthquake loading, the factor of safety was greater than 1.0 in every case. These results satisfy typical slope stability guidelines for new residential development in B.C.

At several cross-sections, including the low bank bedrock slopes upstream of Hudson's Hope and most of the high bank slopes, the computed critical factor of safety at the position of the preliminary Stability Impact Line was higher than 2.0 under both static and seismic loading conditions. These results reflect a general conservative positioning of the line in terms of deep-seated sliding potential. However, other failure mechanisms are also covered by the Stability Impact Line. Upstream of Hudson's Hope, the dominant failure mechanisms are toppling of bedrock and sloughing of sand and gravel near the slope crest, which can cause 5-10 m of slope retrogression in a single event. Likewise, the ultimate slope angles in high bank glaciolacustrine materials are governed by failures in Lake Peace deposits on top of the plateau, which can extend hundreds of metres back from the slope crest.

Further details on slope stability are provided in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines.

11.2.3.9 Landslide-Generated Waves

Landslides with the capability of achieving extremely rapid velocities (greater than 5 m/s) have the potential to generate impulse waves if they enter the reservoir. Six areas were identified for detailed study, including the slopes opposite Lynx Creek, the slopes opposite Farrell Creek, the slopes opposite Halfway River (near the 1973 Attachie Slide), the slopes between Halfway River and Cache Creek, the slopes opposite Cache Creek (Bear Flat), and the slopes opposite Wilder Creek.

These six study sites were selected because they involve high bank slopes with a history of large landslides in the Glacial Lake Mathews and/or Cordilleran Basin glaciolacustrine deposits and are situated across the reservoir from low bank slopes where the potential consequences of inundation could be high. The Landslide-Generated Wave Impact Line assessment was focused on these types of slopes because of the potential for Lake Mathews and Cordilleran Basin glaciolacustrine failures to travel extremely rapidly, similar to the 1973 Attachie Slide, and therefore generate large waves upon impact with the proposed reservoir.

Although large overburden landslides can also originate from the Glacial Lake Peace deposits near the top of the valley slopes, these types of landslides occur progressively in a fluid-like manner and have limited potential for generating large waves by the time they reach reservoir level. Similarly, landslides in the flat-lying bedrock of the reservoir area are not expected to fail rapidly and generate large waves.

The results of the landslide inventory, geotechnical site investigations, and slope stability analyses were used to establish a design landslide volume and velocity for each area in order to assess the landslide-generated wave hazard.

Three stages of landslide-generated wave development can be distinguished: 1) wave generation, 2) wave propagation, and 3) wave runup. The first phase involves the displacement of water by the landslide mass at the impact site, the collapse of the initial turbulent splash, and the development of a well-defined wave, referred to as a gravity wave. The second phase involves the propagation and transformation of the gravity wave across the water body, including attenuation with distance from the source and refraction and shoaling as it enters shallower water near the shoreline. The third phase involves the impact of the wave against the shoreline and its runup onto dry land.

A hybrid modelling approach was adopted that combined empirical wave generation estimates with numerical wave propagation and runup modelling. The results of this modelling methodology were compared with historical physical model tests. Both the physical and numerical modelling methods produced consistent results.

Based on the methods outlined above, it was determined there would be some potential for landslide-generated wave impacts at elevations above the Flood Impact Line east of Lynx Creek and Farrell Creek, and on either side of Halfway River. While there is some potential for landslide-generated waves at the other three study sites, because of the greater reservoir width and/or smaller predicted landslide source volumes, the predicted wave runups do not exceed the Flood Impact Line elevation.

11.2.3.10 Reservoir Impact Lines

Preliminary impact lines have been determined around the proposed Site C reservoir based on information gathered as part of historical and recent geotechnical investigations, and analyses of erosion, seepage, slope stability, and landslide-generated wave potential, as described in the preceding subsections. Four preliminary impact lines are briefly described below, and in detail in Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines. Schematic illustrations of the Flood, Erosion, and Stability Impact Lines at low bank and high bank slopes are shown in Figure 11.2.9.

An overview map showing the location of the impact lines around the proposed reservoir is shown in Figure 11.2.10. A full set of maps and map sheet descriptions showing the impact lines is appended to Volume 2 Appendix B, Part 2 Preliminary Reservoir Impact Lines, and is also available online at www.bchydro.com/sitec.

The impact lines are considered ‘preliminary’ because they currently do not take into account the potential benefits associated with erosion protection and/or slope stabilization measures that could be incorporated into the final designs for the proposed Highway 29 realignment sections. Additionally, small changes to the position of the impact lines could be made based on information that becomes available through additional geotechnical investigations carried out to support the final design of the Project.

11.2.3.10.1 Flood Impact Line

The Flood Impact Line is the boundary beyond which land would not be expected to be affected by floods, wind-generated waves, the operation of the Site C auxiliary spillway, or waves caused by boats and small landslides (Figure 11.2.9). Based on flood and wind-generated wave modelling results described above, the selected Flood Impact Line elevation is 466 m, or approximately 4 m above the maximum normal reservoir level. Because and the Flood Impact Line would typically be located on the reservoir side of the Erosion Impact Line, its position in plan view would change over time as shoreline erosion occurs.

11.2.3.10.2 Erosion Impact Line

The Erosion Impact Line is the boundary beyond which the top of the slope would not be expected to regress due to erosion caused by the creation and operation of the reservoir over a period of 100 years. It considers both predicted shoreline erosion and the formation of a slope above the reservoir shoreline using the eroded slope angles corresponding to the geological units present around the shoreline (Figure 11.2.9). The most active period of erosion would be expected to occur during the first five years of reservoir operation.

11.2.3.10.3 Stability Impact Line

The Stability Impact Line is the boundary beyond which land would not be expected to be affected by landslide events caused by the creation and operation of the reservoir. The position of this line considers extremely unlikely landslide events. It accounts for the predicted amount of shoreline erosion over a 100-year period of reservoir operation, potential changes in groundwater levels, and gradual flattening of slopes above the reservoir shoreline using the ultimate slope angles corresponding to the geological units present around the shoreline (Figure 11.2.9).

11.2.3.10.4 Landslide-Generated Wave Impact Line

The Landslide-Generated Wave Impact Line is a boundary applied to three areas on the north bank of the proposed reservoir (Lynx Creek, Farrell Creek and Halfway River), where landslide-generated waves could temporarily inundate elevations higher than the Flood Impact Line. The position of this line is based on combinations of landslide volumes and velocities that are considered extremely unlikely to occur.

11.2.3.11 Shoreline Classification

The total area contained between the proposed maximum normal reservoir level and the outermost preliminary impact line is 9,648 ha. The areas between the maximum normal reservoir level and the individual impact lines area as follows:

- Flood Impact Line = 648 ha
- Erosion Impact Line = 1,464 ha
- Stability Impact Line = 9,190 ha

The area between the Flood Impact Line and Landslide-Generated Wave Impact Line is 210 ha.

Of the land area encompassed by the impact lines, approximately 70% is steeper than 17°. Terrain steeper than 17° in the Peace River valley is prone to erosion and landslides under natural conditions, and is typically not considered suitable for residential use. Consequently, on their own, the impact lines do not facilitate a direct quantification of the predicted changes to slope stability or potential land use caused by the reservoir. The potential changes to slope stability are quantified based on the results of a shoreline erosion and stability classification before and after reservoir filling.

Shoreline segments were assigned to one or more shoreline erodibility classes based on the material type at the maximum normal reservoir level. Shoreline segments were also assigned to one or more landslide hazard classes as shown in Table 11.2.3. Only landslides capable of moving faster than 1.6 m/s were considered in defining the hazard classes.

Table 11.2.3 Landslide Hazard Class Definitions

Landslide Hazard Class	Applicable To	Definition	Additional Notes
A	Low bank slopes (10–75 m high)	Potential for landslides in bedrock with volumes >10,000 m^3 and generally limited velocities	Total landslide volume may include overlying overburden Peak landslide velocities would typically be less than 13 m/month and are unlikely to exceed 1.8 m/hr, but could exceed 5 m/s where rock falls initiate on near-vertical slopes
B	Low bank slopes (10–75 m high)	Potential for landslides in overburden with volumes >10,000 m^3 and possible extremely rapid velocities	Peak landslide velocities would typically be less than 13 m/month but could exceed 5 m/s where flow slides are generated
C	High bank slopes (>75 m high)	Potential for landslides in bedrock with volumes >100,000 m^3 and generally limited velocities	Total landslide volume may include overlying overburden Peak landslide velocities would typically be less than 13 m/month and are unlikely to exceed 1.8 m/hr
D	High bank slopes (>75 m high)	Potential for landslides in overburden with volumes >100,000 m^3 and possible extremely rapid velocities	Includes potential remobilization of bedrock and overburden colluvium Peak landslide velocities would typically be less than 13 m/month but could exceed 5 m/s where flow slides are generated

Bedrock landslides from low bank slopes associated with Landslide Hazard Class A are rare and typically comprise rock falls, toppling, and shallow slumping along steep valley relaxation joints. Overburden landslides from low bank slopes associated with Landslide Hazard Class B typically comprise shallow translational and rotational landslides and earth flows.

The four dominant types of landslides from high bank slopes are compound bedrock slides, compound soil slides, flow slides, and earth flows. Compound bedrock slides are associated with Landslide Hazard Class C, while Landslide Hazard Class D includes compound soil slides, flow slides, and earth flows.

One of three landslide likelihood classes was assigned to each landslide hazard class for each shoreline segment, as defined in Table 11.2.4.

Table 11.2.4 Landslide Likelihood Class Definitions

Landslide Likelihood Class	Annual Probability	Additional Notes
Two star (**)	>1:100	Likely to occur over 100 years of reservoir operation
One star (*)	1:100 to 1:1,000	Possible over 100 years of reservoir operation
No star	<1:1,000	Unlikely to occur over 100 years of reservoir operation

For current conditions, the landslide likelihood classes were assigned primarily based on interpretation of the landslide inventory. For reservoir conditions, the landslide likelihood classes also consider the influence of predicted shoreline erosion and groundwater changes on slope stability, as determined by slope stability analyses on typical cross-sections.

The resulting shoreline stability classification indicates that the likelihood of Class A landslides in low bank bedrock slopes would not generally be expected to increase under proposed reservoir conditions. The likelihood of Class B landslides in low bank overburden slopes would be expected to increase over a length of approximately 27.9 km of reservoir shoreline, primarily at locations where interbedded sand, silt, and clay would be present at or below the maximum normal reservoir level, and erosion and groundwater changes could affect slope stability.

The likelihood of Class C landslides in high bank bedrock slopes would be expected to increase over a length of approximately 48.7 km of reservoir shoreline, primarily downstream of Wilder Creek, where weak bedding planes associated with previous landslides, including the Tea Creek Slide, would be subject to pore water pressure changes during reservoir impoundment and operation. The likelihood of Class D landslides in high bank overburden slopes would be expected to increase over a length of approximately 66.5 km of reservoir shoreline, primarily at locations where sand and gravel and interbedded sand, silt, and clay would be present at or below the maximum normal reservoir level, and erosion and groundwater changes could affect slope stability.

11.2.3.12 Consideration for Land Use and Public Safety within the Impact Lines

11.2.3.12.1 Land Use

BC Hydro has developed an approach to land use on private property within the impact lines. The approach focuses on public safety, maximizing flexibility for land owners, and minimizing the amount of land required by the project.

No new residential structures would be permitted within the impact lines. Non-residential structures could remain within the impact lines, pending site-specific geotechnical assessment. Existing residential structures within the Flood, Erosion, and Wave Impact Lines would not be permitted to remain, to protect public safety.

Within the Stability Impact Line, and outside the Flood, Erosion, and Wave Impact Lines, existing residential structures could remain for a period of time, at the owner's request and provided a site-specific geotechnical assessment determines that it is safe to do so.

The approach outlined above is consistent with criteria that have been developed and used elsewhere in British Columbia for managing new and existing residential development in landslide-prone areas.

11.2.3.13 Hudson's Hope Shoreline Protection

Shoreline protection adjacent to the community of Hudson's Hope would be constructed prior to filling the reservoir. The proposed shoreline protection includes a combination of a granular berm and slope flattening to prevent shoreline erosion and to offset effects of the reservoir on slope stability (Figure 11.2.11). The shoreline protection would extend from a location where the proposed reservoir shoreline transitions from bedrock to interbedded sand, silt, and clay materials at the upstream end, downstream to beyond the current location of the municipal sewage treatment facility, for a total length of about 2,650 m. As the proposed shoreline protection offsets the predicted effects of the reservoir on erosion and slope stability, an Erosion and Stability Impact Line have not been established through this section. BC Hydro would not acquire rights to restrict land use at the top of this section of slope, but it is anticipated that the District of Hudson's Hope would continue to enforce setback guidelines for new development to address natural erosion and slope stability hazards that would not be mitigated by the shoreline protection.

11.2.3.13.1 Highway 29

Proposed realigned segments of Highway 29 have been located outside of the preliminary impact lines, where practical. The proposed highway realignment at the Halfway River crossing is situated inside the Landslide-Generated Wave Impact Line. The potential for landslide-generated waves has been considered in determining the highway embankment elevation, bridge elevation, and bridge design parameters. The proposed highway and bridge design at Halfway River has been reviewed by the Ministry of Transportation and Infrastructure.

Some existing segments of Highway 29 are currently situated on marginally stable slopes and are located within the Stability Impact Line. Each of these segments has been reviewed by BC Hydro and the Ministry of Transportation and Infrastructure. It has been determined by BC Hydro that the potential changes to the stability of these highway segments as a result of the impoundment and operation of the reservoir are small, and an approach to ongoing highway monitoring and maintenance has been established in collaboration with the Ministry of Transportation and Infrastructure to manage the residual risks.

11.2.3.14 Shoreline Monitoring and Impact Line Updates

An operational monitoring plan will be developed for the Project. As part of this plan, BC Hydro will commit to regular monitoring of shoreline conditions, including groundwater levels, shoreline erosion rates, and landslide activity. An update of the preliminary impact lines will take place following the first five years of reservoir operations based on observations made during and following reservoir filling.

11.2.4 Geochemistry

11.2.4.1 Geochemical Characterization Program

11.2.4.1.1 Overview

A comprehensive geochemical characterization program was developed for the Project consistent with the following regulatory policy for British Columbia and guidance documents:

- Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia, Ministry of Energy and Mines and Ministry of Environment, Lands and Parks, July 1998
- Guidelines for Metal Leaching and Acid Rock Drainage at Minesite in British Columbia, Ministry of Energy and Mines, August 1998
- DRAFT Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia, Ministry of Employment and Investment, April 1997
- List of Potential Information Requirements in Metal Leaching/Acid Rock Drainage Assessment and Mitigation, MEND Report 5.10E, January 2005
- Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials, MEND Report 1.20.1, December 2009
- The Global Acid Rock Drainage Guide, http://www.gardguide.com/index.php/Main_Page, International Network for Acid Prevention INAP, 2012

Since 2008, a geochemical characterization program has been underway to evaluate the acid rock drainage and metal leaching potential of the material that would be excavated, exposed or disturbed by construction activities for the Project, and to develop strategies for the management of potential acid rock drainage and metal leaching issues. The program is at an advanced stage, where there is sufficient understanding of the geochemical behaviour of the materials, that any uncertainties and risks can be addressed by conservative assumptions and estimates, and prevention and mitigation strategies have taken these into account. Volume 2 Appendix B, Part 4 Acid Rock Drainage and Metal Leaching Management Plan describes the prevention and mitigation strategies that have been developed based on the test results obtained to date.

The geochemical characterization program includes static, leachate extraction, and laboratory and field kinetic testing, and takes into account the proposed construction and excavation schedule and volumes. The geochemical characterization program would continue through detail design and procurement, and the results will be used to validate and, if necessary, refine the material management plans for the Project.

Figure 11.2.12 shows schematically the steps used for determining the acid rock drainage and metal leaching potential of the materials that would be excavated, exposed or disturbed by construction activities for the Project. The tests shown on the Figure are described in Section 11.2.4.1.2. No further testing is required if a material is classified as not potentially acid generating in Step 1. The additional tests listed under Steps 2 through 4 are undertaken on materials identified as uncertain or potentially acid generating in Step 1.

The current and planned temporal phases of the geochemical characterization program are:

- Phase 1 – 2008: Preliminary geochemical characterization of dam site south bank bedrock and overburden, including static, leachate, and laboratory kinetic tests
- Phase 2 – 2010: Preliminary geochemical characterization of dam site north bank overburden, including static and leachate tests
- Phase 3 – 2011: Additional geochemical characterization of dam site south bank bedrock and overburden, consisting of field leach barrel construction
- Phase 4 – 2011: Preliminary geochemical characterizations of off-site borrow and road realignment materials, including static and leachate extraction tests
- Phase 5 – 2012: Construction and monitoring of additional field leach barrels and field leach pads at the dam site; and further sampling and testing of samples from the West Pine Quarry and the Portage Mountain Quarry
- Phase 6 – 2012 and 2013 ongoing monitoring of field leach barrels and the field leach pad to provide additional information on the predicted lag times, leachate and water quality under site-specific field conditions

The results of the above testing to the end of 2012 are presented in KCB & SLI 2013~~2~~.

11.2.4.1.2 Tests for Determining Acid Rock Drainage and Metal Leaching Potential

Static acid-base accounting tests are one-time screening tests to determine the balance of acid-generating versus acid-neutralizing components in a geologic unit, and non site-specific screening criteria are used to classify the acid rock drainage and metal leaching potential of each geologic unit. Whole rock and trace elemental analyses are screening tests to determine which concentrations are elevated in the solid-phase that may be released during acid rock drainage and metal leaching potential processes. Mineralogical analyses are used to identify and estimate the abundance of the specific minerals that occur in each geologic unit. The static test results also provide information that is used to guide sample selection for leachate extraction and kinetic tests.

Leachate extraction tests are short-term tests (i.e., hours to days) and provide preliminary analyses of water quality. Shake flask extraction leachate tests are short-term leaching tests to determine the concentrations of readily soluble constituents (e.g., sulphate, acidity, and major and trace elements) typically under near-neutral to alkaline pH conditions for geologic materials. The standard test procedure uses a 3:1 water to solids ratio by weight on material 6.35 mm or smaller, and the sample is gently agitated to provide continuous exposure of particle during the 24-hour test period. These test conditions are considered to be more aggressive than would occur under site-specific field conditions; therefore, the results are considered to represent a more conservative case than the expected water quality under site-specific conditions. The net acid generation tests are aggressive short-term leachate extraction tests that are designed to fully oxidize the sulphide minerals within a sample using hydrogen peroxide. The net acid generation tests are used to confirm acid-base accounting test results and to determine if a sample is likely to generate acid rock drainage in the future, and provide a conservative assessment of leachate quality under acidic pH conditions (e.g., sulphate, acidity, and major and trace elements) for each geologic material tested.

Kinetic tests are performed on sample materials that the static tests indicate are either potentially acid generating or metal leaching or have an uncertain potential. Laboratory humidity cell kinetic tests are temporal tests (i.e., weeks to months) designed to determine the primary rates of acid generation, acid neutralization, and the time to the onset of acid rock drainage. Field kinetic tests are also temporal tests designed to determine overall rates of acid generation, acid neutralization, and the time to onset of acid rock drainage under site-specific field conditions. Additionally, the field kinetic tests allow for the accumulation, storage, and release of secondary weathering products to occur, which the humidity cell is designed to minimize. The leachate generate from field kinetic tests is also considered to be the most representative site-specific concentrations of constituents (e.g., sulphate, acidity, and major and trace elements) for each geologic material. Larger-scale field kinetic tests are also used to evaluate the potential effectiveness of proposed material management strategies.

11.2.4.1.3 Phases 1 through 4

In Phases 1 through 4, a suite of static, leachate extraction, and laboratory kinetic tests were completed on samples of the various geologic units that would be excavated, exposed, or disturbed during Project construction. The extent of testing completed on the samples varied depending on the nature, purpose, and location of the geological materials, and the results of preliminary geochemical testing. Based on the results of Phases 1 through 4, the preliminary geochemical characterizations of the materials that would be excavated are summarized in Sections 11.2.4.2 through 11.2.4.4.

The laboratory kinetic tests undertaken in Phases 1 through 4 were humidity cell tests that accelerate the natural weathering rate of samples so that key indicator secondary weathering products can be used to determine the primary acid-generating and acid-neutralizing reaction rates. The laboratory humidity cell operating conditions can be considerably more aggressive than the site-specific field conditions at the dam site that excavated materials will be exposed to because:

- Laboratory testing is usually conducted at room temperature (~20°C), which is greater than the atmospheric temperature to which the excavated materials will be exposed to for most of each year. Lower temperatures slow both chemical and biological reaction rates involved in acid generation.
- Laboratory testing ensures a rigorous dry air/moist air/water rinse cycle to accelerate sulphide oxidation and to maximize oxidation product flushing. Most sites experience neither the regularity of the dry air/moist air cycle nor the regularity and intensity of wet precipitation corresponding to the water rinse cycle in the humidity cell.
- The water rinse cycle of the humidity cell is conducted to ensure the wetting and rinsing of the entire sample is as complete as possible. Precipitation infiltration into and flow through placed excavated materials is non-uniform due to heterogeneity of

the material, and channelling and complete wetting and rinsing is typically not achieved. Thus, the reactive fraction of sulphide minerals exposed to oxygen and water is typically much lower than in a humidity cell.

The primary acid generation and acid neutralization rates determined from a humidity cell test are used determine if a given sample will become acid generating; however, the estimated lag-time the sample will take to become acid generating is typically conservatively underestimated since the humidity cell operation accelerates sulphide mineral oxidation. The accelerated sulphide oxidation rate also results in accelerated production rates of secondary oxidation products such as acidity, sulphate, and major and trace elements. The major and trace element concentrations in the weekly rinse leachate are likely to be higher than those generated under site-specific field conditions. Therefore, the time periods for excavated materials to become acid generating would be longer than indicated by the humidity cell tests. Nevertheless, the humidity cell tests are useful in determining primary acid-generating and acid-neutralizing rates, and estimating a conservative laboratory-based lag time for materials to become acid generating. Typically humidity cell results are scaled or adjusted to account for these differences between the laboratory operating conditions of the humidity cells and site-specific field conditions. The field kinetic testing described below provides information under site-specific field conditions that assist and provide increased confidence in expected geochemical behavior under site-specific field conditions and the selection of appropriate scaling factors for humidity cell results.

11.2.4.1.4 Phases 5 and 6

Based on the results of the preliminary geochemical characterization program, additional testing has been done in 2012 and will be done in 2013 to provide additional certainty in the geochemical variability and/or acid rock drainage and metal leaching classification of geological units that would be excavated, exposed, or disturbed. The goal is to increase certainty in acid rock drainage and metal leaching predictions that will lead to material management plans for construction that prevent or mitigate acid rock drainage and metal leaching and protect the receiving environment. The following testing will be incorporated into Phases 5 and 6:

- Additional sample collection and static, leachate extraction, and kinetic testing of dam site bedrock units
- Ongoing field leach barrel testing of dam site bedrock units
- Construction and monitoring of a field leach pad using excavated rock from the exploratory adit constructed in 2012
- Ongoing field leach barrel testing of unconsolidated overburden units
- Additional geochemical (static, leachate extraction, and kinetic) testing of off-site materials

The kinetic tests to be undertaken in Phases 5 and 6 are field scale tests that will provide more definitive information on the likely potential of the excavated materials to produce acid rock drainage and metal leaching under site-specific field conditions. The field leach barrel tests consist of 115 l barrels containing bedrock drill core or overburden from different geologic units. The field leach barrels are located at the dam site and exposed to the weather conditions at the dam site. The field leach pad is located in an open area lined with a membrane. Excavated material is placed in the field leach pad by trucks, which emulates how surplus excavated materials would be placed on-site during full-scale dam construction. Leachate from the field leach barrels and field leach pad is sampled periodically for laboratory analysis to provide:

- An assessment of expected aqueous concentrations under site-specific field conditions
- An estimate of production rates of sulphide oxidation from bedrock geologic units under site-specific field conditions
- An estimate the lag time to onset of acid rock drainage under site-specific field conditions
- An estimate of metal leaching production rates from unconsolidated overburden units under site-specific field conditions

11.2.4.2 Dam Site

11.2.4.2.1 Bedrock

A total of 61 bedrock samples were collected from bedrock Unit 1 (lowest) through Unit 9 (highest) and submitted for geochemical characterization (see Figure 11.2.6 for bedrock units). These samples were taken from drill holes on the south bank of the dam site.

Based on the results of the geochemical characterization program to date, the following preliminary material management units have been defined for the bedrock units at the dam site:

- Material management unit 1: bedrock Units 9, 8, 7, 4, 2 and 1 – These bedrock units are acid generating or potentially acid generating. The humidity cell tests indicate a short estimated lag time of one year or less before the onset of acid rock drainage and metal leaching, with an estimated time to exhaustion of sulphide mineral oxidation of five years or less and therefore within the Project construction period.
- Material management unit 2: bedrock Units 6 and 5 – These bedrock units are potentially acid generating. The humidity cell tests indicated a longer estimated lag time before the onset of acid rock drainage and metal leaching of approximately seven to eigth years, and a longer estimated time once acid rock drainage and metal leaching commences. The humidity cell indicated that Uni 6 is estimated to be acid generating for approximately 16 years and Uni 5 for approximately 23 years. Therefore, the estimated time to complete exhaustion of sulphide-sulphur oxidation and acid rock drainage and metal leaching is well beyond Project construction.
- Material management unit 3: Unit 3 is potentially acid generating and is unique since the humidity cell indicated an estimated lag time of one year before the onset of acid rock drainage and metal leaching, but with an estimated time of acid generation of 12 years. Therefore, the estimated time to complete exhaustion of sulphide mineral oxidation and acid rock drainage and metal leaching is well beyond Project construction.

11.2.4.2.2 Overburden

A total of 30 unconsolidated overburden samples were selected from two sonic drill holes on the north bank of the dam site. The unconsolidated overburden units that have been sampled and tested for the dam site have no potential to generate acid. This conclusion is based on a very low to low sulphide mineral content and variable carbonate content, ranging from low to high.

The results of the shake flask extraction tests, however, do indicate a potential for metal leaching. Trace elements readily soluble from the unconsolidated overburden materials at concentrations above the British Columbia Ministry of Environment Approved and Working Water Quality Guidelines are aluminum (Al), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), selenium (Se) and silver (Ag). Sulphate (SO4) was also elevated in several unconsolidated overburden units. Based on the common presence of elevated selenium in leachate from the majority of the unconsolidated overburden units, no specific material management units are defined at this time, and all units require that selenium leaching as well as leaching of other readily soluble trace elements be prevented or mitigated applying the same mitigation strategies.

11.2.4.2.3 Material Management

Figures 4.37, 4.38, and 4.39 in Volume 1 Section 4 Project Description show the areas that have been designated for the relocation of surplus excavated materials at the dam site. Table 4.16 in Volume 1 Section 4 Project Description summarizes the sources of the excavated materials, disposal area and approximate embankment volumes.

Based on the preliminary geochemical characterization of the dam site materials, the main acid rock drainage and metal leaching mitigation strategies for the design of the material relocation areas are:

- Preventing or minimizing water contact with the relocated material, by limiting the infiltration of surface runoff, precipitation, snow melt, or groundwater into the material
- Preventing or minimizing air (oxygen) ingress into the relocated material

More details of the material management are provided in Volume 2 Appendix B, Part 4 Acid Rock Drainage and Metal Leachate Management Plan.

11.2.4.3 Off-Site Construction Materials

Geochemical samples were collected from the following sources of off-site construction materials:

- West Pine Quarry, which would be the source for permanent riprap for the dam, generating station, and spillways
- Wuthrich Quarry, which would be the source of temporary riprap for construction of the dam generating station and spillways
- Portage Mountain Quarry, which would be the source of riprap for the Highway 29 relocations and the Hudson's Hope shoreline protection

Based on the results of the geochemical characterization undertaken in Phases 1 through 4, the following sites contain material that is not potentially acid generating:

- West Pine Quarry
- Wuthrich Quarry

The tests indicated that the metal leaching potential from these quarry materials is low, with the exception of the potential for elevated selenium from the rock from the West Pine Quarry. Additional static, leachate, and kinetic testing would be carried out in 2013 on the West Pine Quarry material to determine the variability in selenium content in the limestone from this quarry site and to undertake a more detailed investigation and assessment of its mobility under the expected site-specific field conditions and intended construction uses. Following the completion of the additional leachate and kinetic testing, an appropriate material management plan will be prepared for the West Pine Quarry.

For the Portage Mountain Quarry site, the testing to date indicates that this material may contain potentially acid-generating lenses or pockets. However, the sulphide mineral content of this material is very low and the likelihood of this material being acid generating is also very low. Confirmation testing will be carried out in 2013 to support that there are no significant acid rock drainage and metal leaching issues for this quarry material.

11.2.4.4 Highway 29 Materials

Geochemical characterization was carried out on 31 samples collected from eight drill holes along the Peace River between Farrell Creek and Hudson’s Hope at location of Highway 29 realignment segments and reservoir slope stabilization near Hudson’s Hope.

The testing on unconsolidated overburden samples collected from the Lynx Creek and Farrell Creek Highway 29 realignment areas indicate that the materials are not potentially acid generating. Additional tests will be carried out on this material to confirm that there are no significant metal leaching issues.

Both unconsolidated overburden and bedrock samples were collected and tested from the Hudson’s Hope reservoir bank stabilization area. The overburden samples were classified as not potentially acid generating.

The bedrock samples yielded acid rock drainage and metal leaching classification ranging from potentially acid generating to not potentially acid generating, with 14 of 17 samples classified as not potentially acid generating. Since the bedrock will not be disturbed during berm construction no management measures will be required.

11.2.4.5 Monitoring

During dam construction, an on-site geochemical characterization program would be implemented for the bedrock units to improve the understanding of the spatial variability of geochemical properties of the bedrock units and make adjustments to the materials management plans as necessary.

More details of the monitoring are provided in Volume 2 Appendix B, Part 4 Acid Rock Drainage and Metal Leachate Management Plan.

11.2.5 Regional Seismicity and Seismic Hazard

As described in Volume 1 Section 4 Project Description, the earthquake design ground motion adopted for the Project has a mean annual exceedance frequency of 1 in 10,000 in accordance with the Canadian Dam Association Dam Safety Guidelines.

This section describes:

- The seismicity of the region of western North America bounded by longitudes 110°W to 140°W and latitudes 45°N to 65°N
- The site-specific seismic hazard assessments undertaken for the Project
- The potential for seismicity induced by reservoir filling
- The potential for seismic seiches and tsunamis
- The current understanding of how petroleum-related activities may affect seismicity
- Ongoing seismic monitoring during operations

11.2.5.1 Regional Seismicity

British Columbia is located along the western margin of the North America tectonic plate (Figure 11.2.13).

The boundary between the North America and Pacific plates lies off the west coast of British Columbia and is a complex seismically active region. On a global scale, the Pacific plate is moving northward relative to the North America plate at a rate in the order of 50 mm/year, along the Queen Charlotte fault. South of the Queen Charlotte fault is the 1100-km-long Cascadia subduction zone that extends from northern Vancouver Island to northern California, in-between the Pacific and North America plates. From north to south, the Cascadia subduction zone consists of the Explorer, Juan de Fuca and Gorda tectonic plates. Along the western edge of these plates, new oceanic crust is being created along spreading ridges and pushed outwards. Along their eastern edge, these plates are being pushed under the North America plate in a process referred to as subduction, at a rate in the order of 40 to 45 mm/year.

As a result of these ongoing active tectonic movements, the plate boundary region dominates the seismicity of B.C. (Figure 11.2.13). The Queen Charlotte fault has produced earthquakes as large as moment magnitude M_W8.1, including the October 29, 2012 Mw 7.7 Haida Gwaii earthquake. Based on palaeoseismic investigations, the Cascadia subduction zone is known to have produced earthquakes as large as about M_W9. Although very large in magnitude, earthquakes such as these occur at too great a distance to be of concern to the Project. However, the cumulative tectonic movements along the plate boundary have strongly influenced the tectonic conditions and stresses that cause earthquakes within the adjoining continental North America plate.

Much of the continental plate is underlain by the North America craton, which comprises geologically ancient and massive rocks, such as those exposed in the Canadian Shield. The craton is generally stable, with little internal deformation and relatively low seismic activity. However, the craton includes some ancient rift fault zones where deformation may still occur, sometimes producing infrequent large magnitude earthquakes. One example is the New Madrid, Missouri area in the central US, where three major earthquakes in 1811-12, estimated to be up to magnitude M_W8 or larger, are attributed to displacements along a reactivated rift structure.

Within the region of North America referred to as the Interior Plains, the craton is overlain by up to several kilometres of sedimentary rocks that were deposited in an inland sea that existed from Jurassic to Cretaceous time. These rocks are now the source of extensive and economically important petroleum deposits.

For purposes of seismic ground motion modelling, and seismic hazard analysis, the eastern edge of the Rocky Mountains is considered to be approximately the western edge of the craton. The northeast corner of B.C. east of the Rocky Mountains is considered to be part of the Interior Plains, while the rest of B.C. consists of a series of northwesterly trending geological belts (Figure 11.2.13) that are defined on the basis of their characteristics and origins. All of these belts include numerous geologically significant faults (Figure 11.2.14) along which past displacements have occurred, in some cases up to tens or even hundreds of kilometres over millions of years.

Inland from the plate boundary region, seismic activity occurs at low to moderate rates across B.C. (Figure 11.2.15). Although various trends and concentrations can be interpreted in the locations of recorded earthquakes, it has generally not been possible to correlate these inland earthquakes with specific fault sources. There are only a small number of faults in southern B.C. that are considered active or potentially active; all of these faults are more than 600 km away and are of no concern to seismic hazard at the Project.

The Project would be physically situated on sedimentary rocks overlying the western margin of the North America craton. The sedimentary rocks are flat-lying and relatively undeformed. Along the Peace River upstream of the Project site several low angle thrust faults are exposed in the near-surface bedrock. These faults are related to the major deformations and major thrust faults associated with the development of the Rocky Mountains and there is no evidence that they are active now. At the proposed dam site, several local shear zones have been mapped in the foundation bedrock. These features are not of tectonic origin and are interpreted to be related to valley rebound resulting from the formation of the modern Peace River valley.

The Project would be located above the Peace River Arch, a feature that developed along the western edge of the North America craton, bordering the early Paleozoic passive margin. The Peace River Arch was the site of recurrent uplift and deformation periodically through the late Mesozoic or early Cenozoic. The western portion of the initial uplift subsequently failed and became a depositional basin, referred to as the Peace River Embayment, through the early Cenozoic. Repeated faulting of the embayment left a series of northeast and northwest-striking faults that bound grabens along the former arch. None of these faults are reported to extend into the middle or upper Cenozoic deposits of the Peace River Embayment.

Earthquakes less than about magnitude M_W5 are too small to cause damage to well-engineered structures. A large region around the Project has a low level of historic seismicity, and within a distance of 200 km there has been one recorded earthquake larger than M_W5, a M_W5.4 event near Dawson Creek in 2001.

11.2.5.2 Site-Specific Seismic Hazard Assessments

The damage potential of an earthquake is determined by how the ground moves and how structures respond to those ground movements.

Expected ground motions can be calculated on the basis of probability and are referred to as seismic hazard. The seismic hazard is described by peak spectral accelerations over a range of vibration periods. The period is the time required for the passage of one full cycle of an earthquake wave of a given frequency. Peak spectral acceleration is a measure of ground motion that takes into account the sustained shaking energy at a particular period. It is a better measure of potential damage than the peak ground acceleration, which is often used as an indication of the strength of the ground motion from an earthquake. Peak ground acceleration and peak spectral accelerations are given in terms of a percentage or decimal fraction of the acceleration due to gravity, e.g., 5.4%g or 0.054g.

The response of a structure to earthquake ground motion depends on the natural frequency or period of the structure. For example, the periods of interest for buildings are typically in the range of 0.2 second to 5.0 seconds depending on the height of the building, with higher buildings having longer periods. The periods of interest for the principal structures of the Project are in the range of 0.3 second to 1.0 second.

In the National Building Code of Canada, earthquake ground motion values are provided in terms of probable exceedance, that is the likelihood of given peak horizontal spectral accelerations or peak horizontal acceleration being exceeded during a particular period of time. The probability used in the National Building Code is a median 0.000404 per annum, which is numerically equivalent to an annual probability of exceedance of 1/2475 or a 2% probability of exceedance over 50 years. This means that, over a 50-year period, there is a 2% chance of an earthquake causing ground motions greater than the given expected value.

The earthquake ground motions provided by the National Building Code of Canada are calculated by probabilistic seismic hazard analyses based on the Cornell-McGuire method. Site-specific analyses based on this method have also been performed for the Project.

The major components of this method are:

- Based on the current understanding of the regional seismicity:
  - Defining seismic sources, either areal sources or linear faults
  - Defining the earthquake recurrence rates within each seismic source
  - Defining the maximum magnitude considered possible in each seismic source
- Defining the attenuation of ground-shaking relationship for earthquakes in the area
- Numerical summation of the contributions of all earthquake magnitudes at all distances from the site from each source

A probabilistic seismic hazard analysis evaluates all possible earthquake magnitude and distance scenarios and provides results that can be summarized in the form of:

- Seismic hazard curves, which plot peak accelerations versus annual frequencies of exceedance

- Uniform hazard response spectra for the range of periods of interest for a range of annual frequencies of exceedance

Uncertainty is taken into account by using alternative weighted model parameters as inputs. For purposes of organizing the inputs in a structured manner, and to visually portray the alternatives and their weightings, these details are summarized in logic trees. As a result, a probabilistic seismic hazard analysis provides mean ground motion hazards and their uncertainties. The Canadian Dam Association recommends the use of mean seismic hazards for design of dams. In comparison, the National Building Code of Canada (2010) adopts median seismic hazards, which are typically lower than mean hazards.

The following subsections describe two separate site-specific probabilistic seismic hazard analyses that were undertaken for the Project. These two assessments gave very similar results and, as described below, the slightly higher values are used for the design of the Project.

11.2.5.2.1 2009 Seismic Hazard Analysis

A site-specific seismic hazard analysis was undertaken in 2009 by the Site C engineering team, with specialist input and review by a consulting seismologist with substantial experience in seismic hazard analysis (Klohn Crippen Berger and SNC Lavalin Inc. 2009).

Several alternative seismic source models were developed, in which seismic sources were all defined as area sources in various configurations. The alternative source models included maximum possible magnitudes of up to M_W7 to $M_W7.2$, albeit at very low rates of occurrence. Contributions from potential seismic sources up to 400 km from the site were included in the analyses.

At the western edge of the North America craton, seismic ground motions attenuate more rapidly with distance in the folded and faulted rocks to the west as compared to attenuation in the more massive rocks to the east. Consequently, different sets of ground motion prediction models have been developed for the regions west and east of the craton margin. Three western ground motion prediction models and one eastern model were included as weighted alternatives in the analyses, since the Project could experience ground motions from earthquakes occurring in either region.

Peak ground accelerations and uniform hazard response spectra for several annual exceedance frequencies down to 1/10,000 were computed. At a mean 1/10,000 annual exceedance frequency, the computed peak ground acceleration was 0.23g.

The analysis concluded that for the mean 1/10,000 annual exceedance frequency seismic hazard:

- The mean magnitudes for the earthquakes giving the peak ground acceleration were $M_W5.8$ to 5.9 at mean distances of 10 km to 50 km
- The range of magnitudes for the 0.2 second period motions was similar and the range of magnitudes for the 0.7 second period motions was slightly higher but still less than $M_W6.3$
- The seismic hazard is dominated by magnitudes in the range $M_W5.8$ to 5.9

11.2.5.2.2 2012 Seismic Hazard Assessment

In 2012, BC Hydro completed a system-wide probabilistic seismic hazard analysis as a Level 3 analysis, in accordance with the guidance provided by the Senior Seismic Hazard Analysis Committee (SSHAC, 1997). The SSHAC guidance originated in the nuclear industry in the 1990s and is now starting to be applied on probabilistic seismic hazard analyses for other types of critical facilities such as dams.

The SSHAC process includes a number of specific roles for suitably qualified participants, including:

- Resource experts – members of the scientific community with specific knowledge and expertise relevant to the probabilistic seismic hazard analysis inputs. These individuals may be consulted by the project team and/or may participate in project meetings and workshops.
- Evaluators – individuals who are responsible for reviewing and evaluating the scientific merit of information and alternative interpretations to be considered in developing inputs to the probabilistic seismic hazard analysis
- Analysts – individuals who are responsible for analyzing scientific data and developing appropriate models to represent those data, or for computing seismic hazard estimates
- Technical Integrators – individuals who are responsible for integrating the alternative interpretations into a composite distribution of models and parameter estimates that represent the opinions of the informed technical community. Technical integrators may also be evaluators.
- Peer Review Panel – a group of senior experts charged with review and validation of the SSHAC process as it is implemented and its viability with respect to achieving the SSHAC goal. The peer review panel is similar to an advisory board on a major engineering project.

These participants are typically earth scientists, seismologists, and engineers with strong expertise in their respective disciplines and in seismic hazard analysis. The SSHAC guidance includes advice on selection of such participants.

The project team for the BC Hydro system-wide probabilistic seismic hazard analysis was composed of over 20 earth scientists, engineers, and seismologists who served as evaluators, analysts, or technical integrators. This team was drawn from several major consulting companies, universities, individual consultants, and BC Hydro. A three-person participatory Peer Review Panel was involved throughout the project, in particular through attendance and feedback at major project workshops and through review of draft and final project reports. During the project, over 25 resource experts formally participated in some manner, and numerous other members of the scientific community were contacted to provide specific information, for example in relation to published technical papers. Resource experts were largely drawn from the Canadian and US Geological Surveys and universities, along with some independent consultants.

The seismic source characterization model started with development of a conceptual tectonic framework for the study region, which provided a foundation for subsequent development of seismic sources. Seismic sources included both faults and area sources.

An important part of the seismic source characterization work was the compilation of a catalogue of historical earthquakes in B.C. and adjacent regions, including removal of duplicates, selection of best epicentral locations and depths, conversion to a common magnitude scale (i.e. M_W), and quantification of uncertainties. This catalogue provided the basis for defining the historical seismicity associated with each seismic source and for developing earthquake recurrence models for each source.

Uncertainties exist for many of the seismic source characterization model parameters, resulting in numerous alternatives being defined for parameters such as source zone boundaries, recurrence models and maximum magnitudes. Different sets of alternative ground motion prediction models were selected for western and eastern attenuation regions.

In terms of the seismic source model, the proposed Project is located within the Peace River Arch areal source zone (labelled PRA on Figure 11.2.15). The Peace River Arch source zone includes the location of the 2001 M_W5.4 Dawson Creek earthquake, which has not been correlated with any specific geologic feature. The Peace River Arch zone is defined by and delineated around a distinctive group of faults in the underlying craton. Although these faults are not known to be active, they are favourably oriented for reactivation relative to the present crustal stress regime. Therefore, as an alternative to the areal source zone, an alternative source model for the Peace River Arch used in the seismic hazard analysis included this set of faults as “embedded faults” that were considered to have some potential to be the location of future earthquakes in the present tectonic environment. As such, these faults provided an alternative model for the spatial distribution of future earthquake occurrences within the Peace River Arch source zone without adding to the overall estimated rate of earthquake occurrences.

Surrounding the Peace River Arch zone to the north, east and south is the Interior Plains zone, an extensive region of very sparse seismicity (labelled IP on Figure 11.2.15). The largest recorded earthquake in this region is less than magnitude M_W5. To the west is the Northern Foreland Belt zone (labelled NFB on Figure 11.2.15), which comprises a large portion of the northern Canadian Cordillera, a region with extensive deformation and faulting, and low seismic activity. Although the largest earthquake of record in the Northern Foreland Belt zone is only about M_W4, the Cordilleran region north of the Northern Foreland Belt has experienced earthquakes as large as the Nahanni M_W6.8 event in 1985. Recognizing that the period of seismic recording for the region around the Project location is relatively short and that large magnitude earthquakes are quite infrequent, comparisons were made with other similar regions in the world. As a result, the seismic source model allows for maximum magnitudes of up to M_W7.6 in the Peace River Arch, Interior Plains, and Northern Foreland Belt zones, though at very low rates and with low weightings.

The BC Hydro probabilistic seismic hazard analysis computed peak ground accelerations and uniform hazard response spectra for a range of annual exceedance frequencies. At a mean 1/10,000 annual exceedance frequency, the computed peak ground acceleration is 0.25g, slightly higher than computed in the 2009 site-specific seismic hazard analysis (BC Hydro 2012b). There is good agreement between the response spectra from both analyses. The results of this 2012 probabilistic seismic hazard analysis will be used for the final design of the Project.

Table 11.2.5 shows the results of the probabilistic seismic hazard analysis for a range of annual exceedance frequencies. There is a range of possible earthquake magnitudes and distances that contribute to the seismic hazard for the Project. For dynamic analysis, time histories meeting the following criteria and scaled to the response spectrum would be representative of the seismic hazard:

- Fault mechanisms: strike-slip, reverse, and reverse-oblique
- Magnitude target: M_W6.6
- Magnitude range; M_W5.5 to 7.5 excluding aftershocks
- Distance target: 50 km
- Distance range: 0 km to 200 km

For a discussion on dynamic analyses using time histories, see the effects of the environment on the Project in Volume 5 Section 37 Requirements for the Federal Environmental Assessment.

Table 11.2.5 Peak Horizontal Ground Accelerations

Annual Exceedance Frequency	Horizontal Peak Ground Acceleration (%g)
1/10,000	0.250
1/2475	0.087
1/1000	0.041
1/475	0.022
1/100	0.005

11.2.5.3 Potential for Seismicity Induced by Reservoir Filling

The state of knowledge about reservoir-triggered seismic phenomena, sometimes referred to as reservoir-induced seismicity, has been documented in Bulletin 137 published by the International Committee on Large Dams (ICOLD, 2011). Bulletin 137 includes a table that lists 66 known cases of reservoir-triggered seismicity. Of the cases listed in Bulletin 137:

- Five earthquakes with magnitudes in the range of 5.7 to 6.3 (ICOLD does not specify any particular magnitude scale in Bulletin 137) were triggered by impounding reservoirs with a depth of 100 m or more. The World Register of Dams lists 793 dams with heights over 100 m, giving a frequency rate of about 0.6%, i.e., reservoir triggered seismicity occurred with 0.6% of dams 100 m or more high.
- Three earthquakes with magnitudes in the range 4.1 to 5.75 were triggered by impounding reservoirs with a depth of 60 m or less. The World Register of Dams lists 34,471 dams with heights 60 m or less, giving a frequency rate of about 0.01%, i.e. reservoir-triggered seismicity occurred with 0.01% of dams 60 m or less high.

The above precedents indicate that the probability of reservoir triggered seismicity at the Project, which has a reservoir depth of 52 m at the dam, is very low.

Impounding a new reservoir may trigger an earthquake under the following conditions:

- Pre-existing tectonic stresses have already created conditions near to failure on nearby active faults
- The weight of the water locally increases the stresses on an area of the Earth's crust
- Water seeping from the reservoir increases water pressures in the bedrock at depth, reducing the resistance to fault rupture

These conditions do not exist at the Project:

- There are no known active faults in the vicinity of the reservoir capable of producing a large earthquake
- As described in Section 11.2.2.1, the rocks of the Peace River valley were subjected to several periods of glaciation:
    - Advance and retreat of the ice would have subjected the rock to loads many times greater than the weight of water in the reservoir
    - Glacial lakes were many times greater in size than the Project reservoir
- The unloading due to downcutting of the river valley was several times greater than the weight of the reservoir

There is also no history of reservoir-triggered seismicity at the upstream dams and reservoirs on the Peace River, which are located in the Northern Foreland Belt (Figure 11.2.15). In particular, the nearby Williston Reservoir is about three times deeper than the Project reservoir and has a volume and weight about 30 times greater than the Project reservoir. There is no history of reservoir-triggered seismicity by the Williston Reservoir.

Even in the remote event that reservoir-triggered seismicity did occur, the resulting earthquakes cannot be larger than would have occurred without the reservoir. ICOLD Bulletin 137 states that the largest reservoir-triggered earthquake on record anywhere in the world is magnitude M6.3. As described above, the seismic hazard analysis for the Project has already accounted for the possibility of larger earthquakes close to the site.

11.2.5.4 Potential for Seismic Seiches and Tsunamis

Seismic seiches are standing waves set up on enclosed or partially enclosed bodies of water such as reservoirs, ponds, lakes, rivers, and harbours when seismic waves from an earthquake pass through the area. In contrast, tsunamis are large waves created by abrupt movement of the floor of an ocean or large lake. Tsunamis can travel long distances across the bodies of water in which they originate, whereas seiches can be created in bodies of water at long distances from the earthquake that generated the seismic waves.

11.2.5.4.1 Seismic Seiches

Seismic seiches are typically associated with large magnitude earthquakes, and can occur both in the epicentral area or at long distances from the epicentre. Some historical examples (USGS, 2012) include:

- The 1959 M7.3 Montana earthquake created a seiche in nearby Hebgen Lake, as well as smaller seiches in other bodies of water up to 545 km away
- Seiches were caused in several Scottish lakes and English harbours and ponds by the 1755 M8.7 earthquake that severely damaged Lisbon, Portugal
- Seiches were caused in fiords and lakes in Norway and England by the 1950 M8.6 Assam (Tibet) earthquake
- The 1964 Mw9.2 Alaska earthquake caused hundreds of seiches across North America and as far away as Australia

A study of the 1964 Alaska earthquake (McGarr and Vorhis, 1968) found that 859 seismic seiches were observed on water bodies after the earthquake but only about 10% of the surface water gauges that could have recorded a seiche did so. In Canada, seiches were measured as far east as Ontario. Seiches measured on rivers and lakes in British Columbia were in the range of 0.01 m to 0.2 m above still water level, the one exception being Seton Lake in British Columbia, which had a height of about 0.45 m above the still water level, which was the maximum observed seiche from all 859 records.

More recently, the 2002 Mw 7.9 Denali Alaska earthquake caused low amplitude seismic seiches at 14 BC Hydro reservoirs located 1500 km to 2400 km from the epicentre (Little and Scott, 2004). The maximum recorded amplitude (0.18 m peak-to-peak, or about 0.09 m above still water level) was again recorded at Seton Lake. No known analysis has been performed to evaluate if Seton Lake has specific characteristics that cause it to experience seismic seiches larger than those at other sites.

The prediction of seismic seiches in the epicentral region near an earthquake is difficult because of the numerous factors that may influence their occurrence, such as the level of shaking, surface tilting, geology, topography, and directional effects. At long distances, most of these factors have no influence, and seismic seiches are considered to be generated solely by seismic surface waves. Theoretical analysis (McGarr and Vorhis, 1968) indicates that the height of a seiche is directly proportional to the horizontal acceleration provided by the surface waves and the predominant periods are five to 15 seconds. The seismic surface waves can excite response in deep, regular bodies of water that have low order modes with periods of five to 15 seconds.

Seismic hazard analyses, including those performed for the Project, do not typically compute spectral accelerations for periods longer than five seconds, as accelerations at those periods do not cause shaking damage to most engineered structures and there are no available ground motion prediction models for those periods. Therefore it is not possible to directly use the results of the seismic hazard analyses to estimate potential seismic seiche effects for the Project.

As noted in Section 11.1.1.2.2, the seismic source model for the seismic hazard analysis includes potential earthquakes as large as Mw7.6, at very low probabilities. Based on the limited historical experience, a local earthquake would have to be close to this magnitude in size to potentially cause a seismic seiche in the epicentral area. The more likely potential causes of seismic seiches in the area of the Project would be large magnitude events at long distances from the Project, such as the 1964 and 2002 Alaska earthquakes. The Project reservoir would have a period of about 12 seconds for the first mode and therefore could theoretically respond to seismic surface waves and produce a seismic seiche from such earthquakes. However, based on the foregoing, it is considered that seismic seiches on the project reservoir would be less than 0.45 m, the largest seiche caused by the 1964 Alaska earthquake.

11.2.5.4.2 Tsunamis

Tsunamis are series of waves created by an abrupt underwater disturbance such as a submarine landslide or a surface displacement caused by an earthquake. A tsunami has a very long wavelength and travels at high velocity in the open ocean, slowing down and increasing in height as it approaches the shore and the water depth decreases.

Landslide-generated waves are discussed in Section 11.2.3.9.

Most destructive tsunamis are caused by surface fault rupture of the ocean floor during major earthquakes. There are no active faults in the reservoir area that could cause movements of the reservoir floor and create conditions similar to an ocean tsunami.

11.2.5.5 Current Understanding of How Petroleum Industry-Related Activities May Affect Seismicity

It has been known for many years that extraction or injection of fluids into the subsurface can induce earthquakes. For example, from 1984 to 1994, small magnitude earthquakes were induced by fluid injection to enhance recovery in conventional petroleum fields near Fort St. John (Horner et al, 1994). Elsewhere, seismic activity has also been associated with geothermal energy projects and more recently, seismic activity associated with hydraulic fracturing to extract shale gas (shale fracking) has been experienced at various locations in the US and other parts of the world.

The process of hydraulic fracturing causes shear movements or creates localized tensile fractures in the host rock, and the energy released by such movements creates very small magnitude earthquakes referred to as “microseismicity”. Such earthquakes are typically less than magnitude M2, and are too small to be felt at surface by humans. Sensitive instruments are used to detect this microseismicity during the fracking process in order to assess its effectiveness.

Recently the US National Research Council (NRC) investigated the scale, scope, and consequences of seismicity induced during fluid injection and withdrawal activities related to geothermal energy development and oil and gas development, including shale gas recovery and carbon capture and storage (National Research Council, 2012). It was found that only a very small fraction of injection and extraction activities at hundreds of thousands of energy development sites in the United States have induced seismicity at levels that are noticeable to the public. With respect to shale gas, it was found that:

- The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events (only one confirmed case in the world)
- Injection for disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, although very few events have been documented over the past several decades relative to the large number of disposal wells in operation

With the expanding shale gas industry in northeastern B.C., the BC Oil & Gas Commission has also investigated the potential for induced earthquakes related to that activity (BC Oil & Gas Commission, 2012) That investigation found that 38 earthquakes from magnitude M_L2.2 to M_L3.8 that occurred in two areas of the Horn River Basin in 2011 were induced by movements on pre-existing faults due to fluid injection during hydraulic fracturing. Only one of these earthquakes was physically felt at surface and there were no reports of injury or property damage.

The Oil & Gas Commission is now establishing procedures and requirements for monitoring and reporting of induced seismicity. Each case of induced seismicity will be evaluated on the basis of its unique site-specific characteristics, but it is proposed that hydraulic fracturing would be suspended upon detection of an earthquake of magnitude M4 or larger. It should be noted that earthquakes less than about magnitude M5 do not release enough energy to cause damage to engineered structures.

11.2.5.6 Ongoing Seismic Monitoring During Operation

The Geological Survey of Canada (GSC) operates a national network of seismographs that is capable of recording and accurately locating earthquakes down to approximately magnitude M~~3~~2.5 to 3. ~~or smaller.~~ The data collected provides a national earthquake catalogue that is important for seismic hazard analyses and also provides other scientific information that improves scientific understanding of seismotectonic processes.

For several decades, BC Hydro has cooperated with the GSC in operating additional seismographs in the regions around its largest dams in order to improve the recording capability down to approximately magnitude M2. ~~or smaller~~. One of those seismographs is located on Bullhead Mountain near the W.A.C. Bennett Dam, and that seismograph already provides good recording coverage for the Project.

The BC Oil & Gas Commission is also planning the installation of a network of about six seismographs in northeastern B.C. This array will not necessarily be permanent, but will be in place for a minimum of 3 years starting in 2013. ~~in late 2012 or early 2013.~~ The purpose of the network will be to investigate the potential causes of earthquakes that occur in the region where substantial shale gas activity is taking place. This network will also contribute to an improved seismic monitoring capability for the entire northeastern B.C. region. Natural Resources Canada has advised that this array will lower the location threshold to about magnitude M2 for all/most of northeastern B.C.

In addition to monitoring seismic activity, BC Hydro also installs strong motion accelerographs (SMAs) at its major dams to record any seismic shaking and the response of the dam and other structures to that shaking. There are several SMAs installed at each of the existing upstream Peace River dams, and several SMAs will be installed as part of the permanent dam safety instrumentation for the Project.

11.3 Land Status, Tenure, and Project Requirements

11.3.1 Overview

BC Hydro's approach to determining land requirements for the Project is to strive to minimize the amount of land acquired for the Project while maximizing land use flexibility.

BC Hydro would acquire permanent or temporary land tenure, as required, from the provincial Crown and private landowners for the construction, operation, and mitigation of the Project. BC Hydro's approach to acquire land tenure is to compensate based on the fair market value of the land or right being acquired, in addition to compensating owners for disturbance damages and reimbursing costs related to the acquisition. The fair market value of the land is determined by qualified independent appraisers.

BC Hydro would acquire limited land tenure – where possible – by way of permanent and temporary statutory rights-of-way, leases, licences of occupation on provincial Crown land, licences on private land, and through land access permits. Where required, BC Hydro would acquire some lands in fee simple. Maps outlining the type of tenure required in the Project activity zone can be found in Volume 2 Appendix C Land Status, Tenure, and Project Requirements Maps, Figure 1 Current ownership overview and Figure 2 (Maps 1 to 9) Current ownership.

The provincial ministries associated with managing tenure over Crown land include the Ministry of Forests, Lands and Natural Resource Operations; the Ministry of Transportation and Infrastructure; and the Ministry of Energy, Mines and Natural Gas.

BC Hydro owns much, but not all, of the land, for which BC Hydro requires fee simple ownership. BC Hydro acquired these lands between 1977 and 1981, when the previous Site C hydroelectric project was put forward for regulatory review by the British Columbia Utilities Commission at the time, and later under BC Hydro's Voluntary Passive Land Acquisition Program. The voluntary program was established in the 1970s and reinstituted following a recommendation from the British Columbia Utilities Commission in 1983 which stated, *"…the Commission recommends that Hydro reinstitute its passive land acquisition program until an energy project certificate is issued.*" Under this program, BC Hydro may purchase property if it is required for the construction, operation, or mitigation of the Project, and if the property owner wishes to sell their property. The program is entirely voluntary.

Wherever possible, farmland, and ranchland acquired by BC Hydro is being maintained in a productive state, either by leasing back the property to the original owner or to another tenant.

While there are privately owned parcels throughout the Project activity zone, the majority of privately owned sites are on the north side of the Peace River. Through the project's Property Owner Liaison program, public consultation program (Volume 1 Section 9.1 Public Information Distribution and Consultation) and one-on-one meetings, BC Hydro continues to be in direct contact with owners whose land is in the Project activity zone.

BC Hydro continues to consult with property owners, as well as provide information and answer questions about the Project, to discuss the Project's land requirements as required, and to answer questions about the process for acquisition of land or rights.

