WUSKWATIM GENERATION PROJECT

ENVIRONMENTAL IMPACT STATEMENT

Manitoba Hydro
and
Nisichawayasihk Cree Nation

April 2003

Volume 4
Physical Environment

Nisichawayasihk Cree Nation

Manitoba Hydro

Available in accessible formats upon request.

PREFACE

Volume 4 (Physical Environment) is one of a series of supporting technical volumes for Manitoba Hydro's and Nisichawayasihk Cree Nation's (NCN's) application for environmental licensing of the Wuskwatim Generation Project (the Project), which is entitled Wuskwatim Generation Project Environmental Impact Statement (EIS), Volume 1 (April 2003).

The Wuskwatim Generation Project EIS is comprised of the following:

- Volume 1 – Wuskwatim Generation Project – Environmental Impact Statement
- Volume 2 – Public Consultation and Involvement
- Volume 3 – Project Description and Evaluation of Alternatives
- Volume 4 – Physical Environment
- Volume 5 – Aquatic Environment
- Volume 6 – Terrestrial Environment
- Volume 7 – Resource Use
- Volume 8 – Socio-Economic Environment
- Volume 9 – Heritage Resources
- Volume 10 – Cumulative Effects Assessment (Framework Approach)

Volume 4 has been prepared by a team of Environmental/Engineering Consultants and Manitoba Hydro. The supporting volumes have contributed to the preparation of the summary Environmental Impact Statement (Volume 1) and have also provided additional technical supporting information to assist in the technical review of the EIS. The supporting documents have been reviewed by Manitoba Hydro and NCN and are technically consistent with the EIS.

All of the sections in Volume 4 share a similar EIS framework in presenting the analysis and results, however, they have been completed by different authors from different firms/companies/departments and therefore differ depending on the subject matter being presented and have not been edited for consistency in style or wording. The style and wording of the various sections may also differ from that of other EIS supporting volumes.

The following is a list of the contributors to this volume:

Tetr*ES* Consultants Inc.	• Introduction; • Climate; • Physiography, Geology & Soils; and • Woody Debris.
J.D. Mollard & Associates Ltd.	• Wuskwatim Lake Erosion.
Acres Manitoba Ltd.	• Ice Processes; • Water Regime; • Riverine Erosion; and • Sedimentation.
NorthWest Hydraulics	• Sedimentation.
Manitoba Hydro - Resource Planning & Market Analysis Department - Hydraulic Engineering & Operations Department - Hydro Power Planning Department	• Climate; and • Water Regime.

All of the firms/companies/departments listed above also contributed to the technical input and review of other sections, as well as the joint compilation of the Residual Effects; Cumulative Effects; Environmental Monitoring and Follow-Up and Glossary sections.

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1.0 INTRODUCTION

Volume 4 (Physical Environment) is one of a series of supporting technical volumes to the Environmental Impact Statement (EIS) for the Wuskwatim Generation Project (the Project). This Volume provides relevant details summarized in Volume 1 and, along with Volume 3 (Project Description), provides the background material for other components of the environmental study to assess Project effects.

The physical environment includes the surficial geology of the land (soils, overburden, rock outcrops, etc.), waterbodies (lakes, rivers, streams, creeks, etc.) and air (air quality and climate). Within Volume 4, the aspects of the physical environment of the Project study area that are described and assessed include: climate; physiography, geology and soils; water regime; ice; erosion (lake and river shorelines); sedimentation and debris. Climate (precipitation, temperature, wind, etc.) and geomorphologic processes are the basic physical (non-living) factors that influence and continuously alter the physical environment within which all life processes exist.

Within the Project study area, the existing physical environment along the Burntwood River system has also been altered, and continues to be influenced, by changes brought about by the Churchill River Diversion (CRD) in the mid-1970s. The CRD resulted in the immediate change in water regime and ice processes along the river system. Lake and riverine erosion, sedimentation and debris generation continues to change as a result of the post-CRD water regime.

Construction and operation of the proposed Project is expected to affect aspects of the physical environment, as follows:

- Project Construction:
  - local air quality;
  - land associated with the footprint of the Project (including the access road, borrow areas and generating station);
  - local sedimentation, suspended solids and water regime during phases of the in-river construction.
- Project Operation:
  - water regime;
  - shoreline erosion;
  - sedimentation;

- ice processes; and
- debris generation.

Sections 2 through 9 describe aspects of the existing physical environment that are expected to be affected by the Project, the anticipated effects as a result of the Project, and proposed mitigation measures as required by the "Guidelines" for the preparation of this EIS (Section 6.1 of the EIS Guidelines, see Appendix 2 of Volume 1). Sections 10 through 12 present a compilation of the residual effects, cumulative effects and the environmental monitoring and follow-up to Sections 2 through 9.

The anticipated effects of the Project on the physical environment are described in terms of their:

- *magnitude* – meaning the size of the effect relative to the parameter being measured in the physical environment; could be a small, moderate or large effect;
- *duration* – meaning how long the effect is expected to last, with:
    - "short-term" defined as lasting no more than five years;
    - "moderate-term" defined as lasting more than 5 years but less than 25 years; and
    - "long-term" defined as lasting more than 25 years.
- *geographical extent* – meaning the spatial extent of the effect, with:
    - "site" meaning that the effect is confined to a small area and is not transportable to other areas;
    - "local" (or "localized" meaning the effect extends slightly to moderately beyond the Project site; and
    - "regional" meaning the effect extends to an area well beyond the Project site.

Information contained in Sections 2 through 9 of this Volume have also been used to assess the expected effects or implications of the Project on living components of the aquatic and terrestrial environments and aspects of the resource use, socioeconomic and heritage resource environments (Volumes 5 through 9, respectively).

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2.0 CLIMATE

2.1 INTRODUCTION

The Guidelines for the Preparation of an Environmental Impact Statement (EIS) for the Wuskwatim Project (Manitoba Conservation 2002; Volume 1, Appendix 2) require that the proponent shall describe the following:

- *general climate conditions with sufficient data provided to predict the effect of the project on climate and the potential effects of climate on the project*; and
- *local air quality potentially affected by the project.*

2.2 APPROACH AND METHODOLOGY

There are no long-term climate recording stations that have operated within the Wuskwatim study area. The nearest climate station that maintains a comprehensive long-term record is based out of Thompson Airport (ID# 5062922), approximately 50 km NE of Wuskwatim Lake. Short-term meteorological data has also been recorded at other sites. For example, research groups contributing to the BOREAS project (Boreal Ecosystem–Atmosphere Study) have collected meteorological data on a research-related specific time basis within the study area (1994-1998). The dataset is seasonal and non-continuous. Additional information on BOREAS can be found in the Resource Use Supporting Document (Volume 8). Since late 1995, Manitoba Hydro has operated a "mini weather station" at their Data Collection Platform (DCP) water-level recording site on Wuskwatim Lake. Data recorded at the site includes air temperature, rainfall, wind speed and direction. The meteorological data recorded during the first two years of station operation is incomplete, but from September 1997 onwards there exists a more complete dataset. The BOREAS and Hydro datasets are too short and incomplete to be of use in describing the general climate of the area. Therefore, the Thompson station data has been relied upon as indicative of the long-term conditions found within the study area. The latest 30-year climate normals data published by Environment Canada (for the period 1971-2000 inclusive) are provided in Section 2.3.2 below.

How the Project may affect climate, and alternatively, how the climate affect the project is a multi faceted issue. Historical variability in local weather conditions has a significant influence on watershed runoff in the Wuskwatim region. This is demonstrated in the historical water level and flow variation that occurs on the CRD system as discussed in Section 4.2 (Volume 4). How the Project deals with this hydrological variability is discussed in Section 4.3. In addition to variability in local weather, is the issue of global climate change and its potential impact on the Project. Discussion on this aspect is provided in Section 2.3.3. The potential of the Project to contribute to global climate change with respect to an increase in potential **greenhouse gas (GHG)** emissions is discussed in the Effects and Mitigation section of this document (i.e., Section 2.4.2). The potential of the project to affect local air quality during construction and operation is discussed in Section 2.4.

2.3 EXISTING ENVIRONMENT

2.3.1 Environmental Influences

The Wuskwatim site is located within a subdivision of the **High Boreal Eco-Climatic Region** in Manitoba (Smith *et al.* 1998). While this subdivision is warmer and more humid than the Region as a whole, it is generally characterized by short cool summers and cold long winters, as described in detail in Section 2.3.2.1. The average growing season is 139 days with about 1000 growing degree-days (days of average temperature over 5°**C**).

2.3.2 Climatic Normals

2.3.2.1 Temperature

The Thompson area exhibits the broad annual temperature range characteristic of a northern temperate, mid-continental climate. The annual mean temperature during the period of record was –3.2°C. Daily mean temperatures ranged from an average high of 15.8°C in the month of July, to an average low of –24.9°C in January (an annual range of 40.7°C).

The Thompson area's diurnal temperature cycle (given here as the range between the average daily maximum and minimum temperatures for each month) is consistently narrow throughout the year (Figure 2.3-1). The broadest average diurnal variation occurred in the month of March (15.3°C difference), while the narrowest occurred in October (8.6°C difference). Extreme temperature events can occur well outside the typical monthly norms. The most pronounced difference in monthly extreme maximum and extreme minimum recorded temperatures occurred in March, with an extreme low of –48.3^{0}C recorded in 1972, and an extreme high of 19.1°C recorded in 1995 (67.4°C difference). An examination of these extreme events indicates that isolated temperature fluctuations away from the established norms (as expressed by the daily mean values) tend to be less pronounced during the summer period (June through September) as compared to the winter period (November through March). However, caution should be exercised with respect to emphasizing isolated events within the context of a long-term climatic overview. A comparison of maxima and minima temperature ranges indicates that, on average, winter period diurnal ranges are less pronounced than those of the summer period (Figure 2.3-2). Therefore, while the potential for extreme temperature events may be greater during the winter period, the overall temperature conditions tend towards greater stability.

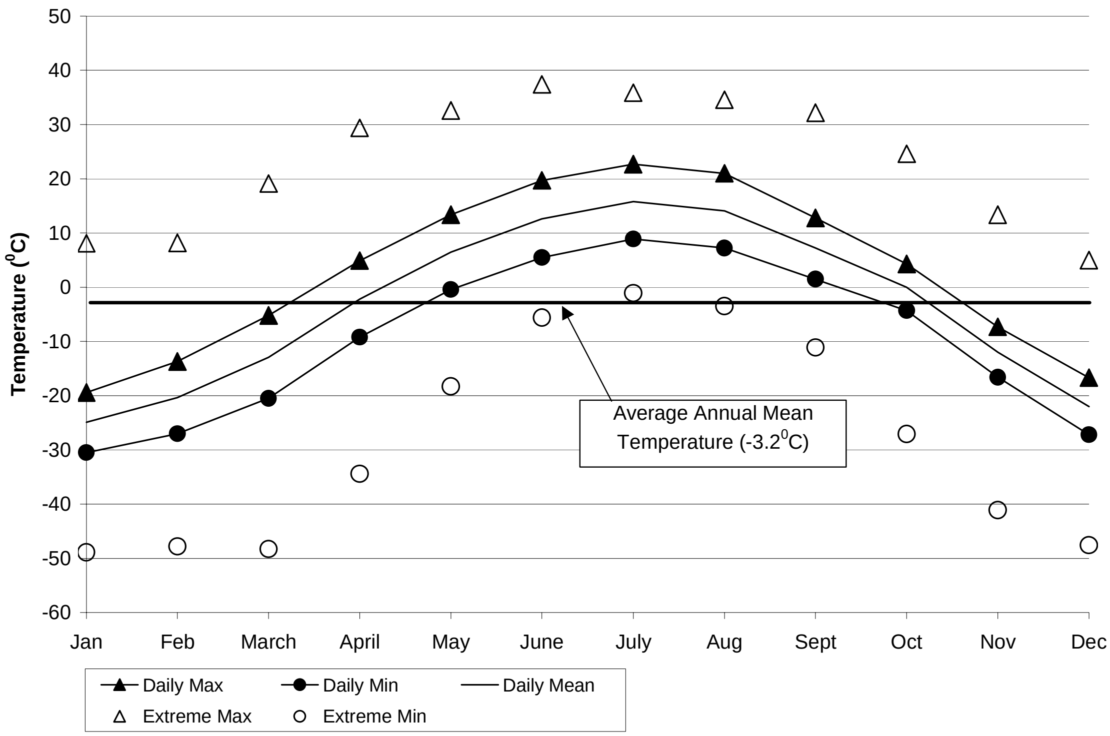


Figure 2.3-1. Temperature normals for the Thompson Area (1971-2000).

Winter conditions are considered to exist during the five-month period of November through March, when the mean daily maximum temperatures stay below 0°C (Figure 2.3-1). Summer conditions are correspondingly ascribed to the four-month period of June through September, when the mean daily minimum temperatures exceed 0⁰C. April, May and October comprise short intermediary periods between the dominant seasonal conditions of winter and summer and are characterized by mean daily maximum temperatures above 0°C, and mean daily minimum temperatures below 0°C. The April and October diurnal temperature cycles oscillate fairly evenly within 10°C on either side of the freezing mark. By contrast, May's mean daily minimum temperature is just slightly below freezing (-0.4°C), accompanied by a mean daily maximum temperature in the low teens (13.4°C). Regardless of whether May could be included within the summer season, the transitional brevity between summer and winter conditions is clearly defined.

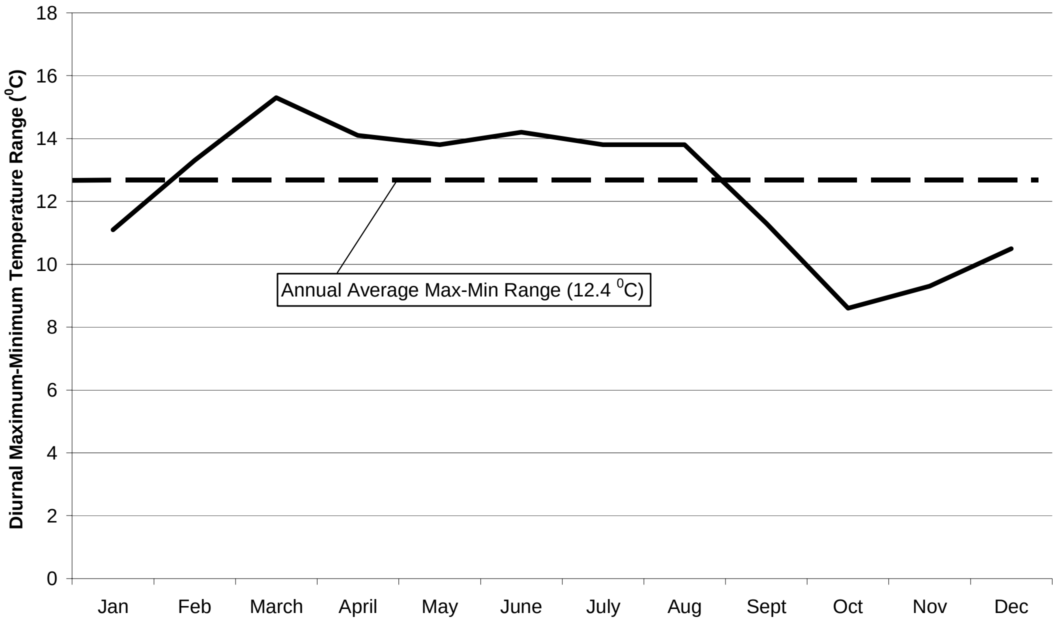


Figure 2.3-2. Average monthly diurnal maximum-minimum temperature ranges are for the Thompson Area (1971-2000).

2.3.2.2 Precipitation

Rainfall accounts for 67.3% of the total annual precipitation in the Thompson area. Figure 2.3-3 details the average monthly percentage of total precipitation occurring as rain. Not unexpectedly, this figure shows the majority of rainfall taking place during the June through September summer period (82.2% of annual total), and that summer precipitation is composed almost entirely of rain (97.8%). Figure 2.3-4 represents the average monthly rainfall levels for the Thompson area over the period of record.

Snowfall has been recorded in measurable amounts throughout nearly the entire year, with the lone exception being the month of July. Figure 2.3-5 charts the average monthly snowfall yields in the Thompson area over the period of record. Nearly all of the snowfall occurs outside of the four-month summer period (97.1%). The amount of annual snowfall is fairly evenly distributed over the months October through May. November typically shows the highest snowfall yields (18.8% of average yearly totals), while May has the lowest (6.4% of average yearly totals). The five-month winter period (November through March) accounts for 67.6% of the total average yearly snowfall during the period of record discussed here.

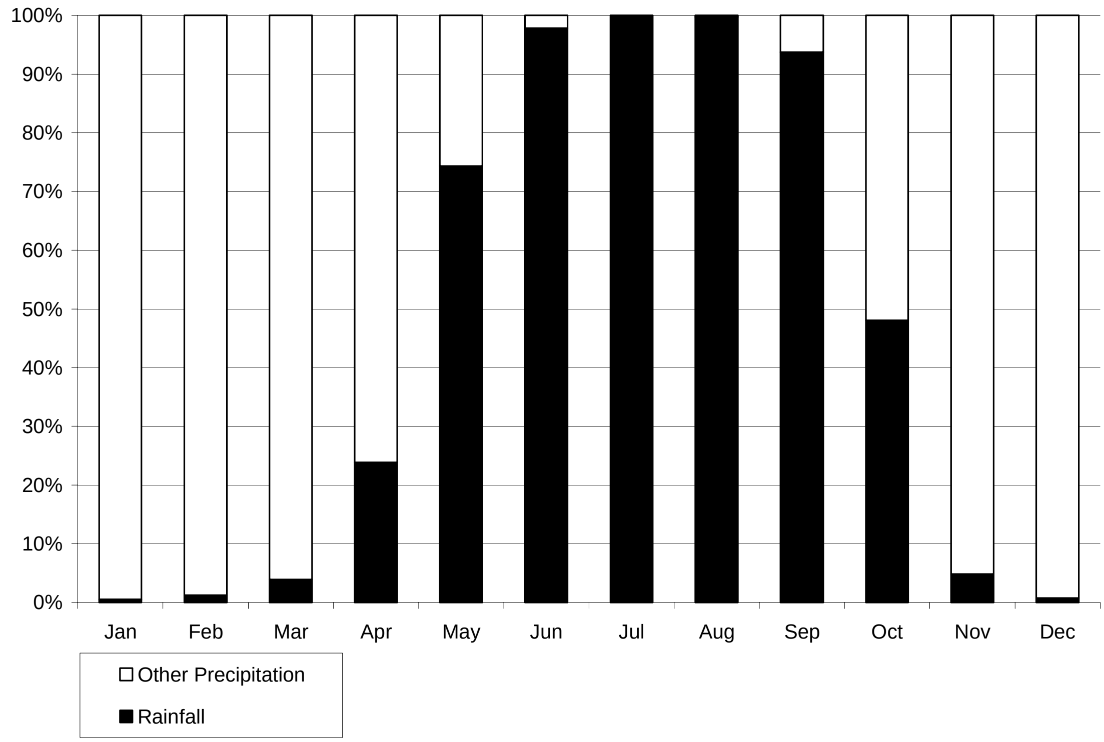


Figure 2.3-3. Percentage of average monthly precipitation comprised by rainfall in the Thompson Area (1971-2000).

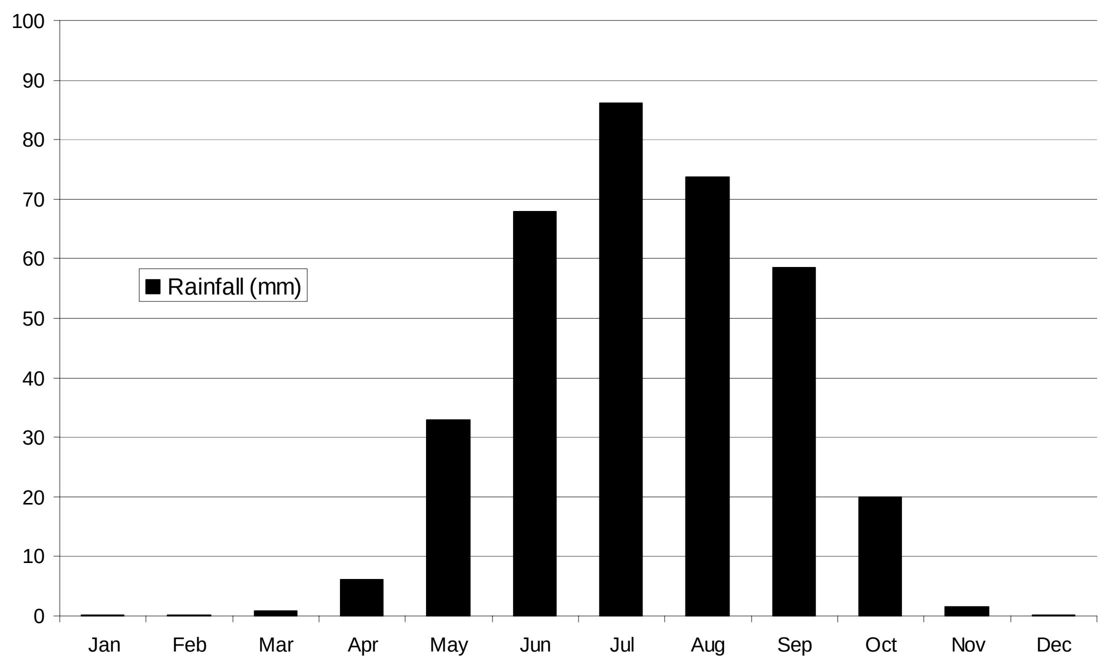


Figure 2.3-4. Average monthly rainfall levels in the Thompson Area (1971-2000).

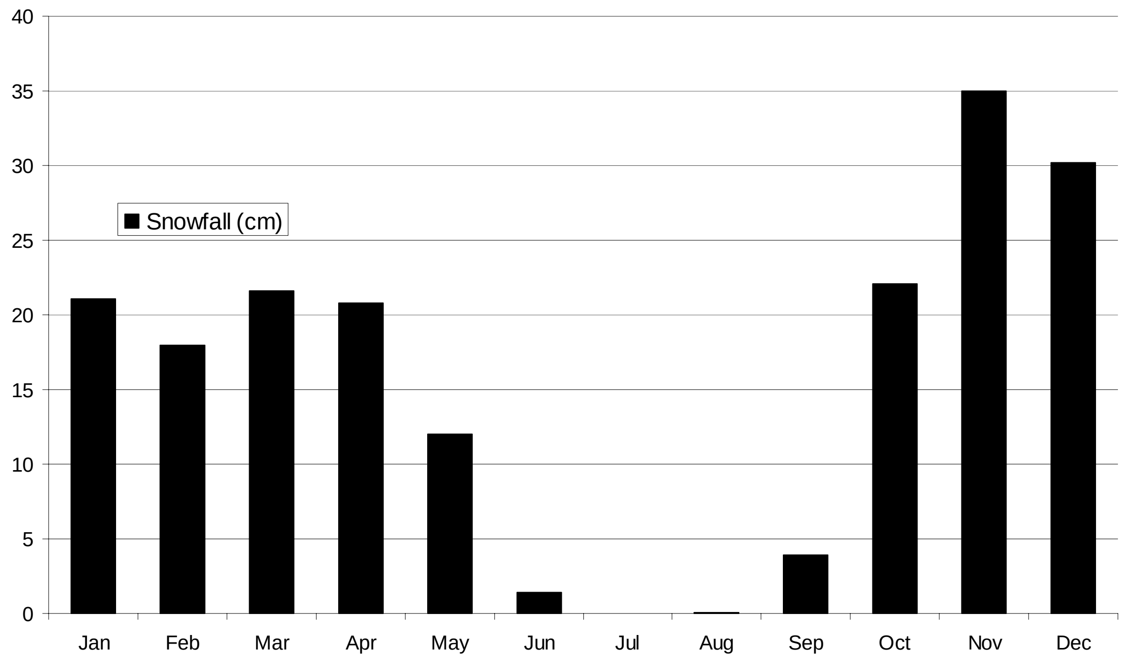


Figure 2.3-5. Average monthly snowfall yields in the Thompson Area (1971-2000).

2.3.2.3 Wind

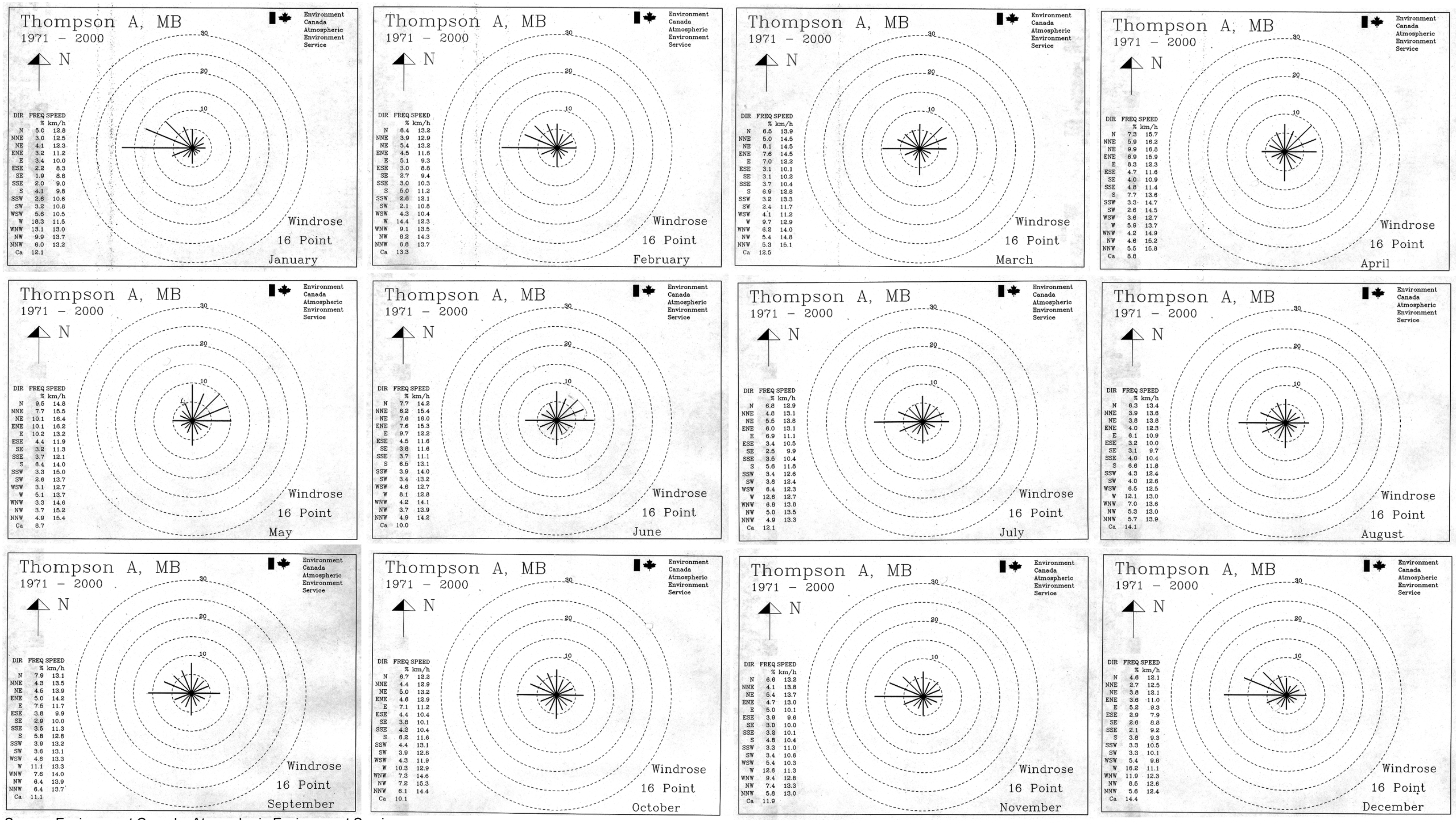
An analysis of average monthly **wind-rose** data and climate-norm data from the Thompson Airport, for the period 1971-2000 (Figure 2.3-6), indicate that prevailing winds are:

- westerly (W) for the 9 months from July through March;
- shifting to north-easterly (NE) for 2 months from April through May; and
- then shifting to easterly (E) during June.

While the prevailing wind conditions are as described above, winds originating from all other directions were observed during the monthly periods of record. Wind speed is quite consistent throughout the year, fluctuating from an average high of 14 km/hr during April and May to an average low of 10 km/hr in December.

2.3.2.4 Air Quality

Air-quality **monitoring** is primarily associated with large urban centers and industrial point sources where pollution concerns become an issue of public safety. Industrial emission monitoring of smelting operations in Thompson (the nearest industrial center) has been conducted during the past decade. The monitoring program focuses primarily



Source: Environment Canada, Atmospheric Environment Service

Figure 2.3-6. Average monthly wind-rose patterns in the Thompson Area (1971-2000).

on sulphur dioxide emissions in accordance with provincial efforts to reduce **acid-rain-**causing pollutants (Manitoba Conservation 1997).

Limited amounts of other air-quality data have also been collected within the Boreal Shield ecozone, from which a general idea of air quality near the Project study area might be inferred. The BOREAS (BOReal Ecosystem–Atmosphere Study) project's Northern Study Area, which was located to the northeast of the community of Nelson House, included studies of general atmospheric conditions and other **parameters** like ambient levels of certain greenhouse gases (principally carbon dioxide and methane) within boreal forest conditions similar to those found around the Wuskwatim area. The length of these studies was typically quite brief, but the data collected may be useful for defining recent baseline atmospheric gas concentrations within the study area (BOREAS 1999; 2002). This baseline data may prove useful if monitoring programs of reservoir-related greenhouse-gas emissions are undertaken.

The Wuskwatim Generating Station study area is not exposed to substantial quantities of airborne **pollutants**. Prevailing wind data recorded at the Thompson climate station (Section 2.3.2.3) suggests that the study area would not typically be subject to deposition from the industrial facilities operating in Thompson. It is noted, however, that Opegano Lake is considered to be within the secondary deposition zone of emissions from INCO smelter. Northeasterly wind conditions that could potentially carry industrial emissions towards the Wuskwatim area have the greatest likelihood of occurring during the Spring period of April through May (Figure 2.3-7). The extent to which emissions of this nature might impact the study area is unknown. Existing air quality at the Project site is considered to be good to excellent.

2.3.2.5 Ice Fog

The **turbulence** created by water flowing over Taskinigup and Wuskwatim Falls creates a mist at these sites that turns into an ice fog during the winter. In the winter this ice fog is clearly visible from the air 20 km away from the site (Groeneveld & Harding *pers. comm.* 2002). When the fog comes in contact with the cooler surrounding land and vegetation, the surfaces become coated with layers of ice that gradually build up over the winter.