11.3.1.1 Fee Simple Tenure

BC Hydro would acquire land in fee simple for portions of the dam site area, reservoir inundation, Old Fort Road realignment, and Highway 29 realignments. Fee simple tenure can be described as full ownership in land. An estimated total of 58 private land holdings, comprising 102 separate parcels of land, would be affected by inundation, Highway 29 realignments, Old Fort Road realignment, or dam site permanent structures. Land holdings are defined as common ownership over either individual or several parcels of land. For example, a farm may consist of five separate parcels of land where the land is contiguous or in the same general area, but as it is commonly owned by one or more individuals or a company, it is considered one land holding. Table 11.3.1 below identifies the fee simple tenure required.

Table 11.3.1 Estimated Fee Simple Tenure Required

Project Component	Area of Private Land (ha)	Area of BC Hydro Land (ha)	Area of Crown Land (ha)	Total (ha)
Inundation	367	667	4,523	5,557
Highway 29 realignments	125	30	91	247
Old Fort Road realignment	3.5	0	0	3.5
Dam site permanent structures Include: dam, warehouse, switchyard/substation, roads, communications tower	0	4	135	139

NOTES:

Due to rounding of the individual areas, the individual areas may not add up to the total area shown; however, the total area is correct.

This table reflects information as of November 15, 2012, and is subject to:

- Changes in property ownership
- Areas required for inundation may be reduced as a result of the construction of the Hudson's Hope shoreline protection, as well as any berms created as a result of the Highway 29 realignments
- Additional Crown or private lands may be purchased in fee simple for sources of construction materials or mitigation. The construction material lands may be available for redevelopment post-Project.

11.3.1.2 Dam Site Area – Permanent Structures

BC Hydro would acquire fee simple title for the dam site structures, including the earthfill dam, generating station, and ancillary structures, as well as internal access roads on Crown land. One hundred and thirty-five hectares of Crown land would be required, but no additional private land.

11.3.1.3 Reservoir – Inundation

In 1957, a reserve under the *Land Act* was put in place by Order-in-Council 2452. Please refer to Section 6.2 for details of the Order-in-Council and the subsequent amendments. The Order-in-Council reserve prevents the alienation of an area of Crown land under the *Land Act*.

Rights to the underlying Crown land for the reservoir would be acquired through the issuance of a *Water Act* permit from the Province.

With respect to privately owned land, BC Hydro proposes to acquire, in fee simple, land between the current river shoreline and the area required for the Site C reservoir, up to the Maximum Normal Reservoir Level, which is 461.8 m above sea level.

Approximately 81% of the lands affected by inundation are Crown lands, 12% are owned by BC Hydro, while the remaining 7% of lands are owned by private companies, private individuals, or government agencies and would be purchased in fee simple.

11.3.1.4 Highway 29 Realignments

To accommodate the Project, BC Hydro would be realigning up to 30 km of the existing Highway 29 in six separate sections. BC Hydro would acquire the private lands required for the realigned highway. Both private and Crown land required by the Project to realign the highway would be dedicated provincial highway.

11.3.1.5 Old Fort Road Realignment

BC Hydro would realign one section of the existing Old Fort Road. BC Hydro would acquire the private lands required for the realigned road and dedicate the land as road.

11.3.2 Permanent Statutory Rights-of-Way Required

Permanent statutory rights-of-way would be required for the flood impact line, erosion and landslide-generated wave impact lines, stability impact line, the transmission line widening, the tie-in locations at both the Peace Canyon Dam and the proposed dam site, the Project access road, north and south bank dam site connecting roads, and the Hudson's Hope shoreline protection. A permanent statutory right-of-way is similar to an easement, in that it grants the right or privilege, acquired through contract, for a specific purpose or purposes. A permanent statutory right-of-way is registered on the title to the property and is perpetual in nature. BC Hydro provides compensation to land owners to acquire a permanent statutory right-of-way.

An estimated total of 106 private land holdings comprising 178 separate parcels of land would be affected by permanent statutory rights-of-way. Note that, of these totals, 52 private land holdings and 79 separate parcels would also be affected by a required fee simple tenure as described above. Table 11.3.2 below identifies the estimated permanent statutory rights-of-way required for the Project.

Table 11.3.2 Estimated Permanent Statutory Rights-of-way Required

Project Component/Activities	Area of Private Land (ha)	Area of BC Hydro Land (ha)	Area of Crown Land (ha)	Total (ha)
Impact lines: flood, erosion, and landslide-generated wave impact lines	190	322	1,377	1,889
Stability impact line	940	398	6,268	7,606
Existing transmission line (118 m)	0	0	0	0
Project access road	12	0	99	111
North and south bank dam site connecting roads	0	3	10	12
Transmission line tie-in at Peace Canyon Dam site	0	12	20	32
Transmission line tie-in at Site C dam site	0	0	51	51
Proposed transmission line widening (34 m)	29	0	222	251
Hudson's Hope shoreline protection	4	1	7	12

NOTES:

The project access road would be 21 m wide and would be partially included within the existing transmission line statutory right-of-way and proposed transmission line widening; therefore, there is some duplication in areas.

Due to rounding of the individual areas, the individual areas may not add up to the total area shown; however, the total area is correct.

This table reflects information as of November 15, 2012, and is subject to change due to changes in property ownership.

11.3.2.1 Reservoir Impact Lines

BC Hydro has developed an approach to land use on private property within the impact lines. The approach focuses on limiting risks to the public, maximizing land use flexibility, and minimizing the amount of land required by the Project. The reservoir impact lines are more fully described in Volume 2 Appendix B Geology, Terrain Stability, and Soil Report, Part 2 Preliminary Reservoir Impact Lines.

BC Hydro would purchase the property rights required within the impact lines by way of a statutory right-of-way and would compensate landowners for the restricted use of their land. A statutory right-of-way would enable title to remain with the private individual or entity, and would allow for most activities that occurred on the land prior to the Project, with some restrictions that would be specified in the statutory right-of-way document.

The statutory right-of-way would specify that no new residential structures would be permitted within impact lines. Non-residential structures could remain, pending site-specific geotechnical assessment. Other activities such as agriculture, grazing, and trapping could continue within the impact lines.

Specifically, within the stability impact zone, existing residential structures could remain, at the owner's request and provided that a site-specific geotechnical assessment conducted by BC Hydro determines that it is safe to do so. Within the flood, erosion, or wave impact lines, however, existing residential structures would not be permitted to remain.

There are currently approximately 30 residential dwellings within: the reservoir inundation area; the flood, erosion, or wave impact lines; the stability impact line; or highway realignment area. BC Hydro is in contact with the property owners to determine how many of these buildings are in use for residential purposes. There is a possibility that some of these residential dwellings could potentially be moved to another area of the existing property, or remain where they are today, pending further site-specific analysis. BC Hydro would continue discussions with property owners and, where appropriate, based on further geotechnical investigations, enter into agreements to address the removal or relocation of these buildings, or outline the conditions upon which the buildings could remain. BC Hydro met directly with property owners who may be impacted to present maps with the reservoir impact lines shown on their specific property, and to discuss their specific property interests.

11.3.2.2 Transmission Line

BC Hydro has an existing statutory right-of-way for a transmission line between the dam site and the existing Peace Canyon Dam. The existing statutory right-of-way contains two 138 kV transmission lines. As part of the Project, BC Hydro would construct, maintain and operate two new 500 kV transmission lines, replacing the two 138 kV transmission lines within the same corridor. The existing statutory right-of-way document allows for these new lines, so the lines can be almost contained entirely within the existing right-of-way area. Any additional rights would be acquired from two private owners and the Province.

At either end of the transmission line corridor, the lines would be tied into a facility at Peace Canyon Dam and at the Site C dam site. For these portions of new right-of-way, and areas where the existing corridor may have to be widened, BC Hydro would acquire a statutory right-of-way on the underlying Crown land.

11.3.2.3 Project Access Road

BC Hydro intends to extend the existing Jackfish Lake Road to connect the existing road directly to the dam site area. This extension, called the Project Access Road, would be constructed mainly inside the north boundary of the transmission line right-of-way. It would be used primarily for hauling construction materials directly to the dam site and would therefore be constructed to a high standard. Given the frequency of construction-related traffic, it is proposed that the road would be classified as a private road to restrict public access to ensure safe operation. As this road would also provide long-term access to both the dam site and the transmission line, BC Hydro would obtain a permanent statutory right-of-way from the Province and two private property owners to accommodate this road.

11.3.3 Temporary Tenure Required

Temporary tenures, including Licences of Occupation, leases, and temporary statutory rights-of-way, would be required within the dam site area, the proposed conveyor route from the 85th Avenue Industrial Lands, construction access and clearing roads, quarried and excavated construction materials, areas of potential disturbance for Highway 29 realignment construction, and a one-time clearing zone along the existing transmission line statutory right-of-way. These tenures would be acquired for a defined period of time and for a specific use or uses, after which they would be returned to the owners.

Table 11.3.3 below provides an estimate of temporary tenures that are anticipated to be required for the Project, pending further information based on procurement and contractor requirements.

Table 11.3.3 Estimated Temporary Tenure Required – Pending Procurement and Contractor Requirements

Project Component/Activities	Area of Private Land (ha)	Area of BC Hydro Land (ha)	Area of Crown Land (ha)	Total (ha)
Proposed conveyor route (85th Avenue Industrial Lands)	11	0*	0	11
Transmission line: one-time clearing zone (14 m)	12	0	91	103
Dam site temporary components, including: worker areas, roads, generating, storage, laydown areas, construction offices	313	241	988	1,543
Construction access and clearing roads	16	1	285	302
Quarried and excavated construction materials	25	96	468	589
Borrow sources and potential aggregate sources	15	10	14	40
Highway 29 realignment – areas of potential disturbance	27	9	10	45

NOTE:

Due to rounding of the individual areas, the individual areas may not add up to the total area shown; however, the total area is correct.

This table reflects information as of November 15, 2012, and is subject to change due to changes in property ownership.

The conveyor portion that would be within the 85th Avenue Industrial Lands is excluded from this table, as this land is owned by BC Hydro.

Additional temporary tenure (temporary statutory right-of-way, licences, leases, etc.) on private and Crown land may be required for:

- Working areas to construct the highway, reslope driveways, etc.
- The extraction of construction materials, quarries, etc.
- Detours to be used during construction of the highway realignments

Quarried and Excavated Construction Materials include: 85th Avenue, Wuthrich, West Pine, Portage Mountain, Del Rio, inundation areas, commercial pits, and Area E. These areas are under consideration for use by BC Hydro.

11.3.3.1 Proposed Conveyor Route (85th Avenue Industrial Lands) to Dam Site Area

As of November 2012, BC Hydro owns 96 ha of land at 85th Avenue south of Fort St. John that is referred to as the 85th Avenue Industrial Lands. BC Hydro would use these lands to extract construction materials and to stockpile material, and for construction offices, laydown, and storage.

Material from the 85th Avenue Industrial Lands would be transported to the dam site on a conveyor belt to a transfer point where the material would be moved by trucks to the dam. Where the route crosses private lands, BC Hydro would acquire tenure for the construction and use of the conveyor belt by way of a temporary statutory right-of-way.

11.3.3.2 Construction Access and Clearing Roads

Temporary access roads would be required for the construction phase of the Project. Where feasible, existing access roads would be used, and upgraded as required.

Rights for the use, upgrade, or construction of access roads would be acquired through the issuance of a licence of occupation from the Province, or from private land owners. In some cases, the existing access roads are already licensed by third parties and BC Hydro would enter into Road Use, Joint Use, or Maintenance Agreements for the use and maintenance of the road. It is expected that any licence issued by the Province where there is an overlapping interest would be provided on the condition that BC Hydro enter into a road use agreement.

BC Hydro would also require temporary licences of occupation on Crown land or temporary statutory rights-of-way for the construction and development of access roads, the use of work and laydown areas, the transportation of construction materials, and to restore disturbed lands as required. These would be required across all Project activity zones at various times during the Project.

For the Highway 29 realignments, the Project would also require temporary tenure to construct the realigned highway outside dedicated areas. These temporary tenures would take the form of a licence of occupation on Crown lands and licences over private lands during construction of the Project to accommodate construction activities (e.g., highway work areas, reinstatement of driveways, laydown areas).

11.3.3.3 Dam Site Area

To facilitate construction of the dam site, BC Hydro would also initially seek a temporary Licence of Occupation over Crown lands required for worker accommodation, construction offices, temporary construction areas, material storage, staging areas, warehouse facilities, maintenance and workshops, concrete batch plants, access roads, and parking areas. Where exclusive use of the land is required, e.g., for worker accommodation, BC Hydro would enter into a lease agreement for specific areas. Some of these facilities would also be constructed on BC Hydro-owned lands.

11.3.3.4 One-Time Clearing Zone

BC Hydro would require licences of occupation on Crown land to permit additional clearing adjacent to the transmission line corridor. Also, BC Hydro may require a temporary licence from two private property owners during the construction of the transmission lines.

11.3.3.5 Quarried and Excavated Construction Materials

To the extent possible, BC Hydro intends to use existing quarries on Crown land to extract construction materials for the Project. To access this resource, a licence would be obtained from the Province with terms consistent with the Ministry of Forests, Lands and Natural Resource Operations Aggregate and Quarry Materials policy. The following sites have been identified as potential construction material sources: 85th Avenue, Wuthrich, West Pine, Portage Mountain, Del Rio, inundated areas, commercial pits, and Area E.

11.3.4 Third-Party Crown Land Tenures

Portions of Crown land may also be subject to third-party tenure previously granted by the Province for commercial use and natural resources including leases, licences, rights-of-way, and registered traplines, as well as map reserves for forestry, guide outfitter territories, tourism and recreation, oil and gas exploration, mineral exploration, aggregate extraction, grazing rights, agriculture, and water rights. BC Hydro continues to identify any overlap between these third-party tenures and BC Hydro's proposed tenure over Crown land and would address them through discussions and, where appropriate, agreements with the tenure holders. The detailed description of these tenures and potential effects of the Project are outlined in Volume 3 Economic and Land and Resource Use Effects Assessment. Table 11.3.4 below identifies the third-party tenures that are within the Project activity zone; maps outlining the location of these tenures relative to the Project activity zone can be reviewed in Volume 2 Appendix C Land Status, Tenure, and Project Requirements Maps, Figures 3 to 10 entitled Forestry tenures, Guide outfitter areas, *Land Act* interests, Oil and gas tenures, Recreation tenures, Trapline areas and *Water Act* tenures.

Table 11.3.4 Third-Party Crown Land Tenure within the Project Activity Zone (Number of Tenures)

Third-Party Crown Land Tenure	Dam Site incl. Sub-station	Reservoir – Inundation	Reservoir – Existing River	Reservoir – Impact Lines	Transmission Line	Quarried & Excavated Construction Materials	Construction Access Roads: Highway 29 Realignment, Clearing, and Conveyor (85th Avenue Industrial Lands)	Total Tenures Impacted Within the Project Activity Zone
Forestry	10	17	16	32	29	23	89	104
Guide outfitter	1	4	4	4	3	4	4	4
Land Act	16	44	36	57	23	35	133	163
Ministry of Energy, Mines and Natural Gas	8	23	22	27	20	23	55	74
Oil and gas	23	64	17	111	70	48	620	714
Recreation	1	8	8	2	N/A	N/A	8	9
Trapline	2	13	13	13	7	9	18	18
Water Act	1	28	10	20	N/A	16	10	46

NOTES:

The above tenures overlap one another as well as the Project activity zone; therefore, there is some duplication in the numbers above.

11.4 Surface Water Regime

Surface water regime refers to the quantity, timing, and rate of change of flow and water level. This subsection describes the existing surface water regime of the Peace River (baseline conditions) and potential changes during the construction and operational phases of the Project. Information on the pre-regulation (i.e., pre-W.A.C. Bennett Dam) surface water regime of the Peace River is also included to provide context for the changes that are expected with the Project.

The spatial boundary selected for the characterization of potential changes to the surface water regime as a result of the Project extends from the outlet of the Peace Canyon Dam to Peace Point, Alberta, over 1,000 km downstream. This downstream boundary was selected because surface water data for that location are available, and because at that location, any changes in the surface water regime were expected to be negligible in relation to the natural variability of the baseline flow regime.

11.4.1 Regulatory and Policy Setting

BC Hydro currently holds water licences for the storage of water and operation of hydroelectric generating stations at G.M. Shrum (Williston Reservoir) and Peace Canyon Dam (Dinosaur Reservoir). Water licences for the storage of water and the generation of power would be required prior to construction of the Project.

At Peace Canyon, BC Hydro is permitted under its water licence to discharge water for the purpose of generating power up to 1,982 m^3/s through turbine generation. Under the August 2007 *Water Act* Order, BC Hydro is also required to maintain, at all times, a minimum flow of 283 m^3/s at Hudson's Hope for fisheries and riparian habitat, downstream water consumption, and recreational access. While the minimum flow may be provided by any combination of spill or turbine generation discharge, under normal operations, it is provided solely by generation.

Spilling is the discharge of water other than through the turbines of the generating station. While infrequent, spills may occur when total project inflows exceed the sum of available storage and the lesser of generation capacity or generation requirement. Operations during such an event are managed with additional due diligence associated with dam and facility safety, public safety, and environmental concerns. BC Hydro's environmental response to forecast spills or actual spills from the Peace River projects, including spill risk assessment, notification, and monitoring, is documented in the Peace Spill Protocol of the Peace Water Use Plan.

11.4.2 Baseline Conditions

11.4.2.1 Overview of Peace River Hydrology and Physiography

The two major headwater tributaries to the Peace River, the Finlay and Parsnip Rivers, originate in the Omineca and Rocky Mountain ranges of north-central B.C. An overview of the Peace River is provided in Volume 1 Section 4.1 Project Location and in Figure 4.1 of this section. The Peace River flows eastward through the Rocky Mountains into Williston Reservoir, a T-shaped reservoir with a total surface area of about 1,770 km^2 at full pool. This reservoir provides the storage and regulation for the G.M. Shrum generating station at W.A.C. Bennett Dam. Downstream of Williston

Reservoir is the Dinosaur Reservoir, impounded by the Peace Canyon Dam located approximately 20 km downstream of G.M. Shrum. The Peace Canyon generating station reuses the water that flows through the G.M. Shrum generating station to generate electricity a second time. Downstream of the dams, the Peace River flows eastward and northeastward across the Alberta Plateau within a deeply incised valley. Below Fort Vermilion, the river drops through a bedrock chute onto the Peace-Athabasca Lowland as it approaches Lake Athabasca in northeastern Alberta. From the Vermilion Chutes to the Slave River confluence, the Peace River flows within a wider, less incised valley. The Slave River flows into Great Slave Lake in the Northwest Territories and the Mackenzie River flows out of Great Slave Lake northwest into the Beaufort Sea. Figure 11.4.1 is a map of the Peace River watershed, and the watershed of its largest tributaries.

Mean annual inflow into the Williston Reservoir is approximately 1,135 m^3/s. Inflows into Williston Reservoir are composed of, on average, 60% snowmelt and 40% rainfall. There are no large glaciers that feed the Williston Reservoir; therefore, glacial melt is a small component of inflows. Figure 11.4.2 illustrates the annual division of total inflow to the Williston Reservoir between the various sources.

The seasonal runoff pattern into Williston Reservoir is characterized by low inflows during December through April, and much higher inflows when the snow melts in late April through July. Heavy summer rains can create high inflows from June through July. Moderate inflows due to rainfall typically occur in August through November. Approximately 63% of the inflow into Williston Reservoir occurs in the May through July period, with the peak inflow typically occurring due to snowmelt between mid-May and mid-June. Only 9 m^3/s of inflow is associated with local tributary inflow into Dinosaur Reservoir downstream of the W.A.C. Bennett Dam.

The average inflows to the Peace River between Peace Canyon Dam and the Site C dam site (i.e., the inflows to the proposed Site C reservoir) are approximately 100 m^3/s. Three-quarters of this inflow typically comes from the Halfway River, about one-tenth comes from the Moberly River, and the rest from Cache Creek, Farrell Creek, Lynx Creek, and residual drainage areas between these tributaries. The seasonal runoff pattern of inflows to the proposed Site C reservoir is similar to that described above for Williston Reservoir, though the spring freshet in this lower-elevation basin typically occurs sooner. Figure 11.4.3 illustrates the sub-basins within the Project watershed.

11.4.2.2 Water Survey of Canada Flow Measurements

The characterization of baseline water levels and flows described in this subsection is based on observations at several Water Survey of Canada hydrometric stations along the Peace River and its tributaries. Table 11.4.1 summarizes the Peace River stations including location (river chainage), drainage area upstream of each gauge, mean annual flow for a common period of record (1992–2010), and corresponding unit runoff (mean annual flow divided by drainage area). The river chainage system is used to identify locations on the Peace River. Chainage refers to the distance downstream of the W.A.C. Bennett Dam (e.g., the Town of Peace River is located near chainage 400 km, or approximately 400 km downstream of the W.A.C. Bennett Dam along the river centreline). Figure 11.4.4 illustrates the location of the Water Survey of Canada stations and the river chainage system.

Table 11.4.1 Water Survey of Canada Stations on the Peace River

Water Survey of Canada Station (Station ID)	Distance from W.A.C. Bennett Dam (km)	Drainage Area (km^2)[a]	Mean Annual Flow (m^3/s)[b]	Unit Runoff ($l/s/km^2$)
Peace River at Hudson's Hope (07EF001)	27.7	73,100	1,176	16.1
Peace River upstream of Pine River (07FA004)	111.4	87,200	1,278	14.7
Peace River near Taylor (07FD002)	123.3	101,000	1,440	14.3
Peace River upstream of Alces River (07FD010)	163.8	121,000	1,546	12.8
Peace River at Dunvegan Bridge (07FD003)	295.7	135,397	n/a	n/a
Peace River at Peace River (07HA001)	396.8	194,374	1,906	9.8
Peace River near Carcajou (07HD001)	650.7	216,813	n/a	n/a
Peace River at Fort Vermilion (07HF001)	831.8	227,026	n/a	n/a
Peace River at Peace Point (07KC001)[c]	1,136	293,000	2,032	6.9

NOTES:

[a] Drainage areas as published by Water Survey of Canada

[b] Mean annual flow is presented for a common period of record (1992–2010) where data are available

[c] Mean annual flow is not available at Peace Point for 2007 and 2009

Table 11.4.2 summarizes the Water Survey of Canada hydrometric stations on the largest tributaries of the Peace River between Peace Canyon Dam and Peace Point, Alberta. As shown, the largest tributary in terms of drainage area and mean annual flow is the Smoky River, which flows into the Peace River just upstream of the Town of Peace River, Alberta. The second largest in terms of drainage area is the Wabasca River, which flows into the Peace River downstream of Fort Vermilion, Alberta. Although the Wabasca River has a drainage area almost three times that of the Pine River in B.C., the Pine River watershed has a higher mean annual flow. The watershed areas of these tributaries are shown on Figure 11.4.1.

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Table 11.4.2 Water Survey of Canada Stations on Major Tributaries of the Peace River

Water Survey of Canada Station (Station ID)	Distance of confluence from W.A.C. Bennett Dam (km)	Drainage Area (km^2)	Mean Annual Flow (m^3/s)[a]	Unit Runoff ($l/s/km^2$)
Halfway River near Farrell Creek (07FA006)	66	9,330	73	7.8
Moberly River near Fort St. John (07FB008)	105	1,520	11	7.2
Pine River at East Pine (07FB001)	121	12,100	181	15.0
Beatton River near Fort St. John (07FC001)	143	15,600	55	3.5
Kiskatinaw River near Farmington (07FD001)	156	3,640	10	2.7
Pouce Coupe River downstream of Henderson Creek (07FD007)	175	2,850	6	2.1
Clear River near Bear Canyon (07FD009)	189	2,880	n/a	n/a
Smoky River at Watino (07GJ001)	389	50,300	294	5.8
Heart River near Nampa (07HA003)	395	1,970	3	1.5
Whitemud River near Dixonville (07HA005)	454	2,010	n/a	n/a
Notikewin River at Manning (07HC001)	565	4,680	12	2.6
Boyer River near Fort Vermilion (07JF002)	841	6,600	n/a	n/a
Ponton River upstream of Boyer River (07JF003)	847	2,440	n/a	n/a
Wabasca River at Highway No. 88 (07JD002)	886	35,800	69	1.9

NOTE:

[a] Mean annual flow is presented for a common period of record (1992–2010) where data are available

11.4.2.3 Changes to Surface Water Regime due to Regulation

The construction of the W.A.C. Bennett Dam and subsequent formation of the Williston Reservoir in the late 1960s and early 1970s resulted in changes in the flow regime of the Peace River. Prior to the regulation of the river, mean winter flows were less, and mean spring/summer flows were greater than they are today. Figure 11.4.5 compares monthly average flow hydrographs at various locations on the Peace River pre- and post-regulation.

Table 11.4.3 and Table 11.4.4 summarize a comparison between pre- and post-regulation maximum and minimum flows at various Water Survey of Canada stations on the Peace River. These flows were calculated by averaging the maximum and minimum daily flows of each year over the pre- and post-regulation periods. As shown, peak daily flows have decreased due to regulation, whereas minimum daily flows have increased.

Table 11.4.3 Average Annual Maximum Daily Flow Pre- and Post-Regulation

Water Survey of Canada Station	Pre-regulation (m^3/s)	Post-regulation (m^3/s)	Difference (m^3/s)	Difference (%)
Hudson's Hope	6,165	2,013	-4,152	-67%
Taylor	7,525	2,926	-4,599	-61%
Town of Peace River	9,157	5,622	-3,535	-39%
Peace Point	9,817	5,927	-3,889	-40%

NOTE:

Due to data availability, the period of record for each station is not the same; hence, flows should not be compared between stations

Table 11.4.4 Average Annual Minimum Daily Flow Pre- and Post-Regulation

Water Survey of Canada Station	Pre-regulation (m^3/s)	Post-regulation (m^3/s)	Difference (m^3/s)	Difference (%)
Hudson's Hope	198	344	146	+74%
Taylor	229	576	347	+152%
Town of Peace River	252	742	490	+195%
Peace Point	336	939	603	+179%

NOTE:

Due to data availability, the period of record for each station is not the same; hence, flows should not be compared between stations

The daily pattern of flows on the Peace River has also been influenced by regulation. Prior to regulation, changes in river flows and levels were generally more gradual, with the possible exception of the spring freshet period. Today, regulated flows vary to match electricity demand, typically with higher flows during the day and lower flows at night. The regulated flow pattern is more prominent directly downstream of the point of regulation (i.e., downstream of Peace Canyon Dam) and diminishes in the downstream direction due to natural attenuation and tributary inflows.

The following section describes the current post-regulation flow regime of the Peace River in more detail.

11.4.2.4 Baseline Flows and Water Levels

Flows in the Peace River downstream of the BC Hydro facilities are dependent on Peace Canyon outflows as well as natural inflows from tributaries. Water levels on the Peace River are dependent on flow rate, the size and shape of the channel, the slope of the riverbed, the roughness of the channel bottom, and the ice conditions in the river. Baseline flows and water levels in the Peace River are described in this subsection at monthly, daily, and within-day time frames for the purpose of characterizing seasonal flows, extreme high and low flows, and within-day patterns of flow.

The current post-regulation flow regime reflects not only the variability of the Peace River inflows but also the changes over time in BC Hydro's system load, system resources, and electricity market conditions. For this reason, it is important to consider the historical flow regime as dynamic. Although long-term (i.e., multi-year) average flows have not changed due to operations, the pattern of releases has and will continue to be dependent on these variables, with or without the Project.

BC Hydro's existing facilities on the Peace River are described in Volume 2 Section 11.1 Previous Development. Operation of BC Hydro's existing Peace River facilities follows a pattern similar to that of domestic electricity use, with higher generation and water discharges in the winter, and lower generation and discharges in the spring. Similarly, discharges from existing facilities can be higher during weekdays and lower on weekends, and higher in the daytime and lower at night. These are long-term historical patterns. However, for any particular day, there may be operational constraints or other issues that lead to a deviation from these patterns, as long as reservoir levels and power plant discharges remain within water licence requirements.

11.4.2.4.1 Seasonal Flows

It is useful to analyze monthly average flows to understand the seasonal pattern of flows in the Peace River. As described above, the operation of the existing hydroelectric projects on the Peace River have an influence on the Peace River flows downstream, the extent of which depends on the location and on the time of year. The relative contribution of flow from Peace Canyon to the total Peace River flow decreases with increasing distance downstream due to the inputs from other major tributaries such as those listed in Table 11.4.2. The regulated component of the total flow downstream is higher in the winter when Peace Canyon generation is high and natural tributary inflows are low. In the spring the opposite is true: Peace Canyon generation is typically low and tributary inflows are high.

Figure 11.4.6 illustrates the average monthly flow at Hudson's Hope (located approximately 7 km downstream of Peace Canyon Dam) and at several locations downstream in B.C. and Alberta. This Figure is similar to the bottom chart of Figure 11.4.5, but additional stations are included, and the period of record is shorter (to ensure a common period of record for all stations: 1992–2010). As shown in Figure 11.4.6~~7~~, the relative contribution of regulated flows (i.e., flows observed at Hudson's Hope) to the total flow at downstream locations is highest in the winter.

11.4.2.4.2 Daily Average Flows and Water Levels

From one day to the next, there is variability in flow and water level on the Peace River due to the pattern of hydroelectric generation at Peace Canyon as well as the natural tributary inflows to the river. Daily average flows at the Hudson's Hope Water Survey of Canada gauge are representative of the pattern of hydroelectric generation, as there are no major tributaries between Peace Canyon Dam and this gauge. As more tributaries enter the Peace River with increasing distance from Peace Canyon Dam, the seasonal pattern of tributary inflows becomes more apparent. Figure 11.4.7 through Figure 11.4.10 illustrate daily average flow hydrographs based on observed Water Survey of Canada gauged flows at Hudson's Hope, Taylor, the Town of Peace River, and Peace Point from 1973 to 2010 (where data are available). Five individual years (1983, 1986, 1990, 1996, and 2002) are highlighted by coloured traces to more clearly illustrate the variability throughout some example years; the average daily hydrograph is also shown. Operational spills occurred from the Williston Reservoir in three of the highlighted years (1983, 1996, and 2002). As shown on Figure 11.4.7, flows at Hudson's Hope vary over a small range compared to the locations downstream, typically between about 350 m^3/s and 2,000 m^3/s. Further downstream, natural variability is more pronounced, and spring freshet becomes more apparent; these characteristics reflect the natural inflows from tributaries downstream of the Peace Canyon Dam.

11.4.2.4.3 Within-Day Flow and Water Level Variations

Within-day variations in flow and water level on the Peace River occur in part due to hydroelectric operations at Peace Canyon, where outflows fluctuate within the water licence limits throughout the day to meet variable electricity demand. The variability is most pronounced directly downstream of Peace Canyon; in general, this variation is reduced with distance downstream.

To characterize the frequency and magnitude of within-day water level variations, the daily range of water levels were analyzed based on three recent years of observed data (2008, 2009, and 2010). Table 11.4.5 summarizes the daily range of water levels at various Water Survey of Canada stations on the Peace River for three recent years. In general, the range is reduced with distance downstream, from approximately 0.5 m at Hudson's Hope, to 0.1 m at Fort Vermilion. One apparent anomaly is at the Water Survey of Canada gauge at the Alces River location, which has a higher daily range than further upstream at Taylor; this is due to the relatively narrow cross-section of the river at this location, leading to a greater change in water level in response to a change in flow.

Table 11.4.5 Daily Water Level Range (2008–2010)

Water Survey of Canada Station	Daily Water Level Range (m)			
	2008	2009	2010	Average
Peace River at Hudson's Hope	0.51	0.51	0.60	0.54
Peace River near Taylor	0.26	0.25	0.28	0.26
Peace River upstream of Alces River	0.34	0.34	0.45	0.38
Peace River at Dunvegan	0.26	0.25	0.28	0.26
Peace River at Peace River	0.14	0.13	0.15	0.14
Peace River at Fort Vermilion	0.08	0.09	0.08	0.08
Peace River at Peace Point	0.09	0.11	0.09	0.10

11.4.3 Surface Water Conditions During Construction

This section describes the approach and methods used to identify potential changes in surface water conditions during the construction of the Project, the expected changes based on the outcome of these studies, and the uncertainties related to the study predictions. The Site C dam site construction phase activities are described in Volume 1 Section 4 Project Description.

11.4.3.1 Approach and Methods

To investigate the changes to upstream and downstream flows and water levels during the channelization and diversion periods of construction, a decade of historical Peace River flows was simulated using hydraulic models representing each stage of construction. A one-dimensional numerical hydraulic model (MIKE 11) of the Peace River between Peace Canyon Dam and Peace Point, Alberta was set up and calibrated for existing conditions as described in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 2 Downstream Flow Modelling (1D). For the analysis of changes during construction, the geometry of the river was modified in the model to represent the hydraulics during the channelization and diversion stages of construction. The hydraulic model predicts water levels, wetted width, average cross-sectional velocity, and other hydraulic parameters based on flow and river geometry. Water years 2000 to 2009 were selected for the analysis of hydraulic changes associated with construction. This period includes representative wet, dry, and average annual flows, and captures unique extreme events pertinent for the analysis of potential changes during construction. Specifically, the highest recorded flow on the Halfway River occurred in 2001 and there was a spill from the upstream Peace Canyon hydroelectric facility in 2002.

Additionally, a two-dimensional, depth-averaged hydraulic modelling software (River2D) was used to analyze the two-dimensional flow patterns, velocities, and bed shear stress estimates in the vicinity of the Site C dam site under existing conditions and during the channelization and diversion stages of construction. The model of existing conditions extends from approximately 1 km upstream of the Site C dam site to approximately 5.5 km downstream at the town of Old Fort. The model of the channelization stage has the same geographic extents, but includes the north bank and south bank Stage 1 cofferdams. The model of the diversion stage extends from the outlet of the diversion tunnels to Old Fort. Figure 11.4.11 illustrates the model domain for each scenario.

The downstream boundary condition specified in the River2D model was a rating curve (relationship between flow and water level) derived based on the one-dimensional hydraulic model described above. The upstream boundary condition was specified as a constant flow in the Peace River. A range of flow scenarios were modelled.

Calibration of the River2D model was completed based on flows of 838 m^3/s and 2,069 m^3/s and corresponding water levels measured in June and August 2011, respectively, along the banks of the two islands in the vicinity of the proposed Site C dam site. The channel bed roughness coefficient was the primary calibration parameter, and it was adjusted (within standard ranges) so that simulated water levels matched observed water levels. The model was calibrated such that simulated water levels were within 0.1 m of observed water levels. Once the River2D model was calibrated for existing river conditions, other model scenarios were developed using the existing river model as a baseline and adding in hydraulic structures to represent configurations during both stages of construction.

11.4.3.2 Expected Changes

This section describes the results of the hydraulic simulation of the channelization and diversion periods. A description of periodic flow changes that would be expected during other stages of construction (i.e., river closure and reservoir filling) is also provided.

Figure 11.4.11 presents predicted depth-averaged velocities in the vicinity of the Site C dam site under existing conditions and during Stages 1 and 2 of construction for a flow of 2,100 m^3/s (roughly equal to the sum of the maximum licensed flow from Peace Canyon Dam and the mean annual flow from the tributaries that flow into the Peace River between the Peace Canyon Dam and the Site C dam site). These results (from the River2D modelling described above) suggest that local changes in velocity profiles would be expected in the vicinity of the structures, but that the changes further downstream would be minimal.

11.4.3.2.1 Channelization

Confinement of the main river channel would result in an increase in upstream water levels relative to current conditions, due to the reduced channel conveyance capacity (ability to pass a certain flow at a given water level). At the upstream end of the river constriction, where changes would be most pronounced, water levels would be up to 1 m higher than existing conditions. Water levels further upstream would also rise, but the change (termed a backwater effect) would be reduced with increasing distance upstream. Table 11.4.6 compares the simulated water levels for existing conditions and for the channelization stage. Specifically, the 10th, 50th, and 90th percentile water levels, as well as the maximum and minimum water level over the 10 years of simulation, are compared.

Table 11.4.6 Summary of Changes in Upstream Water Levels during Channelization (2000–2009 Simulation)

Percentile	Water Level at Upstream End of River Constriction		
	Existing Conditions	Channelization	Change
Maximum	412.9 m	413.8 m	0.9 m
90th	411.7 m	412.4 m	0.7 m
50th	411.3 m	411.9 m	0.6 m
10th	410.5 m	411.0 m	0.5 m
Minimum	409.9 m	410.3 m	0.4 m

The top panel of Figure 11.4.12 illustrates the water surface profile upstream of the river constriction for a flow corresponding to the 90th percentile water level (412.4 m) at the upstream end of the river constriction (shown in Volume 1 Section 4.3 Project Description, Figure 4.38). This Figure illustrates the near-maximum influence of the channelization on upstream water levels; the water surface profile for the same flow under existing conditions is included for comparison. Figure 11.4.13 illustrates a plan view of the headpond inundation corresponding to the 50th and 90th percentile water levels during the channelization stage. The 10th percentile water level is not shown, as water levels would be contained within the existing river channel.

Downstream flows and water levels would be unaffected, with the exception of a small increase in water level at the downstream end of the river constriction in the order of 20 cm on average. This change would be negligible within 2 km downstream of the construction site.

11.4.3.2.2 River Closure

This is a transition phase between channelization and diversion stages, during which the Peace River would be diverted from the main river channel through the diversion tunnels. To initiate river closure, flows from Peace Canyon Dam would be reduced to minimum (283 m^3/s) for about one week to allow for construction of the closure berm. Then, for the next five weeks, river flows would be slowly increased as the main cofferdam height is increased. After this six-week river closure period, full Peace Canyon generating station operations would resume. River closure is planned to occur in the fall to allow for the main cofferdam to be completed prior to the following flood season.

11.4.3.2.3 Diversion

During the second stage of construction the Peace River would flow through the diversion tunnels for a period of about 39 months. The diversion tunnels would operate unregulated during this stage and the flow through the tunnels would depend entirely on the head or elevation of the headpond and the capacity of the diversion tunnels. As Peace River flows increase, the headpond level would rise and the diversion tunnel flows would increase; correspondingly, as Peace River flows decrease, the headpond level would fall, and the diversion tunnel flows would decrease. The headpond would dampen changes in Peace River flow rates, resulting in smaller, smoother changes in Peace River flows downstream of the construction site.

Changes to upstream levels during the diversion period would be more pronounced than during channelization due to the reduced flow capacity of the diversion tunnels as compared to the channelized river. Table 11.4.7 compares the maximum, minimum, and 10^{th}, 50^{th}, and 90^{th} percentile simulated water levels at the location of the upstream cofferdam (shown in Volume 1 Section 4.3 Project Description, Figure 4.39) for existing conditions and for the diversion stage of construction. As shown, results suggest that water levels would be increased by 1.5 m or more 90% of the time, and water levels would be increased by 8.6 m or more 10% of the time. The maximum simulated increase in water level was coincident with the flood of record on the Halfway River in 2001, the estimated return period of which is greater than 50 years.

Table 11.4.7 Summary of Changes in Upstream Water Levels during Diversion (2000–2009 Simulation)

Percentile	Water Level at Upstream Cofferdam		
	Existing Conditions	Diversion	Change
Maximum	412.9 m	434.8 m	21.9 m
90^{th}	411.7 m	420.3 m	8.6 m
50^{th}	411.3 m	416.4 m	5.1 m
10^{th}	410.5 m	412.0 m	1.5 m
Minimum	409.9 m	410.5 m	0.6 m

The bottom panel of Figure 11.4.12 illustrates the water surface profile upstream of the diversion for the 90^{th} percentile headpond water level of 420.3 m. This Figure illustrates the influence of the diversion on upstream water levels; the water surface profile for the same flow under existing conditions is included for comparison. Figure 11.4.14 illustrates (in plan view) the headpond inundation corresponding to the 50^{th} and 90^{th} percentile water levels during the diversion stage. The 10th percentile water level is not shown, as water levels would be contained within the existing channel.

Downstream of the diversion tunnel outlets, both the extreme maximum and minimum water levels as well as the rate of change of water levels would be less than under existing conditions. Hydraulic changes would be negligible at Taylor and further downstream.

11.4.3.2.4 Reservoir Filling

Volume 1 Appendix B Reservoir Filling Plan includes a description of the expected changes to the surface water regime of the Peace River during this phase of construction.

11.4.3.3 Uncertainties

The following is a summary of the main sources of uncertainty in the prediction of changes to the surface water regime during construction.

- The one-dimensional MIKE 11 hydraulic model of the existing river has been calibrated to within 0.3 m of observed water levels for a range of flows, as described in Volume 2 Appendix D Surface Water Regime, Part 2 Downstream Flow Modelling (1D). The model of the channelization period has a similar accuracy; the uncertainty in the predictions of water level during the diversion period is governed by the diversion tunnel design noted below.
- The two-dimensional River2D hydraulic model of the existing river has been calibrated to within 0.1 m of observed water levels for a range of flows. The model of the channelization period is expected to have a similar accuracy; the uncertainty in the predictions during the diversion period is governed by the diversion tunnel design noted below.
- Since the analysis described in Section 11.4.3.1 was completed, the diversion tunnel design was updated and the diameter of the diversion tunnels was increased (10.8 m instead of 9.8 m). Larger diversion tunnels would lead to less influence on the flow regime, as the tunnel capacity would be more similar to existing conditions. Hence, the results presented herein present a conservative estimate of the expected changes during this phase of construction.

11.4.4 Surface Water Conditions During Operation (Reservoir)

A description of the proposed Site C reservoir is provided in Volume 1 Section 4.3.2 Reservoir. This includes a summary of reservoir characteristics such as volume, bathymetry, maximum and minimum surface areas, active storage volume, and residence time. Mapping of the land flooded by the Site C reservoir is provided in Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report.

This section provides an overview of the approach and methods used for the analysis of BC Hydro operations with and without the Project, the expected reservoir levels and change in operational releases, and the uncertainties related to the predictions. Further details are provided in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 1 Operations Study.

11.4.4.1 Approach and Methods

To assess the potential changes to the surface water regime during operation of the Project, optimization modelling was completed to estimate possible future operations of the Peace River hydroelectric facilities in combination with the three largest hydroelectric facilities on the Columbia River. Two future scenarios were simulated: with and without the Project. This modelling captures the operation of the entire BC Hydro energy system, including planned generating assets, transmission capabilities, loads, and market conditions. A 60-year historical inflow sequence was input to the models to capture the historical variability of flows; forecasted loads and market prices for electricity for the year 2028–2029 were also input to the model. With this knowledge about future conditions (also referred to as foresight), the models calculate the most economically optimal way to dispatch the various generation resources to maximize the value of the system generation. The operations predicted by the model are more economically optimal and have lower operational variability than could be achieved in reality, where foresight of inflows, loads, and electricity prices is inherently subject to some uncertainty. Hence, optimization modelling is better suited for analyzing differences between modelled scenarios than for predicting actual operations in the future.

The Hydro Simulation Model (HYSIM) was used first to simulate the operation of BC Hydro's generation system on a monthly basis over the entire 60-year study period. The Generalized Optimization Model (GOM) was subsequently used to optimize the hourly operation of the hydropower system, guided by the month-end storage targets predicted by HYSIM for the Williston and Kinbasket reservoirs, which are the two main storage reservoirs of BC Hydro's integrated hydroelectric system. Outputs of the models include reservoir water levels and outflows from each of BC Hydro's major hydroelectric generating facilities.

A sensitivity analysis was used to assess Site C reservoir levels under a different BC Hydro future load/resource balance from that assumed in the GOM study. The analysis considered an additional scenario, one that assumes that the Project would be more heavily relied upon to meet system load requirements, and limits foresight related to market and inflow conditions to one week.

Inflow uncertainty is an important cause of spills in actual operations. Because the GOM model assumes perfect foresight of inflows, the frequency and magnitude of spills are likely under-represented by the model results. A re-operation of the GOM model was conducted to limit inflow foresight, which led to a more reasonable estimation of the frequency of project spills. This foresight limitation was not applied for predicting normal reservoir releases because the shaping of reservoir releases between months, which would be facilitated by the forecast of seasonal inflow patterns spanning several months, is an important determinant in the actual operation of the Williston Reservoir. A supplemental analysis based on historical flows was also conducted to gain perspective on the project spills that would result based on historical flows. This approach is explained further in Section 11.4.4.2.3.

11.4.4.2 Expected Changes

11.4.4.2.1 Site C Reservoir Water Levels

As mentioned above, two approaches were used to estimate the operation of the Site C reservoir; it is expected that actual conditions would be somewhere between the two results. The GOM model results describe how the Site C reservoir would be operated under a base case future resource development and load growth scenario. Under this modelled load/resource balance, the Site C reservoir would be operated near the normal maximum reservoir level for the majority of the time with drawdown of the reservoir beyond the top 0.6 m required less than 1% of the time. An alternate scenario analysis describes how the Site C reservoir would be operated under a different future load/resource balance – for example, where planned resource development is delayed, load growth is exceeded, or transmission capacity to external markets is expanded. That approach predicted that reservoir levels would be maintained within the top 0.6 m of the normal operating range 83% of the time and within the top 1.2 m 94% of the time.

The daily range of Site C reservoir levels (i.e., the difference between the maximum and minimum reservoir level in one day) was also predicted using the two approaches. Actual conditions are expected to be somewhere between the two results. The GOM model results suggest the daily range would be less than 0.6 m over 99 percent of the time. The scenario analysis predicted that the daily range could be larger particularly in the winter period, when the daily range is expected to be 0.6 m or less 60% of the time, and 1.0 m or less 75% of the time. Figure 11.4.15 presents an illustration of the expected range of Site C reservoir levels during operation of the Project.

11.4.4.2.2 Operational Flow Releases

The operation of the Project would be co-ordinated with the operation of existing facilities upstream on the Peace River, as well as other available system resources, to meet provincial demand for electricity in a safe, reliable, and efficient manner. Accordingly, Project discharges would follow the same general pattern as the provincial demand for electricity: higher during the winter and lower during the summer on a seasonal basis, higher during weekdays and lower during weekends on a weekly basis, and higher during daylight hours and lower during late night hours on a daily basis.

Although upstream operations would be maintained within their current water licences, the optimization model results suggest that the Project would lead to differences in the timing of releases from the upstream facilities. The difference in monthly average flows at the Site C tailrace between the two scenarios was estimated to be within two percent with the exception of the months of August, September, October, and November. With the Project, monthly average flows were predicted to be lower in October and November (seven and six percent lower, respectively), and higher in August and September (seven and 14 percent higher, respectively), than without the Project. The magnitude and direction of these changes varied for each month within the 60 year simulation period; however, the changes were within the variability of the existing pattern of releases. Figure 11.4.16 presents the comparison of simulated Peace Canyon Dam hourly releases on an annual and seasonal basis using duration curves. A duration curve is a graphical summary of data that shows the percentage of time that any data value is equalled or exceeded over the period of consideration. These percentages are referred to as exceedance probabilities. The three seasons for which results are presented are as follows:

- Typical winter operations period (November 15 – February 15)
- Typical freshet operations period (May 1 – July 15)
- Typical summer operations period (July 16 – September 30)

Figure 11.4.17 presents the comparison of simulated hourly flows at the Site C dam site with the Project (i.e., operational releases from Site C generating station) and without the Project (i.e., operational releases from Peace Canyon generating station plus tributary inflows, routed downstream to the Site C dam site using a hydraulic model, as described in Section 11.4.5 below).

11.4.4.2.3 Spill Frequency, Magnitude, Duration and Seasonality

The Site C spillway is being designed to safely pass a design flood that is defined as the most severe flood that may reasonably be expected to occur at a particular location. The design flood and spillway capacity are described in Volume 1 Section 4 Project Description and in Volume 5 Section 37 Requirements for the Federal Environmental Assessment. At the other end of the spectrum, lower magnitude spills, though infrequent, are expected under normal operations and could occur at any time. These events are driven by normal operating requirements, including uncertainties associated with inflows, unit outages, transmission restrictions, electricity market prices, and system energy needs.

The combined turbine capacity of the Site C generating station would be approximately 2,520 m^3/s which is about 25% greater than the current turbine capacity of the G.M. Shrum or Peace Canyon generating stations. This increased capacity, along with an active storage volume of roughly six times that of the Dinosaur Reservoir, would provide the Project with operating flexibility to limit the occurrence of spills.

For the characterization of expected frequency, duration, and magnitude of spills at the Site C dam, two approaches were used: one based on a forecasted future operation using the GOM model, the other based on historical flows at the location of the Site C dam site. Both approaches predict the spills that could occur considering one particular set of conditions (inflows, load/resource balance, unit outages, transmission availability, and market conditions) and hence a range of possible outcomes is provided. In addition to spills that may results from regular operations, spills would be expected to occur during Project commissioning and spillway testing.

The first approach used the GOM model with inflow foresight limited to one month. Given that the model is able to operate the Site C reservoir within its normal 1.8 m water level range, it typically chooses to drawdown the reservoir level prior to large inflows that would otherwise lead to spill. Due to its tendency to react in this manner, the model could underestimate the incidence of spills due to short-term inflow events that are difficult to accurately forecast (e.g., rainstorm-driven inflows). On the other hand, inflow foresight of one month could lead the model to overestimate spill at times when forecasts are accurate further than one month into the future (e.g., actual forecasts for the spring freshet period based on basin snowpack observations).

The second approach was based on historical flows at the location of the Site C dam, taken as the flows measured at Water Survey of Canada station Peace River upstream of the Pine River confluence (period of record 1979–2012). In this analysis, spill was assumed to occur whenever the flow exceeded the Site C generating station turbine capacity, and no operation of the Site C reservoir was considered (i.e., the reservoir was fixed at a constant water level). It was assumed that one of the six turbine units was out of service for annual maintenance, such that a spill occurred whenever the total flow exceeded the capacity of five Site C turbines (approximately 2,100 m^3/s). While simple in method, this approach captures historical variability in flows that occurred due to unexpected circumstances at G.M. Shrum and Peace Canyon generation stations. Table 11.4.8 summarizes the results of the two analyses.

Table 11.4.8 Estimated Project Spills

	Generalized Optimization Model	Historical Analysis
Frequency	Five of 60 years with spill (average one year in 12), total of nine spill events	13 of 33 years with spill (average one year in three), total of 18 spill events
Magnitude	Average 226 m^3/s (maximum daily flow 879 m^3/s)	Average 416 m^3/s (maximum daily flow 1,940 m^3/s)
Duration	Average 39 days (range: three to 93 days)	Average four days (range: one to 19 days)

While both approaches have limitations, together the two approaches provide perspective on the frequency, magnitude, and duration of spills that could be expected at the Site C dam.

Regarding the expected seasonality of spills from the Project, operational spills could be expected at any time of year, whereas spills due to local basin floods would be expected to occur in June or July, consistent with the typical timing of the peak freshet flow on the Halfway River.

11.4.4.3 Uncertainties

The current operation of BC Hydro's existing hydroelectric system has the fundamental objectives of generating sufficient electricity to meet domestic demand, and maximizing the value of generation through electricity trade. Within the current licensed operational ranges and within the physical and operational constraints of all of BC Hydro's generating assets, flows are released to meet the above-noted objectives. These objectives would not change as a result of the Project.

Simulation of the future operation of the BC Hydro integrated hydroelectric system with or without the Project is subject to the uncertainties inherent in the forecasts used as input to the models. The main source of this uncertainty is the natural inflows. This uncertainty has been addressed by modelling 60 years of historical inflow records to capture a range of inflow conditions.

The purpose of the optimization model is not to provide a single definitive forecast of actual expected operations, but rather to facilitate an unbiased comparison of different operational scenarios under an otherwise common set of input assumptions. Therefore, despite uncertainty in the inputs to the optimization model, the results are useful for the prediction of the influence of the Project on flow releases to the Peace River.

11.4.5 Surface Water Conditions During Operation (Downstream)

11.4.5.1 Approach and Methods

For the analysis of changes to the surface water regime downstream of the Site C dam, results of the operational modelling were input into a hydraulic model of the downstream river. This one-dimensional backwater hydraulic model extends from the outlet of the Peace Canyon Dam to Peace Point, Alberta, approximately 1,100 km downstream. A 10-year subset of hourly GOM model output for the scenarios with and without the Project were simulated in the downstream reach to produce estimates of flow, water level, wetted width, and average cross-sectional velocity in the Peace River. Measured and estimated inflows from major tributaries were included in the modelling. Additional details on the model setup, inputs, and calibration are included in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 2 Downstream Flow Modelling (1D).

A two-dimensional hydraulic model was used to conduct a more detailed analysis of potential changes in flows and water levels in the vicinity of four side-channel areas between the Site C dam site and Old Fort, at Pallings Flat and Raspberry Islands in B.C., and at Many Islands in Alberta. These reaches have more complex flow patterns and thus two-dimensional modelling was required. Inundation mapping was prepared to compare maximum and minimum wetted areas and depths with and without the Project. Additional details on the model setup, inputs, and calibration are included in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 3 Downstream Flow Modelling (2D).

11.4.5.2 Expected Changes

Changes to downstream flows and water levels would be more noticeable directly downstream of the Site C dam, and less noticeable with increasing distance downstream. Section 11.4.5.2.1 describes the reasons that changes in the surface water regime would be expected with the Project. The subsequent sections describe the study results in terms of changes in the timing of releases, the frequency and magnitude of high and low flows, daily water level fluctuation, wetted width, and average cross-sectional velocity. Detailed results are presented in Volume 2 Appendix D Surface Water Regime, Part 2 Downstream Flow Modelling (1D).

There is a fixed relationship between flow and water level for each cross-section in the hydraulic model based on the channel shape, channel bed material, and slope of the channel bed. Results are typically presented in terms of water level, as that parameter is more tangible than flow rate. It should also be noted that the hydraulic modelling does not consider the hydraulic influence of ice. The objective of the analysis of potential changes in the surface water regime is to provide an indication of the relative changes that could be expected due to the Project. Hence, the presentation of hydraulic model results assuming open water conditions (no ice) is still valuable.

11.4.5.2.1 Reasons to Expect Change

Prior to describing the results of the analyses outlined above, the following is an explanation of why changes to the surface water regime would be expected with the addition of the Project.

The Site C reservoir water level would be relatively stable, with limited daily storage, and would typically operate in approximate hydraulic balance with the upstream facilities over any given day. As such, the water flowing into the Site C reservoir would be approximately equal to the water released through the turbines. In general, the limited amount of active storage (storage within the normal operating range) limits the degree to which the Project could change the downstream flow regime. The factors that would be expected to influence the downstream flow regime include the following. Each point is discussed further below.

- Shifting the point of regulation of the Peace River from the Peace Canyon Dam to a location 85 km downstream
- Having the ability to capture a portion of the spring freshet flows from the tributaries that flow into the Peace River between Peace Canyon Dam and the Site C dam
- Having a different range of operational releases at the farthest facility downstream
- Adding the Site C generating station to the integrated hydroelectric generation system

Under existing conditions, the greatest daily variability in flows and water levels is experienced immediately downstream of the point of regulation (i.e., at the Peace Canyon Dam outlet or tailrace). This daily variability is generally reduced in the downstream direction due to natural attenuation and tributary inflows. The Project would shift the existing point of regulation by a distance of 85 km downstream (along the river centreline) and hence increase the daily variability of flows and water levels at that location, and for some distance downstream.

During the spring, when natural inflows are typically high in the tributaries between Peace Canyon and the Site C dam site (including flows from the Halfway and Moberly Rivers), there would be the potential for the Site C reservoir to store some of the inflows, thereby reducing the peak flow experienced downstream.

The operational releases of the Peace Canyon Dam are bounded by the minimum flow requirement of 283 m^3/s and the maximum licensed discharge of 1,982 m^3/s. The proposed minimum flow for the Project is 390 m^3/s; this value was calculated by adding the current minimum flow requirement of 283 m^3/s at Hudson‘s Hope to the mean annual flow of the drainage basin between the Peace Canyon Dam and the Site C dam. The proposed maximum discharge capacity of the Project is about 2,540~~520~~ m^3/s. This larger range of operational releases with the Project would lead to more rapid fluctuations in flows and water levels immediately downstream of the Site C dam at times when releases were varied from minimum to maximum or vice versa.

As would be expected from the addition of any new resource to the integrated electrical generation system, it is likely that the dispatch of the various resources would be different with the addition of the Site C generation station. In the operations study (Volume 2 Appendix D Surface Water Regime, Part 1 Operations Study), these differences were analyzed by holding other assumptions (including load, inflow, and market conditions) constant between the two future scenarios, with and without the Project.

11.4.5.2.2 Timing of Release

The timing of releases from the Site C generating station would be expected to follow the BC Hydro system load pattern and hence would be similar to the timing of releases from the Peace Canyon Dam today. Due to the time required for water to flow between the Peace Canyon outlet and the location of the proposed Site C tailrace, operational changes at points downstream of the Site C dam would be noticed approximately 10 to 12 hours sooner with the Project. For example, if flow releases were increased from Peace Canyon at 6 a.m. today, the flow increase would be noticeable at the Site C dam site between 4 p.m. and 6 p.m. (depending on the magnitude of the flow). With the Project, the flow increase at the Site C tailrace would be evident immediately (i.e., 10 to 12 hours sooner than under current conditions).

As is the case today, at a certain point downstream of the dam the daily pattern of operational releases would not be apparent due to natural hydraulic attenuation and the inflow from tributaries. This location is dependent on the flow condition but in general the daily pattern is largely attenuated by the Town of Peace River.

11.4.5.2.3 Magnitude of High and Low Flows

Flows immediately downstream of the Site C dam would be less extreme than flows at the same location under current conditions. Currently, the annual maximum flows at this location typically occur either due to high operational releases from Peace Canyon or due to the spring freshet of the Halfway River, the largest tributary of the drainage area between Peace Canyon Dam and the Site C dam. Of these annual maximum flows, the highest flows observed at this location have coincided with the peak of the Halfway River freshet. With the Project, flows from the Halfway River would enter the Site C reservoir, which would have the potential to store some flow, thus reducing the peak flow downstream.

Sixteen kilometres downstream of the Site C dam site on the Peace River is the confluence with the Pine River. The mean annual flow of this tributary is approximately 70% greater than the mean annual flow of the drainage area between Peace Canyon and the Site C dam site. Although the peak flows immediately downstream of the Site C dam would be reduced as described above, the spring freshet of the Pine River (which has peak freshet flows that are on average two and a half times greater than Halfway River peak flows) would not be influenced by the Project. Therefore, the reduction in the most extreme high flows would only be apparent in the 16 km reach between the Site C dam and the Pine River confluence.

At the other end of the spectrum, the lowest flows at the location of the Site C tailrace today typically occur either during early spring or late summer (i.e., before or after the spring freshet of the Halfway River), when electricity demand is low and inflows into upstream reservoirs are typically stored for use in the following winter. Since 1994, there has been a minimum flow requirement of 283 m^3/s at Hudson's Hope (approximately 7 km downstream of the Peace Canyon Dam). Operationally, the minimum release from Peace Canyon has been slightly higher (approximately 310 m^3/s) due to high vibrations experienced at lower flows, which can reduce the life of the turbine. The lowest flows at the location of the proposed Site C dam occur when tributary inflows are low and the Peace Canyon Dam is releasing near its minimum flow. Flows at this location have been as low as 360 m^3/s since 1994. The minimum flow from the Project is proposed to be

390 m^3/s as described above; hence, it is expected that the lowest flows in the reach downstream would be higher with the Project than the lowest flows that can occur today.