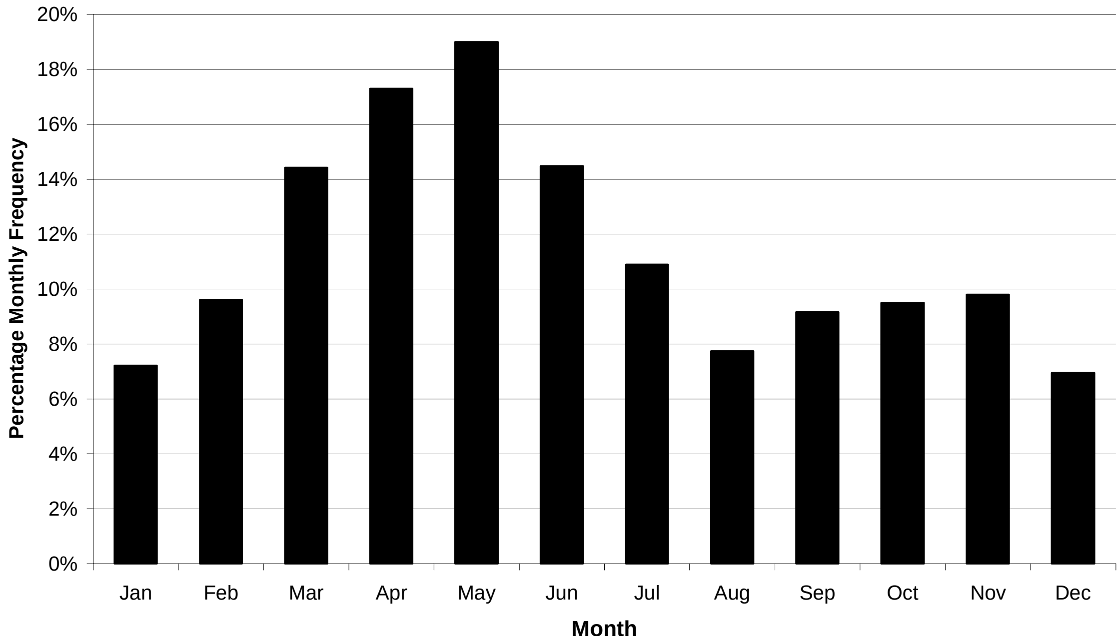


Figure 2.3-7. Average monthly frequency of northeasterly winds for the Thompson Area (1971-2000).

2.3.3 Global Climate Change

Climate change is defined as a long-term shift or alteration in the climate of a specific region and is manifested as changes in temperature, precipitation, atmospheric processes and overall variability in weather patterns and extremes. It is recognized that climate change is driven by natural processes such as solar activity, alterations in the earth's orbit and volcanic activity. In addition, there is consensus among scientists that anthropogenic (man-made) activities are having a discernible impact on the global climate. However, there is uncertainty regarding the degree to which specific causal mechanisms drive climate change. There is also a significant uncertainty associated with feedback mechanisms that could accentuate or dampen the greenhouse gas effect.

Natural greenhouse gases, including water vapour, carbon dioxide, methane, nitrous oxide and ozone, trap infrared heat energy that would otherwise be released into space, raising the temperature of the lower atmosphere and the Earth's surface. Anthropogenic greenhouse gases originating from the burning of **fossil fuels**, deforestation and other land-management practices accelerate the warming effect. Airborne particulates of natural and human origin, as well as land cover changes from changes in forest cover, crops and human development would have a cooling effect on the lower atmosphere and Earth's surface.

Beyond the global uncertainties, regional climate impacts face another layer of increased uncertainty because the global climate predictions apply to large geographic areas. In addition, effects of climate change on precipitation at the regional level presents the greatest level of uncertainty because predictions of temperature change are more accurate than predictions of precipitation change.

2.3.3.1 Global Climate Models

Global Climate Models (GCMs) offer useful insights into future climate change scenarios. These models are based on fundamental laws of physics and conservation of mass, momentum and energy, and express the complex climate system in a series of mathematical expressions to simulate the complex relationships between atmospheric processes, ocean currents and land masses, over a range of scenarios of assumed greenhouse gas and aerosol concentrations.

GCMs allow scientists to explore and experiment with different global climate drivers, feedback influences, and emission scenarios. Scientists have been developing global climate models over the past two decades for analyzing various scenarios of greenhouse-gas induced climate change induced by greenhouse gas emissions. Projected responses of climate to changing conditions depend on GCM model design, estimates of future greenhouse gas emissions, aerosol and aerosol precursor concentrations, their duration in the atmosphere, and their **radiative** properties. Currently about 20 GCMs are being used worldwide to evaluate the impacts on these complex processes on the global climate. The International Panel on Climate Change (IPCC) states: "*GCMs are the only credible tools available currently for simulating the physical process that determine climate change*" (IPCC 2001).

The scientific community cautions that GCMs are used only to conduct experiments of possible future climate scenarios with GCMs. They do not use GCMs to make absolute predictions about future climate, because of the many levels of uncertainty in global climate modeling, compounded by uncertainty about the effects of future policies and regulations, changes in societal values and practices, and the impact of these changes on the factors contributing to climate change.

2.3.3.2 Regional Climate Models

Regional climate models are numerical models capable of achieving higher spatial resolution than is technically feasible with global climate models. The resolution of current GCMs is on the order of 500 km by 500 km, while the resolution of regional climate models is about 50 km by 50 km. Regional climate models use output from the GCMs to define the climate conditions at their boundaries. A regional climate model has been developed in Canada by the Canadian Regional Climate Model development team at the University of Quebec in Montreal (http://www.mrcc.uqam.ca/E_v/index_e.html).

GCMs are continually being developed to improve the resolution of the global modeling framework into much finer grid points. This may result in the translation of GCM output into finer scale inputs to regional climate models. For example, the modeling of complex interactions between the atmosphere and local geographic features such as mountains, water bodies and forests will become possible when higher resolution GCMs are developed. However, increasing model resolution does not necessarily imply climate change impact projections of higher certainty. The increased resolution of models addresses a small portion of the overall uncertainties.

2.3.3.3 Possible Range of Implications from Climate Change

Manitoba Hydro has been tracking the results of the various Global Climate Models (GCMs) and generally concluded that all GCMs tend to agree regarding long-term temperature trends. The most recent consensus from the international body of scientists that comprise Working Group I of the Intergovernmental Panel on Climate Change (IPCC 2001) is that there could be an increase of 1 to 3°C in annual mean surface temperature in the Nelson-Churchill basin by 2020 and an increase of 2 to 7°C in annual mean temperature by 2080.

However, the various GCMs are not consistent in their projections of long-term precipitation trends. The Canadian Institute for Climate Studies' (CICS) Canadian Climate Impacts Scenarios Project at the University of Victoria provides a web-based tool for evaluating a range of possible climate scenarios for specific regions, using the results of all GCMs currently in use (http://www.cics.uvic.ca/scenarios/primer.cgi?Background). The CICS website illustrates a broad range of possible temperature and precipitation trends for the Wuskwatim region, ranging from "warmer, wetter" GCM scenarios, which indicate annual precipitation may increase as the average annual temperature increases, to "warmer, drier" scenarios, which show a decrease in precipitation for a similar temperature increase. It is noted that all models project an increase in temperature associated with an increase in greenhouse gas emissions, but vary significantly in their projections of precipitation. The effect on runoff and river flow is even more uncertain.

Due to the level of uncertainty about the effects of climate change and when these effects can be expected to occur, Manitoba Hydro cannot project a particular climate scenario on the Wuskwatim resource region to predict the impacts of climate change. Until global climate models and regional climate models are improved such that they can be calibrated to predict current climate regimes, they cannot be used with enough confidence to predict future climate trends in the Wuskwatim Generation Project area. However, the information posted publicly at the CICS website provides a means to develop illustrative examples of possible climate scenarios. These examples may be used to illustrate possible impacts in the various resource sectors.

2.4 EFFECTS AND MITIGATION

2.4.1 Construction

As discussed in the Project Description Supporting Document (Volume 3, Section 4), construction activities may result in temporary localized changes to air quality, particularly dust impacts relating to road traffic and blasting and crushing operations.

The potential dust emissions from vehicular traffic along the main gravel access road would depend on a number of factors, including but not limited to, the volume of traffic, average speed of the vehicle fleet, fraction of silt in the road surface materials, moisture content of surface materials and general climatic conditions. Dust impacts would be expected to be aggravated during relatively dry periods, and when large volumes of traffic are using the road. To reduce dust effects and to maintain efficient traffic flow, the Contractor will be required to keep roads well maintained. A variety of options exist to control dust emissions and these fall within three general categories:

- Vehicle Restrictions (e.g., speed, weight, volume);
- Surface Improvement (e.g., grading); and
- Surface Treatment (e.g., watering, chemical dust suppressants).

Dust effects from vehicular road traffic are therefore considered to be localized, short-term, and mitigable with respect to air quality.

The contractor will also operate a rock crusher on site to manufacture coarse **aggregate** for use in making concrete as discussed in the Volume 3 (Section 4.6.6). The rock crusher will be located in the Contractor's work area. Rock crushing could either be done all at once or done as required during concrete production (i.e., Year 2006 through to Year 2008). All phases of this operation are a potential source of emissions. The amount of process and **fugitive** emissions will be influenced by wind dynamics, moisture on the surface of the rock and type of rock, general weather conditions, as well as transport-related factors.

The construction of the generation station will require the blasting and excavating of approximately 806,000 m^3 of rock from the location of the powerhouse structures. Blasting will occur on a daily basis from August through November 2005. The blasting operation will likely cause brief elevated dust levels that will be subject to a similar set of influences as described for the crushing operation.

Dust emissions from rock-crushing and blasting operations are largely unavoidable, but are expected to be localized and brief with respect to air quality.

2.4.2 Operation

2.4.2.1 Ice Fog

The only foreseeable climatic effect from Project operations relates to ice fog. Once Wuskwatim Falls and Taskinigup Falls are flooded by the impoundment of the Wuskwatim Generation Station, the formation of ice fog at the site will be greatly diminished (Groeneveld & Harding *pers. comm.* 2002). This decrease in ice fog will be a site-specific, long-term unavoidable effect of Project operations.

2.4.2.2 Greenhouse Gas and Other Emissions

Greenhouse Gas Emissions

There is growing concern about the impacts of greenhouse-gas (GHG) emissions. This section deals with the GHG implications of the Wuskwatim Project, including the considerable net benefits with respect to reducing all of these emissions.

Recently the Pembina Institute for Appropriate Development (Pembina Institute 2003) completed a comparison of seven prominent electricity supply options for Manitoba including the proposed Wuskwatim Project and six typical non-hydro generation projects using a range of different fuels. This report is entitled "*Life Cycle Evaluation of GHG Emissions and Land Change Related to Selected Power Generation Options in Manitoba*" and is provided in Appendix A2.1. These options have been compared on the basis of lifecycle GHG emissions and land change per **GWh** of electricity delivered.

Within the Pembina Institute assessment, the assessment of the Wuskwatim Project (because it is currently under detailed study and review) has been more thorough and inclusive of potential carbon impacts than the assessments for the other more generic resources, which have not been planned to the same level of detail. For instance, the impacts of associated transmission and access roads are included for the Wuskwatim Project but are not accounted for with respect to the other resources. The land-use change assumptions used by the Pembina Institute for the Wuskwatim Project were based on preliminary estimates of carbon stocks prepared for the Environmental Impact Statement (see following section). While there have been changes as these estimates were finalized, these changes have not had a significant impact on the total magnitude or relative distribution of source components of GHG implications.

Figure 2.4-1 and Table 2.4-1 presents **levelized** GHG emission results from the Pembina Institute analysis of Manitoba resource options. It clearly shows that renewable technologies such as hydropower, wind and biomass are dramatically lower in emissions than fossil-fuelled resources. Total lifecycle GHG emissions are found to be lowest for the Wuskwatim Project and wind options, 3.8 and 7.9 tonnes of CO_2 equivalent emissions per GWh of energy produced respectively (t CO_{2e} / GWh). These emissions are two or more orders of magnitude less than emissions expected from fossil fuel-powered options, of which the pulverized coal option has the greatest emissions, 1,108 t CO_{2e} / GWh.

Figure 2.4-1 demonstrates that more than 40% of the Wuskwatim Project's GHG emissions result from associated transmission and access roads. It is important to note that for the other resource options studied, the impacts of building transmission and access roads was not included in the analysis. Approximately 50% of the Project's lifecycle GHG emissions result from the manufacturing of the generating station components, the transportation of materials to the site, on-site construction activities and any equipment replacement or maintenance.

The reservoir does not play a significant role in the Project's lifecycle emissions. The Pembina Institute study analysis (Pembina Institute 2003) results in reservoir emission estimates that account for only about 5% of the Wuskwatim Project’s total lifecycle emissions. The Pembina Institute study used assumptions supplied by Manitoba Hydro. These assumptions were intended to demonstrate that, even if very exaggerated assumptions are used, reservoir emissions are not significant for Wuskwatim. This estimate assumes that 60% of the total flooded **biomass** decomposes over the life of the project and that 7% of the carbon is emitted as methane (1% more typical over the life of most reservoirs). Most Canadian reservoirs that have significant amounts of associated flooding demonstrate increased emissions for the first several years after which they seem to emit within the range seen from comparable un-flooded water bodies. Since the increased emissions in the early years does not account for a significant portion of the flooded biomass, it is possible that a large portion of the flooded biomass does not decompose (i.e., significantly less than 60%). Also, there are also several significant offsetting factors that have not been included in this analysis, such as the role of reservoir

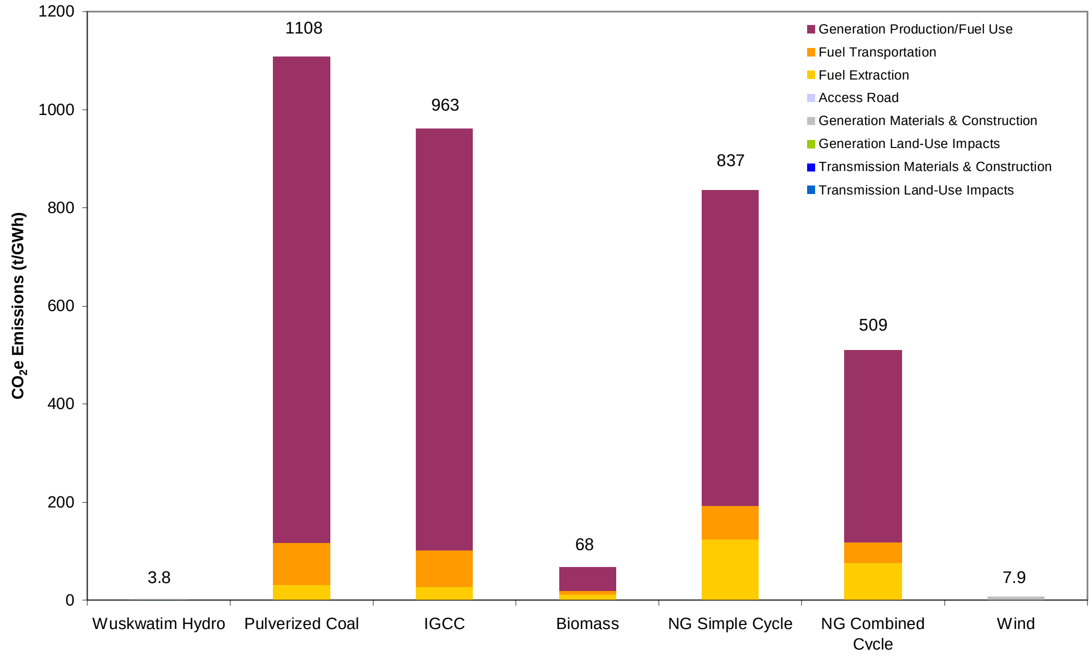


Figure 2.4-1: Lifecycle GHG Emissions (Pembina Institute 2003).

Table 2.4-1: Lifecycle GHG Emissions (tCO_{2e}/GWh)
(based on Pembina Institute 2003)

Electricity Supply Option	GENERATION					OTHER			Total
	Construction & Materials	Land-Use Change GHG Impacts	Fuel Extraction	Fuel Transportation	Electricity Production Fuel Use	Access Road	Transmission Materials & Construction	Transmission Land-Use Impacts	
Wuskwatim Hydro	1.56	0.39	0	0	0.20	0.41	0.18	1.01	**3.8**
Pulverized Coal	0.32	-	31	85	992	-	-	-	**1,108**
IGCC	0.32	-	27	75	860	-	-	-	**963**
Biomass	0.29	-	11.5	8.2	48	-	-	-	**68**
NG Simple Cycle	0.18	-	124	68	644	-	-	-	**837**
NG Combined Cycle	0.18	-	76	42	392	-	-	-	**509**
Wind	7.70	-	0	0	0.1	-	-	-	**7.9**

sediments as sinks and the elimination of peatlands as methane sources. Since reservoir emissions only account for a very small portion of a very small total lifecycle-emission estimate for the Wuskwatim Project, even with all these imbedded assumptions that lead to an overestimation of the potential impacts, reservoir emissions are not a significant concern.

From a GHG perspective, it is clear that it would be very difficult to identify an alternative form of generation with lower emissions than the Wuskwatim Project. The Wuskwatim Project will deliver significant benefits in terms of reducing global GHG emissions. Electricity production at the Wuskwatim Project will offset similar generation from coal and natural gas (predominantly outside of Manitoba). The resulting net global emission reductions are more than 760,000 tonnes of CO_{2e} per year even if a conservative assumption is made that the Wuskwatim Project only displaces the less GHG intensive combined cycle natural gas generation at 500 t CO_2 / GWh (509 t / GWh - 3.8 t / GWh).

Carbon Stock Summary

As indicated in the previous section, when the GHG implications of carbon-stock changes associated with the Wuskwatim Project are considered in the context of the GHG implications of other resources, the Wuskwatim Project's implications are very small. Table 2.4-2 summarizes the estimated changes in biomass carbon stocks for the generating station, roads and borrow pits (Plus4 Consulting and Agriculture & Agri Food Canada Research Branch, 2003).

Several broad land-cover types were used that best suit the assessment of carbon-stock changes based on the type and detail of information available regarding carbon stocks in biomass and in soils. These land-cover types are derived from the Manitoba Forestry Resource Inventory (FRI) data.

Project-specific activities associated with clearing will affect carbon stocks in the Project area. For terrestrial land-cover types such as rocks, exposed mineral soil and water, little if any alteration will occur, and therefore these cover types are considered stable relative to carbon stocks and proposed Project activities (i.e., no effects on carbon stocks will result). For more productive areas, natural and enhanced post-Project recovery will regenerate significant biomass carbon stocks. The level of disturbance and productivity of specific areas will affect the amount of time required to regenerate biomass stocks. The perspective taken here for carbon-stock analysis is a long-term perspective over the assumed 100-year life of the Project.

This carbon-stock analysis tends to overestimate the implications for biomass (i.e., assumes that all biomass carbon is lost). It does not account for possible timber salvage and utilization or conversion of biomass carbon to the dead organic matter (DOM) and soil organic carbon (SOC) pools.

Table 2.4-2: Wuskwatim Project Carbon-Stock Summary

(based on Plus4 Consulting and Agriculture & Agri-Food Canada Research Branch 2003)

	Pre-Project			Post-Project			
Land Cover Type	Affected Area (ha)	Biomass Carbon (t C/ha)	Biomass Carbon Stocks(t C)	Areas with Significant Long-term Biomass (ha)	Biomass Carbon (t C/ha)	Biomass Carbon Stocks (t C)	**Net Longterm Impact on Biomass Stocks C (t)**
GS Footprint							
Prod. Forest	126.0	55.6	7006	70.0	55.6	3892	3114
Non-prod. Land	14.0	8.0	112	na	na	0	112
Other	2.1	0.0	0	na	na	0	0
Sub-total	142.1	63.6	7118	70.0	55.6	3892	**3226**
Flooded Area							
Prod. Forest	33.5	55.6	1863	na	na	0	1863
Non-prod. Land	5.1	8.0	41	na	na	0	41
Sub-total	38.6	63.6	1903	na	na	0	**1903**
Access Roads							
Prod. Forest	310.6	55.6	17269	310.6	0	0	17269
Non-prod. Land	150.6	8.0	1205	150.6	0	0	1205
Other	21	0.0	0	0	0	0	0
Sub-total	482.2	63.6	18474	461.2	0	0	**18474**
Borrow Pits							
Prod. Forest	43.0	55.6	2391	23.0	55.6	1279	1112
Non-prod. Land	13.8	8.0	110	13.8	8	110.4	0
Other	5.7	0.0	0	5.7	0	0	0
Sub-total	62.5	63.6	2501	42.5	63.6	1389	**1112**
T-Line Project							
Prod. Forest	1337.4	52.5	70214	1332.9	8	10663	59550
Non-prod. Land	1161.2	8.0	9290	1161.2	8	9289.6	0
Other	287.7	0.0	0	287.7	0	0	0
Sub-total	2786.3	60.5	79503	2781.8	16	19953	**59550**
Wuskwatim Project Grand Total	**3511.7**	**314.9**	**109499**	**3355.5**	**135.2**	**25234**	**84265**

Other Emissions

While specific studies have not been undertaken for the Wuskwatim Project, other studies are available such as the International Energy Agency report (May 2000), which indicate that hydropower is virtually free of NO_X and SO_2 emissions on a lifecycle basis. Accordingly, similar to GHG, the Project offers significant global reductions in other, non-GHG, emissions such as NO_X, SO_2.

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APPENDIX A2.1

PEMBINA INSTITUTE FOR APPROPRIATE DEVELOPMENT REPORT (2003):

"Life Cycle Evaluation of GHG Emissions and Land Change Related to Selected Power Generation Options in Manitoba"

Life Cycle Evaluation of GHG Emissions and Land Change Related to Selected Power Generation Options in Manitoba

February 25, 2003

Project: 256-001

Prepared by:
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Jaisel Vadgama

Pembina Institute
for Appropriate Development

About the Pembina Institute

The Pembina Institute is an independent, citizen-based organization involved in environmental education, research, public policy development, and corporate environmental management services. Its mandate is to research, develop, and promote policies and programs that lead to environmental protection, resource conservation, and environmentally sound and sustainable resource management. Incorporated in 1985, the Institute's main office is in Drayton Valley, Alberta, with additional offices in Calgary and Ottawa, and research associates in Edmonton, Toronto, Saskatoon, Vancouver, and other locations across Canada. The Institute's mission is to implement holistic and practical solutions for a sustainable world.

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Disclaimer

The Pembina Institute was engaged by Manitoba Hydro to complete a streamlined life cycle analysis of the selected energy supply options discussed in this paper. The analysis is limited to an assessment of greenhouse gases and land change only and should not be considered a comprehensive environmental or social analysis of the options evaluated.

Seven options were considered: a hydroelectric generating facility (the Wuskwatim Generating Station and Transmission Project), proposed by Manitoba Hydro, as well as six hypothetical generation projects involving different fuels. Factual information on the Wuskwatim project was provided by Manitoba Hydro, as were all major assumptions associated with the hypothetical options evaluated.

Although conducting a life cycle analysis improves understanding of the environmental considerations associated with different energy supply options, it cannot in any manner be construed as an endorsement by the Pembina Institute of any one of these options.

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Tables

1.0 Introduction

The Pembina Institute was engaged by Manitoba Hydro to provide an assessment of the greenhouse gas (GHG) emissions and land changes associated with the proposed Wuskwatim Hydro project and six other options for electricity generation. Factual information and data have been used for the Wuskwatim analysis, while the remaining analyses are based on hypothetical parameters that are considered to be realistic. Each option is considered to be a prominent alternative to the Wuskwatim Hydro project for near-term power generation.

All seven options evaluated in this study are described in outline in Table 1.1. A detailed exposition of the operating parameters and assumptions used in analyzing the impacts of each system is provided in the appendices to this document.

The methodology used in the analysis is based on the principles of life cycle value assessment (LCVA) – a tool that integrates environmental and social considerations into decision-making processes. LCVA offers two key advantages: (i) a system for including upstream and downstream impacts in project thinking, and (ii) a system for identifying and responding to key environmental and social factors at the project design phase. The general LCVA methodology is presented in section 1.1 for reference.

This evaluation for Manitoba Hydro only draws on a subset of the full LCVA toolkit. Upstream and downstream impacts are incorporated in the evaluation, however the study is limited to a quantitative assessment of greenhouse gas emissions and land change. Emissions and land impacts are reported without being placed in the context of either existing emission profiles or ecological sensitivities for given geographical regions. No design improvement opportunities are addressed. A more detailed explanation of the methodology and limitations is provided in section 1.2.

Finally, it should be highlighted that this analysis does not evaluate demand-side management (DSM) strategies as an alternative to new power generation infrastructure. DSM activities must play an integral role in any comprehensive plan for energy provision and should be considered alongside the options studied in this report.

1.1 Principles of Life Cycle Value Assessment Methodology

A complete life cycle value assessment (LCVA) involves six distinct steps: goal definition, scoping, inventory assessment, impact analysis, design improvement, and reporting. These steps are laid out in general terms below. Section 1.2 describes the steps which have been included in this life cycle evaluation of electricity supply options.

An LCVA is normally used to inform a particular decision, such as the development of a new project. The **goal definition** lays out the options being considered as well as the key questions that will be answered about each option.

Scoping consists of sub-dividing each option, or system, into individual activities that occur during planning, production, use and retirement phases of the life cycle. Each activity is called a unit process, and a preliminary assessment is made as to which unit processes may have significant environmental or social impacts.

The **inventory assessment** involves collecting data to quantify selected inputs and outputs of the unit processes in every system. These data are entered into a model which aggregates the information to provide net input and output information for each system.

The **impact analysis stage** involves assessing these input and output results in terms of their environmental, social and financial impacts. This step considers the relative change in total environmental loadings and the sensitivity of exposed areas, along with capital and operational costs.

Design improvement is a series of steps taken in tandem with the four main analysis stages. When undertaken systematically, a design improvement analysis ensures that a comprehensive and serious effort is made to find opportunities for reducing the financial, environmental and social impacts of process activities and material supply choices across the full life cycle.

Reporting involves presenting a synthesis and summary of the findings, along with conclusions and recommendations about the project decision being studied. The results are usually compiled in a report or presentation to decision-makers that are responsible for project approval.

1.2 Methodology Used in this Life Cycle Evaluation of Electricity Supply Options

This life cycle evaluation uses elements of the LCVA methodology, but provides an analysis of more limited scope. In particular, this evaluation does not include a thorough impact analysis or present any design improvement recommendations.

Instead, the goal definition restricts this study's focus to a quantitative assessment of greenhouse gas (GHG) emissions and land changed associated with the various electricity supply options. A complete scoping analysis has been conducted for each option, along with a full inventory assessment. However, only the direct GHG and land change results of this assessment are presented in the report. There is no comprehensive analysis of the environmental and social **impacts** of either factor.

A unique exception is the evaluation of the GHG emission impacts of land change. Terrestrial ecosystems are an important repository for organic carbon, and land changes may result in the net release of carbon to the atmosphere or the net sequestration of carbon from the atmosphere. In order to provide a more complete quantitative analysis of GHG emissions, it was deemed necessary to consider this particular environmental impact of land change.

Initial estimates suggested that in the Wuskwatim Hydro system, land-related GHG emissions would be roughly equal to emissions from other sources such as construction activities. Although there is significant uncertainty associated with quantifying carbon flows resulting from land change, these emissions were considered to be an indispensable component of the overall results. By contrast, GHG emissions due to land change were estimated to be less than 0.05 times the emissions from other sources in the remaining six systems. As a result, no land-related GHG emissions were included in the analysis due to the combination of high uncertainties and a limited expected effect on the final results. A full explanation of the assumptions regarding land-related GHG impacts is presented in Appendix 7.

In summary, this evaluation takes advantage of the life cycle perspective in calculating complete 'cradle to grave' estimates of GHG emissions and land change for each electricity supply option studied. It does not, however, consider the social and environmental impacts of these two quantities, except where the GHG emissions implications of land change are significant.

Table 1.1: Description of Electricity Supply Options Compared in the Study

Name of Electricity Supply Option	Capacity (MW)	Technology	Generating Facility Location	Fuel	Fuel Source	Requirement for New Transmission Infrastructure?	Operating Factor[1]	Project Life (years)	Lifetime Generation (GWh)	Trans-mission Losses	Lifetime Delivered Power (GWh)
Wuskwatim Hydro	200	Hydroelectric generating station	Taskinigup Falls	n/a	n/a	Yes[2]	0.87	100	152,400	10%	137,200
Pulverized Coal	400	Pulverized coal boiler + steam turbine	Brandon	Sub-bituminous coal	Powder River Basin, Montana	No	0.85	30	89,400	5%	84,900
IGCC	570	Coal-fed Integrated Gasification Combined Cycle system	Brandon	Sub-bituminous coal	Powder River Basin, Montana	No	0.85	30	127,300	5%	120,900
Biomass[3]	25	Flax straw boiler + steam turbine	Southwest Manitoba	Flax straw	Farms in Southwest. Manitoba	No[4]	0.95	30	6,200	5%	5,900
Natural Gas (NG) Simple Cycle	250	Two 125 MW gas turbines	Brandon	Natural gas	Alberta	No	0.95	30	62,400	5%	59,300
Natural Gas (NG) Combined Cycle	250	One 250 MW gas + steam combined cycle system	Brandon	Natural gas	Alberta	No	0.93	30	61,100	5%	58,000
Wind	50	Thirty 1.65 MW turbines	Southwest Manitoba	n/a	n/a	No[4]	0.35	30	4,600	5%	4,400

[1] 'Operating Factor' refers to the fraction of time during which a facility is available to generate electricity at 100% of total capacity (i.e. not restricted by maintenance or fuel supply limitations). In fact, many facilities may not be operated during the entire time that they are available. This would lead to a lower annual and lifetime electricity output than is shown in the table, and would tend to increase the life cycle emissions and land change calculated for 'one-time' activities (e.g. facility construction) where impacts are averaged over the project life cycle.
[2] The Wuskwatim Hydro proposal includes 300 km of new high-voltage transmission lines, connecting the generating station to the grid at Birchtree. The requirement for significant new transmission infrastructure is a result of the large capacity and remote location of the Wuskwatim facility.
[3] The *economic* viability of the biomass system is beyond the scope of this analysis. It is estimated that sufficient flax straw is produced in the province of Manitoba to fuel a 25 MW generating plant; however, it is not known whether (a) the opportunity costs of using flax straw for fuel production and (b) the actual costs of collecting and transporting the straw would fall within reasonable bounds.
[4] No specific site has been designated for the biomass and wind generating facilities. However, for this study, Manitoba Hydro has limited the set of possible locations to within 10 km of existing transmission lines. Thus, any additional transmission infrastructure required for these alternatives may be considered negligible.

2.0 Comparing Electrical Generation Systems

This analysis estimates the extent of GHG emissions and land change *that would be caused by producing 1 GWh of delivered electricity*[1] under each of the seven generation scenarios. Impacts are reported per GWh to facilitate comparison between systems which have different total instantaneous outputs of electricity (capacities), different average annual energy production and different project lifespans.

Although this type of analysis provides important insights, there are many limitations. In particular, it is important to note that a GWh of electricity is not equivalent in each system, since it cannot be generated under the same time and load specifications in each case. It is also critical to note that each electricity supply option *will not* generate an equivalent amount of electricity and that the options are not being considered as direct substitutes for one another.

Some of the operating factors that distinguish the various options are:

Capacity: The peak capacity of each option is different. For example, the wind option has a 50 MW peak output, while the pulverized coal option has a 400 MW peak output.

Dispatchability: With certain options, such as pulverized coal, a lengthy start-up period is required before the plant operates at full capacity. Thus, the system cannot be brought on-line and off-line "on demand," and is instead likely to be kept running continuously. In the wind option, generation levels depend on airflow speeds, which change throughout the day and cannot be controlled. By contrast, the hydropower and natural gas combustion technologies offer quick start-up times and are more flexible for supplying varying demands.

Fuel availability and stability: The certainty and reliability of fuel supply is different for each option. For instance, the power that can be generated by the Wuskwatim Hydro facility may vary from year to year, depending on annual rainfall. While combustion fuels are almost always available, their prices can vary significantly. Natural gas prices, for example, change continually, and have been relatively volatile in recent years. The price of coal, by contrast, has tended to be stable for many years.

Lifespan: The Wuskwatim Hydro project has an estimated lifespan of 100 years, while the other options have estimated lifespans of approximately 30 years.

[1] Delivered electricity refers to the amount of electricity that is supplied to consumers at their point of connection to the grid. This number is lower than the amount of electricity produced at generating plants due to losses during transmission. Assumptions regarding transmission losses are given in Table 1.1.

3.0 Life Cycle Greenhouse Gas Emissions

Emissions resulting from human activities, particularly the burning of fossil fuels, are increasing the atmospheric concentrations of several greenhouse gases (GHGs), notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This process is enhancing the greenhouse effect, contributing to an overall warming of the Earth's surface.[1] In this analysis, the quantity of CO_2, CH_4, and N_2O emissions expected for each electricity supply option was estimated, and is reported in terms of CO_2 equivalents, or CO_2e.[2]

Sulphur hexafluoride (SF_6) is another, especially potent, greenhouse gas associated with electricity generation. In particular, SF_6 is used as an insulator in transformer equipment, and is currently deployed at several Manitoba Hydro facilities. However, expected emissions of SF_6 arising from the electricity options under study are low relative to emissions of CO_2, CH_4, and N_2O[3], and are not expected to vary significantly between the options. Thus, SF_6 emissions were not included as a quantitative component in the analysis.

3.1 Results

Table 3.1 presents the total greenhouse gas emissions associated with each electricity supply option considered, as well as the distribution of emissions across the various life cycle stages. Figure 3.1 presents these results graphically.

Life cycle greenhouse gas emissions were found to be highest for the two coal-fired options: 1,108 and 963 t CO_2e/GWh for the pulverized coal and IGCC cases, respectively. Emissions are lower for natural gas–fired generation, at 837 and 509 t CO_2e/GWh for the simple cycle and combined cycle cases, respectively. The lower emissions for the combined cycle option reflect the greater efficiency of this technology, and, in particular, the large difference between simple cycle and combined cycle efficiencies assumed in this study (see Table A1.1 for a list of assumed efficiencies). In all four cases, the operation stage of the life cycle accounts for the majority of emissions. Fuel combustion (electricity generation) is the largest contributor to emissions in this stage, although fuel extraction and fuel transportation are also significant. By contrast, emissions during the construction stage of the life cycle are insignificant, accounting for less than 0.05% of total emissions when normalized over the project lifespan in each case.

Emissions from the biomass option are an order of magnitude lower than in the fossil fuel options: 68 t CO_2e/GWh over the project life cycle. Again, the operation stage accounts for the majority of emissions, and fuel combustion (electricity generation) is the largest contributor to emissions in this stage. CO_2 generated during the combustion of biomass is *not* counted in the combustion emission totals, since the CO_2 released is assumed to be equivalent to the amount of CO_2 sequestered by photosynthesis when the biomass was grown. Instead, the fuel combustion emissions of 48 t CO_2e/GWh are comprised entirely of CH_4 and N_2O.

Life cycle emissions in the Wuskwatim Hydro and wind options are a further order of magnitude lower than the biomass option, and are the lowest among the alternatives considered in this study. Emissions are

[1] *Summary for Policy Makers: A Report of Working Group 1of the International Panel on Climate Change.* Geneva: IPCC, 2001.

[2] CH_4 and N_2O have 100-year global warming factors of 21 and 310 times that of CO_2, respectively. The combined effect of these emissions is presented as an equivalent of CO_2, or CO_2e.

[3] "VCR 2002 Update, Electricity and Natural Gas Operations." Manitoba Hydro. Electricity generation for 2001 was 32,000 GWh. Total SF_6 emissions were 5 kilotonnes for the same year. This equates to 0.156 t CO_2e/GWh and is considered to be relatively insignificant. SF_6 has a global warming capacity of 23,900 that of CO_2.

3.8 and 7.9 t CO_2e/GWh for the Wuskwatim Hydro and wind cases, respectively. In contrast to all of the other systems, the majority of emissions for hydroelectricity and wind are associated with the construction stage of the life cycle.

Results for the Wuskwatim Hydro option are subdivided further in Table 3.2 and Figure 3.2. Emissions are broken down into the four parts of the construction stage: building material manufacturing, building material transportation, on-site construction activities (equipment operation) and forest clearing. The analysis also separates emissions associated with building the dam and generating facility from emissions associated with building transmission lines. Significant new transmission infrastructure is an integral requirement for the Wuskwatim project because of the relatively large capacity (200 MW) of the facility and the remote location of the generating station. Under the assumptions used in this study, none of the other electricity supply options meets these dual criteria of large capacity and remote location, and thus no other project is said to require significant new transmission infrastructure.

The greatest quantity of GHG emissions in the Wuskwatim case is associated with forest clearing: 1.60 t CO_2e / GWh. The extent of GHG production due to forest clearing is difficult to predict, and depends on a multitude of factors such as the method of clearing and the fate of cleared vegetation (e.g. incineration, decay, or re-use in lumber products). Appendix 7 lists the factors assumed in this study, and provides a qualitative sensitivity analysis of the assumptions used.

The remaining emissions sources during the construction phase are building material manufacturing – 1.19 t CO_2e / GWh, on-site construction activities (fuel combustion for equipment operation) – 0.33 t CO_2e / GWh, and building material transportation – 0.08 t CO_2e / GWh.

During facility operation, two sources of GHG emissions are significant in the Wuskwatim Hydro option: manufacturing and transport of replacement parts – 0.20 t CO_2e / GWh, and CO_2 and CH_4 emissions from the dam reservoir – 0.20 t CO_2e / GWh. Reservoir emissions are highly uncertain, and depend heavily on the particular morphology and geography of the flooded area. Assumptions used in calculating the reported emissions figures are presented in Appendix 7.

Table 3.1 Life Cycle GHG Emissions per Unit of Delivered Power for Each Electricity Supply Option

Electricity Supply Option	Life Cycle GHG Emissions per Unit of Delivered Power (t CO_2e/GWh)					Total Life Cycle GHG Emissions (kt CO_2e)				
	Construction[1]	Operation			Total	Construction[1]	Operation			Total
		Fuel Extraction	Fuel Transportation	Electricity Generation			Fuel Extraction	Fuel Transportation	Electricity Generation	
Wuskwatim Hydro	3.35	0	0	0.4	**3.8**	460	0	0	56	520
Pulverized Coal	0.32	31	85	992	**1,108**	27	2,600	7,220	84,200	94,100
IGCC	0.32	27	75	860	**963**	39	3,270	9,100	104,000	116,000
Biomass	0.29	11.5	8.2	48	**68**	1.7	68	48	280	400
NG Simple Cycle	0.18	124	68	644	**837**	11	7,370	4,050	38,200	49,600
NG Combined Cycle	0.18	76	42	392	**509**	11	4,390	2,410	22,740	29,600
Wind	7.7	0	0	0.1	**7.9**	34	0	0	0.5	34

Table 3.2 Breakdown of Life Cycle GHG Emissions for the Wuskwatim Hydro Option

Facility Component	Life Cycle GHG Emissions per Unit of Delivered Power (t CO_2e/GWh)					
	Construction				Operation	Total
	Building Material Manufacturing	Building Material Transportation	On-site Construction Activities (Equipment Operation)	Forest Clearing	Electricity Generation	
Generating Station	1.19	0.07	0.30	0.18	0.41[2]	2.15
Access Road	0	0	0[2]	0.41	0	0.41
Transmission Lines	0.14	0.01	0.03	1.01	0	1.19
Total	1.32	0.08	0.33	1.60	0.41	**3.8**

[1] Construction emissions cover: (i) construction material manufacturing, (ii) construction material transportation, and (iii) on-site construction activities (equipment operation). In the case of the Wuskwatim Hydro option, construction emissions also include (iv) carbon loss from tree clearing (to build the generating facility as well as transmission lines). Tree clearing is insignificant in all other systems.
[2] Electricity generation emissions in the Wuskwatim Hydro case are due to equipment replacement (0.20 t / GWh) and to reservoir carbon dioxide and methane emissions (0.20 t / GWh)
[3] Equipment operation emissions associated with building the access road are included in the Generating Station figure, 0.30 t / GWh.

Figure 3.1 Life Cycle GHG Emissions per Unit of Delivered Power for Each Electricity Supply Option

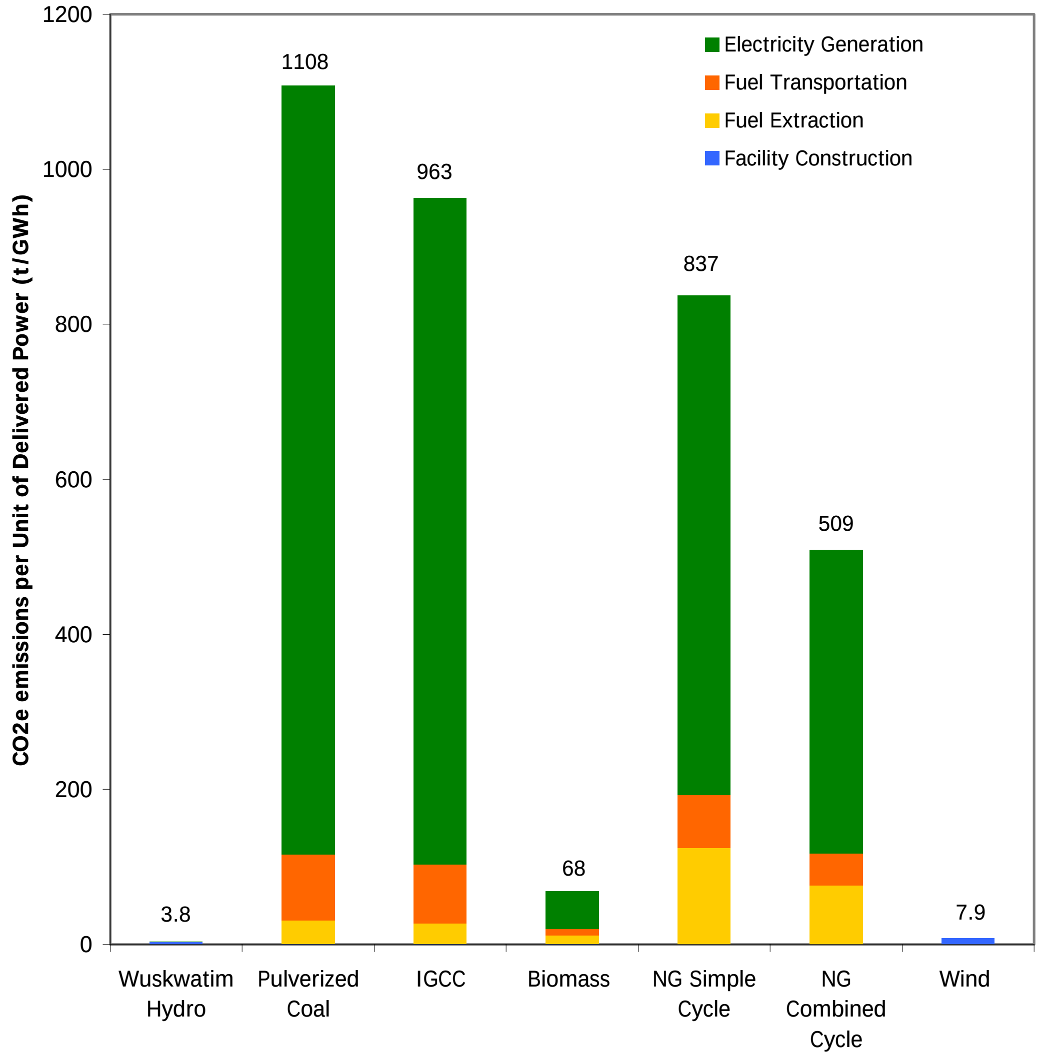
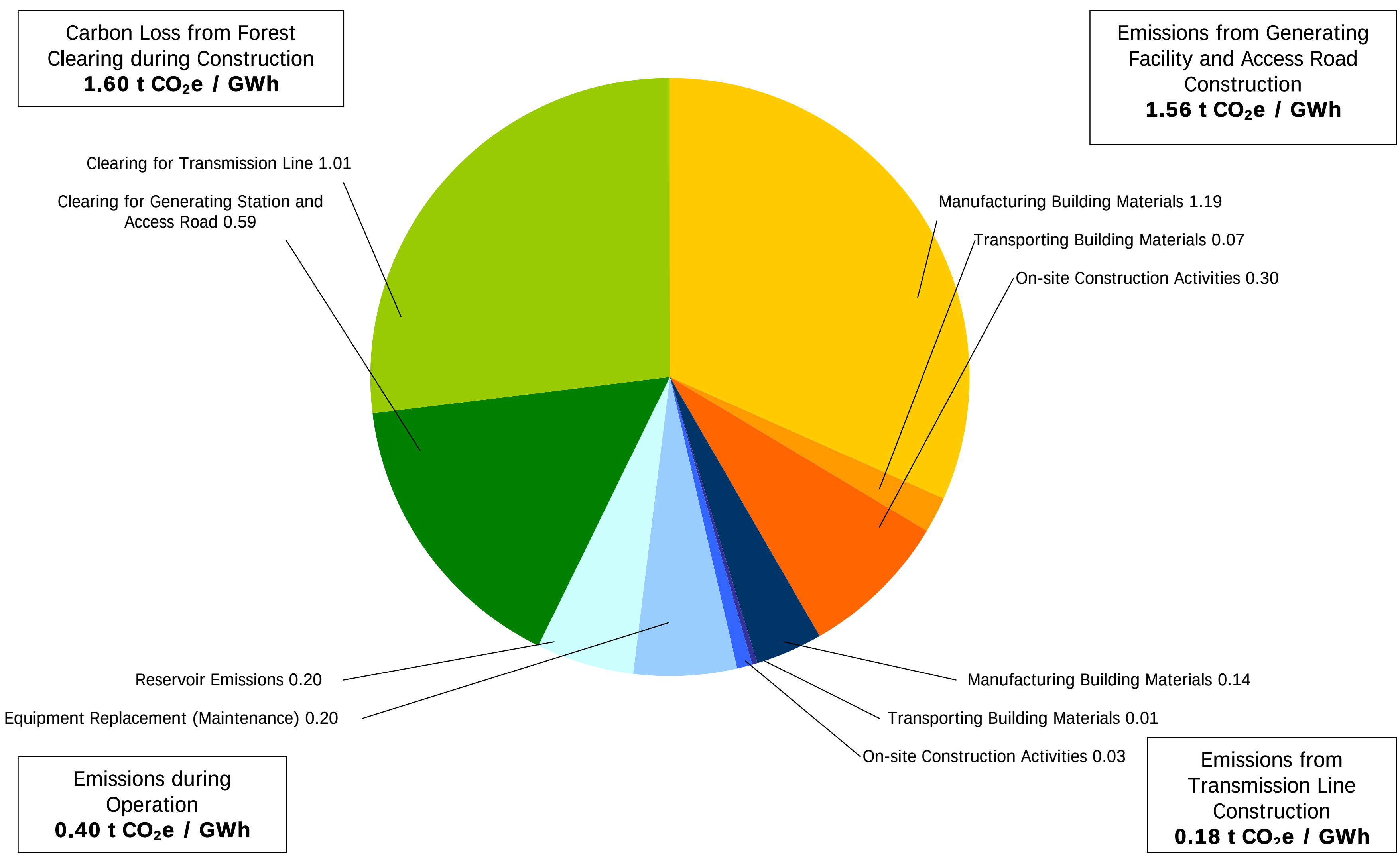


Figure 3.2 Breakdown of Life Cycle GHG Emissions per Unit of Delivered Power for the Wuskwatim Hydro Option (t CO_2e / GWh)



4.0 Life Cycle Land Change

Land impacts may include effects on existing land uses, on the suitability of land for future use, on the environmental quality of land, and on wildlife habitat, etc. However, the varied nature of land and the nebulous concept of "impacts" makes the quantification of land impacts inherently difficult. This analysis focuses on one aspect of land impact – namely, land change – to give a preliminary indication of how each of the seven electricity options would affect land. For each system, the analysis estimates land change as the total area of land whose surface characteristics would be altered at any point during the project life cycle. Land change is reported both in hectares (ha) and in the normalized units of m^2/GWh of delivered electricity.

4.1 Results

Table 4.1 presents the land change associated with each electricity supply option considered in this study. The results are subdivided into construction-related and operation-related land change. Figure 4.1 presents these results graphically, indicating the type of land (e.g. forest, farmland) changed.

Construction-related activities include: (i) off-site manufacturing of building materials, (ii) building material transportation, and (iii) on-site construction activities including forest clearing. Off-site building material production is expected to have negligible land change effects. No new production infrastructure (e.g., new manufacturing facilities) is expected for any of the projects assessed, and a proportional allocation of land change caused by *existing* production infrastructure is generally insignificant.[1] Transportation of building materials is expected to cause negligible land change for the same reasons: no new transportation infrastructure is expected, and a proportional allocation of land change caused by *existing* infrastructure is insignificant. Thus, on-site facility construction accounts for the majority of construction-related land change.

Operation-related activities include: (i) fuel extraction, (ii) fuel transportation, and (iii) on-site electricity generation. Fuel transportation is expected to cause minimal land change for the same reasons as building material transportation, outlined above. On-site power generation makes use of facilities built during construction and affects no more land than has already been changed. Thus, fuel extraction accounts for the majority of land change in the operation stage of the project life cycles.

Life cycle land change is found to be greatest for the two natural gas–fired options, at 1,070 m^2/GWh and 650 m^2/GWh for the simple cycle and combined cycle options, respectively. The impact occurs almost entirely (more than 99.9%) in the fuel extraction step, during natural gas exploration and well development. Land change is lower for the Wuskwatim Hydro option, at 200 m^2/GWh. In this case, however, all of the land change occurs during the on-site construction step of the life cycle. Of the total, 130 m^2/GWh (65%) of land change is caused by construction of transmission lines and transmission right-of-ways, 65 m^2/GWh (33%) is caused by construction of the generating station and an access road, and 3 m^2/GWh (2%) is caused by flooding.

Land change caused by the two coal-fired options is an order of magnitude lower than the natural gas and Wuskwatim Hydro options. The altered area is 31 m^2/GWh and 28 m^2/GWh for the pulverized coal and IGCC options, respectively. Most of the land change (about 99%) occurs during the fuel extraction step – surface mining in the Powder River Basin of Montana.

[1] Existing facilities supply numerous customers, or even entire markets, and since the required project materials are very small relative to a given facility's total output, each project is only responsible for a small fraction of that facility's impacts.

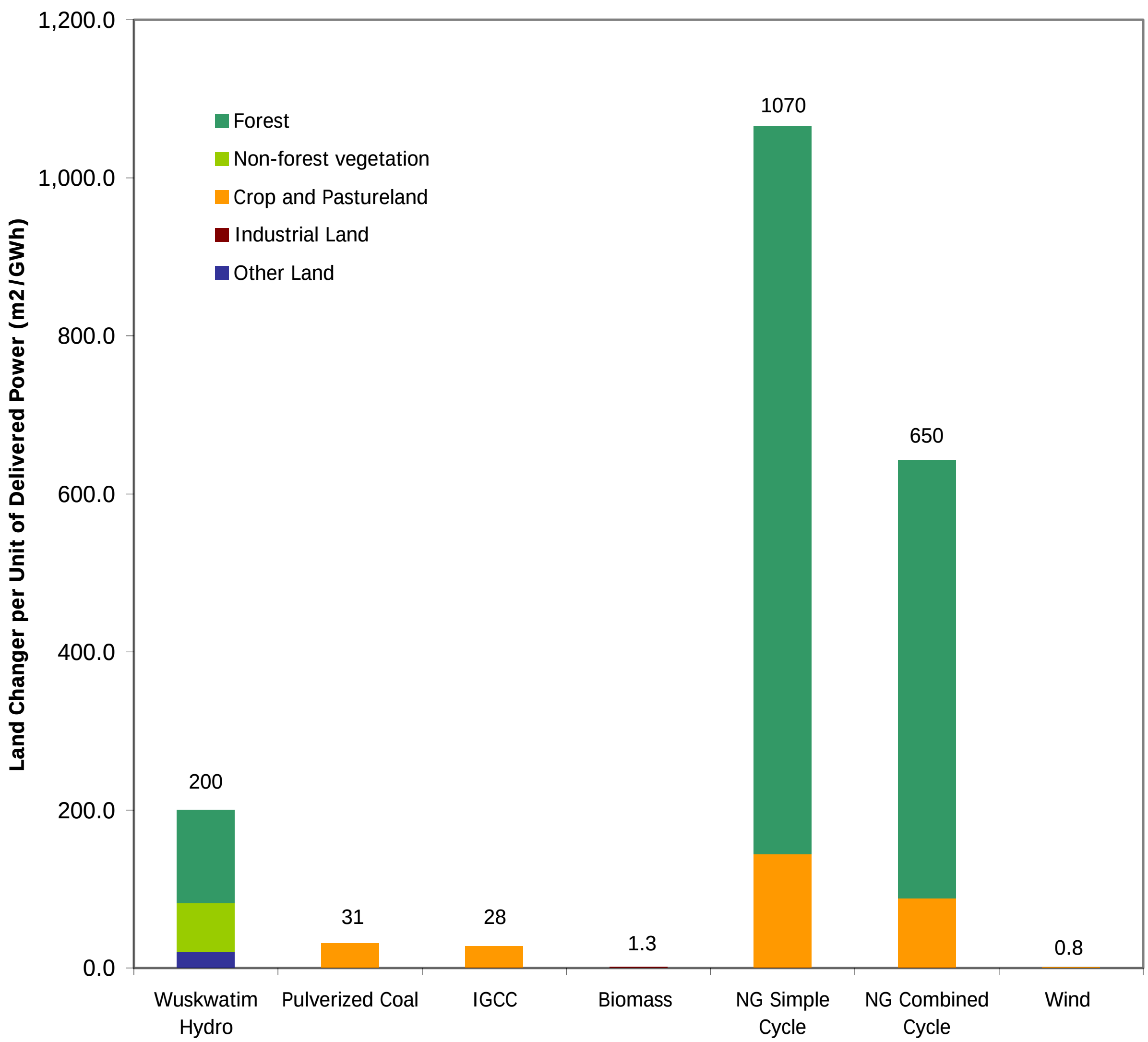
Life cycle land change is lowest for the biomass and wind options, a further order of magnitude lower than the two coal alternatives. The altered area is 1.3 m^2/GWh and 0.8 m^2/GWh for the biomass and wind options, respectively. In both cases, land change is entirely due to construction of the generating facility. However, although there is no land *change* caused by fuel extraction in the biomass system, a large area of farmland would be required to supply adequate quantities of fuel for the boiler. This area is two orders of magnitude larger than even the natural gas simple cycle land change result, at 235,000 m^2/GWh.

Table 4.1 Life Cycle Land Change for Each Electricity Supply Option

Electricity Supply Option	CONSTRUCTION-RELATED					OPERATION-RELATED					TOTAL	
	Activity	Area of Land Change (ha)	Area of Land Change per Unit of Power Delivered (m^2/GWh)	Original Land Type	Changed Land Type	Activity	Area of Land Change (ha)	Area of Land Change per Unit of Power Delivered (m^2/GWh)	Original Land Type	Changed Land Type	Area of Land Change (ha)	Area of Land Change per Unit of Power Delivered (m^2/GWh)
Wuskwatim Hydro	Build Generating Facility	84	6.1	Forest	Cleared withGeneration Infrastructure			n/a			2,720	**200**
		330	24	Forest	Temporarily Disturbed and/or Cleared During Construction							
	Build Access Road	324	24	Forest	Cleared with Access Road							
		158	11.5	Non-forest Vegetation	Cleared with Access Road							
	Flood Forebay Area	34	2.5	Forest	Cleared, then flooded							
		5	0.4	Peat Bogs	Flooded							
	Build Transmission Lines	850	62	Forest	Cleared withTransmission Infrastructure							
		680	50	Non-forest Vegetation	Cleared with Transmission Infrastructure							
		260	20	Other	Cleared with Transmission Infrastructure							
Pulverized Coal	Build Generating Facility	4	0.5	Vacant Industrial Land	Generation Infrastructure	Mine Coal	263	31	Crop and Pasture Land	Coal Pits, Mine Infrastructure	270	**31**
IGCC	Build Generating Facility	4	0.3	Vacant Industrial Land	Generation Infrastructure	Mine Coal	332	27	Crop and Pasture Land	Coal Pits, Mine Infrastructure	340	**28**
Biomass	Build Generating Facility	0.8	1.3	Crop and Pasture Land	Generation Infrastructure	Grow and Harvest Flax Straw	0[1]	0[1]	Crop Land	Crop Land	0.8	**1.3**
NG Simple Cycle	Build Generating Facility	2	0.3	Vacant Industrial Land	Generation Infrastructure	Extract NG	5,470	840	Forest	Cleared Right-of-ways, NG Extraction Infrastructure	6,320	**1,070**
							850	230	Crop and Pasture Land	NG Extraction Infrastructure		
NG Combined Cycle	Build Generating Facility	2	0.3	Vacant Industrial Land	Generation Infrastructure	Extract NG	3,250	530	Forest	Cleared Right-of-ways, NG Extraction Infrastructure	3,760	**650**
							510	120	Crop and Pasture Land	NG Extraction Infrastructure		
Wind	Build Generating Facility	0.3	0.8	Crop and Pasture Land	Generation Infrastructure			n/a			0.3	**0.8**

[1] Flax straw fuel would be supplied by existing flax farming operations in the biomass system. Hence, the area of *changed* land associated with this fuel extraction step is zero: the farmland would continue to be used as farmland. However, a very large area of existing farmland would be required to supply adequate fuel: 139,000 ha in total, or roughly 235,000 m^2/GWh of electricity.

Figure 4.1 Life Cycle Land Change per Unit of Delivered Power for Each Electricity Supply Option



4.2 Qualitative Analysis of Land Change Patterns

In trying to reach a more complete understanding of the overall land impacts of each project, many additional factors need to be studied alongside the area of land altered. For instance, what were the land characteristics before any changes took place? How would the altered land be spatially distributed – would the impact be concentrated in a small area, or spread out in patches over a larger area? What would the effect on surrounding land be? On wildlife? On nearby communities? Would the alteration be permanent? If not, would the land be restored to its original state? How long would restoration take?

In short, several qualitative aspects of a given land change need to be considered, including the exact nature of the affected land and its ecosystem, the time scale of change, and indirect or cumulative effects of the impact. Although addressing these issues comprehensively is beyond the scope of this report, two qualitative analyses have been included to begin a discussion on these topics. Table 4.1 above provides some background on the characteristics of affected land, both before and after alteration. Figures 4.2 and 4.3 on the following pages illustrate patterns of land impact for each system – i.e., how changed areas would be situated within surrounding land. From the illustrations, it is clear that altered land is more concentrated in some systems and more fragmented in others. In particular, land change due to fuel extraction in the natural gas systems is spread out over large areas of forest and farmland in Alberta. These areas, estimated at 25,000 m^2/GWh and 15,000 m^2/GWh for the natural gas simple cycle and combined cycle options, respectively, are far greater than direct land change areas calculated for any of the other systems studied.

Figure 4.2 Construction-Related Land Change – Illustration of Impact Patterns

The schematic illustrations on this page depict how changed land is situated within surrounding land types. Changed land is represented in all cases as white, with a uniform scale across illustrations. Therefore, the size of white spaces in each illustration can be compared across systems to determine the relative magnitudes of land change in each case.

In this figure, each mm^2 of white space represents 1.3 m^2/GWh of changed land. (Note: this is a different scale from Figure 4.3.) The amount of surrounding land, however, is only **approximately** scaled on this figure (on a per GWh basis) to give a sense of the area over which land changes may be spread. The areas of surrounding land have **not** been analytically quantified.

Wuskwatim Hydro

Changed land totals 200 m^2/GWh, and is comprised of the following:

- (i) Land flooded to create a reservoir for the generating station (3 m^2/GWh)
- (ii) Land cleared for the generating station, or disturbed during construction (30 m^2/GWh)
- (iii) Land cleared for the access road (35 m^2/GWh)
- (iv) Land cleared for transmission line right-of-ways (130 m^2/GWh)

(i) The generating station would require some flooding of the banks of the Burntwood River, upstream of Taskinigup Falls. The changed land (white) is largely forest that would be cleared and then flooded, and is depicted as two narrow strips on either side of a river (blue), at the top of the illustration.

(ii) Land affected by the Wuskwatim generating station and borrow pits would be largely forest land. The land would be concentrated in two or three areas near Taskinigup Falls, and is depicted as a white block in the illustration. The borrow pits and construction areas (24 m^2/GWh) would be restored and reforested when construction is complete. The generating site (6 m^2/GWh) would remain cleared throughout the 100-year project life.

(iii), (iv) The access road and transmission lines would require long, narrow right-of-ways: roughly 100 m by 48 km for the road, and 60 m by 300 km for the transmission lines. The right-of-ways would pass through a mixture of forest land (dark green) and non-forest vegetation (light green), and would remain largely cleared throughout the 100-year project life. Some borrow material for the roadbed would be obtained from the right-of-way clearing. For simplicity, the two right-of-ways are combined on the diagram. Additionally, the two land types (forest and non-forest vegetation) are shown as distinct blocks, although, in reality, the land types would be interspersed.

Pulverized Coal

Changed land is simply the land used to build a generating facility. This is assumed to be a parcel of industrial land adjacent to the current Brandon generating complex, totaling 0.4 m^2/GWh. The site would be surrounded by other industrial park land.

IGCC

Changed land is simply the land used to build a generating facility. This is assumed to be a parcel of industrial land adjacent to the current Brandon generating complex, totaling 0.3 m^2/GWh. The site would be surrounded by other industrial park land.

Biomass

Changed land is simply the land used to build a generating facility. This is assumed to be a parcel of crop and pasture land in rural Southwest Manitoba, totaling 1.3 m^2/GWh. The site would be surrounded by other crop and pasture land

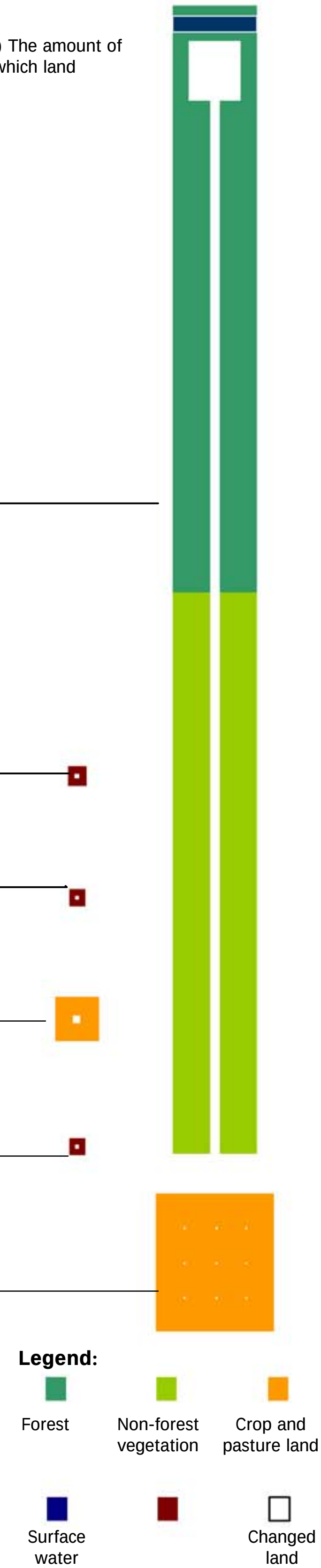
NG Simple Cycle & Combined Cycle

For both scenarios, changed land is simply the land used to build a generating facility. This is assumed to be a parcel of industrial land within the current Brandon generating complex, totaling 0.3 m^2/GWh. The site would be surrounded by other industrial park land.