11.4.5.2.4 Frequency of High and Low Flows

As described above, if the Project were constructed, the magnitude of the highest and lowest flows at the location of the Site C tailrace would be less extreme than under current conditions. However, the frequency of high and low flows would be expected to increase with the Project. This result is apparent in Figure 11.4.17, which presents flow duration curves at the outlet of the Site C dam (with and without the Project) based on the 10 years of downstream flow modelling. As shown in the full year plot, results suggest that flows would exceed 2,000 m^3/s approximately 5% of the time with the Project, compared to less than 1% of the time without the Project. At the other end of the flow range, results suggest that flows would be less than 500 m^3/s approximately 21% of the time with the Project, compared to only 7% of the time without the Project. An investigation into potential changes during particular seasons suggests that the change in the frequency of high and low flows could be different depending on the time of year (see Figure 11.4.17).

The above-noted changes in the frequency of high and low flows at the outlet of the Site C dam would be diminished with increasing distance downstream. At Taylor, there would be little difference in the frequency of any particular flow. Smaller changes are apparent further downstream when particular times of the year are viewed in isolation. This relates to the shift in the timing of releases from upstream facilities between months, as described above in Section 11.4.4.2.2. and shown in Figure 11.4.16. The resulting downstream changes are apparent in the flow duration curves included in Appendix D of Volume 2 Appendix D Surface Water Regime, Part 2 Downstream Flow Modelling (1D).

The downstream boundary of the surface water regime study is at Peace Point. In light of comments received regarding the spatial scope of the environmental assessment, including requests to include the Peace Athabasca Delta in the assessment area (as referred to in Section 8.4.1 of the EIS Guidelines), the predicted changes at the downstream boundary were analysed to determine whether there was a technically valid concern with respect to the downstream study boundary. As explained below, consideration of the magnitude and timing of the predicted change and the mechanisms that are understood to be related to the flooding of the Peace Athabasca Delta demonstrates that the spatial boundary is appropriate.

The simulated operation of the integrated hydroelectric system suggests differences between the cases with and without the Project. Differences are expected when using this type of model; the optimal operation determined by the model is dependent on the inputs, some of which are necessarily different in the two scenarios. The downstream hydraulic routing of the simulated operational releases under the two scenarios (with and without the Project) [as described in Volume 2 Appendix D Surface Water Regime, Part 2 Downstream Flow Modelling (1D)], demonstrates that the differences between scenarios become less apparent with increasing distance from the point of regulation (i.e. the Peace Canyon Dam in one scenario and the Site C dam in the other). At Peace Point, the downstream extent of the hydraulic model (approximately 1,030 km downstream of the Site C dam site), a small increase in the frequency of low flows with the Project, particularly in the typical winter operations period (defined in this study as

November 15 to February 15), is predicted. Further analysis shows that with the Project, the frequency of low releases was predicted to be greater during the months of October and November, and a corresponding increase in the frequency of relatively higher flows was predicted for the months of August and September. The predicted changes are small relative to the range and natural variability of flows at Peace Point and would not have any influence on the hydrology of the Peace Athabasca Delta in the open water period. However, the hydrology of the Peace Athabasca Delta is influenced by the frequency of ice-jams in the lower reaches of the Peace River. Freeze-up in the lower Peace River typically occurs in November. The possibility of a relationship between the freeze-up stage (water level) and the probability of dynamic break-up and ice-jams in the spring has been researched (Ashton 2003; Beltaos et al. 2006). It is unlikely that the probability of ice jamming would be influenced by the relatively lower flows that are predicted to occur periodically in October and November with the Project. Ice cover set in at a low level during a period of relatively low flow in November would re-freeze at a higher level as flows increase in December. This is because with increasing flows, the floating portion of the ice cover in the main channel would release from the border ice attached to the banks, float up to accommodate a higher flow beneath it, and re-freeze to the banks at a new, higher freeze-in level. This phenomenon is described by Beltaos et al. (2006). Consequently, low flows in November would not influence the freeze-in level that may be related to the frequency of ice-jams in the lower reaches of the Peace River. The small predicted changes do not justify extension of the spatial boundary.

11.4.5.2.5 Daily Water Level Range

Results suggest that, with the Project, the range of water levels over a day would typically be greater at the Site C tailrace compared to existing conditions. This result would be expected due to the shifting of the point of regulation from Peace Canyon to a location 85 km downstream. Today, the water level fluctuations that are apparent at the Peace Canyon tailrace are naturally attenuated along this river length. The difference is also due to the larger operational flow range that would be expected with the Project.

Table 11.4.9 presents the average simulated daily water level fluctuation at the Site C tailrace and locations downstream based on the 10-year simulation.

Table 11.4.9 Average Simulated Daily Range of Water Levels (with and without the Project)

	Without the Project	With the Project	Difference
Site C Tailrace	0.48 m	1.01 m	0.53 m
Taylor	0.43 m	0.76 m	0.33 m
Alces	0.50 m	0.85 m	0.35 m
Town of Peace River	0.16 m	0.20 m	0.04 m
Peace Point	0.07 m	0.07 m	0.00 m

11.4.5.2.6 Wetted Width and Average Cross-Sectional Velocity

Wetted width is defined as the horizontal distance across the wetted portion of the channel, calculated at model cross-sections. At each model cross-section, there is a specific relationship between wetted width and flow and between average cross-sectional velocity and flow. The influence of the Project on wetted width and average cross-sectional velocity follow the same general patterns as the influence of the Project on flow and/or water level.

11.4.5.2.7 Summary of Expected Changes

As described in Section 11.4.5.2.1, the limited amount of active storage in the Site C reservoir limits the degree to which the Project could change the downstream flow regime. The analysis predicts changes of varying magnitudes throughout the study reach; however, the changes predicted downstream of the Town of Peace River are negligible, considering the magnitude of the predicted change in relation to the natural variability of the baseline flow regime. The most notable changes expected as a result of the Project are as follows.

- Reduction in the magnitude of peak flows; negligible change downstream of the Pine River confluence. Over the 10-year simulation period, the maximum simulated flow at Taylor (located approximately 2 km downstream of the Pine River confluence) with the Project is within one percent of the maximum simulated flow without the Project.
- More frequent high flows; negligible change at Taylor and further downstream. The following are examples of the predicted changes at Taylor that are considered to be negligible:
  - The frequency of flows in excess of 2,000 cms without the Project is 7.0 %, and with the Project is 11.8 %.
  - The frequency of flows in excess of 2,500 cms without the Project is 1.6 %, and with the Project is 2.1 %.
- More frequent low flows; negligible change at Taylor and further downstream. The following are examples of the predicted changes at Taylor that are considered to be negligible:
  - The frequency of flows less than 700 cms without the Project is 8.2%, and with the Project is 11.2%.
  - The frequency of flows less than 500 cms without the Project is 0.3%, and with the Project is 2.3%
- Increase in daily range of water levels; negligible change at Town of Peace River and further downstream. As shown in Table 11.4.9, the predicted change in average daily range of water level is 4 cm at the Town of Peace River and 0 cm at Peace Point

11.4.5.3 Uncertainties

Uncertainty in the results of the downstream flow modelling can be divided into two parts: the uncertainty in the flow inputs predicted through the operations modelling (described in Section 11.4.4.3), and the uncertainty in the hydraulic model, described below.

The one-dimensional hydraulic model that was used to predict flows and water levels on the Peace River based on the results of the operations modelling was calibrated at eight Water of Survey of Canada hydrometric stations between Hudson's Hope and Peace Point (see Figure 11.4.4), and at five additional locations between Hudson's Hope and

Old Fort. Maximum water level differences were within 0.3 m, and the timing of observed flow patterns were adequately reproduced by the model (modelled flows were generally within one to two hours of observed flows). This calibration result provides confidence that the model can reliably be used for the prediction of the relative difference in flows and water levels under two scenarios (with and without the Project), given the time series of operational releases obtained through the operations modelling (the uncertainty of which is described in Section 11.4.4.3).

11.4.5.4 Influence on Existing Hydrometric Stations

The creation of the Site C reservoir would flood the Water Survey of Canada hydrometric station located at Hudson's Hope (Station 07EF001), which is shown on Figure 11.4.4. Another Water Survey of Canada hydrometric station exists on the Halfway River near Farrell Creek (Station 07FA006), approximately 20 km upstream of the confluence with the Peace River. It is unclear whether or not the Site C reservoir would lead to a backwater effect to this location.

It is expected that other Water Survey of Canada hydrometric stations on the Peace River and its tributaries would not be affected by the Project.

11.4.6 Climate Change

As part of its climate change adaptation strategy, BC Hydro has been working to determine how climate change has affected the water supply in the past and to predict potential changes in the future. BC Hydro has conducted internal studies to investigate the historical influence of climate change on reservoir inflows, and has partnered with the Pacific Climate Impacts Consortium and the Western Canadian Cryospheric Network to collaborate on studying the potential influence of climate change on the water resources managed as part of BC Hydro's hydroelectric generating system. Volume 2 Appendix T Climate Change Summary Report provides a summary of the work that has been conducted specific to the Peace River region. The main findings of the studies are as follows:

- Although not statistically significant, the BC Hydro analysis of historical trends in reservoir inflow suggests that annual inflows to the Williston Reservoir have increased over the 1984 to 2007 period, and that trends exist in the seasonality of inflows over this period: fall-winter inflows have increased and late summer flows have declined
- Despite uncertainty in the magnitude of projected changes, there is scientific consensus on the direction of climate change with respect to natural inflows to the Peace River. Annual streamflow is projected to increase, though late summer flows are expected to decline. There is evidence of an earlier spring freshet onset and a shift in peak flows from June to May.

The influence of the Project on the surface water regime of the Peace River has been analyzed based on 60 years of historical inflows, including wet and dry years, as described in Section 11.4.5.2.1. The median projected change in annual streamflow for the 2050s and 2080s periods is within the variability observed in the historical 60-year inflow record used in operations modelling. Therefore, the operation of BC Hydro's generating facilities on the Peace River under a future climate with higher inflows could be inferred from the simulation of operations in years with higher inflows. No requirement for changes to the existing water licences would be expected as a result of climate change.

As a federal requirement of the environmental assessment of the Project, a discussion of the effects of climate change on the Project (in terms of electricity generation potential and extreme floods) is described in Volume 5 Section 37.1.

11.5 Water Quality

This section describes existing water quality conditions and sediment quality in the Peace River and its tributaries in accordance with Section 9.3.2 of the EIS Guidelines for the Project. Water quality parameters discussed include nutrient and metal concentrations, suspended sediment levels, dissolved gas pressure levels, pH, alkalinity, and temperature. Sediment quality parameters discussed include metal and polycyclic aromatic hydrocarbon concentrations.

11.5.1 Regulatory and Policy Setting

Water quality data were compared to guidelines to evaluate baseline conditions. Water quality guidelines used were British Columbia guidelines for the protection of aquatic life, drinking water, wildlife, recreation and aesthetics, irrigation and livestock watering (BCMOE 2010); Canadian Council of Ministers of the Environment (CCME) guidelines for protection of aquatic life, and recreation and aesthetics (CCME 2012a); guidelines for drinking water (Health Canada 2012); and Alberta water quality guidelines for the protection of aquatic life, human health, and wildlife health (Alberta Environment and Water 1999). Guidelines from multiple sources were included because no single source has a guideline for every parameter.

Sediment results were compared to CCME sediment quality guideline for the protection of aquatic life (CCME 2012b), including the lower interim sediment quality guideline (ISQG) and the higher probable effects level (PEL) guideline.

11.5.2 Baseline Conditions Water Quality

The technical study area for water quality extends from the forebay of the Williston Reservoir, through the Dinosaur Reservoir and the Peace River valley to upstream of the confluence with the Alces River (Figure 11.5.1). The technical study area also incorporates the major tributaries, including Maurice Creek, Lynx Creek, Farrell Creek, Halfway River, Cache Creek, Moberly River, Pine River, and Beatton River that drain to the Peace River. The downstream boundary of the technical study area was chosen to correspond to the limit in which changes to water quality from the Project would be negligible (i.e., 10% or less from baseline). A difference of 10% or less is acceptable because analytical uncertainty can be as high or higher than 10%; a difference of 10% or less is unlikely to be statistically significant, and effects to aquatic organisms are unlikely to be detectable for a change of 10% or less in a substance concentration (Volume 2 Appendix P Aquatic Productivity Reports, Part 2 Hydrodynamic, Water Quality, and Productivity Modelling for the Site C Project).

Baseline water quality conditions were determined by completing a review of 1) data collected through field programs in support of the Project; and 2) available monitoring data collected by government agencies (1971 to 2011). Water quality field data were collected in the technical study area for the period of 2006 to 2011, excluding 2009, at stations established for the Project. There were no water quality field programs conducted in 2009. In total, 23 stations were established (Table 11.5.1). Locations of sampling locations are shown on Figure 11.5.1 and provided in Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River. Data collected from government agencies were included to better understand baseline variability.

The water bodies within the technical study area have been categorized into three main groups, as follows:

- Reservoirs
    - Williston Reservoir in the dam forebay upstream of W.A.C. Bennett Dam (W-01, water samples collected at shallow and deep water depths)
    - Dinosaur Reservoir – downstream of W.A.C. Bennett Dam to upstream of the Peace Canyon Dam (Dino-US, Dino-MID, Dino-DS; water samples collected at shallow and deep water depths)
- Peace River Mainstem
    - Downstream of the Peace Canyon Dam, but above the proposed Site C dam location (Peace-01, Peace-02, Peace-03)
    - Downstream of the proposed Site C dam to the confluence with the Alces River (Peace-04, Peace-14, Peace-15, Peace-05)
- Tributaries
    - Tributaries between Peace Canyon Dam and the proposed Site C dam (Lynx Creek, Farrell Creek, Halfway River, Boudreau Creek, Cache Creek, Moberly River)
    - Tributaries between the proposed Site C dam to the confluence with the Alces River (Pine River, Beatton River)

Table 11.5.1 Water Quality Stations in the Technical Study Area and Sampling Effort

Water Body Group	Stations	Years Water Quality Samples Collected				
		2006	2007	2008	2010	2011
Reservoirs	W-01	—	—	—	yes	yes
	Dino-US	—	—	—	yes	yes
	Dino-MID	—	—	—	yes	yes
	Dino-DS	—	—	—	yes	yes
Peace River	Peace-01	—	yes	yes	yes	yes
Tributaries	Lynx 10	—	yes	yes	—	—
	Farrell 11	—	yes	yes	—	—
Peace River	Peace-02	—	yes	yes	yes	yes
Tributaries	Halfway-DS	—	yes	yes	yes	yes
	Halfway-MID	—	yes	yes	yes	yes
	Halfway-US	—	—	—	—	yes
	Boudreau 13	—	yes	yes	—	—
	Cache 12	—	yes	yes	—	—
Peace River	Peace-03	yes	yes	yes	yes	yes
Tributaries	Moberly-DS	—	—	—	yes	yes
	Moberly-US	—	yes	yes	yes	yes
	Moberly-US far	—	yes	yes	—	—
Peace River	Peace-04	yes	yes	yes	yes	yes

Water Body Group	Stations	Years Water Quality Samples Collected				
		2006	2007	2008	2010	2011
Tributary	Pine-16	—	—	—	yes	yes
Peace River	Peace-14	—	—	—	yes	yes
Tributary	Beatton-17	—	—	—	yes	yes
Peace River	Peace-15	—	—	—	yes	yes
	Peace-05	yes	yes	yes	—	—

NOTES:

— not sampled

Stations shown on Figure 11.5.1

More details provided in Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River

The following sections summarize baseline conditions for water quality in the existing reservoirs, the Peace River mainstream, and the tributaries of the technical study area. Detailed information on baseline conditions of water and sediment quality in the technical study area are provided in Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River.

11.5.2.1 Total Dissolved Gas Pressure

Total dissolved gas (TDG) pressure is a measure of nitrogen, oxygen, and other gases in solution. TDG is relevant to fish health since it can result in gas bubble disease/trauma resulting from supersaturation of gases in solution (Golder 2009). The guideline to protect aquatic life is ≤110% saturation (BCMOE 2004).

TDG was measured in 1972 to 1974, and 1995 to 1998, at the Peace River W.A.C. Bennett Dam and generating station and at the Peace Canyon Dam and generating station to understand seasonal variability as it relates to dam and generating station operations (BC Hydro 1999). The measurements showed that elevated levels of TDG occurred during periods of spillway discharge and periods of low discharge. TDG pressure averaged 125% during an emergency spillway release in the summer of 1996 (due to dam safety concerns during high river discharge), but during moderate discharge periods, TDG levels did not exceed 110%.

TDG pressure was measured in Dinosaur Reservoir and the Peace River in 2008 (Golder 2009). In the Peace River, TDG often reached, but seldom exceeded, 103%. In Dinosaur Reservoir, TDG was most variable at the upstream station, and at all stations, was highest at the 5 m and 10 m depth, as compared to surface or deeper stations. In the reservoir, TDG ranged from 103% to 111%.

11.5.2.2 Temperature

Williston and Dinosaur reservoirs are mainly isothermic (i.e., same water temperature through the water column), but they do show evidence of weak stratification occurring in the summer period (i.e., July and August) (Volume 2 Appendix P Aquatic Productivity Reports, Part 1 Baseline Aquatic Productivity in the Upper Peace River). Surface waters in the reservoirs, Peace River, and tributaries freeze in the winter, and reach highs of 16ºC to 17ºC in the summer. More information on the current thermal regime and ice conditions in the Peace River is provided in Section 11.7 Thermal and Ice Regime, and in Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report.

11.5.2.3 Dissolved Oxygen

Surface water in the technical study area is well oxygenated, with mean values of 10 mg/L (90% saturation) or higher in the reservoirs, Peace River, and tributaries across all seasons and stations. Dissolved oxygen is above the most stringent guideline for aquatic life (more than 9.5 mg/L for early life cold water species); therefore, the waters are considered well oxygenated.

11.5.2.4 Total Suspended Solids

Total suspended solids (TSS) include all solid particles suspended in the water column. Elevated TSS levels on fish can affect fish behaviour, physiology, and habitat (Robertson et al. 2006). Many riverine ecosystems such as the Peace River have concentrations of TSS that fluctuate naturally over the seasons, due to runoff from the watershed, and aquatic biota have adapted to these conditions. The CCME protection of aquatic life guideline for TSS is a narrative guideline that recognizes two separate flow conditions: clear flow and high flow. The narratives concerning these two flow conditions are as follows:

- **Clear Flow** Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-hour period); maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 hours and 30 days)
- **High Flow** Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L; should not increase more than 10% of background levels when background is >250 mg/L

TSS concentrations ranged from 1.5 to 2,760 mg/L across all samples. Measured TSS concentrations are lower in the reservoirs than in the tributaries and the Peace River (See Figure 3-6 in Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River). The lower concentrations of TSS in the reservoirs compared to the Peace River or tributaries is due to the settling out of TSS in the lower energy (still water) environment of the reservoir.

TSS was highest in spring, compared to summer or fall in the reservoirs, Peace River, and tributaries. In the Peace River, there was also an increase in TSS from upstream of the Halfway River (Station Peace-02, overall mean through all seasons = 17 mg/L) to downstream of the Halfway River (Peace-03; overall mean through all seasons = 75 mg/L).

Studies were also conducted on fluvial geomorphology and sediment transport for the EIS. Findings of these studies are provided in Section 11.8 Fluvial Geomorphology and Sediment Transport, and Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report.

11.5.2.5 Alkalinity and pH

Total alkalinity varies seasonally and spatially, and ranged from 27 to 458 mg/L across samples collected in the reservoirs, Peace River, and tributaries. Total alkalinity concentrations were similar in the reservoirs and Peace River, but higher in the tributaries (Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River).

In the reservoirs, median total alkalinity concentrations were 85 mg/L in spring, 81 mg/L in summer, and 77 mg/L in fall. In the Peace River, median alkalinity concentrations were 89 mg/L in spring, 85 mg/L in summer, and 82 mg/L in fall. In the tributaries, median alkalinity was 100 mg/L in spring, 152 mg/L in summer, and 152 mg/L in fall. These measured concentrations of total alkalinity in the technical study area indicate that the waters are well buffered against acid deposition. There are no Canadian guidelines for alkalinity.

Measured pH ranged from 5.8 to 8.8 across all samples, and pH in the technical study area is described as neutral to slightly basic. One of 393 measurements had values below the lower chronic aquatic life limit guideline value of 6.5 for the protection of aquatic life (Peace-04, winter).

11.5.2.6 Nutrients

Nutrients include nitrogen and phosphorus compounds that are required in small quantities for plant growth. Nitrogen in fresh waters may be present in various forms, such as ammonia, nitrate, nitrite, and organic nitrogen. Total phosphorus includes measures of particulate phosphorus, dissolved organic phosphorus, and dissolved inorganic phosphorus.

Total Kjeldahl nitrogen (TKN), which is the sum of organic nitrogen and ammonia, ranged from 0.025 to 0.51 mg/L in the reservoirs, from 0.025 to 2.5 mg/L in the Peace River, and from 0.025 to 4.3 mg/L in the tributaries. There are no Canadian guidelines for TKN, but measured concentrations of TKN provide information on nitrogen in the aquatic ecosystem.

Total ammonia ranged between 0% and 46% of TKN in the samples. Ammonia concentrations ranged from 0.0002 mg/L (Williston Reservoir) up to 0.21 mg/L (maximum level recorded at Cache Creek in the winter). Total ammonia concentrations did not exceed guidelines for the range of temperatures and pH conditions during sampling within the technical study area. The ammonia guideline is for unionized ammonia; the amount of unionized ammonia in a sample increases as pH and temperature increase. Seasonal (spring, summer, and fall) median concentrations of ammonia were similar in the Peace River (0.01 mg/L, 0.01 mg/L, and 0.0034 mg/L, respectively) and tributaries (0.01 mg/L, 0.01 mg/L, and 0.0043 mg/L, respectively), and were lower in the reservoir (0.0024 mg/L, 0.067 mg/L, and 0.0029 mg/L, respectively).

Nitrate concentrations did not exceed the chronic or acute guidelines for the protection of aquatic species, or guidelines for drinking water quality. Median concentrations of nitrate by season (spring, summer, and fall) were similar in the reservoirs (0.051 mg/L, 0.052 mg/L, and 0.051 mg/L, respectively) and the Peace River (0.05 mg/L, 0.041 mg/L, and 0.041 mg/L, respectively), but lower in the tributaries (0.026 mg/L, 0.0074 mg/L, and 0.0016 mg/L, respectively).

Concentrations of total phosphorus ranged from 0.001 mg/L to 2.3 mg/L in 307 measurements, with the maximum concentration recorded at Cache Creek. Total phosphorus is often positively correlated with TSS because the molecule adsorbs onto colloidal particles. As with TSS, there was a similar spatial trend of total phosphorus in the Peace River in spring, and less distinct spatial differences in summer and fall. Median total phosphorus across all stations on the Peace River was highest in the spring (0.069 mg/L) and lower in the summer (0.017 mg/L) and fall (0.012 mg/L). Monitoring data indicate that all tributaries contribute similar concentrations of total phosphorus to the Peace River in the spring, but the Halfway River and the Moberly River contribute higher concentrations of total phosphorus to the Peace River in summer. Variability in total phosphorus concentrations is due to weathering of materials in the watershed that are flushed downstream during high flows and biological uptake of dissolved forms during biologically active periods (summer and fall) (Volume 2 Appendix P Aquatic Productivity Reports, Part 1 Baseline Aquatic Productivity in the Upper Peace River).

11.5.2.7 Metals

Metals are naturally present in surface waters in small quantities (typically less than 1 mg/L). The level at which metals are toxic varies by metal and can be dependent on the hardness of the water.

Detailed and specialized studies were conducted on methylmercury with results provided in Section 11.9 Methylmercury and Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report. A summary of metals measured in the reservoirs, the Peace River, and the tributaries of the technical study area are summarized in this section and in Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River.

Metals with at least one value that exceeded a total metal guideline included aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc. Dissolved metal parameters with at least one value that exceeded a guideline included aluminum and iron. Aquatic life guidelines were developed to provide protection to aquatic life from anthropogenic stressors (CCME 1999), but it is recognized that aquatic ecosystems may naturally have concentrations of water quality constituents above guidelines, as based on local factors such as geology, soils, climate, and weather. In these cases, aquatic organisms have adapted to their environment, and exceedance of guidelines does not imply that the aquatic system is unhealthy. Understanding of baseline conditions prior to anthropogenic disturbances is necessary to understand the sensitivities of the aquatic environment, and to track potential future changes. Guidelines are developed and updated based on the most recent toxicological data (CCME 1999). As toxicological data are not available for all metals measured in water, not all metals have guidelines; as such, baseline data provide benchmarks for use in future studies.

Concentrations of total metals that most often exceeded guidelines included aluminum, dissolved aluminum, arsenic, cadmium, chromium, copper, iron, dissolved iron, lead, and zinc. The proportion of samples, by water body group (i.e., reservoir, Peace River, tributaries), with total metal concentrations that exceeded the lowest guideline (chronic aquatic life) are provided in Table 11.5.2. Other guidelines that were also exceeded are as follows:

- Acute aquatic life (aluminum, arsenic, chromium, copper, iron, and zinc)
- Drinking water (aluminum, arsenic, lead)
- Human health (aluminum and lead)

- Wildlife health (aluminum)

Table 11.5.2 Percent of Samples with Concentrations Above Guidelines (by Water Body Type and Metal)

Metal	Reservoirs	Peace River	Tributaries
Aluminum	76%	83%	94%
Aluminum – dissolved	5%	7%	22%
Arsenic	0%	5%	13%
Cadmium	19%	54%	67%
Chromium	6%	43%	67%
Copper	5%	34%	45%
Iron	10%	53%	82%
Iron – dissolved	0%	3%	8%
Lead	0%	11%	24%
Selenium	2%	1%	34%
Zinc	3%	15%	34%

Of all metals, total aluminum most often exceeded the guideline (in 76% of samples from the reservoirs, 83% of samples from the Peace River, and 94% of samples from the tributaries). Dissolved aluminum exceeded the guideline in less than 10% of samples (5% of samples from the reservoirs, 7% of samples from the Peace River, and 22% of samples from the tributaries. For all metals summarized in Table 11.5.2, tributaries had the highest percentage of samples with concentrations that exceeded the guidelines, while reservoirs had the lowest percentage of samples with concentrations that exceeded the guidelines.

Many of the total metals have a positive correlation to TSS, and similar trends are evident in their hydrologic distributions, with highest concentrations of metals measured in the tributaries, moderate concentrations in the Peace River, and lowest concentrations in the reservoirs. High concentrations of metals are expected during conditions of high flows and high TSS movement. TSS concentrations were highest in the tributaries, lower in the Peace River, and lowest in the reservoirs, as such highest concentrations of total metal concentrations in the tributaries is not unexpected.

For most metals, there was also a strong spatial trend, where the proportion of samples with concentrations exceeding guidelines increased with distance downstream from the Peace Canyon Dam. For many metals, concentrations were higher downstream of the Halfway River (Peace-03) as compared to downstream of the Peace Canyon Dam (Peace-01), and then higher again downstream of the Kiskatinaw River (Peace-05) as compared to upstream of the Kiskatinaw River (Peace-15). This spatial trend was most evident in the spring as compared to the summer or fall (i.e., during freshet, when weathered materials are flushed downstream). This downstream spatial trend is also not unexpected because the size of the contributing watershed increases in a downstream direction, and thus the potential contribution of metals, or other parameters, also increases in a downstream direction.

11.5.2.8 Drinking Water Sources

Public drinking water sources within the technical study area have been reviewed and are discussed in detail in Volume 4 Section 30 Community Infrastructure and Services. Communities and drinking water sources in the technical study area are summarized in Table 11.5.3. There are also 48 registered and seven non-registered drinking water wells within a 2 km distance from the proposed reservoir (Volume 2 Appendix F Groundwater Regime Technical Data Report).

Table 11.5.3 List of Communities and Water Sources in the Technical Study Area

Community	Water Source
Fort St. John	Groundwater (formerly Charlie Lake) Peace River (future expansion)
Taylor	Shallow wells in the Peace River (near the confluence of Pine and Peace Rivers)
Hudson's Hope	Peace River

NOTE:
See Volume 4 Section 30 Community Infrastructure and Services for more information on community drinking water sources

11.5.3 Baseline Conditions Sediment Quality

Baseline sediment quality conditions were determined by completing a review of data collected through field programs in support of the Project. Sediment quality field data were collected in the technical study area in 2007, at stations established for the Project. Sediment data were not available for B.C. from government agencies.

The technical study area for sediment quality is the same as the technical study area for water quality. The technical study area extends from the forebay of the Williston Reservoir, the Dinosaur Reservoir, and the Peace River valley to the confluence with the Alces River, including major tributaries (Cache Creek, Halfway River, Moberly River, Pine River, Beatton River) (Figure 11.5.1).

Thirteen samples were collected in 2007 for sediment quality analysis from stations on the Peace River, Moberly River, and Halfway River. Depositional areas were targeted for sampling. Sediment composition was classified as sandy. Arsenic exceeded the ISQG in all samples except from one station on the Peace River upstream of the Halfway River. Cadmium exceeded the ISQG in three samples (Peace-02, Peace-03, and Halfway River). In all other samples, cadmium was less than the ISQG. No other metals had concentrations above the ISQG, and no metals had concentrations above the PEL.

A review of metal data in the sediments does not show a strong spatial trend with increasing concentrations in a downstream direction. Concentrations of polycyclic aromatic hydrocarbons did not exceed the PEL. Concentrations of 2-methylnaphthalene were above ISQG guidelines in 10 samples, concentrations of naphthalene were above ISQG guidelines in four samples, and concentrations of phenanthrene were above ISQG guidelines in seven samples. Concentrations were not above the PEL values.

11.6 Groundwater Regime

11.6.1 Introduction

The following subsections describe the groundwater regime in terms of both baseline conditions and potential changes as a result of the reservoir creation. A detailed description of the groundwater regime is presented in Volume 2 Appendix F Groundwater Regime Technical Data Report. Additional information on the groundwater regime can be found in Volume 2 Appendix B Geology, Terrain Stability, and Soil Reports, Part 1 Terrain Stability Mapping, Part 2 Preliminary Reservoir Impact Lines, and Part 3 Contaminated Sites Report.

The component of the Project that would influence the groundwater regime is the reservoir. Reservoir creation would cause the groundwater table to rise in certain areas inland from the reservoir shoreline. The distance inland and the amount of groundwater table rise depends on the geology, the groundwater levels, and the amount of rise in the surface water from the creation of the reservoir. An understanding of the groundwater flow regime and of potential changes to the groundwater flow caused by the creation of the reservoir were used in the evaluation of potential effects of the Project on agriculture (Volume 3 Section 20 Agriculture), on groundwater use, and on underground infrastructure such as municipal water systems (Volume 4 Section 30 Community Infrastructure and Services).

An evaluation of project construction on groundwater quality indicated that there is a low likelihood that groundwater chemistry would undergo change and affect groundwater use.

11.6.2 Technical Study Area

The technical study area for the groundwater regime study is from Peace Canyon Dam to the Site C dam. This can be defined as the region to be covered by the reservoir (i.e., the area to be flooded), including the tributary valleys that would be inundated by the reservoir. Areas adjacent to the reservoir that would undergo influence on physical groundwater flow as a result of the creation of the reservoir have also been included within the technical study area (see Figure 11.6.1).

11.6.3 Regulatory and Policy Setting

Groundwater in B.C. is regulated under the B.C. *Water Act,* the B.C. Ground Water Protection Regulation, the B.C. *Environmental Management Act*, and the B.C. Contaminated Sites Regulation.

The B.C. Water Quality Guidelines (B.C. Ministry of Environment 2006, 2010) are not directly applicable to assessing groundwater quality, as the guidelines were developed for protecting surface water quality. However, the groundwater analytical results were screened against the guidelines to evaluate whether or not the groundwater contains naturally occurring constituents that, upon discharge to surface water, may influence surface water quality.

The B.C. Contaminated Sites Regulation (B.C. Ministry of Environment 2011) provides standards to determine if concentrations of substances in groundwater are acceptable for the water uses (e.g., drinking water, aquatic life) present at a site. In addition to the chemical contaminants listed in the Contaminated Sites Regulation, the Guidelines for Canadian Drinking Water Quality: Summary Table (Health Canada 2012) provides guidelines to address microbiological and radiological contaminants as well as physical characteristics that could affect taste and odour.

11.6.4 Approach and Methods

The groundwater regime, terrain stability, and preliminary impact line studies were informed by the same data, and the three studies provide information on baseline conditions and on potential changes to groundwater elevations as a result of reservoir creation. The specific approach and methodology associated with the data collection and analytical approach is described in detail in the following sections of the EIS:

- Volume 2 Section 11.2 Geology, Terrain, and Soils
- Volume 2 Section 11.2.3.5 Groundwater Flow
- Volume 2 Appendix B Geology, Terrain Stability, and Soil
    - Part 1 Terrain Stability Mapping
    - Part 2 Preliminary Reservoir Impact Lines
- Volume 2 Appendix F Groundwater Regime Technical Data Report

The description below provides a summary of the tasks completed to define the baseline (i.e., prior to creation of the reservoir) and to predict future potential changes to the groundwater regime (flow and quality).

11.6.4.1 Review of data sources

Geology

The following geological studies in the technical study area were reviewed:

- Investigations of bedrock and overburden materials by Irish (1958), Mathews (1978), Stott (1982), Cornish and Moore (1985), Hartman (2005), and Hartman and Claque (2008)
- A surficial map of the area by Hickins and Fournier (2011)
- Extensive surface and subsurface investigations associated with the proposed Site C dam, completed by Thurber Consultants Ltd. (1978) and BC Hydro (1981)
- Engineering geology work documented by Imrie (1991), Bidwell (1999), and Klohn Crippen Berger Ltd. and SNC-Lavalin (2009)
- Recent detailed surface mapping and drilling completed by BGC (BGC 2012)

Information on geology, terrain, and soils in the technical study area can be found in Volume 2 Section 11.2 Geology, Terrain, and Soils.

Groundwater Elevations, Seepage Locations, and Springs

Groundwater elevation, seepage data and project-specific historical geotechnical data were reviewed. Additional geotechnical surface mapping was conducted in 2010 and

2011 (BGC 2012). Forty-five new drill holes were completed and piezometers installed and instrumented for groundwater seepage, slope stability, and groundwater quality analysis. Groundwater level data were obtained from these locations, and hydraulic conductivity tests were performed to gain an understanding of the local groundwater regime (BGC 2012). The surface mapping, drilling, water level, and hydraulic conductivity data were analyzed and used to construct representative geological cross-sections for two-dimensional seepage analysis. They were also used to predict groundwater levels and the occurrence of potential seepage locations and springs, and to support slope stability modelling work.

Drinking Water

A regional water well search was conducted using the Ministry of Environment online water well registry databases, to assist in identifying water wells within a 2 km lateral distance from the proposed reservoir. In addition, a mail-in survey was sent to property owners within the site area in April 2011 in an effort to identify additional “non-registered” water wells in the region. The results of this work identified 48 registered and seven non-registered drinking water wells within a 2 km lateral distance from the proposed reservoir.

Infrastructure and Land Use

Infrastructure and land use information was obtained from various sources, including:

- Historical aerial photographs, orthophotos, and satellite imagery
- Utility and service maps
- Ministry of the Environment databases containing information pertinent to water well licences, permits, and site registry listings
- Municipal water and wastewater coverage information obtained from the District of Hope and the Peace River Regional District
- Terrestrial ecosystem mapping data

Assessment of Contaminated Sites

Findings from the potential contaminated sites study within the project region were reviewed (see Volume 2 Appendix B Geology, Terrain Stability, and Soil Reports, Part 3 Contaminated Sites Report).

11.6.4.2 Field Study

Piezometer Installation

A total of 63 standpipe piezometers and two vibrating wire piezometers were installed in existing boreholes in 2011. The locations of the piezometers are shown in Volume 2 Appendix F Groundwater Regime Technical Data Report. Piezometers were installed with depths ranging from 7 m to 145 m below ground. Prior to the commencement of piezometer installation, drill holes were flushed with water to remove remaining drilling cuttings and residual drilling fluid.

Groundwater Monitoring and Sampling

Current groundwater conditions within the proposed inundation area were evaluated through records of seepage during surface inspections, measuring water levels in the installed standpipe piezometers by using dip meters, and estimating hydraulic conductivity through packer and slug testing. Level recorders were installed in 10 piezometers in the south bank drill holes in October 2011. Level recorders were installed in drill holes on the north bank in March 2012.

Piezometer Sampling

Baseline groundwater quality was evaluated through monitoring and sampling of 15 piezometers and associated nested piezometers within various lithologies to establish the baseline groundwater chemistry. Samples were collected in August 2012. A total of 21 samples were analyzed for the following parameters:

- Dissolved metals
- Dissolved anions
- Speciated alkalinity
- Total dissolved solids (TDS)
- Total suspended solids (TSS)
- Dissolved organic carbon (DOC)

Results were compared to the B.C. Water Quality guidelines (B.C. Ministry of Environment 2006, 2010).

Drinking Water Well Sampling

Baseline groundwater quality was also evaluated through drinking water well sampling. Samples were collected from five drinking water wells in July 2012. The samples were analyzed for the following parameters:

- Alkalinity
- Colour
- Hardness
- pH
- Total dissolved solids (TDS)
- Turbidity
- Chloride
- Fluoride
- Nitrate
- Nitrite
- Sulphate
- Dissolved Metals

- Total Metals
- Coliforms

Results were compared to the Guidelines for Canadian Drinking Water Quality (Health Canada 2012) and the B.C. Contaminated Sites Regulation (B.C. Ministry of Environment 2011).

11.6.4.3 Flow Models

Twenty-five geologic cross-sections were created for both the low bank and high bank slopes along the proposed reservoir, using new and historical data along with surface LiDAR topography. Each cross-section is 600 m to 2,000 m long, generally perpendicular to the Peace River. These geologic cross-sections were combined with hydraulic conductivity testing results and a review of historical data and regional literature to develop a conceptual hydrogeological model for the river valley (BGC 2012).

The conceptual hydrogeological model was used to develop a series of cross-sectional numerical groundwater flow models, aligned with the geological cross-sections. Each cross-section was imported into SEEP/W (GeoStudio 2007, Version 7.17), an industry standard two-dimensional finite element groundwater seepage analysis software developed by GEOSLOPE International Ltd. The resulting 25 seepage models were calibrated against field-observed water level and hydraulic conductivity test data. The water table and pore water pressure results were used for stability analysis as well as in the evaluation of changes to groundwater levels due to inundation of the proposed reservoir.

11.6.4.4 Analysis

Groundwater level changes due to the proposed reservoir were predicted along 25 cross-sections, using SEEP/W. Changes to the water table elevation (i.e., head increase) and subsurface pore pressures were evaluated along each simulated cross-section. The specific predictions along the cross-sections were used to estimate groundwater level and pore pressure impacts at other locations along the reservoir.

To determine the likelihood that reservoir formation (i.e., water table rise) could influence groundwater quality due to the presence of the potentially contaminated sites, the locations of these properties were cross-referenced with the predicted rise in water table at set transects/cross-sections located along the reservoir. In situations where the predicted water table elevation increased by greater than 1 m (within model accuracy) beneath the contaminated site, it was considered possible that the groundwater quality could be influenced by potentially contaminated soils existing immediately beneath the property. This 1 m rule was not applied at properties where a perched aquifer is present, as the perched aquifer would be at a relatively higher elevation and not in communication with the regional water table and therefore not influenced by the reservoir formation.

Determination of the influence on groundwater chemistry due to water table rise into new geologic materials was analyzed by similar methods. The geologic cross-sections used for model construction and model-predicted flow were viewed to see where the water table rise would result in groundwater coming into contact with new geologic materials. Areas where the predicted water table rise would occur within new geologic materials and those geologic materials were unsaturated (i.e., no perched water tables within them) were considered potential regions where the groundwater chemistry could be influenced.

11.6.5 Results

11.6.5.1 Baseline Conditions

The groundwater regime within the slopes adjacent to the proposed reservoir typically consists of water tables perched on lower permeability silt and clay or bedrock units, with the sandier interbeds providing drainage to the slope face, resulting in groundwater exiting as springs. Further description of the baseline groundwater flow regime is provided in Volume 2 Section 11.2 Geology, Terrain, and Soils, Section 11.2.3.5 Groundwater Flow.

Baseline drinking water and groundwater monitoring indicated the presence of parameters in excess of guidelines/criteria. Specifically, samples collected from accessible drinking water wells in the Technical Study Area were found to be in exceedance of the Guidelines for Canadian Drinking Water Quality for various parameters (pH, total dissolved solids, barium, iron, manganese, and sodium). One drinking water sample exceeded the B.C. Contaminated Sites Regulation standard for sodium. Coliforms were also present in three of the five wells. The results of the drinking water well monitoring program are presented in Table 4-4: Drinking Water Analytical Results, found in Volume 2 Appendix F Groundwater Regime Technical Data Report.

Each of the 21 analyzed samples collected from the piezometer sampling program exhibited alkalinity and/or concentrations of at least one of the analyzed metals greater than the B.C. Water Quality Guidelines. The results of the piezometer monitoring program are presented in Table 4-3: Groundwater Analytical Results – Piezometers, found in Volume 2 Appendix F Groundwater Regime Technical Data Report.

The groundwater geochemistry within the piezometers varied, based on spatial location within the technical study area as well as geologic unit sampled. This variation is anticipated, as the groundwater chemistry reflects the mineralogy of the different lithologic units over which the piezometers were screened.

No anthropogenic sources for the non-coliform exceedances were apparent, and therefore the exceedances may be natural background concentrations.

11.6.5.2 Groundwater Regime Predictions

On a reservoir-wide scale, the smallest predicted changes in groundwater levels occur upstream, where the reservoir would have little effect on surface water levels, while the largest changes would occur closer to the Site C dam site, where the reservoir water level would increase by up to 50 m compared to the current Peace River water level. The stratified bedrock and overburden sediments near the reservoir edge would limit changes in groundwater levels within the overburden, due to reservoir formation. The results show that changes in groundwater level do occur, due to reservoir level rise in some of the modelled reservoir cross-section locations. The predicted increases in the deeper groundwater elevations in the valley slopes at the proposed reservoir shoreline range from 1.6 m to 14 m. Groundwater level increases of up to 6 m are predicted at distances up to 1,600 m from the reservoir shoreline in one cross-section containing a local buried valley. For the majority of sections analyzed, the predicted increase in groundwater level is less than 3 m at a distance of 1,600 m from the proposed shoreline.

A series of two-dimensional cross-sections at representative reservoir locations where reservoir filling could affect slope stability, land, or resource use are shown in Volume 2 Appendix F Groundwater Regime Technical Data Report, Appendix B Figures 1 to 21. In the cross-sections, subsurface geology, aquifers, and water table positions are shown for the baseline conditions and estimated for reservoir conditions.

The locations of existing water wells, springs, infrastructure, and land use that could be affected by changes are shown in Volume 2 Appendix F Groundwater Regime Technical Data Report, Figures 8 to 24, and are described in the section below. In accordance with page 3 of Section 1.2 of the EIS Guidelines, information about the locations of potentially contaminated sites has not been provided.

11.6.6 Potential Implications of Groundwater Regime Changes

Future potential changes to groundwater quality are directly linked to the amount of rise in the water table. If the water table elevation increases beneath a site, causing the groundwater to come into contact with contaminated soils (if present), groundwater quality may be locally influenced. Results of the predictive modelling indicate that only five properties with potentially contaminated sites may experience a sufficient (i.e., in the order of several metres above baseline conditions) water table rise to influence groundwater quality. The limited number is in part attributable to the fact that these potential contaminated properties are primarily located either in Hudson’s Hope or Fort St. John. Generally, reservoir levels and therefore groundwater levels are expected to increase the most in the vicinity of the dam site and increase the least furthest upstream (Hudson’s Hope area). Fort St. John is located well above the proposed reservoir level, and Hudson’s Hope is furthest upstream on the proposed reservoir. In addition to potential changes to groundwater quality, direct inundation of these sites may also influence surface water quality. In accordance with page 3 of Section 1.2 of the EIS Guidelines, information about the locations of potentially contaminated sites has not been provided.

There are also agricultural lands within the proposed reservoir area. Upon reservoir formation, these properties would experience full or partial inundation and water table rises, which may influence both groundwater and surface water quality if pesticides, herbicides, or fertilizers were used and are present in soil or groundwater. The potential for pesticides, herbicides, or fertilizers to be present in soil and groundwater is dependent on many factors (e.g. chemical content, rates of application, absorption, solubility, persistence, soil type, etc.). Management of these lands is discussed in Section 11.6.9.

When an increase in groundwater table elevation occurs and results in the groundwater coming into contact with new geologic materials (e.g., soil/rock types) of different composition, the groundwater chemistry may be influenced. Based on the predicted water table rise in the technical study area, there is a low likelihood that groundwater chemistry would change as a result of groundwater coming into contact with new geologic materials. Some localized influence on groundwater chemistry may occur in areas where the water table rises into thin units (if present) that differ in physical characteristics and chemical composition.

11.6.7 Groundwater Use

Many of the existing water wells would experience some degree of influence. Of the approximately 55 known/identified water wells along the reservoir, six are expected to undergo direct submersion (i.e., reservoir would submerge the wells). The remaining wells are anticipated to experience a relative increase in the water level in the well ranging from less than 1 m to 10 m, depending on their relative location along the reservoir and distance away from the reservoir edge. The increase in water level is not anticipated to influence the quality of the groundwater within the well or influence operation but may, in fact, result in greater well yield due to increasing the amount of water in the well. However, groundwater quality could become influenced in situations where either a flooded septic field or a contaminated site with impacted groundwater is located in close proximity to an operating water well. General regions where this may occur are adjacent to the proposed reservoir in the Hudson's Hope, Lynx Creek, and Farrell Creek areas.

11.6.8 Infrastructure and Land Use

Groundwater-related influence on infrastructure (e.g., building foundations and septic fields) is anticipated in regions where these structures are located in close proximity to the future reservoir. As the majority (approximately 90%) of the lands containing infrastructure are located topographically above the proposed reservoir levels, only limited inundation or influence related to water table rise is anticipated. These include single residential properties containing buildings and likely septic fields.

Groundwater-related influence on agricultural land use may occur in areas where the water table is anticipated to rise within 1 m of ground surface. Agricultural properties located in low terraces and banks near the proposed reservoir may experience reduced agricultural capacity. However, the majority of the cultivated lands within the technical study area are located topographically above the proposed reservoir levels by more than a metre, and therefore only limited inundation or influence related to water table rise is anticipated. These areas are primarily limited to low bank areas in the vicinity of the creeks (e.g. Lynx Creek, Dry Creek, Farrell Creek, south bank of KM 49-62 (BC Hydro River Kilometre markings, measured downstream from Bennett Dam along the main channel of Peace River), Halfway River, Cache Creek, Wilder Creek) and the Peace River. Loss of agricultural land may extend from the reservoir's edge to directly adjacent land as a result of an increase in groundwater elevation in the underlying soils.

11.6.9 Management of Potential Implications

Prior to reservoir filling, building infrastructure, groundwater wells, and septic tanks/fields at properties within the proposed inundation area would be decommissioned to reduce the potential for affecting groundwater quality for existing water well users.

Prior to reservoir inundation, further investigation and, as warranted, site remediation, would be conducted on potentially contaminated properties and on properties where residual pesticides and herbicides may be present at concentrations of concern.

11.6.10 Conclusions

The following conclusions are formulated based on the results of this study:

- Perched conditions and dry monitoring wells are common in the overburden hydrostratigraphic units below the plateau and in the valley slopes. Bedrock hydraulic conductivities are low and impede groundwater seepage. Where the bedrock contact is above the Peace River elevation, the water table generally occurs in the overburden near the top of the bedrock.
- Baseline (prior to creation of the reservoir) groundwater monitoring indicates the presence of parameters in excess of B.C. Water Quality Guidelines and the Contaminated Sites Regulation standards for the protection of drinking water and aquatic life. Exceedances of the Guidelines for Canadian Drinking Water Quality were also observed.
- Predicted groundwater level changes are influenced by the local geology, current groundwater conditions, distance from the proposed reservoir shoreline, and topography
- The stratified bedrock and overburden sediments near the reservoir edge would limit changes in groundwater levels within the overburden due to reservoir formation. Around most of the proposed reservoir, this results in a low potential for the proposed reservoir to influence groundwater flow in the overburden sediments above the operating reservoir elevation of 461.8 m (maximum normal reservoir level).
- Predicted increases in the deeper groundwater elevations at the proposed reservoir shoreline range from 1.6 m to 14 m. The largest predicted changes occurred within the glacially carved bedrock depression in the Hudson's Hope to Farrell Creek stretch of the Peace River, and between Halfway River and Cache Creek. At a distance of 1,600 m from the proposed shoreline for the majority of sections analyzed, the predicted increase in groundwater level is generally less than 3 m.
- Five out of 40 of the identified potentially contaminated sites properties may experience adequate water table rise to potentially influence groundwater quality
- There is a low likelihood that groundwater chemistry would undergo change affecting groundwater use as a result of it coming into contact with new geologic materials. Some localized influence on groundwater chemistry may occur in areas where the water table rises into thin interbedded units (if present) that differ in physical characteristics and chemical composition.
- Six out of 55 known water wells would likely undergo direct inundation during reservoir infilling. A rise in the height of the water table ranging from <1 m to 10 m is anticipated for the remaining known wells. The rise in the water levels is expected to result in increased well yield.
- The majority (approximately 90%) of the lands within the technical study area containing infrastructure or designated within the Agricultural Land Reserve are located topographically above the proposed reservoir levels. Inundation or influence related to water table rise would only be anticipated below the maximum proposed reservoir levels and in directly adjacent areas where groundwater elevation may

affect crop growth (i.e., at locations where groundwater is anticipated to rise within 1 m of ground surface).

- Contaminated Site and Groundwater Quality Management Plans would be developed prior to construction to mitigate potential influences from potentially contaminated sites and septic systems

11.7 Thermal and Ice Regime

The section summarizes more detailed analyses presented in Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report, Volume 2 Appendix G Downstream Ice Regime Technical Data Report, and Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River (namely, water temperature analysis). Three technical study areas are outlined for these analyses. The technical study area for the reservoir water temperature and ice regime was the Site C reservoir (between the Peace Canyon Dam and the Site C dam) at the maximum normal operating level. For the downstream ice regime study, the technical study area extended from the Peace Canyon Dam (for the scenario without the Project) or the Site C Dam (for the scenario with the Project) to Fort Vermillion, AB, approximately 726 km downstream. This location was selected as the downstream boundary as this is usually the first location at which the ice front location is recorded in each ice season. Also, previous modelling results indicated that this location is well downstream of where changes to the ice regime would occur as a result of the Project. Finally, changes to water temperature downstream of the Site C dam were analysed as part of the water quality study, the boundaries of which extended from the forebay of the Williston Reservoir to upstream of the confluence with the Alces River.

11.7.1 Baseline Conditions

The geography of the Peace River is shown in Figure 11.7.1, along with a number of locations relevant to the thermal and ice regime. The Peace River flows eastward from the W.A.C. Bennett and Peace Canyon dams for about 400 km towards the Town of Peace River, Alberta, where the river turns north. Approximately 300 km downstream of the Town of Peace River is Tompkins Landing, a ferry crossing near High Level. From there, the river turns east and flows for another 550 km, passing through the town of Fort Vermilion and the community of Peace Point, before joining with a number of tributaries to form the Slave River, which eventually flows into Great Slave Lake in the Northwest Territories.

The following sections describe the baseline thermal and ice conditions in the Peace River.

11.7.1.1 Baseline Thermal Regime

The Peace River is regulated by the W.A.C. Bennett Dam, which impounds Williston Reservoir, and to a lesser extent by the Peace Canyon Dam, which impounds Dinosaur Reservoir. The hydrologic characteristics of the Peace River, its tributaries, and variations in flow due to regulation are described in Volume 2 Section 11.4 Surface Water Regime. The baseline thermal and ice conditions in the Peace River include the influence of existing reservoirs and regulated discharges. The primary consequences of regulation are the storage of water in Williston Reservoir and the release of that water throughout the year, resulting in a different seasonal pattern of flows than the pre-regulation period. This storage of water can also be considered a reservoir of thermal energy. In the winter, relatively warm water exits Williston Reservoir and gradually loses heat to the cold ambient air as it moves downstream through Dinosaur Reservoir and then the Peace River. At some point, this water cools to a point where ice starts to form. Similarly, in summer, water that is relatively cool leaving the reservoir is warmed by solar energy and heat transferred from the ambient air as it travels downstream.

For the characterization of the baseline thermal regime, water temperature data were collected at three locations in Dinosaur Reservoir, at five locations in the Peace River, and at eight tributaries between 2007 and 2010 (Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River). The monitoring stations discussed in this section are shown in Figure 11.7.1. Temperature was recorded hourly by BC Hydro in the tailrace (outlet) of Peace Canyon Dam from 1999 to 2012, and in the tailraces of the W.A.C. Bennett Dam from 2009 to 2012. Hourly records of the existing Peace River temperatures near Old Fort, 6.5 km downstream of the proposed Site C dam, were available from the Water Survey of Canada hydrometric station 07FA004 (Peace Above Pine) from 2007 to 2012. Hourly records of the existing Peace River temperatures at the Alces River confluence, 4.3 km upstream of the B.C.–Alberta border, were available from 2007 to 2008 at the Peace 5 station.

Hourly temperature time series data collected at locations downstream of the proposed Site C dam (i.e., the Peace Above Pine Water Survey of Canada hydrometric station and the Peace 5 station) are useful for comparison with predicted water temperatures with the Project to characterize changes due to the Project. Upstream of the Site C dam, there would be a different thermal regime than today, as the existing river would be transformed to a deep reservoir. The expected thermal regime in the Site C reservoir is described separately from the Peace River thermal regime in Section 11.7.3.3.

Daily average temperatures at the Peace Canyon Dam, Peace Above Pine, and Peace 5 stations are presented in Figure 11.7.2. The periods of record for the Peace 5 and Peace Above Pine temperature data overlap for one year, 2008, and this period is used to characterize the existing thermal regime. The following is a discussion of the existing thermal regime of the Peace River, with an explanation of how the existing reservoirs influence water temperature downstream.

Williston Reservoir has a large volume of water, and water temperature changes are slow, compared to a river. This leads to cooler outlet water temperatures in the spring and warmer outlet water temperatures in the fall than would be expected without Williston Reservoir. Due to small volume and the short flow-through times of the Dinosaur Reservoir, it has little influence on temperatures when compared to the influence of Williston Reservoir. Close to the Peace Canyon Dam, water temperatures in the Peace River are determined by the temperatures in the upstream reservoir. As water moves downstream, its temperature is influenced by air temperature and local meteorological conditions. For example, temperatures observed in the Peace Canyon tailrace peak an average of 40 days later than river temperatures 89 km downstream at the Peace Above Pine station, based on four years of data. Temperatures a further 51 km downstream at Peace 5 peak at the same time as Peace Above Pine, based on one year of overlapping data. The maximum summer temperatures at Peace Above Pine are between 5 and 6°C warmer than at Peace Canyon Dam, while the temperatures at the Peace 5 station are up to 9.5°C warmer than at the outlet of Peace Canyon Dam. This pattern is reversed in winter, with water at Peace 5 cooling earlier than at Peace Above Pine, and the greatest temperature decreases are near 2°C at Peace Above Pine and 3°C at Peace 5.

11.7.1.2 Baseline Ice Regime

This section describes ice formation processes and terminology as well as the observed ice conditions in the Peace River. Water at the outlet of the Peace Canyon Dam never freezes, nor does the immediate downstream reach of the Peace River. As discussed above in Section 11.7.1.1, during winter, water cools as it flows down the Peace River due to its exposure to cooler air temperatures. The point at which the water temperature reaches 0°C, allowing ice formation to begin, is referred to as the zero-degree isotherm.

Near this zero-degree isotherm, suspended frazil ice, or small ice crystals, starts to form throughout the water column. The frazil ice eventually sticks together and floats to the water surface as its buoyancy overcomes the river's turbulence. After the frazil ice rises to the water surface, it forms frazil pans or circular ice floes of a few metres in diameter. These pans continue to travel downstream, growing in number and extent, and can join together to form frazil rafts. The pans also start to solidify and thicken, forming a hard-frozen crust on the top, while more 'slushy' frazil ice rises to the surface and deposits on the underside of the ice pans or ice cover.

On the Peace River, the frazil pans can have solid ice crusts that range from a few centimetres thick up to 20 to 30 cm. Total ice pan thickness, which includes the frozen crust underlain by porous slush, can be 30 cm to 1 m thick. The solid ice that forms the top of these floes is referred to as thermal ice.

Initially, frazil ice forms, remains suspended in the water, and flows downstream along with the river. Downstream of the zero-degree isotherm, stationary border ice, which is attached to the shore of the river, also starts to grow. This border ice forms in low velocity areas close to shore, in back channels and around gravel bars. Border ice reduces the channel width, and at some point frazil pans or rafts jam, and solid ice covers the entire width of the river. Once ice cover starts developing, frazil pans or rafts accumulate at the upstream leading edge of the ice cover and the location of this stoppage point advances upstream. The initial stoppage point is known as lodgement, and the leading ice edge is also referred to as an ice front.

Since 1973, observations of the locations of the ice front in the Peace River have been collected annually by Alberta Environment and BC Hydro (Figure 11.7.3). When plotted as an overlapping time series, the ice front locations with respect to the W.A.C. Bennett Dam provide a concise representation of the timing of freeze-up and breakup and the duration of the ice cover each year at any location along the river. The colours of the lines in this Figure represent the degree-days of freezing of the winter, a measure of the severity of the winter in terms of air temperatures. Degree-days of freezing is calculated as the cumulative total of daily average below freezing air temperatures. The modelled winters cover the range of observed ice conditions in the Peace River.

As the ice front advances upstream, water levels typically rise by between 1 m and 5 m due to the increased resistance and thickness of the ice cover. It is important to note that this increase in water level is not attributable to any change in the flow releases from upstream dams during the ice cover formation period. Peak winter water levels are generally higher than the summer peak water levels, but below bank-full levels.

How much the water level increases as a result of the ice cover formation depends on whether the ice cover is juxtaposed or consolidated. With a juxtaposed ice cover, the ice floes initially arrive at the ice front and gently come to rest edge to edge, without overturning, to form an ice cover that consists of ice pans that are a single layer thick. This can cause the river stage, or water level, to increase approximately 1 m to 2 m. A photograph of a juxtaposed ice cover on the Peace River is shown in Figure 11.7.4.

In certain reaches of the river, the juxtaposed ice cover can collapse and consolidate. As the ice pans build up for tens of kilometres, compressive forces from water drag on the ice cover and the river slope can cause the juxtaposed ice cover to collapse. The ice pans then overturn on each other and can thicken the ice cover from less than a metre to several metres thick in just a few minutes. A photograph of a consolidated ice cover on the Peace River is shown in Figure 11.7.4. This process typically occurs every few hours as the ice front is advancing, and is generally limited to the first 2 km to 5 km of ice cover downstream of the ice front. These types of collapses are termed primary consolidations and produce a relatively uniform, thick ice cover over many kilometres of channel length. The thickened ice cover provides a greater contact area between the channel banks and the ice mass, thereby transferring the downstream forces on the ice cover laterally to the banks rather than to ice downstream, strengthening the ice against further collapse. A consolidated ice cover can cause the river stage, or water level, to increase approximately 3 m to 5 m.

A secondary consolidation can also occur, especially during freeze-thaw cycles. For example, an ice cover can advance through the process of juxtaposition up to 100 km upstream over several days. The entire 100 km length can then suddenly consolidate, and due to the buildup of momentum, the collapse can extend downstream of the newly formed ice into a previously consolidated ice cover, increasing water levels another 1 m to 4 m above the 3 m to 5 m already associated with the initial consolidation event. These secondary consolidations can be triggered by a warming in the weather after a cold spell.

River stage, or water level, can also gradually decrease over time due to ice transport processes. Once freeze-up occurs at a specific location, the frazil slush underneath the cover is eroded from fast-moving areas and deposited in slower-moving areas. This process increases the channel conveyance capacity and causes the river level to gradually decrease after freeze-up even if discharges remain constant or increase. Water levels can slowly decrease by 0.5 m to 1.5 m over several months due to this mechanism. This phenomenon allows for increasing generation and outflows from the BC Hydro hydroelectric facilities later in the winter once the ice cover has sufficiently solidified.

The thermal and ice regime in the Peace River has been simulated by BC Hydro using the Comprehensive River Ice Simulation System Program (CRISSP) model to aid in managing the risk of ice-related flooding downstream. CRISSP is a comprehensive state-of-the-art ice simulation model that is able to simulate river ice processes and associated flow conditions. The ice processes include water temperature; the concentration of suspended and surface ice; ice cover formation, progression, and consolidation; undercover transport and accumulation; ice jam evolution; thermal growth and decay of the ice cover, including the influence of a snow cover; cover stability; initiation of breakup; breakup ice runs; and jam formation. The reliability and uncertainty of CRISSP and other models are discussed in Section 11.7.3.2 below.

11.7.1.3 Timing of Ice Formation and Breakup

The location of ice lodgement, the point that initiates the ice front, on the Peace River is not well known because the initial formation of the ice cover has proven difficult to observe. However, it is thought to form either somewhere in the slower and milder-sloped reaches between Tompkins Landing (km 694) and the Vermilion Chutes (km 912) or farther downstream in the Peace-Athabasca Delta reach. (Note that, in this section, locations on the Peace River are referenced based on river chainage, which is indicated as the distance in kilometres downstream of the W.A.C. Bennett Dam.) It is also possible that multiple lodgement sites occur, and since systematic observations of freeze-up in these reaches have not been made, it is not known exactly how and where the ice cover begins. This lack of observational data is not problematic for this study, as lodgement in the model was set each year to correspond with the observed date at which the ice front arrived at the downstream end of the model (near Fort Vermilion).

Once lodgement occurs, the leading edge of the ice cover (or ice front) continues to advance upstream. Depending on the severity of the winter, freeze-up at Fort Vermilion can occur anytime between mid-November and late December. At the Town of Peace River, it can occur anywhere from early December to late February. Figure 11.7.3 shows the observed ice front location during the winters of 1973–1974 to 2010–2011. The start of the ice front line does not indicate the lodgement locations, but rather the first observation at Fort Vermilion. The lines move upstream (down the vertical axis) with time until they reach the maximum ice front extent, and then retreat downstream (up the vertical axis) as the ice cover breaks up.

After freeze-up at the Town of Peace River, historically between late December and late February, the ice cover continues to advance farther upstream and generally reaches its maximum upstream extent sometime in March. The post-regulation historical range of its maximum extent is from just downstream of Dunvegan (km 300) in warm years to around the proposed Site C dam site (km 105) in cold years. However, the winter of 2011–2012 was the warmest on record, and the ice front advanced upstream only as far Shaftesbury Crossing (km 368), about 27 km upstream of the Town of Peace River. There have been no extreme cold winters in the last 15 years, and as a result, the ice front has not advanced upstream of Taylor (km 123) since 1997.

With the onset of warming temperatures, longer days, and increased solar radiation in March, the ice front starts receding downstream. It has historically passed through the Town of Peace River anywhere from late March to late April. In most years, the breakup at the Town of Peace River is relatively benign, with the ice cover melting in place, resulting in little or no increase in water level. This is known as a thermal breakup. In some years, discharges in the river at breakup can increase dramatically as a result of snowmelt runoff from the prairies. A major source of this runoff is the Smoky River, which enters the Peace River just 6 km upstream of the Town of Peace River. This runoff can cause a dynamic breakup that can lead to the formation of ice jams and potentially flooding. Three conditions must be met before a breakup ice event at the Town of Peace River becomes a potential threat:

- The ice front on the Peace River is located upstream of the Town of Peace River
- The snow pack in the lower elevation (prairie portion) of the Smoky River Basin is above normal

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- There is a rapid and sustained warming in the weather

A historical and statistical analysis of breakups from 1971 to 1999 indicated that dynamic breakups can threaten the Town of Peace River with flooding in about 30% of the years; in 70% of the years, the breakup was determined to be a benign thermal event (Andres 2002). A dynamic breakup at the Town of Peace River has typically occurred sometime in the first three weeks of April. The timing of a thermal breakup at the Town of Peace River can range from mid-March to late April.

The ice front has reached the Site C dam location twice in the past 17 years (Figure 11.7.3); the Peace River in the reservoir area has otherwise been ice cover-free under current conditions, with short episodes of flowing frazil ice pans during cold spells almost every winter.

11.7.2 Thermal and Ice Regime During Construction

The thermal and ice regime in the Peace River during existing conditions were simulated using the CRISSP model, and these results were used to predict the regime during construction of the Site C dam.

Construction of the Site C dam would occur in two stages. Stage 1 (channelization) consists of restricting the channel, and Stage 2 (diversion) consists of diverting the flow through tunnels in order to isolate the area where the earthfill dam would be constructed across the Peace River. Stage 1 would constrict the river to a width of 220 m within the deeper main portion of the channel. In Stage 2 of construction, the river would be diverted through two diversion tunnels approximately 10 m in diameter and 700 to 800 m in length.

11.7.2.1 Construction Stage 1 – Approach and Expected Changes

The Stage 1 channelization is expected to last through two or three winters. CRISSP simulations of the existing Peace River were used to predict ice conditions at the construction site. An analysis of hydraulics during Stage 1 using the River2D model (described in Section 11.4 Surface Water Regime) indicates that the river would move quickly enough through the construction areas that ice would not lodge at the Stage 1 constriction. Therefore, the amount of ice passing this reach would not differ from the existing conditions. The increase in residence time upstream of the Stage 1 constriction would be negligible, so the hydraulic or thermal heat exchange would be similarly negligible.

11.7.2.2 Construction Stage 2 – Approach and Expected Changes

In Stage 2 of construction, expected to last through three winters, the two tunnels would flow full and be submerged at both ends for all flow conditions; the discharge through them would be governed by upstream flows and the difference in water level between the upstream headpond and downstream tailrace ends of the tunnels. The headpond water level could vary by approximately 15 m for the full operational range of Peace Canyon Dam (283 to 1,982 m^3/s), with higher flows resulting in higher water levels in the headpond.

At low flows and water levels, ice would be drawn down through the tunnels. However, winter discharges are typically on the higher end of the operational range due to seasonal power demand and, therefore, headpond levels are expected to be in the top 5 m of the 15 m range. The Stage 2 headpond is predicted to trap some ice during high flows and water levels. Ice cover during high flows would reduce heat loss, since the headpond would be insulated by ice cover at times and it is deeper than the natural channel. These factors would cause the zero-degree isotherm and the maximum upstream extent of the ice cover to be somewhat downstream of the baseline condition.

Based on the hydraulics of the Stage 2 headpond, it is expected that the ice regime downstream of the Stage 2 diversion would be somewhere in-between the existing conditions and those with the Site C dam in place. The ice regime upstream of the Stage 2 diversion would depend on the releases from Peace Canyon Dam, with the downstream thermal and ice regime changing less during low headpond water levels. Even at high water levels, the Stage 2 headpond would be approximately half the depth of Dinosaur Reservoir and three-quarters of the length. The residence time of water in the headpond must therefore be much shorter than that of Dinosaur Reservoir and the thermal influence of the headpond proportionally smaller than that of the upstream reservoir.

It is expected that under low headpond elevations (i.e., low Peace Canyon discharges), ice would pass through the tunnels and that, under high flows, ice would be held upstream of the tunnels in the headpond. The velocity through the tunnels would range from 2 m/s to 13 m/s for the operational range of Peace Canyon discharges. These velocities are well above the erosion velocity of 1.5 m/s for ice. Therefore, ice is not expected to jam inside the tunnels, and any potential issues with ice in the headpond can be operationally addressed by maintaining higher discharges out of Peace Canyon.

11.7.3 Thermal and Ice Regime During Operation

11.7.3.1 Approach and Methods

Potential changes to the thermal and ice regime in the Peace River during operation of the Project were investigated using a series of numerical models. Models, when calibrated and validated to existing conditions or similar environments, can represent the changes of a system in response to external events such as the construction of a dam. Three models were used to represent different aspects of the reservoir and downstream changes.

Thermal and ice characteristics of the Site C reservoir were modelled using a three-dimensional hydrodynamic model, H3D (Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report). This model integrated input flow with water temperature and atmospheric data to predict the water temperature within the Site C reservoir and the outflowing water. H3D also predicted the ice characteristics of the reservoir in the form of ice cover and thickness. Water temperatures and ice cover were simulated based on observed and estimated atmospheric and flow conditions from 1995 to 2011.

The thermal characteristics of the Peace River downstream of the proposed Site C dam were simulated using CE-QUAL-W2, a two-dimensional hydrodynamic and water quality model that was used for aquatic productivity modelling as discussed in Section 11.5 Water Quality and Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River. This model used predicted outflow temperatures at the Site C dam from the H3D model, as well as meteorological, hydrologic, and water quality data to simulate water temperature, dissolved oxygen, nutrients, total suspended solids, and phytoplankton and periphyton biomasses for the years 2000–2009. Water temperature was simulated for the river's reach between the Site C dam and the Water Survey of Canada station Peace River at Alces River, 62 km downstream.

The downstream ice regime in the Peace River was simulated using the CRISSP model, introduced in Section 11.7.1.2 above.

The general approach to each numerical modelling study is similar. First, a model is set up for existing conditions to check that it produces realistic results in a measurable way. The time period chosen is generally a historical period with sufficient observational data to serve as both model input and results comparison. The H3D and CE-QUAL-W2 models were both validated against water temperature observations from the existing Dinosaur Reservoir. The downstream implementation of CE-QUAL-W2 was validated against water temperature observations from the Peace River. The CRISSP model was validated against historical ice front observations, water temperatures, water levels, and surface ice concentrations. Details on the calibration and validation of the models are included in Section 11.7.3.2 below.

Following calibration and validation, the models were run during the same historical time period with and without the Site C dam and reservoir in place. The differences between the modelled post-construction case and the modelled existing conditions case could then be attributed to the Project. This approach was used for the models of the downstream temperature (CE-QUAL-W2), and downstream ice (CRISSP). An additional scenario based on the presence of the proposed Dunvegan project was examined using the CRISSP model. The Site C reservoir temperature and ice model (H3D) was validated against observations in the existing Dinosaur Reservoir and results from H3D were compared against observations. The results of all modelling studies are discussed in terms of the historical time period used for comparison; for example, the ice conditions were modelled for the winter of 1996–1997 as if the reservoir had existed at that time.

The Dunvegan project is a potential run-of-river hydroelectric facility in Alberta near Dunvegan. The location of the project, as indicated in Figure 11.7.1, would be about 190 km downstream of the Site C dam. The headpond would be entirely contained within the natural river channel and would be 26 km long. Glacier Power, a wholly owned subsidiary of Canadian Hydro, received environmental approval for the project in 2008. Since then, the project was purchased by TransAlta Corporation, and construction has not started as of this writing. Additional information about the Dunvegan project can be found in the Environmental Impact Assessment for the Dunvegan Project (Jacques Whitford 2006), and the details of the ice regime analysis are described in Andres and Healy (2006). The CRISSP ice simulations were run for three scenarios: the existing case, with the Project, and with the Project and the Dunvegan Project.

The CRISSP model was also used to evaluate the influence of projected climate change on the thermal and ice regime of the Peace River. For these simulations, estimates of future air temperature changes were applied to the meteorological data used as input to the CRISSP model. While other climate variables such as precipitation might be different with climate change, ice modelling experience suggests that air temperature would be the single most important change for ice conditions, so other climatic components were assumed to remain unchanged from historical conditions.

11.7.3.2 Model Validation, Sensitivity and Uncertainty

Details of model structure, validation, sensitivity, and uncertainty can be found in the respective technical data reports (Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River, Volume 2 Appendix G Downstream Ice Regime Technical Data Report, and Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report) and are summarized here.

The accuracy of the H3D model was quantified by modelling a similar water body, Dinosaur Reservoir, located just upstream of the Site C reservoir. Water temperature measurements in Dinosaur Reservoir and observed data on ice formation were used to calibrate and validate the model. H3D was able to simulate temperatures at the outlet of Dinosaur Reservoir, with a root-mean-square difference of 0.2°C, and a long-term average difference of -0.01°C. The root-mean-square difference is a measure of instantaneous accuracy in temperature prediction, whether positive or negative; the long-term average difference is an average of the difference between observed and predicted results, and a near-zero value indicates that there is no persistent temperature offset or bias in the results.

The sensitivity of the modelled Site C outlet temperatures was tested in scenarios with increased wind speeds, alternate intake hydraulics near the dam, and using an implementation of H3D with suspended sediment included. For most tests, the sensitivity of the outlet temperature was within 0.1°C. The sensitivity to a different assumption regarding outlet hydraulics (stronger currents at depth) was up to 0.4°C in the summer, but still less than 0.1°C for the rest of the year. The sensitivity of outlet temperatures to air temperature is discussed in regards to climate change in Section 11.7.3.4 below.

CE-QUAL-W2 was calibrated and validated in a similar manner to H3D against temperature observations in the existing Dinosaur Reservoir. The downstream Peace River implementation of CE-QUAL-W2 was validated against the Peace 4 and Peace 5 stations (locations shown in Figure 11.7.1). Calibration resulted in modelled temperature predictions within 1° of observations and presenting no temperature offset. This calibration resulted in root-mean-square and long-term average differences of 0.5°C and -0.02°C, respectively.

The calibration and validation of the H3D and CE-QUAL-W2 models for the simulation of water temperatures in Dinosaur Reservoir and the Peace River provides confidence in the use of the models for the prediction of potential changes in water temperature resulting from the Project. The sensitivity of the model to the various inputs was tested, and results suggest that the conclusions made are reliable.

Calibration of the CRISSP model has been ongoing since its development in 2006. The original calibration was based on four winters: 1995–1996, 2002–2003, 2003–2004, and 2005–2006. The last three winters were chosen, as they contained the most comprehensive field data to date, and 1995–1996 was chosen in order to include a very cold year that did not occur during the intensive three-year field program. The first step in the CRISSP calibration was to ensure that water temperatures and the timing of the zero-degree isotherm were modelled correctly. This was done by first selecting a suitable heat transfer coefficient. Next, the porosity of the frazil slush in the frazil pans had to be incorporated into the model to reproduce observed frazil ice pan thickness and surface ice concentrations. Then ice jam parameters, such as hydraulic roughness, needed to be selected to give the correct total ice cover thickness and correct rate of ice front recession, and to reproduce water levels at measured locations.

When these calibration coefficients were applied to the other 12 years in the study, the model was reasonably accurate in predicting the ice fronts for those years as well. This accuracy was quantified by comparing the observed freeze-up and breakup dates at the Town of Peace River as well as the most upstream extent of the ice covers (Table 11.7.1).

Table 11.7.1 Comparison of Observed and Simulated Baseline Maximum Upstream Ice Cover Extents and Freeze-up and Breakup Dates at the Town of Peace River

	Max. Ice Front Progression (km)			Date of Freeze-Up at Town of Peace River			Date of Breakup at Town of Peace River		
Winter	Observed	Simulated	Difference	Observed	Simulated	Difference (days)	Observed	Simulated	Difference (days)
1995–1996*	101	98	-4	10-Dec-95	10-Dec-95	0	20-Apr-96	21-Apr-96	1
1996–1997*	125	123	-2	21-Dec-96	21-Dec-96	0	17-Apr-97	19-Apr-97	2
1997–1998	280	270	-10	13-Jan-98	13-Jan-98	0	29-Mar-98	27-Mar-98	-2
1998–1999	217	215	-3	05-Jan-99	06-Jan-99	1	03-Apr-99	03-Apr-99	0
1999–2000	219	220	1	16-Jan-00	14-Jan-00	-2	31-Mar-00	30-Mar-00	-1
2000–2001	298	298	0	10-Feb-01	10-Feb-01	0	19-Mar-01	15-Mar-01	-4
2001–2002*	207	197	-10	19-Jan-02	17-Jan-02	-2	22-Apr-02	26-Apr-02	4
2002–2003	228	226	-1	27-Jan-03	29-Jan-03	2	14-Apr-03	15-Apr-03	1
2003–2004	217	226	9	9-Jan-04	11-Jan-04	2	3-Apr-04	3-Apr-04	0
2004–2005*	169	174	6	5-Jan-05	5-Jan-05	0	3-Apr-05	29-Mar-05	-5
2005–2006	310	289	-21	27-Feb-06	26-Feb-06	-1	3-Apr-06	5-Apr-06	2
2006–2007	178	178	-1	11-Jan-07	13-Jan-07	2	24-Apr-07	22-Apr-07	-2
2007–2008	205	202	-3	10-Jan-08	8-Jan-08	-2	30-Mar-08	1-Apr-08	2
2008–2009*	195	193	-2	27-Dec-08	27-Dec-08	0	13-Apr-09	17-Apr-09	4
2009–2010	254	227	-27	31-Dec-09	30-Dec-09	-1	21-Mar-10	30-Mar-10	9
2010–2011	140	134	-6	29-Dec-10	26-Dec-10	-3	19-Apr-11	20-Apr-11	1
Average	209	204	-5	11-Jan	11-Jan	0	07-Apr	08-Apr	1
Standard Deviation	59	56		19	19		11	12	

NOTE:

* – indicates a winter in which there was at least one juxtaposed reach imposed

The comparisons of ice front progression, freeze-up dates, and breakup dates show that the CRISSP ice front simulations are a reliable representation of the observed ice front positions. The differences between observed and simulated ice conditions help to characterize the model’s uncertainty. The CRISSP model was able to simulate the maximum upstream extent of the ice cover in most years to within 10 km, with some outliers of up to 30 km. Simulation of the timing of freeze-up of the ice cover at the Town of Peace River was accurate to within three days and breakup to within nine days. The CRISSP model was able to reproduce normal ice-related water levels and open water levels to within about 0.5 m. CRISSP cannot accurately simulate secondary consolidations at freeze-up and thus cannot predict extreme high water levels resulting from these events. The model is also unable to simulate a dynamic breakup of the Peace River triggered by breakup of the Smoky River, and thus cannot predict extreme high water levels resulting from these events. However, since the model is able to simulate the necessary conditions for these to occur (i.e., the presence or absence of an ice cover), this is not an impediment for assessing the influence of the Site C dam on the frequency of secondary consolidations and dynamic breakup events triggered by the Smoky River.

The calibration of the CRISSP model to adequately simulate the observed ice fronts, water levels, water temperatures, and ice production and melt rates gives confidence in the reliability of the model. The fact that the model is able to simulate 16 winters with the same calibration coefficients indicates that uncertainties in the input variables and calibration coefficients are not high enough to manifest themselves as large errors in the output.

11.7.3.3 Expected Changes

Changes to the thermal and ice regime of the Peace River due to the Project are described separately for the Site C reservoir and the Peace River downstream of the Site C dam.

11.7.3.3.1 Expected Thermal Regime in the Site C Reservoir

The H3D model results for the Site C reservoir indicated that it would acquire the characteristics of a moderately deep lake, forming a two-layer thermal structure, separated by a thermocline (stratifying layer) forming in the summer and winter, and mixing completely in the fall and spring. A thermocline is a layer in a lake or reservoir where temperature changes quickly with depth, in the summer separating warm water near the surface from cooler water at depth. This vertical variation, or stratification, occurs naturally in lakes in both summer and winter. Winter stratification is due to the fact that fresh water is most dense at 4°C, and water at this ‘warm’ temperature can exist at the lake bottom during sub-zero air temperatures, while colder water (and ice) remains at the surface. Stratification can be destroyed by energy from strong winds (when there is no ice cover), by gradual cooling of the surface in the fall or, in the case of a reservoir, by withdrawal of both distinct layers out through the intakes of a dam. The residence time of a body of water is defined as the mean flow rate through the water body divided by the volume of the water body, and can be thought of as the time it takes for a typical parcel of water to travel through the water body. The average residence time of the water in the Site C reservoir would be about 22 days, as opposed to two to three days for Dinosaur Reservoir and within one day for an 83 km stretch of the existing Peace River.

In the first 20 km of the Site C reservoir, just downstream of Peace Canyon Dam, the model predicted that shallow bathymetry and consequently high velocities would result in a vertically uniform temperature. At greater distances downstream, the surface warming in summer would result in a stable thermocline. The reservoir would develop 5 to 15 degrees of temperature stratification in most summers. Stratified conditions would typically start in the middle of May after reservoir water temperatures exceed 4°C. Mixing is predicted to occur in the fall, typically in mid-October. This reduction and loss of stratification, which is often referred to as the fall overturn, results from factors such as increased vertical mixing due to winds and cooling surface waters. Maximum surface temperatures are predicted to reach between 16°C and 21°C in the years modelled, while the temperatures at the bottom of the reservoir gradually increase throughout the summer, but reach only 9 to 11°C before mixing completely with surface waters during the fall overturn.

In winter, there would be reverse stratification in the reservoir, with temperatures ranging from nearly 0°C under the ice at the surface to 2°C at the bottom of the reservoir. The reverse stratification arises due to the density processes described above; the reservoir would cool more at the surface than at the bottom, while simultaneously being protected from wind mixing energy by ice cover.

11.7.3.3.2 Expected Thermal Regime at the Site C Dam Outlet

Simulated water temperatures at the Site C outlet were compared with existing Peace River water temperatures at the Peace Above Pine hydrometric station, 6 km downstream of the proposed dam. The outlet of the Site C reservoir (i.e., the intakes to the Site C generating station) would span depths between approximately 3 m and 21 m, blending water from both the warm surface waters and cooler waters at depth during stratified conditions in the summer. The modelled monthly average temperatures at the Site C intakes were compared to observed temperatures at Peace Above Pine (Figure 11.7.5), for the period October 2007 to October 2012. This time period corresponds with available temperature observations at the Peace Above Pine hydrometric station. The daily range in modelled and observed temperatures is displayed on the Figure as vertical error bars.

Modelled temperatures at the outlet of the Site C dam were warmer than observed temperatures between July and January, ranging from 0.3°C higher than existing conditions in July to 1.5°C higher than existing conditions in October. The monthly average modelled outlet temperatures were between 0.4°C and 0.9°C cooler from March to June and, in all months, had a smaller daily range than the existing river.

The changes in temperature due to the Site C reservoir can partially be characterized as a time delay instead of an absolute difference. Instead of measuring the vertical distance (i.e., temperature) between the simulated and observed time series in Figure 11.7.5, the horizontal distance between the curves represents time. The differences in time indicate that, seasonally, water temperatures in the Peace River with the reservoir in place would be approximately one to two weeks late compared to existing conditions.

11.7.3.3.3 Expected Thermal Regime in the Peace River Downstream of the Site C Dam

The water temperature of the Peace River between the Site C dam and the confluence of the Alces River, approximately 62 km downstream, was modelled with CE-QUAL-W2. The expected water temperatures at the Site C dam served as the upstream input to the downstream water quality model, and CE-QUAL-W2 simulated temperature, along with other water quality components for two scenarios: existing conditions, and with the Project in place. Comparison of the two scenarios identified the changes in water temperature due to the presence of the Project. The monthly average modelled temperatures were compared at the Peace 5 station, the location of which is shown on

Figure 11.7.1, which is the downstream boundary of the CE-QUAL-W2 modelling study. Model results with and without the Project are shown in Figure 11.7.6. The predicted temperature changes range from 0.9°C cooler in May to 0.7°C warmer in November. The predicted temperature changes at Peace 5 are less than the changes predicted at Peace Above Pine, reflecting the increased distance from the Site C dam over which the Peace River temperatures are influenced by atmospheric conditions, solar radiation, and inflows from tributaries.

11.7.3.3.4 Expected Ice Regime in the Site C Reservoir

The H3D model predicts ice cover in the Site C reservoir in terms of area covered and ice thickness. Ice cover in the Peace River upstream of the project location is rare under the baseline regulated flow regime, but ice would be expected to form on the Site C reservoir. The model predicted that ice would start forming in tributary arms of the reservoir at the beginning of the winter in November or December. Later in the winter, ice would start forming first near the Site C dam, where the reservoir would be deeper and wider with lower velocities, and then propagate upstream. In the winter of 2007–2008, which was an average winter based on air temperatures, the first major onset of ice covered two-thirds of the reservoir in 11 days before partially melting again. The ice would form faster on the north side of the reservoir than on the south side due to the deflection of flowing water to the south by the Coriolis effect. The last area to be covered by ice would be the centre of the reservoir, which would also be the first place to melt.

Figure 11.7.7 shows a time series of the air temperature, the percentage of the reservoir covered by ice (area covered by ice divided by total area of the reservoir), and the mean ice thickness over the ice-covered part of the reservoir (calculated as the volume of ice divided by the ice-covered area of the reservoir), as predicted by the H3D model for the years 1995–2011. During most of the cold periods, the reservoir ice cover extended upstream past the Halfway River (about 60% coverage) and, during the coldest days, it reached Lynx Creek (about 90% coverage). Cycles of formation and melting occurred a couple of times during most winters, depending on the air temperature and wind conditions. A typical amount of ice melt in one event would be 20% of the reservoir area. The upstream 20 km of the reservoir from the Peace Canyon Dam, which includes Hudson’s Hope, would occasionally be covered by ice. This part of the Site C reservoir closest to the Peace Canyon Dam would have higher velocities, which reduces ice formation, and the temperature of water exiting the Peace Canyon Dam is always above 0°C, suppressing ice formation. Higher velocities near Lynx Creek and downstream of Farrell Creek also inhibit ice formation, whereas a widening of the reservoir at Hudson’s Hope allows a thin ice cover to form. The maximum coverage over the simulation period occurred in mid-January 1996, reaching 98% coverage after nearly a week with air temperatures below -40°C. Typical annual maximum ice cover for the simulation period was between 80% and 90% of the reservoir area, and occurred in late January or February. Annual maximum average ice thicknesses were typically about 0.5 m and occurred in late February or early March, after the maximum ice cover.

11.7.3.3.5 Expected Ice Regime in the Peace River Downstream of the Site C Dam

The expected changes to the ice regime in the Peace River downstream of the Project were characterized by comparing CRISSP model predictions of baseline conditions with model predictions of the scenario with the Project. Results were compared to determine the potential change of the following characteristics as a result of the Project:

- Timing of ice cover formation and breakup
- Maximum upstream extent of ice cover
- Ice thickness
- Conditions that affect river transportation

CRISSP predicted that both the Project and the combination of the Project with the Dunvegan Project would change the maximum upstream extent of the ice cover on the Peace River. Figure 11.7.8 and Figure 11.7.9 show an example of the ice front simulation results for two of the 16 winters analyzed, the first for a relatively cold winter, and the second for a warmer winter. The figures show that the presence of the Project would generally move the maximum upstream extent of the ice cover farther downstream, compared to existing conditions. The ice front cannot propagate as far upstream due to the warmer water exiting the dam in winter, as compared with existing conditions (Figure 11.7.5), and because ice generated in the Site C reservoir would remain behind the dam.

When the Project and the Dunvegan project were considered together, the ice front behaviour was more complex. The Dunvegan project would provide a lodgement location and would trap ice floes, initiating a second ice front upstream of it. The second ice front can be seen in Figure 11.7.8 and Figure 11.7.9 as a green line starting at Dunvegan in late December. Even with the Site C dam in place, the Dunvegan ice front would occasionally travel farther upstream than the historical ice front, especially in warmer winters, such as in Figure 11.7.9. Further details on the interactions of the Project and the Dunvegan project are presented in Volume 2 Appendix G Downstream Ice Regime Technical Data Report.

Results suggested that on average, over the 16 winters simulated, no changes would be expected at Carcajou, which is approximately 550 km downstream of the Site C dam. These results indicate that the Fort Vermilion downstream boundary of the ice models was far enough downstream to capture the entire extent of Project's influence. Under baseline conditions, the thermal ice usually gains sufficient thickness (5 to 10 cm) to support an individual or a large animal within a day or two of the ice cover formation, and this is not expected to change with the Project alone or with the combination of the Project and the Dunvegan project.

Some general statements can be made about annual ice-related events and probabilities for various locations:

- **Site C dam:** The modelling suggested that the ice front would never advance upstream to the Site C dam, with or without the Dunvegan project in place
- **District of Taylor:** With the Project, the ice cover would not reach the District of Taylor, even if the Dunvegan project were in place
- **British Columbia–Alberta Border:** Under the existing conditions, the annual probability of the ice front advancing into B.C. is about 22%. With the Project, this would decrease to about 10%. With both the Project and the Dunvegan project, the annual probability of the ice cover advancing into B.C. is about 16%.

- **Shaftesbury Crossing:** Under existing conditions, the ice cover has always advanced upstream as far as Shaftesbury Crossing. This would not change with the Project. With both the Project and the Dunvegan project, the annual probability of ice cover advancing upstream to Shaftesbury Crossing is reduced to about 88%.
- **The Town of Peace River:** Under all scenarios, the 16 years of simulation indicated that ice cover would advance past the Town of Peace River every winter

The date of freeze-up and breakup at the Town of Peace River is another way to present the changes due to the Project. Table 11.7.2 presents the existing date of freeze-up and breakup, as well as the number of days the freeze-up or breakup would change due to the presence of the Project alone, or the Project and the Dunvegan project together. A negative 'delay' indicates that the predicted date with the project(s) in place is earlier than the existing scenario.

Table 11.7.2 Changes in Timing of Ice Freeze-up and Breakup at the Town of Peace River

	Freeze-Up			Breakup		
Winter	Existing Date	Delay Due to the Project (days)	Delay Due to the Project + Dunvegan (days)	Existing Date	Delay Due to the Project (days)	Delay Due to the Project + Dunvegan (days)
1995–1996	10-Dec-95	4	8	21-Apr-96	2	1
1996–1997	21-Dec-96	3	3	19-Apr-97	3	3
1997–1998	13-Jan-98	2	14	27-Mar-98	1	2
1998–1999	6-Jan-99	3	12	3-Apr-99	0	0
1999–2000	14-Jan-00	3	19	30-Mar-00	1	0
2000–2001	10-Feb-01	3	8	15-Mar-01	-2	-1
2001–2002	17-Jan-02	6	8	26-Apr-02	0	-1
2002–2003	29-Jan-03	6	18	15-Apr-03	-2	-2
2003–2004	11-Jan-04	5	13	3-Apr-04	1	1
2004–2005	5-Jan-05	2	7	29-Mar-05	0	0
2005–2006	26-Feb-06	3	16	5-Apr-06	-2	-5
2006–2007	13-Jan-07	1	9	22-Apr-07	0	-2
2007–2008	8-Jan-08	3	7	1-Apr-08	4	3
2008–2009	27-Dec-08	2	6	17-Apr-09	-1	-1
2009–2010	30-Dec-09	3	6	30-Mar-10	1	-1
2010–2011	26-Dec-10	3	9	20-Apr-11	-1	-1
Average	11-Jan	3	10	8-Apr	0	0

11.7.3.3.6 Ice Bridge and Ferry Crossing at Shaftesbury

Both the Project and the Dunvegan project have the potential to change the timing and duration of the ice bridge crossing and ferry operations at Shaftesbury. The Shaftesbury crossing is located about 25 km upstream of the Town of Peace River or about 266 km downstream of the Site C dam site. Vehicles cross at the location by ferry in the summer and by ice bridge in the winter. There are a few weeks, or even months in some years, where neither ferry nor ice bridge crossing is possible.

Typically, the ferry starts operating soon after the ice front recedes past the crossing location at km 370.6 between late March and the middle of April. High ice concentrations typically end ferry operations in November or December. Additional time is required after ferry operations end for the ice front to arrive at Shaftsbury and for the ice cover to gain sufficient strength for an ice bridge to be constructed. The ice bridge can commence operations as early as December in a cold year or as late as March in a warm winter. In the warmest of winters, ice bridge construction is not possible. The ice bridge remains in place until shortly before breakup of the ice cover. CRISSP model results were used to predict the times during which ferry or ice bridge crossings are both possible under baseline conditions, with the Project in place, and with both the Project and the Dunvegan project in place.

On average, there would be no delay in the start-up dates of ferry operations as a result of the Project alone, or with both the Project and the Dunvegan project. The ending date of ferry operations was predicted to be extended by an average of four days with the Project in place. In some years, the model suggested that the ferry could operate for a few weeks longer before freeze-up occurs. With both the Project and the Dunvegan project in place, the average delay of ferry closure is three days, compared to a delay of four days with the Project alone. However, there are a few outlying years that skew the calculation from the average. Calculation using the median values suggested that there is almost no change in the ferry closure date with either the Project alone or with both the Project and the Dunvegan project in place.

Results suggest that with the Project in place, ice bridge operations would start on average five days later than under existing conditions, with a year-to-year range of between zero and 14 days later. With both the Project and the Dunvegan project in place, the average delay would be 17 days. With both projects in place, the results suggested that, out of the 16 years simulated, there would be two years when the required ice thickness would not be attained.

For the purposes of modelling changes, the date the ice bridge crossing was closed was assumed to be the day the ice front receded past Shaftesbury Crossing, and the number of days during which the ice bridge was operable was calculated. The results showed that the ice bridge would be usable for an average of 75 days under existing conditions, 71 days with the Project, and 58 days with both the Project and the Dunvegan project. However, the decrease in ice bridge days with the Project would be nearly the same as the projected increase in days during which the ferry was operable. Therefore, the Project is not predicted to change the total number of crossing days at Shaftesbury. On average, the Project and the Dunvegan project combined would reduce the number of crossing days by 15 days.

11.7.3.3.7 Freeze-up and Breakup Water Levels

The CRISSP models of the Peace River, under existing conditions, with the Project alone, and with both the Project and the Dunvegan project, included prediction of water levels. The model simulated the process of primary consolidation, or the initial collapse of the juxtaposed ice cover and the associated increase in water levels. Secondary consolidations, which can produce the largest increases in water level, were not simulated. However, the risk of a secondary consolidation is highest during swings in temperature that drive a rapid advance of the ice front. Models with the Project in place suggested that the speed of ice front advance would be slower than existing conditions, and therefore the risk of secondary consolidation could be slightly reduced.

Comparisons of the water levels at freeze-up between the three model scenarios suggest that there would be no systematic change in water level due to the Project alone or the combination of the Project and the Dunvegan project. However, freeze-up water levels depend on the timing of ice formation at a particular location, and the atmospheric and flow conditions that exist at the time of freeze-up. As described above, a small delay in the timing of ice formation is expected (an average of three days at the Town of Peace River) so there could be small changes in freeze-up water levels due to different conditions at the time of freeze-up, but these changes would not be systematic and would be within the variability of freeze-up water levels experienced today.

High water levels at breakup would remain unchanged from existing conditions, as they occur when the Smoky River ice cover breaks up dynamically into an intact Peace River ice cover. Since neither the Project alone nor the combination of the Project and the Dunvegan project would change the average timing of the thermal breakup of the Peace River ice cover at the Town of Peace River, peak breakup water levels would not change from those experienced under existing conditions.

The response time in implementing flow regulation that helps to mitigate the risk of flooding due to ice breakup would improve with the Project in place. Under existing conditions, flows from the Peace Canyon Dam are controlled during certain periods to mitigate ice breakup risks. Since the Site C dam is about 85 km closer to the Town of Peace River than Peace Canyon Dam, reduction of flow at the Site C dam would lead to a reduction of water levels at the town about 12 hours sooner than under existing conditions, where flow is controlled at Peace Canyon Dam. This faster response time could reduce ice flooding risks at the Town of Peace River.

11.7.3.4 Climate Change

As described in Volume 2 Appendix T Climate Change Summary Report, air temperatures in the Peace region have increased approximately 1.2°C over the past century, and are projected to increase 1.9°C to 2.5°C by the 2050s and 2.5°C to 3.9°C by the 2080s. The increase in mean air temperatures has been, and is expected to be, mostly due to warmer temperatures in winter. An increase in tributary flow and earlier freshets are expected in the Peace region. The sensitivity of temperatures in the Site C reservoir to climate change was tested with a series of H3D model runs, and the sensitivity of the downstream ice regime to climate change was tested with the CRISSP model.

11.7.3.4.1 Thermal Regime with Climate Change

A series of H3D model runs were conducted with air temperature increases ranging from 1°C to 4°C. These constant increases are simpler than time-varying climate change scenarios, but span the range of temperature increases projected for the 2050s and 2080s time periods.

The model predicted that the increase in outflow temperature at the Site C dam averaged 20% of the air temperature increase for the months of March through October. Winter temperature increases were less than 5% of the air temperature increase. For example, for a 4°C increase in air temperatures, outflowing water is expected to be about 0.8°C warmer in the summer and fall, and less than 0.2°C warmer in winter.

The response of the Site C reservoir to climate change would also depend on the response of Williston Reservoir to a warming climate, but in the absence of quantitative predictions in Williston, the Site C reservoir response was tested without changing the temperature of the inflowing water. Studies in the Great Lakes predicted that surface water temperatures will increase along with air temperature. However, bottom waters were predicted to warm less than surface waters (Great Lakes 2003). Assuming the same pattern in Williston Reservoir, and considering that most of the water at the W.A.C. Bennett Dam is drawn at depth, it is expected that waters entering the Site C reservoir would warm less than predicted future air temperatures. An additional sensitivity test with warmer inflowing water confirmed that the assumption of no change in inflow temperatures is the most conservative in terms of evaluating the influence of the Site C reservoir on water temperatures (i.e., this approach led to a larger change attributable to the Project).

The ice conditions on the existing Peace River under future climate scenarios corresponding to the 2050s and 2080s time periods were modelled with CRISSP during the months of November through April. The water temperatures in the 2050s are predicted to be warmer by 0.3°C at Peace 5, and by 0.6°C at the Town of Peace River. In the 2080s, the water temperatures are predicted to be warmer by 0.4°C at Peace 5 and by 1.0°C at the Town of Peace River. Presented relative to the projected air temperature increase for the 2050s and 2080s, the warming predicted for the existing Peace River at Peace 5 is 10% to 16% of the air temperature increase, and 24% to 40% at the Town of Peace River.

11.7.3.4.2 Ice Regime with Climate Change

The 16 winters considered in the downstream ice study were simulated under two future climate scenarios corresponding to the 2050s and 2080s time periods. Monthly air temperature offsets were applied to hourly historical data from the three climate stations used in the CRISSP model (Fort St. John, Town of Peace River, and High Level) over the same 16 simulated years. The Peace Canyon and Site C reservoir outlet water temperatures were assumed to be unchanged with climate change in the ice study, as it was reasonable to ignore the 5% sensitivity to warmer air temperatures in winter predicted by the H3D model.

The influences of the changed climate on the ice front locations in two representative winters, for the various development scenarios, are shown in Figure 11.7.10 and Figure 11.7.11. These can be directly compared to the ice front simulations without climate change in Figure 11.7.8 and Figure 11.7.9. The ice fronts for all scenarios under climate change conditions would be farther downstream than under current conditions.

According to the CRISSP analysis, changes to the ice regime due to a future climate would be of a similar magnitude to those attributable to the Project alone, or the Project and the Dunvegan project combined. The ice front in a future climate would be pushed further downstream in the order of a few tens of kilometres to about 100 km, depending on its location and depending on winter severity.

Results suggest that there is no difference between project scenarios downstream of about km 650, with and without climate change, indicating the downstream boundary is sufficiently far removed that it is not affected by changes to the ice regime due to the Project alone or the Project and the Dunvegan project combined. It also can be concluded that the influence of the Project on downstream ice conditions is predicted to be similar whether under a baseline climate, a 2050s climate, or a 2080s climate.

11.7.4 Summary of Expected Changes

Model results for the Site C reservoir indicated that it would behave like a lake, forming a two-layer thermal structure. The reservoir is predicted to develop 5 to 15 degrees of temperature stratification in most summers. Stratified conditions typically start in the middle of May, whereas the fall overturn typically occurs in mid-October. Maximum surface temperatures are predicted to reach between 16°C and 21°C in the years modelled, while the temperatures at the bottom of the reservoir would gradually increase throughout the summer but would reach only 9 to 11°C before mixing completely with surface waters during the fall overturn.

Modelled temperatures in the Peace River just downstream of the Site C dam were warmer than existing conditions between July and January, with differences ranging from 0.3°C in July to 1.5°C in October. The monthly average temperatures are expected to be between 0.4°C and 0.9°C cooler from March to June, and in all months to have a smaller daily range than the existing river. The monthly average modelled temperatures were also compared to a location 62 km downstream of the Site C dam. The temperature changes at the downstream station would range from 0.9°C cooler in May to 0.7°C warmer in November.

Typical maximum ice cover in the Site C reservoir is predicted to be between 80% and 90% of the reservoir area, and to occur in late January or February. Typical average ice thicknesses are expected to peak at approximately 0.5 m and occur in late February or early March, after the maximum ice cover.

The behaviour of the ice front in the Peace River is also expected to change due to the presence of the Project. Modelling predicts that the maximum upstream extent of the ice front would generally move farther downstream, compared to existing conditions. When the Project and the Dunvegan project are considered together, the change in ice front locations would behave differently. The Dunvegan project would provide a lodgement location and would trap ice floes, thereby initiating a second ice front upstream of the Dunvegan dam. Whether the Project or the Dunvegan Project would have greater influence on the maximum upstream extent of the ice cover in any one year would depend on the winter severity.

It is expected that changes to the ice regime due to a general climate warming would be similar in magnitude as those attributable to the Project and the Dunvegan Project; the ice front would be pushed further downstream in the order of a few tens of kilometres to about 100 km, depending on its location and on the winter severity. However, results suggest that there would be no difference in ice front location between project scenarios downstream about km 650 under a climate change scenario.

The ice front model results show that the ice bridge at Shaftesbury is usable for an average of 75 days under existing conditions, 71 days with the Project alone, and 58 days with both the Project and the Dunvegan project. However, the decrease in ice bridge days with the Project would be nearly the same as the projected increase in days during which the ferry is operable. Therefore, the Project is not predicted to change the total number of crossing days at Shaftesbury. On average, the Project and the Dunvegan project combined would reduce the number of crossing days by 15 days.

Results of the downstream ice study show that there is no difference in the ice regime between project scenarios downstream of Carcajou (near km 650), with or without consideration of climate change. This indicates that the downstream boundary of the study is sufficiently far removed to capture the entire extent of the Project's influence.

11.8 Fluvial Geomorphology and Sediment Transport Regime

11.8.1 Background

Fluvial geomorphology refers to the physical geometry and bed material characteristics of the river channel. Changes in fluvial geomorphology can occur due to bank or bed erosion, sediment deposition, and/or vegetation encroachment. Sediment transport regime refers to the quantity, temporal pattern, grain-size distribution, and mode of transport of particulate matter by river flows. The sediment transport regime of a river can be altered by the introduction of new sediment sources, by changes in flow patterns, which govern the sediment transport capacity of a river, or by the interruption of downstream sediment transport in sediment sinks such as reservoirs.

Prior to hydroelectric development in 1967, the fluvial geomorphology and sediment transport regime in the Peace River were naturally dynamic due to the localized nature of sediment inputs from tributaries and valley-wall landslides, and due to a seasonal range in flows. Since 1967, the fluvial geomorphology and sediment transport regimes in the Peace River have been in a state of adjustment to the regulated flow conditions. The potential changes in fluvial geomorphology and sediment transport regimes related to the Project have been considered in light of the fact that the baseline conditions in the Peace River are both naturally variable and are undergoing a long-term response to regulation. Thus, not all future changes in the Peace River would necessarily be attributable to the Project. Rather, the potential changes induced by the Project would combine with the changes that would have resulted from the current, ongoing response to river regulation in the absence of the Project. The characterization of past geomorphologic changes and ongoing geomorphologic response to regulation in this section of the EIS draws on long-term research studies by Dr. Michael Church from the University of British Columbia, Department of Geography (Church 2011).

This section of the EIS summarizes the information presented in Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report.

11.8.2 Technical Study Areas

Two spatial technical study areas are considered for the fluvial geomorphology and sediment transport study: the reservoir study area and the downstream study area.

1. The reservoir study area comprises the Peace River valley from the Peace Canyon Dam to the Site C dam site, and the lower reaches of the reservoir tributary valleys. The reservoir study area extends up the tributary valleys (i.e., tributary embayments of the reservoir) to the maximum extent of inundation at full supply level. In the two largest reservoir tributaries, the Halfway and Moberly Rivers, the reservoir study area extends another 10 km up the tributary valleys beyond the extent of reservoir inundation to encompass the potential zones of bedload (gravel and sand) accumulation that may occur upstream of the reservoir confluences. The reservoir study area is shown in Figure 11.8.1.
2. The downstream study area comprises the Peace River valley from the Site C dam site to the community of Peace Point, Alberta. Peace Point is located approximately 108 km upstream of the Peace River confluence with the Slave River, and

corresponds to the downstream limit of the closely related surface water regime study area (Volume 2 Section 11.4 Surface Water Regime). In the downstream study area, the magnitude of the potential changes related to the Project would diminish in a downstream direction due to the moderating influence of water and sediment inputs from tributaries. Project-related changes in fluvial geomorphology and sediment transport regime were expected to be negligible downstream of Peace Point when the downstream study area was established. The study results presented in this section of the EIS confirm this to be the case. The downstream study area is shown in Figure 11.8.2.

Potential changes in fluvial geomorphology and sediment transport during the construction and operational phases of the Project have been analyzed in this study, including separate considerations of the channelization and diversion stages of construction. In the operations phase, sediment dynamics in the reservoir and downstream of the dam site have been considered for the first 10 years of operations. This period was selected to provide a range of annual and seasonal conditions. One aspect of sediment dynamics in the reservoir – deposition on the reservoir bottom – has also been considered over a 50-year time period. The longer time period was selected for this analysis to assess the cumulative sediment deposition that would occur over a period of time containing many floods.

11.8.3 Baseline Conditions

11.8.3.1 River Definition

The Peace River channel was mapped from the Peace Canyon Dam to Peace Point using remote sensing imagery in order to define the baseline planform (map view pattern and dimensions) of the river. The river channel maps delineate “active” and “inactive” channel zone areas based on vegetative and topographic indicators. The channel zone is defined by the outermost river banks, within which the wetted channel, bars, and islands are contained. The “active” portion of the channel zone comprises the wetted channel (at the time of image capture) plus unvegetated bars, which are wetted or overridden by ice with sufficient regularity to inhibit vegetative colonization. The “inactive” portion of the channel zone comprises vegetated bars and wooded islands. Vegetated bars are formerly active portions of the channel that have been colonized by vegetation due to natural river migration and/or due to the lowered flood levels associated with upstream river regulation.

The total area of the Site C reservoir is estimated to be 9,330 ha. The areas of river channel and land that would be inundated by the Site C reservoir are as follows:

- Active river channel inundated: 3,773 ha
- Land inundated (including vegetated river bars and islands): 5,557 ha

The river was divided into six reaches for geomorphic characterization, based on the river definition maps and overview information provided in Church (2011). The reach extents and a summary of geomorphic characteristics are presented in Table 11.8.1. The river chainage system used to define the reach breaks refers to channel distance downstream of the W.A.C. Bennett Dam.

Table 11.8.1 Geomorphic Study Reaches – Summary of Key Characteristics

Peace River Reach		River Chainage (km)		Reach Average Gradient (m/m)	Dominant Bed Material Size
		Start	End		
Reach 1	Peace Canyon Dam to Site C Dam Site	20.4	105.5	0.0005	Gravel/cobble
Reach 2	Site C Dam Site to Alces River Confluence	105.5	163.8	0.0005	Gravel
Reach 3	Alces River Confluence to Smoky River Confluence	163.8	388.6	0.0003	Fine gravel
Reach 4	Smoky River Confluence to Wolverine River Confluence	388.6	655.6	0.0002	Sandy gravel
Reach 5	Wolverine River Confluence to Vermilion Chutes	655.6	916.0	0.0001	Coarse/medium sand
Reach 6	Vermilion Chutes to Peace Point	916.0	1,135.0	0.0001	Medium/fine sand

11.8.3.2 Suspended Sediment Transport

The baseline suspended sediment transport regime was characterized by means of sampling programs in the reservoir study area and in the proximal portion of the downstream study area where the relative changes due to the Project would be greatest. Published information was available for more distal portions of the downstream study area, which permitted a characterization of suspended sediment regime all the way to Peace Point.

The proximal portion of the downstream study area was defined as the section of Peace River between the Site C dam site and the Water Survey of Canada gauging station located immediately upstream of the Alces River confluence (Station 07FD010, Peace River above Alces River). This section of river includes the confluences of three major tributaries – the Pine, Beatton, and Kiskatinaw rivers – which contribute relatively large suspended sediment loads compared to the loads transported out of the reservoir study area. The gauging station near the Alces River confluence was selected as a logical point at which the flows and sediment loads of these three tributaries and the residual drainage area between the tributary confluences could be computed.

Sampling Methods

The suspended sediment gauging program was used to develop relationships between discharge, suspended sediment concentration, and turbidity for all Peace River tributaries (including minor ungauged tributaries and residual drainage areas) between the Peace Canyon Dam and the Alces River confluence. These relationships were used to generate synthetic daily time series of discharge, suspended sediment concentration and load, and turbidity for each tributary and for the Peace River mainstem for the 10-year period 2000-2009. This period was selected because it represents recent (current) hydro-climatic conditions, and because this period contains a range of hydrologic conditions, including a large flood event on the Halfway River and several other Peace River tributaries in 2001.

Suspended sediment gauging programs were carried out in 1975 and 2010–2011. These programs focused on the Peace River and tributaries in the reservoir study area and in the proximal portion of the downstream study area between the Peace Canyon Dam and the Alces River confluence. Sample data collected by the Water Survey of Canada were also available in these areas to augment the baseline studies.

Standard guidelines for a suspended sediment gauging study are provided by ASTM International (ASTM 2009), formerly known as the American Society for Testing and Materials. The ASTM International guidelines draw upon more detailed guidelines for specific study components, primarily developed by the United States Geological Survey (USGS). The 2010–2011 suspended sediment gauging program followed the ASTM International guidelines, as well as the more detailed USGS guidelines for suspended sediment gauging, or the equivalent provincial (British Columbia) guidelines for those portions of the study for which such guidelines exist.

The methodology for installing and operating a streamflow gauging station in British Columbia is provided by the B.C. Ministry of Environment (BCMOE 2009). However, the provincial manual does not cover the use of Acoustic Doppler Current Profiler (ADCP) instrumentation to measure instantaneous discharge. ADCP technology is now widely used by the Water Survey of Canada and USGS. The USGS provides the most comprehensive manual on the use of ADCP (Mueller and Wagner 2009). The Project baseline studies followed the provincial guidelines for the overall streamflow gauging program and the USGS manual for instantaneous discharge measurements using ADCP. The most comprehensive guidelines for installing and operating turbidity sensors for the purpose of estimating suspended sediment concentration are provided by the USGS (Rasmussen et al. 2011). The Project baseline studies followed these guidelines (which were first presented in 2009 and revised in 2011) for the collection of turbidity records in the 2010-2011 gauging program. The most comprehensive guidelines for the collection of representative suspended sediment samples are provided by the USGS (Edwards and Glysson 1999). The Project baseline studies followed these guidelines for sample collection, which include the use of Federal Interagency Sedimentation Project (FISP) depth-integrated samplers to collect depth-integrated samples of the river water column, and the compilation of multiple depth-integrated vertical samples to obtain cross-sectional average concentration values.

Results

The estimated mean annual suspended sediment load at various locations in the Peace River between the Peace Canyon Dam and the Alces River confluence for the period 2000–2009 are provided in Table 11.8.2.

Table 11.8.2 Mean Annual Suspended Sediment Load in the Peace River (2000-2009) – Peace Canyon Dam to Alces River Confluence

Peace River Location	Mean Annual Suspended Sediment Load (t/year)
Peace Canyon Dam	Negligible
Site C Dam	1,360,000
Alces River Confluence	8,730,000

The Halfway River contributes an estimated 75% of the suspended sediment load that passes the Site C dam site. The Pine and Beatton Rivers contribute approximately

1.6 times and 2.8 times the load, respectively, of the Peace River at the Site C dam site. The mean annual suspended load at the Alces River confluence is approximately 6.4 times the load at the Site C dam site.

Further downstream, from Dunvegan to Peace Point, Church (2011) presents the following estimates of mean annual suspended sediment load for the period 1971–1990 (Table 11.8.3).

Table 11.8.3 Mean Annual Suspended Sediment Load in the Peace River (1971-1990) – Dunvegan to Peace Point

Peace River Location	Mean Annual Suspended Sediment Load (t/year)
Dunvegan	15,600,000
Town of Peace River	38,000,000
Peace Point	38,200,000

The large incremental increase in suspended sediment load between the communities of Dunvegan and Peace River is primarily due to inflow from the Smoky River. The small incremental increase between the communities of Peace River and Peace Point is due to low sediment yield downstream of the Smoky River and to net deposition of a portion of the suspended sand load contributed by the Smoky River (Church 2011).

The incremental suspended sediment load inputs from tributaries are shown visually in Figure 11.8.3 (Peace Canyon Dam to the Alces River confluence) and Figure 11.8.4 (Peace Canyon Dam to Peace Point).

Suspended sediment inputs from the tributaries are greatest during the spring snowmelt freshet and during rainstorms. The spring freshet typically peaks in June for tributaries with headwaters in the Rocky Mountains (Halfway, Pine, and Smoky rivers) and in May for other tributaries, which are located mainly on the Alberta Plateau. This results in variable suspended sediment concentration and load in the Peace River throughout the year. The annual and seasonal concentration duration curves for three locations on the Peace River are provided in Figures 11.8.5 and 11.8.6, respectively. On an annual basis (Figure 11.8.5), immediately upstream of the Halfway River confluence, suspended sediment concentration exceeds 20 mg/L approximately 4% of the time. Immediately downstream of the Halfway River confluence, suspended sediment concentration exceeds 20 mg/L approximately 20% of the time.

11.8.3.3 Suspended Sediment Grain Size

The estimated average grain-size composition of the suspended sediments in the Peace River at the Site C dam site is 37% clay (less than 4 μm), 55% silt (4 to 62 μm), and 8% fine sand (62 to 200 μm). These results are based on summing the tributary loads and their sampled grain-size distributions in the reservoir study area tributaries.

Clay and silt do not settle out of suspension in flowing water, but some silt does accumulate in side channels and on channel margins in the Peace River. The sand is marginally in suspension and does settle out or transitions from suspended to bedload under some flow conditions. However, the river also entrains sediment into suspension from within its channel under certain flow conditions. Samples collected in the Peace River indicate grain-size composition similar to the composition derived from the sum of the tributaries, indicating that net deposition of fine sand along the river channel is not large, relative to the total load.

11.8.3.4 Lateral Mixing of Tributary Sediment Inputs

Lateral variability in suspended sediment concentration in the Peace River arises from the long distances required for mixing of tributary sediment inputs. Cross-sectional turbidity transects were collected on the Peace River to characterize the lateral and longitudinal patterns of sediment mixing below major tributary confluences. The results of the turbidity transects indicate that sediment inputs from major tributaries such as the Halfway and Pine rivers create lateral gradients in turbidity (and suspended sediment concentration) for tens of kilometres downstream from the confluences. More complex lateral patterns are found where multiple upstream tributaries contribute to the lateral suspended sediment profile. These lateral patterns exist along the entire length of the Peace River between the Peace Canyon Dam and the Alces River confluence. By logical extension, lateral variability in suspended sediment concentration likely exists for at least tens of kilometres downstream of all major tributary confluences, and further downstream as well, all the way down to Peace Point.

11.8.3.5 Bed Material Grain Size

Bed material grain-size has been characterized at numerous sites along the Peace River between the Peace Canyon Dam and Peace Point. Generalized grain-size information from Church (2011) is summarized by geomorphic reach in Table 11.8.1. A more detailed description of bed material characteristics, based on BC Hydro and other studies conducted between the Peace Canyon Dam and the Alces River confluence, is provided below. This encompasses the reservoir study area, where the riverbed would be inundated by the reservoir and subject to fine sediment deposition, and the proximal portion of the downstream study area, where the relative changes in sediment transport regime would be greatest.

Manual bed material samples (Wolman pebble counts) were collected on the surfaces of exposed gravel bars along the Peace River between the Peace Canyon Dam and the Alces River confluence. At each sample site, a large number of stones (usually 100) was randomly selected and the diameter of each stone was measured. In the local vicinity of the Site C dam site, underwater video sampling of the riverbed surface was conducted in the wetted river channel. Stone dimensions were measured using an automated image analysis software to process selected video images.

The manual surface samples indicate that the bed (bar) material generally becomes finer (smaller) in the downstream direction between Peace Canyon Dam and the Site C dam site. The median bed material particle size (D_{50}) averages about 90 mm toward the upstream end of this reach and 50 mm toward the downstream end of this reach. The overall trend does not continue downstream between the Site C dam site and the Alces River confluence, where D_{50} values also average around 50 mm.

Underwater bed material video sampling in the vicinity of the Site C dam site indicated D_{50} values ranging from 19 mm to 62 mm, which generally agrees with the manual surface samples collected on the exposed gravel bars near the dam site (average D_{50} of 50 mm, as discussed above). Two areas of exposed bedrock were also identified in the underwater video sampling.

Manual bulk samples of subsurface bed material were excavated and sieved at selected sites between the Peace Canyon Dam and the Alces River confluence. The subsurface sample results indicate D_{50} values averaging around 25 mm. It is common for subsurface riverbed material to contain more fines than the surface material and thus to have finer median grain size.

11.8.3.6 Bed Material Mobility

Gravel is supplied in relatively small quantities to the Peace River by the erosion of glaciofluvial and alluvial deposits along the main channel and tributary channels, and from mountain sources in the headwaters of tributaries draining from the Rocky Mountains. Bedload transport in the Peace River has always been much lower in magnitude than the transport of suspended sediment, by an estimated factor of 1% or less (Church 2011). Since the onset of flow regulation in the Peace River, bedload transport in the cobble- and gravel-bed reaches of the Peace River has ceased to occur under the normal range of flow conditions because the flows are not competent to mobilize the bed material. Church (2011) estimated a threshold discharge of 3,000 m^3/s for the initiation of bed material mobilization between the Peace Canyon Dam and the Alces River confluence. Further downstream, the riverbed material becomes finer and the flow regime has been less affected by regulation, so bedload transport continues to occur.