Wind

Changed land (depicted as small white dots) totals 0.7 m^2/GWh and comprises the foundations for individual wind turbines. These would be spaced out across a much larger farm area, about 370 m^2/GWh for a typical rectangular grid arrangement of turbines, spaced 200 m apart.

Depending on the location of the wind farm, a new access road may also be needed. The road right-of-way would likely replace crop and pasture land. Assuming a 10 m width for the right-of-way, each km of road would cause a land type change equivalent to 2.3 m^2/GWh. This land change has not been included in the quantitative analysis, since the wind scenario does not specify a wind farm location or road length.



Scale: The white "changed land" square in the legend represents 10 m^2/Gwh.

Figure 4.3 Operation-Related Land Change – Illustration of Impact Patterns

The schematic illustrations on this page depict how changed land is situated within surrounding land types. Changed land is represented in all cases as white, with a uniform scale across illustrations. Therefore, the size of white spaces in each illustration can be compared across systems to determine the relative magnitudes of land change in each case. In this figure, each mm^2 of white space represents 7.5 m^2/GWh of changed land. (Note: This is a different scale from Figure 4.2.) The amount of surrounding land has been drawn to the same scale. An explanation of how surrounding land has been defined and quantified is given below for each system.

Legend:

Forest | Crop and pasture land | Changed land

Scale: The white "changed land" square in the legend represents 75 m^2/GWh.

Wuskwatim Hydro

There would be no land change associated with fuel extraction in the Wuskwatim Hydro proposal. Land change associated with constructing generating and transmission facilities is illustrated in Figure 4.2.

Pulverized Coal

Changed land (depicted as a white box) is comprised of coal pits and infrastructure concentrated in a few sections of a larger designated mine lease in the Powder River Basin of Montana. The mine lease that surrounds the changed land is grassland and pasture land (orange). For the mine considered in this study, Spring Creek Mine, the area of changed land would be 31 m^2/GWh. The area of the surrounding mine lease would be about 88 m^2/GWh.

IGCC

Like the pulverized coal system, changed land (depicted as a white box) in this case occurs within a larger mine lease. The mine lease that surrounds the changed land is grassland and pasture land (orange). For the mine considered in this study, the area of changed land would be 28 m^2/GWh. The area of the surrounding mine lease would be about 79 m^2/GWh.

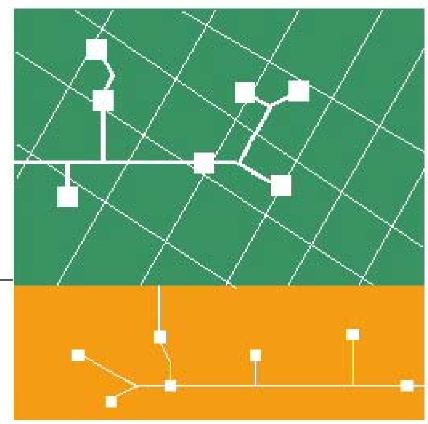
NG Simple Cycle

Changed land (white) totals 1,070 m^2/GWh and is associated with exploration for natural gas and well development in Alberta. Natural gas extraction occurs on both forest land (green) and crop and pasture land (orange) in the province.

In forest areas, trees are cleared for seismic surveys (thin diagonal lines), drilling pads (square blocks), and right-of-ways for access roads and gas collection pipes (thick lines). All cleared area is considered to be changed land. Forest begins to regrow on some of this land immediately (e.g., seismic lines), since clearing is only needed for a one-time exploration task. Other areas of land (e.g., around a well, collection pipe, or right-of-way) are kept cleared throughout the well's life (10 to 30 years), and trees are left to regrow only after this infrastructure is decommissioned.

In crop and pasture land areas, no clearing is necessary for exploration. Here, land change occurs only when farmland is cordoned off to make way for well-pads (square blocks) or roads and collection pipes (thick lines). This land change lasts at least as long as the infrastructure is in service.

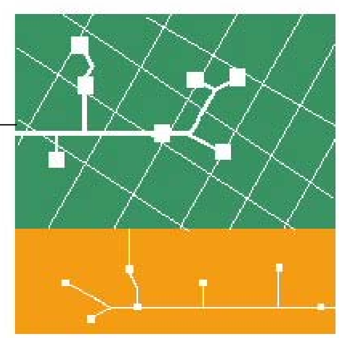
The pattern and density of clearing and infrastructure vary from region to region; a theoretical pattern is illustrated here as an example. On average, for natural gas originating in Alberta, about 80% of the gas would be produced from forest areas, and 20% from farm areas. Based on well productivity and typical infrastructure requirements in each region, this translates to about 840 m^2/GWh of changed land in forest areas, and 230 m^2/GWh of changed land in farm areas. Based on typical well densities for each region, the change due to forest wells would be spread out over about 16,300 m^2/GWh of forest, while the change due to farm area wells would be spread out over about 8,500 m^2/GWh of farmland.[1]



NG Combined Cycle

Impact patterns for the NG combined cycle scenario are equivalent to those in the NG simple cycle scenario, although total areas are smaller. Changed land (white) comprises about 530 m^2/GWh in forest areas and 120 m^2/GWh in farm areas. The change due to forest wells is spread over about 10,000 m^2/GWh of forest, while the change due to farm area wells is spread over about 5,200 m^2/GWh of farmland.[1]

[1] For a detailed calculation of land area changed during NG extraction, see Appendix, Section 7.



Biomass

Flax straw fuel would be supplied by existing flax farming operations in the biomass system. There would be no land **change** associated with this fuel extraction step – the farmland would continue to be used as farmland. However, a very large area would be involved: 139,000 ha in total, or roughly 235,000 m^2/GWh of electricity.

Wind

There would be no land change associated with fuel extraction in the wind system. Land change associated with constructing generating and transmission facilities is illustrated in Figure 4.2.

5.0 Conclusions

Seven prominent electricity supply options for the province of Manitoba have been compared on the basis of life cycle GHG emissions and land change per GWh of electricity delivered. These options include the proposed Wuskwatim Hydro generation and transmission project, as well as six hypothetical generation projects that use a variety of different fuels.

There are a number of key limitations to the analysis:
(i) a comparison of GHG emissions and land change per GWh delivered does not account for differences in generating system capacity and dispatchability, or in fuel availability and stability, which may influence the selection of generation technologies;
(ii) a quantitative assessment of GHG emissions and land change does not directly address the environmental and social implications of these factors, but rather provides a starting point for thinking about broader impacts;
(iii) a quantification GHG emissions which result from land change involves significant uncertainties, and has only been completed for the Wuskwatim Hydro option;
(iv) although demand-side management programs have not been included in the analysis, DSM options are often preferable to new generation capacity from a life cycle perspective.

Greenhouse gas emissions are found to be lowest for the Wuskwatim Hydro and wind options, at 3.8 t CO_2e/GWh and 7.9 t CO_2e/GWh, respectively. These emissions are more than two orders of magnitude lower than emissions expected from the fossil fuel–powered options, of which the pulverized coal option has the greatest emissions, at 1,108 t CO_2e/GWh.

The area of altered land is found to be lowest for the wind and biomass options, at 0.8 m^2/GWh and 1.3 m^2/GWh, respectively. (Note, however, that the biomass option requires the collection of agricultural residue from large areas of existing farmland to supply adequate fuel, amounting to about 235,000 m^2/GWh.) These land change results are more than two orders of magnitude lower than altered areas expected from the Wuskwatim Hydro option (200 m^2/GWh) or the natural gas simple cycle and combined cycle options (1,070 m^2/GWh and 650 m^2/GWh, respectively). For the two natural gas options, the altered land area is expected to be particularly fragmented and spread out over a large region, thus affecting an area even larger than reported in the land change totals.

Appendices

Appendix 1: Basic Operating Parameters for Each System

Table A1.1 Basic Operating Parameters for the Electricity Supply Proposals and Scenarios Under Analysis

Name of Electricity Supply Option	Capa-city (MW)	Technology	Operating Factor[a]	Project Life (years)	Lifetime Output (GWh)	Location	Fuel	Fuel Source	Heat Rate – HHV basis[b] (BTU/kWh)	Efficiency – HHV basis[b]	Requirement for New Transmission Infrastructure	Transmission Losses
Wuskwatim Hydro	200	Hydroelectric generating station	0.87	100	152,400	Taskinigup Falls	n/a	n/a	n/a	n/a	Yes	10 %
Pulverized Coal	400	Pulverized coal boiler + steam turbine	0.85	30	89,400	Brandon	Sub-bituminous Coal	Powder River Basin, Montana	9,294	36.7 %	No	5 %
IGCC	570	Coal-fed Integrated Gasification Combined Cycle system	0.85	30	127,300	Brandon	Sub-bituminous Coal	Powder River Basin, Montana	8,225	41.5 %	No	5 %
Biomass[c]	25[1]	Flax straw boiler + steam turbine	0.95	30	6,200	S.W. Manitoba	Flax Straw	Farms in S.W. Manitoba	13,600[2]	25.0 %[2]	No[d]	5 %
NG Simple Cycle	250	Two 125 MW gas turbines	0.95	30	62,400	Brandon	Natural Gas	Alberta	11,500	29.7 %	No	5 %
NG Combined Cycle	250	One 250 MW gas + steam combined cycle system	0.93	30	61,100	Brandon	Natural Gas	Alberta	7,000	48.8 %	No	5 %
Wind	50	Thirty 1.65 MW turbines	0.35	30	4,600	S.W. Manitoba	n/a	n/a	n/a	n/a	No[d]	5 %

Data Sources:

All parameter values provided by Manitoba Hydro, with the following exceptions:

[1] The capacity of a flax straw-fueled biomass facility is limited by the availability of flax straw in Manitoba. A capacity of 25 MW is close to the maximum capacity possible, given current straw supplies.

[2] Value chosen is typical for a biomass generating plant. Source: Wiltsee, G. *Lessons learned from existing Biomass Power Plants*. Golden, Colorado: National Renewable Energy Laboratory (NREL). 2000.

Additional Clarifications:

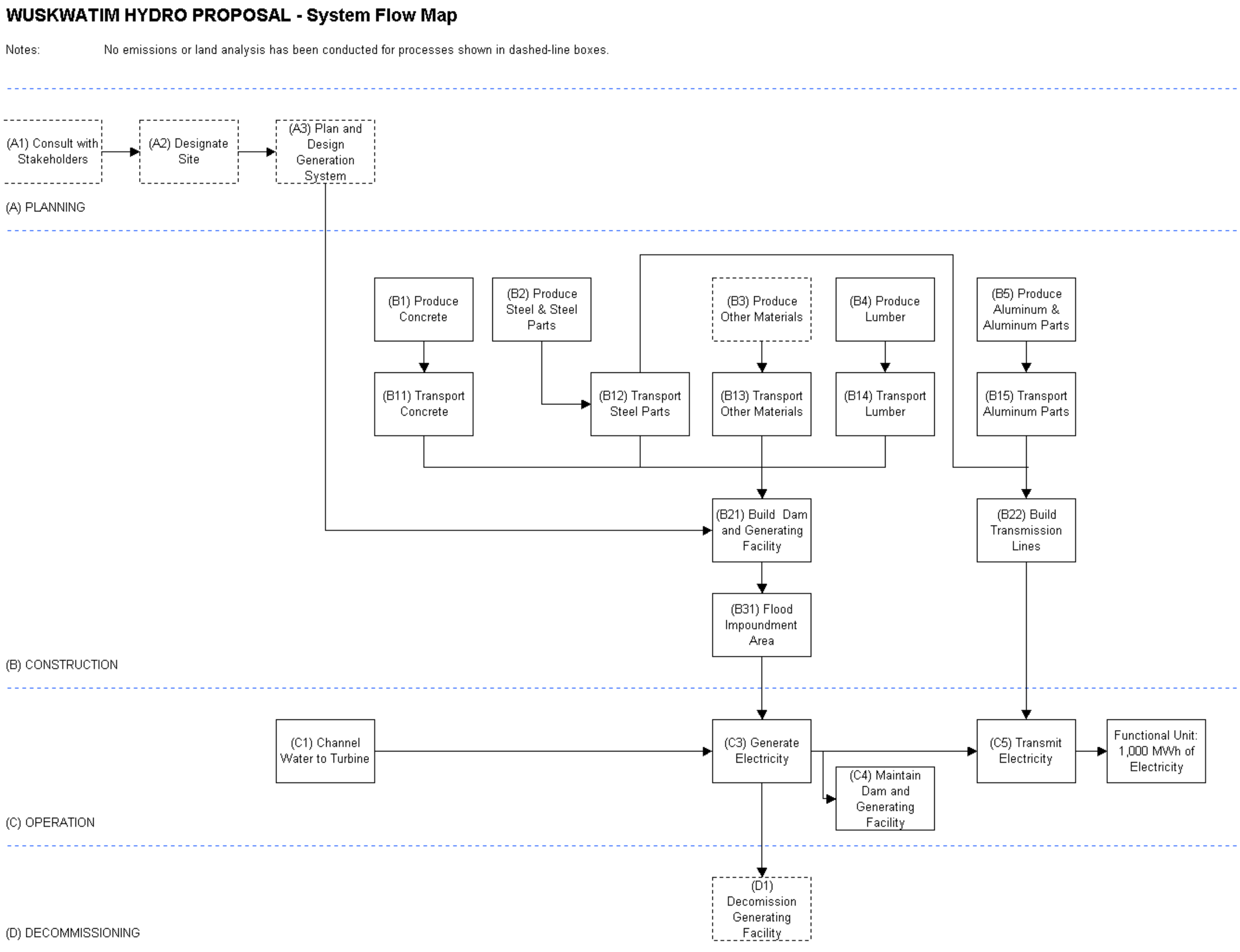
[a] "Operating factor" refers to the fraction of time during which the facility is able to generate electricity at 100% of total capacity. In the carbon-fueled options, an availability of less than 1 reflects operating limitations due to maintenance 'down-time'. In the Wind option, the relatively low availability factor reflects the fact that wind speeds are variable. In fact, many facilities may be operated for periods that shorter than the available limit. For instance, a Natural Gas Single Cycle plant may only be used to supply peak demand, and be run 30% rather than 95% of the time. If the availability factor is reduced, lifetime power production will also be reduced proportionally.

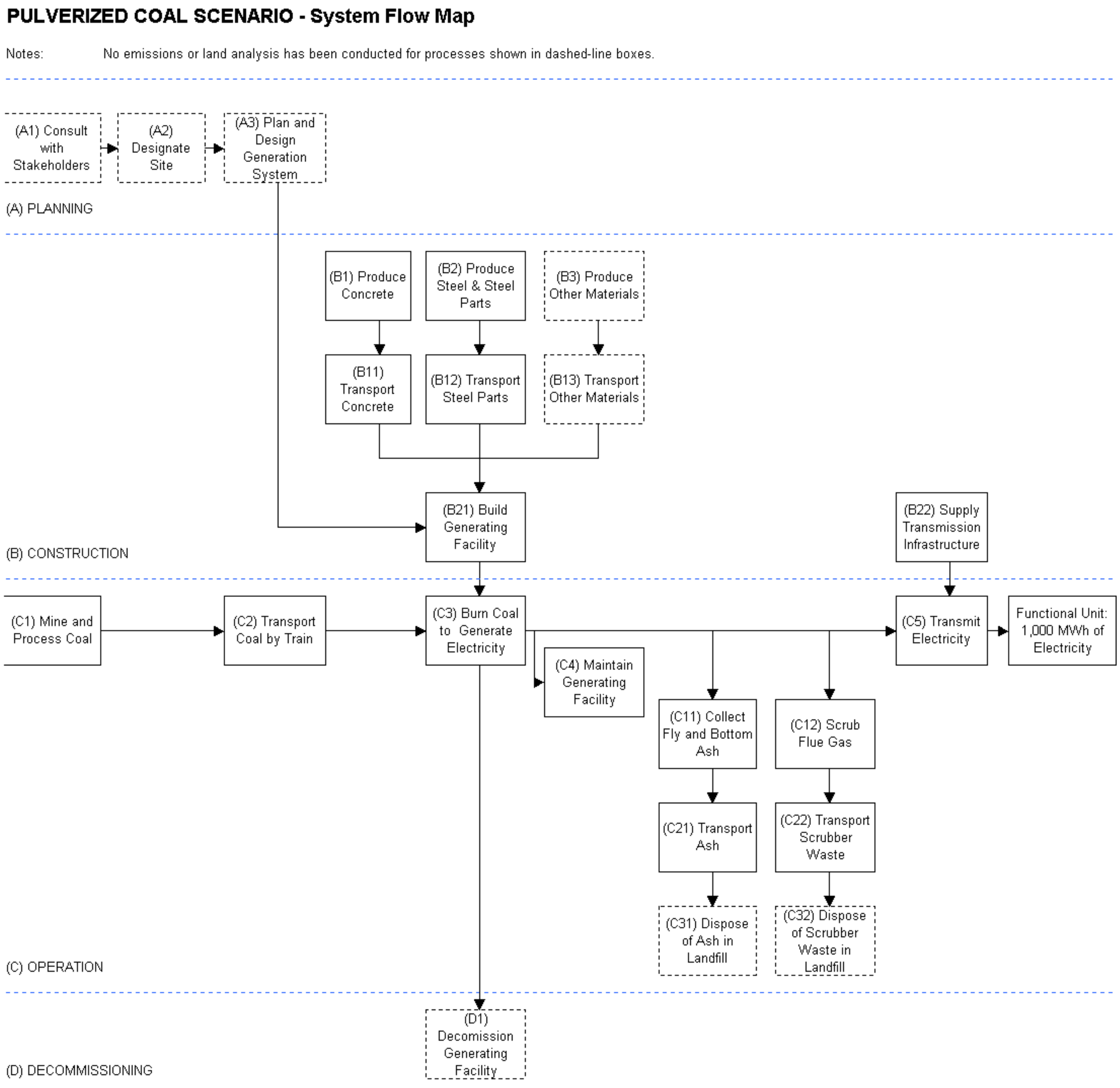
[b] Heat rates and efficiencies are expressed in terms of the Higher Heating Value (HHV) of carbon fuels throughout this report.

[c] The *economic* viability of the biomass system is beyond the scope of this analysis. It is estimated that sufficient flax straw is produced in the province of Manitoba to fuel a 25 MW generating plant, however it is not known whether (a) the opportunity costs of using the straw for fuel production, and (b) the actual costs of collecting and transporting the straw would fall within reasonable bounds.

[d] No specific site has been provided for the biomass and wind generating facilities. However, Manitoba Hydro has limited the set of possible sites to locations within 10 km of existing transmission lines. Thus, any additional transmission infrastructure required for these alternatives may be considered negligible.

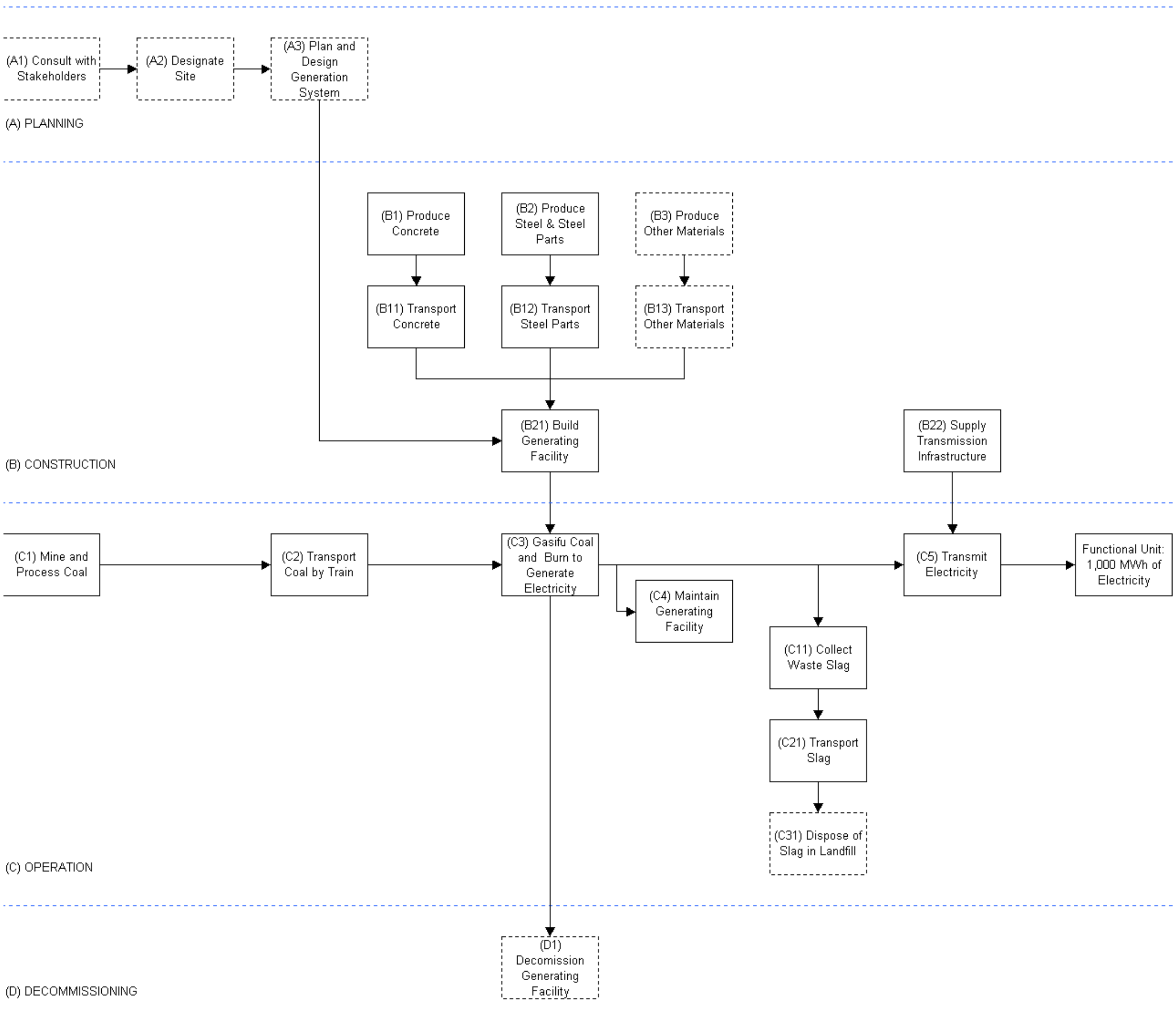
Appendix 2: System Flow Maps




PULVERIZED COAL SCENARIO - System Flow Map
Notes:
No emissions or land analysis has been conducted for processes shown in dashed-line boxes.
(A1) Consult with Stakeholders
(A2) Designate Site
(A3) Plan and Design Generation System
(A) PLANNING
(B1) Produce Concrete
(B2) Produce Steel & Steel Parts
(B3) Produce Other Materials
(B11) Transport Concrete
(B12) Transport Steel Parts
(B13) Transport Other Materials
(B21) Build Generating Facility
(B22) Supply Transmission Infrastructure
(B) CONSTRUCTION
(C1) Mine and Process Coal
(C2) Transport Coal by Train
(C3) Burn Coal to Generate Electricity
(C4) Maintain Generating Facility
(C5) Transmit Electricity
Functional Unit: 1,000 MWh of Electricity
(C11) Collect Fly and Bottom Ash
(C12) Scrub Flue Gas
(C21) Transport Ash
(C22) Transport Scrubber Waste
(C31) Dispose of Ash in Landfill
(C32) Dispose of Scrubber Waste in Landfill
(C) OPERATION
(D1) Decomission Generating Facility
(D) DECOMMISSIONING

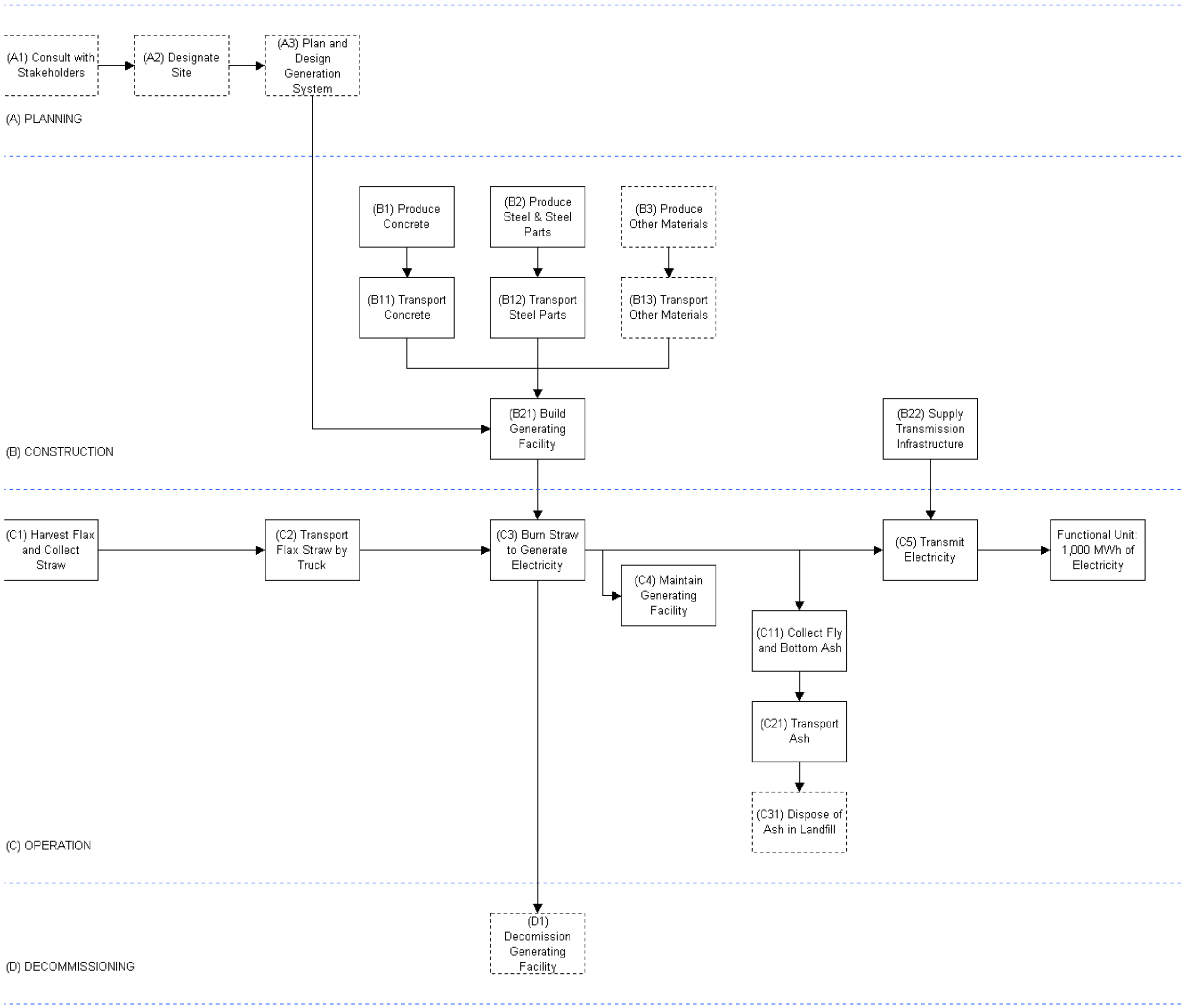
IGCC SCENARIO - System Flow Map

Notes: No emissions or land analysis has been conducted for processes shown in dashed-line boxes.



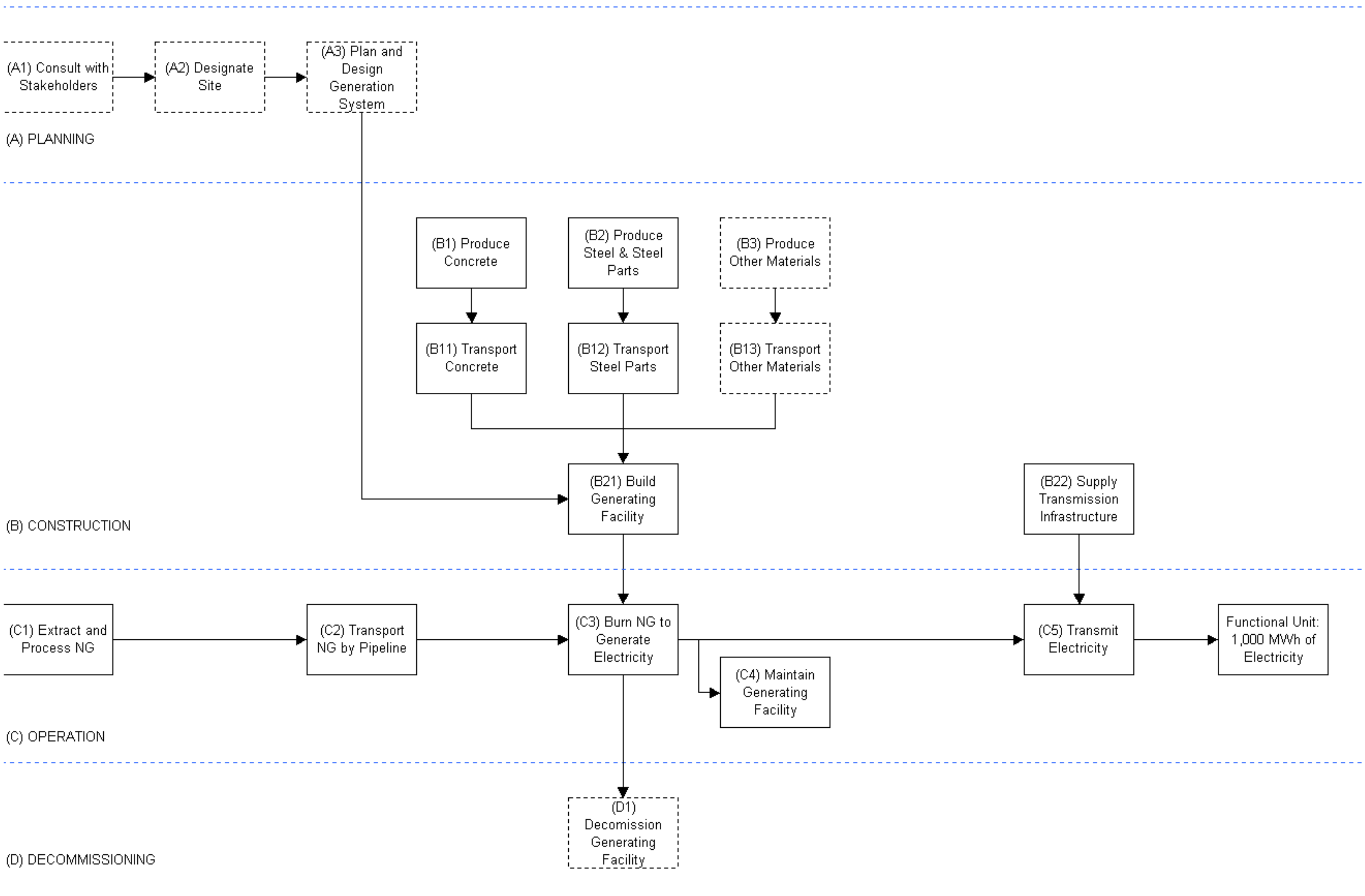
BIOMASS SCENARIO - System Flow Map

Notes: No emissions or land analysis has been conducted for processes shown in dashed-line boxes.