Bed material mobility was assessed in the Peace River between the Moberly River confluence and the Highway 97 crossing near Taylor. The particular area of interest was the section of river extending approximately 3 km downstream from the Moberly River confluence, where bedload material delivered by the Moberly River has been accumulating in the Peace River channel since the onset of flow regulation due to reduced peak flows and corresponding reduction in sediment transport capacity. This section of river was of particular interest because it would be subject to modified hydraulic conditions during construction and operations, and because the reservoir would eliminate bedload supply to the Peace River immediately downstream of the Site C dam site.

Bed material grain-size characteristics were compiled from historical information sources and a more detailed investigation using underwater videography, as described in the previous section. A two-dimensional (2D) hydrodynamic model (River2D) was used to compute bed shear stresses in the Peace River between the Moberly River confluence and Old Fort. At any given flow condition, channel bed areas where the bed shear stress exceeded the critical shear stress for bed mobilization (i.e., areas of competent flow) were identified. Flow competence refers to the ability of a given flow condition to mobilize the bed material in a river. The River2D model is described further in Section 11.4 Surface Water Regime.

The areas of flow competence at a discharge condition of 4,000 m^3/s are shown in Figure 11.8.7. This is a flow condition that has been exceeded at the Site C dam site during only one event since 1967: the 1996 drawdown of Williston Reservoir for dam repairs. Much of the riverbed is shown to be immobile at this flow condition, but some mid-channel bars are shown to be mobilized, including the mid-channel bar near km 107, approximately 2 km downstream from the Moberly River confluence (photograph shown in Figure 11.8.8).

11.8.3.7 Historical Erosion and Deposition Patterns

Three approaches were undertaken to characterize baseline channel erosion and deposition patterns in the Peace River, based on comparisons of river information collected over a period of several decades, which provide characterizations of cumulative erosion and deposition resulting from long periods of gradual change and/or many discrete events. The three approaches are maps of riverbank lines and other river features, cross-sectional bed elevation profiles, and stage-discharge (i.e., water level-flow) rating curve relationships at Water Survey of Canada gauging stations.

The results of these analyses show that the Peace River has responded, and continues to respond, to flow regulation in the following ways:

- Tributary bedload material has been accumulating in the Peace River channel below tributary confluences since the onset of river regulation, including the areas downstream of the Moberly and Pine river confluences
- Alluvial fans at tributary confluences have expanded laterally into the Peace River, forcing the river to erode its banks opposite from the confluences
- Terrestrial vegetation has encroached onto formerly active gravel bars and into secondary channels

11.8.4 Construction

11.8.4.1 Suspended Sediment Regime Downstream of the Site C Dam Site

Approach and Methods

Two potential sources of suspended sediment during construction were considered: in-stream construction activities and shoreline erosion in the diversion-stage headpond.

- In-stream construction activities – The timing and sediment loading of various in-stream activities were estimated by Klohn Crippen Berger Ltd. The analysis is presented in Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report, Appendix H.
- Shoreline erosion in the diversion-stage headpond – The timing and sediment loading from shoreline erosion were estimated by J.D. Mollard and Associates. The analysis is presented in Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report, Appendix F.

In addition to these two sediment sources, sediment would likely be generated from onshore construction activities in the vicinity of the dam site. Sediment inputs to the river from onshore construction activities would need to be kept below the effluent criteria to be set out in the Environmental Management Plan (Volume 5 Section 35 Summary of Environmental Management Plans).

The suspended sediment load of the Peace River comprises sediment finer than 200 μm, so 200 μm was selected as the upper limit for sediment size considered in the in-stream construction and headpond shoreline analyses. The sediment inputs due to in-stream construction activities and headpond shoreline erosion were treated as event-type pulses, which reflects the probable nature of their timing and produces greater potential increases in concentration than if the sediment loads were introduced over longer periods of time. For each sediment input event, a range of incremental increases in suspended sediment concentration was computed, based on a consideration of the ranges in input load, ambient river flow, and the fraction of the river flow into which the sediment would be mixed. The sediment input events were grouped by season for comparison to seasonal baseline concentration values.

In-stream Construction Activities

Seventeen construction activities with an in-stream component were identified. The in-stream construction activities would occur in three periods of time:

1. In Year 1, at the start of the river channelization stage, as the north bank haul road, lateral cofferdams and containment dykes are constructed
2. In Year 4, at the start of the river diversion stage, as the inlet and outlet channels are excavated, and the diversion channels and tunnels are flushed
3. In Year 7, toward the end of the river diversion stage, as the tailrace/discharge channel is excavated and flushed

The fine sediment loads associated with each activity were estimated based on a consideration of construction material volume and grain size, and the historical range of river flows, levels, and velocities encountered in the corresponding season in which the construction activity is planned to occur. The estimates were made using the finest grain-size gradation curve for the construction materials and contain no special allowances to minimize sediment generation. Therefore, these are considered to be upper bound estimates that could be reduced if mitigative practices or adjustments in the timing of works were applied.

The minimum duration of wetted work associated with each activity was estimated based on construction volumes, equipment productivity rates, and the seasonal range of river levels. For a given sediment loading, the minimum duration of wetted work provides the maximum incremental increase in concentration. The minimum durations of wetted work for most of the activities range from a few hours to a few days.

The range of concentration computed for each activity reflects the range in activity duration and ambient river discharge into which the sediment inputs would be diluted. For each activity, the associated concentration in 5% of the river discharge and 100% of the river discharge were computed. The former condition is expected to be observed relatively close to the construction site, whereas full mixing into 100% of the river discharge would occur far downstream, beyond the Pine River confluence. The latter assertion is based on the understanding of lateral mixing patterns that was developed from the turbidity transects described in Section 11.8.3.4 Lateral Mixing of Tributary Sediment Inputs. The exception to this is the flushing of the diversion channels and tunnels at the start of the river diversion stage; the sediment entrained in this activity would be fully mixed in the confined turbulent flow within the tunnels.

Headpond Shoreline Erosion

Headpond shoreline erosion was estimated on a daily basis using a wave-energy erosion model. The seasonal distribution of sediment input events reflects the distribution of windy days. Autumn and winter are the windiest seasons (averaging 15 and 12 daily events per season, respectively), while spring and summer are the calmest seasons (averaging seven daily events per season each). The range in concentration in each season reflects the variability in erosion event magnitudes and the river discharge into which the sediment inputs would be diluted. The headpond shoreline sediment would be fully mixed with the river discharge as it passes through the diversion tunnels. The computed increases in concentration refer to a location downstream of the tunnel outlets in fully mixed flow.

Expected Changes

The estimated fine sediment input from in-stream construction activities during the eight-year construction phase ranges from approximately 18,000 t to 30,000 t. For comparison, the mean annual suspended sediment load in the Peace River is 1.36 million t/year. Averaged over the eight-year construction phase, the fine sediment inputs related to in-stream construction activities would represent a 0.2% to 0.3% increase above baseline.

The estimated fine sediment input from headpond shoreline erosion during the four-year diversion stage of construction is 56,000 t. For comparison, the estimated mean annual suspended sediment load of the Peace River at the Site C dam site is 1.36 million t/year. Averaged over the four-year diversion stage, the fine sediment inputs related to headpond shoreline erosion would represent a 1% increase above baseline.

The fine sediment inputs from in-stream construction activities and headpond shoreline erosion would occur in an episodic manner, so short-term increases in suspended sediment concentration would be greater than the comparison of annual loads (above) would suggest. These episodic events are described below in chronological order.

Year 1

In Year 1 of the construction phase, in-stream construction activity would consist of haul road construction along the north river bank, and lateral cofferdam and containment dyke construction on the north side of the river to set up the river channelization stage of construction. Seven discrete in-stream activities have been identified, each of which would have a minimum duration of wetted work in the order of a few hours to a few days. The incremental increase in suspended sediment concentration from each activity, considered independently from one another, is estimated to be in the order of 300 to 1,200 mg/L at a location close to the source where the sediment is mixed into 5% of the ambient river flow, and 15 to 60 mg/L further downstream once the sediment is fully mixed into 100% of the river flow. All of the activities would occur on the north side of the river, so the elevated suspended sediment concentrations would occur close to the north shore of the river, with the incremental concentration levels diminishing in a downstream direction as the sediment mixes laterally across the river. Full mixing would occur somewhere downstream of the Pine River confluence.

Years 2–3

No in-stream construction activities are planned for Years 2 or 3. All construction activity would occur onshore and site runoff would be managed according to an Environmental Management Plan (see Volume 5 Chapter 35 Summary of Environmental Management Plans).

Year 4

In Year 4 of the construction phase, the diversion channels at the tunnel inlets and outlets would be excavated in preparation for river diversion. The start of river diversion would then result in a flushing of the diversion channels and tunnels.

- The excavation of each of the two diversion channels would result in elevated suspended sediment concentration for a duration of one to two months. The incremental increases in suspended sediment concentration would be in the order of 10 to 30 mg/L close to the source where the sediment is mixed into 5% of the river flow along the north side of the river, diminishing to around 1 mg/L at a downstream location where the sediment is fully mixed into 100% of the river flow. These values refer to each of the diversion channels (inlet and outlet), so would be additive if the channels were excavated in unison.
- Associated with diversion channel excavation, the construction of an excavation berm in each channel would result in a short (one day) pulse of elevated suspended sediment concentration. The incremental increase in suspended sediment concentration would be in the order of 400 to 1,000 mg/L close to the source where the sediment is mixed into 5% of the river flow along the north side of the river, diminishing to around 20 to 50 mg/L at a downstream location where the sediment is fully mixed into 100% of the river flow. These values refer to each of the diversion channels (inlet and outlet), so would be additive if the excavation berms were excavated in unison.
- The flushing of the diversion tunnels when they are first opened to receive river flow would result in a short (one hour) pulse of increased suspended sediment concentration in the order of 340 to 520 mg/L. This sediment would be fully mixed into 100% of the river flow as it passes through the tunnels.

Years 4–8

The river diversion stage of construction would start when the diversion tunnels start to convey river flow. The tunnels would have a smaller cross-sectional area than the natural river channel, so a headpond would form upstream of the tunnel inlets under high flow conditions. Headpond shoreline erosion is expected to occur in an episodic manner, primarily during windstorm events when the headpond level is high. It is expected that shoreline erosion events of a one-day duration would generate incremental increases in suspended sediment concentration in the order of 1 to 20 mg/L, as observed in fully mixed river flow downstream of the tunnel outlets. These events would be most common in the autumn and winter (averaging 12 and 15 daily events per season, per year), and least common in the spring and summer (averaging seven daily events per season, per year), due to seasonal differences in wind conditions and wave energy in the headpond.

Year 7

Toward the end of Year 7, one final set of in-stream construction activities would take place: the excavation and flushing of the tailrace/discharge channel. These activities would result in moderately elevated suspended sediment concentration for a period of approximately 11 days, followed by a short (one hour) pulse of higher suspended sediment concentration when the channel is opened to river flow.

- The first set of activities (11 days' duration) would generate an incremental increase in suspended sediment concentration in the order of 8 to 25 mg/L close to the source where the sediment is mixed into 5% of the river flow along the south side of the river, diminishing to around 1 mg/L at a downstream location where the sediment is fully mixed into 100% of the river flow
- The short pulse (one hour) of sediment associated with the opening and flushing of the channel would generate an incremental increase in suspended sediment concentration in the order of 500 to 1,200 mg/L close to the source where the sediment is mixed into 5% of the river flow along the south side of the river, diminishing to around 25 to 60 mg/L at a downstream location where the sediment is fully mixed into 100% of the river flow

Uncertainty, Sensitivity, and Reliability

The estimation of fine sediment loading due to in-stream construction activities was computed analytically. The input information and calculation methods contained the following sources of uncertainty.

- Grain-size gradation of construction materials: The in-stream construction materials consist of river gravels and riprap. The river gravels to be excavated and/or placed during construction have a range of grain-size gradations. The fine sediment (less than 200 μm) content of the river gravels ranges from 0% to 10%. The finest gradation curve (10% fines) was used in the analysis to provide an upper bound estimate on the availability of fines for entrainment in the river.
- Fraction of fine sediment eroded from construction berms: All fine sediments were assumed to be eroded from the full thickness of construction berms constructed perpendicular to the river flow. All fine sediments were assumed to be eroded from the riverside slope, but not the full thickness, of construction berms constructed parallel to the river flow. These assumptions likely overestimate the actual fraction of fine sediment that would be eroded.
- River flow conditions: The quantity of construction materials exposed to river flow is dependent on river levels. Three river flow/level conditions were considered for each season (5%, 50%, and 95% exceedance). Therefore, a full range of flow conditions was considered.
- Mitigative measures: No special mitigative measures were considered in the analysis, such as pre-washing the river gravels to reduce fine sediment content or targeting construction activities to avoid certain flow conditions. Opportunities to reduce sediment loading through the application of these or other mitigative measures likely exist.

The estimation of incremental increases in suspended sediment concentration due to in-stream construction activities was computed analytically. The input information and calculation methods contained the following sources of uncertainty.

- Duration of construction activities: The minimum duration of in-stream construction activities was computed from equipment productivity rates. The application of these minimum durations provides an upper bound on concentration estimates for a given sediment load.

- Timing of construction activities: The incremental suspended sediment concentration associated with each in-stream construction activity was computed and presented independently. This is thought to represent the likely reality that individual activities would be conducted asynchronously rather than simultaneously. Unlike most of the other sources of uncertainty, this source can be controlled by the construction team.
- Incremental suspended sediment concentrations were not computed at specific locations, but rather at unspecified locations where the construction sediments would be mixed into 5% and 100% of the river flow. In this case, it was decided to avoid introducing uncertainty by trying to predict where these mixing ratios would occur.

The estimation of fine sediment loading due to wave-driven shoreline erosion in the diversion stage headpond was computed analytically. The input information and calculation methods contained the following sources of uncertainty.

- Wave energy: Wave energy in the headpond was modelled based on historical wind speed and direction data from Fort St. John, adjusted to the Peace River valley according to a comparison of in-valley wind data. Uncertainty in wave energy arises from variability in the relationship between wind speed and direction at Fort St. John and in the Peace River valley. The wave modelling is discussed in Volume 2 Appendix B Geology, Terrain Stability, and Soil Reports, Part 2 Preliminary Reservoir Impact Lines, and a statistical evaluation of the wind relationship is discussed in Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report, Appendix B.
- Characterization of headpond shoreline materials: The grain-size distributions and bulk densities of shoreline materials were estimated based on surficial test pit and drill core samples. Some grain-size bias occurred during sampling. The final grain size curves were estimated. The spatial resolution of the shoreline characterization was limited by site access and sample site density. Where sites were not visited in the field, LiDAR imagery and orthophotos were used for interpretation of shoreline material types exposed at key headpond levels.
- Erodibility of headpond shoreline materials: Erodibility coefficients were estimated with dimensions of volume per unit of wave energy guided by observations of shoreline erosion on Williston Reservoir, Dinosaur Reservoir, and other reservoirs with similar geological conditions.
- Headpond levels: High headpond levels were used in the analysis in order to generate conservative estimates of wave energy and shoreline erosion. The headpond surface elevations used in the analysis were 421 m for the higher flow months of November through February, and 417 m for the remainder of the year. These elevations have exceedance frequencies (the percentage of time the value is equalled or exceeded) of approximately 5% and 40% in the respective periods of year specified. Thus, the winter wave energy and erosion results represent upper bound estimates, whereas the non-winter results are closer to median estimates.

The estimation of incremental increases in suspended sediment concentration due to headpond shoreline erosion was computed analytically. The input information and calculation methods contained the following sources of uncertainty.

- Wave erosion events: Monthly erosion loads were grouped into daily events in which daily wave energy exceeded an arbitrary threshold that was exceeded on approximately 12% of the days. This was done to generate higher incremental increases in concentration than would have resulted using monthly erosion values.
- Timing of events: The wave erosion events were treated as discrete events, asynchronous with the in-stream construction activities.
- Sediment settling in the headpond: All fine sediment (less than 200 µm) was assumed to be entrained into suspension and transported downstream out of the headpond on the day of the erosion event. In reality, the transport process would likely be more complex, with some settling of sand and silt in the headpond under high water level conditions, and subsequent re-entrainment and downstream transport during falling water level conditions.

In summary, the information sources and methods used to estimate fine sediment loads due to in-stream construction activities and headpond shoreline erosion are subject to various sources of uncertainty. Analytical sensitivity was addressed by using a range of information inputs to characterize variability (e.g., river flow/level conditions) or else a single value was selected that contributed to an upper bound estimate of sediment loading. The information sources and methods that were used to estimate incremental increases in suspended sediment concentration also contained sources of uncertainty. Here, values were selected to generate upper bound estimates of incremental concentration, and correspondingly, lower bound estimates of elevated concentration duration. The sediment loading events were treated as individual, asynchronous events, which is a likely scenario but not a certain one. Overall, the results are reliable for characterizing expected changes due to the Project.

11.8.5 Operation

11.8.5.1 Suspended Sediment Dynamics in the Reservoir

Approach and Methods

The following approach was used to assess the changes in fluvial geomorphology and sediment transport due to the Project during the operations phase:

- A three-dimensional hydrodynamic and sediment transport model was developed for the Site C reservoir (described below and in Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report)
- Baseline meteorology, hydrology, and suspended sediment transport data for the period 2000 to 2009 were used as inputs to the model
- A new type of sediment source due to wave erosion on the reservoir shoreline was estimated and input to the model as well

The model was run for the 10-year period to generate:

- Suspended sediment concentrations and turbidity in the reservoir
- Suspended sediment outflux load to the downstream study area
- Sediment deposition patterns on the reservoir bed

The period 2000–2009 was selected as the reference baseline period because it represents recent (current) hydro-climatic conditions, and because this period contains a range of hydrologic conditions, including a large flood event in 2001 and low flow years in 2006 and 2009, so is suitable to characterize the range of conditions that could be expected in the reservoir. However, the mean annual suspended sediment load during that decade was estimated to be 13% lower than the 46-year mean, so a separate longer-term (50 years) modelling exercise was undertaken to characterize cumulative sediment deposition with different tributary sediment input conditions. A five-year period was modelled using low (5^{th} percentile), average, and high (95^{th} percentile) tributary sediment inputs and a morphological scale factor of 10 was applied to “accelerate” the morphological evolution of the reservoir bed. This means that a multiplier of 10 was applied to any resultant scour or deposition at each time step in the model run. The morphological scale factor was used to reduce the model run time required for this type of simulation. The scale factor does not alter the sediment concentrations or the water densities in the model, and consequently the main physical processes are not altered unrealistically. This factor only speeds up the scour and deposition at each time step.

Modelling of reservoir sediment dynamics, using the proprietary model H3D, was used to characterize reservoir temperature, as reported in Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report. This tool has been used in a number of studies. Two of the most relevant studies that involve sediment transport in lakes/reservoirs are:

- Cleveland Dam East Abutment Environmental Impact Assessment Study: The model was used to assess the impacts of proposed remedial operations on reservoir turbidity, sedimentation, sediment production, and water supply. The model investigated turbidity and suspended sediment fate in the reservoir during a 7.6 m drawdown of water level for construction purposes.
- Kelowna Waterfront Sediment Transport Study: The model was used to provide the City of Kelowna with baseline sediment transport characteristics for Lake Okanagan from which waterfront development opportunities could be assessed. The model included tributary delta formation for Mission Creek.

Expected Changes

The estimated annual input of fine sediment to the reservoir due to shoreline erosion is 1.1 million t/year in Year 1 of reservoir operation, dropping to 0.55 million t/year by Year 10 as beach platforms develop, reducing the energy of wave impact. The mean annual fine sediment input from the shorelines in the first 10 years is estimated to be 0.78 million t/year, or approximately 57% of the annual suspended sediment inputs from tributaries.

A typical pattern of reservoir surface turbidity during spring freshet is presented in Figure 11.8.9. This Figure illustrates the dominance of the Halfway River in terms of tributary sediment inputs and shows the spatial distribution of near-surface turbidity during the 2007 freshet. Annual and seasonal concentration duration curves for two locations in the reservoir (indicated in Figure 11.8.9) are provided in Figures 11.8.10 and 11.8.11.

In the first 10 years of reservoir life, the average annual outflow of suspended sediment at the dam site is estimated to be about 30% of the total sediment input into the reservoir from both tributary and shoreline sources. The sediment outflow would comprise 98% clay and 2% silt on average.

The remainder of the tributary and shoreline sediment is predicted to be deposited within the reservoir. The estimated thickness of sediment deposition in the reservoir after 10 years would be variable with more deposition near tributary confluences and highly erodible shoreline segments. It is estimated that the deposition thicknesses would range from about 0.1 m in the main reservoir to over 2 m at the Halfway confluence and adjacent to some shoreline segments.

After 50 years of operation, the estimated thickness of reservoir sediment deposition under average sediment load conditions would range from about 0.3 to about 0.5 m in the main reservoir and 3 m to 4 m near some shoreline sections, as shown in Figure 11.8.12. In the Halfway River embayment, a deposition thickness of 3 m to 4 m is expected throughout the embayment, with up to 8 m near some shoreline segments, as shown in Figure 11.8.13.

The initial volume of the entire reservoir is 2,310 million m^3. The modelled sediment deposition volume for the entire reservoir after the first decade is approximately 12 million m^3, or 0.5% of the initial reservoir volume. The modelled deposition volume for the entire reservoir after 50 years is approximately 58 million m^3, or 2.5% of the initial reservoir volume, assuming average sediment input conditions. For the 5^{th} and 95^{th} percentile sediment input conditions for Halfway River, the 50-year deposition volumes in the reservoir would be 46 million m^3 (2.0% of reservoir volume) and 68 million m^3 (3.0% of reservoir volume), respectively.

The initial water volume of the Halfway River embayment at the start of reservoir operations would be approximately 90 million m^3. The sediment deposition volume after the first decade is estimated at 4 million m^3, or less than 5% of the initial embayment water volume. Depending on the sediment input rate, it is estimated that the Halfway embayment would infill by 22% to 35% after 50 years and would infill completely in 150 to 220 years. Once the embayment had infilled, the Halfway River would likely flow in a gravel-bed channel with a meandering or braided pattern within a valley bottom floodplain, and would have a delta slope extending out into the main body of the reservoir.

Uncertainty, Sensitivity, and Reliability

Suspended sediment modelling in the reservoir was subject to uncertainty in the following areas:

- Estimation of meteorological, hydrological, and tributary sediment load data inputs for the period 2000–2009
    - Meteorological inputs were computed based on historical records from Fort St. John, adjusted to the Peace River valley according to a comparison of in-valley meteorology data. Uncertainty in meteorological inputs arises from variability in the relationship between meteorology at Fort St. John and in the Peace River valley. A statistical evaluation of the wind relationship is discussed in Appendix B of Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report.

- Hydrologic inputs were obtained from the Water Survey of Canada streamflow records on the Peace River and its two main tributaries in the reservoir study area: the Halfway and Moberly Rivers. These data were collected within the reservoir study area according to the highest available standards, so represent the least source of uncertainty.
- Tributary sediment inputs were generated based on suspended sediment samples collected in several different years with varying flow conditions, including sampling during peak runoff events. As such, the samples provide good coverage of sediment transport conditions. The main uncertainty in the estimation of tributary sediment inputs lies in the development of discharge-concentration rating curves for use in computing sediment loads during periods other than those directly sampled. Separate rating curves were developed for rising and falling flow conditions for the seasonal snowmelt freshet and large rainstorm runoff events, but some residual scatter remained around the two curves for each tributary. Standard procedures were followed for this work and the level uncertainty in the results is within the normal range, but has not been explicitly quantified.

- Estimation of reservoir shoreline sediment inputs
  - Wave energy: Wave energy in the reservoir was computed based on historical wind speed and direction data from Fort St. John, adjusted to the Peace River valley according to a comparison of in-valley wind data. Uncertainty in wave energy arises from variability in the relationship between wind speed and direction at Fort St. John and in the Peace River valley. The wave modelling is discussed in Volume 2 Appendix B Geology, Terrain Stability, and Soil Reports, Part 2 Preliminary Reservoir Impact Lines, and a statistical evaluation of the wind relationship is discussed in Appendix B of Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report.
  - Characterization of headpond shoreline materials: The grain-size distributions and bulk densities of shoreline materials were estimated based on surficial test pit and drill core samples. Some grain-size bias occurred during sampling. The final grain-size curves were estimated. The spatial resolution of the shoreline characterization was limited by site access and sample site density. Where sites were not visited in the field, LiDAR imagery and orthophotos were used for interpretation of shoreline material types exposed at the reservoir level. The thickness of colluvial deposits overlying in situ materials was estimated using LiDAR imagery and available local subsurface data.
  - Erodibility of headpond shoreline materials: Erodibility coefficients with dimensions of volume per unit of wave energy were guided by observations of shoreline erosion on Williston Reservoir, Dinosaur Reservoir, and other reservoirs with similar geological conditions
  - Wave erosion events: Annual erosion loads were grouped into daily events in which daily wave energy exceeded an arbitrary threshold that was exceeded approximately 15% of the days. This was done to generate higher incremental increases in concentration than would have resulted using average daily erosion values (i.e., annual erosion values divided by 365).

- Representativeness of the period 2000–2009 relative to longer-term future conditions
  - The period 2000–2009 was selected as the reference baseline period because it represents recent (current) hydro-climatic conditions, and because this period contains a range of hydrologic conditions including a large flood event in 2001 and low flow years in 2006 and 2009, so is suitable to characterize the range of conditions that could be expected in the reservoir
  - The mean annual suspended sediment load during that decade was estimated to be 13% lower than the 46-year mean, so a separate longer-term (50 years) modelling exercise was undertaken to characterize cumulative sediment deposition with different tributary sediment input conditions. A five-year period was modelled using low (5th percentile), average, and high (95th percentile) tributary sediment inputs.
- Accuracy of the reservoir model in representing sediment dynamics in the reservoir
  - Model physics: H3D is a sophisticated 3D model that represents all of the fundamental physical processes relevant to sediment dynamics. The calibration and validation of the hydrodynamic model is detailed in Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report. The model was capable of matching observed temperatures in the existing Dinosaur Reservoir and therefore the uncertainty of the underlying physics in the sediment model is low. A mass balance confirmed that all sediment input to the model was either deposited in or transported out of the reservoir.
  - Representation of sediment: One source of uncertainty in sediment transport modelling is the representation of a near-infinite variety of grain sizes with statistical measures such as the median and 90th percentile grain sizes. For this study, sediment was split into three common size classes: sand, silt, and clay, with specific median grain sizes. This approach was used in a similar study on an existing reservoir and turbidity was predicted with a normalized root-mean-square error of 15%.
  - Model resolution: The model grid size was established to provide a balance between computational efficiency and increased resolution in key areas – primarily near the reservoir surface (in the vertical) and near tributary mouths (in the horizontal). The model resolution is sufficient to predict large-scale trends, but not small-scale features such as the development of beaches, wetlands, or distributary channels on tributary deltas.
  - Model time step: The model time step for the first 10 years (represented by input data for the period 2000–2009) ranged from 20 to 40 seconds, whereas the temporal resolution of the input data ranged from hourly to daily. Therefore, the model time step was sufficiently short to properly distribute the incoming inputs of mass and energy.
  - Model time step: To simulate sediment deposition over a longer time period of 50 years, a morphological scale factor of 10 was applied to “accelerate” the morphological evolution in a separate five-year model run. This was achieved by applying a multiplier of 10 to any resultant scour or deposition for every time step. The morphological scale factor was used to reduce the model run time required for a 50-year simulation. The scale factor did not alter the sediment

concentrations or the water densities in the model, and consequently the main physical processes were not altered unrealistically. This factor only sped up the scour and deposition at each time step. The greatest uncertainty in the accelerated methodology would appear in areas with both scour and deposition, such as the upper tributary embayments. However, most of the reservoir is a depositional environment where the accelerated methodology is appropriate.

In summary, spatial and temporal variability in meteorological, hydrological, and sediment transport processes contributes to uncertainty in the estimation of reservoir inputs. These sources of uncertainty are considered to be far greater than the uncertainties associated with the internal mechanics of the reservoir model. In other words, the reservoir model represents the dynamics of sediment in the reservoir with reasonable accuracy, given a specified set of meteorological, hydrological and sediment inputs. The sensitivity of model results to the period of model inputs was considered and addressed by selecting appropriate periods for specific analyses. Overall, the results provide a reliable characterization of the expected changes due to the Project.

11.8.5.2 Suspended Sediment Regime Downstream of the Site C Dam Site

Approach and Methods

Daily suspended sediment loads and concentrations downstream of the Site C dam site to the Alces River confluence were computed analytically using the daily sediment outflux at the Site C dam site generated by H3D, combined with daily baseline loads for downstream tributaries calculated in the baseline study.

Expected Changes

The estimated mean annual suspended sediment load immediately downstream from the Site C dam site under operational conditions is 620,000 t/year, or 46% of the baseline load (i.e., a 54% reduction compared to baseline conditions). Most of the suspended load reduction would occur in the spring, when baseline loads are greatest. The average seasonal suspended load would actually increase slightly in the autumn and winter, when baseline loads are lowest, due to shoreline erosion in the reservoir.

The differences between baseline and predicted operational suspended sediment concentration immediately downstream of the Site C dam site are illustrated in a series of three figures – a time series Figure (Figure 11.8.14) and annual and seasonal concentration duration figures (Figures 11.8.15 and 11.8.16, respectively). These figures illustrate the relatively large reductions in concentration that would occur during baseline peak transport events, and the relatively small increases in concentration that would occur during baseline non-peak periods (i.e., when reservoir tributary inputs are low).

The expected changes in median daily suspended sediment concentration immediately downstream of the Site C dam site during each season are presented in Table 11.8.5.

Table 11.8.4 Expected Median Daily Suspended Sediment Concentration Immediately Downstream of the Site C Dam Site (Baseline and Operations Phase)

Season	Baseline (mg/l)	Operations (mg/l)
Winter (Jan–Mar)	0.1	0.6
Spring (Apr–Jun)	39.6	14.3
Summer (Jul–Sep)	3.2	11.6
Autumn (Oct–Dec)	0.1	6.9

The relative changes in suspended sediment concentration below the Site C dam site would be most pronounced between the dam site and the Pine River confluence, and would diminish in a downstream direction due to tributary flow and sediment inputs. The downstream diminishment of changes would occur at tributary confluences if the cross-sections were laterally mixed. However, changes in suspended sediment concentration would be expected to persist along the left (north) bank of the Peace River downstream of the Pine River confluence due to the long mixing length of the tributary inflows, which varies depending on relative flows in the two rivers and would not change substantially as a result of the Project.

The mean annual suspended sediment load immediately downstream of the Site C dam site during Years 1–10 of operations would be reduced by 54% compared to the baseline condition. The percentage reductions in mean annual load further downstream are presented in Table 11.8.5.

Table 11.8.5 Expected Changes in Mean Annual Suspended Sediment Load in the Peace River (Operations Phase)

Peace River Location	Change in Annual Load
Site C Dam Site	- 54%
Pine River Confluence	- 21%
Alces River Confluence	- 8%
Dunvegan	- 5%
Town of Peace River	- 2%
Peace Point	- 2%

Uncertainty, Sensitivity, and Reliability

The estimate of suspended sediment inputs from tributaries were summed along the Peace River, and net deposition of suspended sediment along the river channel was assumed to be negligible. The primary sources of uncertainty in this analysis are the accuracy of modelled sediment outflows from the reservoir (see Uncertainty, Sensitivity, and Reliability in Section 11.8.5.1 above), the accuracy of estimated baseline sediment inputs from tributaries downstream of the dam (same as in reservoir tributaries, see Section 11.8.5.1, Uncertainty, Sensitivity and Reliability above), and the potential net deposition of a portion of the suspended sediment load along the river. The net deposition in the river has been shown to represent a negligible fraction of the total load based on the similarity of grain-size distributions in the tributaries and the Peace River mainstem, where suspended sediment deposition would comprise primarily fine sand

and would lead to a reduced sand fraction in the Peace River grain-size distribution. Overall, the results provide a reliable characterization of the expected changes due to the Project.

11.8.5.3 Channel Erosion and Deposition Patterns Downstream of the Site C Dam Site

Approach and Methods

The Peace River flow regime below the Site C dam site would not be substantially altered by the Project during the operations phase (refer to Section 11.4 Surface Water Regime). However, channel hydraulics would be altered locally downstream of the tailrace and spillway, bedload supply from upstream of the dam would be eliminated, and some localized changes due to these combined factors are anticipated.

The following modelling exercises were undertaken to assess the influence of locally modified hydraulic conditions and upstream bedload interception:

- A two-dimensional (2D) hydrodynamic model (River2D) was used to assess flow competence during the operational phase. The model is described in Section 11.4 Surface Water Regime. Flow competence was assessed at 4000 m^3/s.
- A one-dimensional (1D) morphodynamic model (HEC-RAS) was developed to assess the potential extent of channel gradation adjustment below the Site C dam site under an extreme flow scenario of 5,000 m^3/s for one year. This flow condition is similar to the high flows recorded during the summer of 1996, but with approximately eight times longer duration, and was selected to provide an upper bound on potential channel change. The HEC-RAS model was calibrated to match the MIKE 11 model described in Section 11.4 Surface Water Regime.

These two models are freely available and widely used for hydraulic and sediment transport analyses. River2D was developed at the University of Alberta (Steffler and Blackburn 2002), while HEC-RAS was developed by the United States Army Corps of Engineers (USACE 2010).

Expected Changes

The Project would intercept the Moberly River bedload material that has been accumulating in the Peace River channel below the confluence since the onset of regulation.

Bed material in the Peace River is rarely mobilized under the normal range of regulated baseline flow conditions, but was likely mobilized in some areas during the Williston Reservoir drawdown in the summer of 1996, when flows exceeded 4,000 m^3/s for 45 consecutive days at the Site C dam site. Under an operational flow scenario of 5,000 m^3/s for one year (i.e., eight times the duration of the 1996 drawdown event), the Peace River bed would degrade (bed elevation could decrease) by approximately 1 m to 1.5 m in a 2 km stretch below the tailrace (generating station outlet) due to bed material mobilization and lack of bedload replenishment from upstream. Much of the scoured bed material would accumulate in a 2 km aggradation (net deposition) zone downstream of the degradation (net erosion) zone, as shown in Figure 11.8.17.

Elsewhere, the Project is not expected to result in any changes in channel erosion or deposition patterns, which are either natural (i.e., valley wall erosion and landslides along the river), or are driven by the ongoing response of the river channel to upstream flow regulation that started in 1967 (i.e., aggradation below tributary confluences, local bank erosion opposite from tributary confluences, and vegetative encroachment onto gravel bars and into secondary channels).

Uncertainty, Sensitivity, and Reliability

The primary sources of uncertainty in this analysis are the characterization of subsurface riverbed material, characterization of hydraulic conditions in the river, and computing of bedload transport based on the above.

- A large number of bed material grain-size samples were collected on the surfaces of exposed gravel bars and on the wetted channel bed surface. These samples give some indication of the bulk characteristics of the subsurface material, but the latter typically contains a greater component of finer sediment. A smaller number of subsurface bulk samples was used to characterize the subsurface grain-size characteristics. Subsurface sediments tend to be less spatially variable because they tend to be deposited during large flood events and are not exposed to subsequent variable flow conditions at the riverbed surface, so the smaller number of subsurface samples is adequate.
- A one-dimensional (1D) model, HEC-RAS, was used to characterize hydraulic conditions in the river. HEC-RAS is a widely used hydraulic model developed by the US Army Corps of Engineers. A 1D model represents cross-sectional average depth and velocity conditions, but does not capture lateral variability. Such a model was adequate for the intended purpose of estimating average bed degradation depth and longitudinal extent. It was not intended to represent detailed patterns of scour and deposition at scales of less than one channel width.
- The Meyer Peter Muller bedload transport formula was employed to compute transport within the HEC-RAS model. This is one of the most widely used bedload transport formulae used in gravel bed rivers.

The channel erosion analysis contains uncertainty with respect to the spatial variability of bed material composition, the probability of extreme high flow conditions, and the accuracy with which bedload transport can be computed (limited by the state of the science). The analysis used the best estimates of bed material composition and bedload computation methods, and a high estimate for extreme high flow conditions, in order to generate an upper bound estimate of channel change. The results provide a reliable characterization of how much channel change could be expected due to the Project.

11.8.6 Summary of Expected Changes

Construction Phase – Downstream Suspended Sediment

In-stream construction activities would be carried out in Years 1, 4, and 7. Onshore construction activities would be conducted throughout the eight-year construction phase in isolation from the river, with site runoff managed according to an Environmental Management Plan. Headpond shoreline erosion would occur during periods of high flow during the diversion stage of construction.

Over the eight-year construction phase, the fine sediment inputs related to in-stream construction activities would represent an estimated increase of 0.2% to 0.3% above mean annual baseline sediment load immediately downstream of the Site C dam site. Over the four-year diversion stage of construction, the fine sediment inputs related to headpond shoreline erosion would represent an estimated increase of 1% above mean annual baseline sediment load immediately downstream of the Site C dam site. The sediment inputs would likely occur as asynchronous event-type pulses.

The in-stream construction activities are expected to generate elevated suspended sediment concentrations for durations ranging from a few hours to a few months. The incremental increases in suspended sediment concentration would be in the order of 10 to 1000 mg/L at locations close to the source (i.e., mixed into 5% of the river flow), decreasing to lower levels once fully mixed in the river flow at some location downstream of the Pine River confluence. The exception to this is the flushing of the diversion channels and tunnels at the start of the river diversion stage (Year 4), when a brief (one hour) pulse of high concentration would occur: 300 to 500 mg/L in fully mixed flow immediately downstream of the tunnel outlets. The headpond shoreline erosion events are expected to generate incremental increases in suspended sediment concentration in the order of 1 to 20 mg/L in the fully mixed river flow immediately downstream of the tunnel outlets. These events would occur on approximately 12% of the days during the four-year diversion stage of construction, with greater frequency in the autumn and winter and lower frequency in the spring and summer.

Operations Phase – Reservoir

The proposed reservoir would trap a portion of the sediment delivered from tributaries, while the remainder (mostly clay) would be transported out of the reservoir and down the Peace River.

Wind-driven waves in the reservoir would erode the valley slopes and create a new source of sediment in the reservoir/river system. A portion of this sediment would be trapped in the reservoir, while the remainder (mostly clay) would pass through the dam and travel down the Peace River.

After 50 years, the depth of sediment deposition throughout most of the reservoir would range from 0.3 to 0.5 m, while depths of several metres would accumulate near some of the more erodible shoreline sections and in the Halfway River embayment.

Operations Phase – Downstream Suspended Sediment

The mean annual suspended sediment load in the Peace River immediately downstream of the Site C dam site would be reduced by approximately 54% over the first 10 years of reservoir life. The load would further diminish through time as reservoir shoreline erosion rates decline.

The relative reduction in mean annual suspended sediment load during the first 10 years of reservoir life diminishes in a downstream direction, from 54% at the Site C dam site to 2% at the Town of Peace River and 2% at Peace Point.

The reduction in suspended sediment load would occur primarily during baseline peak events (spring snowmelt and summer rainstorms). Due to reservoir attenuation, the median daily concentration downstream of the dam would actually increase in summer, autumn, and winter (by a small amount from low baseline values), and would only decline in the spring (by a larger amount from higher baseline values).

Downstream Channel Erosion and Deposition Patterns

The Site C dam would intercept bedload and locally alter hydraulic conditions in the Peace River. In the event of sustained high flows – similar in magnitude to the summer of 1996 when Williston Reservoir was drawn down, but with eight times the duration – the bed of the Peace River would erode vertically by 1 to 1.5 m over a 2 km length downstream from the dam. Most of the eroded bed material would accumulate in a deposition zone in the next 2 km downstream. This is an extreme high flow scenario that was modelled for the purpose of establishing an upper bound estimate in downstream channel change.

Further downstream, channel erosion and deposition patterns are governed primarily by river flows and tributary bedload inputs. Changes in river flows due to the Project are not expected to influence the erosion and deposition patterns; therefore, no incremental changes to the dynamic baseline patterns are predicted.

All of the expected changes are well contained within the specified study areas.

11.8.7 Climate Change

Baseline conditions in the Peace River are intrinsically linked to the prevailing climate, particularly the magnitude and temporal distribution of seasonal and storm-event runoff volumes in the tributaries that join the Peace River downstream of the two existing hydropower dams.

Suspended and bedload sediment transport are positively related to streamflow discharge, and the relationships are non-linear. Most of the sediment transport occurs during a relatively small fraction of time when flows are the highest. The linkages between climate, runoff, and sediment transport in the Peace River tributaries are described below.

Snowmelt runoff in mountain-headwater tributaries such as the Pine River occurs in the late spring and early summer (typically peaking in June), which coincides with the time of year that is prone to the most intense rainstorms. Therefore, peak flows in these tributaries often result from a combination of rainfall and snowmelt. Snowmelt runoff in plateau tributaries such as the Kiskatinaw River occurs in early to mid-spring (typically peaking in May), and is less synchronized with the timing of the most intense rainstorms. The largest peak flows in these tributaries usually result from summer rainstorms. Streamflows in mountain-headwater and plateau tributaries currently reach their minimum levels in late winter.

Future climate trends in the Peace River watershed (summarized in Volume 2 Appendix T Climate Change Summary Report) suggest that the following changes are likely to occur by the 2050s time period (with the same general patterns for the 2080s time period):

- Increased temperature year-round, with the greatest increases in the winter
- Increased precipitation year-round, with the greatest increases in the winter and spring
- Negligible change in snowpack in the Rocky Mountains (net balance between increased winter precipitation and increased winter temperature)

- Decreased snowpack on the Alberta Plateau (increased winter temperature dominates over increased winter precipitation)
- Increased annual streamflow in Peace River tributaries (mountains and plateau), with the greatest increases in the autumn, winter, and spring, and reduced flows in late summer
- Earlier onset of spring snowmelt freshet in the mountain-headwater tributaries, with a shift in the peak from June to May

Based on the above, the following changes in streamflow patterns relevant to sediment transport regime are hypothesized:

- Increased annual and seasonal precipitation may correspond with increased rainstorm intensity and increased storm runoff
- Larger snowmelt runoff volumes are predicted in the mountain-headwater tributaries, but with potentially less synchronization of snowmelt and rainstorm runoff in these tributaries. The net change in peak flow magnitude in the mountain-headwater tributaries due to increased early spring rainfall, stable snowmelt runoff, increased rainstorm intensity, and reduced synchronization between snowmelt and late spring rainstorms is difficult to predict from the available information. However, the most likely result would seem to be an overall increase in runoff volume, peak flow magnitude, and sediment transport capacity.
- Decreased snowmelt runoff volumes are predicted in the plateau tributaries, but an increase in late spring and summer rainstorm intensity would result in increased peak flows. These peak flows mainly occur in the absence of snowmelt already, so the reduced snowmelt would not be expected to counteract this change. The increased peak flows would result in increased sediment transport capacity.

The most likely changes that can be expected from the available information are for increased suspended sediment and bedload transport loads in mountain-headwater and plateau tributaries of the Peace River. These in turn would result in a greater turbidity and deposition in the proposed reservoir, greater suspended sediment loads and turbidity in the Peace River downstream of the Site C dam site, and greater bedload deposition at tributary mouths downstream of the dam site. Although it is not currently possible to quantify the magnitude of the potential increase in sediment inputs due to climate change, it is thought to be within the range of uncertainty in the baseline data collection and modelling studies of project-related changes, and would not result in a materially different description of sediment dynamics in the reservoir or in the Peace River downstream of the dam site.

11.9 Methylmercury

11.9.1 Objective and Section Structure

This section on methylmercury describes the approach used to: a) describe baseline conditions of mercury (Hg) and methylmercury (MeHg) in the technical study area for methylmercury, b) explore specific factors that influence mercury methylation in general and in the proposed Site C reservoir specifically, c) review the models and other lines of evidence that were used to determine how operation of the Project may change these conditions, and d) predict changes in MeHg concentration in the aquatic food web, with a focus on fish in the Site C reservoir and downstream. This prediction has been used to inform the human health risk assessment (HHRA) for methylmercury (Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modeling) and Volume 4 Section 33 Human Health. This section is organized according to the following subsections:

- Reservoir creation and methylmercury dynamics – This subsection explores the relationship between inundation of terrestrial soils during reservoir creation and enhanced methylmercury generation, with a discussion of the general trends that have been observed in other Canadian reservoirs.
- Technical study area – The technical study area includes the Site C reservoir and the Peace River, extending as far downstream as Many Islands, Alberta. Mercury may be transported downstream of the reservoir, adhered to sediment particles and organic material, as well as directly in the tissue of plankton and fish that are discharged or entrained downstream. Fisheries investigations indicate that fish populations within the Peace River move between the Site C dam and Many Islands (Volume 2 Appendix O Fish and Fish Habitat Technical Data Report). Fish that feed on injured or stunned fish entrained from the reservoir that have accumulated MeHg may become distributed within the Peace River, potentially as far as Many Islands.
- Site-specific factors of the Project – Several key physical, chemical, and ecological parameters affect the rates of Hg methylation/demethylation, bioaccumulation and biomagnification of MeHg within aquatic food webs of rivers, lakes, and reservoirs. This subsection summarizes relevant terrestrial (i.e., existing areas forecast to be inundated during reservoir creation) and aquatic baseline information pertinent to establishing baseline conditions for the Site C reservoir. This includes mercury and methylmercury concentrations in terrestrial (soil, vegetation) and aquatic (water, sediment, invertebrates, fish) media.
- Predicting changes in mercury in fish – Three independent lines of evidence were used to determine how mercury in fish would change following creation of the Site C reservoir. These included a simple regression model (Harris and Hutchinson 2012), a complex mechanistic model called RESMERC (Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling) and a 'weight-of-evidence' or matrix approach, whereby many physical, chemical, and ecological parameters associated with increased methylation rates observed in several Canadian reservoirs were contrasted with baseline and predicted conditions within the Site C reservoir (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

- Integrated assessment of changes to fish mercury concentrations for the Project – Each of the above lines of evidence were integrated together to determine the change in fish methylmercury concentrations within the Site C reservoir and downstream. This is expressed as a multiplier of existing baseline concentrations. Finally, the duration that concentrations in fish are predicted to be elevated before returning to baseline is estimated.

The information underlying the discussion of this section can be found in the following documents: Mercury Technical Synthesis Report (Part 1 of Volume 2 Appendix J Mercury Technical Reports), Reservoir Modelling Report (Part 3 of Volume 2 Appendix J Mercury Technical Reports). This information also informs Volume 4 Section 33 Human Health.

11.9.2 Mercury Terminology

This subsection clarifies terminology used when referring to inorganic mercury (Hg) and organic or methylmercury (MeHg). When referring to ‗total mercury‘, this is the sum of all forms of Hg, whether in the inorganic or organic forms, primarily MeHg. Both of these forms of mercury occur naturally in the environment and their concentrations vary widely according to which media (e.g., water, sediment, aquatic insects, fish) is being referred to. For example, the concentration of MeHg in fish is many million times more concentrated than in water. Furthermore, the proportion of the total Hg concentration that comprises MeHg also varies according to media. This is often termed as the methyl: total ratio. For example, in all environmental media (except fish), the ratio of MeHg relative to total Hg is small and difficult to measure, except using sophisticated methods by a small number of specialized laboratories. To illustrate this, the typical percentage of the total Hg concentration that comprises MeHg in various environmental media is as follows:

- In vegetation, soil and sediment, ~~and soil,~~ MeHg makes up less than 2% of total mercury
- In water, MeHg usually comprises less than 5% of the total mercury
- ~~In vegetation and soil, MeHg makes up less than 2% of the total Hg measured~~
- In benthic invertebrates, MeHg comprises 30 – 50% of total Hg
- In fish, nearly all of the measured mercury is present as MeHg (Bloom 1992). Also, the absolute concentration of MeHg in fish is much higher in fish than in all other media, especially water, soil, vegetation, and sediment.

Thus, when referring to fish Hg concentrations, although the term Hg is used, it is assumed that it is entirely MeHg. This is why commercial laboratories measure for total Hg in fish, not MeHg, which is more complex and costly.

11.9.3 Reservoir Formation and Methylmercury Dynamics

Under natural conditions, Hg is present in low concentrations in all environmental media including water, soil, sediment, and plants, and in all terrestrial and aquatic animals. As noted above, methylmercury occurs in far lower concentration than does inorganic Hg in all environmental media except fish. In soils, water, and sediment, inorganic Hg is the prevalent form and originates from atmospheric (natural or anthropogenic) and geologic sources. Over time, inorganic Hg captured from the atmosphere by the leaves and needles of plants falls to the ground and accumulates, being sequestered and concentrated into terrestrial soils. Under these conditions, the natural rate of Hg methylation is low. However, when soils are flooded, degradation of the organic material creates favourable and accelerated conditions for sulphate-reducing bacteria that transform or “methylate” some of the inorganic Hg into organic mercury, primarily methylmercury (although there are other forms). The rate of bacterial activity and mercury methylation is governed by many factors such as the amount and quality of organic carbon, pH, and sulphate, not necessarily the mass of inorganic Hg available.

Methylmercury is much more easily absorbed and accumulated by animals than inorganic Hg. Once MeHg is incorporated by bacterial tissue, it becomes part of the food chain. MeHg accumulates at a greater rate than it degrades or is eliminated, accumulating over time within an organism (i.e., bioaccumulation), and becoming more concentrated through successive trophic levels (i.e., biomagnification). Thus, MeHg concentrations are higher in large-bodied, longer-living animals, especially those at the top of the food chain such as predatory fish (Potter et al. 1975; Abernathy and Cumbie 1977; Bodaly and Hecky 1979; Bodaly et al. 1984, 1987; Hall et al. 1997).

Flooding of terrestrial soil and vegetation to form new reservoirs creates conditions favourable for accelerating methylation rates. The degree to which this happens and how long these conditions persist varies among reservoirs. The rate and magnitude of MeHg production is affected by many factors, and the response to inundation and reservoir creation differs among reservoirs. This is explored in detail in the Mercury Technical Synthesis report (Part 1 of Volume 2 Appendix J Mercury Technical Reports). Data from Canadian reservoirs agree in the general pattern of changes in fish Hg concentration over time. Mercury in adults of large, predatory species increases rapidly, with peak concentrations three to eight years after impoundment, after which levels decline to eventually reach pre-impoundment (or baseline) concentrations 15 to 25 years later (Schetagne et al. 2003; Munthe et al. 2007).

Fish-eating species (e.g., lake trout, bull trout) have the highest peak Hg concentrations, take the longest to reach maximum levels, and take longer to return to a baseline level, although there is variability in each of these endpoints (Bodaly et al. 1997, 2007; Schetagne et al. 2003). These differences are related to many reservoir-specific conditions, especially water residence time, ratio of reservoir area to original wetted area, organic carbon in soils, water pH, amount of flooded wetland, and food web complexity. The physical, chemical, and ecological factors that contribute to this are explored below and in detail within the Canadian reservoirs comparison matrix of the Hg Synthesis Report (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

11.9.4 Technical Study Area

The change in MeHg concentration in environmental media will occur primarily within the Site C reservoir, but also downstream in the Peace River, extending as far as Many Islands Alberta (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

Within the reservoir, changes will occur between Peace Canyon Dam to the Site C dam and in the lower reaches of the larger tributaries (Halfway and Moberly). A strong factor influencing the containment of MeHg within a new reservoir is the degree of erosion and export of carbon and MeHg in water, sediment, and biota out of the new reservoir. Some of this might occur during the construction phase, which is not accounted for here, and will make predictions slightly more conservative because it is assumed that no carbon is exported before the reservoir is impounded. The main factors that influence sedimentation rates are reservoir depth, water residence time, and particle settling time. The Volume 2 Appendix I Fluvial Geomorphology and Sediment Transport Technical Data Report suggests that there may be considerable erosion of banks and sediment deposition (principally gravel and sand, and some silt) throughout the reservoir, especially during the first 10 years after impoundment. This would have the effect of reducing Hg methylation by burying organic soils under a thin layer of inorganic material. This may also reduce the export of Hg that is adhered to organic matter from being transported out of the reservoir and discharged downstream.

In addition to changes within newly created reservoirs, changes may also extend downstream. For example, downstream export of inorganic Hg adhered to carbon has been observed in some Quebec reservoirs (Schetagne et al. 2000), Southern Indian Lake, Manitoba (Bodaly et al. 1997) and in the Churchill River downstream of Smallwood Reservoir, Labrador (Anderson 2011). Changes to Hg concentrations in fish downstream of reservoirs occurs either when a fish species increases its consumption of fish, or shifts its diet from algae and invertebrates (e.g., longnose sucker or whitefish) to a diet with a higher proportion of fish, such as when targeting fish that have been injured or killed from passage through turbines. An increased diet of fish with elevated Hg may increase Hg in some downstream fish (Brouard et al. 1994). The increase is not related to export of MeHg dissolved in water, as food remains the dominant source of MeHg in fish (Hall et al. 1997). In upstream reservoirs with a long hydraulic residence time and large settling capacity, the implications for accumulation of Hg for downstream fish appear to be reduced. The degree to which an increase of Hg in fish may occur downstream of a new reservoir in some individuals of some species that do not normally consume fish and may be exacerbated in some fish consumers such as bull trout and lake trout is difficult to predict.

The downstream extent of changes in fish Hg for the Project may extend to the area of Many Islands. This is the furthest downstream extent that local fish populations have been shown to migrate upstream from, to as far as the Site C dam site, based on fish tagging studies (Volume 2 Section 12 Fish and Fish Habitat).

11.9.5 Site-Specific Factors Relevant for Predicting Changes in Fish Methylmercury Concentration

Several key physical, chemical, and ecological parameters affect the rates of Hg methylation/demethylation, bioaccumulation, and biomagnification of MeHg within the food web. The most important factors are baseline MeHg concentrations in environmental media, hydraulic residence time, flooded area relative to original area, pH of water/sediment, the amount and chemical composition of the newly flooded soil, and invertebrate and fish community structure (particularly the number of trophic levels). Reservoir-specific differences in these factors are responsible for the substantial variability in the number of years for fish to reach peak mercury concentrations, the magnitude of those peaks, and the return time to pre-flooding conditions that has been observed among reservoirs (Bodaly et al. 2007; Schetagne et al. 2003).

The following subsections summarize relevant terrestrial (i.e., existing terrestrial areas inundated as a result of reservoir creation) and aquatic baseline information pertinent to establishing the starting conditions for the Site C reservoir.

11.9.5.1 Baseline Terrestrial Media

Organic soils in flooded terrestrial habitats are the medium for accelerated bacterially mediated methylation rates and mobilization of MeHg into aquatic food chains in newly created reservoirs. In addition to Hg concentrations (mg/kg) in terrestrial soils and vegetation, inventories or the mass of mercury (kg Hg/ha) and carbon (metric tonnes C/ha) in these environmental media are important drivers of Hg methylation. The most important component is the uppermost organic fraction represented by the litter, fermentation, and humus horizons, within several centimetres (<5 cm) of the surface. Labile (i.e., easily decomposable, bioavailable) carbon and Hg in these horizons also supports mercury methylation.

As described in detail in the Mercury Technical Synthesis Report (Part 1 of Volume 2 Appendix J Mercury Technical Reports), terrestrial ecosystem mapping (TEM) was used to stratify the relative spatial abundance (ha) of different habitat types. Organic soils beneath well-developed deciduous and coniferous forests contain the vast majority of the mass of Hg and organic nutrients to fuel the methylation process. Mercury and carbon pool sizes (i.e., the mass of Hg or carbon stored per m^2 of habitat) were estimated across flooded habitats using organic soil horizon thickness, soil bulk density, and soil total Hg concentrations. Mercury was also measured in vegetation, including leaves and needles from dominant trees (e.g., spruce, balsam, willow, alder), shrubs (e.g., prickly rose, willow, and dogwood), and grasses (e.g., horsetail, sedge, reeds, cattail). However, vegetation is a minor source of Hg relative to soil contribution, and woody debris from trees is not a major contributor to the methylation process.

Total Hg concentration in all plant tissues in the study area was low, in most cases just above the laboratory detection limit of 0.005 mg/kg dw. Methylmercury was not measured, as MeHg comprises a very low proportion (<2%) of total Hg concentration in plants (Rasmussen 1995; Grigal 2003). The most abundant shrub (<0.008 mg/kg dw) and tree species (<0.005 to 0.019 mg/kg) had low and similar Hg concentrations.

The average total Hg concentration of all organic soils within the upper 5 cm (i.e., the zone available for methylation) within the area forecast to be inundated by the Site C reservoir was 0.079 ± 0.03 mg/kg dw, ranging from 0.02 to 0.17 mg/kg dw. This is consistent with the range in Hg concentrations in soils (0.01 to 0.2 mg Hg/kg) measured elsewhere from background non-mineralized areas (e.g., Rasmussen 1994; Lodenius 1994; McKeague and Kloosterman 1974). Soil organic layer thickness, organic content, and Hg concentration were integrated across the inundation area to estimate carbon (kg C/m^2) and mercury (µg Hg/m^2) pools for use in Hg modelling (see the RESMERC report in Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modeling). These were estimated at 0.54 – 1.2 kg C/m^2 and 0.16 – 0.36 mg Hg/m^2, respectively.

11.9.5.2 Baseline Aquatic Media

Key parameters in the aquatic environment that influence generation and bioaccumulation of MeHg are hydrology, limnology, and specific water and sediment chemistry parameters (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report). The current ratio of inorganic to organic mercury in total Hg was measured in aquatic environmental media within the technical study area from Dinosaur Reservoir to downstream of Peace Canyon Dam in the Peace River and, in some cases, as far as Many Islands. The majority (>95%) of Peace River water between the Peace Canyon Dam and the Site C dam is discharged from Williston/Dinosaur reservoirs and is highly influential on the chemistry and ecology of the general area. Water discharged from Williston Reservoir is nutrient poor (ultra-oligotrophic), cold (<14oC) and well oxygenated all year (Stockner et al. 2005), of moderate to slightly basic pH (7.8 – 8.2), low in organic carbon content (<2 mg/L), and with low total suspended solids concentrations (<3 mg/L) during all times of the year (Golder 2009a, b). The only exception is during freshet or flood flows from large tributary streams such as Halfway River.

Water quality baseline conditions are not expected to markedly change, given the influence of Williston Reservoir upstream, which will continue to influence mercury methylation rates in the downstream reservoir. Given the short hydraulic residence time of water in the Site C reservoir (approximately 23 days), water discharged from Williston Reservoir will continue to influence downstream water temperature, oxygen, nutrients, suspended solids inputs, and biota, even during operation of the Site C reservoir (Volume 2 Section 11.4 Surface Water Regime, Section 11.5 Water Quality, and Section 11.7 Thermal and Ice Regime).