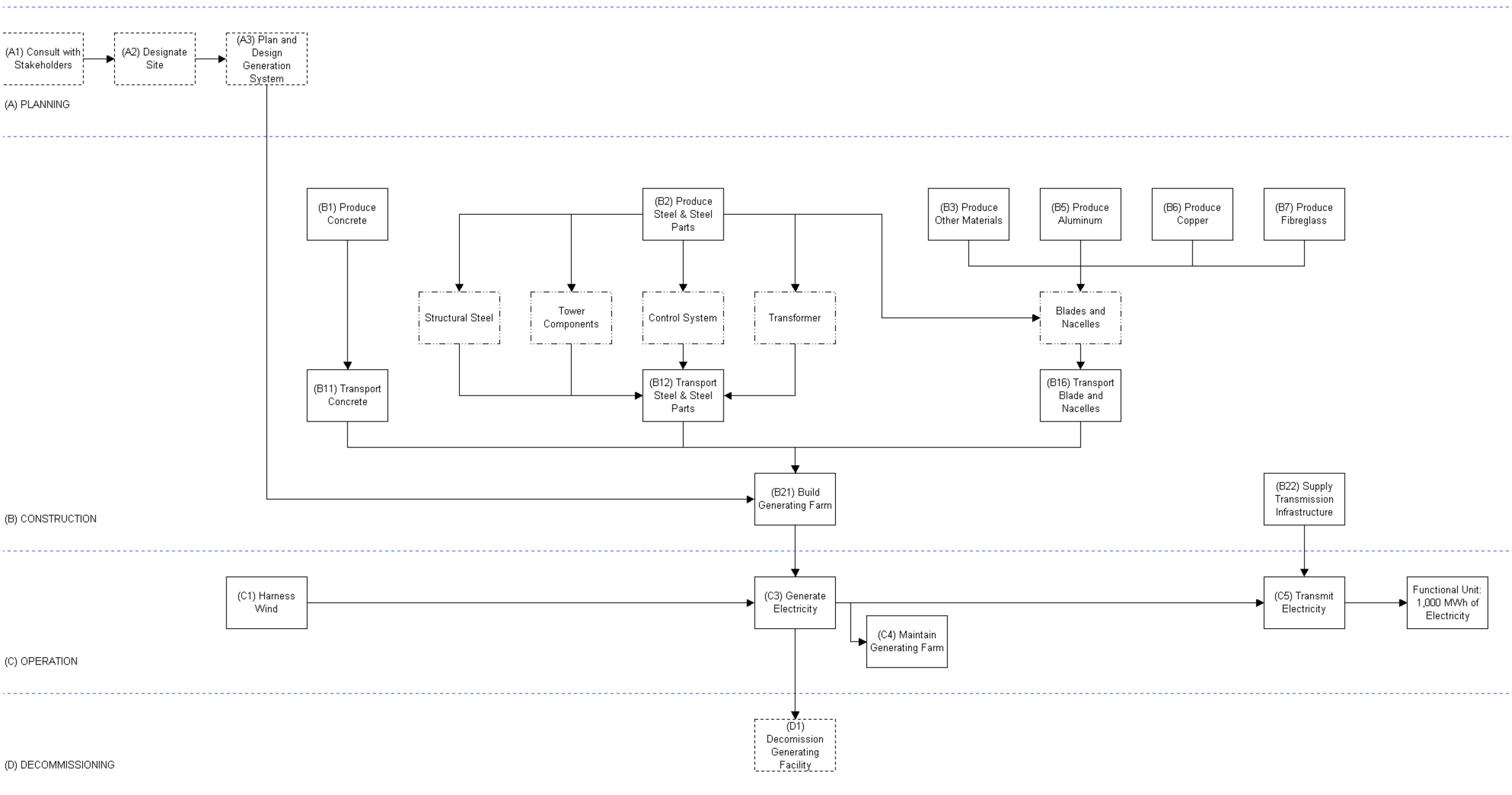
NG SIMPLE CYCLE and COMBINED CYCLE SCENARIOS - System Flow Map

Notes: No emissions or land analysis has been conducted for processes shown in dashed-line boxes.



WIND SCENARIO - System Flow Map

Notes: No emissions or land analysis has been conducted for processes shown in dashed-line boxes.



Appendix 3: Key Parameters and Assumptions Listed by System

Table A3.1 Key Parameters and Assumptions for the Wuskwatim Hydro Option

ID #	Process	GHG-related Parameter / Assumption → Rationale	Land Change-related Parameter / Assumption	→	Rationale
A1-A3	Planning	(No quantitative analysis conducted)	(No quantitative analysis conducted)		
B1-B5	Produce Building Materials	(See **Appendix 5** for building material quantities)	• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-B15	Transport Building Materials to Site	(See **Appendix 5** for transportation distances)	• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities) (See **Appendix 7** for GHG emissions due to land impacts of facility construction)	Construction-related land change would occur in three areas: [i] Generating station land, [ii] Construction area and borrow pits, and [iii] Access road right-of-way: • [i] Generating station would replace: 84 ha of forest Land would remain changed throughout 100-yr project life. • [ii] Construction camps and borrow pits would involve clearing and/or disturbing: 330 ha of forest Land is expected to be fully restored once construction is complete. • [iii] Access road right-of-way would replace: 324 ha of forest 158 ha non-forest vegetation[d] Land would remain changed throughout 100-yr project life.	 → → →	 Current proposal for Wuskwatim generating station[1] Current proposal for Wuskwatim generating station[1] Current proposal for Wuskwatim generating station[1]
B22	Build Transmission Lines	(See **Appendix 5** for fuel consumption quantities) (See **Appendix 7** for GHG emissions due to land impacts of transmission line construction)	• Transmission right-of-way would replace: 850 ha of forest 680 ha non-forest vegetation[d] 288 ha other land[e] Land would remain changed throughout 100-yr project life.	→	Current proposal for Wuskwatim generating station[1f]
B31	Flood Reservoir Area	(Reservoir emissions are accounted for in C3)	• TheWuskwatim reservoir would involve clearing, and then flooding: 34 ha of forest 5 ha peat bogs Land would remain changed throughout 100-yr project life.	→	Current proposal for Wuskwatim generating station[1]
C1	Channel Water to Turbine	(No direct impact on GHG emissions)	(Land change accounted for elsewhere)		Would occur on land already changed by flooding (B31), and generating facility construction (B21).
C3	Generate Electricity	(See **Appendix 7** for CO_2 and CH_4 emissions from the reservoir)	(Land change accounted for elsewhere)	→	Generation would occur on land already changed during facility construction (B21)

Table A3.1 Key Parameters and Assumptions for the Wuskwatim Hydro Option - Continued

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
C4	Maintain Facility	• Negligible emissions due to gasoline combustion in maintenance vehicles	→	Based on data from Manitoba Hydro's Jenpeg generation station[g]	(Land change accounted for elsewhere)	→	Maintenance would occur on land already changed during generating facility construction (B21)
		• Turbine and Generator would during project life	→	Assumption			
	Transmit Electricity	(No direct impact on GHG emissions)			(Land change account for elsewhere)	→	T ready c construction (B22)
D1	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:
[1] Data on land types and land areas has been obtained from preliminary work on the Wuskwatim project EIS. The information is provided by Manitoba Hydro.

Additional Clarification:
[a] If the Wuskwatim Hydro proposal uses some part of a facility, say x%, then it is responsible for x% of land change caused by that facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.
[b] When forest is cleared, and felled trees are left to decay, carbon in the trees will be released to the atmosphere. If new trees are allowed to grow in the clearing, an equivalent amount of carbon will eventually be sequestered from the atmosphere. In the Wuskwatim proposal, there are two time-frames for clearing and re-growth:

Type (a) forest is cleared for construction, and reforested **during** the project life: borrow pits (696 ha)

Type (b) forest is cleared for construction, kept cleared throughout the 100 year project life, and reforested **after** project completion: Generating facility site (383 ha), access road right-of-way (311 ha), transmission line right-of-way (1340 ha).

For land type (a), since both clearing and re-growth occur during the project life, the net emission of CO_2 to the atmosphere is said to be 0.
For land type (b), since only clearing occurs during the project life, the net emission of CO_2 is said to be equal to emissions caused by clearing: 186 t / ha. [2]
(In fact, the transfer of carbon to the atmosphere in both cases is non-zero, but temporary. In (a), carbon from felled trees remains in the atmosphere for a relatively short period of time until new trees regrow (30-50 years), resulting in a relatively smaller impact on the environment. In (b), carbon remains in the atmosphere for a relatively longer period (> 100 years), with a greater impact on the environment).
[c] The analysis assumes that trees are a significant source of carbon, while other vegetation is not. Thus, any clearing of land with non-forest vegetation (i.e. grassland, fens, bogs) releases negligible quantities of CO_2 to the atmosphere. Similarly, any low vegetation (shrubs, grasses) which grows on cleared land involves only a negligible CO_2 uptake from the atmosphere and does not affect net CO_2 emissions significantly.
[d] Non-forest vegetation refers to fens, bogs, and grasslands.
[e] Other land refers to exposed rock, bare mineral soil and surface water
[f] The transmission line includes three segments. Two segments would be built only if the Wuskwatim generating station is completed. The third segment has been independently planned and is expected to be required whether or not the Wuskwatim project comes on-line The segment will, however, be built two years early if Wuskwatim is commissioned. This segment is not included in the land change totals since the one-time land change cannot be directly attributed to Wuskwatim. As a result, there are also no GHG implications of the land change caused by this segment's construction.
[g] Emissions from vehicle operation at the Jenpeg generating station (97 MW) are 0.003 t CO_2e / GWh. Assuming linear scaling of maintenance emissions with generating station capacity, estimated emissions for the Wuskwatim Hydro project (200 MW) are 0.006 t CO_2e / GWh. This is equivalent to ~ 0.1 % of total emissions for the Wuskwatim Hydro project (5.9 t CO_2e / GWh), and is considered negligible.

Table A3.2 Key Parameters and Assumptions for the Pulverized Coal Option

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
A1-A3	Planning				(No quantitative analysis conducted)		
B1-B3	Produce Building Materials	(See **Appendix 5** for building material quantities)			• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-B13	Transport Building Materials to Site	ansportation distances)			• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities)			• Coal plant would occupy 10 acres of land in Brandon, adjacent to current MB Hydro generation site	→	As
B22	Build Transmission Lines		→	Only minimal new transmiss infrastructure would be required[6]	• Negligible land change		Only minimal new transmission infrastructure would be required[6]
C1		• Coal would be supplied by the Spring Creek mine in Montana (surface mine)	→	Current source of sub-bituminous coal for MB Hydro[b]	• 27.5 % of Spring Creek mine reserves would be required to supply fuel for the Pulverized Coal scenario	→	46,800,000 tons (US) of coal would be needed over the 30-yr project life[2]; 170,000,000 tons (US) of recoverable reserves exist at Spring Creek mine[3]
		• Emissions for coal mining at Spring Creek are equivalent to the U.S. average for surface mining		Best data available[1]	• Mines & mine infrastructure needed to provide coal for this scenario would larger, 750 ha mine lease	→	Area figures are 27.5 % of the totals for Spring Creek mine: 950 ha of impacted land within a
C2	Transport Coal	• Coal is transported 2030 km by train from Spring Creek to Brandon	→	Calculated from current routing of coal purchased by MB Hydro[5]		→	Would use only a small fraction of existing transportation infrastructure[a]
		• Coal haul losses during transport are 5%		Estimate used by NREL[1]			
C3	Burn Coal to Generate Electricity	(See **Appendix 6** for emissions factors)			(Land change accounted for elsewhere)	→	Generation would occur on land already
C4	Maintain Generating Facility	• Negligible emissions	→	Involves diesel/gas combustion to run coal combustion for power generation)	(Land change accounted for elsewhere)		Maintenance would occur on land already truction (B21)
C5	Transmit Electricity	(No direct impact on GHG emissions)			(Land change accounted for elsewhere)	→	Transmission would occur on land already changed during transmission line construction (B22)
C11	Collect Fly & Bottom Ash	• Negligible emissions	→	No fugitive emissions; involves diesel combustion to run equipment only (negligible compared to coal combustion for power generation)	(Land change accounted for elsewhere)	→	Ash disposal would occur on-site, on land already changed during facility construction (B21)

Table continued next page

Table A3.2 Key Parameters and Assumptions for the Pulverized Coal Option - Continued

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
C12	Scrub Flue Gases	• Emissions would be 4.4 t CO_2e / GWh, including: (i) fugitive emissions in the scrubber, (ii) emissions from upstream lime/limestone production.	→	Based on NREL data for Illinois No. 6 coal and typical scrubbing technology (best data available)[1c]	(Land change accounted for elsewhere)	→	Scrubbing would occur on land already changed during generating facility construction (B21)
	Transport Wastes to Landfill	• Ash disposed of on generating facility site • Scrubber waste transported 25 km to landfill	 →	Current MB Hydro practice at Brandon Assumption	• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
C31-C32	Dispose of Waste in Landfill	• Negligible emissions	→	No fugitive emissions; involves diesel combustion to run equipment combustion of coal for power generation)			Would use only a small fraction of existing waste disposal infrastructure[a]
	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:

[1] Spath, Pamela et al. *Life Cycle Analysis of Coal-fired Power Production*. Golden, Colorado: National Renewable Energy Laboratory (NREL). 1999.

[2] Result follows directly from basic operating parameters (Table A1.1) & assumed heat rates (Table A5.1) for the Pulverized Coal scenario: (1 t / 1000 kg) * (0.454 kg / 1 lb) * (1 lb coal mined / 0.95 lb coal delivered) * (1 lb coal / 9,350 BTU) * (9,294 BTU / kWh produced) * (1000 kWh / MWh) * (400 MW capacity x 0.85 operating factor x (24 hr / day) x (365 day / yr) x 30 yrs) = 42,500,000 t = 46,800,000 tons (US) during lifetime

[3] Information provided by the Kennecott Energy Company, in: *Guide to Coal Mines served by Burlington Northern and Santa Fe railway*. Fort Worth: Coal Business Unit, BNSF Railway.

[4] Information provided by Neil Harrington at the Industrial & Energy Materials Bureau, Department of Environmental Quality, State of Montana

[5] Routing: Spring Creek – Sheridan – Glendive – Fargo – Minot – Northgate – Brandon. Information provided by Gregory Richie at the Burlington Northern and Santa Fe Railway Coal Business Unit

[6] Basic operating parameter (Table A1.1) for the Pulverized Coal scenario

Additional Clarifications:

[a] If the Pulverized Coal scenario uses x% of a facility, then it is responsible for x% of land change caused by that facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.

[b] It is possible that coal would be supplied by a few different mines over the life of the Pulverized Coal plant. It is likely, however, that all of these mines would be in the Powder River region of Montana and Wyoming. To make a simple estimate of land change due to mining in this region, the analysis assumes that coal is supplied by a single mine, Spring Creek, in Montana.

[c] Estimate assumes that fugitive and upstream limestone-related emissions per GWh are simply proportional to the sulfur content of coal. Thus, Illinois coal with 3.4% sulfur by weight causes 44 t / GWh of CO_2e emissions (NREL data)[1], and Spring Creek coal with 0.34% sulfur by weight[3] causes 4.4 t / GWh of CO_2e emissions.

Table A3.3 Key Parameters and Assumptions for the IGCC Option

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
A1-A3	P	(No quantitative analysis conducted)			(No quantitative analysis conducted)		
B1-B3	Produce Building Materials	(See **Appendix 5** for building material quantities)			• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-	Transport Building Materials to Site	**Appendix 5** for transportation distances)			• Negligible land change	→	on of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities)			• IGCC plant would occupy 10 acres of land in Brandon, adjacent to current MB Hydro generation site.	→	Assumption
B22	Bu ission Lines	• Negligible emissions	→	infrastructure would be required[6]	• Negligible land change	→	sion infrastructure would be required[6]
C1	Mine Coal	• Coal would be supplied by the Spring)	→	urce of sub-bituminous coal for MB Hydro[b]	• 34.8% of Spring Creek mine reserves IGCC scenario	→	59,000,000 tons (US) of coal would be needed over the 30-yr project life[2]; 170,000,000 tons (US) of recoverable reserves exist at Spring Creek mine[3]
		• Emissions for coal mining at Spring Creek are equivalent to the U.S. average for surface mining	→	Best data available[1]	• Mines & mine infrastructure needed to provide coal for the IGCC scenario eplace 260 ha of grazing land within a larger, 750 ha mine lease	→	Area figures of 34.8 % of the totals for Spring Creek mine: 950 ha of impacted land within a larger, 2730 ha mine lease[4]
	Transport Coal	• Coal is transported 2030 km by train from Spring Creek to Brandon		Current routing of coal purchased by		→	Would use only a small fraction of existing transportation infrastructure[a]
		• Coal haul losses during transport are 5%		Estimate used by NREL[1]			
C3	Burn Coal to Generate Electricity	(See **Appendix 6** for emissions factors)			(Land change accounted for elsewhere)	→	Generation would occur on land already changed during facility construction (B21)
C4	Maintain Generating Facility	• Negligible emissions	→	Involves diesel/gas combustion to run vehicles only (negligible compared to coal combustion for power generation)	(Land change accounted for elsewhere)	→	Maintenance would occur on land already changed during facility construction (B21)
C5	Transmit Electricity	(No direct impact on GHG emissions)			(Land change accounted for elsewhere)	→	Transmission would occur on land already changed during transmission line construction (B22)
C11-C31	Collect & Dispose of Waste Slag	• Negligible emissions	→	No fugitive emissions; involves diesel combustion to run equipment only (negligible compared to coal combustion for power generation)	(Land change accounted for elsewhere)	→	On-site disposal or sale of slag to industrial customers[c]. No additional land would be changed.
D1	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:

[1] Spath, Pamela et al. *Life Cycle Analysis of Coal-fired Power Production*. Golden, Colorado: National Renewable Energy Laboratory (NREL). 1999.

[2] Result follows directly from basic operating parameters (Table A1.1) & assumed heat rates (Table A5.1) for the IGCC scenario: (1 t / 1000 kg) * (0.454 kg / 1 lb) * (1 lb coal mined / 0.95 lb coal delivered) * (1 lb coal / 9,350 BTU) * (8,225 BTU / kWh produced) * (1000 kWh / MWh) * (570 MW capacity x 0.85 operating factor x (24 hr / day) x (365 day / yr) x 30 yrs) = 53,500,000 t = 59,000,000 tons (US) during lifetime

[3] Information provided by the Kennecott Energy Company, in: *Guide to Coal Mines served by Burlington Northern and Santa Fe railway*. Fort Worth: Coal Business Unit, BNSF Railway.

[4] Information provided by Neil Harrington at the Industrial & Energy Materials Bureau, Department of Environmental Quality, State of Montana
[5] Routing: Spring Creek – Sheridan – Glendive – Fargo – Minot – Northgate – Brandon. Information provided by Gregory Richie at the Burlington Northern and Santa Fe Railway Coal Business Unit
[6] Basic operating parameter (Table A1.1) for the IGCC scenario.

Additional Clarifications:
[a] If the IGCC scenario uses x% of a facility, then it is responsible for x% of land change caused by the facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.
[b] It is possible that coal would be supplied by a few different mines over the life of the IGCC plant. It is likely, however, that all of these mines would be in the Powder River region of Montana and Wyoming. To make a simple estimate of land change due to mining in this region, the analysis assumes that coal is supplied by a single mine, Spring Creek, in Montana.
[c] On-site slag disposal and sale of slag to industrial customers are both viable options for an IGCC plant. A preferred option has not been specified in the MB Hydro IGCC scenario.

Table A3.4 Key Parameters and Assumptions for the Biomass Option

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
A1-A3	Planning	(No quantitative analysis conducted)			(No quantitative analysis conducted)		
B1-B3	Produce Building Materials	(See **Appendix 5** for building material quantities)			• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-B13	Transport Building Materials to Site	(See **Appendix 5** for transportation distances)			• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities)			• Generating plant would occupy 2 acres of farmland in S.W. Manitoba	→	Assumption (to be confirmed)
B22	Build Transmission Lines	• Negligible emissions	→	Only minimal new transmission infrastructure would be required[6]	• Negligible land change	→	Only minimal new transmission infrastructure would be required[6]
C1	Harvest Flax & Collect Straw	• Flax straw would be obtained from exisiting flax farming operations in S.W. Manitoba	→	176,000 t of flax straw required each year[1]; 221,000 t flax straw produced in Manitoba each year[2]; ∴ sufficient straw is available[b]	• No land change	→	Flax straw would be obtained from existing farm operations
		• 170.3 m^3 diesel is required to harvest a flax crop yielding 1 t of flax seed and 1 t of flax straw	→	0.514 t flax straw harvested per acre[3]; 1370 MJ fuel needed per ha of flax harvested[4]; assume exclusive use of diesel for harvesting			
		• 2.64% of flax harvesting emissions (from diesel combustion) allocated to flax straw	→	Based on market value of flax and flax straw[3c]			
C2	Transport Flax by Truck	• Flax is transported by truck an average of 100 km to generating facility.	→	Estimate[5]	• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
C3	Burn Flax Straw to Generate Electricity	(See **Appendix 6** for emissions factors)			(Land change accounted for elsewhere)	→	Generation would occur on land already changed during facility construction (B21)
C4	Maintain Generating Facility	• Negligible emissions	→	Involves diesel/gas combustion to run vehicles only (negligible compared to straw combustion for power generation)	(Land change accounted for elsewhere)	→	Maintenance would occur on land already changed during facility construction (B21)
C5	Transmit Electricity	(No direct impact on GHG emissions)			(Land change accounted for elsewhere)	→	Transmission would occur on land already changed during transmission line construction (B22)
C11-C31	Collect & Dispose of Ash	• Negligible emissions	→	No fugitive emissions; involves diesel combustion to run equipment only (negligible compared to straw combustion for power generation)	(Land change accounted for elsewhere)	→	On-site disposal on land already changed during facility construction (B21)
D1	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:

[1] Result follows directly from basic operating parameters (Table A1.1) & assumed heat rates (Table A5.1): (1 t / 1000 kg) * (0.454 kg / 1 lb) * (1 lb straw / 7,300 BTU) * (13,600 BTU / kWh produced) * (1000 kWh / MWh) * (25 MW capacity x 0.95 operating factor x (24 hr / day) x (365 day / yr)) = 176,000 t straw / yr

[2] Based on [i] assumed 1:1 (mass) ratio of flax seed to flax straw production (standard assumption for grains), and [ii] annual Manitoba flax seed production (2000) statistics: Manitoba Agriculture[3]

[3] Manitoba Agriculture and Food: *Manitoba Grains & Oilseeds Industry Profiles 2000 – Flaxseed Sector* at: http://www.gov.mb.ca/agriculture/statistics/aac04s07.html

[4] Coxworth, E. et al. *Net Carbon Balance Effects of Low Disturbance Seeding Systems on Fuel, Fertilizer, Herbicide and Machinery usage in Western Canadian Agriculture: Final Report to a Major Western Utility*. 1994.

[5] Agricultural areas in Manitoba fall within an area of ~ 200 km radius, ∴ 100 km is an average distance travelled to a centrally-located biomass plant.

[6] Basic operating parameter for the biomass scenario (Table A1.1)

Additional Clarifications:

[a] If the Biomass scenario uses x% of a facility, then it is responsible for x% of land change caused by that facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.

[b] Although an estimated 221,000 t of flax straw are produced in Manitoba each year, at least 135,000 t were sold for use in diverse industries (e.g. fine fibre for cigarette paper and currency)[3]. A proportion of the remainder was left on fields. As a result, it is not clear whether the alternative use of flax straw for power generation would be economically viable: other uses may reap more value from flax straw, and in addition, transportation costs to a biomass plant may be prohibitive. An economic analysis must therefore play a critical role in evaluating this biomass scenario.

[c] Emissions data are available for a combined harvest of flax and flax straw. The fuel-combustion emissions are allocated between the products based on market value: for a tonne of combined harvest (0.5 t straw, 0.5 t seed), the total market value is in the proportion 98.4 % seed to 2.6 % straw[3].

Table A3.5 Key Parameters and Assumptions for the Natural Gas Simple Cycle and Combined Cycle Options

ID #	Process	GHG-related Parameters / Assumptions	→	Rationale	Land Change-related Parameter / Assumption	→	Rationale
A1-A3	Planning	(No quantitative analysis conducted)			(No quantitative analysis conducted)		
B1-B3	Produce Building Materials	(See **Appendix 5** for building material quantities)			• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-B13	Transport Building Materials to Site	(See **Appendix 5** for transportation distances)			• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities)			• NG Simple or Combined Cycle plant would occupy 5 acres of land within the current Brandon site	→	
B22	Build Transmission Lines	• Negligible emissions	→	Only minimal new transmission infrastructure would be required[3]	• Negligible land change	→	Only minimal new transmission infrastructure would be required[3]
C1	Extract and process NG	• All NG is produced in Alberta • 126 m^3 of raw gas are extracted for every 100 m^3 of saleable NG	→ →	Assumption[b] Estimate[1]	(See **Appendix C** for data on land change related to NG extraction)		
C2	Transport NG	• NG travels an average of 1700 km to Brandon via the TransCanada pipeline • 1.4 % of raw gas extracted is lost as fugitive emissions during processing and transportation	→ →	Estimate based on Hanmore Compressor station (NW Alberta) as an average point of origin NREL best estimate (Industry consensus range: 1-4%)[2]	• Negligible land change	→	[i] Would use only a small fraction of existing pipeline infrastructure[c] [ii] The TransCanada pipeline is largely underground; only minimal surface land change has occurred as a result of the pipeline[c]
C3	Burn NG to Generate Electricity	(See **Appendix 6** for emissions factors)			(Land change accounted for elsewhere)	→	Generation would occur on land already changed during facility construction (B21)
C4	Maintain Generating Facility	• Negligible	→	Involves diesel/gas combustion to run vehicles only (negligible compared to NG combustion for power generation)	(Land change accounted for elsewhere)	→	Maintenance would occur on land already changed during facility construction (B21)
C5	Transmit Electricity	(No direct impact on GHG emissions)			(Land change accounted for elsewhere)	→	Transmission would occur on land already changed during transmission line construction (B22)
D1	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:
[1] Alberta average data compiled from a variety of sources
[2] Spath, Pamela et al. *Life Cycle Analysis of a Natural Gas Combined Cycle Power Generation System*. Golden, Colorado: National Renewable Energy Laboratory (NREL). 2000.
[3] Basic operating parameter for the NG scenarios
[4] TransCanada operations data at http://www.transcanada.com
[5] Information provided by Srikanth Venugopal at TransCanada

Additional Clarification:
[a] If the NG scenario uses x% of a facility, then it is responsible for x% of land change caused by the facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.

[b] NG in the TransCanada pipeline originates primarily in Alberta, although some gas is sourced from NE British Columbia, Saskatchewan and the NWT. To make a simple estimate of emissions related to compressor station energy use and of land change due to NG extraction, the analysis assumes that NG is supplied exclusively from Alberta. Supply is allocated to different regions within Alberta based on estimates of existing reserves (see Appendix C for more detailed information).

[C] In the case of the TransCanada pipeline, [i] use of existing infrastructure is small on an annual basis: the Simple Cycle scenario would require 1.1% of the Trans Canada pipeline daily throughput (= 6,700 mmcf/day, 2001 average figure)[4] for 30 years, [ii] land change due to the pipeline is minimal, since the Canadian mainline is largely underground, and does not change land use on the surface right-of-way, except at compressor stations (land use above the pipeline is largely agricultural; the right-of-way is 220 ft.)[5] Thus, the mathematical product: "(land change due to the TransCanada pipeline) * (% of land change allocated to the NG scenarios)" is negligible.

Table A3.6 Key Parameters and Assumptions for the Wind Option

ID #	Process	GHG-related Parameter / Assumption	→	Rationale	Land Change-related Parameters / Assumptions	→	Rationale
A1-A3	Planning	(No quantitative analysis conducted)			(No quantitative analysis conducted)		
B1-B7	Produce Building Materials	(See **Appendix 5** for building material quantities)			• Negligible land change	→	Would use only a small fraction of existing industrial infrastructure[a]
B11-B16	Transport Building Materials to Site	(See **Appendix 5** for transportation distances)			• Negligible land change	→	Would use only a small fraction of existing transportation infrastructure[a]
B21	Build Generating Facility	(See **Appendix 5** for fuel consumption quantities)			• Wind turbines located on farmland, arranged in a square grid pattern, with 200 m spacing between turbines	→	Typical arrangement[1]
					• Each turbine foundation replaces 110 m^2 of farmland[1]; the remainder of the land within the farm remains unchanged	→	Changed land area in the wind scenario is simply the combined area of all fifty turbine foundations
					• Access road right-of-way may be needed. No quantification since windfarm location unknown	→	Assumption
B22	Build Transmission Lines	• Negligible land change	→	Only minimal new transmission infrastructure would be required[2]	• Negligible land change	→	Only minimal new transmission infrastructure would be required[2]
C1	Harness Wind	(No direct impact on emissions)			(Land change accounted for elsewhere)	→	Would occur on land already changed during facility construction (B21)
C3	Generate Electricity	(No direct impact on emissions)			(Land change accounted for elsewhere)	→	Generation would occur on land already changed during facility construction (B21)
C4	Maintain Generating Facility	• 750 l gasoline consumed per turbine per year[1]	→	(Land change accounted for elsewhere) →	Land change accounted for elsewhere)	→	Maintenance would occur on land already changed during facility construction (B21)
C5	Transmit Electricity	(No direct impact on GHG emissions)			(Land change accounted for elsewhere)	→	Transmission would occur on land already changed during transmission line construction (B22)
D1	Decommission Generating Facility	(No quantitative analysis conducted)			(No quantitative analysis conducted)		

Data Sources:
[1] Information provided by VisionQuest Wind Electric
[2] Basic operating parameter for the wind scenario (see Table A1.1)

Additional Clarifications:
[a] If the Wind scenario uses x% of a facility, then it is responsible for x% of land change caused by that facility. In many cases, this land change is negligible since the percentage use (x) is negligible. For instance, plant construction may require just a few hundred trips on a highway is used for millions of trips over its lifetime.

Appendix 4: Construction Materials and Transportation Distances

Table A4.1: Construction Materials and Transportation Distances – Wuskwatim Hydro Option

	Building Materia					Building Material Transportation Distances - Average by Material (km)					Fuel use during Construction (l)
	Cement	Steel & St	Lumber	Aluminum	Other	Concrete, by Truck (km)	Steel & Steel Parts, by Truck	Lumber, by Truck	Aluminum, by Truck	Other, by Truck	Diesel
Wuskwatim Hydro[1]	32,500	28,000	4,400	1,500	5,400	1,380	2,710	820	3,300	880	17,500,000

Table A4.2: Construction Materials and Transportation Distances – Carbon Fuel–based Options

Electricity Supply Option	Building Material Quantities (t)[a]		Building Material Transportation Distances - Average by Material (km)			Fuel use during Construction (l)		
	Concrete	Steel & Steel	Concrete, by Truck	Steel & Steel Parts, by Truck	Steel & Steel Parts, by Ship	Diesel	Gasoline	Propane
Pulverized Coal[2]	18,700	4,710	15	1,850	4,500	665,500	0	47,000
IGCC[2]	26,730	6,770	15	1,850	4,500	948,500	153,000	67,000
Biomass[2]	1,	290	100	1,950	4,500	41,500		3,000
NG Simple Cycle[2]	7,320	1,840	15	1,850	4,500	260,000		18,500
NG Combined Cycle[2]	7,320	1,840	15	1,850	4,500	260,000		18,500

Table A4.3: Construction Materials and Transportation Distances – Wind Option

	Building Material Quantities (t)							Building Material Transportation Distances - Average by Material (km)				Fuel use during Construction (l)
	Concrete	Steel &	Specialized Parts (Blades, Hubs and Nacelles), comprising:					Concrete, by Truck	Steel & Steel Parts, by Truck	Specialized Parts, by Truck	Specialized Parts, by Ship	Diesel
			Steel	Aluminum	Fibreglass	Copper	Other					
Wind[3]	6,500	6,730	2,150	950	980	150	45	100	2,400	2,800	14,000	187,500

Data Sources:

[1] Information provided by Manitoba Hydro based on the current Wuskwatim Hydro proposal

[2] Information for the NG Simple Cycle option is based on data from a Single Cycle NG power plant built by Manitoba Hydro at Brandon in 2002 . Information for other scenarios is derived from these figures as follows:

- NG Combined Cycle: material quantities and fuel consumption are assumed to be the same as in the NG Simple Cycle case. In reality, the material requirements for a combined cycle plant may be slightly higher than requirements for a simple cycle plant of identical capacity. However, given the relatively minor contribution of construction-related emissions to the overall total for Natural Gas-fired technologies, this distinction is considered to be insignificant.
- Pulverized coal: material quantities and fuel consumption are adjusted for higher capacity (multiplying factor 400 MW/250 MW = 1.6) and greater complexity (multiplying factor = 1.6)[b] of the coal plant. Transportation distances are identical (same proposed site).
- IGCC: material quantities and fuel consumption are adjusted for higher capacity (multiplying factor 570 MW/250 MW = 2.3) and greater complexity (multiplying factor = 1.6)[b] of the plant. Transportation distances are identical (same proposed site).
- Biomass: material quantities and fuel consumption are adjusted for lower capacity (multiplying factory = 25 MW/250 MW = 0.1) and greater complexity (multiplying factor = 1.6)[b] of the plant. Transportation distances are adjusted for a hypothetical site 100 km from Brandon.

[3] Information derived from data on a wind farm in Pincher Creek, Alberta provided by VisionQuest Wind Electric. Material quantities have been adjusted to account for a larger turbine size (1.65 MW vs 660 kW in the original data, multiplying factor per turbine = 5 provided by VisionQuest). Transportation distances have been adjusted for a hypothetical site 100 km from Brandon.

Additional Clarifications:

[a] Other building materials (e.g. iron, aluminum) are not included as they account for less than 1% of the total building mass.

[b] The complexity multiplying factor is derived from a comparison of plant material quantities in two reports by the National Renewable Energy Laboratory (NREL): [i] Spath, Pamela et al. *Life Cycle Analysis of Coal-fired Power Production*. Golden, Colorado: NREL. 1999. [ii] Spath, Pamela et al. *Life Cycle Analysis of a Natural Gas Combined Cycle Power Generation System*. Golden, Colorado: NREL. 2000.

Appendix 5: Fuel and Combustion Data for Carbon Fuel–based Scenarios

Table A5.1: Fuel and Combustion Data for Carbon Fuel–based Scenarios

Electricity Supply Option	Fuel	Net Heat Rate of Generating Plant – HHV basis (BTU / kWh)	Fuel Heating Value – HHV basis (BTU / lb)	Emissions Factors		
				Carbon Dioxide - CO_2 (kg / t fuel)	Methane - CH_4 (kg / t fuel)	Nitrogen Oxide – N_2O (kg / t fuel)
Pulverized Coal	Sub-bituminous Coal	9,294[1]	9,350[2]	2,046[3]	0.02[3]	0.1[3]
IGCC			9,350[2]	2,046[3]	0.02[3]	0.1[3]
Biomass	Flax Straw	13,600[1]	7,300[4]	0[5]	0.15[6]	0.16[6]
NG Simple Cycle	Natural Gas	11,500[1]	23,000[7]	2,691[7]	0.32[7]	0[7]
NG Combined Cycle	Natural Gas	7,000[1]	23,000[7]	2,691[7]	0.32[7]	0[7]

Data Sources & Additional Clarifications:

[1] Basic operating parameters for each scenario

[2] Figure is an average value for coal from the Spring Creek mine (assumed source of coal, see Tables A3.2 and A3.3). Information provided by Kennecott Energy Company, in: *Guide to Coal Mines served by Burlington Northern and Santa Fe Railway*. Fort Worth: Coal Business Unit, BNSF railway.

[3] CO_2 and CH_4 factors are average for sub-bituminous coal. N_2O factor is the minimum of a range of values (0.1-2.11 kg / t) for sub-bituminous coal. Source: *Canada's Energy Outlook 1996-2020*. Ottawa: Natural Resources Canada. 1997.

[4] Figure is for flax straw containing 15% moisture by weight. LHV heating value obtained from: *Research Update #719*. Humboldt, Saskatchewan: Prairie Agricultural Machinery Institute. 1995. Adjusted to HHV heating value based on flax straw hydrogen content of 6.2 %, obtained from: Hörnell, Christina. *Thermochemical and Catalytic Upgrading in a fuel context: Peat, Biomass and Alkenes* (Dissertation). Stockholm: Royal Institute of Technology. 2001.

[5] Net emissions of CO_2 are 0 for flax fuel (and other biofuels). During combustion, CO_2 is emitted to the atmosphere, however an equivalent amount of CO_2 was removed from the atmosphere by the growing flax plant. Thus, over the life-cycle of growth and combustion, no net CO_2 is released.

[6] Factors are for wood / wood waste (best data available). Source: *Canada's Greenhouse Gas Inventory – 1997 Emissions and Removals with Trends*. Ottawa: Environment Canada. 1999.

[7] Factors are for a typical sample of NG containing 94.4% methane, 3.1% ethane, 0.5% propane, 1.1% N_2, 0.5% CO_2, and 0.4% other hydrocarbons. Source: Spath, Pamela et al. *Life Cycle Analysis of a Natural Gas Combined Cycle Power Generation System*. Golden, Colorado: National Renewable Energy Laboratory (NREL). 2000.

Table A5.2 Material and Transportation Fuel Emission Factors

Activity	Greenhouse Gas Emissions Factors (kg CO_2e / m^3 or kg CO_2e / t)
Gasoline Comb n (^{3} [1]	2,360
Diesel Combustion (m^3)[1]	2,730
Steel Production (	3,200
Concrete Production (m^3)[3]	1,080
Aluminum Pro on (t)[2]	8,000

Data Sources
1 – "Trends in Canada's Greenhouse Gas Emissions 1990 - 1995", A. Jaques, F. Neitzert, P.Boileau. 1997. A report for Environment Canada.
2 - "Life Cycle Inventories for Packaging", Vol 1, Swiss Agency for Environment, Forests, and Landscape, (SAEFL) 1998.
3 – U.S. EPA AP-42 series, Fifth edition, Chapter 11, Mineral Products Industry, section 11.12. 1995.

Appendix 6: Fuel Extraction-Related Land Change for NG Simple Cycle & Combined Cycle Scenarios

This appendix covers the calculation of land changes associated with NG extraction.
Detailed calculations are provided in Tables A6.1 and A6.2 for the Simple Cycle and Combined Cycle scenarios respectively.
In addition, two overall assumptions should be noted:

NG is supplied from the Trans-Canada Pipeline (TCPL), and is a mixture of gas from all of the wells that supply TCPL. For the simple cycle scenario, 77 mmcf/day NG is needed. TCPL transports ~ 6,700 mmcf/day through its Canadian mainline which would supply the Brandon plant. Thus, the NG Simple Cycle scenario accounts for ~ 1.1% of total TCPL throughput.

To evaluate land change, a modelling assumption is made that dedicated wells would supply the generating facility. I.e. rather than allocating 1.1% of the impact of **all** wells supplying TCPL to the project, the number of wells needed to supply 77 mmcf/day for 30 years (= 843 bcf) is calculated, and the entire impact of these wells is allocated to the project.

The number of 'dedicated' wells is calculated as:
(the number of **new** wells needed each year to **maintain** a production of 77 mmcf/day) * (30 years), using initial production and decline data for wells[1].

All NG is assumed to come from Alberta where some wells are in forested areas, and others in farmland area.

In forested areas, land is cleared for exploration: seismic surveys, drilling and access roads. When exploration is complete, some of the cleared land is still required to operate successful wells: well-pads, access roads, and collection pipelines. Land change in forested areas is defined as the total of initially **cleared** land, since clearing involves a non-temporary change (restoration may take 30-50 years or more)[2].

In farmland areas, exploration does not involve any change of land type. Changes are only associated with developed wells: well-pads, access roads, and collection pipelines, which occupy land that can no longer be used for agriculture. Thus, land change in farmland areas is defined as the total of **occupied** land.

[1] An equivalent result can be obtained using life-time production data for wells. The number of 'dedicated' wells is equal to: (843 bcf) / (lifetime production per well)
[2] MacFarlane, Arin. *Revegetation of Wellsites and Seismic Lines in the Boreal Forest* (Dissertation). Edmonton: University of Alberta. 1999.

Table A6.1 Land Change Calculations for the NG Simple Cycle Scenario

Overall Parameters

45.6 mmcf/day NG supplied from Alberta for 30 years[a]

Assessment of Alberta NG reserves in 2001: 82% in NE+NW+SW quadrants (largely forested), 18% in SE quadrant (largely farmland)[b].

∴ Estimate that 80 % of supply will come from forest in NE+NW+SW and 20 % from farm areas in SE.

FORESTED AREAS (80% of total supply)	FARMLAND AREAS (20% of total supply)
Number of Wells Required Forest production required: 36.5 mmcf/day Well initial production (average): 0.7 mmcf/day[b] Well annual decline rate (average): 20%[b] ∴ 10.4 new wells / year needed to maintain production. ∴ 310 wells developed to supply project over 30 yrs.	**Number of Wells Required** Farmland production required: 9.1 mmcf/day Well initial production (average): 0.14 mmcf/day[b] Well annual decline rate (average): 20%[b] ∴ 13 new wells / year needed to maintain production. ∴ 390 wells developed to supply project over 30 yrs.
Type of Land Change ▪ One-time forest clearing for drilling, seismic surveys and to install roads and pipelines. ▪ Part of cleared land then occupied by infrastructure (wellhead, roads, pipelines) throughout life of well. Remainder of cleared land (seismic, drillpad) allowed to begin regenerating. ∴ Forest → Cleared land, partially occupied by infrastructure	**Type of Land Change** ▪ Farmland occupied by infrastructure (wellhead, roads, pipelines) throughout life of well. ∴ Farmland → land occupied by infrastructure
Area of Cleared Land and Occupied Land 1.7 drills / developed well[c] 1 ha cleared / drill[d] 0.04 ha occupied / developed well[e] 10.4 km seismic right-of-way / developed well[f] 6 m width cleared for seismic right-of-way[f] 0 m width occupied by seismic 0.8 km road & pipeline right-of-way / developed well[g] 30 m width cleared for road & pipeline right-of-way[e] 10 m width occupied by road & pipeline[e] ∴ 10.4 ha cleared / well ∴ 0.86 ha occupied / well	**Area of Occupied Land** 1.7 drills / developed well[c] 0.04 ha occupied / developed well[e] 8.2 km seismic right-of-way / developed well[f] 0 m width occupied by seismic 1.2 km road & pipeline right-of-way / developed well[g] 10 m width occupied by road & pipeline[e] ∴ 1.3 ha occupied / well
Density of Wells 1.4 developed wells / section of land[h] ∴ 0.7 section of land / developed well ∴ 180 ha land / developed well	**Density of Wells** 3.3 developed wells / section of land[h] ∴ 0.3 section of land / developed well ∴ 80 ha land / developed well
Forest Sub-Total over the Project Life (30 years) ∴ 310 wells and 3,250 ha changed land (= cleared land) ∴ 310 wells spread out over 57,000 ha area	**Farmland Sub-Total over the Project Life (30 years)** ∴ 390 wells and 500 ha changed land (= occupied land) ∴ 390 wells spread out over 30,000 ha area

Total over Project Life (30 years)

∴ 700 wells and 3,750 ha changed land (= cleared or occupied land)

∴ 700 wells spread out over 87,000 ha area

Table A6.2 Land Change Calculations for the NG Combined Cycle Scenario

Overall Parameters

76.6 mmcf/day NG supplied from Alberta for 30 years[a]

Assessment of Alberta NG reserves in 2001: 82% in NE+NW+SW quadrants (largely forested), 18% in SE quadrant (largely farmland)[b].

∴ Estimate that 80 % of supply will come from forest in NE+NW+SW and 20 % from farm areas in SE.

FORESTED AREAS (80% of total supply)

Number of Wells Required

Forest production required: 61.3 mmcf/day
Well initial production (average): 0.7 mmcf/day[b]
Well annual decline rate (average): 20%[b]

∴ 17.5 new wells / year needed to maintain production.
∴ 525 wells developed to supply project over 30 yrs.

Type of Land Change

- One-time forest clearing for drilling, seismic surveys and to install roads and pipelines.
- Part of cleared land then occupied by infrastructure (wellhead, roads, pipelines) throughout life of well. Remainder of cleared land (seismic, drillpad) allowed to begin regenerating.

∴ Forest → Cleared land, partially occupied by infrastructure

Area of Cleared Land and Occupied Land

1.7 drills / developed well[c]
1 ha cleared / drill[d]
0.04 ha occupied / developed well[e]

10.4 km seismic right-of-way / developed well[f]
6 m width cleared for seismic right-of-way[f]
0 m width occupied by seismic

0.8 km road & pipeline right-of-way / developed well[df]
30 m width cleared for road & pipeline right-of-way[e]
10 m width occupied by road & pipeline[e]

∴ 10.4 ha cleared / well
∴ 0.86 ha occupied / well

Density of Wells

1.4 developed wells / section of landh[g]

∴ 0.7 section of land / developed well
∴ 180 ha land / developed well

Forest Sub-Total over the Project Life (30 years)

∴ 525 wells and 5,450 ha changed land (= cleared land)
∴ 525 wells spread out over 95,000 ha area

FARMLAND AREAS (20% of total supply)

Number of Wells Required

Farmland production required: 15.3 mmcf/day
Well initial production (average): 0.14 mmcf/day[b]
Well annual decline rate (average): 20%[b]

∴ 21.9 new wells / year needed to maintain production.
∴ 655 wells developed to supply project over 30 yrs.

Type of Land Change

- Farmland occupied by infrastructure (wellhead, roads, pipelines) throughout life of well.

∴ Farmland → land occupied by infrastructure

Area of Occupied Land

1.7 drills / developed well[c]
0.04 ha occupied / developed well[e]

8.2 km seismic right-of-way / developed well[f]
0 m width occupied by seismic

1.2 km road & pipeline right-of-way / developed well[df]
10 m width occupied by road & pipeline[e]

∴ 1.3 ha occupied / well

Density of Wells

3.3 developed wells / section of land[g]

∴ 0.3 section of land / developed well
∴ 80 ha land / developed well

Farmland Sub-Total over the Project Life (30 years)

∴ 655 wells and 850 ha changed land (= occupied land)
∴ 655 wells spread out over 51,000 ha area

Total over Project Life (30 years)

∴ 1180 wells and 8,300 ha changed land (= cleared or occupied land)
∴ 1180 wells spread out over 146,000 ha area

Data Sources:

[a] Result follows from basic operating parameters defined for the NG scenarios.
[b] Jamal, Al. *Gas Supply and Demand Update – Markets balanced...but for how long?*. Transcript of a presentation made to the TransCanada 'Inside Track Customer Meeting'. Spring 2002.
[c] Crowfoot, Carol. *Supply and Demand Forecasts for Natural Gas*. Transcript of a presentation made to the Economics Society of Calgary Fall Conference. November 30, 2000.
[d] Schneider, Richard. *The Oil & Gas Industry in Alberta – Practices, Regulations and Environmental Impact.* Edmonton: Alberta Center for Boreal Studies. 2001.
[e] Estimate

[f] Based on Alberta Environment Land and Forest Service data. Source: *The Final Frontier: Protecting Landscape and Biological Diversity within Alberta's Boreal Forest Natural Region, Protected Areas Report #13*. Edmonton: Alberta Environmental Protection. 1998.
[g] Based on AEUB data to year end 1996. Source: *The Final Frontier: Protecting Landscape and Biological Diversity within Alberta's Boreal Forest Natural Region, Protected Areas Report #13*. Edmonton: Alberta Environmental Protection. 1998.
[h] Conservative estimate (lower end of a typical range for developed well density)

Appendix 7: GHG Emissions due to Land Changes in the Wuskwatim Hydro System

This appendix describes how GHG emissions due to land change are estimated for the Wuskwatim Hydro System. Although there are precise estimates of how much land area would be visibly changed by the Wuskwatim project, the nature of these land changes and their impact on eco-system carbon stocks are highly uncertain. As a result, several assumptions are required in order to estimate GHG emissions.

First, the analysis is limited to three types of GHG releases or sequestration:
(i) *Vegetation clearing:* Cleared trees and other vegetation may be used as lumber, left to decay, or burned. If trees are used as lumber, then the carbon in the trees is not released. If trees or vegetation are left to decay, aerobic decomposition releases CO_2. If trees or vegetation are burned, combustion releases CO_2, CH_4 and N_2O.
(ii) *Peat or soil submergence under water*: When organic matter is submerged under water, it will decay partially. Both aerobic and anaerobic decomposition are possible, releasing CO_2 and CH_4 respectively.
(iii *Vegetation growth*: when trees or other vegetation grow, CO_2 is sequestered from the atmosphere through photosynthesis.

Second, the analysis is limited to GHG releases and sequestration that occur *during the construction and operation phases of the project*. Therefore, if land is cleared during construction, kept cleared during operation, and restored *after* project decommissioning, GHG emissions due to clearing are counted, while GHG sequestration due to vegetation re-growth after decommissioning is not counted. By contrast, if land is cleared during construction and restored during operation, both GHG release and sequestration are counted (and assumed to be equivalent) so that net emissions are said to be 0.[1]

Third, assumptions are made about the carbon content of vegetation and soils in order to quantify emissions. These 'organic carbon stock' parameters are listed in Table A7.1, and were provided by Manitoba Hydro based on empirical data.

Finally, specific assumptions are made about which of the processes (i) through (iii) above will occur during the Wuskwatim project, and on what timescale. Calculations have been made for a likely scenario, presented in Table A7.2. Since the assumptions have a strong influence on the estimate of net GHG emissions, the effect of changing various assumptions is also sketched out in the table.

[1] In fact, the transfer of carbon to the atmosphere is non-zero, but temporary in both cases. If restoration occurs *after* decommissioning, the carbon remains in the atmosphere for a relatively longer time (and has a greater impact on climate) than if restoration occurs *during* operation. Thus, a more accurate analysis might consider ton-years of carbon temporarily transferred to the atmosphere. Given the broad assumptions made in the remainder of the calculation, however, this level of detail is unwarranted and could not supported by sufficiently accurate data.

Table A7.1: Carbon Content of Vegetation and Soil

	Forest Land				Non-forest Vegetation			Peat Bogs	
	Area of Land Change (ha)	Carbon Content			Area of Land Change (ha)	Carbon Content		Area of Land Change (ha)	Carbon Content
		Original Forest Vegetation	Soil	Shrub Re-growth During Operation		Original Vegetation	Shrub re-growth During Operation		Peat
Generating Station & Construction Areas	383	55.6							
Access Road Right-of-way	324	55.6		8	158	8	8		
Flooded Area	34	55.6	125					5	891
Transmission Line Right-of-Way	850	52.5		8	680	8	8		

Table A7.2: GHG Releases & Sequestration from a Likely Emissions Scenario

Area of Land Change	GHG-releasing and GHG-sequestering Activities		Assumed GHG Emissions due to Construction & Operation Activities	Notes
	During Construction	During Operation		
Generating Station	▪ All vegetation cleared, *Note - Built infrastructure (concrete, asphalt etc.) covers entire land area*		100 % of carbon in vegetation (trees+shrub) released as CO_2	used as lumber (rather than being left to decay) GHG emissions may be higher if vegetation is burned[1].
Construction Area & Borrow Pits	▪ Some vegetation cleared, ▪ Some soil removed *Note – No built infrastructure*	▪ All vegetation re-grows ▪ All soil replaced	No net emissions (Trees, shrubs and soil are completely restored during operation, resulting in 0 net emissions)	.
Flooded Area	▪ All vegetation cleared ▪ Remaining peat and soil completely submerged under water *Note – No built infrastructure*	▪ No restoration	100% of carbon in cleared vegetation (trees+shrub) released as CO_2 60 % of carbon in submerged peat and soil released, of which 7% is CH_4 (anaerobic decay), 93% is CO_2. (aerobic decay)	Actual GHG emissions may be lower if a lesser proportion of submerged soil & peat decay, and if aerobic decay predominates. GHG emissions may be higher if a greater proportion of soil & peat decays, and if anaerobic decay is more common.
Access Road Right-of-Way	▪ All vegetation cleared *Note – Built infrastructure (road bed) covers fraction of total right-of-way*	▪ Shrubs re-grow ▪ No trees re-grow	100% of carbon in trees released as CO_2 (Shrubs are cleared during construction, but re-grow during operation, resulting in 0 net emissions).	Actual GHG emissions will be lower if trees are re-used as lumber (rather than being left to decay) GHG emissions may be higher if vegetation is burned[1].
Transmission Line Right-of-Way	▪ All vegetation cleared *Note – Built infrastructure (concrete tower foundations) covers fraction of total right-of-way*	▪ Shrubs re-grow ▪ No trees re-grow	100% of carbon in trees released as CO_2 (Shrubs are cleared during construction, but re-grow during operation, resulting in 0 net emissions).	Actual GHG emissions will be lower if trees are re-used as lumber (rather than being left to decay) GHG emissions may be higher if vegetation is burned[1].

[1] GHG emissions are higher if vegetation is burned since N_2O is produced. Some carbon may also be released to the atmosphere as CH_4 rather than CO_2 increasing the CO_2e value of overall emissions.

Appendix 8: Note on Units and Conventions Used in the Report

Units used in the analysis and in the presentation of results are given wherever figures are reported. Three general points may also be noted:

1. Masses are generally reported in **metric** tons (t). Where exceptions occur, these are denoted by the unit 'tons (US)'.

2. Greenhouse gas emissions are always reported in terms of 'carbon dioxide equivalents' or CO_2e. This measure takes into account the fact that different greenhouse gases have a different degree of effect on global warming. In particular, CH_4 and N_2O respectively have global warming factors of 21 and 310 times that of CO_2. Thus, quantities of CH_4 are multiplied by 21, before being added to the CO_2e total for a given system, and likewise for N_2O.

3. Fuel heating values (BTU/lb or BTU/m^3) and combustion efficiencies (kWh generated / BTU fuel) are always reported in terms of the Higher Heating Value (HHV) of fuel. The HHV gives the amount of energy that is released when a fuel at 25°C is (i) completely combusted to carbon dioxide (CO_2) and water (H_2O) and (ii) these products are cooled to 25°C. Any heat value and efficiency data that was expressed in other terms has been converted to HHV in this report, ensuring the full consistency of all calculations.

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3.0 PHYSIOGRAPHY, GEOLOGY AND SOILS

3.1 INTRODUCTION

The Guidelines for the Preparation of an Environmental Impact Statement (EIS) for the Wuskwatim Project (Manitoba Conservation 2002) require that the proponent shall describe:

- *local and regional land and geology; and*
- *the potential impacts of the project on the land.*

To address "*local and regional land and geology*", this section will provide an overview of the general physiography of the area including the general and site-specific geology and soils of the area.

To address "*potential impacts of the project on the land*", this section will focus on the direct effects of the Project on the physical land mass in terms of footprint area and use of local material to build the Project (i.e., granular borrow areas, rock excavations/quarries, etc.). Changes to the existing Water Regime (Section 4) and the potential effects of these changes are described in separate stand-alone sections in this Physical Environment Supporting Document, for example Wuskwatim Lake Erosion (Section 6), Riverine Erosion (Section 7) and Sedimentation (Section 8).

The major physical land-based components of the Project include the:

- access road to the Project site;
- construction camp and related infrastructure at the Project site; and
- construction and/or operation of the Project's primary and secondary structures (i.e., main dam, powerhouse, spillway, dyke, etc.).

This section also describes testing of the suitability of local construction materials for placement in an aquatic environment (i.e., granular materials and rock) and testing of excavated/quarried rock for its **leachability**.

In summary, the discussion in this section will focus mainly on how the Wuskwatim Project affects the physical land mass. As previously stated, changes in water regime and the potential effects of this change on the land mass are described elsewhere in this Volume. Potential indirect effects on wildlife or aquatic life associated with these physical effects are discussed in the Terrestrial and Aquatic Supporting Documents (Volumes 5 and 6, respectively).

3.2 APPROACH AND METHODOLOGY

The information described in this section comes from a synthesis of material from a variety of literature sources and personal communications with persons having knowledge of the **physiography**, **geology** and **soils** of the subject area. No field activities were conducted.

Information on material requirements, **footprint** areas and physical land types for the various component parts were obtained from the Project Description Supporting Document (Volume 3). The geology of the area was defined based on available provincial geology reports and site geological engineering studies. The Soils, Lands and Resource Unit, a joint federal and provincial agency, provided the general description of the soils of the area.

Previous geological investigations at the Wuskwatim site were carried out in four phases as follows (Norquay and Reynolds 2001):

- In mid 1960s - preliminary drilling and sampling program consisting of 13 drill holes (Gibb, Underwood and McLellan 1966);
- In 1971 - detailed foundation drilling and construction-material search program consisting of 265 drill holes (Manitoba Hydro 1972);
- In 1979 - definition of bedrock surface to evaluate the primary structure arrangement program consisting of 53 drill holes (Manitoba Hydro 1980);
- In 1985 - drilling program consisting of 13 drill holes, 137 auger holes, borrow investigations, bedrock probes, geological mapping and field surveys to acquire information to allow development of design criteria and cost estimates for Stage 3 studies (Manitoba Hydro 1986); and
- In 1999, additional site investigations conducted including the drilling of 27 diamond drill holes and 114 auger holes and a seismic refraction survey (Thomson and Sikora 1999).

Laboratory testing was also conducted on some of the construction materials (i.e., granular and rock fill), which are to be placed in the aquatic environment or become newly exposed to the atmosphere as part of the Project. The purpose of this testing was to determine the potential of this material to generate acidic **leachate** and/or release metals (Section 3.4.1.4). Testing was conducted by B.C. Research, an accredited laboratory that routinely conducts this type of analysis. Details are provided in Appendix A3.1 and Appendix A3.2.

3.3 EXISTING ENVIRONMENT

3.3.1 Physiography

The Wuskwatim Project site is located at Taskinigup Falls on the Burntwood River at the outlet of Wuskwatim Lake (Volume 3, Section 2.2). The Wuskwatim Lake area is part of the **Three Point Lake Ecodistrict** (Smith *et. al.* 1998). The area is underlain by **Precambrian bedrock** (complex of **gneisses** and younger **intrusive** material), which controls the physiography. Figure 5.3-27 in the Terrestrial Environment Supporting Document (Volume 6) shows the contour elevations around Wuskwatim Lake up to Early Morning Rapids and down to Opegano Lake. Figure 2.4-2 in the Project Description Supporting Document (Volume 3) provides a plan view of the construction site and shows more detailed contour elevations for this area. The general **topography** of the **region** has been considerably modified by the deposition of glacial **outwash** material and by glacial Lake Agassiz clays, which mantle the region. Rock **outcrops** are generally smooth and rounded, exhibiting glacial **striae** with a mean **azimuth** of 100^0 and minor glacial polish. Below the mantle of glacial material, the bedrock surface is characterized by irregular **undulations**. **Varved clays** predominate the area with thicknesses generally ranging from 0-10 m.

The general land cover in the Wuskwatim Study Area consists predominantly of closed forest with open treed areas, beaver flood and treeless wetlands and water (Section 3.3.3).

3.3.2 Geology

3.3.2.1 Regional Overview

The area in the vicinity of the Wuskwatim site is typical of the **Precambrian** Shield and does not differ greatly from the rest of the Churchill **Geological Province** of which it is part (Manitoba Hydro 1982). It is underlain by **high-grade**, regionally **metamorphosed** Precambrian rocks of the Early **Proterozoic** Kisseynew Gneiss **Belt** and is proximal to the north-northeast-trending Churchill-Superior Boundary Zone (Norquay and Reynolds 2001). The Burntwood **Suite** is the most extensive **supracrustal** component in the Kisseynew Belt and is predominantly composed of rocks that are the **metamorphic** equivalent of **greywacke** and **mudstone**.

The Burntwood Suite is overlain by the metamorphosed **alluvial** deposits of the Sickle **Group** in areas proximal to the Lynn Lake Belt, and by similar rocks of the Missi Group in areas proximal to the Flin Flon Belt (Norquay and Reynolds 2001). The high-grade equivalents of these rocks have been designated the Sickle Suite and the Missi Suite, respectively.

Subsequent to the deposition of the Burntwood rocks, the Kisseynew Belt was intruded by **ultramafic** to **felsic**, pre- to post-Sickle/Missi **plutonic** rocks. These plutonic rocks display a range of textures from **granoblastic** or gneissic (pre-**tectonic** intrusions) to **massive** or **foliated** (late-tectonic intrusions; Norquay and Reynolds 2001).

3.3.2.2 Local Overview

An overview of the geology of the Wuskwatim Lake area is shown in Figure 3.3-1. The bedrock consists of a complex of gneisses and younger intrusive material showing good interlocking **crystalline texture**, resulting in excellent rock strength characteristics. The bedrock is generally considered to be competent throughout the area and is generally masked by fine-textured glaciolacustrine sediments. Consequently, extensive bedrock outcrops are uncommon.

3.3.3 Soils and Permafrost

Clayey and fine silty, varved, **calcareous** glaciolacustrine sediments in the form of deep blankets and shallow **veneers** characterize the uplands (Smith *et al.* 1998). Course-textured non-calcareous to weakly calcareous **surficial** materials are limited. The district contains some sandy and gravelly glaciofluvial deposits and associated sandy glaciolacustrine sediments, and very limited areas of non-calcareous, sandy and cobbly till in the form of veneers and **pockets**. The shallow and deep **peatlands**, found in large and small basins and depressions and on lower slopes of uplands, invariably overlie clayey, **glaciolacustrine sediments** and are derived from sedges and brown mosses as well as from Sphagnum and feather mosses and forest debris.