11.9.5.2.1 Water Chemistry and Mercury

Key parameters known to influence Hg methylation and total MeHg concentrations in environmental media are summarized here, with further detail in Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report and Volume 2 Appendix E Water Quality Baseline Conditions in the Peace River. The technical study area of the Peace River downstream of Williston Reservoir is slightly alkaline with a mean pH of 8.1 (7.5 to 8.4). Major tributary stream (e.g., Halfway, Moberly, and Pine) pH is slightly higher than mainstem pH values. Total suspended solids (TSS) concentrations vary considerably seasonally, episodically, and annually depending on rainfall and freshet flow volume within the Peace River downstream of Williston Reservoir (Golder 2009a). During most of the year, TSS in the mainstem of Peace River technical study area is below the routine laboratory detection limit of 3 mg/L. Tributary streams, especially Halfway, Moberly, and Pine, contribute high TSS during freshet or high rainfall events, with concentrations ranging in the hundreds of mg/L, which can increase Peace River concentrations (tens of mg/L). Total organic carbon concentrations (TOC) in Dinosaur Reservoir, Peace River between Peace Canyon dam and the Site C dam, Halfway and Moberly rivers were less than 5 mg/L, with dissolved concentrations making up >90% of the TOC. TOC concentrations in excess of 5 mg/L are associated with greater rates of MeHg production.

Total Hg concentrations in water from remote, pristine areas removed from industrial activities and natural sources (i.e., mineralized areas, volcanoes) range from <1 ng/L – 5 ng/L, or parts per trillion (i.e., <0.001 – 0.005 µg/L) (e.g., Hurley et al. 1995; Krabbenhoft et al. 1999, 2007). In the Peace River technical study area, exclusive of high TSS events during freshet, total Hg concentration seldom exceeded 1 ng/L. This low total mercury concentration is a reflection of low Hg water discharged from Williston

Reservoir. Similarly low concentrations were measured from Williston Reservoir in the early 2000s (Baker et al. 2002), and these data suggest that conditions have not changed over the last nearly 15 years.

Methylmercury concentration in Peace River and tributary stream water within the technical study area was consistently below the laboratory detection limit of 0.05 ng/L in nearly all samples. The only exceptions occurred during 2011 in the Moberly River (332 mg/L; 0.13 ng/L MeHg) and Halfway River (1960 mg/L; 0.34 ng/L MeHg) during a high flow event.

11.9.5.2.2 Sediment

Total Hg concentration in sediment along the Peace River in 2007 was either below the laboratory DL (0.05 mg/kg) or in low concentration (0.053 to 0.110 mg/kg dw) when detectable (Golder 2009b; Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report). Total Hg was non-detectable in Halfway and Farrell rivers, except for one sample from Moberly River (0.057 mg/kg dw). These low Hg concentrations are partly due to the sandy grain size of the river sediments (48% to 80% sand) and low TOC content (<1%) of sediment biomass. Subsequent sampling targeted fine sediments (>85% silt/clay) within and beneath the sand/gravel/cobble substrate measured 0.03 – 0.06 mg Hg/kg dw and 0.05 – 0.06 mg Hg/kg in Farrell, Halfway, and Moberly rivers. Methylmercury concentrations in Peace River (0.15 to 1.2 µg/kg) and tributaries (0.6 – 2.5 µg/kg) from the technical study area were similar and comprised <3% of the total concentration. These values are low and similar to or less than sediment Hg concentrations elsewhere in B.C. and elsewhere in Canada.

11.9.5.2.3 Aquatic Invertebrates

The dominant dietary organisms for fish in the Peace River technical study area were epibenthic invertebrates dominated by caddisflies and mayflies, with fewer numbers of stoneflies, water boatmen, snails, mites, clams, and chironomid fly larvae (Volume 2 Appendix P Aquatic Productivity Reports, Part 1 Baseline Aquatic Productivity in the Upper Peace River). The Peace River downstream of Williston Reservoir does not have a resident zooplankton community. Instead, zooplankton within the Peace River upstream of the Site C dam to Peace Canyon Dam is representative of what has been discharged out of Williston Reservoir downstream. Consequently, Hg/MeHg concentrations in zooplankton in the Peace River technical study area are very similar to that in zooplankton from Williston Reservoir. Total Hg in zooplankton in the Peace River downstream of the Peace Canyon Dam to the Site C dam site ranged from 0.004 to 0.009 mg/kg (ww). This concentration in zooplankton is similar to what was observed in Williston Reservoir 12 years earlier (Baker et al. 2002). The MeHg concentration in zooplankton from the technical study area was only 5 – 10% the total Hg concentration (0.0001 – 0.0007 mg/kg ww).

Total mercury concentration in benthic invertebrates collected from the Peace River mainstem of the technical study area (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report) ranged from 0.010 to 0.082 mg/kg ww. Methylmercury concentrations ranged from 0.003 to 0.030 mg/kg ww, ranging from 20% – 63% of total Hg concentration. There was variation among discrete taxa groups, as chironomid larvae (0.06 mg/kg total and <0.04 mg/kg methylmercury) and water boatmen (Corixidae) had higher Hg concentrations (0.05 mg/kg total and 0.04 methyl) and total to methyl ratios than aquatic insects (e.g., Trichoptera 0.016 mg/kg ww total Hg, 0.005 mg/kg MeHg) (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

These concentrations are comparable to or slightly lower than concentrations observed in reservoirs studies elsewhere in Canada, including La Grande, Quebec (0.013 to 0.026 mg/kg ww; Tremblay et al. 1996), Manitoba (0.02 to 0.21 mg/kg ww; Jackson 1988) and Finland (0.018 to 0.14 mg/kg; Sarkka 1979).

11.9.5.2.4 Fish

The fish community of the Peace River technical study area has been studied extensively (e.g., Aquatic Resources Ltd. 1991; Mainstream Aquatics 2009, 2010, 2011) and Hg concentration data have been collected periodically dating back to the early 1990s (e.g., Pattenden et al. 1991). Tissue Hg analysis has mainly focused on the dominant species observed downstream of Williston Reservoir to the Site C dam site including bull trout, lake trout, Arctic grayling, burbot, lake whitefish, mountain whitefish, rainbow trout, longnose sucker, and redside shiner. Mercury concentration data have also been collected from fish species found downstream of Site C as well, as far as Many Islands (northern pike, walleye, goldeye, burbot) and those whose habitat extends into Alberta.

The main influencing factors of fish Hg concentrations are MeHg in prey, age, and size of fish, growth rates, bioenergetics and reproduction. Because MeHg accumulated by fish is primarily from dietary sources, body burden concentration is highly dependent on concentrations in their food, and trophic status. Invertebrate MeHg concentration data described above were used as baseline values from which changes to invertebrate MeHg and fish Hg concentrations in the Site C reservoir were predicted using the RESMERC model (Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling).

Table 11.9.1 summarizes recent fish mercury data for Dinosaur Reservoir and the Peace River technical study area as far downstream as Many Islands. Only data from burbot are reported from as far downstream as the Dunvegan project. Despite the diversity of fish species and their dietary habits, differences in mercury concentrations among species were small.

Results of fish Hg concentrations from the technical study area are:

- Bull trout Hg concentration ranged between 0.03 – 0.34 mg/kg, with a mean of 0.08 mg/kg, less than from Dinosaur Reservoir (0.12 mg/kg). It is noteworthy that only one bull trout measured 0.34; all other fish were <0.18 mg/kg.
- Mean Hg concentration in mountain whitefish and rainbow trout from Peace River and Dinosaur Reservoir were low and within a narrow range (0.03 to 0.09 mg/kg)
- Mercury in longnose sucker downstream of Peace Canyon Dam to the Site C dam was 0.05 mg/kg and 0.06 mg/kg downstream to Many Islands, Alberta
- Mean Hg of redside shiner downstream from the Site C dam site was 0.05 mg/kg
- Mercury concentrations in fish found only downstream of Site C dam site into Alberta including walleye (0.08 – 0.33 mg/kg), goldeye (0.13 – 0.31) and burbot (0.02 –

0.14 mg/kg) had higher concentrations than fish residing upstream of the B.C.–Alberta border. No northern pike were captured and there are no Hg data for this fish species.

Mean Hg concentrations of all fish species in the Peace River between the Peace Canyon Dam and the Site C dam were less than 0.10 mg/kg, with concentrations in nearly all fish less than 0.20 mg/kg. These are low concentrations, especially for the large piscivorous species bull trout and lake trout. These concentrations lower than for the same species of a similar size in all other B.C. lakes and reservoirs for which there are Hg data (Rieberger 1992; Baker 2002) (Table 11.9.2) and among the lowest in Canada (Depew et al. 2012).

Table 11.9.1 Recent (2008–2011) Peace River Technical Study Area Fish Mercury Concentrations

Species	Area	Year[1]	Sample Size	Length (mm)		Weight (g)		Hg (mg/kg ww)		Reference
				Range	Mean	Range	Mean	Range	Mean	
Bull trout										
	Peace River – Site C study area	2008	21	248 - 741	484	166 – 5450	1684	0.042 – 0.14	0.08	Mainstream 2009a
	Peace River – Downstream[2]	2008	4	211 - 544	336	100 – 1798	618	0.018 – 0.12	0.07	Mainstream 2009a
	Dinosaur Reservoir	2010/2011	6	285 - 811	476	262 – 7775	2519	0.038 – 0.34	0.12	Volume 2 Appendix J, Part 1
	Peace River – Site C study area	2010/2011	19	292 - 806	470	308 – 7160	1635	0.031 – 0.34	0.07	Volume 2 Appendix J, Part 1
	Peace River – Downstream	2011	2	500 - 558	529	1350 – 1822	1586	0.077 – 0.09	0.08	Volume 2 Appendix J, Part 1
Burbot										
	Peace River – Dunvegan	2008	43	274 – 790	474	132 – 2550	753	0.018 – 0.14	0.06	Mainstream 2009b
Goldeye										
	Peace River – Downstream	2010/2011	10	310 – 410	379	314 – 854	600	0.136 – 0.31	0.24	Volume 2 Appendix J, Part 1
Lake trout										
	Dinosaur Reservoir	2010/2011	28	304 – 630	414	262 – 2676	865	0.029 – 0.14	0.09	Volume 2 Appendix J, Part 1
	Peace River – Site C study area	2010	1	—	391	—	570	—	0.07	Volume 2 Appendix J, Part 1
Longnose sucker										
	Dinosaur Reservoir	2010/2011	12	268 – 434	393	240 – 1074	755	0.063 – 0.36	0.20	Volume 2 Appendix J, Part 1
	Peace River – Site C study area	2010/2011	31	295 – 442	388	362 – 1172	770	0.017 – 0.17	0.05	Volume 2 Appendix J, Part 1
	Peace River – Downstream	2011	10	373 – 442	403	654 – 990	779	0.019 – 0.10	0.06	Volume 2 Appendix J, Part 1
Mountain whitefish										
	Peace River – Site C study area	2008	30	209 – 466	340	94 – 1180	483	0.018 – 0.09	0.04	Mainstream 2009a
	Peace River – Downstream	2008	31	202 – 512	355	74 – 1526	570	0.014 – 0.09	0.04	Mainstream 2009a
	Dinosaur Reservoir	2010/2011	21	246 – 395	317	192 – 692	364	0.022 – 0.07	0.05	Volume 2 Appendix J, Part 1
	Peace River – Site C study area	2010/2011	39	211 – 480	345	108 – 1252	498	0.010 – 0.17	0.04	Volume 2 Appendix J, Part 1
	Peace River – Downstream	2010/2011	10	237 – 396	319	158 – 622	366	0.016 – 0.07	0.04	Volume 2 Appendix J, Part 1
Rainbow trout										
	Dinosaur Reservoir	2010/2011	10	265 – 313	292	178 – 286	242	0.036 – 0.06	0.05	Volume 2 Appendix J, Part 1
	Peace River – Site C study area	2011	10	215 – 440	330	128 – 984	433	0.022 – 0.09	0.04	Volume 2 Appendix J, Part 1
Redside shiner										
	Peace River – Downstream	2011	11	85 – 119	99	6 – 26	14	0.034 – 0.07	0.05	Volume 2 Appendix J, Part 1
Walleye										
	Peace River – Downstream	2011	16	399 – 479	431	630 – 1204	885	0.085 – 0.33	0.18	Volume 2 Appendix J, Part 1

Table 11.9.2 Fish Mercury Concentrations in Select BC Hydro Reservoirs and Lakes

Species	Area	Year	Sample Size	Length (mm)		Sample Size	Weight (g)		Sample Size	Hg (mg/kg ww)		Reference[1]
				Range	Mean		Range	Mean		Range	Mean	
Bull trout												
	Arrow Reservoir	1987	23	410 – 790	628	23	740 – 7000	3163	23	0.14 – 1.40	0.43	Baker 2002
	Arrow Reservoir	1995	16	430 – 760	588	16	800 – 5300	2488	16	0.10 – 0.28	0.17	Foster and Gadbois 1998
	Kinbaset Reservoir	1987	7	285 – 530	362	7	200 – 640	381	7	0.23 – 0.92	0.41	Baker 2002
	Kinbaset Reservoir	1995	11	580 – 860	736	11	2000 – 7300	5509	11	0.23 – 0.41	0.39	Foster and Gadbois 1998
	Revelstoke Reservoir	1987	25	260 – 565	365	25	160 – 2025	572	25	0.14 – 0.82	0.41	Baker 2002
	Revelstoke Reservoir	1995	17	510 – 890	670	17	1400 - 10300	4282	17	0.12 – 0.64	0.30	Foster and Gadbois 1998
Lake trout												
	Babine Lake	1979	28	480 – 710	589	28	500 – 4200	1991	28	0.10 – 0.50	0.25	Baker 2002
	Stuart Lake	2000	21	351 – 829	566	21	500 – 6050	2271	21	0.10 – 1.0	0.31	Baker 2001
	Trembleur Lake	2000	13	498 – 765	621	13	1325 – 6000	2927	13	0.11 – 0.72	0.32	Baker 2001
Lake whitefish												
	Stuart Lake	2000	31	161 – 515	312	31	50 – 1450	454	31	0.04 – 0.22	0.09	Baker 2001
	Trembleur Lake	2000	31	122 – 450	255	31	25 – 1175	286	31	0.02 – 0.26	0.08	Baker 2001
Mountain whitefish												
	Carpenter Reservoir	2000	11	182 – 275	228	11	75 – 275	145	11	0.09 – 0.19	0.13	Baker 2001
Rainbow trout												
	Arrow Reservoir	1986	13	335 – 650	442	13	410 – 4200	1187	13	0.07 – 0.31	0.14	Baker 2002
	Kinbaset Reservoir	1985-1987	13	310 – 440	395	13	390 – 830	715	13	0.05 – 0.27	0.14	Baker 2002
	Revelstoke Reservoir	1987	11	270 – 500	406	11	270 – 1100	754	11	0.12 – 0.57	0.23	Baker 2002

11.9.6 Predicting Changes in Fish Mercury Concentrations at Site C

The accumulated knowledge gained over the last 30–40 years of research and monitoring of Hg dynamics in new reservoirs provides a foundation upon which predictions regarding changes to fish mercury concentrations can be made, from the time of first impoundment to a return to baseline Hg concentrations. However, each reservoir has unique physical, chemical, and ecological conditions, and there is no single accepted tool or method to forecast what will happen within different reservoirs. For this reason, several lines of evidence were used to determine the most likely magnitude of change in MeHg concentrations in environmental media within the Site C reservoir. The three predictive tools were integrated together to derive a single, most likely estimate of change. The three tools employed at Site C were:

- Harris-Hutchinson (2012) Regression Model – This is a linear regression model that uses simple input parameters including original and flooded area (ha) and hydraulic residence time (or flow) to predict the relative degree to which fish mercury concentrations will increase and peak, relative to baseline values. Results of this exercise are presented as an Appendix within the RESMERC model report (Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling).
- RESMERC Model – The RESMERC model (Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling) is a complex, quantitative, mechanistic model that includes the latest understanding from scientific studies on methylmercury dynamics in aquatic systems. RESMERC mimics the production, destruction, and bioaccumulation of MeHg in various environmental media in reservoirs using mass balance calculations over time. The key outputs of this model are predictions of Hg and MeHg concentrations in water and biota (e.g., invertebrates, insects, fish) at any point in time, in this case, within the Site C reservoir.
- Canadian Reservoir Comparison Matrix – Chapter 5 of the Mercury Technical Synthesis Report (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report) undertook a comprehensive review of many key physical, chemical, and ecological factors that are associated with creating conditions that enhance mercury methylation in reservoirs. Fifteen large reservoirs from Manitoba, Quebec, B.C. and Labrador were evaluated. Baseline and predicted values for these parameters from the Site C technical study area were contrasted against what has been observed elsewhere in Canada, to put the Site C Project in perspective with other large Canadian hydroelectric projects, with a focus on changes in fish Hg concentrations over time.

11.9.6.1 Harris-Hutchinson Regression Model

The Harris-Hutchinson regression model (Harris and Hutchinson 2012; Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling) predicts the relative increase in fish Hg concentration over baseline for a new reservoir, using only three input parameters: flooded area, total area, and mean annual hydraulic residence time (Equation 1). The outcome is a peak increase factor (e.g., 3x or 5x). This is the number that is used to multiply baseline fish Hg concentrations in order to predict peak Hg concentrations for a particular species or size class in a new reservoir. However, the model only predicts peak concentrations, and does not predict the timing of the response, nor the return period back to a baseline condition.

This approach assumes that the primary source of MeHg in a new reservoir is the flooded terrain (numerator in Equation 1), while MeHg removal (denominator in Equation 1) is more efficient in reservoirs with a short replacement or residence time. When hydraulic residence times are longer, outflow is less effective at removing MeHg and other mechanisms become more important, including bacterial demethylation, photochemical degradation, and sedimentation.

$$\text{Peak Increase factor} = k_1\left(\frac{A_{\text{Flooded}}}{(Q + k_2 A_{\text{total}})}\right) + k3 \qquad \text{(Equation 1)}$$

Where:

Peak increase factor	=	peak increase factor in fish MeHg
$A_{flooded}$	=	flooded area (km^2)
A_{total}	=	Total reservoir area (km^2)
Q	=	mean annual flow (km^3/year); or removal rate
k_1 and k_2	=	regression coefficients (km/year)
k_3	=	regression coefficient (dimensionless)

The calibrated version of Equation 1 is as follows:

Peak increase factor = 0.427 * (Af/(Q+0.075At)) + 1.77

No long-term monitoring data were available to calibrate the model for conditions in British Columbia for bull trout or other fish species. Consequently, the regression developed for northern pike was used as a surrogate for bull trout, as bull trout and northern pike are both large predatory fish species. To account for potential long-term variation in discharge from Williston Reservoir, the 5^{th} percentile (sustained low discharge), the 95^{th} percentile (sustained high discharge), and the long-term mean discharge were used to depict the possible range in change in fish Hg concentration under these different discharge scenarios. Results are shown in Figure 11.9.1.

Predicted peak increase factors for the Site C reservoir ranged from 2.1 to 2.8, depending on 2000–2010 discharge rates from Williston. Assuming that long-term mean discharge patterns from Williston Reservoir are similar moving forward (Volume 2 Appendix D Surface Water Regime Technical Memos), the model predicts a 2.3x increase in fish Hg concentration above current baseline. That is, assuming a mean baseline concentration of 0.08 mg/kg concentration for a 50 cm bull trout from the Site C technical study area, the predicted mean Hg concentration for a similar size bull trout within the reservoir would peak at 0.20 mg/kg.

11.9.6.2 Summary of Findings from RESMERC

RESMERC is a process-based simulation model that was designed to predict changes in Hg and MeHg concentrations in environmental media in new reservoirs over time (Harris et al. 2009). The model was originally developed and calibrated from experimental reservoirs at the Experimental Lakes Area, Ontario (Bodaly et al. 2004; St. Louis et al. 2004). Model compartments include the water column, sediments, and a simplified food web of phytoplankton, zooplankton, benthos, and several fish species

(Figure 11.9.2). Fish Hg concentrations are followed in different size classes and the model predicts Hg and MeHg concentrations over time. RESMERC processes include atmospheric deposition, inflows and outflows, particulate settling, re-suspension, burial, in situ transformations (methylation, demethylation, photodegradation) and MeHg uptake kinetics in plankton and partitioning in benthos and fish. Additional information on RESMERC is available in Volume 2 Appendix J Mercury Technical Reports, Part 3 Mercury Reservoir Modelling.

The approach used to apply RESMERC to the Project was as follows:

- The model calibration was updated by applying it to two full-scale reservoirs created in the 1970s that had long-term fish Hg datasets: Robert Bourassa Reservoir (LG2), Quebec, and Notigi Reservoir, Manitoba
- The model was then applied to pre-flood conditions in the Peace River between the Peace Canyon Dam downstream to the Site C dam location, using data from baseline studies. This step was necessary to establish that RESMERC could predict baseline conditions prior to predicting conditions within the Site C reservoir. Simulated pre-flood or baseline concentrations of MeHg in mountain whitefish and bull trout are shown in Figure 11.9.3.
- RESMERC was then applied to the Site C reservoir to predict changes in Hg concentrations in water, sediments, and the food web, including key fish species

Once calibrated and run to simulate baseline conditions, RESMERC was used to predict changes in MeHg concentrations in water, flooded soils, and biota in the Site C reservoir during the operating phase. Construction phase effects during operations were not simulated because there is currently insufficient information on potential physical changes brought about by fluctuating water levels upstream of the Site C cofferdam prior to operations. The effect of construction-related fluctuations in water levels and periodic inundation of soils may cause erosion and transport or organic material downstream and/or burial of organic sediments within the reservoir. By not accounting for this, RESMERC may be conservative in terms of predicting peak fish Hg concentrations, as Hg methylation may be extended over a slightly longer period of time and would produce lower peak fish Hg concentrations on a reservoir-wide basis.

The Site C reservoir is predicted to thermally stratify during summer at the lower end of the reservoir (Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report). Two reaches of the reservoir were therefore simulated. The upper reach (25 km in length) would not stratify, while the lower 58 km was predicted to thermally stratify for a portion of the ice-free season. Simulations were carried out for both reaches; however, given the likelihood of fish moving between the modeled reaches in the reservoir, predictions for the two reaches were combined into an overall reservoir-wide prediction for fish, using an area-weighted approach.

RESMERC predictions for Hg in water, sediment (stratified by reach), and fish (combined) for the Site C reservoir are shown in Figure 11.9.4**.** MeHg concentrations in the water column are predicted to roughly double during the first decade after flooding to reach 0.04 ng/L (annual average), with short term peaks up to 0.06 ng/L. While these concentrations represent increases due to reservoir inundation, they remain within the typical range of background concentrations for natural water bodies (St. Louis et al. 1995; Bodaly et al.; 2004; Volume 2 Appendix P Aquatic Productivity Reports, Part 1

Baseline Aquatic Productivity in the Upper Peace River). MeHg concentration in newly flooded soils would increase by a factor of up to 10x above baseline in the range of 0.02 µg/g (20 µg /kg).

Mercury concentrations for lower trophic level fish species, redside shiner (0.12 mg/kg), mountain whitefish (0.15 mg/kg; 30 cm fish) and longnose sucker (0.14 mg/kg; 30 cm fish) are predicted to reach peak levels between four and six years after full impoundment of the Site C reservoir. Mercury concentrations are predicted to be higher for larger fish. Rainbow trout are predicted to reach 0.16 mg/kg six years after inundation. Bull trout will take longer (eight years) and peak at a higher level (0.45 mg/kg for a large 60 cm fish) because of their slower growth rate and highly piscivorous diet (Figure 11.9.4). This increase above baseline is greater than what was predicted by the regression model and relative to what would be expected when compared to many other Canadian reservoirs.

RESMERC predicts that fish Hg concentrations will return to background concentrations after approximately 18–25 years or more, depending on the species. Small forage species like redside shiner will return more quickly, while long-lived species like bull trout may take longer. Note that the timing of return to a ‘baseline condition’ does not necessarily mean pre-impoundment concentrations. Given long-term global increases in atmospheric mercury emission and deposition, it is reasonable to expect that fish mercury concentrations may be higher than the present day. Furthermore, RESMERC may overestimate the return period for some species because it does not account for the influence of Williston Reservoir, just upstream. This reservoir will continue to rapidly flush the Site C reservoir with oligotrophic water that is very low in mercury and biota, which may result in a more rapid return to a new baseline than RESMERC predicts.

The increases in fish Hg concentrations within the Site C reservoir as predicted by RESMERC are conservative because of the following two reasons. First, with the exception of bank erosion and slumping events that are episodic and transitory, Volume 2 Appendix I Sediment Transport Technical Report predicts that, during the first 10 years following impoundment, a substantial increase and settling of inorganic solids is predicted to occur throughout the new reservoir. In most areas, the depth of material exceeds 3–5 cm and is up to 30 cm in some areas. Deposition of inorganic material over top of organic sediment at the rates predicted would depress methylation rates to such an extent that methylation would nearly cease within the reservoir. However, given that a depression in methylation to this degree has not been observed in other newly formed reservoirs, the full influence of sedimentation within the Site C reservoir was not taken into account. The effect of not considering sedimentation is that increases in fish Hg concentrations would be lower than predicted by RESMERC.

Secondly, it was assumed that increases in benthic and epibenthic invertebrate tissue MeHg concentrations were more closely linked to increases in MeHg concentrations in sediments than the overlying water column. This would result in higher predicted fish Hg concentrations than if dietary items for fish were linked less to MeHg in sediment and more to the water column. This might be true for most important dietary items such as mayflies and caddisflies, which are some of the most important dietary organisms in Peace River technical study area fish (Volume 2 Appendix O Fish and Fish Habitat Technical Data Report). While the future conditions report (Volume 2 Appendix P Aquatic Productivity Reports, Part 3 Future Conditions in the Peace River) predicts benthic organisms to be an important component of the post-flood food web in the reservoir, it is not known whether the MeHg in these organisms may be more closely linked to MeHg in the sediments or overlying waters. RESMERC conservatively linked benthos more closely to exposure to MeHg generated in sediment than from the water column. This assumption may over-predict fish Hg concentrations.

11.9.6.3 Findings of the Canadian Reservoirs Comparison Matrix

The Canadian reservoirs comparison matrix (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report) reviews the physical, chemical, and ecological parameters that are positively associated with increases in mercury and methylation rates, based on what was observed in 15 Canadian reservoirs (Manitoba, Quebec, Labrador, and Williston Reservoir in B.C.). How these parameters ultimately influence fish mercury concentrations were contrasted against baseline and predicted conditions within the Site C reservoir. Comparing and contrasting results from many other reservoirs to the Site C reservoir provides insights into where Site C fits within the spectrum of reservoir types – as it relates to MeHg magnification in environmental media. An advantage of this approach is that it relies on real data from a range of reservoir types across Canada, to provide insights into what factors drive fish Hg concentrations.

A series of matrices were developed to compare a large number of physical, chemical, and ecological factors across many reservoirs. The reservoirs comparison matrices are large and complex, and full details are presented in Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report.

Key factors were identified from seven Manitoba reservoirs (Keeyask, Limestone, Long Spruce, Notigi, Southern Indian Lake, Stephens, and Wuskwatim), five Quebec reservoirs (Caniapiscau, LG1, LG2 [Robert Bourassa], LG3, and Opinaca), two Labrador reservoirs (Gull and Muskrat) and Williston Reservoir (B.C.). Among the large number of factors considered, both as important input parameters to RESMERC as well as the contributors to methylation potential at the Site C Project, the most important physical factors associated with enhanced mercury methylation were:

- Total reservoir area – Larger reservoirs have fish with higher Hg concentrations and take longer to return to baseline or background (relative to nearby lakes)
- Ratio of total reservoir area (original area) – The higher the ratio, the greater amount of MeHg that is generated
- Water residence time – Fish from longer residence time reservoirs have higher Hg concentrations that persist for a longer period

The most important chemical factors were:

- Slightly acidic pH (<6.5) water and sediment is associated with higher Hg concentrations in fish
- Higher total or dissolved organic carbon (TOC/DOC) concentrations in water (>5 mg/L) are weakly but positively correlated with the magnitude of increase in fish Hg

- Labile or easily degradable carbon, best represented by the amount (% of total and/or hectares) of wetland within the reservoir has been found to be a key contributor to elevated mercury methylation rates

The most important ecological factors are:

- Lower trophic level Hg concentration – Lakes/rivers with higher baseline MeHg concentrations in benthos result in higher MeHg increases post-flood and contribute to higher rates of bioaccumulation and biomagnification by fish
- Reservoir productivity – Larger reservoirs with more in situ nutrients, and nutrient inputs from upstream and/or tributaries, have greater biomass production and higher Hg methylation potential and, consequently, higher MeHg concentrations in biota

Each of the reservoirs evaluated was placed into one of two categories, either ‘low’ or ‘high’, based on the magnitude of increase in fish Hg concentration relative to baseline, or reference data (i.e., nearby water bodies not influenced by flooding). A value of less than 3x above baseline was defined as producing a ‘low’ increase in fish Hg concentration, while an increase of more than 3x baseline was defined as a producing a ‘high’ increase in fish Hg concentration. The value of 3x baseline was chosen as a cutoff value, which is approximately half the increase in what is seen in most ‘worst-case’ scenario increase reservoirs (an increase of 6–7x baseline). A 3x increase factor is conservative, yet high enough that it is statistically distinguishable from baseline, and the return to baseline can be measured with greater precision (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

A summary matrix (Table 11.9.3) illustrates where the Site C reservoir would fit within the range of either a ‘low’ increase (<3x baseline) or ‘high’ increase (>3x baseline) for each of the physical, chemical, and ecological parameters evaluated from the reservoirs considered.

Table 11.9.3 Canadian Reservoirs Comparison Matrix Summary

Reservoir Characteristics	Low Magnitude Increase Reservoirs (Fish Mercury <3x Baseline)	High Magnitude Increase Reservoirs (Fish Mercury >3x Baseline)	Predicted Site C Result
Magnitude of Fish Mercury Increase above Baseline	Muskrat Falls, Gull Island (Nfld/Lab); Limestone, Long Spruce, Wuskwatim, Southern Indian Lake (MB) for some fish species	LG-1, LG-2, LG-3, Opinaca, Caniapiscau Quebec; Southern Indian Lake, MB (for some species) Williston, B.C.	
Physical Parameters			
Total Reservoir Area	Less than 200 $km^{2,}$ ranging from 28 (Limestone) – 200 km^2 (Gull Island) for all reservoirs	Very large, with most exceeding 2,000 km^2 except Opinaca (1,040 km^2), Williston (1,779 km^2)	Site C predicted area = 93.3 km^2 and falls into LOW increase category
Ratio of Total Reservoir Area: Original Area ~~Original: Flooded Area~~	Less than 2 at Muskrat (1.5) and Gull (1.7) Nfld/Lab and Limestone (1.3), Long Spruce (1.9), and Wuskwatim, MB (1.5)	A ratio well in excess of 2 at LG1 (2.3), LG2 (13.8), LG3 (9.9), Opinaca (3.5), Caniapiscau (5), Williston (22), with a lower ratio at SIL (1.2)	Site C predicted ratio is 2.3 and would fall into the upper end of the LOW increase category; although similar to LG1, the influence of LG2 on Hg in LG1 fish was anomalous
Water Residence Time	In the order of days and typically less than one month in Muskrat (7d), Gull (26d), Limestone (5d), and Long Spruce (10 d)	Residence time much longer, typically greater than 5 months including LG2 (7m), LG3 (11m), Opinaca (3.8m), Caniapiscau (26m), and SIL (8m)	With a water residence time of 23 d, Site C falls into the LOW category
Chemical Parameters			
pH	Usually pH of 7.5 or greater, especially in Manitoba reservoirs (7.5 – 8.5) and Williston (8.5); approximately pH 7 in Gull/Muskrat	A pH of <6.5 for all reservoirs including LG1 (6.5), LG2 (6.2), LG3 (<6.5), Caniapiscau (5.8 – 6.4) and Opinaca (5.9 – 6.3)	Peace River has pH of 7.8 – 8.6 and not predicted to change, clearly placing Site C in the LOW increase category
TOC/DOC	TOC/DOC concentrations are 2.6 – 4.6 mg/L in Muskrat/Gull; 8 – 12 mg/L in MB; 2 – 3 mg/L in Williston	TOC tends to be slightly higher, averaging 6.4 mg/L in LG1, 9 – 29 mg/L in LG2, 7 – 10 mg/L in LG3, 4 – 6 mg/L in Caniapiscau and 7 – 10 mg/L in Opinaca	TOC/DOC slightly higher in high increase reservoirs. Influence of low TOC water from upstream will likely place Site C in LOW increase category, with some uncertainty

Reservoir Characteristics	Low Magnitude Increase Reservoirs (Fish Mercury <3x Baseline)	High Magnitude Increase Reservoirs (Fish Mercury >3x Baseline)	Predicted Site C Result
Labile Carbon/ %Wetland	There are few good data for most reservoirs. However, the trend is for % wetland to be 3% or less including Williston (<1%) and Site C (<2%); Few data on labile carbon or biomass except for Nfld/Lab (2.7 kg/m2) and Site C (5 kg/m^2)	PQ reservoirs have a high percentage of flooded wetland: LG1 and LG2 (5%), LG3 (10%), Caniapiscau (7%) and Opinaca (16%); No data for Williston; SIL in MB was also high >5%. Carbon pool was also high with 16 – 23 kg/m^2 in peat soils, 9 – 42 kg/m^2 in wetlands and 7 kg/m^2 in forest soil	Site C has a low carbon biomass relative to other reservoirs for which this is known and a low percentage of wetland (<2%), placing Site C in the LOW increase category
Ecological Parameters			
THg/MeHg in Lower Trophic Level Biota	Pre-impoundment THg in Gull/Muskrat Nfld zooplankton 0.07 – 0.26 ppm THg and 0.002 – 0.07 ppm MeHg. At Williston post-impoundment (2000, 2001) THg in zooplankton is 0.06 – 0.18 and 0.03 – 0.05 ppm of which 35% is MeHg; In benthos THg is 0.2 – 0.57 and 0.15 – 0.28 ppm of which 20% is MeHg. Peace River (2011) baseline benthos is 0.07 ppm THg in zooplankton and 0.016 ppm THg in benthos of which approximately 10% is MeHg	The best data sets are for PQ reservoirs; values are on a dw basis. THg in zooplankton (baseline) is 0.03 – 0.57 ppm; 0.03 – 0.51 MeHg; Post-flood range 0.45 – 0.67 THg and 0.45 – 0.82 MeHg. In benthos, baseline THg ranges from 0.28 – 0.45 ppm and 0.25 – 0.8 ppm depending on taxa; MeHg 0.2 – 0.6 and 0.02 – 0.15 ppm post-flood; In SIL post-flood zooplankton was 0.3 – 3.0 and benthos 0.1 – 3.5 depending on taxa and organism size	Peace River baseline THg and MeHg fall into lower range of zooplankton and benthos concentrations. Percentage MeHg of THg is also low (<15%). Low baseline lower trophic level Hg concentrations are consistent with a low magnitude increase in fish Hg and place Site C in the LOW increase category
Reservoir Productivity Features	Tend to be run-of-river, have upstream reservoirs that limit nutrient/biota introductions, limited tributary/river inflow, lower carbon biomass and limited connectivity with larger waterbodies. Lack of nutrients and high turnover limit reservoir productivity and thus Hg bioaccumulation.	Tend to be spatially large, have higher nutrient inputs, greater connectivity to tributaries and lakes, longer residence time (lower nutrient export), and are more productive, even supporting commercial fisheries (e.g., SIL)	Site C is a run-of-river reservoir receiving very low nutrient water from upstream with limited connectivity and small tributary stream and nutrient inputs. Its low productivity status is consistent with LOW magnitude fish Hg increases.

NOTES:

THg = total mercury; MeHg = methylmercury; dw = dry weight; MB = Manitoba, PQ = Quebec; SIL = Southern Indian Lake (MB)

None of the parameters that are associated with increases in fish Hg concentrations of greater than 3x baseline are projected to be present within the Site C reservoir based on data from 13 large Canadian reservoirs (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report). In particular, these include presence of an upstream oligotrophic reservoir, low TOC and nutrients in water, alkaline pH, low temperature and high oxygen, low baseline MeHg concentrations in water and biota, small increase in reservoir area relative to river area, small area of flooded wetland, and short hydraulic residence time. In summary, among the physical, chemical, and ecological factors primarily responsible for mercury methylation in new reservoirs, the Site C reservoir was clearly classified as having a strong likelihood of producing a less than 3x increase in fish mercury concentrations above baseline for all parameters evaluated.

11.9.7 Predicted Changes in Fish Methylmercury Concentration Within the Site C Technical Study Area

11.9.7.1 Site C Reservoir

Results of the three lines of evidence (i.e., Harris-Hutchinson (2012) regression model, RESMERC model, and Canadian reservoirs comparison matrix) were integrated to determine the most likely relative increase factor to predict changes to fish Hg concentrations within the Site C reservoir following inundation relative to baseline conditions. Key results from each line of evidence are:

- Harris-Hutchinson regression model – Fish Hg concentrations in the Site C reservoir were predicted to increase by 2.3x above baseline at peak levels. The model does not provide information regarding the timing of the peak concentration, nor the duration of elevated fish Hg concentrations.
- RESMERC – Fish Hg concentrations are predicted to increase by up to 4 to 6x above baseline at peak levels, depending on the species, five to eight years after impoundment. Following the peak, fish Hg concentrations are expected to decline to 'baseline' over a 15- to >20-year period. The magnitude and duration of elevated Hg concentrations depends on fish species and fish size. Larger, older fish will ultimately achieve higher concentrations.
- Canadian reservoirs comparison matrix – Fish Hg concentrations are predicted to increase by less than 3x baseline concentrations, based on a large suite of physical, chemical, and ecological features from 15 Canadian reservoirs

It is important to note here that baseline fish Hg concentrations in the Peace River are lower than reported anywhere else in British Columbia (Baker 2002) and are among the lowest reported for their size in Canada (Depew et al. 2012). This is an unusual situation, as no reservoir has been created starting with such low baseline fish Hg concentrations. Given that most of our understanding of Hg dynamics has been generated from eastern and central Canadian reservoirs (i.e., all three prediction methods were developed based on reservoirs from other Canadian regions), there is some uncertainty in the application of these tools at the Site C reservoir. Nevertheless, taken together, these diverse approaches provide a robust characterization of potential increases in fish mercury concentrations within the reservoir.

An integrated approach was taken to harmonize and reconcile the three lines of evidence to determine the most likely magnitude of increase in fish Hg concentration with the Site C reservoir. These approaches provide lower and upper bound estimates of increase in fish mercury. Two of the three lines of evidence suggest a low magnitude of increase – 2.3x based on the Harris and Hutchinson model, and less than 3x based on the Canadian reservoirs comparison matrix. Although RESMERC predicts a maximum increase of 4 to 6x above baseline (depending on species), there is inherent conservatism in the model (e.g., assumption of negligible sedimentation during the construction phase) that would suggest a lower increase than what is predicted using this method. Consequently, based on the available information, the harmonized peak increase factor for all species is likely to be approximately 3x. This value retains some conservatism relative to the results of the empirical evidence of the regression and matrix approaches, but also some uncertainty relative to RESMERC. Given that uncertainty, it is less likely, but possible, that the peak increase factor could reach 4x, but is unlikely to be higher. For the purposes of assessing the potential effect on humans of mercury-related changes to fish associated with Site C, it is recommended that a peak increase factor of 4x be used to reduce the possibility of underestimating fish mercury concentrations. This value was used to inform the HHRA (Volume 2 Appendix J Mercury Technical Reports, Part 2 Mercury Human Health Risk Assessment).

As Figure 11.9.4 illustrates, the peak increase factor and the magnitude of mercury concentration will vary according to fish species and by size for most species. This phenomenon has been observed in all other reservoirs, and RESMERC accurately predicts the relative difference in fish mercury concentrations across species and across size ranges.

Table 11.9.4 compares predicted peak (applying both the 3x and 4x factors) and baseline mercury concentrations for five fish species for the Site C reservoir. Given that fish mercury concentrations are often correlated to size, the results are reported for the size most commonly captured and targeted by sport fishers (e.g., bull trout, rainbow trout; Volume 2 Appendix J Mercury Technical Reports, Part 2 Mercury Human Health Risk Assessment). For food web species such as mountain whitefish, longnose sucker, and redside shiner, where there is a weak or no relationship between mercury concentration and fish size, the mean size for a large or adult fish was used.

The mean mercury concentration value was used for adult bull trout, not the maximum concentration. Although smaller fish will have a lower absolute mercury increase and larger fish may have a higher concentration, use of the mean better approximates typical exposure to humans. For example, although the maximum mercury concentration of the 50 bull trout measured from the Site C technical study area since 2008 was 0.34 mg/kg, the next highest value was 0.17 mg/kg. All other fish had lower concentrations than 0.17 mg/kg (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report).

Table 11.9.4 Predicted Changes in Fish Mercury for Site C Fish Relative to Baseline Conditions

Fish Species/Size	Mercury concentration (mg/kg ww)				
	Bull trout	**Rainbow trout**	**Mountain whitefish**	**Longnose sucker**	**Redside shiner**
	50 cm; 1.6 kg	**40 cm; 0.5 kg**	**35 cm; 0.5 kg**	**30 cm; 0.6 kg**	**10 cm; 14 g**
Baseline Concentration	0.067[1]	0.050[1]	0.036[1]	0.052[2]	0.054[2]
3x Increase Factor	0.20	0.15	0.11	0.16	0.16
4x Increase Factor	0.27	0.20	0.14	0.21	0.22

NOTES:

[1] Baseline concentration estimated for standardized fish using Hg-size relationships (Volume 2 Appendix J Mercury Technical Reports, Part 1 Mercury Technical Synthesis Report; Azimuth 2011)

[2] Baseline concentration estimated based on mean of fish caught

11.9.7.2 Downstream Changes to Fish Mercury

Monitoring programs for boreal reservoirs have demonstrated that some fish have increased mercury concentrations as far downstream as 275 km in Quebec (Schetagne and Verdon 1999a, 1999b), Manitoba (Bodaly et al. 2007) and Labrador (Anderson 2011). The extent and duration of downstream changes to fish Hg levels vary from system to system, depending on the hydrological and biological characteristics of the rivers and reservoirs. For example, the extent of dilution from tributaries below the reservoir and the presence of large deep lakes (Schetagne and Verdon 1999b) may affect mercury concentrations in water. In addition, mercury concentrations may increase in some fish in the event an individual shifts its dietary preference from lower trophic level organisms (algae, benthos) to fish (e.g., easy prey that are injured or killed from passage through the turbines). Downstream of the Smallwood Reservoir in Labrador, for example, mercury concentrations in lake whitefish increased by 5x above baseline, higher than the reservoir itself; brook trout increased by 3x, the same magnitude as within the reservoir (Anderson 2011).

The degree to which this may occur downstream of the Site C reservoir is uncertain and difficult to predict. As described in Section 11.9.4, the downstream extent of exposure to fish with elevated MeHg concentrations from the Site C Project may extend as far as Many Islands. As described above, mercury may be exported from the Site C reservoir via water (i.e., inorganic Hg adhered to sediment particles or MeHg dissolved in water) or directly, in biota (e.g., tissue Hg in invertebrates or fish). These two pathways generally result in different patterns of change in fish tissue concentrations in the downstream environment. Water-borne Hg may lead to low magnitude changes across a broad spatial extent, while biota-based mercury exports may lead to higher magnitude changes in a more localized area, such as the tailrace area of a dam. While water-borne mercury exports may lead to minor changes in downstream fish mercury concentrations, the importance of this pathway was considered secondary, relative to biota-related mercury exports, and was not pursued further.

The degree to which mercury concentrations in individual fish may increase downstream of the Site C reservoir will vary by species, fish size, the biomass and mercury concentration of fish entrained out of the reservoir, and the dietary preference of individual fish. For non-piscivorous species, tissue mercury concentrations are unlikely to change substantially relative to baseline. For normally piscivorous species feeding in the tailrace area, the magnitude of increase may match what is observed within Site C. For normally non-piscivorous species that switch to a predominantly fish-based diet, their tissue mercury concentrations may increase more than what is seen within the Site C reservoir. This has been observed in Quebec (Schetagne et al. 2003) and Labrador (Anderson 2011), where downstream lake whitefish mercury concentrations were 1.5–2x higher than what was observed in the upstream reservoir.

From a population perspective, only a small portion of fish may potentially be affected downstream of the Site C dam to Many Islands. This is mainly because the mass of Hg contained within fish entrained out of Site C reservoir is likely insufficient to result in a widespread increase in Hg in most fish, combined with the small number of fish within the greater population that may switch to a piscivorous diet. Changes of the magnitudes seen in other Canadian reservoirs would be limited largely to those few piscivorous fish feeding predominantly in the tailrace area.

Nevertheless, if it is conservatively assumed that the general fish population downstream of the Site C reservoir was to double in concentration for key species presented in Table 11.9.4, this would result in mean mercury concentration for local populations of less than 0.10 mg/kg. The only exception is bull trout, with a mean of 0.16 mg/kg. Despite this increase, these are very low concentrations relative to other fish populations in B.C. (Baker 2002) and elsewhere in Canada (Depew et al. 2012).

11.9.7.3 Timing of Return to Baseline

The timing of a return of reservoir fish Hg concentrations to baseline can be inferred from the Canadian reservoirs comparison matrix as well as from RESMERC. Based on information from other Canadian reservoirs, those with a short hydraulic residence time, small reservoir to original basin ratio, minimal flooded wetland, and a large upstream oligotrophic lake or reservoir will have shorter return periods, depending on the species, in the order of 15–20 years following impoundment (Table 11.9.3). RESMERC predicts a return time of between 20 and 25 or more years, depending on the species. Redside shiner, sucker, and rainbow trout that consume lower mercury dietary items will return to a baseline more quickly than omnivorous whitefish and piscivorous bull trout.

Given the above two estimates, a return to baseline is likely closer to 20 years after impoundment than >25, because of the weight of evidence presented by the Canadian reservoirs comparison matrix and the presence of a large, oligotrophic, low-Hg reservoir upstream that will continue to dominate water chemistry in a post-Site C environment. Furthermore, the effects of sedimentation, which were not considered by RESMERC, would result in lower peak concentrations and reduced time required to return to baseline.

With respect to downstream fish, it is acknowledged that the return to baseline is much shorter. For example, lake whitefish in the Caniapisco River in northern Quebec returned to background levels within 2–4 years, while concentrations in lake trout remained high for 4–8 years (Schetagne and Verdon 1999b). Downstream of the Smallwood Reservoir in Labrador, fish mercury concentrations had returned to baseline within 7–8 years after impoundment.

Based on the weight of evidence from other Canadian reservoirs and the presence of a large, oligotrophic upstream reservoir, the return to baseline mercury concentrations within the Peace River technical study area is predicted to be on the shorter end of what has been observed elsewhere, likely 4–6 years after impoundment of the Site C dam occurs.

11.10 Microclimate

11.10.1 Introduction

The existing and predicted future microclimatic conditions in the Peace River valley and at the North Peace Regional airport are described in the following section. Both current conditions and potential changes as a result of the Project are described. Predicted microclimate was modelled to quantitatively evaluate how the construction of the proposed Site C dam and the formation of the reservoir might influence the local and regional climate.

Details of the microclimate analyses are presented in the Volume 2 Appendix K Microclimate Technical Data Report. Predicted changes in microclimate were used to assess the potential effects of the Project on agriculture (Volume 3 Section 20 Agriculture), navigation (Volume 3 Section 26 Navigation), and transportation (Volume 4 Section 31 Transportation).

Weather is defined as the state of the atmosphere at a given time and place with respect to variables such as temperature, moisture, wind velocity, and barometric pressure. Climate is the long-term average of weather. In this context, the term average refers not only to the simple arithmetic average, such as the average temperature for an area, but also to the average occurrence of extreme weather, for example, the average summertime extreme temperature or the average number of storms per year. Common atmospheric state variables, such as temperature or wind speed, are applicable to both meteorological and climatological studies. As such, the terms atmospheric measurements or climatological measurements may refer to the same quantities, and only differ by the context in which they are examined.

The term microclimate has been adopted as the term for the climate of the section of the Peace River valley where the proposed Site C reservoir would lie. However, the term microclimate more properly refers to climates on horizontal scale of tens to hundreds of metres (Oke 1987). As such, there is no one single microclimate, but rather a collection of microclimates. The technical term for climate on the scale of the Peace River valley would be mesoclimate.

11.10.2 Methodology

The microclimate study comprised the following elements:

- Review of baseline climatic data
- Application of a mesoscale meteorological model with land cover and terrain set to reflect current conditions
- Application of the same model to include topographical changes resulting from reservoir formation
- Description of changes in microclimate inferred by the difference between the two model runs
- Statistical analysis to determine significance of results

The technical study area, which encompassed the entire reservoir, is 108 km east to west, by 68 km north to south, corresponding to a 108 by 68 one-kilometre modelling grid. This area covers the reservoir with a rectangular model grid with a large enough buffer around the reservoir edges to encompass the expected extent of changes from the proposed reservoir. The technical study area is shown in Figure 11.10.1.

To quantify potential changes in microclimate induced by the potential Site C reservoir formation, two model scenarios were examined, the existing Baseline Case and the Future Case with the Project, using the Weather Research and Forecasting (WRF) numerical meteorological model.

The WRF model combines large-scale weather information and the geophysical description of the Earth's surface to simulate local-scale meteorology. By running the model for periods of a year or longer, monthly, seasonal, and annual average estimates of the average meteorological conditions and, hence, the climate of a given region may be developed. The longer term average climate was estimated by selecting a model study year that was typical of the most recent 30-year climate record.

Along these lines, each grid cell of the WRF model results may be considered to be the solution for the microclimate of the topographical area represented by that grid cell. Therefore, by examining the model results for different model grid cells, changes to the microclimate of various locations within the technical study area may be examined.

Changes in microclimate were examined in terms of the following meteorological parameters:

- Temperature
- Wind speed
- Humidity (Mixing Ratio)
- Precipitation
- Fog and visibility

Humidity is the amount of moisture in the atmosphere. It may be described in relative or absolute terms. Relative humidity presents atmospheric water content as a percentage of the total that the atmosphere could possibly hold at that time. It depends on the temperature and pressure as well as the actual amount of water present. Absolute humidity is the actual amount of water regardless of atmospheric capacity and is usually expressed as a mixing ratio, giving the mass of water vapour compared to the mass of dry air in a known volume of moist air. Historical measurements are typically given in relative humidity, but modelling studies are typically conducted using mixing ratio. As a result, both quantities are used in the context where most appropriate.

Visibility is defined as the greatest distance (expressed in kilometres) at which a black object of suitable dimensions can be seen and recognized. During the hours of darkness, it can also be seen if under the same daylight conditions. Fog refers to conditions where visibility is less than 1 km. Visibility in meteorological records is recorded either by an observer or by an instrument called a nephelometer. In either case, the same quantity cannot be directly reproduced by the WRF model or calculated from its outputs. Therefore, changes in visibility were estimated using a formula for calculating light extinction that can use WRF outputs. Although this means that model results are not directly comparable to the historical record, they can be used to determine relative changes between the Baseline Case and the Future Case with the Project.

A single year that is characteristic of the long-term climate record for purposes of modelling may be selected by comparing a sample year to the long-term mean and standard deviation, to ensure that the sample year is within the bounds of normal year-to-year variation and does not represent a non-typical year. Differences between model runs for this typical single year would then provide a representative estimate of differences that would result for the long-term mean.

To support an evaluation of the microclimate of the study area, BC Hydro installed a network of climate stations in the Peace River valley. The locations of the stations within the Peace River valley are shown in Figure 11.10.2, along with other meteorological stations in the area. The locations and monitoring periods are summarized in Table 11.10.1. The stations were installed across a number of different geographical settings. The first full year of climate measurements at all stations was completed in January 2012.

Other meteorological stations inside the technical study area are North Peace Regional airport (Environment Canada), Taylor South Hill (MOE), Taylor Townsite (BCMOE), PMD (BC Hydro), and Hudson’s Hope (BCMOF). North Peace Regional airport is located 12 km east of the proposed Site C reservoir and is the closest station with a long measurement record (several decades); Taylor South Hill and Taylor Townsite are about 15 km downstream of the proposed Site C reservoir.

The BC Hydro stations measure a range of meteorological parameters, including wind speed and direction, temperature, and precipitation. A selection of the stations also measure barometric pressure, humidity, solar radiation, and heat influx. Though these extra parameters provide additional information for describing the climate of a location, they are not commonly associated with studies of climate and there are no long-term measurements to compare them with. These extra parameters are, therefore, not included in the current analysis, but constitute part of future monitoring and reporting.

The influence of global climate change on the local microclimate was determined by examining previous studies of global climate change and extracting results for the Peace River valley. For the purposes of this study, the influences of global and local climate change were considered additive. That is, the influence of the two combined would be equal to the sum of the two acting separately. The estimate of future climate change does not include any other anthropogenic changes to land use in the study area.

Table 11.10.1 BC Hydro Climate Station Locations and Monitoring Periods

Station	Location UTM NAD 83 (m)	Type	Measurement Period[a]
Station 1 – Attachie Flat Upper Terrace	597983 Easting 6232938 Northing	Climate	January 15, 2011 to present
Station 2 – Attachie Flat Lower Terrace	597721 Easting 6231898 Northing	Climate	January 13, 2011 to present
Station 3 – Attachie Flat Plateau	595065 Easting 6233032 Northing	Climate	November 4, 2010 to present
Station 4 – Bear Flat	610669 Easting 6238135 Northing	Climate	December 1, 2010 to present
Station 5 – Hudson's Hope	570577 Easting 6213303 Northing	Climate	December 12, 2010 to present
Station 6 – Farrell Creek	580779 Easting 6220238 Northing	Wind	April 1, 2009 to present
Station 7 – Site C Dam	629517 Easting 6230875 Northing	Climate	November 27, 2010 to present

NOTE:

[a] All stations were originally installed in 2009 as measuring wind only. All except Station 6 – Farrell Creek have been upgraded to measure additional parameters. Where applicable, installation date refers to date of upgrade.

11.10.3 Baseline Climate

The region around Fort St. John experiences a continental subarctic climate characterized by long, cold, and dry winters with short, mild summers. Normal daily average temperatures range from -14.2°C in January to 15.7°C in July, with normal total annual precipitation totalling 465 mm, of which 65% falls between May and September.

North Peace Regional airport is the only location close to the study area where long-term climate information is available. This station has been in operation since 1942 and is run by Environment Canada. Climate normals from 1971 through 2000, the most recent 30-year period for which Environment Canada has published them, were reviewed. In addition, the standard deviations of the parameters that were used to evaluate the performance of the WRF model – temperature, wind speed, and precipitation – were calculated to evaluate annual and monthly climate variability. Over the length of record, there was a 1.5°C increase in mean annual temperature. The trend for wind speed shows a decrease over the period of record of approximately 6 km/h. The record shows no change in mean annual total precipitation.

Climate normals from North Peace Regional airport for the parameters that were examined in the microclimate study are listed in Table 11.10.2. The full climate normal listing for North Peace Regional airport is provided in the Microclimate Technical Data Report (Volume 2 Appendix K). Note that, for completeness, the long-term visibility observations are shown; however, as stated above, these are measured using a different method than what was used to estimate visibility from the WRF model results. Per the definition, the occurrence of fog in Table 11.10.2 is given by visibility of less than 1 km.

The results for the first year of observations at the BC Hydro climate stations are summarized in Table 11.10.3. This first year of record was warmer and wetter, and had higher wind speeds than a normal year, as measured at North Peace Regional airport. There were small differences in temperature between the BC Hydro stations, and wind speed and direction were influenced by local topography. Spatial differences in precipitation exist, but may be due to differences in instruments across the network. For ongoing monitoring, the performance of the precipitation gauges would need to be examined and the instruments upgraded or replaced as necessary.

Although there are relatively small differences in measured climate parameters between stations in the first year of observation, the differences that are present demonstrate that each station exists in its own microclimate. Differences in factors such as elevation, moisture availability, surface cover, and topography all contribute to the differences seen between stations. Until the record of measurement becomes longer, it is not known if these differences in measured parameters observed during the first year are reflective of long-term trends.

Table 11.10.2 Selected Climate Normals for Fort St. John

Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily average (°C)	-14.2	-10.5	-4.4	4	10	13.8	15.7	14.6	9.9	3.9	-6.7	-12.1	2
Daily maximum (°C)	-9.9	-6	0.3	9.3	15.7	19.2	21.2	20.2	15.1	8.2	-2.9	-8	6.9
Daily minimum (°C)	-18.4	-15	-9.1	-1.3	4.1	8.2	10.2	8.9	4.6	-0.4	-10.4	-16.2	-2.9
Extreme maximum (°C)	11.6	12.8	18	27.9	31.8	31.7	33.3	33.6	30	25.6	18.3	11.4	N/A
Extreme minimum (°C)	-47.2	-42.2	-36.7	-28.9	-10.6	-0.6	0.7	-2.9	-12.8	-25	-39.2	-44.6	N/A
Precipitation													
Rainfall (mm)	0.4	0.5	0.7	8.8	35.5	70.9	83.2	56.1	41.1	11.5	3.4	0.6	312.6
Snowfall (cm)	32.2	28.3	25.3	10.6	4.1	0.4	0	0.8	4.8	16.5	30.3	32.4	185.6
Precipitation (mm)	26	21.9	21.4	18.8	39.7	71.4	83.2	56.9	45.7	25.8	28.5	26.5	465.6
Wind													
Speed (km/h)	13.7	14.3	13.8	14.4	14.3	13.6	12.3	11.9	13	15.4	13.8	13.7	13.7
Maximum hourly speed (km/h)	89	84	68	77	77	64	80	58	64	80	74	97	N/A
Humidity													
Average vapour pressure (kPa)	0.2	0.2	0.3	0.4	0.6	0.9	1.2	1.1	0.8	0.6	0.3	0.2	0.6
Average relative humidity – 0600LST (%)	73	73.4	73.8	69.3	69	75.6	81.2	84.9	84.1	77.3	78.9	74.4	76.2
Average relative humidity – 1500LST (%)	69.1	63.8	55	42.6	40.6	47.3	51.3	52.7	53.6	56.9	71.8	71.6	56.4
Visibility (hours with)													
< 1 km	14.5	6.5	5.2	2.7	3.3	3.9	7.6	13	14	15.4	25.7	18.5	130.3
1 to 9 km	92.4	76.6	59	25.5	16	20.4	18.8	29	31.3	39	82.1	92.5	582.7
> 9 km	637.1	595.1	679.7	691.8	724.7	695.7	717.6	702	674.8	689.6	612.2	633	8053.2

Table 11.10.3 Summary of Measured Climate Parameters

Station	Mean Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Total Precipitation (mm)	Mean wind speed (m/s)
Station 1 – Attachie Flat Upper Terrace	3.1	29.9	-33.5	447	2.5
Station 2 – Attachie Flat Lower Terrace	3.1	30.6	-35.6	415	2.3
Station 3 – Attachie Flat Plateau	3.3	28.6	-34.2	509	2.8
Station 4 – Bear Flat	2.9	29.3	-35.4	414	1.6
Station 5 – Hudson's Hope	3.7	30.8	-36.3	521	1.9
Station 6 – Farrell Creek	—	—	—	—	1.8
Station 7 – Site C Dam	3.9	29.2	-33.1	541	2.8
North Peace Regional airport	2.9	27.7	-32.9	626	4.3
Max. difference in values	1.0	3.1	3.4	212	2.7

NOTES:
— indicates no data collected

11.10.3.1 Weather Research and Forecasting (WRF) Model

The purpose of the microclimate modelling study was to evaluate quantitatively how the construction of the proposed Site C dam and the formation of the reservoir might influence the local and regional climate. Modelling was conducted because historical measurements by themselves are not sufficient to predict future local climate changes. Past monitoring establishes current baseline conditions, and future monitoring would capture actual changes in climate as they occur, but historical data only permit a subjective and/or qualitative estimate of future changes. Modelling is the only means of objective and quantitative prediction of future changes before the Project is built. The results of the model study allow site-specific estimates of changes in local microclimate well in advance of actual construction.

Potential future microclimate changes were estimated using the WRF model version 3.2.1, released August 2010. This was the most recent model release at the time the study commenced, and the model version was kept the same for the duration of the model study.

The WRF model solves the fundamental equations of atmospheric motion on a three-dimensional (3-D) grid. It may be used to forecast future weather events or to investigate historical weather occurrences. In either mode, WRF makes use of terrain data and land-cover characteristic information. When applied to examine historical events, WRF also makes use of actual observations of meteorology. The model incorporates parameters that influence atmospheric conditions, such as turbulence, convection and cloud formation, precipitation, radiation, surface heat transfer, and moisture. Thus, WRF is able to simulate various weather conditions, including wind shears, mountain and valley drainage flows, and other topographically induced wind flow patterns.

In simpler terms, WRF provides a 3-D estimate of the wind, temperature, humidity, and several other variables for each hour throughout the period modelled. The model output provides hourly estimates of weather conditions at any 3-D point within the model domain. By contrast, a meteorological station, although it is a direct measurement of actual meteorology, can only provide information for a single point in space. Furthermore, when applied over a period of a year or longer, WRF can supply an estimate of long-term average meteorological conditions, i.e., the climate of an area.

The main inputs to WRF are the historical data used to set the starting meteorology and to set the meteorology of the model edges as it runs (referred to as the initial and boundary conditions, respectively), and the geophysical data used to define the earth surface in the model. This is shown schematically in Figure 11.10.3. If either of the input streams is changed to reflect future rather than current conditions, then the model can be used to predict the resulting future local microclimate.

The initial and boundary conditions for the WRF model were set using the North American Regional Reanalysis (National Centers for Environmental Prediction 2011). This consists of results from large-scale weather models that are adjusted, or reanalyzed, using surface, upper air, and satellite observation to give a more accurate historical snapshot of past weather conditions. The geophysical data are derived from global databases compiled by the United States Geological Survey that are provided with the WRF model codes for use with the model preprocessors. For the Future Case with the Project, the geophysical data was supplemented with outputs from a lake surface model, described below, to set the temperature and ice cover of the proposed reservoir surface.

The model was applied in a nested configuration with an outer domain simulating meteorological parameters every 12 km over much of western Canada, an intermediate domain with 4 km spacing, and finally a 1 km resolution model domain of 108 by 68 grid cells covering the proposed reservoir and the surrounding valley, including Fort St. John. The 1 km resolution model domain corresponds to the technical study area for the microclimate study. The nested domain configuration is shown in Figure 11.10.4. The innermost domain in Figure 11.10.4 corresponds to the technical study area as shown in Figure 11.10.1.

The model was run for a one-year period, from October 2004 through September 2005. This model year was chosen by selecting a recent consecutive 12-month period that was hydrologically normal in terms of water flows, and was also typical of 30-year climate normals from the Fort St. John station. A statistical comparison of the model period to the historical record of meteorological observations at North Peace Regional airport confirmed that the model year was representative of typical meteorological conditions within the area.

The 1 km domain was run in two configurations: a Baseline Case to reflect the existing Peace River valley and the Future Case with the Project to estimate meteorological conditions in the technical study area when the proposed Site C reservoir is filled to capacity. The Future Case with the Project was constructed by editing the terrain elevation and land cover classification data used by the model to reflect changes as a result of creating the reservoir. For both cases, boundary and initial conditions for the WRF model runs were set using North American Regional Reanalysis (National Centers for Environmental Prediction 2011). For the Future Case with the Project, the temperature and ice cover of the proposed reservoir surface were included in the evaluation by incorporating outputs from the Hydrodynamics in Three Dimensions (H3D) model (Volume 2 Appendix H Reservoir Water Temperature and Ice Regime Technical Data Report). The incorporation of the H3D results is illustrated in Figure 11.10.3, showing the WRF model inputs streams.

The differences between the two model runs were used to investigate changes in meteorology and microclimate that might result from creating the Site C reservoir.

11.10.4 Statistical Significance of Model Predictions

In addition to calculating absolute difference between the Baseline Case and the Future Case with the Project, a statistical analysis of the predicted changes was conducted to quantify the probability that the model predictions represent a statistically significant change. This analysis was conducted using Bayesian two-sample comparisons. This method compares the mean and variance of two samples to determine if there is a statistically significant difference between them. In this application, the two samples being tested are the Baseline Case and the Future Case with the Project model results for a particular meteorological parameter. The statistical significance is described in terms of a confidence interval. The terms likely and extremely likely correspond to 90% and 95% confidence intervals, respectively.

11.10.5 Weather Research and Forecasting Model Performance Evaluation

To be sure that the WRF model was providing results that are representative of actual conditions in the technical study area, numerical WRF model output for the October 2004 through September 2005 model year was compared statistically against observations at North Peace Regional airport for the same period. The model was deemed capable of predicting observed temperature at the BC Hydro climate stations. The model produced wind speeds and directions similar to those observed at North Peace Regional airport. Predicted precipitation during the 2004–2005 model year was closer to the long-term climate mean at North Peace Regional airport than the typical year-to-year variability observed in the long-term climate record. The WRF model is not sensitive enough to predict these small differences among the BC Hydro climate stations, but the results indicate that model predictions for precipitation were within historic norms.

To further confirm model performance, WRF was also run using the Baseline Case terrain elevation and land-cover characteristic inputs (no reservoir) for one year from January 2011 through January 2012, corresponding to the first full year of observations from the BC Hydro climate station network for the six stations that recorded wind temperature and precipitation. The meteorological observations collected during the first year at these six field stations, which were located along or near the proposed reservoir, were similar to the observations at the North Peace Regional airport for the same period.

The model evaluation shows that WRF reproduced the monthly, seasonal, and annual observations at the BC Hydro climate stations well enough that differences between the Baseline Case and the Future Case with the Project for the model study year would be indicative of changes in local meteorology and climate resulting from creation of the proposed Site C reservoir.

11.10.6 Predicted Changes to Microclimate

The differences between the Baseline Case and the Future Case with the Project WRF runs were examined to evaluate local meteorological changes after the Site C reservoir is filled.

Meteorological parameters of interest were examined in terms of annual and seasonal averages as well as daily maxima and minima for the model year. Detailed results over all periods are provided in the Microclimate Technical Data Report (Volume 2 Appendix K). It was predicted that there would be no changes more than 1 km from the proposed reservoir that are statistically distinguishable from year-to-year variations. Statistically significant changes were predicted only in some sections within 1 km of the proposed reservoir for parts of the year for temperature, wind, and mixing ratio. These changes are described in more detail in the next subsections.

11.10.7 Temperature

The analysis of model results for temperature examined annual average, extreme minimum and maximum, and daily average, as well as minimum and maximum by month.

For areas within 1 km of the reservoir, annual average temperatures were predicted to increase by a maximum of 1°C. Extreme temperatures were predicted to be moderated, with warmer minimum temperatures in winter and cooler maximum temperatures in summer. Largest short-term changes in temperature were predicted in winter during periods when H3D predicted that a portion of the water surface would be ice-free.

Predicted changes in monthly temperature are shown in Figure 11.10.5, with statistical significance of predictions plotted in Figure 11.10.6. All 12 months were analyzed separately. A characteristic month for each season is shown for simplicity. There are no statistically significant changes predicted beyond 1 km from the reservoir. The largest changes are seen all along the edge of the reservoir in fall, where the open water surface is warmer than the cooler ambient air, and in the southwest during winter, when this area of the reservoir remains ice-free.

Figure 11.10.7 shows the daily change in average temperature at the climate station locations. The largest short-term variations, up to 6°C, are predicted during winter near areas where there is no ice cover. Predicted changes are decreased for stations further away.

11.10.8 Wind Speed

There is an approximately 10% change in annual average and maximum over water wind speed. This is due to the reduced roughness of the proposed reservoir water surface compared with the existing river valley. Figure 11.10.8 shows changes in monthly average wind speed. All 12 months were analyzed separately. A characteristic month is shown for simplicity. The largest absolute changes are seen in fall and winter. However, the existing wind speed is also highest during these times. The largest relative changes are predicted in spring and summer. During these times, the synoptic winds from large-scale weather patterns are the weakest, so the winds influenced by local topography dominate.

Figure 11.10.9 shows the statistical significance of the predicted changes shown in Figure 11.10.8. No statistically significant changes beyond 1 km of the proposed reservoir are predicted.

A wind rose for the Baseline Case and the Future Case with the Project at Station 1 Attachie Flat Upper Terrace is shown in Figure 11.10.10. The Future Case with the Project at this location shows a shift in wind direction to the southwest. This is due to the reservoir surface changing the configuration of the valley bottom and thus the manner in which winds are channelled. The change in wind direction experienced by a given location depends on the specific terrain geometry before and after formation of the reservoir. The wind rose for Attachie Flat Upper Terrace shows the largest shift among the climate stations.

The predicted change in maximum hourly wind speed for the Site C climate station locations is given in Table 11.10.4. Monthly results have been compiled into seasons to simplify the table. The maximum hourly wind speeds reported for each season is the highest hourly wind speed predicted in that season. Hudson's Hope was predicted to experience the greatest change, with an increase of 3.4 km per hour in spring and summer, 7.5 km per hour in the fall, and 8.7 km per hour in winter. At some locations and times, the maximum wind speed is predicted to decrease. In these instances, the reduced surface roughness of the water (which tends to increase wind speeds) is probably dominated by reduced topographic forcing (which decreases influence of local wind systems) from the reservoir filling the valley.

Table 11.10.4 Seasonal Change in Maximum Hourly Wind Speed

Difference (Future Case with the Project – Baseline Case)	Spring	Summer	Fall	Winter	Year
North Peace Regional airport	-0.7 (43.3)	-0.2 (44.7)	0.4 (44.7)	0.4 (43.0)	0.4 (44.7)
Station 1 – Attachie Flat Upper Terrace	5.5 (38.0)	1.0 (39.0)	4.4 (42.8)	5.8 (35.6)	4.4 (42.8)
Station 2 – Attachie Flat Lower Terrace	2.6 (39.2)	4.7 (38.1)	6.9 (42.7)	6.3 (39.0)	6.9 (42.7)
Station 3 – Attachie Flat Plateau	1.2 (37.8)	1.7 (41.3)	4.9 (51.1)	4.4 (43.8)	4.9 (51.1)
Station 4 – Bear Flat	-5.0 (41.4)	-2.4 (37.6)	1.3 (49.6)	-1.0 (41.2)	1.3 (49.6)
Station 5 – Hudson's Hope	3.4 (35.3)	3.4 (46.2)	7.5 (53.7)	8.7 (55.5)	8.7 (55.5)
Station 6 – Farrell Creek	3.6 (35.6)	-0.6 (42.5)	5.2 (47.7)	5.5 (42.3)	5.2 (47.7)
Station 7 – Site C Dam	2.6 (38.9)	-2.1 (37.4)	1.0 (52.4)	3.6 (42.4)	1.0 (52.4)

NOTE:
All values in kilometres per hour. Baseline maximum wind speed for same period is shown in parentheses.

11.10.9 Mixing Ratio

Model results for humidity were analyzed in terms of monthly and annual averages. The WRF model provides outputs of humidity in terms of mixing ratio.

Water vapour mixing ratio shows increases at all locations adjacent to the reservoir, as would be expected close to a large water body. Predicted changes in seasonal mixing ratio are shown in Figure 11.10.11. All 12 months were analyzed separately. A characteristic month for each season is shown for simplicity. The greatest changes are seen in fall and summer. This is due to the open water surface providing a source of moisture and the increased overall capacity of the air to hold water caused by the increased daily minimum (i.e., warmer nights) from the influence of the reservoir. The smallest changes are seen in winter, due to the frozen reservoir surface that is very similar to snow-covered conditions that currently occur. Areas where the reservoir remains open in winter show larger differences.

Figure 11.10.12 shows the statistical significance of the predicted changes shown in Figure 11.10.11. No statistically significant changes are predicted beyond 1 km of proposed reservoir.

The mixing ratio at elevations above ground level was also examined, as this may be of concern to some transportation activities. At all levels extracted, increases or decreases predicted by the WRF model are less than 0.04 grams of water per kilogram of dry air, which is less than 1% of the saturated mixing ratio and, at most, a few per cent of typical mixing ratios at these levels. Such a difference would be unobservable in measurement and therefore should not represent any meaningful change in mixing ratio. As an illustration, Figure 11.10.13 shows the change in monthly average mixing ratio at approximately 800 m above sea level, or about 110 m above the ground at North Peace Regional airport.

The change in seasonal and annual mixing ratio for the Site C climate station locations is given in Table 11.10.5. Monthly results have been compiled into seasons to simplify the table.

Atmospheric moisture was predicted to increase at all locations adjacent to the proposed Site C reservoir. This result was expected, as moisture would be more readily available with the presence of the proposed Site C reservoir. Evaporation is expected to increase at the surface and increase atmospheric moisture near the reservoir. Typical mixing ratios in the technical study area are on the order of less than 1.0 g/ kg of dry air in winter and over 10 g/ kg of dry air on a hot humid summer day.

The greatest changes are predicted to occur in the summer at the Bear Flat and proposed Site C dam station locations where changes were found to be statistically significant. The largest change in humidity is predicted to occur in summer at the proposed Site C dam with an increase of 0.98 g/kg of dry air or about a 15% increase in atmospheric moisture. Stations closest to the reservoir show the highest changes.

Table 11.10.5 Seasonal Change in Water Vapour Mixing Ratio

Difference (Future Case with the Project – Baseline Case)	Spring	Summer	Fall	Winter	Year
North Peace Regional airport	0.00	0.03	0.02	0.00	0.01
Station 1 – Attachie Flat Upper Terrace	0.41	0.86	0.81	0.03	0.53
Station 2 – Attachie Flat Lower Terrace	0.41	0.83	0.85	0.02	0.53
Station 3 – Attachie Flat Plateau	0.00	0.06	0.09	0.00	0.04
Station 4 – Bear Flat	0.38	0.90	0.79	0.02	0.52
Station 5 – Hudson's Hope	-0.02	0.03	0.12	0.04	0.04
Station 6 – Farrell Creek	0.00	0.03	0.10	0.02	0.04
Station 7 – Site C Dam	0.41	0.98	0.77	0.02	0.55

NOTE:

All values in grams of water vapour per kilogram of dry air.

11.10.10 Precipitation

The model results for precipitation were examined in terms of monthly and annual totals.

Predicted changes in monthly precipitation are shown in Figure 11.10.14. All 12 months were analyzed separately. A characteristic month for each season is shown for simplicity. All seasons show changes of less than 20 mm. Changes are smallest for fall and winter. This period is easier to model because it is dominated by synoptic effects that are well captured in large-scale inputs. Also, the proposed reservoir ice cover at this time of year is not much different than the snow-covered Baseline Case. There is more variation across the domain in the summer, but this is due to the convective nature of precipitation that is more randomly distributed than in winter.

Table 11.10.6 shows predicted changes in precipitation in the study area. Monthly results have been compiled into seasons to simplify the table. Changes at Farrell Creek are greatest, with a decrease in total annual precipitation of 18 mm. Attachie Flat Upper Terrace, Attachie Flat Lower Terrace, and the proposed Site C dam site are predicted to have a decrease of greater than 10 mm of total annual precipitation. All other locations are predicted to have a change less than 10 mm of total precipitation on an annual basis, while measured precipitation at the station locations ranges from around 400 mm to 600 mm per year. The predicted changes are statistically indistinguishable from the large inter-annual and intra-annual variability of precipitation for all of the stations.

Table 11.10.6 Seasonal Change in Total Precipitation

Difference (Future Case with the Project – Baseline Case)	Spring	Summer	Fall	Winter	Year
North Peace Regional airport	2.7	-10.5	-0.2	0.3	-7.7
Station 1 – Attachie Flat Upper Terrace	-12.2	-0.1	-2.8	-0.5	-15.6
Station 2 – Attachie Flat Lower Terrace	-3.6	-2.2	-3.2	-2.6	-11.6

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Difference (Future Case with the Project – Baseline Case)	Spring	Summer	Fall	Winter	Year
Station 3 – Attachie Flat Plateau	-7.0	0.9	-1.4	2.4	-5.1
Station 4 – Bear Flat	-19.3	13.0	-1.8	2.0	-6.2
Station 5 – Hudson's Hope	1.4	3.3	-1.7	0.2	3.2
Station 6 – Farrell Creek	-10.4	-6.3	-1.1	-0.2	-18.0
Station 7 – Site C Dam	-5.0	-8.4	-0.4	2.5	-11.3

NOTE:

All values in millimetre water equivalent.

11.10.11 Fog and Visibility

The model-derived visibility changes were examined in terms of monthly and annual number of hours of fog occurrence. Fog frequency and density were evaluated at the locations of the seven BC Hydro climate stations close to the proposed Site C reservoir, at North Peace Regional airport and at Taylor Bridge (see Table 11.10.7 and Table 11.10.8). Fog hours have been compiled into seasonal and annual totals for presentation in the tables. The number of normal fog hours, defined as visibility less than 1 km, is predicted to decrease at five out of nine locations, but increase at the North Peace Regional airport (seven hours per year), Taylor Bridge (eight hours per year), Hudson's Hope (one hour per year), and Attachie Flat Lower Terrace (nine hours per year) locations. The number of heavy fog hours, defined as visibility less than 500 m, decreases at most locations except North Peace Regional airport, where an increase of six hours per year is predicted, and Taylor Bridge, where an increase of 118 hours is predicted.

Table 11.10.7 Predicted Change in Fog from Baseline Case to Future Case with the Project

Station	Spring		Summer		Fall		Winter		Year	
North Peace Regional airport	-6	(208)	4	(177)	16	(484)	-7	(692)	7	(1561)
Station 1 – Attachie Flat Upper Terrace	-7	(199)	-10	(177)	11	(359)	2	(437)	-4	(1172)
Station 2 – Attachie Flat Lower Terrace	4	(200)	-2	(179)	10	(353)	-3	(443)	9	(1175)
Station 3 – Attachie Flat Plateau	-10	(229)	-14	(195)	3	(365)	-4	(462)	-25	(1251)
Station 4 – Bear Flat	-18	(227)	2	(155)	-7	(393)	-7	(520)	-30	(1295)
Station 5 – Hudson's Hope	-8	(210)	0	(172)	9	(350)	0	(353)	1	(1085)
Station 6 – Farrell Creek	-4	(210)	6	(178)	-14	(365)	-1	(492)	-13	(1245)
Station 7 – Site C Dam	-8	(216)	-7	(171)	-7	(427)	4	(560)	-18	(1374)
Taylor Bridge	7	(151)	5	(136)	-3	(350)	-1	(496)	8	(1133)

NOTE:

Shown are changes in normal fog hours, with baseline hours in brackets

Table 11.10.8 Predicted Change in Heavy Fog from Baseline Case to Future Case with the Project

Station	Spring		Summer		Fall		Winter		Year	
North Peace Regional airport	-4	(188)	1	(155)	14	(468)	-5	(678)	6	(1489)
Station 1 – Attachie Flat Upper Terrace	-9	(171)	-11	(156)	9	(338)	-4	(432)	-15	(1097)
Station 2 – Attachie Flat Lower Terrace	-5	(174)	-5	(151)	1	(336)	-5	(429)	-14	(1090)
Station 3 – Attachie Flat Plateau	1	(197)	-6	(166)	0	(351)	-4	(453)	-9	(1167)
Station 4 – Bear Flat	-16	(192)	-1	(133)	-6	(376)	-10	(508)	-33	(1209)
Station 5 – Hudson's Hope	-10	(187)	-4	(153)	9	(341)	1	(521)	-4	(1202)
Station 6 – Farrell Creek	-3	(183)	6	(158)	-13	(354)	-1	(481)	-11	(1176)
Station 7 – Site C Dam	-14	(182)	-4	(142)	-7	(401)	5	(547)	-20	(1272)
Taylor Bridge	46	(130)	8	(124)	41	(329)	23	(475)	118	(1058)

NOTE:

Shown are changes in heavy fog hours, with baseline hours in brackets.

Visibility, as classed into various ranges from less than 500 m to greater than 20 km, was examined to determine the potential for change at the North Peace Regional airport as a result of the proposed Site C reservoir (see Table 11.10.9). The combined total number of clear hours with visibility greater than 20 km and hours with visibility 10 km to 20 km was predicted to be reduced by 15 hours over the year, while the number of hours with visibility in the range of 1 km to 10 km was predicted to increase by eight hours over the year. The number of hours of poor visibility (less than 500 m) was predicted to increase by six hours per year with the addition of the reservoir.

Due to the nature of the calculation, a statistical significance test was not possible. Both visibility and fog calculation give results that are placed into class ranges, as opposed to other parameters such as temperature, which gives a continuous hourly time series result. This classification makes developments of a robust statistical test difficult. However, the occurrence of fog and atmospheric visibility are both determined by the base quantities of temperature and moisture, for which statistically significant changes were limited to within 1 km of the reservoir. It is reasonable to conclude that any quantity derived from temperature and moisture would provide similar results.

Table 11.10.9 Predicted Changes in Visibility at North Peace Regional Airport

Seasons	Visibility					
	Clear		Moderate		Poor	
	> 20 km	10–20 km	5–10 km	1–5 km	0.5–1 km	< 0.5 km
Spring						
Baseline Case	1,914	9	16	37	20	188
Future Case with the Project	1,919 (-5)	9 (0)	9 (-7)	45 (8)	18 (-2)	184 (-4)
Summer						
Baseline Case	1,980	8	10	33	22	155
Future Case with the Project	1,977 (-3)	5 (-3)	14 (4)	31 (-2)	25 (3)	156 (1)
Fall						
Baseline Case	1,689	9	7	19	16	468
Future Case with the Project	1,674 (-5)	7 (-2)	6 (-1)	21 (2)	18 (2)	482 (14)
Winter						
Baseline Case	1,441	2	8	17	14	684
Future Case with the Project	1,444 (3)	2 (0)	7 (-1)	22 (5)	12 (2)	679 (-5)
Year						
Baseline Case	7,024	28	41	106	72	1,495
Future Case with the Project	7,014 (-10)	23 (-5)	36 (-5)	119 (13)	73 (1)	1,501 (6)

NOTE:
Shown are hours per year within each visibility class. The change is given in brackets.

11.10.12 Global Climate Change

WRF model predictions for changes in temperature and precipitation within the technical study area were compared to projections of the influence of global climate changes in the technical study area as calculated by several global circulation models. The lower bounds for estimates of the influence of global climate change are for increases of about 2°C for temperature and approximately 15% for precipitation.

As seen in the plots and tables of WRF model results for changes in temperature, for some sections along the proposed reservoir, in the fall and winter, mean-temperature changes from the proposed reservoir and regional mean-temperature increases caused by global climate change were predicted to be of similar strength. At other times and elsewhere, predicted changes due to the reservoir were smaller and sometimes partly cancel regional temperature increases. For most of the technical study area, the magnitude of predicted changes in microclimate would be statistically insignificant when compared to global climate change. Changes in precipitation due to the reservoir were found to be statistically insignificant everywhere in the technical study area; therefore, they would by definition be dominated by any statistically significant influence of global climate change.

11.11 Air Quality

11.11.1 Introduction

Construction and operation of the Project have the potential to change local and regional air quality.

During construction, activities that would contribute to combustion and fugitive dust emissions include operating construction vehicles and equipment, clearing and burning vegetation and debris, and extracting and transporting construction materials. These activities would take place at the dam, generating station, and spillways; in quarries, gravel pits and borrow pits; and along roads, the railway, and the transmission corridor.

During operations, the Site C reservoir could potentially influence local air quality during dry periods of the year when the reservoir water level is lower than normal. Exposed reservoir shorelines have been sources of fugitive dust emissions when wind speeds are high enough to move and entrain dry sediments. However, wind erosion is not expected to pose an air quality issue, given the reservoir configuration, steep reservoir banks, and the small reservoir level operating range. Other potential emission sources during operation are combustion emissions from maintenance vehicles and vessels. Emissions during operations would be much lower than during construction.

This section of the EIS provides an overview and summary of the air quality study. Details regarding the approach and findings are provided in Volume 2 Appendix L Air Quality Technical Data Report. Information obtained in the air quality study was used in evaluating potential effects of the Project on human health (Volume 4 Section 33 Human Health).

11.11.2 Objectives and Scope

The objectives of the Air Quality study were to:

- Characterize the existing baseline air quality in terms of measured ambient air quality and emissions of criteria air contaminants
- Estimate emissions due to Project construction and operation
- Predict changes to ambient air quality in the dam site area due to Project construction
- Discuss potential changes to ambient air quality during Project operation

This study focuses on criteria air contaminants, i.e., contaminants for which there are either ambient air quality objectives or Canada-wide standards (see Section 11.11.3), including particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO).

11.11.3 Ambient Air Quality Criteria

To provide context for baseline ambient air quality conditions and for predicted changes to ambient air quality in the dam site area during Project construction, existing and predicted concentrations of criteria air contaminants are compared to ambient air quality criteria, which are developed by environment and health authorities. British Columbia ambient air quality objectives and Canada-wide standards for the criteria air contaminants included in the Air Quality study are listed in Table 11.11.1.

There are provincial ambient air quality objectives for all criteria air contaminants except NO_2. For the purposes of this study, federal ambient air quality objectives were used in place of provincial objectives for NO_2. Provincial ambient air quality objectives are divided into three categories designated as Levels A, B, and C, with Level A being the most stringent. These three levels correspond roughly to federal levels, as defined below:

- Level A is equivalent to the federal maximum desirable objective, which is a long-term goal for air quality and provides a basis for an anti-degradation policy for unpolluted areas, and for continuing development of control technology
- Level B is equivalent to the federal maximum acceptable objective, which is intended to provide adequate protection against effects on soil, water, vegetation, materials, visibility, personal comfort, and well-being
- Level C is equivalent to the federal maximum tolerable objective, which denotes time-based concentrations of air contaminants beyond which, due to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general public

Canada-wide standards have been developed for $PM_{2.5}$ and ozone. Canada-wide standards are established by the Canadian Council of Ministers of the Environment as a step towards the long-term goal of minimizing risks to human health and the environment. They represent a balance between the desire to achieve the best health and environmental protection possible in the relative near term, and the feasibility and costs of reducing the pollutant emissions that contribute to elevated ambient concentrations.

Table 11.11.1 B.C. Ambient Air Quality Objectives and Canada-wide Standards

Contaminant	Averaging Period	Objectives/Standards (µg/m³) British Columbia Level A	Level B	Level C	Canada-Wide Standard
Total suspended particulate	24-hour	150	200	260	—
	Annual	60	70	75	
Particulate matter less than 10 µm (PM_{10})	24-hour	50			—
	Annual	—			—
Particulate matter less than 2.5 µm ($PM_{2.5}$)	24-hour	25[a]			27 to 30[b]
	Annual	8[c]			8.8 to 10[d]
Dustfall[e]	24-hour	1.75 mg/dm²/d residential, 2.9 mg/dm²/d non-residential			—
Nitrogen dioxide[f]	1-hour	—	400	1,000	—
	24-hour	—	200	300	
	Annual	60	100	—	
Sulphur dioxide	1-hour	450	900	900-1,300	—
	24-hour	160	260	360	
	Annual	25	50	80	
Carbon monoxide	1-hour	14,300	28,000	35,000	—
	8-hour	5,500	11,000	14,300	
Ozone	8-hour	—			62 to 65 ppb[g]

NOTES:

[a] Compliance based on annual 98th percentile value

[b] Current objective of 30 µg/m³ is proposed to change to 28 µg/m³ in 2015 and 27 µg/m³ in 2020; compliance based on annual 98th percentile value, averaged over three consecutive years

[c] B.C. also has a planning goal for annual $PM_{2.5}$ of 6 µg/m³

[d] There are currently no annual Canada-wide standards for annual $PM_{2.5}$, but there is a proposed objective of 10.0 µg/m³ for 2015 and 8.8 µg/m³ for 2020

[e] 24-hour average based on 30-day sample

[f] B.C. does not have ambient air quality objectives for NO_2 and therefore, the federal maximum acceptable (Level A), desirable (Level B), and tolerable (Level C) objectives are presented

[g] Current objective of 65 ppb is proposed to change to 63 ppb in 2015 and 62 ppb in 2020; compliance based on fourth highest annual value, averaged over three consecutive years

— not collected

SOURCES:

BCMOE 2009; Canadian Council of Ministers of the Environment 2006, 2012

11.11.4 Approach and Methods

11.11.4.1 Technical Study Areas

Two study areas were used to analyze air quality including: (a) a technical study area and (b) a dispersion modelling study area. These two study areas are illustrated in Figure 11.11.1.

The technical study area is a 138 km by 102 km area that encompasses the Project activity zone, including the West Pine Quarry as well as the City of Fort St. John and the

District of Taylor. Emissions from all Project components during construction and operation were estimated for the technical study area.

Due to the extent of construction activities at the Site C dam site and its proximity to the City of Fort St. John, dispersion modelling was conducted for the dam site area and surroundings to predict ambient air quality concentrations resulting from Project construction emissions. The dispersion modelling study area is a 26 km by 27 km rectangle specified to include a minimum 5 km buffer around the dam site area, Wuthrich Quarry, and Area E (a potential source of granular material), and extended north and east to include the community of Charlie Lake and the District of Taylor, respectively.

Sub-areas within the technical study area were defined around the construction material source areas (Wuthrich Quarry, West Pine Quarry, 85th Avenue Industrial Lands, Portage Mountain and Del Rio Pit) and Hudson's Hope Shoreline Protection to further characterize baseline settings and Project emissions in these areas. These sub-areas are 12 km by 12 km squares, specified to include a minimum 5 km buffer around each Project component.

11.11.4.2 Field Surveys

Field surveys consisted of operating two ambient air quality monitoring stations and a BC Hydro network of meteorological stations. The ambient air quality monitoring stations, located at Attachie Flat and Old Fort, were installed to collect baseline particulate matter data and to provide ongoing monitoring during all phases of the Project. The six meteorological stations located between Taylor and Hudson's Hope, and one wind station located in Farrell Creek, were installed to collect data for the microclimate study (Volume 2 Appendix K Microclimate Technical Data Report) and dispersion modelling. Details on the ambient air quality and meteorological stations, including station co-ordinates and operating time periods, are provided in Volume 2 Appendix L Air Quality Technical Data Report.

11.11.4.3 Baseline Air Quality

Baseline air quality conditions were determined based on existing provincial and national emission inventories and on historical ambient air quality monitoring data.

Baseline emissions were determined by extracting information from provincial and national emission inventories. Emission estimates of criteria air contaminants for area and mobile sources were obtained from the B.C. Ministry of Environment (McCormick 2012, pers. comm.), based on their most recent provincial emission inventory in 2000. Emissions from point sources were determined from Environment Canada's National Pollutant Release Inventory (Environment Canada 2012) for the year 2010.

Baseline ambient concentrations were determined by reviewing air quality monitoring data collected primarily from field surveys and from the BCMOE network of monitoring stations in the province (BCMOE 2012). Additional information was obtained from the Clean Air Strategic Alliance Data Warehouse (2012) where necessary. Dustfall monitoring data from the Quintette and Bullmoose mines, now closed, and the existing Brule, Dillon, and Willow Creek coal mines were obtained from public reports on the Environmental Assessment Office website and reviewed for baseline air quality characterization.

11.11.4.4 Emission Estimation

Project construction emissions were estimated for every year of the expected eight-year construction period. The emission inventory was subdivided by Project component (i.e., dam, generating station, and spillways; quarried and excavated construction material; road and rail access; and transmission line). Project operation emissions were estimated for ongoing Site C dam site operations, including maintenance activities at the generating station.

The scope of the emission inventory included the following emission sources, where applicable:

- Clearing activities
- Open burning and incineration of clearing debris
- Extraction, processing, movement, and placement of construction and waste materials
- Drilling
- Explosives detonation and blasting
- Material handling and transfers
- Concrete batch plant operations
- Material processing
- Stockpile wind erosion
- Grading and scraping
- Fugitive emissions of road dust on paved and unpaved access roads
- Mobile vehicle exhaust
- Diesel-fuelled equipment and generators
- Boats
- Aircraft
- Asphalt production

Project emissions were estimated using published emission factors obtained primarily from the United States Environmental Protection Agency (US EPA) Compilation of Air Pollutant Emission Factors known as AP-42 (US EPA 1995–2011) and US EPA emission models. Other sources of emission information include Environment Canada's Criteria Air Contaminants Emission Inventory 2002 Guidebook (Environment Canada 2006), the Air and Waste Management Association's Air Pollution Engineering Manual (AWMA 2000), the Western Regional Air Partnership's Fugitive Dust Handbook (WRAP 2006), and The Chamber of Shipping's Ocean-Going Vessels Emissions Inventory Report (Chamber of Shipping 2007).

11.11.4.5 Dispersion Modelling

The dispersion modelling methodology was based on the Guidelines for Air Quality Dispersion Modelling in British Columbia (BCMOE 2008). A conceptual model plan was submitted to and agreed upon by the BCMOE. Technical options were selected based on the Guidelines for Air Quality Dispersion Modelling in British Columbia or set to model defaults. Details are provided in the Air Quality Technical Data Report (Volume 2 Appendix L).

Dispersion modelling was conducted using the CALPUFF model in full three-dimensional CALMET mode, as is appropriate for the complex terrain and wind patterns in the Peace River Valley. CALMET is a meteorological preprocessor that develops hourly three-dimensional meteorological fields of wind and temperature used to drive pollutant transport within CALPUFF. CALPUFF is a multi-layer, multi-species, non-steady-state puff dispersion model. It simulates the influences of time- and space-varying meteorological conditions on pollutant transport, transformation, and deposition.

Project construction emissions within the dispersion modelling study area, including emissions from the dam, generating station and spillways, Wuthrich Quarry, 85th Avenue Industrial Lands, and Area E, were entered in a dispersion model to predict maximum ambient concentrations of criteria air contaminants and dustfall deposition rates. All estimated emissions were included in the modelling except road dust and emissions from clearing activities, including burning vegetation. Volume 2 Appendix L Air Quality Technical Data Report provides the rationale for excluding these emissions from the dispersion modelling.

To assess the cumulative air quality changes of the Project, background concentrations were added to ambient concentrations predicted from dispersion modelling. These background concentrations, which are single values applied to every hour and every location in the dispersion modelling study area, are used as a simplified approach to represent the contribution from all other natural and human-caused sources (i.e., the baseline setting). Representative background concentrations were calculated based on the Guidelines for Air Quality Dispersion Modelling in British Columbia (BCMOE 2008) or developed based on discussions with the BCMOE.

11.11.4.6 Study Limitations

A number of limitations are inherent in the air quality study. These include limitations in emissions estimation and limitations in dispersion modelling.

Emissions have been estimated based on Project-specific activity data where available, and default activity data from the US EPA where Project-specific information are not available. Default activity data are based on the average of conditions observed at a limited number of project sites, mainly in the Unites States, which may not be representative of the Project. The use of published emission factors is associated with inherent limitations in that such factors are based on averages of available data, which may not be sufficient to extrapolate for Project-specific activity parameters (e.g. vehicle speed, material silt content, etc.) outside the observed range of these parameters. Furthermore, these published emission factors are typically representative of long-term averages and the use of such emission factors for estimating short-term emission rates for dispersion modelling are associated with uncertainties.

By definition, air quality dispersion models can only approximate atmospheric processes. Many assumptions and simplifications are required to describe real phenomena in mathematical equations. Model uncertainties can result from:

- Simplifications and accuracy limitations related to source data
- Extrapolation of meteorological data from selected locations to a larger region
- Simplifications of model physics to replicate the random nature of atmospheric dispersion processes

Models are reasonable and reliable in estimating the maximum concentrations occurring on an average basis. That is, the maximum predicted concentration that may occur at some time somewhere within the model domain, as opposed to the exact concentration at a point at a given time, will usually be within the ±10% to ±40% range (US EPA 2003) of the observed maximum concentration. Typically, a model is viewed as replicating dispersion processes if it can predict within a factor of two (from one-half to double the actual value), and if it can replicate the temporal and meteorological variations associated with monitoring data. Model predictions at a specific site and for a specific hour, however, may correlate poorly with the associated observations, due to the above-indicated uncertainties. For example, an uncertainty of 5 to 10 degrees in the measured wind direction can result in concentration errors of 20% to 70% for an individual event (US EPA 2003).

This uncertainty in the model is dealt with in air quality studies by selecting inputs that attempt to ensure that the model will err on the conservative side of the uncertainty, which is to say that they will typically over-predict changes to air quality.

11.11.5 Baseline Air Quality Description

The technical and dispersion modelling study areas are characterized by mostly low population densities in rural settings. Forestry, agriculture, oil and gas, mining, and power generation are the main industries and emission sources in the region. The City of Fort St. John is the largest population centre, with a population of over 19,000. Within population centres, emissions from vehicle traffic and residential wood heating are important factors to local air quality, as are emissions from vehicle traffic along major roads, in particular Highway 97 (i.e., the Alaska Highway).

11.11.5.1 Baseline Emissions

Baseline emissions in the technical study area are illustrated in Figure 11.11.2. Point sources contribute 17% to $PM_{2.5}$ and between 40% and 64% to the other five criteria air contaminants. Area sources contribute 49% to $PM_{2.5}$ and between 11% and 31% to the other criteria air contaminants except SO_x, to which they contribute less than 1%. Mobile sources contribute between 23% and 43% to all six criteria air contaminants.

Of the three source categories, point sources emit the most total suspended particulate and PM_{10}, while area sources emit the most $PM_{2.5}$. Agriculture is an important source of particulate matter emissions, contributing from 15% of $PM_{2.5}$ to 19% of total suspended particulate emissions. Off-road vehicles emit almost all of the $PM_{2.5}$, PM_{10}, and total suspended particulate from mobile sources.

The main sources of NO_x, SO_x and CO emissions are point sources and mobile sources. This is particularly true for SO_x, for which the area source category emits less than 1% of total emissions. Area sources emit 11% of NO_x (mainly agriculture) and 16% of CO.

Baseline emissions in the dispersion modelling study area are illustrated in Figure 11.11.3. In the dispersion modelling study area, point source contributions to NO_x and SO_x are 62% and 51%, respectively. The contribution of point sources to other criteria air contaminants is less than 23%. Area sources contribute between 43% and 56% to all particulate matter emissions, 19% to total CO, 5% to total NO_x, and less than 1% to total SO_x. Mobile sources contribute between 33% and 58% to all six criteria air contaminants.

The contribution of point sources to particulate matter emissions is less in the dispersion modelling study area than in the technical study area; the largest industrial contributor to particulate matter emissions in the technical study area (i.e., Willow Creek Mine) is located outside the dispersion modelling study area. Area and mobile sources contribute most to all size fractions of particulate matter. Similar to the technical study area, agriculture is an important area source of particulate matter emissions in the dispersion modelling study area, contributing from 10% of $PM_{2.5}$ to 25% of total suspended particulate emissions. Residential wood heating contributes a larger fraction of particulate matter emissions in the dispersion modelling study area than in the technical study area, contributing from 10% of total suspended particulate to 28% of $PM_{2.5}$ emissions.

Point sources dominate NO_x emissions in the dispersion modelling study area, followed by mobile sources. The industrial and mobile source categories emit roughly 50% each to total SO_x emissions. The majority of the CO emissions are emitted by mobile sources, particularly off-road sources.

11.11.5.2 Baseline Ambient Air Quality

Historical monitoring data were reviewed to characterize baseline air quality. Overall, observed concentrations were less than the relevant ambient air quality objectives for all criteria air contaminants. Some exceedances of the provincial objectives for dustfall were observed near the mine sites. Details are provided in Volume 2 Appendix L Air Quality Technical Data Report.

Representative background concentrations used for assessing cumulative changes are summarized in Table 11.11.2. The rationale for selecting these background concentrations is discussed in Volume 2 Appendix L Air Quality Technical Data Report.

Table 11.11.2 Representative Background Concentrations

Pollutant	Averaging Period	Background Value (μg/m³)	Data Source for Value
TSP	24-Hour	26	Old Fort PM_{10} monitoring data
	Annual	5.4	
PM_{10}	24-Hour	26	Old Fort monitoring data
$PM_{2.5}$	24-Hour	15	
	Annual	5.0	
Dustfall[a]	24-Hour	0.8 mg/dm²/d	Willow Creek Mine monitoring data
NO_2	1-Hour	0.0	BCMOE recommendation
	24-Hour		
	Annual		
SO_2	1-Hour	0.0	BCMOE recommendation
	24-Hour		
	Annual		
CO	1-Hour	229	BCMOE recommendation
	8-Hour[b]	160	
Ozone	1-Hour	64 ppb	Taylor Townsite monitoring data
	24-Hour	19 ppb	
	Annual	19 ppb	

NOTES:

[a] 24-hour average based on 30-day sample

[b] The eight-hour average concentration is calculated by applying a scaling factor of 0.7 (BCMOE 2008) to the specified one-hour average concentration

11.11.6 Project Emissions

The emission estimates associated with Project construction are presented in Section 11.11.6.1 and the emission estimates from Project operation and maintenance are presented in Section 11.11.6.2.

11.11.6.1 Construction

Detailed estimates are provided in Volume 2 Appendix L Air Quality Technical Data Report. For summary purposes, only selected estimates are provided in this section.

Total annual Project construction emissions are shown in Table 11.11.3 and compared to baseline emissions in the technical study area. Estimated emissions of total suspended particulate are greatest in Year 5, estimated emissions of PM_{10} are greatest in Year 2, estimated emissions of $PM_{2.5}$ and CO are greatest in Year 1 and estimated emissions of NO_X and SO_X are greatest in Year 4.

The largest sources of Project construction emissions are the construction of the dam, generating station and spillways, construction of infrastructure for road and rail access, and burning and incineration.

Table 11.11.3 Estimate of Total Annual Project Construction Emissions (in Tonnes)

Pollutant	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Baseline 2000/2010
TSP	9,012	10,161	10,801	10,529	11,270	10,012	8,736	2,080	13,200
PM_{10}	3,210	3,463	3,403	3,200	3,444	2,876	2,476	589	6,570
$PM_{2.5}$	1,456	1,373	827	634	650	326	287	65	2,250
NO_X	916	1,028	1,067	1,413	1,397	301	256	43	13,800
SO_X	18.6	251	555	1,015	1,015	1.23	0.938	0.1	21,600
CO	15,009	13,036	5,463	2,571	2,568	238	190	49	38,100

Emissions included in the dispersion modelling are summarized in Table 11.11.4. These represent Project construction emissions for components located inside the dispersion modelling study area for a select year, as discussed below. As explained in Volume 2 Appendix L Air Quality Technical Data Report, emissions from road dust entrainment and from burning and incineration are excluded from dispersion modelling, and therefore are not included in the totals shown in Table 11.11.4.

Table 11.11.4 Total Annual Emissions Used in Dispersion Modelling (in Tonnes)

Pollutant	TSP	PM_{10}	$PM_{2.5}$	NO_X	SO_X	CO
Dam, generating station, and spillways	573	197	66	334	0.7	193
Wuthrich Quarry	16	5.3	2.0	7.2	0.1	7.6
85th Avenue Industrial Lands	30	10	3.4	7.8	0.01	4.3
Area E	25	9.7	2.0	6.1	0.01	2.9
Vehicles in transit	0.2	0.2	0.2	1.3	0.08	4.5

The largest source of total suspended particulate and PM_{10} emissions from the construction of the dam, generating station and spillways is estimated to be the movement and placement of construction and waste materials via bulldozers; the largest source of $PM_{2.5}$, NO_x and CO emissions is estimated to be diesel-fuelled equipment; and the largest source of SO_x emissions is estimated to be explosives detonation. Modelling of dam site area construction emissions was based on Year 3, for which particulate matter and NO_x emissions were the highest.

The largest sources of particulate matter emissions at Wuthrich Quarry include bulldozing, drilling, blasting, and diesel-fuelled equipment. The largest source of NO_x emissions is estimated to be diesel-fuelled equipment and the largest source of SO_x and CO emissions is estimated to be explosives detonation. Modelling of Wuthrich Quarry was based on Year 2, as this represents the year in which the most material is expected to be extracted, resulting in the highest emissions.

The largest sources of particulate matter emissions at the 85th Avenue Industrial Lands are estimated to be grading, scraping, and bulldozing. For NO_x, SO_x, and CO, the largest source of emissions is estimated to be diesel-fuelled equipment. Modelling of the 85th

Avenue Industrial Lands was based on Year 5, corresponding to the year when emissions are expected to be greatest.

Area E, a potential source of granular material in Year 7 in the event that Zone 3 in the dam site area does not have sufficient material, was conservatively included in the dispersion modelling, but was not included in the Project construction emissions presented in Table 11.11.3.

Emissions from vehicles in transit are tabulated separately in Table 11.11.4 and represent travel on public roads outside of dam construction boundaries. The modelled year for vehicles in transit was dependent on activity. Vehicles in transit from Wuthrich Quarry were based on Year 2, and vehicles in transit from Area E were based on Year 7. Vehicles in transit to/from the City of Fort St. John and the District of Taylor comprise worker transportation and service vehicles, for which vehicle travel is expected to be relatively constant throughout the duration of Site C dam site construction. As a result, modelling for these vehicles was based on Year 1, when regulatory tailpipe emission standards that are integrated into the emission estimates are the least stringent, and therefore estimated emissions are greatest. Vehicles in transit to/from West Pine Quarry, Hudson’s Hope, and Chetwynd were not included in dispersion modelling, since the length of road associated with these routes that lies within the dispersion modelling study area is small.

11.11.6.2 Operation and Maintenance

Estimated emissions from ongoing operation and maintenance at the Site C dam site are shown in Table 11.11.5. The largest source of total suspended particulate and PM_{10} emissions is estimated to be the entrainment of road dust from paved roads (88.8% and 60.4%, respectively) and diesel-fuelled heavy equipment is estimated to be the largest source of $PM_{2.5}$ (51.5%) and CO (44.4%) emissions. Boats account for 64.3% of NO_X emissions and 91.5% of SO_X emissions. Emissions from the switch yard and microwave station account for less than 1% of total emissions from operation and maintenance activities.

Table 11.11.5 Total Annual Emissions from Project Operation and Maintenance (in Tonnes)

Activity	TSP	PM_{10}	$PM_{2.5}$	NO_X	SO_X	CO
Road dust	0.4	0.08	0.02	—	—	—
Vehicle exhaust	0.002	0.002	0.001	0.02	0.0001	0.1
Diesel equipment	0.04	0.04	0.03	0.3	0.0005	0.1
Diesel generators	0.003	0.003	0.003	0.09	0.0001	0.02
Boats	0.01	0.01	0.01	0.6	0.008	0.04
Total	0.5	0.1	0.07	1.0	0.009	0.3

The potential for fugitive dust emissions from shoreline exposures in the proposed reservoir was investigated by Nickling Environmental Ltd., and described in their Project Memorandum dated August 14, 2012 (Nickling 2012). The Nickling report concludes that it is unlikely that dust emissions would be a major problem at the proposed Site C Reservoir. This is attributed to:

- The small annual drawdown and the associated small area of exposed shoreline

- The relatively coarse texture of a large proportion of the sediments
- The amount of bedrock exposure at the shoreline that would reduce sediment input

11.11.7 Dispersion Modelling Results

Selected dispersion modelling results for Project construction are presented in this section. Detailed results are provided in Volume 2 Appendix L Air Quality Technical Data Report.

Maximum predicted concentrations for particulate matter with background included are presented in Table 11.11.6 and illustrated in Figure 11.11.4 through Figure 11.11.9. The highest predicted concentrations that exceed relevant objectives were predicted in the vicinity of Wuthrich Quarry, in an area for which there are no known sensitive receptors. Some exceedances of the objectives were also predicted along the construction boundary for Area E and by the river close to the construction boundary for the dam site area.

At sensitive receptors, exceedances of the B.C. Level A and B objectives for 24-hour total suspended particulate (Figure 11.11.4), the 24-hour PM_{10} (Figure 11.11.6), and both the 24-hour and annual $PM_{2.5}$ objectives (Figure 11.11.7 and Figure 11.11.8, respectively) were predicted at the north camp site, located within the dam site area. Exceedances of PM_{10} were also predicted at one residence located within the dam site area and at several non-residences in the vicinity of the Site C dam site. Exceedances of $PM_{2.5}$ were also predicted at the south camp site located within the dam site area for the 24-hour averaging period and at several non-residences in the vicinity of the Site C dam site for both the 24-hour and annual averaging periods. No exceedances for dustfall were predicted at any sensitive receptors.

Table 11.11.6 Maximum Predicted Concentrations for Particulate Matter including Background (in µg/m³)

Contaminant	TSP		PM_{10}	$PM_{2.5}$		Dustfall[a]
Averaging Period	**24-hour**	**Annual**	**24-hour**	**24-hour**	**Annual**	**24-hour**
Overall max (outside dam site area)	**644**	**136**	**278**	**84**	**25**	**3.3**
Fort St. John	45	8.5	32	18	5.8	0.9
Taylor	32	6.4	28	16	5.2	0.8
Ground-truthed residence	109	17	**51**	24	7.3	1.2
Ground-truthed non-residence	115	37	**67**	**37**	**11**	1.4
Unknown building	32	6.3	28	16	5.3	0.8
North camp site	**210**	45	**90**	**45**	**13**	1.6
South camp site	74	16	47	**26**	7.6	1.0
Schools	35	6.7	29	16	5.3	0.8
Child care facilities	35	6.8	29	17	5.3	0.8
Health care facilities	35	6.1	29	16	5.2	0.8
Senior care facilities	33	6.3	29	16	5.2	0.8
Objective	*150 to 260*	*60 to 75*	*50*	*25*	*8*	*1.75 or 2.9*[b]

NOTES:

Values in bold and shaded exceed relevant objectives

[a] 24-hour average based on 30-day sample, expressed in mg/dm²-d

[b] Provincial objective is 1.75 mg/dm²/d for residential areas and 2.9 mg/dm²-d for non-residential areas

Similar to particulate matter, the highest concentrations for NO_2, SO_2, and CO were predicted in the vicinity of Wuthrich Quarry. Maximum predicted concentrations for these contaminants were well below relevant objectives as shown in Table 11.11.7.

Table 11.11.7 Maximum Predicted Concentrations for NO2, SO2 and CO Including Background (in µg/m3)

Contaminant	NO_2			SO_2			CO	
Averaging Period	**1-hour**	**24-hour**	**Annual**	**1-hour**	**24-hour**	**Annual**	**1-hour**	**8-hour**
Overall max (outside dam site area)	306	78	45	75	21	1.6	2,962	2,078
Fort St. John	145	27	3.3	1.6	0.1	0.01	325	191
Taylor	63	8.0	1.0	0.2	0.05	0.003	258	170
Ground-truthed residence	170	44	8.2	3.3	0.4	0.03	422	240
Ground-truthed non-residence	182	49	24	4.5	0.5	0.06	571	280
Unknown building	81	10	1.4	0.5	0.06	0.004	274	173
North camp site	194	54	26	14	1.5	0.1	783	326
South camp site	165	45	13	1.1	0.2	0.03	421	241
Schools	106	12	1.3	0.7	0.1	0.005	277	177
Child care facilities	109	13	1.4	0.7	0.1	0.01	278	178
Health care facilities	87	10	0.9	0.5	0.05	0.003	268	174
Senior care facilities	73	10	1.0	0.3	0.04	0.004	261	171
Objective	400 to 1,000	200 to 300	60 to 100	450 to 1,300	160 to 360	25 to 80	14,300 to 35,000	5,500 to 14,300

11.12 Noise and Vibration

11.12.1 Introduction

This section describes the baseline and potential future noise and vibration levels in the Project activity zone. Current levels and potential changes as a result of Project activities are described.

The purpose of the noise and vibration study was to:

- Characterize the baseline noise environment
- Evaluate the potential for construction and operation of the Project to change the baseline noise environment
- Evaluate the amount of blasting noise or airborne vibration that may occur due to blasting during construction
- Provide a description of potential changes in local noise levels at human receptors
- Provide a spatial description of potential noise levels in support of the wildlife assessment

Details of the noise and vibration analyses are presented in Volume 2 Appendix M Noise and Vibration Technical Data Report. Predicted changes in noise and vibration levels are directly used to assess the potential effects of the Project on human health in Volume 4 Section 33 Human Health. Spatial results of the noise and vibration study are used in the wildlife assessment in Volume 2 Section 14 Wildlife Resources.

11.12.2 Methods

11.12.2.1 Approach

There are no British Columbia province-wide regulations regarding noise. The noise evaluation for construction was based on the methods and criteria outlined in the B.C. Oil and Gas Commission (BCOGC) Noise Control Best Practices Guideline (BCOGC 2009). The BCOGC Guideline outlines the expectations for evaluating noise levels, provides guidance on how to define noise sensitive receptors and study areas, and defines relevant criteria for identified receptors. However, this Guideline does not directly address wildlife, traffic noise, or vibration.

B.C. Ministry of Transportation and Infrastructure (BCMOT) guidance for highway noise mitigation was reviewed as potential sound level guidance for Highway 29 traffic noise (BCMOT 1993). However, the BCMOT guidance is intended as a controlled access highway design document and was not developed with environmental or human health effect criteria. Therefore, Highway 29 traffic noise was evaluated against the overall change in noise levels based on changes in traffic volumes predicted in the Project Traffic Analyses Report (Volume 4 Appendix B).

The evaluation of blasting noise or airborne vibration included review of guidance from the US Office of Surface Mining (USOSM 1986) and the Ontario Ministry of Environment (ONMOE No date). The Ontario guidance was found to be more stringent; therefore, it was used to compare against the calculations of airborne vibration from blasting for the Project.

11.12.2.2 Technical Study Area

The BCOGC Guideline characterizes noise levels at human receptors, which are defined as any permanent or seasonally occupied dwelling. In areas where there are no nearby residents, the guideline sets a limit on the noise levels at a distance of 1.5 km from the "facility fence line". For the purpose of the Project noise study, the facility fence line, and thus the technical study area for noise, has been defined as 1.5 km from the Project activity zone. This includes the local boundaries for individual activities such as quarries or highway construction. The technical study area was then used to identify potentially affected dwellings as noise sensitive receptors. Project-related changes in noise levels were predicted for residences within 1.5 km of project activities.

While the BCOGC Guideline does not apply to blasting noise or airborne vibration, this distance is appropriate to the evaluation of airborne vibration changes. The residences that may be most affected by blast noise or airborne vibration are expected to be those within 1.5 km of Project activities. Where residences were not present within 1.5 km, the effects at the technical study area boundary were considered.

For the baseline noise survey, locations representative of the receptors, particularly of the various densities of residential development and proximities to existing noise sources, were selected for the measurement program. The technical study area is shown in Figure 11.12.1. Complete lists of receptors analyzed are available in Volume 2 Appendix M Noise and Vibration Technical Data Report.

11.12.2.3 Criteria

The BCOGC Guideline outlines a specific process for determining the sound level criteria for each identified receptor on the basis of the level of local development and proximity to heavily travelled transportation routes. The process considers the time of day, the duration of the activity, and existing or baseline sound levels. Section 2 of the BCOGC Guideline provides the specific method for determining the criteria, which is called a permissible sound level (PSL).

Environmental noise levels typically vary with time. To account for the time varying nature of environmental noise, the PSL uses a single number descriptor: an 'average' sound level-known as energy equivalent sound level or L_{eq}, the energy-averaged A-weighted sound level for a specified time period. It is the steady, continuous sound level over a specified time period that has the same acoustic energy as the actual varying sound levels occurring over the same time period. The L_{eq} values are based on A-weighted sound levels expressed in units of dBA (A-weighted decibels). The A-weightings are assigned to reflect the response of the human ear to different frequencies of sound. The human ear is more sensitive to higher frequency sound than lower-frequency sound; this is reflected in the A-weighting scale.

The L_{eq} is a single-number representation of naturally variable sound energy measured over a time interval. The time intervals used for the noise study are as follows:

- Night: the nighttime period $L_{eq(9)}$, a 9-hour L_{eq} determined for the hours of 22:00 through 07:00

- Day: the daytime period $L_{eq(15)}$, a 15-hr L_{eq} determined for the hours of 07:00 through 22:00

Noise criteria were established at each receptor based on the BCOGC Guideline values outlined in Table 11.2.1 (BCOGC 2009). The values are based on land use categories and reflect the expected variation in ambient sound level associated with the different degrees of area development. The daytime PSL includes a +10 dBA adjustment as defined in the BCOGC Guideline.

Table 11.12.1 B.C. Oil and Gas Commission Guideline Table 1: Base Permissible Sound Levels by Land Use Category

Proximity to Transportation	Dwelling Unit Density Per Quarter Section of Land		
	1 – 8 dwellings; 22:00 – 07:00 (nighttime) (dBA L_{eq})	9 – 160 dwellings; 22:00 – 07:00 (nighttime) (dBA L_{eq})	>160 dwellings; 22:00 – 07:00 (nighttime) (dBA L_{eq})
Category 1	40	43	46
Category 2	45	48	51
Category 3	50	53	56

NOTES:

Category 1 – dwelling units more than 500 m from heavily travelled roads and/or rail lines and not subject to frequent aircraft flyovers

Category 2 – dwelling units more than 30 m but less than 500 m from heavily travelled roads and/or rail lines and not subject to frequent aircraft flyovers

Category 3 – dwelling units less than 30 m from heavily travelled roads and/or rail lines and/or subject to frequent aircraft flyovers

Density per quarter section – refers to a quarter section with the affected dwelling at the centre (a 451 m radius). For quarter sections with various land uses or with mixed densities, the density chosen is then averaged for the area under consideration.

Conformance with the BCOGC Guideline is achieved when the cumulative noise level at a receptor, comprising the Project sound level contribution plus the ambient sound level, is equal to or less than the PSL.

The BCOGC Guideline defines the natural ambient sound level (ASL) as 5 dBA less than the base PSL. As no specific influences on local sound levels were identified, other than domestic and traffic activity already accounted for in Table 11.12.1, no ambient noise level adjustments were applied and the calculated ambient sound levels were determined using the 5 dBA less rule.

According to the BCOGC Guideline, compliance with the PSL guidance is achieved when the cumulative noise level at a receptor, comprising the Project sound level contribution plus the ambient sound level, is equal to or less than the PSL (BCOGC 2009).