Soils are predominantly complexes of **Gray Luvisols** developed in calcareous clayey surface materials and patches of very poorly drained deep and shallow **Mesisolic Organic** soils derived from sedge and woody peat (Smith *et al.* 1998). **Humic Gleysols** generally occur in the transition zone between Luvisols and Organic soils. Local pockets of well to excessively drained **Dystric Brunisols** have developed on deep glaciofluvial deposits (e.g. the ridges described below) or on shallow, sandy textured, stony veneers of water-worked glacial till.

Figure 3.3-2 shows the distribution of primary and secondary surface materials in the **Sub-Region**. Calcareous, **clayey** glaciolacustrine sediments are the most widespread and

LEGEND

- **5** Amphibolitic gneiss; dark grey and black, fine to coarse-grained gneiss; occurs as discontinuous layers, lenses and/or boudins; **5a** layered hornblende-diopside gneiss ± hypersthene; **5b** hornblende, plagioclase gneiss ± garnet, hypersthene; **5c** garnet amphibolite -meta-iron formation; coarse grained, thinly layered garnet-hornblende-hypersthene-diopside-quartz-plagioclase gneiss, local skarn; **5d**, 5c without garnet; **5e**, 5a + quartzite
- **4** Basic gneiss; dark grey. brown and green to black, fine- to medium-grained gneiss. Occurs as thin discontinuous layers and boudins within units 1-3 and 12; **4a** pyroxene amphibolite; **4b** pyroxene gneiss; **4c** hornblende-plagioclase gneiss
- **3** Diatectic greywacke gneiss (Diatexite); granitic to tonalitic gneisses with less than 25% rafts or schlieren of paragneiss (units 1 and 2). Granitoid fraction ranges from white pegmatite and/or aplite to grey coarsely granular segregations containing feldspar, biotite, garnet and cordierite; **3a** agmatite complex; mesocratic mobilizate; **3b** agmatite complex, leucocratic mobilizate; **3c** schlieren complex; **3d** nebulitic complex
- **2** Metatectic greywacke; interlayered sequence of paragneiss restite (unit 1) with 25-750;0 aplitic to pegmatitic segregations of garnetiferous tonalite to granite; **2a** psammite, semipelite and pelite restite; **2b** mainly semipelite restite; **2c** sheet complex with local dominant 'granitic' component; **2d** agmatite complex
- **1** Meta-greywacke gneiss; interlayered grey psammitic and semi-pelitic gneiss and pelitic schist with minor calc-silicate layers and boudins. Up to 250;0 vein lets, sills and dykes of granitic segregations; **1a** psammitic gneiss dominant; **1b** pelitic and/or semipelitic schist and gneiss dominant; **1c** weakly layered biotite gneiss ± garnet; **1d** quartz.plagioclase.hypersthene-biotite gneiss
- **13** Porphyritic pink quartz monzonite to monzonite; **13a** porphyroblastic quartz monzonite with magnetite and hornblende; **13b** porphyroclastic 13a with sillimanite and hematite; **13c** foliated quartz monzonite with magnetite, hornblende ± diopside ± hypersthene; **13d** pegmatitic complex with magnetite and hornblende; **13e** monzonite; **13f** pink equigranular gneissic quartz-rich quartz monzonite with pegmatitic and nebulitic patches
- **12** Granite to quartz diorite; white or pink foliated stocks, sills, dykes and veins occurring as mobilizate in migmatite (units 1,2 and 3), and larger independent bodies; **12a** white alaskite leucotonalite/leucogranite characterized by isolated garnet clots and bimodal pegmatite/granite fractions; **12b** grey, medium grained equigranular homogeneous biotite-rich granodiorite; **12c** pink sporadically porphyritic quartz monzonite; **12d** white, coarse grained leucotonalite/leucogranodiorite containing large isolated garnet clots surrounded by leucocratic haloes; **12e** light grey 'speckled' granodiorite; **12f** sillimanite-hematite bearing cataclastic derivative; **12g** augen gneiss
- fault (defined - unbroken line or approximate - broken line)

Figure 3.3-1: Geology of the Wuskwatim Lake area

Source: Manitoba Department of Mines, Natural Resources & Environment, Mineral Resources Branch (1979) abundant surface materials in the portion of the Sub-Region with surface material information. Polygons where clayey surface materials account for at least 85% of the polygon area cover 21% of the area (Table 3.3-1) while polygons with clayey materials as the only primary or secondary surface material cover 48% and 20% of the land area, respectively. Bog and **fen** are the next most abundant primary surface material categories. Polygons where either bog or fen interspersed with bog are the primary and/ or secondary surface material cover 22% and 50% of the land area, respectively. A very large bog and fen complex is found in the northeast quadrant of the Sub-Region (area outlined by dashed black line in Figure 3.3-2). Widespread to continuous high ice-content **permafrost** is found throughout the Sub-Region, primarily as **peat plateau** and **palsa bogs**, and, secondarily as veneer bogs. Continuous permafrost occurs within the primary surface materials in polygons that comprise 22% of the area. All of these polygons are peatland dominated. Permafrost may also occur under mature, closed forest cover, but ice content is generally low (Veldhuis *pers. comm.* 2002).

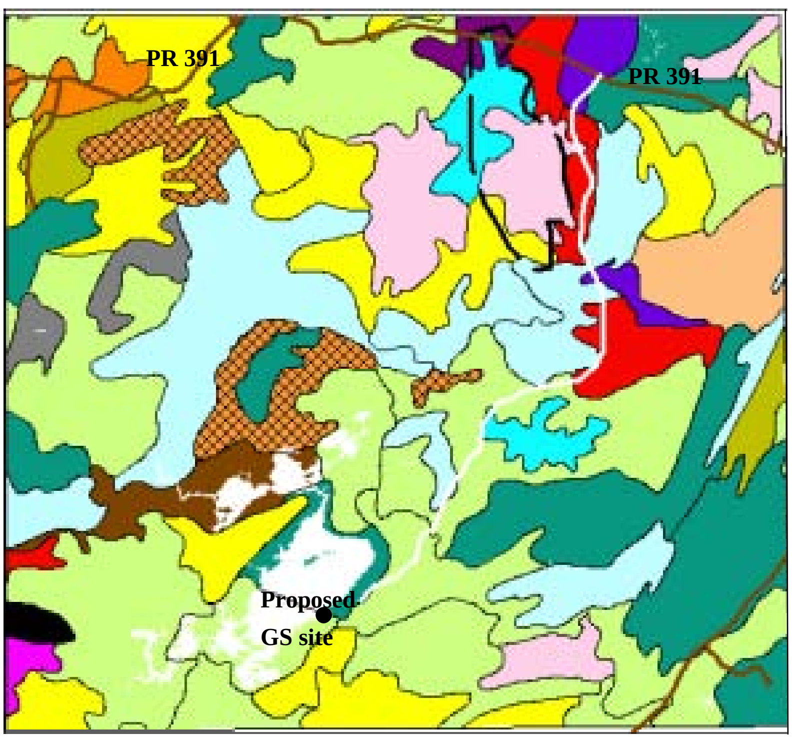

Figure 3.3-2: Distribution of primary and secondary surface materials in the Sub-Region.

Source: H. Veldhuis. 1:250,000 ecological land classification for NTS sheet 63O.

TABLE 3.3-1: Breakdown of the composition, area and percent coverage of surface materials shown in Figure 3.3-1.

SURFACE MATERIALS (PRIMARY/ SECONDARY)	AREA (ha)	PERCENT COVERAGE
All Materials	1,084	0
Bedrock/ Bog or Fen	3,830	1
Bog	1,093	0
Bog/ Weakly Broken, Deep Clayey	15,954	6
Fen	6,507	2
Fen/ Weakly Broken Clayey	38,986	14
Clayey- Deep, Moderately Broken / Fen & Bog	7,490	3
Clayey- Deep, Moderately Broken/ Deep Clayey	5,704	2
Clayey- Deep, Weakly Broken/ Bog & Fen	88,764	32
Clayey- Deep, Weakly Broken/ Clayey	39,900	14
Clayey- Shallow, Moderately Broken/ Deep Clayey	2,862	1
Clayey- Shallow, Moderately Broken/ Fen & Bog	17,404	6
Clayey- Shallow, Weakly Broken/ Bog & Fen	18,999	7
Clayey- Shallow, Weakly Broken/ Very Shallow Clayey	10,020	4
Sand- Deep, Weakly Broken	58	0
Sand- Very Weakly Broken/ Deep Sandy	8,944	3
Sandy- Deep, Weakly Broken/ All Materials	4,972	2
Silty- Deep, Weakly Broken	3,824	1
Silty- Shallow, Weakly Broken/ Fen & Bog	1,842	1
All Types	278,238	100

A flat-topped ridge of wave-washed, glaciofluvial material (**interlobate ridge**) runs in a roughly north-south to north-northeast direction, adjacent to and east of the large bog and fen complex (Figure 3.3-2). The access road to the Project site will be located on the eastern side of the southern end of this ridge. The largest borrow areas (proposed to provide material for Project construction; Volume 3, Section 3.7) are also located on the side of this ridge (see sand areas in Figure 3.3-2).

As previously indicated in Section 3.3.2.2, bedrock outcrops occur throughout the Sub-Region, but are uncommon. Bedrock in these areas generally has a thin cover of clayey glaciolacustrine sediments and some shallow till deposits. Areas with bog, fen, silty and sandy dominated surface material types are uncommon in the Sub-Region.

3.3.4 Local Granular Deposits

Granular material is one of the two principle materials that will be used for constructing the proposed generating station, the other being rock. Investigations were carried out to identify granular sites within close proximity of the Project site. These studies indicated that there are principally 3 nearby deposits, namely Deposit G, H and J within 20 to 30 km of the site (Volume 3, Section 4.5, Figure 4.5-1). As discussed in Volume 3, Section 4.5, all of these deposits have sufficient quantities of granular material to meet the needs of the Project, however, some deposits are better suited for producing concrete than others.

Granular material required to construct the site access road will come from local **borrow pits** close to the access road.

3.4 EFFECTS ASSESSMENT AND MITIGATION

The Project will affect the physical environment both during construction (e.g., excavation activities, roads, camp, generation station, etc.) and after operation (e.g., flooding of lands). The following section details these effects. Changes to the abiotic or physical characteristics may in turn affect biotic factors (i.e., vegetation, animals, fish, etc.) to varying degrees. As discussed in the Introduction (Section 3.1), however, potential indirect effects on other environments (e.g., aquatic, terrestrial, socioeconomic) and/or resource use are discussed in the respective EIS Supporting Documents describing and discussing these areas (i.e., Volumes 5 through 8).

3.4.1 Construction

The proposed construction program and schedule for the Wuskwatim Generation Station is discussed in the Project Description Supporting Document (Volume 3, Section 4). The potential effects of the construction work are primarily related to modifications to the local environment surficial soils and geology.

The following components from the construction of the Wuskwatim Generating Station Project will create changes on the physical environment:

- access road(s);
- site clearing for Project infrastructure (including construction camp and contractor work site), immediate forebay and generating station;
- off-site construction material extractions (e.g., granular materials);
- generating station construction (excavation, powerhouse and spillway structures, dyke, main dam);
- excavated material placement area (i.e., excess rock and overburden); and
- channel excavations at Wuskwatim Falls to improve flow conveyance.

Section 3.3.3 identified that high ice-content permafrost may be encountered in moderate and deep bog formations. It is not anticipated that extensive permafrost will be encountered in areas of the construction infrastructure or where the permanent Project will be located. All overburden will be removed in the footprint area of the generating station so it can be founded on bedrock. It is possible that the access road may encounter permafrost sections as it crosses bog formations. Depending on the extent of the permafrost present, mitigative measures to minimize permafrost thawing may be required (Volume 3, Section 4.6.3.3).

3.4.1.1 Access Road

Access to the generation site will be provided by the construction of a 48-km (479 ha) long gravel-surfaced all-weather access road leading from Provincial Road 391 to the site (Volume 3, Section 4.6.3 and Figure 4.6.3-1). The proposed access road will be very similar to the existing PR 391. As indicated in Section 3.3.3, the proposed access road will be constructed along an existing glaciofluvial ridge. This will minimize routing through wetland areas and avoid environmental sensitive areas such as caribou-calving sites (see Terrestrial Environment Supporting Document, Volume 6).

Road construction will follow Manitoba Transportation and Government Services' "Grading and Surfacing Specifications" and will basically involve clearing of a right-of-way (approximately 60 to 100 m wide depending on sight distances and alignment), stripping of organics under the roadbed, placement of clay fill to build up roadbed and topping with 600 mm of granular fill. Clay and granular fill will come from borrow sites along the access road.

The roadway will be broken into two portions: a northern portion from PR 391 to the main granular borrow areas which will be constructed with a normal 9.4 m top width; and a southern portion from the granular borrow sites to the GS site that will have a 13.4 m top width to facilitate the increased truck haulage on this section of the road.

A variety of measures are proposed to reduce erosion. These include: seeding of exposed surfaces, stone riprap at culvert inverts and on steep ditch slopes, straw erosion control blankets on grade and backslopes for soils with high erodibility etc (Volume 3, Section 4.6.3).

3.4.1.2 Project Clearing

The amount of land required for the construction, operation and maintenance of Wuskwatim Generation Station (excluding the permanent transmission lines and associated works) are summarized in Volume 3, Table 2.3-1. The total area of land required for the construction of the Project supporting infrastructure and permanent facilities is 147 ha.

Project clearing is described in Section 4.4.1 of Volume 3. Grubbing, which is the removal of roots and top organic layer, will only be undertaken where essential. Areas that are anticipated to require grubbing include areas that will be occupied by the generation-station structures, site infrastructure and access roads.

Clearing, grubbing and disposal of non-merchantable timber will be undertaken in compliance with government guidelines and in accordance with the Project's **EnvPP**. As described in Project Description Supporting Document (Volume 3, Section 4.4.1), merchantable wood will be salvaged where economically feasible; see also the Terrestrial Environment Supporting Document (Volume 6).

3.4.1.3 Construction Materials

To construct the Wuskwatim Generation Station and the supporting infrastructure will require the use of naturally occurring materials, such as sand (granular) and silty clay (impervious), or manufactured materials from *in situ* excavated and/or crushed rock (i.e., rockfill, riprap and concrete aggregate).

Required excavation of the overburden and rock for the powerhouse and spillway structures will provide for all the rock and impervious fill requirements for the Project. The required excavations will generate surplus material that will have to be disposed of in an excavated materials placement area (Section 3.4.1.6).

The only material not available on-site is granular or sand fill. It is estimated that the Generating Station and site infrastructure (excluding access road) will require approximately 329,000 m^3 of granular material (Volume 3, Table 4.5-1). As discussed previously in Section 3.3.4, there are 3 granular deposits, Deposits G, H, and J within close proximity of the site (Volume 3, Figure 4.5-1). These resources are non-renewable, however, the estimated quantity of granular materials to be used in construction is only 5.6% of local available granular materials. Following construction borrow sites will be rehabilitated as described in the EnvPP and the Manitoba *Mines & Minerals Act* (1991; C.C.S.M. c.M162). The use of granular resources for the Project is therefore considered to be a long-term, localized and small effect with respect to granular resources in the area.

Sand and rock materials have been tested for their suitability for placement in an aquatic environment. Details are provided in Appendix 3A-1 and Appendix 3A-2. The sand-sample materials were tested for the potential for long-term metals leachability and the rock material was tested for its acid-leachate potential.

As outlined in Appendix A3.1, 23 sand borrow samples were tested for a number of constituents. The results of the testing indicated that some samples contain metal concentrations (specifically aluminum, cadmium, copper and thallium) that exceed draft Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOG). To determine the significance of these results, the detected concentrations were compared to the respective natural **background** concentrations of the metals in the water column. The results indicate that the concentrations of aluminum found to leach from the borrow materials do not exceed the Wuskwatim area natural background concentrations and, therefore, are not of significant environmental concern (Table A3.1-2). Copper concentrations found to leach from the borrow materials, however, require a 2 to 11x dilution to meet average natural background copper concentrations in the Wuskwatim area and a dilution of 1.1 to 7x to meet the draft copper MWQSOG (Table A3.1-2). These dilution rates would be achievable in the Burntwood River and Wuskwatim Lake.

As outlined in Appendix A3.2, rock samples have been tested for their potential to generate acidic **runoff** because the bedrock is similar to those seen in nickel, copper, zinc and lead ore mines located at INCO in Thompson, MB; at HBM&S in Flin Flon, MB; and at Lynn Lake, MB, all of which have experienced acid-generating rock problems. Importantly, though, the rock at Wuskwatim does not generally contain the same nickel, copper, zinc and lead minerals as seen in these mining areas.

Acidic runoff may be generated as a result of weathering of iron and sulphur-containing minerals (like iron pyrite, or “fools gold”) when previously unexposed rock is exposed to air and water, and the action of soil bacteria. The process depends on the size of the rock pieces; fine pieces are usually a greater source of acid than coarse pieces. Mining methods intentionally finely crush the rock to extract ore minerals, thereby producing fine rock wastes, whereas construction activities intentionally produce generally coarse material through blasting and fine material through rock crushing (e.g., to create concrete aggregate). Acidic runoff is therefore more commonly associated with mining, though activities at construction sites that produce fine material that will not be used (e.g., size fraction of fine material that is not appropriate for concrete use) should also be evaluated.

Given the potential for acid-runoff generation in the general area and that Project construction activities will produce some “unusable” or waste fine material as a result of concrete aggregate production, 24 rock samples were tested. The basis for sample selection is described in Appendix A3.2. Initial results from testing indicated that the potential for acid-leachate generation existed in at least one 5-m interval in 5 of 8 **boreholes** tested (Appendix A3.2). This initial assessment did not indicate the rates of **weathering** of sulphur and metals; accordingly, three samples were submitted for a weathering (or "kinetic") test to estimate how quickly sulphate, metals and acid might be released.

During 20 weeks of kinetic testing, all three samples generated non-acidic water containing low concentrations of metals. The test results indicate that the sulphur-weathering rate could be estimated from the sulphur content of the sample. Based on these test results, it is projected that rock with a sulphur concentration less than about 0.2% will not weather rapidly enough to produce acid. On the other hand, rock with a sulphur content >0.3% could eventually generate acidic water, however, this could take years or even decades. If acid generation did occur in the future from rock containing greater than 0.3% sulphur, the runoff would probably contain metals like iron and aluminum; metals like copper and zinc would only be released in low concentrations, based on the overall low metal concentrations in the rock samples tested.

The test results for those samples located in areas that are to be excavated as part of Project construction do not generally contain elevated sulphur levels (i.e., sulphur concentrations greater than 0.3%; Appendix A3.2). Given that the distribution of sulphur in all of the rock to be excavated is not fully understood, and that the unusable fine rock material generated from the processing of rock for concrete aggregate will be collected in settling pond(s) on the Project site and then moved into the excavated materials placement area (see Appendix A3.2), it is recommended that the fine-rock material be amended with crushed limestone (e.g., in a settling pond(s)). The addition of crushed limestone will augment the natural acid-neutralizing capacity of the rock, thereby reducing the potential for acidic leachate generation in the future.

3.4.1.4 Main Construction Camp and Construction Facilities

To support construction of the Wuskwatim generating station will require the following facilities (Volume 3, Section 4.6 and Figure 4.6-4):

- construction camp and associated infrastructure;
- contractor's work area;
- Manitoba Hydro work area; and,
- on-site access roads.

As described in Section 3.4.1.2, the above sites will be cleared and grubbed to mineral soils to provide adequate foundations for the various facilities. During clearing, merchantable timber will be salvaged where economically feasible. The organic layer that is stripped will be stockpiled for later use to assist in natural re-growth of the site following decommissioning of the construction site. Details of site **rehabilitation** are discussed in the Project EnvPP.

As described in Project Description Supporting Document (Volume 3, Section 4.6.4), the main construction camp includes a full service 625-person mobile trailer camp with water treatment plant and sewage lagoon. The camp will also include additional areas for a recreation/training building, a gymnasium, a helicopter land pad and recreation fields for baseball and soccer.

The contractor's work area will contain the contractor's office trailers, storage facilities, maintenance shops, a fuel storage and vehicle-refueling facility, concrete batch plant, an aggregate processing area, a carpenters' shop, a pre-cast concrete storage yard, as well as explosives magazine. The EnvPP will specify provincial and federal regulations with respect to storage of fuels, explosives etc. that be adhered to by Manitoba Hydro and its contractors.

3.4.1.5 Generation Station

The Project Description Supporting Document (Volume 3) divides the generation station into two principal components: primary structures and secondary structures. Primary structures consist of the spillway, powerhouse and various dam sections (non-overflow gravity, main dam and transition structures), while secondary structures include the channels for the spillway, powerhouse and upstream channel excavations. The Generating Station's structures (i.e., spillway, powerhouse, dam, etc.) will have a final footprint of approximately 18 ha. Materials not used in the construction of these structures will be disposed in the excavated material placement area (Section 3.4.1.6).

As indicated in Section 3.4.1.4, following Project construction, much of the supporting infrastructure used to build the generation station will be removed and the areas affected by this infrastructure will be rehabilitated as defined in the EnvPP.

3.4.1.6 Excavated Material Placement Area

The construction of the powerhouse and the spillway for the Project will require the excavation of over 817,000 m^3 of overburden (mostly silty-clay) and the excavation of 806,000 m^3 of bedrock. While a portion of this material can be used in the construction of the Project (i.e., 146,000 m^3 of the silty clay can be used as impervious fill for the Project and 414,000 m^3 of rock can be used in various aspects of Project), approximately

1,063,000 m^3 of material will require disposal near the immediate site (Volume 3, Section 4.5.1 and Table 4.5-1).

It is proposed that excess material would be placed in a 43-**ha** area immediately north of the Generating Station (Volume 3, Figure 4.5-1). The excavated material placement area would be approximately 1,100 m long by 600 m wide and the material could be placed to a height of up to 8 m. The central portion of the placement area would consist mostly of the silt and clay overburden material and rock-filled berms would be used at both ends of the placement area to prevent erosion (Volume 3, Figure 4.5-1). Organic material removed during the initial excavation will be placed on top of the excavated material placement area to promote natural re-growth. It is anticipated that due to the nature of the material being placed in the disposal and the method of placement (i.e., end dumping) that over time there will be differential settling in the excavated material placement area and likely creating an undulating surface to the placement area.

3.4.1.7 Channel Excavations

The immediate forebay of the Wuskwatim Generation Project is separated from Wuskwatim Lake by Wuskwatim Falls, which will be flooded out with the Project. To maintain water levels on Wuskwatim Lake at or near the 234.0 m elevation under high-flow conditions on the CRD, it will be necessary to improve the hydraulic conveyance capacity at Wuskwatim Falls. This will be accomplished by constructing a channel through a bedrock peninsula on the east side of the falls (Volume 3, Section 4.8 and Figure 4.8-1). The channel will be approximately 125 m wide and the floor of the excavation will be 229 m. The excavation will require the removal of approximately 60,000 m^3 of overburden and 95,000 m^3 of rock, with the material being placed in the excavated material placement area (Section 3.4.1.6). Blasting will be used to break up the rocks for removal (Volume 3, Section 4.5.1).

3.4.1.8 Summary of Physical Effects from Project Construction

Project construction and its resulting final footprint on the physical landscape (both land and river bottom) will create an unavoidable, long-term, localized effect on the physical environment. The significance of the changes to the physical environment to the aquatic, terrestrial and socioeconomic environments and resource use is discussed in Volumes 5 through 8.

Following Project construction, the supporting infrastructure used to build the generating station will be removed and areas rehabilitated as defined in the EnvPP. Borrow areas will also be rehabilitated as defined in the EnvPP and the Manitoba *Mines & Minerals*

Act (1991; C.C.S.M. C.M162). The physical effects of the Project infrastructure on the physical environment are therefore considered localized and short-term.

3.4.2 Operation

The completion of the Wuskwatim Project will result in water levels rising 7 m in the immediate forebay of the Generating Station and the flooding of 37 ha of land between Wuskwatim Falls and Taskinigup Falls (Volume 3, Table 4.4-1 and Figure 4.2-10). This area will be cleared of trees in the September to December 2008 timeframe just prior to impoundment. As a result of the Project, Taskinigup and Wuskwatim Falls will no longer exist. This is an unavoidable effect of the Project. The significance of this effect to the aquatic, terrestrial, and socio-economic environments and resource use is discussed in Volumes 5 through 8.

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APPENDIX A3.1

SUMMARY OF GRANULAR-BORROW MATERIAL TESTING

ASSESSING ENVIRONMENTAL SENSITIVITY OF GRANULAR BORROW MATERIAL

Both the Canadian Council of Ministers of the Environment (CCME 1999) and the provinces provide guidance on sediments in an aquatic environment. Ontario goes further in providing guidelines for evaluating the "suitability" of fill to be placed in an aquatic environment.

Early leachate testing of Wuskwatim area borrow material by Manitoba Hydro yielded inconclusive results for comparison with 2001 Draft Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOG; Manitoba Conservation 2001). Additional testing was therefore recommended and undertaken to further characterize any potential environmental issues that could be associated with the utilization of the aggregate material in the Wuskwatim area (Tetr*ES* 2002). A total of 23 samples (7 samples from H-west and 16 samples from the larger J site; Figures A3.1-1 through A3.1-3) were chosen based on availability and even spatial distribution over each deposit-site area for Meteoric Water Mobility Procedure (MWMP) analysis (Tetr*ES* 2002).

The MWMP analysis is designed to evaluate the potential for dissolution and mobility of certain constituents from the samples by meteoric water and to determine the suitability of the borrow materials for use in the proposed applications during the construction of the Wuskwatim GS. A detailed description of the procedure is provided in Attachment A to the report (Tetr*ES* 2002). This method was chosen over the Receiving Water Simulation Test (RWST) because RWST results often do not provide much information with respect to the prediction of future problems because the dilution factor is very high (i.e., many parameters are reported as being below detection limits; Day, *pers. comm.*, 2002).

The MWMP analytical results are provided in Table A3.1-1. Comparison of the results to both the guidelines stipulated by CCME (1999) and the province (i.e., draft MWQSOG; Manitoba Conservation 2001) for freshwater aquatic life (Table A3.1-2) indicates that:

- some samples contain leachable metals concentrations (specifically aluminum, cadmium, copper and thallium) that exceed CCME guidelines and/or the draft MWQSOG; and
- one sample also contains leachable mercury at a concentration equal to the instrument-detection limit and equal to the stipulated guideline (i.e., 0.1 ppb).

To determine the significance of the two metals found to exceed both the CCME guidelines and MWQSOG (i.e., copper [14/22 samples analyzed] and aluminum [7/22 samples analyzed]; Table A3.1-2), the natural background concentrations of these two metals in the aquatic environment at Wuskwatim were examined; consistent with the application of the Ontario guidelines. As indicated in the "Aquatic Environment Support Document – Water and Sediment Chemistry" report (Volume 5) concentrations of some metals (including aluminum and iron) *"…are elevated in the Study Area as a whole …at least an order of magnitude above MWQSOGs for the protection of aquatic life…"* and states: *"both have been elevated in this system for decades…"*. With respect to other metals/metalloids (e.g., copper), Volume 5 reports that, at times (two measurements at Birch Tree Lake, one measurement at Wuskwatim Lake), these have been *"…elevated above MWQSOGs for the protection of aquatic life in the Study Area…"*.

The concentrations of aluminum found to leach from the borrow materials do not exceed the Wuskwatim area natural background concentrations and, therefore, are not of significant environmental concern (Table A3.1-2). Conversely, the copper concentrations found to leach from the borrow materials require a 2 to 11x dilution to meet the "average" natural background copper concentrations in the Wuskwatim area and a dilution of 1.1 to 7x to meet the draft copper MWQSOG (Table A3.1-2). These dilution rates would be achievable in areas adjacent to the Burntwood River or Wuskwatim Lake. These rates, however, may not be achievable with respect to land-drainage areas to tributaries. Alternatively, those areas identified as containing elevated copper concentrations could be avoided (i.e., no granular-borrow materials mined from these areas).