In addition to using noise guidelines established using BCOGC, the change in ambient sound levels was analyzed. A 3 dBA change in L_{eq} noise level is considered to be the "Just Noticeable Difference" for human perception (Crocker 2007). Changes in noise levels at receptors were reviewed to identify locations where changes in noise levels greater than 3 dBA may occur. As the BCOGC Guideline specifically excludes traffic noise (traffic noise is considered part of ambient – not a potential effect), Highway 29 traffic noise was evaluated against the overall change in noise levels only.

Blasting activities are identified as a potential source for airborne vibration, or blasting noise. The level of airborne vibration experienced by receptors is evaluated using the peak pressure level or L_{peak} measured in linear (unweighted) decibels (dBL). The criteria from the US Office of Surface Mining (USOSM 1986) was reviewed and compared with available Canadian guidance. The Cautionary Limit from the Noise Pollution Control Publication 119 by Ontario Ministry of the Environment was found to be more stringent. Therefore, the NPC-119 Cautionary Limit was used as the criterion for airborne vibration at any receptor (ONMOE No date). This guideline is provided in Table 11.12.2.

Table 11.12.2 Ontario Noise Pollution Control Publication 119 Guideline for Blasting Activity

Vibration Type	Unit	Guideline[a]
Blasting Noise	Peak pressure level L_{peak} (dBL)	120

NOTES:

dBL – linear decibel.

[a] Cautionary Limit as published in Noise Pollution Control Publication 119 by the Ontario Ministry of the Environment (ONMMOE No date)

11.12.2.4 Baseline Field Program

A baseline field program was completed in May and June 2011 to determine representative environmental noise levels and to identify existing sources of sound that may not be accounted for in the BCOGC approach. A blasting noise baseline survey was not necessary, as airborne vibrations are event based, so typically are not part of normal background.

The noise measurement equipment consisted of Brüel and Kjær model 2250 and Larson Davis model 831 Type 1 precision integrating sound level meters with audio recording capability. The noise monitors were calibrated before and after each noise measurement period to verify that the sound meter variance was within 0.5 dB. The noise meters were programmed to continuously measure the parameters identified and to make a continuous audio recording of measured noise events.

For this survey, wind speed and precipitation data reported in the Microclimate Technical Data Report (Volume 2 Appendix K Microclimate Technical Data Report) or from the North Peace Regional airport Environment Canada weather station were used.

The noise recordings were reviewed to identify sources of noise from the sound recordings and to filter out data that indicated interference with the microphone or abnormal sound sources such as technician activities, excessive wind, rain, vehicles that are close to the microphone, and low-flying aircraft noise. Local traffic is a major source of noise for most locations, and is, therefore, included in the hourly calculations. Hourly values were then calculated from the continuous measurements. Daily and nightly values were calculated per the BCOGC Guidance as described in Volume 2 Appendix M Noise and Vibration Technical Data Report.

11.12.2.5 Prediction and Characterization

The noise modelling for all activities except helicopter usage and airborne vibrations was conducted using CadnaA (Version 4.2.139) noise prediction software. This software uses the environmental sound propagation calculation methods prescribed by the

International Organization for Standardization (ISO) Standard 9613 (ISO 1993, 1996). The ISO 9613 sound propagation method predicts noise levels under moderately developed temperature inversion and downwind conditions that enhance sound propagation to the receptor. Model parameters were selected to reflect the propagation of sound during a summertime condition where attenuation due to weather conditions was minimized, such as during evening temperature inversions or mild downwind conditions. Summer is considered the most sensitive period for changes in outdoor noise levels, as it is the time of year when windows are open at night when people are trying to sleep.

Sound emission data for the various sources were established using measurements from similar equipment, vendor data, or theoretical formulae. Details on settings for the predictive modelling are found in the Volume 2 Appendix M Noise and Vibration Technical Data Report.

The noise from helicopter usage for the Project was analyzed using the SELCal version 1.0.2 flyover noise software from the United States Air Force (USAF 2002). This software was designed to analyze the amount of sound at specific locations due to a single aircraft flying, landing, taking off, or hovering. Aircraft sound emission data are integral to the software and were selected within the software based on the expected aircraft used by the Project.

For blasting noise, the L_{peak} values were calculated to determine the instantaneous maximum noise level during a blast event. Blasting noise levels were calculated in linear decibel levels (dBL) to assure that low-frequency energy, typically associated with blasting, is accounted for. The standard formulae used from the International Society of Explosives Engineers (Stiehr 2011) are detailed in Volume 2 Appendix M Noise and Vibration Technical Data Report.

The project activities evaluated varied in the amount of detail with which predictions were performed. Details on each scenario evaluated are provided in Volume 2 Appendix M Noise and Vibration Technical Data Report. The project components where construction or operation activities were evaluated for noise, and the level of detail in the analysis, are as follows:

- Construction
    - Dam site, including Site C dam and 85th Avenue Industrial Lands (site-specific modelling)
    - Quarries and pits (representative modelling)
    - Reservoir (representative modelling)
    - Highway 29 realignment (representative modelling)
    - Transmission line (representative modelling)
    - Hudson’s Hope berm (site-specific modelling)
- Operation
    - Dam site (qualitative discussion)
    - Reservoir (qualitative discussion)

- Highway 29 realignment (site-specific modelling)
- Transmission line (qualitative discussion)

11.12.2.6 Data Quality and Prediction Uncertainty

The methods and predictive modelling used in the analysis of environmental noise and airborne vibration has a level of uncertainty that is dependent on three factors: the accuracy of the source data, the precision of the noise propagation model, and the accuracy of locations and quantities of noise sources.

The accuracy or degree of uncertainty with individual measurements or pieces of data cannot be quantified due to the number of variables that influence the measurement or calculation of sound emissions. As uncertainties in sound emissions or model inputs increase, so does the amount of conservatism in the predictions.

The ISO 9613 propagation algorithms utilized by the CadnaA model software used for most of the modelling have a published accuracy of +/-3 dBA over source-receiver distances between 100 and 1,000 m. A similar degree of accuracy would be expected over the distances considered in this evaluation. The accuracy would be less at larger distances.

In addition, the ISO 9613 model produces results that are representative of meteorological conditions favouring sound propagation (e.g., downwind and/or inversion conditions). These conditions do not occur all the time and, therefore, the model predictions are expected to be conservative, and actual sound levels at the receptors may be less than predicted for much of the time.

Locations for equipment or specific blasts were not available at the time of this study. In order to add further conservatism to the predictions, the equipment in some areas has been modelled as area sources to represent the greatest spatial extent of noise during the activity.

Based on the above, there is a high level of confidence that the predicted noise levels at receptors can be considered to be ‘worst case’.

11.12.3 Baseline Conditions

11.12.3.1 Measurement Survey

The results of the baseline noise monitoring for the representative measurement locations are summarized in Table 11.12.3.

Table 11.12.3 Summary of Baseline Noise Levels

Noise Measurement Location	Calculated A-Weighted (dBA) Noise Levels (L_{eq})			
	Daytime Noise Level (L_{day}) (07:00 to 22:00)	Daytime L_{eq} Averaging Duration (hh:mm)	Nighttime Noise Level (L_{night}) (22:00 to 07:00)	Nighttime L_{eq} Averaging Duration (hh:mm)
Lynx Creek 1	45.3	9:39	40.4	8:48
Lynx Creek 2	44.6	13:15	35.9	7:55
Hudson Hope	43.5	12:26	43.3	9:00
Halfway Creek 1	46.1	12:10	39.0	9:00
Halfway Creek 2	53.0	13:05	48.9	9:00
Farrell Creek	42.1	10:51	39.8	8:52
Bear Flat 1	48.8	9:44	42.8	8:54
Bear Flat 2	42.0	12:50	36.4	8:49
Bear Flat 3	54.0	11:42	48.2	9:00
Dam Site 1	40.3	9:40	40.6	8:19
Dam Site 2	37.1	8:24	34.1	8:58
85th Avenue Industrial Lands 1	48.0	12:55	40.9	8:45
85th Avenue Industrial Lands 2	49.6	12:51	42.4	9:00

11.12.3.2 Baseline Summary

The evaluation method for environmental noise compared the measured baseline with the BCOGC-calculated ambient sound levels to estimate where there is evidence of existing noise sources influencing the background noise levels. Baseline noise level measurements were conducted at locations representative of the residential noise receptors within the technical study area based on relative location and proximity to existing sound sources.

The comparison of BCOGC ambient sound levels and representative baseline noise levels indicates that the nighttime ambient levels, adjusted according to BCOGC procedure for this time period, are within 1 to 5 dBA of representative measured values. Based on the sound recordings and observations, this difference is consistent with the natural variability that occurs in environmental sound. Therefore, the BCOGC calculated ambient sound levels (ASLs) were used for the evaluation of changes in noise levels at specific receptors. Detailed ASL values for each receptor and the above analysis are found in Volume 2 Appendix M Noise and Vibration Technical Data Report.

For blasting noise, existing L_{peak} values are zero at the dam site and quarries, as the L_{peak} is event based. No existing activities near the Project were noted as being a possible source of blasting noise.

11.12.3.3 Baseline Traffic Noise Levels

Sound generated by traffic is dependent on the volume of traffic, which fluctuates with time of day, week, or season. Therefore, existing sound levels from traffic on

Highway 29 were modelled using the CadnaA software to establish a base level for comparison with modelled results of Project construction related traffic on Highway 29.

Traffic analysis data from Volume 4 Appendix B Project Traffic Analyses Report were used to model the current traffic noise levels based on annual data. The results of the model for receptors of interest are provided in Table 11.12.4.

Table 11.12.4 Baseline Traffic Noise Levels

Noise Receptor	Existing Highway Sound Level	
	(daytime)	(nighttime)
	(dBA L_{eq})	(dBA L_{eq})
HWY_19	26	19
HWY_20	27	20
HWY_21	30	23

11.12.4 Predicted Construction Noise Levels

The following summarizes the results of the detailed analysis of construction activities. Only those receptors where noise levels are predicted to be higher than the BCOGC Guideline or to change by more than 3 dBA are reported within the EIS. For detailed results for all scenarios, please see the Volume 2 Appendix M Noise and Vibration Technical Data Report.

11.12.4.1 Dam Site

For the purposes of the noise study, the dam site includes the following components: the dam and generating station facilities, related construction site facilities, and the 85th Avenue Industrial Lands. Activity on the dam site is described in Volume 1 Section 4 Project Description.

Two periods with the most scheduled activity on the site were selected for the noise analysis, based on the construction schedule described in Volume 1 Section 4 Project Description. These were Year 3 and Year 5. These periods of activity also defined the placement of noise sources in the model, as they vary from year to year. The number and type of sound emission sources were established using available Project design data for the appropriate years.

The results of the analysis indicate that changes in noise level greater than 3 dBA and levels higher than the BCOGC Guideline criteria are possible during both Year 3 and 5. Results for those receptors that may be affected are shown in Table 11.12.5.

Table 11.12.5 Predicted Changes in Noise Levels from Dam Site Activities

Noise Receptor	Predicted Sound Level at Receptor	Ambient Sound Level	Cumulative Sound Level	Change in Sound Level	Guideline Sound Level	Meets Guideline
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(Y/N)
Year 3 – Day						
DS_NR2	50	48	52	4	53	Y
DS_NR3	53	48	55	7	53	N
DS_NR4	48	48	51	3	53	Y
DS_NR5	50	48	52	4	53	Y
Year 5 – Day						
DS_NR2	54	48	55	7	53	N
DS_NR3	51	48	53	5	53	Y
DS_NR4	51	48	53	5	53	Y
DS_NR5	52	48	53	5	53	N
DS_NR8	49	48	51	3	53	Y
Year 5 – Night						
DS_NR2	44	38	45	7	43	N
DS_NR3	46	38	47	9	43	N
DS_NR4	46	38	47	9	43	N
DS_NR5	43	38	44	6	43	N
DS_NR8	41	38	43	5	43	Y
DS_NR9	41	38	42	4	43	Y
DS_NR10	38	38	41	3	43	Y

The highest predicted change in noise level is expected in Year 5, particularly at night. Sound level contours for the dam site scenario in Year 5 are provided in Figure 11.12.2 and Figure 11.12.3.

As shown in Table 11.2.5, the results indicate that changes in noise level at some receptors could result in daytime and nighttime noise levels higher than the BCOGC Guideline in Year 3 and 5. The primary source of sound at the receptors affected by the dam site scenario would be caused by extraction of materials from the 85th Avenue Industrial Lands.

Blasting is also planned within the dam site construction area. The airborne vibration calculations indicate that L_{peak} levels would be below the 120 dBL NPC-119 Cautionary Limit (ONMOE No date) within 16 m of the blast and would reduce to 82 dBL at the boundary of the technical study area. No receptors would experience airborne vibration above the NPC-119 Cautionary Limit. Blasting noise (airborne vibration) may be distinguishable from background inside and outside the technical study area due to the nature of airborne vibration.

11.12.4.2 Quarries and Pits

Rock and aggregate materials would be acquired from a number of areas remote to the dam site for the construction of the dam. No dwelling receptors were identified within the technical study area for any of the quarry or borrow areas. The Wuthrich Quarry was modelled to represent the spatial extent of changes in noise level for all quarries. The 1.5 km technical study area boundary was used as the receptor point in the absence of dwelling receptors.

Results from modelling earth moving equipment at Wuthrich Quarry indicate that noise from this activity would diminish to below 35 dBA at between 1,000 m and 1,500 m from the activity. Access road noise would diminish to below 35 dBA at 300 m to 500 m from the road. The 35 dBA value is the BCOGC nighttime ambient sound level for rural areas. Predictions equal to or less than 35 dBA mean that the BCOGC Guideline at 1.5 km from activity are met and changes to ambient sound levels would be 3 dBA or less.

For quarries where blasting would be required, the blast noise analysis indicates that airborne vibration would be below the 120 dBL ONMOE criteria within 13 m of the blast and would be reduced to 76 dBL at 1.5 km from the activity (the technical study area boundary).

11.12.4.3 Clearing

Tree and brush clearing during the construction phase would be a source of sound over the entire clearing areas. The nature of clearing work means that the activities would occur in a number of small areas, anywhere within the Project activity zone and at any particular time. Given the transient nature of the sound associated with clearing, a general approach to identify potential setbacks or zones where noise from clearing activity may result in changes in noise level at receptors was used. A CadnaA model was constructed to determine the amount of noise generated by the activities based on distance. Activities included in the analysis are brush and tree cutting, skidding/moving of material, and loading logs onto highway trucks. All activities were modelled as occurring simultaneously, over a 2 km by 500 m area.

The results in Table 11.12.6 indicate that clearing activity may result in noise levels that exceed the BCOGC Guideline criteria at 500 m from the activity. Clearing activity would be within a 500 m proximity of any affected receptor for a period of a few days, and would then progress to the next area to be cleared. These distances would apply wherever clearing was required for Project construction.

Table 11.12.6 Predicted Noise Levels for Clearing

	Distance from Clearing Boundary (m)					
Day (dBA)	50	100	200	500	1000	1500
East	56.4	54.9	52.6	48.1	43.2	39.5
North	57.8	56.1	53.7	48.8	43.7	39.9
South	67.5	63.6	59.3	52.3	46.1	41.8
West	44.0	42.6	41.1	38.1	34.9	32.2

11.12.4.4 Highway 29 Realignment

Similar to the clearing noise analysis, highway construction work would occur in a limited area, progressing along the planned alignment, with roadbed preparation and material movements occurring along varying portions of the highway alignment at a particular time. Therefore, a general approach was used to identify potential setbacks where highway construction activity may result in changes in noise level at receptors of greater than 3 dBA or noise levels higher than the BCOGC Guideline. A CadnaA model was constructed to determine the amount of noise generated by the activities based on distance. Activities included in the analysis included roadbed grading or preparation, paving and bridge construction.

The results in Table 11.12.7 indicate that predicted noise levels from roadbed preparation (grading, and cut and fill activity) would attenuate to less than the BCOGC Guideline levels within 500 m of the activity. Roadbed preparation could occur within 500 m of any particular section of alignment for several months. For bridge construction, noise is below the criteria within 200 m of activity; however, the activity could occur for a period of over a year.

Table 11.12.7 Predicted Noise Levels from Highway Construction Activities

	Distance from Construction Boundary (m)					
Day (dBA)	50	100	200	500	1000	1500
Grading/cut/fill	61.4	42.9	55.6	49.4	58.7	38.5
Bridge Construction	56.6	53.8	50.3	44.1	38.9	35.2

Highway 29 traffic noise looks at the period where the most expected traffic would occur based on Volume 4 Appendix B Project Traffic Analyses Report. The period with the most traffic is predicted to occur during the dam site construction period rather than in future years, so construction data were used to evaluate potential changes in receptor noise levels due to Project related traffic. Traffic analysis data from Volume 4 Appendix B were used to model the current traffic noise levels based on annual data, and then Project traffic noise levels were modelled and compared to estimate potential for noticeable changes for both the daytime and nighttime periods.

The results of the traffic modelling for the construction year 7, the year with the highest amount of traffic predicted, are provided in Table 11.12.8. The results indicate that a just noticeable change in noise level (approximately 3 dBA) may occur for three receptors during daytime hours, due to construction traffic volumes. Receptors are shown in Figure 11.12.4.

Table 11.12.8 Existing and Predicted Noise Levels at Receptors for Highway Operations

Noise Receptor	Existing Highway Sound Level		Highway Operation Sound Level		Changes in Sound Levels	
	(daytime)	(nighttime)	(daytime)	(nighttime)	(daytime)	(nighttime)
	(dBA L_{eq})	(dBA L_{eq})	(dBA L_{eq})	(dBA L_{eq})	(dBA L_{eq})	(dBA L_{eq})
HWY_19	26	19	30	22	3	3
HWY_20	27	20	30	22	3	3
HWY_21	30	23	33	25	3	3

11.12.4.5 Transmission Line

Clearing noise for the transmission line would be similar to the activity evaluated for the reservoir, in Section 11.12.4.3. Equipment from construction of the tower foundations is not expected to change noise levels at receptors, as described in Volume 2 Appendix M Noise and Vibration Technical Data Report.

Helicopter use for tower erection was also identified as a key activity. Helicopter usage creates short-term noise events of five to 30 minutes in duration. These events could occur several times a day. Results of the helicopter modelling indicate that helicopters in flight (passing by) that are lower than 120 m altitude when within 100 lateral metres of a receptor, may result in noise levels higher than the BCOGC Guideline at the time of the pass-by event. Table 11.12.9 indicates that helicopters landing or hovering may generate noise levels higher than the BCOGC Guideline at 400 lateral metres and 100 lateral metres respectively.

Table 11.12.9 Predicted Noise Levels from Helicopter Activities

Distance to Noise Receptor	Predicted Levels for Landing (L_{eq})	Predicted Levels for Hovering (L_{eq}) (23 m height)
50	71.3	55.3
100	66.9	50.9
200	61.5	45.5
400	54.8	38.8
800	45.2	31.2
1000	41.5	25.5

11.12.4.6 Hudson's Hope Shoreline Protection

Operation of earth-moving equipment and truck traffic are the primary sources of sound during construction of the shoreline protection at Hudson's Hope.

There are a number of residences in the technical study area near the proposed berm. Four receptors representative of all the homes within 1.5 km of the berm were used to evaluate noise levels. Results of the modelling are provided in Table 11.12.10. Receptors, contours from equipment on the berm, and the access road are in Figure 11.12.5.

Table 11.12.10 Daytime Predicted Noise Levels at Receptors near Hudson's Hope Shoreline Protection during Construction

Noise Receptor	Predicted Sound Level at Receptor (dBA)	Ambient Sound Level (dBA)	Cumulative Sound Level (dBA)	Changes in Sound Level (dBA)	PSL Guideline (dBA)	Meets Guideline (Y/N)
HH_1	58.8	53	59.8	6.8	58	N
HH_2	58.9	53	59.9	6.9	58	N
HH_3	65.5	53	65.7	12.7	58	N
HH_4	67.4	53	67.6	14.6	58	N

The receptor results indicate that the nearest residences to this activity may experience noise levels that exceed the BCOGC daytime criteria during the active construction periods.

11.12.5 Operation

11.12.5.1 Dam Site

During operation of the Project, sounds would be expected from the generating station, the spillway, and the substation; and from maintenance activities on the reservoir near the dam. The sound generated from these operations or activities may be noticed as a change in the environment near the sources, but the sound emissions are lower from this equipment when compared to the volume of equipment used for construction; therefore, changes at receptors are expected to be less than 3 dBA.

The sound from water movement in the river downstream of the dam, or over the spillway, is expected to be similar to the current sound from the river. It is also expected to be the dominant sound from the site, when it occurs. Sound from the substation transformers may be noticeable at the fence line of the substation (within the Project activity zone), but would not affect the nearest residence, over 3 km away.

11.12.5.2 Reservoir

During the operation phase, the reservoir may be used for more recreational activities than currently occur on the river. River or water movement sounds would diminish. Human sounds such as recreational boats may increase, but would be intermittent. These sounds reflect a change in the acoustic environment, but would not be under BC Hydro direct control.

For sound from reservoir maintenance, occasional short-term noise events at receptors may occur when small motor boats travel the reservoir checking on debris or shoreline conditions. These events would occur during the daytime and no more than once a day. Single events would not affect the 15-hour daytime L_{eq} noise levels.

Helicopters may also be used to conduct inspections or aid with debris removal. Noise from helicopter usage, as described in Section 11.12.4.5, would apply to usage for maintenance activities, assuming that similar aircraft are used for maintenance as for construction.

11.12.5.3 Transmission Line

During operation, there is no expectation of major noise contribution from the transmission line. Corona noise, commonly described as “line hum”, may be audible within close proximity (typically within the right-of-way) of the transmission line. The corona noise from the existing transmission line has been estimated at the edge of the existing right-of-way as 38.2 dBA. Corona noise from the proposed 500 kV configuration is estimated at 51.1 dBA at the edge of the right-of-way. These values would diminish with distance from the right of way, with the 500 kV corona noise diminishing to below 40 dBA at 200 m to 250 m from the right-of-way, well within the 1.5 km technical study area. The receptors near the transmission line are more than 1 km from the right-of-way, so no changes in noise levels at those receptors are expected, as BCOGC Guidance is met within 250 m.

11.12.6 Summary of Predicted Changes

The analysis of noise at receptors due to sound from construction activities in the technical study area indicates that exceedances of the BCOGC guidelines or increases of more than 3 dBA may occur. Specifically, construction activities in the following areas show increased noise levels: the dam site near the 85th Avenue Industrial Lands, during clearing activity within 500 m of receptors, during Highway 29 realignment within 500 m of receptors, and during construction of the Hudson’s Hope shoreline protection.

Blasting noise (airborne vibration) may be distinguishable from background inside and outside the technical study Area, but the blast designs would comply with the NPC-119 guidance for blasting noise.

Volume 4 Section 33 Human Health evaluates whether the predicted changes would have an effect on human health. Potential for Project noise to affect wildlife is discussed in Volume 2 Section 14 Wildlife Resources.

11.13 Electric and Magnetic Fields

11.13.1 Introduction

This section details the electric and magnetic field (EMF) profiles for the existing 138 kV lines (circuits 1L374 and 1L360) and the proposed two 500 kV lines that would replace the existing 138 kV lines. These profiles were calculated using the Corona and Field Effects Program Version 3 (Bonneville Power Authority 1991), which is used throughout the industry for calculating electric and magnetic fields. Potential human health effects of project-induced electric and magnetic field levels are assessed and evaluated in Volume 4 Section 33 Human Health.

EMF is found wherever electricity is generated, delivered, or used, including power transmission and distribution lines, wiring in homes, workplace equipment, electrical appliances, power tools, and electric motors. Transmission lines produce both electric and magnetic fields. Electric fields are measured in kilovolts per metre (kV/m) and magnetic fields in milligauss (mG) or microteslas (μT). Electric fields are the result of voltages applied to electrical conductors and equipment. Most objects, including fences, shrubbery, and buildings easily block electric fields. Magnetic fields are produced by the flow of electric currents; however, unlike electric fields, most materials do not readily block magnetic fields. The intensity of both electric and magnetic fields diminishes with increasing distance from the source.

Electric fields are mainly influenced by the line voltage, tower head dimensions, and configuration and the height of the conductors above the ground. Magnetic fields are influenced by the line current, the phase-to-phase spacing, the tower head configuration, and the height of the conductors above ground.

Electric and magnetic field levels were calculated based on the maximum load for which the line is built. This provides a conservative basis for calculating EMF.

11.13.2 Baseline Conditions

Structural drawings, plans, and profiles for the existing 138 kV lines were used in determining the line configuration and the average conductor height above ground. The right-of-way width varies along the current 138 kV lines due to the placement of the existing lines within the right-of-way. For the purposes of this study, the average right-of-way width of 29 m was used. With the two 138 kV lines side by side, each line in a wishbone configuration, the distance from the circuit centreline to the right-of-way edge is 9 m. Figure 11.13.1 shows the line configuration and right-of-way width for the existing 138 kV lines.

Electric field profiles were calculated for the existing 138 kV lines using the operating voltage of 144.9 kV. Table 11.13.1 below summarizes the calculated electric fields.

Table 11.13.1 Electric Field Calculations for the Existing 138 kV Lines

Distance from Edge of Right-of-Way	Electric Field
Highest peak on right-of-way	0.721 kV/m
Edge of right-of-way	0.53 kV/m
Edge of right-of-way + 25 m	0.137 kV/m
Edge of right-of-way + 50 m	0.048 kV/m

Figure 11.13.2 shows the electric field profile for the existing 138 kV lines at 1 m above ground.

Magnetic field profiles were calculated for the maximum loading during normal operation of the lines using an average conductor height of 11 m and a loading of 295 A and 300 A.

Table 11.13.2 Magnetic Field Calculations for the Existing 138 kV Lines

Distance from Edge of Right-of-Way	Magnetic Field
Highest peak right-of-way	23.88 mG
Edge of right-of-way	16.91 mG
Edge of right-of-way + 25 m	3.35 mG
Edge of right-of-way + 50 m	1.29 mG

Figure 11.13.3 shows the magnetic field profile for the existing 138 kV lines at 1 m above ground.

11.13.3 Future Levels

The existing 138 kV lines would be replaced with two 500 kV lines. Electric and magnetic fields were calculated for the new lines. Final right-of-way width had not been determined when this analysis was done. A width of 111 m was selected for the analysis, which provides a conservative estimate of the EMF profiles at the actual right-of-way edge. The actual EMF profile would be lower at the edge because the actual right-of-way would be 118 m, and EMF decreases with distance. The right-of-way width of 111 m results in a 32 m distance from the circuit centreline to the right-of-way edge. For the proposed 500 kV circuits, a typical four-conductor bundle with a conductor diameter of 25.4 mm and a bundle spacing of 0.45 m would be used. Phase spacing was 12 m and an average conductor to ground height was taken at 16 m.

Figure 11.13.4 shows the line configuration and right-of-way width for two new 500 kV lines.

Electric field profiles were produced for the proposed two 500 kV lines using the 500 kV line operating voltage of 525 kV. Table 11.13.3 below summarizes the electric fields.

Table 11.13.3 Electric Field Calculations for Two New 500 kV Lines

Distance from Edge of Right-of-Way	Electric Field
Highest peak on right-of-way	5.391 kV/m
Edge of right-of-way	2.228 kV/m
Edge of right-of-way + 25 m	0.523 kV/m
Edge of right-of-way + 50 m	0.195 kV/m

Figure 11.13.5 shows the electric field profile for two new 500 kV lines at 1 m above ground.

Magnetic field profiles were produced for the maximum loading during normal operation of the lines with an average conductor height of 16 m and a loading of 700 A each.

Table 11.13.4 Magnetic Field Calculations for 1L374 and 1L360

Distance from Edge of Right-of-Way	Magnetic Field
Highest peak on right-of-way	73.40 mG
Edge of right-of-way	29.67 mG
Edge of right-of-way + 25 m	11.41 mG
Edge of right-of-way + 50 m	6.03 mG

Figure 11.13.6 shows the magnetic field profile for two 500 kV lines at 1 m above ground.

11.13.4 Summary of Expected Changes

The expected changes to the electric and magnetic field levels would arise once the new lines are constructed and put into service. The maximum electric field on the right-of-way would be 5.391 kV/m and 2.228 kV/m at the edge of the right-of-way. The maximum magnetic field on the right-of-way would be 73.40 mG and 29.67 mG at the edge of the right-of-way. Potential public health effects of electric and magnetic field levels are assessed and evaluated in EIS Volume 4 Section 33 Human Health.

References

References for Section 11.1 - Previous Development

Alberta/British Columbia Instream Flow Needs Sub-Committee. 1991. Peace River Instream Flow Needs. Report to the Peace River Technical Advisory Committee on Alberta/British Columbia Transboundary Water Issues.

Ashton, G.D. 2003. Ice jam flooding on the Peace River near the Peace Athabasca Delta. Canadian Water Resources Association 56th Annual Conference: Water Stewardship: How are we managing? Vancouver, B.C. June 11-13, 2003 315– 323.

BC Hydro. 2003. Consultative Committee Report: Peace Water Use Plan. Prepared by B.C. Hydro, Vancouver B.C.

BC Hydro. 2007. Peace Project Water Use Plan, Revised for Acceptance for the Comptroller of Water Rights.

Beltaos, S., T. Prowse, and T. Carter. 2006. Ice regime of the lower Peace River and ice-jam flooding of the Peace Athabasca Delta. *Hydrological Processes* 20(19):4009–4029.

Blood, D.A. 1979. Peace River Site C hydroelectric development environmental and socio-economic assessment. Wildlife sub-report. Prepared for BC Hydro and Power Authority.

Church, M. 1995. Geomorphic response to river flow regulation: Case studies and time-scales. *Regulated Rivers: Research & Management.* 11(1) 3–22.

Church, M., J. Xu, A. Moy, and L. Uunila. 1997. Changes in morphology and riparian vegetation following flow regulation, Peace River, 1968 and 1993. Northern River Basins Study, Project Report 102. Alberta Environmental Protection. Edmonton, AB.

EVS Environment Consultants. 1999. 1998 Status of Fish Mercury Concentrations in BC Hydro Reservoirs. Final Report. Prepared for BC Hydro and Power Authority.

Hildebrand, L. 1990. Investigations of fish and habitat resources of the Peace River in Alberta, Volume 1. Prepared for Alberta Environment, Planning Division and Alberta Fish and Wildlife division, Peace River Region. March 1990.

Keenhan, T., US Panu, and V.C. Kartha. (1982). Analysis of freeze-up ice jams on the Peace River near Taylor, British Columbia. *Canadian Journal of Civil Engineering*. *9*(2):176–188.

Millar, S. and K. Wilby. 1999. Total Gas Pressure at Peace Generating Facilities. Strategic Fisheries Report No. SF98-PR-01. June 1999. Prepared for BC Hydro, Vancouver, B.C.

Peters, D.L. and J.M. Buttle. 2009, The effects of flow regulation and climatic variability on obstructed drainage and reverse flow contribution in a northern river-lake-delta complex, Mackenzie Basin Headwaters. *Rivers Research and Applications*. 26(9):1065–1089.

Simpson, K. 1991. Peace River Site C hydroelectric development environmental assessment consumptive wildlife resources. Prepared for BC Hydro and Power Authority.

Shaw, R.D., L.R. Norton, and G.W. Guenther. 1990. Water quality of the Peace River in Alberta. Environmental Quality Monitoring Branch, Environmental Assessment Division, Environmental Protection Services, Alberta Environment, Edmonton, AB.

Stockner, J., A. Langston, D. Sebastian, and G. Wilson. 2005. The limnology of Williston Reservoir: British Columbia's largest lacustrine ecosystem. *Water Quality Research Journal of Canada*, *40*(1):28–50.

Timoney, K. 2002. A dying delta? A case study of a wetland paradigm. *Wetlands.* 22(2):282–303.

Timoney, K. 2006. Landscape cover change in the Peace-Athabasca Delta, 1927–2001. *Wetlands.* 26(3):765–778.

Uunila, L.S. 1997. Effects of river ice on bank morphology and riparian vegetation along Peace River, Clayhurst to Fort Vermilion. Proceedings of the 9th Workshop on River Ice. 24-26.

Wolfe, B.B., R.I. Hall, T.W.D. Edwards, and J.W. Johnston. 2012. Developing temporal hydroecological perspectives to inform stewardship of a northern floodplain landscape subject to multiple stressors: paleolimnological investigations of the Peace Athabasca Delta. *Environmental Reviews*. 20(3):191-210.

References for Section 11.2 - Geology, Terrain, and Soils

BC Hydro. 2012a. Hydrological impacts of climate change at Site C, a synthesis report of climate change impacts on Site C. July 2012.

BC Hydro. 2012b. memorandum, Site C Clean Energy Project, Probabilistic Seismic Hazard Analysis Results, October 2012, File YM80003

BC Oil and Gas Commission, August 2012, Investigation of Observed Seismicity in the Horn River Basin

Horner, R.B., J.E. Barclays, and J.M. Macrae, 1994, Earthquakes and hydrocarbon production in the Fort St. John area of northeastern British Columbia, Canadian Journal of Exploration Geophysics, Vol. 30, No. 1, Pp 38-50

International Commission on Large Dams (ICOLD) Bulletin 134, Weak Rocks and Shales in Dams, 2008

International Commission on Large Dams (ICOLD), Bulletin 137, Reservoirs and Seismicity, 2011

Klohn Crippen Berger Ltd. and SNC-Lavalin Inc., 2009, Site C Clean Energy Project, Task 2: Establish the Maximum Design Earthquake (MDE), Seismic Hazard Assessment, Report No. P05032A02-02-001 R1. April

Klohn Crippen Berger Ltd. and SNC-Lavalin Inc., 2013, Site C Clean Energy Project. Geochemical Characterization – Status at the end of 2012. January 2013.

Little, T.E. and D.L. Scott, 2004, Effects of the 03 November 2002 M7.9 Alaska Earthquake at Dams in British Columbia, Canada, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, Paper No. 1827, 13 Pp.

McGarr, A. and Vorhis, R. C., Seismic Seiches from the March 1964 Alaska Earthquake, Geological Survey Professional paper 544-E, US Government Printing Office, 1968

Senior Seismic Hazard Analysis Committee (SSHAC), 1997, "Recommendations for probabilistic seismic hazard analysis: guidance on uncertainty and use of experts", prepared for the US Nuclear Regulatory Commission, Vol. 1, NUREG/CR-6372.

Klohn Crippen Berger and SNC Lavalin Inc., 2009, Site C Clean Energy Project, Seismic Hazard Assessment, Report No. P05032A02-001 R1, April

US National Research Council, 2012, Induced Seismicity Potential in Energy Technologies, The National Academies Press, Washington, D.C., Prepublication, 239 pp.

Internet Sites

http://earthquake.usgs.gov/learn/topics/seiche.php, November 7, 2012

References for Section 11.3 – Land Status, Tenure, and Project Requirements

None

References for Section 11.4 – Surface Water Regime

Ashton, G.D. 2003. Ice jam flooding on the Peace River near the Peace Athabasca Delta. Canadian Water Resources Association 56th Annual Conference: Water Stewardship: How are we managing? Vancouver, B.C. June 11-13, 2003 315– 323.

Beltaos, S., T. Prowse, and T. Carter. 2006. Ice regime of the lower Peace River and ice-jam flooding of the Peace Athabasca Delta. *Hydrological Processes* 20(19):4009–4029.

References for Section 11.5 – Water Quality

Alberta Environment and Water. 1999. Surface Water Quality Guidelines for Use in Alberta. Environmental Service, Environmental Sciences Division. Edmonton, AB.

BC Hydro. 1999. Total Gas Pressure at Peace River Generating Facilities. Strategic Fisheries Report No. SF98-PR-01. Vancouver, B.C.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian Water Quality Guidelines for the Protection of Aquatic Life: Introduction. In: Canadian Environmental Quality Guidelines, 1999. Winnipeg, MB.

Canadian Council of Ministers of the Environment (CCME). 2012a. Canadian Water Quality Guidelines: Summary Table. In Canadian Council of Ministers of the Environment Canadian Environmental Quality Guidelines 1999. Updates to 2012. Winnipeg, MB.

Canadian Council of Ministers of the Environment (CCME). 2012b. Canadian Sediment Quality Guidelines: Summary Table. In Canadian Council of Ministers of the Environment Canadian Environmental Quality Guidelines 1999. Updates to 2012. Winnipeg, MB.

Golder Associates Ltd. (Golder). 2009. Peace River Watershed Water Quality and Dinosaur Lake Limnology Sampling – 2008: Baseline Data Collection. Prepared for BC Hydro. Vancouver, B.C.

Health Canada. 2012. Guidelines for Canadian Drinking Water Quality Summary Table. Prepared by the Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial-Territorial Committee on Environmental and Occupational Health, Ottawa, ON.

Robertson, M.J., D.A. Scrunton, R.S. Gregory, and K.D. Clarke. 2006. Effect of Suspended Sediment on Freshwater Fish and Fish Habitat. Canadian Technical Report on Fisheries and Aquatic Sciences 2644. Fisheries and Oceans Canada. St. John's, NL.

Internet Sites

British Columbia Ministry of Environment (BCMOE). 2004. Water Quality Guidelines for Total Gas Pressure: First Update. Overview Report. September 2004. Available at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/tgp/tgp_over.html. Accessed: October 2012.

British Columbia Ministry of Environment (BCMOE). 2010. Water Quality Guidelines (Criteria) Reports. January 2010. Available at: http://www.env.gov.bc.ca /wat/wq/wq_guidelines.html#working. Accessed: October 2012.

References for Section 11.6 – Groundwater Regime

BC Hydro, 1981. Peace River Site C Report on Reservoir Slopes. Hydroelectric Generation Projects Division, Report Number H 1361.

BGC Engineering Inc. 2012. Site C Clean Energy Project, Reservoir Slope and Shoreline Design Consultation Services Site Investigation Report (Revised Draft). Issued to BC Hydro May 2012.

Bidwell, 1999. The engineering geology of the Fort St.John area. University of Alberta, Department of Civil and Environmental Engineering

BC Ministry of the Environment, 2006. A Compendium of Working Water Quality Guidelines for British Columbia

BC Ministry of the Environment, 2010. British Columbia Approved Water Quality Guidelines

BC Ministry of the Environment, 2011. BC Environmental Management Act, Contaminated Sites Regulation, B.C. Reg. 375/96, including amendments up to B.C. Reg. 97/2011

Cornish and Moore, 1985. Dam foundation investigations for a project on soft shale. BC Hydro Engineering, Vancouver, BC.

Hartman, G. 2005. Quaternary stratigraphy and geologic history of the Charlie Llake (NTS 94A) Map Area, British Columbia. Unpublished MSc thesis, Simon Fraser University.

Hartman and Clague, 2008. Quaternary stratigraphy and glacial history of the Peace River valley, northeast British Columbia. Canadian journal of earth sciences 45: 549-564

Health Canada, 2012. Guidelines for Canadian Drinking Water Quality—Summary Table. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Imrie, 1991. Stress-induced response from both natural and construction-related processes in the deepening of the Peace rover valley, B.C. BC Hydro February.

Klohn Crippen Berger Ltd. and SNC-Lavalin Inc. 2009. Peace River Site C Hydro Project, Reservoir Shoreline Impacts Methodology and Criteria. Doc. 05-0010, Issued to BC Hydro September 2009.

Matthews, 1978. Quaternary stratigraphy and geomorphology of Charlie lake (94A) map area, British Columbia. Geological Survey paper 76-20

Stott, 1982. Lower cretaceous Fort St.John group and upper cretaceous dunvegan formation of the foothills and plains of Alberta, British Columbia, district of Mackenzie and Yukon territory. Geological Survey, bulletin 328

Thurber Consultants, 1978. Site C reservoir shoreline stability assessment. Thurber Consultants LTD. A report to B.C. Hydro and power authority.

Maps

Hickins, A.S. and Fournier, M.A. 2011. Compilation of Geological Survey of Canada surficial geology maps for NTS 94A and 93P; BC Ministry of Energy and Mines, Energy Open File 2011-02, Geoscience BC Map 2011-08-1, 1:250 000 scale map.

Irish, E.J.W. 1958. Charlie Lake, British Columbia. Geological Survey of Canada, Map 17-1958.

References for Section 11.7 – Thermal and Ice Regime

Andres, D. 2002. Dunvegan Hydroelectric Project Information Update – Appendix F-3 – Analysis of the Potential Risks of the Dunvegan Project to the Town of Peace River During Ice

Season: Historical Review and Monte Carlo Analysis. Report prepared for Glacier Power and Canadian Hydro by Trillium Engineering and Hydrographics Inc.

Andres, D., D. Healy. 2006. Effects of the Dunvegan hydropower project on the ice regime of the Peace River. Report prepared by Northwest Hydraulic Consultants Ltd. for Glacier Power Ltd.

Great Lakes Water Quality Board (Great Lakes). 2003. Climate Change and Water Quality in the Great Lakes Basin. August 2003.

Jacques Whitford. 2006. Final Report – Environmental Impact Assessment – Dunvegan Hydroelectric Project. Submitted to Alberta Environment.

References for Section 11.8 – Fluvial Geomorphology and Sediment Transport Regime

ASTM International (ASTM). 2009. Standard Guide for Monitoring of Suspended-Sediment Concentration in Open Channel Flow Using Optical Instrumentation. ASTM International. West Conshohocken, PA.

B.C. Ministry of Environment. 2009. Manual of British Columbia Hydrometric Standards. The Province of British Columbia. Victoria, B.C.

Church, M. 2011. Chapter 2 – The regulation of Peace River. Unpublished manuscript.

Edwards, T.K. and D.G. Glysson. 1999. Field Methods for Measurement of Fluvial Sediments. US Geological Survey. Denver, CO.

Mueller , D.S. and C.R. Wagner. 2009. Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat. US Geological Survey. Reston, VA.

Rasmussen, P.R., J.R. Gray, G.D. Glysson, and A.C. Ziegler. 2011. Guidelines and Procedures for Computing Time-Series Suspended-Sediment Concentration and Loads from In-Stream Turbidity-Sensor and Streamflow Data. US Geological Survey. Reston, VA.

Steffler, P. and Blackburn, J. 2002. River2D: Two-Dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat – Introduction to Depth Averaged Modelling and User's Manual. Unpublished. University of Alberta. Edmonton, AB.

Stronach, J.A., J.O. Backhaus, and T.S. Murty. 1993. An update on the numerical simulation of oceanographic processes in the waters between Vancouver Island and the mainland: the GF8 model. *Oceanography and Marine Biology: An Annual Review*. Vol. 31. University College London Press. London, UK.

United States Army Corps of Engineers (USACE). 2010. Hydrologic Engineering Center. HEC-RAS River Analysis System, Hydraulic Reference Manual. Version 4.1. January 2010. Davis, CA.

References for Section 11.9 – Methymercury

Abernathy, A.R. and P.M. Cumbie. 1977. Mercury accumulation by largemouth bass (*Mictropterus salmoides*) in recently impounded reservoirs. *Bulletin of Environmental Contamination and Toxicology* 17: 595–602.

Anderson, M.R. 2011. Duration and extent of elevated mercury levels in fish downstream following reservoir creation. *River Systems* 19 (3):167–176.

Aquatic Resources Ltd. 1991. Peace River Site C Development: Fisheries habitat and tributary surveys. A report prepared for BC Hydro by Aquatic Resources Ltd. Vancouver, B.C. July 1991.

Azimuth Consulting Group (Azimuth). 2011. 2010 Status of Mercury in Environmental Media for Site C Planning – Peace River and Dinosaur Reservoir. Project no. BCH-10-01. July 2011. Vancouver, B.C.

Baker, R.F. 2001. Fish mercury database – 2001. British Columbia. A report prepared by Aqualibrium Environmental Consulting Inc. for BC Hydro. Burnaby, B.C.

Baker, R.F., R.R. Turner, and D. Gass. 2002. Mercury in environmental media of Finlay Reach, Williston Reservoir, 2000 – 2001 data summary. A report prepared by EVS Environment Consultants for BC Hydro. March 2002. North Vancouver, B.C.

Bloom, N.S. 1992. On the chemical form of mercury in edible fish and marine invertebrate tissue. *Canadian Journal of Fisheries and Aquatic Sciences*. 49:1010–1017.

Bodaly, R.A. and R.E. Hecky. 1979. Post-impoundment increases in fish mercury levels in the Southern Indian Lake reservoir, Manitoba. Canadian Fisheries and Marine Service Manuscript Rep. 1531: iv + 15 p.

Bodaly, R.A, R.E. Hecky, and R.J.P. Fudge. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 682-691.

Bodaly, R. A., N.E. Strange, R.E. Hecky, R.J.P. Fudge, and C. Anema. 1987. Mercury content of soil, lake sediment, vegetation, and forage fish in the area of the Churchill River diversion, Manitoba, 1981-82. Canadian Data Report of Fisheries and Aquatic Sciences. 610.

Bodaly, R.A., V.L. St. Louis, M.J. Paterson, R.J.P. Fudge, B.D. Hall, D.M. Rosenberg, and J.W.M. Rudd. 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. In A. Sigel and H. Sigel (eds). *Metal Ions in Biological Systems.* Vol. 34. Mercury and its effects on environmental biology. Marcel Dekker, Inc. 259–287.

Bodaly, R.A., K.G. Beaty, L.H. Hendzel, A.R. Majewski, M.J. Paterson, K.R. Rolfhus, A.F. Penn, B.D. Hall, C.J. Mathews, K.A. Cherewyk., M. Mailman, J.P. Hurley, S.L. Schiff, and J.J. Venkiteswaran. 2004. Experimenting with hydroelectric reservoirs. *Environmental Science and Technology* 38(18):346A–352A.

Bodaly, R. A., W.A., Jansen, A.R. Majewski, R.J.P. Fudge, N.E. Strange, A.J. Derksen, and A. Green. 2007. Postimpoundment Time Course of Increased Mercury Concentrations in Fish in Hydroelectric Reservoirs of Northern Manitoba, Canada. *Archives of Environmental Contamination and Toxicology* 53(3):379–389.

Brouard, D, Doyon, J.F. and Schetagne, R. 1994. Amplification of mercury concentrations in lake whitefish (*Coregonus clupeaformis*) downstream from the La Grande 2 reservoir, James Bay, Québec. p. 369-379, In: Watras C.J., and Huckabee, J.W., eds. *Mercury Pollution: Integration and Synthesis*. Lewis CRC Press, Boca Raton.

Depew, D., N.M. Burgess, M.R. Anderson, R.F. Baker, P.B. Satyendra, R.A. Bodaly, C.S. Eckley, M.S. Evans, N. Gantner, J.A. Graydon, K. Jacobs, J.E. LeBlanc, V.L. St. Louis and L.M. Campbell. 2012. An overview of mercury (Hg) concentrations in freshwater fish species: A national Hg fish data set for Canada. *Canadian Journal of Fisheries and Aquatic Sciences.* Accepted.

Foster, K. and B. Gadbois. 1998. A preliminary examination of the concentration of mercury in fish from the Kinbasket, Revelstoke and Upper Arrow Reservoirs, 1995. Unpublished Report. BC Hydro – Power Supply. Burnaby, B.C.

Golder. 2009a. Peace River watershed water quality and Dinosaur Lake limnology sampling – 2008. Golder Associates Report No. 06-1430-0016. A report prepared for BC Hydro. August 2009. Vancouver B.C.

Golder. 2009b. Water quality, river sediment, soil and vegetation samples from the Peace River watershed – 2007. Golder Associates Report No. 06-1490-006. A report prepared for BC Hydro. May 15, 2009. Vancouver B.C.

Grigal, D.F. 2003. Mercury sequestration in forests and peatlands: A review. *Journal of Environmental Quality*. 32(2):393–405.

Hall, B.D., R.A., Bodaly, R.J.P. Fudge, J.W.M. Rudd, and D.M. Rosenberg. 1997. Food as the Dominant Pathway of Methylmercury Uptake by Fish. *Water, Air, & Soil Pollution* 100(1-2):13–24.

Harris, R.C., D. Hutchinson, and D. Beals. 2009. Predicting mercury cycling and bioaccumulation in reservoirs: Development and Application of the RESMERC Simulation Model. Final Report, April 2009. Prepared for Manitoba Hydro.

Harris, R. and D. Hutchinson. 2012. Screening level predictions of peak mercury concentrations in bull trout for the Site C development. A report prepared for Azimuth Consulting Group, Vancouver by R. Harris Environmental. July 2012. Oakville, ON.

Hurley, J.P., J.M. Benoit, C.L. Babiarz, M.M. Shafer, A.W. Andren, J.R. Sullivan, R. Hammond, and D.A. Webb. 1995. Influences of Watershed Characteristics on Mercury Levels in Wisconsin Rivers. *Environmental Science and Technology* 29(7):1867–1875.

Jackson, T. A. 1988. Accumulation of mercury by plankton and benthic invertebrates in riverine lakes of northern Manitoba (Canada): importance of regionally and seasonally varying environmental factors. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 1744–1757.

Krabbenhoft, D.P., J.G. Wiener, W.G. Brumbaugh, M.L. Olson, J.F. DeWild, and T.J. Sabin. 1999. A national pilot study of Hg contamination of aquatic ecosystems along multiple gradients. In D.W. Morganwal and H.T. Buxton (eds.). US Geological Survey Toxic Substances Hydrology Program – Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999 – Volume 2 – Contamination of Hydrologic Systems and Related Ecosystems: US Geological Survey Water-Resources Investigations Report 99-4018B. 147–160.

Krabbenhoft, D.P., D. Engstrom, C.C. Gilmour, R. Harris, J. Hurley, and R.P. Mason. 2007. Monitoring and evaluating trends in sediment and water indicators. In R. Harris, D.P. Krabbenhoft, R.P. Mason, M.W. Murray, R. Reash, and T. Saltman (eds.). *Ecosystem Responses to Mercury Contamination: Indicators of Change*. SETAC. CRC Press. Boca Raton, FL. Published Feb. 2007. 47–86.

Lodenius, M. 1994. Mercury in terrestrial ecosystems: A review. pp. 343-354 IN C. Watras and J. Huckabee (eds). *Mercury Pollution*: Towards Integration and Synthesis. Boca Ratton, Fla.

Mainstream Aquatics Ltd (Mainstream). 2009. Site C fisheries studies – 2009 Peace River fish inventory. A report prepared for BC Hydro. August 2010. Vancouver, B.C.

Mainstream Aquatics Ltd (Mainstream). 2010. Site C fisheries studies – 2010 Peace River fish inventory. A report prepared for BC Hydro. October 2011. Vancouver, B.C.

Mainstream Aquatics Ltd (Mainstream). 2011. Site C fisheries studies – 2011 Peace River fish inventory. A report prepared for BC Hydro. August 2012. Vancouver, B.C.

McKeague, J.A. and B. Kloosterman. 1974. Mercury in horizons of some soil profiles in Canada. *Canadian Journal of Soil Science* 54: 503-507.

Munthe, J., R.A. Bodaly, B.A. Branfireun, C.T. Driscoll, C.C. Gilmour, R.R. Harris, R. Horvat, M. Lucotte, and O. Malm. 2007. Recovery of mercury-contaminated fisheries. *Ambio* 36: 33-44.

Pattenden, R., C. McLeod, G. Ash, and K. English. 1991. Peace River Site C Hydroelectric Development Pre-construction Fisheries Studies – Fish Movements and Population Status. 1990 Studies. Interim Final Report. Prepared for BC Hydro by RL&L Environmental Services Ltd. and LGL Ltd. pp. 126.

Potter, L., C. Kidd, and D. Standiford. 1975. Mercury levels in Lake Powell. Bioamplification of Mercury in Man-Made Desert Reservoir. *Environmental Science and Technology* 9(1):41–46.

Rasmussen, P.E. 1994. Current methods of estimating atmospheric mercury fluxes in remote areas. *Environmental Science and Technol*ogy. 28: 2233-2244.

Rasmussen, P.E., 1995. Mercury in vegetation of the PreCambrian Shield. p. 417-425. In C.J. Watras and Huckabee, J.W. (eds) *Mercury pollution*: Integration and synthesis. Lewis Publ. Boca Raton Fla.

Rieberger, K. 1992. Metal concentrations in fish tissue from uncontaminated B.C. lakes. B.C. Water Management Division, Water Quality Branch Ministry of Environment Lands and Parks, B.C. August 1992.

Sarkka, J. 1979. Mercury and chlorinated hydrocarbons in zooplankton of Lake Paijanne, Finland. *Archives of Environmental Contamination and Toxicology* 8:161–173.

Schetagne, R. and R. Verdon. 1999a. Mercury in fish of natural lakes of northern Quebec. In M. Lucotte, R. Schetagne, N., Thérien, C. Langlois and A. Tremblay (eds.). *Mercury in the Biogeochemical Cycle*. Springer-Verlag, Berlin. 115–130.

Schetagne, R. and R. Verdon. 1999b. Post-impoundment evolution of fish mercury levels at the La Grande Complex, Quebec, Canada (from 1978 to 1996). In M. Lucotte, R. Schetagne, N. Thérien, C. Langlois, and A. Tremblay (eds.). *Mercury in the Biogeochemical Cycle*. Springer-Verlag, Berlin. 235–258.

Schetagne, R., J-F. Doyon, and J.J. Fournier. 2000. Export of mercury downstream from reservoirs. *Science of the Total Environment* 260:135–145.

Schetagne, R., J. Therrien, and R. Lalumiere. 2003. Environmental monitoring at the La Grande complex. Evolution of fish mercury levels. Summary report. 1978–2000. Direction Barrages et Environnement, Hydro-Québec Production and Groupe conseil GENIVAR Inc., 185 pp. and Appendices.

St. Louis, V.L., J.W.M. Rudd, C.A. Kelly, and L.A. Barrie. 1995. Wet deposition of methylmercury in northwestern Ontario compared to other geographic locations. *Water, Air, & Soil Pollution* 80:405–414.

St. Louis, V.L., J.W.M. Rudd, C.A. Kelly, R.A. Bodaly, M.J. Paterson, K.G. Beaty, R.H. Hesslein, A. Heyes, and A. Majewski. 2004. The rise and fall of mercury methylation in an experimental reservoir. *Environmental Science and Technology* 38:1348–1358.

Stockner, J., A. Langston, D. Sebastian, and G. Wilson. 2005. The limnology of Williston Reservoir: British Columbia's largest lacustrine ecosystem. *Water Quality Resources Journal Canada* 40(1):28–50.

Tremblay, A., M. Lucotte, and I. Rheault. 1996. Methylmercury in a benthic food web of two hydroelectric reservoirs and a natural lake of northern Quebec. *Water, Air, & Soil Pollution* 91:255–264

References for Section 11.10 - Microclimate

Oke, T.R. 1987. *Boundary Layer Climates 2nd ed*. Routledge. London, UK.

Internet Sites

National Centers for Environmental Prediction (NCEP). 2011. North American Regional Reanalysis. Camp Springs, Maryland. Available at: http://www.emc.ncep.noaa.gov/mmb/rreanl. Accessed December 7, 2012.

References for Section 11.11 – Air Quality

Air & Waste Management Association (AWMA). 2000. Air Pollution Engineering Manual, Second Edition. ISBN: 0-471-33333-6.

B.C. Ministry of Environment (BCMOE). 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Environmental Protection Division. Environmental Quality Branch, Air Protection Section. Victoria, B.C.

B.C. Ministry of Environment (BCMOE). 2009. Air Quality Objectives and Standards.

Canadian Council of Ministers of the Environment. 2006. Canada-wide Standards for Particulate Matter and Ozone. Five Year Report: 2000–2005.

Canadian Council of Ministers of the Environment. 2012. Guidance Document on Achievement Determination of Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone.

The Chamber of Shipping. 2007. BC Ocean-Going Vessel Emissions Inventory Report.

Environment Canada. 2006. Criteria Air Contaminants Emissions Inventory 2002 Guidebook.

Environment Canada. 2012. Environment Canada's National Pollutant Release Inventory.

Nickling, W.G. Nickling Environmental Ltd. 2012. Project Memorandum.

United States Environmental Protection Agency (US EPA). 1995–2011. AP-42, Fifth Edition. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources. Published 1995 with amended data to 2011.

United States Environmental Protection Agency (US EPA). 2003. Appendix W to Part 51 – Guideline on Air Quality Models. July 2003 Edition.

Western Regional Air Partnership (WRAP). 2006. Fugitive Dust Handbook.

Internet Sites

B.C. Ministry of Environment (BCMOE). 2012. BC Air Data Archive Website. Available at: http://envistaweb.env.gov.bc.ca/ Accessed: June 2012.

Clean Air Strategic Alliance Data Warehouse. 2012. Available at: http://www.casadata.org/ Accessed: June 2012.

Personal Communication

McCormick, W. B.C. Ministry of Environment, Victoria, B.C. Email. September 4, 2012.

References for Section 11.12 – Noise and Vibration

British Columbia Ministry of Transportation and Infrastructure (BCMOT). 1993. Mitigating the Effects of Traffic Noise from Freeways and Expressways. Highway Environment Branch.

British Columbia Oil and Gas Commission (BCOGC). 2009. British Columbia Noise Control Best Practices Guideline.

Crocker. 2007. *Handbook of Noise and Vibration Control*. Wiley and Sons, New York. ISBN-10: 0471395994. October 2007.

International Organization for Standardization (ISO). 1993. ISO 9613. Acoustics – Attenuation of sound during propagation outdoors, Part 1. Switzerland.

International Organization for Standardization (ISO). 1996. ISO 9613. Acoustics – Attenuation of sound during propagation outdoors, Part 2. Switzerland.

Stiehr, J.F. 2011. International Society of Explosives Engineers (ISEE) Blasters' Handbook, 18th edition. Ohio.

Ontario Ministry of Environment (ONMOE). No date. Noise Pollution Control Publication 119 (NCP-119). Blasting.

US Air Force (USAF). 2002. SELCal2 Flyover Software Ver 1.0.2., USAF AFRL/HECB Aural Displays and Bioacoustics Branch, Ohio. May 2002.

US Office of Surface Mining (USOSM). 1986. OSM Blasting Performance Standards 30. Code of Federal Regulations, Sec. 8816.61: Use of Explosives: General requirements.

References for Section 11.13 – Electric and Magnetic Field

Bonneville Power Authority. 1991. Corona and Field Effects Program Version 3. US Department of Energy. Washington, DC.

International Organization for Standardization (ISO). 1993. ISO 9613. Acoustics – Attenuation of sound during propagation outdoors, Part 1. Switzerland.

International Organization for Standardization (ISO). 1996. ISO 9613. Acoustics – Attenuation of sound during propagation outdoors, Part 2. Switzerland.

Stiehr, J.F. 2011. International Society of Explosives Engineers (ISEE) Blasters' Handbook, 18th edition. Ohio.

Ontario Ministry of Environment (ONMOE). No date. Noise Pollution Control Publication 119 (NCP-119). Blasting.

US Air Force (USAF). 2002. SELCal2 Flyover Software Ver 1.0.2., USAF AFRL/HECB Aural Displays and Bioacoustics Branch, Ohio. May 2002.

US Office of Surface Mining (USOSM). 1986. OSM Blasting Performance Standards 30. Code of Federal Regulations, Sec. 8816.61: Use of Explosives: General requirements.

References for Section 11.13 – Electric and Magnetic Field

Bonneville Power Authority. 1991. Corona and Field Effects Program Version 3. US Department of Energy. Washington, DC.