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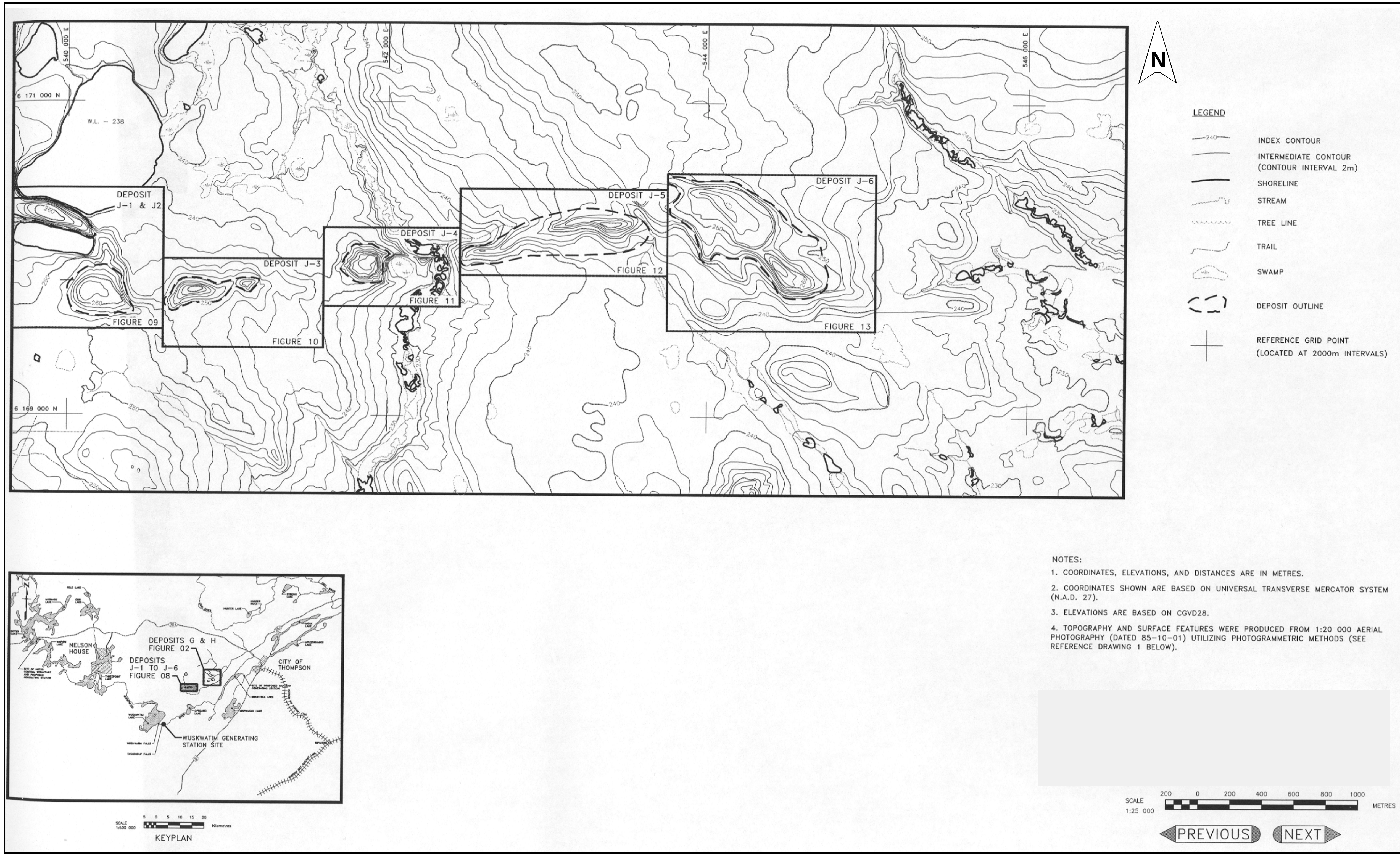
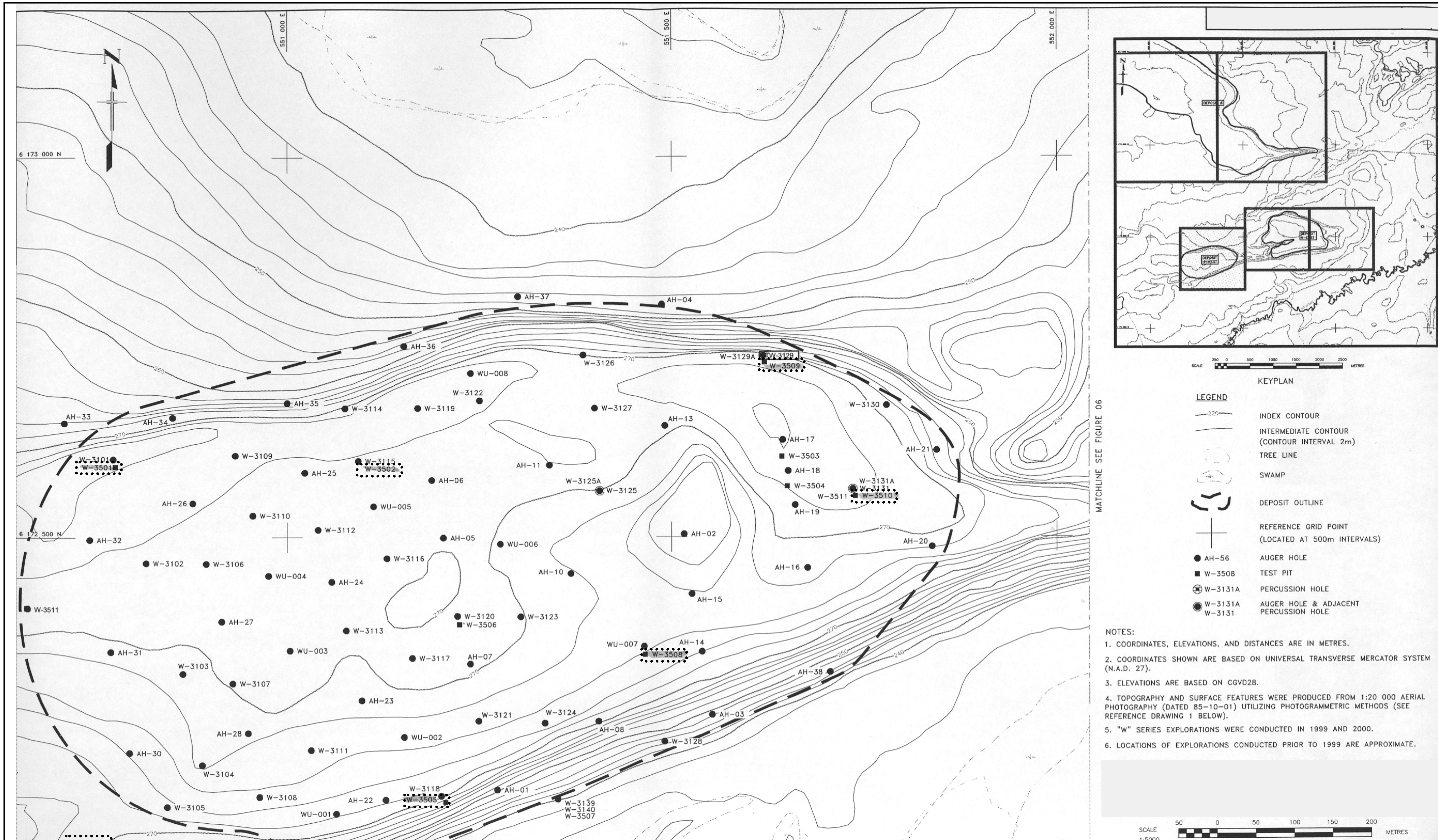


Source: ACRES, 2001

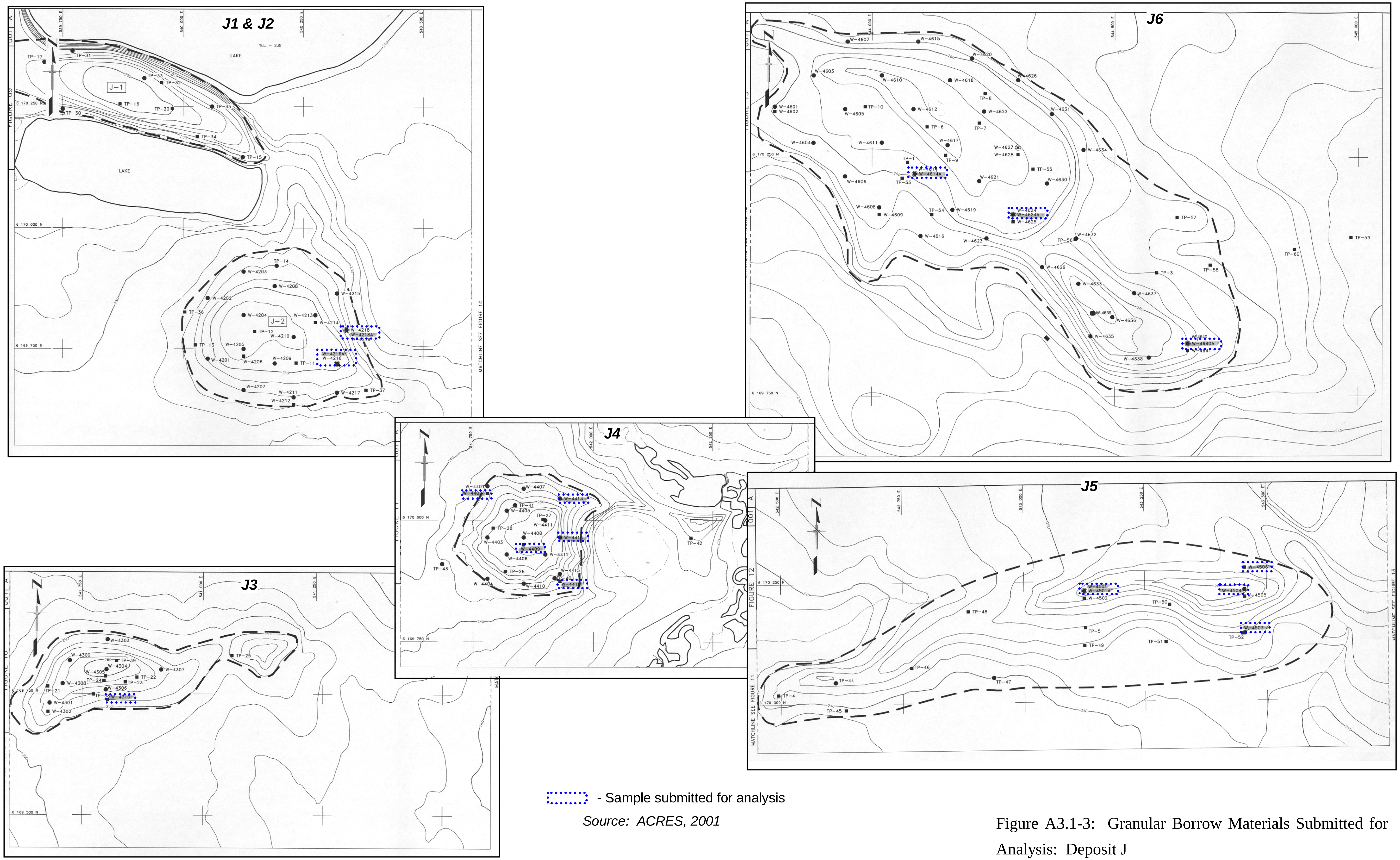
Figure A3.1-1: Location of Granular Borrow Deposits



Source: *ACRES, 2001*

- Sample submitted for analysis

Figure A3.1-2: Granular Borrow Materials Submitted for Analysis: Deposit H-West



- Sample submitted for analysis

Source: ACRES, 2001

Figure A3.1-3: Granular Borrow Materials Submitted for Analysis: Deposit J

wuskleach3; ms\01\0221\29

TABLE A3.1-1: Meteoric Water Mobility Procedure on Selected Wuskwatim Samples

Charge Dry Wt.: 5.00 Kg.
Input pH: 5.00

Sample	Eff. pH	Sulphate (mg/L)	Alkalinity ($mgCaCO_3/L$)	Ag ppb	Al ppb	As ppb	Au ppb	B ppb	Ba ppb	Be ppb	Bi ppb	Br ppb	Ca ppb	Cd ppb	Ce ppb	Cl ppm	Co ppb	Cr ppb	Cs ppb	Cu ppb
4310	7.96	3	57	< .05	23	< 1	< .05	< 20	14.63	< .05	< .05	32	24831	< .05	0.01	< 1	0.03	< .5	0.04	2.2
4409	6.16	4	7	< .05	352	< 1	< .05	< 20	18.32	< .05	< .05	16	4262	< .05	9.32	< 1	0.87	2.7	< .01	12.4
4501A	7.73	4	29	< .05	25	< 1	< .05	< 20	4.96	< .05	< .05	45	10221	0.21	0.03	< 1	0.19	1.8	< .01	2.4
3510	8.00	5	74	< .05	40	1	< .05	< 20	19.7	< .05	< .05	26	28074	0.35	0.2	5	0.09	1.1	< .01	7.6
4614A	7.75	5	20	< .05	54	1	< .05	< 20	3.99	< .05	< .05	25	4797	0.38	0.07	4	0.06	1.8	0.01	2.4
3508	7.88	6	42	< .05	126	1	< .05	< 20	9.51	0.21	< .05	21	14053	0.3	1.21	3	0.17	1.5	< .01	23.2
4218A	7.93	9	64	< .05	28	1	< .05	< 20	10.76	0.21	< .05	22	20041	0.81	0.01	4	0.25	1	0.01	5.2
4501	7.67	8	39	< .05	170	< 1	< .05	< 20	9.45	< .05	< .05	37	8004	0.38	1.29	3	0.34	2	< .01	17.2
4624A	7.98	8	37	< .05	91	< 1	< .05	< 20	6.16	< .05	< .05	16	11618	0.5	< .01	3	0.03	1.3	0.01	1.2
3501	6.64	3	5	< .05	41	< 1	< .05	< 20	3.51	< .05	< .05	12	1469	0.19	1.78	3	0.28	0.8	< .01	7.9
3502	6.91	3	7	< .05	93	< 1	< .05	< 20	5.36	< .05	< .05	15	2452	0.25	2.85	1	0.26	0.9	< .01	12.2
3505	7.41	9	27	< .05	122	< 1	< .05	< 20	10.85	0.43	< .05	27	10106	0.25	10.49	1	0.71	2.7	< .01	44.4
3509	7.05	<1	6	< .05	50	< 1	< .05	< 20	1.35	< .05	< .05	6	1825	0.16	0.07	1	0.41	0.9	< .01	1.9
4413	7.75	3	38	< .05	191	< 1	< .05	< 20	4.83	< .05	< .05	18	10738	0.19	0.17	1	0.06	2.1	< .01	7.7
4416	7.73	3	38	< .05	51	< 1	< .05	< 20	4.7	0.21	< .05	14	8911	0.09	0.04	1	0.33	0.8	< .01	7.3
3137	7.97	7	53	< .05	74	3	< .05	< 20	13.56	< .05	< .05	59	17249	0.15	0.39	4	0.1	1.4	< .01	8.3
4414	7.87	5	62	< .05	69	< 1	< .05	< 20	11.64	< .05	< .05	27	20817	0.12	0.11	2	0.09	1.8	< .01	11.2
4503	7.71	4	106	< .05	44	1	< .05	< 20	22.82	0.22	< .05	38	31667	0.24	1.43	2	0.23	2.5	< .01	25.5
4504	7.63	5	44	< .05	166	< 1	< .05	< 20	8.06	< .05	< .05	32	10414	0.17	1.3	2	0.23	1.4	< .01	14.5
Blank	4.99	<1	<1	< .05	1	< 1	< .05	< 20	0.11	< .05	< .05	< 5	100	0.1	< .01	1	< .02	< .5	< .01	0.2
4402	7.83	2	72	< .05	131	< 1	< .05	< 20	16.14	< .05	< .05	19	18305	0.13	0.66	1	0.14	1.2	< .01	11.2
4216A	7.81	5	43	< .05	48	< 1	< .05	< 20	7.57	0.22	< .05	29	12439	0.6	0.02	2	0.55	1.3	< .01	3
4640A	7.40	4	39	< .05	212	1	< .05	< 20	8.81	< .05	< .05	27	9318	1.03	0.26	2	0.35	1	< .01	5.7
Duplicates																				
RE 4640				< .05	202	1	< .05	< 20	8.97	< .05	< .05	28	9565	1.08	0.25	2	0.34	1	< .01	5.6
RE 3505				< .05	122	< 1	< .05	< 20	10.35	< .05	< .05	29	9932	0.24	10.35	1	0.72	2.9	< .01	45.7
3509		<1																		
4503		4																		
4402			69																	
3137			5																	

Sample	Dy ppb	Er ppb	Eu ppb	Fe ppb	Ga ppb	Gd ppb	Ge ppb	Hf ppb	Hg ppb	Ho ppb	I ppb	In ppb	Ir ppb	K ppb	La ppb	Li ppb	Lu ppb	Mg ppb	Mn ppb	Mo ppb	Na ppb	Nb ppb
4310	< .01	< .01	< .01	< 10	< .05	< .01	< .05	< .02	< .1	< .01	5	< .01	< .05	1812	< .01	6	< .01	4698	1.51	9.5	3132	< .01
4409	0.65	0.34	0.37	136	< .05	0.9	< .05	0.07	< .1	0.12	8	< .01	< .05	990	6.06	1	0.04	2103	70.53	0.4	853	0.01
4501A	< .01	< .01	< .01	< 10	0.07	< .01	< .05	< .02	< .1	< .01	3	< .01	< .05	1682	0.02	3	< .01	5110	77.6	2.1	4879	< .01
3510	0.01	< .01	< .01	33	0.11	0.02	< .05	< .02	< .1	< .01	8	< .01	< .05	1673	0.26	< 1	< .01	4001	21.68	4.7	1863	< .01
4614A	< .01	< .01	< .01	12	0.15	0.01	< .05	< .02	< .1	< .01	2	< .01	< .05	1619	0.07	3	< .01	2215	13.12	3.1	3477	< .01
3508	0.23	0.15	0.09	64	0.13	0.33	< .05	0.02	< .1	0.05	4	< .01	< .05	1799	2.08	2	0.02	2963	6.99	0.8	1022	0.01
4218A	< .01	< .01	< .01	12	0.14	< .01	< .05	< .02	0.1	< .01	2	< .01	< .05	3844	0.01	8	< .01	5456	58.09	2.1	3887	< .01
4501	0.05	0.03	0.03	181	0.11	0.07	< .05	< .02	< .1	0.01	7	< .01	< .05	1721	1.01	1	< .01	4264	37.57	2.7	6607	0.02
4624A	< .01	< .01	< .01	< 10	0.12	< .01	< .05	< .02	< .1	< .01	1	< .01	< .05	2999	< .01	6	< .01	2768	11.74	2.9	1637	< .01
3501	0.07	0.04	0.05	39	< .05	0.12	< .05	< .02	< .1	0.01	2	< .01	< .05	586	1.05	1	< .01	454	29.11	0.5	796	< .01
3502	0.13	0.08	0.09	70	< .05	0.26	< .05	< .02	< .1	0.03	5	< .01	< .05	933	2.22	1	0.01	749	23.73	0.7	1104	0.01
3505	0.46	0.23	0.21	93	0.07	0.72	< .05	0.05	< .1	0.09	6	< .01	< .05	867	8.02	< 1	0.03	2727	66.18	0.9	1607	0.02
3509	< .01	< .01	< .01	18	< .05	< .01	< .05	< .02	< .1	< .01	< 1	< .01	< .05	438	0.04	< 1	< .01	253	6.72	0.2	290	< .01
4413	< .01	< .01	< .01	31	0.2	0.02	< .05	< .02	< .1	< .01	2	< .01	< .05	1779	0.14	< 1	< .01	1872	0.86	1	2509	< .01
4416	< .01	< .01	< .01	< 10	0.12	0.01	< .05	< .02	< .1	< .01	2	< .01	< .05	1511	0.06	3	< .01	3139	5.63	1.2	1091	< .01
3137	0.01	< .01	< .01	50	0.23	0.03	< .05	< .02	< .1	< .01	3	< .01	< .05	2106	0.27	1	< .01	2118	4.92	2.5	6612	0.01
4414	0.01	< .01	< .01	< 10	0.18	0.01	< .05	< .02	< .1	< .01	3	< .01	< .05	2608	0.1	2	< .01	3422	8.73	2.6	3739	< .01
4503	0.09	0.06	0.04	48	< .05	0.14	< .05	0.02	< .1	0.02	8	< .01	< .05	2749	1.53	2	< .01	6453	8.87	3	6281	0.01
4504	0.04	0.02	0.02	182	0.21	0.07	< .05	< .02	< .1	< .01	4	< .01	< .05	2144	1.1	< 1	< .01	3191	14.92	2.3	5121	0.02
Blank	< .01	< .01	< .01	< 10	< .05	< .01	< .05	< .02	< .1	< .01	< 1	< .01	< .05	< 50	< .01	< 1	< .01	< 50	0.07	< .1	< 50	< .01
4402	0.04	0.01	0.01	74	0.14	0.06	< .05	< .02	< .1	< .01	3	< .01	< .05	2396	0.61	< 1	< .01	6674	13.2	2.3	1244	0.01
4216A	< .01	< .01	< .01	< 10	0.19	< .01	< .05	< .02	< .1	< .01	< 1	< .01	< .05	2923	0.02	5	< .01	4716	39.9	1.7	3544	< .01
4640A	< .01	< .01	< .01	116	0.09	0.02	< .05	< .02	< .1	< .01	3	< .01	< .05	2049	0.13	2	< .01	4243	101.1	5.4	4726	0.01
Duplicates																						
RE 4640	< .01	< .01	< .01	123	0.11	0.01	< .05	< .02	< .1	< .01	3	< .01	< .05	2107	0.12	3	< .01	4323	104.1	5.5	4661	0.01
RE 3505	0.48	0.23	0.22	100	< .05	0.71	< .05	0.06	< .1	0.08	6	< .01	< .05	850	7.96	2	0.03	2787	68.48	1	1629	0.02
3509																						
4503																						
4402																						
3137																						

Note: Sample 4506 did not drain sufficiently to obtain extract.

Table 4: Continued

Sample	Nd ppb	Ni ppb	Os ppb	P ppb	Pb ppb	Pd ppb	Pr ppb	Pt ppb	Rb ppb	Re ppb	Rh ppb	Ru ppb	Sb ppb	Sc ppb
4310	< .01	< .2	< .05	< 20	0.2	< .2	< .01	< .01	0.72	< .01	< .01	< .05	0.18	0.76
4409	6.46	4.6	< .05	78	0.5	< .2	1.52	< .01	1.96	< .01	< .01	< .05	< .05	1.53
4501A	0.03	0.7	< .05	< 20	< .1	< .2	< .01	< .01	0.77	< .01	< .01	< .05	< .05	0.18
3510	0.2	< .2	< .05	58	0.1	< .2	0.05	< .01	1.62	< .01	< .01	< .05	0.89	1.59
4614A	0.05	0.2	< .05	< 20	0.2	< .2	0.01	< .01	0.36	< .01	< .01	< .05	< .05	1.46
3508	2.54	2.9	< .05	49	0.1	< .2	0.54	< .01	1.19	< .01	< .01	< .05	0.16	1.69
4218A	0.01	1	< .05	28	0.1	< .2	< .01	< .01	1.4	< .01	< .01	< .05	0.06	2.02
4501	0.84	2.1	< .05	47	0.3	< .2	0.2	< .01	0.65	< .01	< .01	< .05	< .05	2.11
4624A	< .01	< .2	< .05	< 20	0.3	< .2	< .01	< .01	0.7	< .01	< .01	< .05	< .05	0.93
3501	1.45	1	< .05	< 20	0.5	< .2	0.32	< .01	0.96	< .01	< .01	< .05	< .05	1.27
3502	2.84	1.1	< .05	21	0.9	< .2	0.64	< .01	1.15	< .01	< .01	< .05	< .05	2.23
3505	7.12	2.2	< .05	36	0.2	< .2	1.75	< .01	0.96	< .01	< .01	< .05	0.16	3.07
3509	0.04	0.6	< .05	< 20	0.2	< .2	0.01	< .01	0.63	< .01	< .01	< .05	< .05	0.28
4413	0.14	< .2	< .05	< 20	0.1	< .2	0.03	< .01	0.64	< .01	< .01	< .05	< .05	0.97
4416	0.07	1.2	< .05	< 20	0.1	< .2	0.01	< .01	0.73	< .01	< .01	< .05	< .05	1.17
3137	0.22	0.4	< .05	< 20	0.1	< .2	0.05	< .01	0.52	< .01	< .01	< .05	0.06	2.71
4414	0.09	< .2	< .05	< 20	0.1	< .2	0.02	< .01	0.61	< .01	< .01	< .05	< .05	1.79
4503	1.21	1.1	< .05	22	0.4	< .2	0.28	< .01	0.63	< .01	< .01	< .05	< .05	2.49
4504	0.85	0.7	< .05	< 20	0.3	< .2	0.2	< .01	0.46	< .01	< .01	< .05	< .05	2.05
Blank	< .01	< .2	< .05	< 20	0.3	< .2	< .01	< .01	0.01	< .01	< .01	< .05	< .05	< .05
4402	0.38	< .2	< .05	32	0.2	< .2	0.1	< .01	1.52	< .01	< .01	< .05	0.07	1.48
4216A	0.01	1.3	< .05	21	0.1	< .2	< .01	< .01	1.6	< .01	< .01	< .05	< .05	1.57
4640A	0.1	1.5	< .05	< 20	0.2	< .2	0.02	< .01	0.45	< .01	< .01	< .05	< .05	2.66
RE 3505	7.33	2.4	< .05	39	0.2	< .2	1.76	< .01	0.97	< .01	< .01	< .05	0.16	3.02
RE 4640A	0.1	1.7	< .05	< 20	0.3	< .2	0.02	< .01	0.45	< .01	< .01	< .05	< .05	2.77

Sample	Se ppb	Si ppb	Sm ppb	Sn ppb	Sr ppb	Ta ppb	Tb ppb	Te ppb	Th ppb	Ti ppb	Tl ppb	Tm ppb	U ppb	V ppb	W ppb	Y ppb	Yb ppb	Zn ppb	Zr ppb
4310	< .5	5759	< .05	0.14	32.91	< .05	< .01	< .05	< .05	< 10	0.01	< .01	0.8	< 1	0.2	0.01	< .01	0.9	< .5
4409	< .5	3378	1.15	0.3	22.03	< .05	0.13	< .05	0.93	< 10	0.01	0.05	0.4	< 1	< .1	3.8	0.28	6.2	1.2
4501A	< .5	4293	< .05	0.38	18.47	< .05	< .01	< .05	< .05	< 10	< .01	< .01	< .05	< 1	1.9	0.03	< .01	6.2	< .5
3510	< .5	3202	< .05	0.29	69.32	< .05	< .01	< .05	< .05	< 10	0.01	< .01	1.34	< 1	0.2	0.07	0.01	6.8	< .5
4614A	< .5	3081	< .05	0.16	12.07	< .05	< .01	< .05	< .05	< 10	0.01	< .01	0.1	< 1	4.2	0.02	< .01	1.6	< .5
3508	< .5	2296	0.46	0.08	22.04	< .05	0.05	< .05	0.35	< 10	0.01	0.02	1.1	< 1	< .1	1.64	0.12	1.8	0.7
4218A	< .5	3914	< .05	0.14	38.68	< .05	< .01	< .05	< .05	< 10	0.01	< .01	0.78	< 1	2.7	0.02	< .01	4.2	< .5
4501	0.5	3718	0.11	0.14	30.66	< .05	0.01	< .05	0.13	< 10	< .01	< .01	0.37	< 1	1.8	0.35	0.02	2.2	< .5
4624A	< .5	1859	< .05	0.32	16.75	< .05	< .01	< .05	< .05	< 10	< .01	< .01	0.34	< 1	1.2	< .01	< .01	2.4	< .5
3501	< .5	2295	0.22	0.07	8.57	< .05	0.01	< .05	0.08	< 10	< .01	< .01	0.11	< 1	< .1	0.43	0.04	4.6	< .5
3502	< .5	3746	0.42	0.13	17.3	< .05	0.03	< .05	0.14	< 10	0.01	0.01	0.17	< 1	< .1	0.98	0.07	5.1	< .5
3505	0.6	3437	1.12	0.11	32.27	< .05	0.11	< .05	1.14	< 10	0.01	0.03	0.39	< 1	0.1	2.61	0.19	5.1	1.8
3509	< .5	474	< .05	0.22	4.47	< .05	< .01	< .05	< .05	< 10	< .01	< .01	< .05	< 1	0.1	0.01	< .01	2	< .5
4413	< .5	1543	< .05	0.12	22.73	< .05	< .01	< .05	< .05	< 10	< .01	< .01	0.51	< 1	1.2	0.07	< .01	0.8	< .5
4416	< .5	2177	< .05	0.1	21.68	< .05	< .01	< .05	< .05	< 10	< .01	< .01	0.42	< 1	0.1	0.08	< .01	1.1	< .5
3137	0.6	4955	< .05	0.27	22.79	< .05	< .01	< .05	< .05	< 10	0.01	< .01	1.22	< 1	2	0.12	< .01	0.6	< .5
4414	< .5	3310	< .05	0.13	35.87	< .05	< .01	< .05	< .05	< 10	< .01	< .01	1.1	< 1	2.4	0.09	< .01	13.6	< .5
4503	< .5	3579	0.18	0.08	63.9	< .05	0.02	< .05	0.2	< 10	< .01	< .01	1.86	< 1	1.4	0.72	0.05	3.9	0.9
4504	0.6	3435	0.12	0.25	32.34	< .05	0.01	< .05	0.14	< 10	0.01	< .01	0.55	< 1	1.7	0.3	0.02	2.7	< .5
Blank	< .5	12	< .05	< .05	0.05	< .05	< .01	< .05	< .05	< 10	< .01	< .01	< .05	< 1	< .1	< .01	< .01	0.8	< .5
4402	0.5	2368	0.06	0.07	66.96	< .05	< .01	< .05	0.08	< 10	0.01	< .01	1.9	< 1	0.1	0.24	0.01	1	< .5
4216A	< .5	2813	< .05	0.12	26.12	< .05	< .01	< .05	< .05	< 10	< .01	< .01	0.51	< 1	1.6	0.02	< .01	1.3	< .5
4640A	0.7	4751	< .05	0.09	25.14	< .05	< .01	< .05	< .05	< 10	< .01	< .01	< .05	< 1	0.7	0.05	< .01	3.8	< .5
RE 3505	< .5	3437	1.1	0.13	32.43	< .05	0.1	< .05	1.16	< 10	0.01	0.03	0.41	< 1	0.1	2.72	0.19	5.2	1.9
RE 4640A	< .5	4833	< .05	0.07	25.6	< .05	< .01	< .05	< .05	< 10	< .01	< .01	< .05	< 1	0.8	0.06	< .01	4	< .5

TABLE A3.1-2: Comparison of Meteoric Water Mobility Procedure Results with CCME 1999 Guidelines and Draft MWQSOG (for the Protection of Aquatic Life).

Charge Dry Wt.: 5.00 Kg.
Input pH: 5.00

Sample	Deposit Location	Eff. pH	Sulphate (mg/L)	Alkalinity (mgCaCO3/L)	Ag ppb	Al ppb	As ppb	Au ppb	B ppb	Ba ppb	Be ppb	Bi ppb	Br ppb	Ca ppb	Cd ppb	Cl ppm	Co ppb	Cr ppb
CCME Guideline (1999):					0.1	5-100	5	-	-	-	-	-	-	-	0.017	-	-	8.9
draft MWQSOG (from draft N-S report):					-	5-100	5	-	-	-	-	-	-	-	1.4-1.7	-	-	47-59
4310	J-3	7.96	3	57	< .05	23	< 1	< .05	< 20	14.63	< .05	< .05	32	24831	< .05	< 1	0.03	< .5
4409	J-4	6.16	4	7	< .05	352	< 1	< .05	< 20	18.32	< .05	< .05	16	4262	< .05	< 1	0.87	2.7
4501A	J-5	7.73	4	29	< .05	25	< 1	< .05	< 20	4.96	< .05	< .05	45	10221	0.21	< 1	0.19	1.8
3510	H-west	8.00	5	74	< .05	40	1	< .05	< 20	19.7	< .05	< .05	26	28074	0.35	5	0.09	1.1
4614A	J-2	7.75	5	20	< .05	54	1	< .05	< 20	3.99	< .05	< .05	25	4797	0.38	4	0.06	1.8
3508	H-west	7.88	6	42	< .05	126	1	< .05	< 20	9.51	0.21	< .05	21	14053	0.3	3	0.17	1.5
4218A	J-2	7.93	9	64	< .05	28	1	< .05	< 20	10.76	0.21	< .05	22	20041	0.81	4	0.25	1
4501	J-5	7.67	8	39	< .05	170	< 1	< .05	< 20	9.45	< .05	< .05	37	8004	0.38	3	0.34	2
4624A	J-6	7.98	8	37	< .05	91	< 1	< .05	< 20	6.16	< .05	< .05	16	11618	0.5	3	0.03	1.3
3501	H-west	6.64	3	5	< .05	41	< 1	< .05	< 20	3.51	< .05	< .05	12	1469	0.19	3	0.28	0.8
3502	H-west	6.91	3	7	< .05	93	< 1	< .05	< 20	5.36	< .05	< .05	15	2452	0.25	1	0.26	0.9
3505	H-west	7.41	9	27	< .05	122	< 1	< .05	< 20	10.85	0.43	< .05	27	10106	0.25	1	0.71	2.7
3509	H-west	7.05	<1	6	< .05	50	< 1	< .05	< 20	1.35	< .05	< .05	6	1825	0.16	1	0.41	0.9
4413	J-4	7.75	3	38	< .05	191	< 1	< .05	< 20	4.83	< .05	< .05	18	10738	0.19	1	0.06	2.1
4416	J-4	7.73	3	38	< .05	51	< 1	< .05	< 20	4.7	0.21	< .05	14	8911	0.09	1	0.33	0.8
3137	H-west	7.97	7	53	< .05	74	3	< .05	< 20	13.56	< .05	< .05	59	17249	0.15	4	0.1	1.4
4414	J-4	7.87	5	62	< .05	69	< 1	< .05	< 20	11.64	< .05	< .05	27	20817	0.12	2	0.09	1.8
4503	J-5	7.71	4	106	< .05	44	1	< .05	< 20	22.82	0.22	< .05	38	31667	0.24	2	0.23	2.5
4504	J-5	7.63	5	44	< .05	166	< 1	< .05	< 20	8.06	< .05	< .05	32	10414	0.17	2	0.23	1.4
Blank		4.99	<1	<1	< .05	1	< 1	< .05	< 20	0.11	< .05	< .05	< 5	100	0.1	1	< .02	< .5
4402	J-4	7.83	2	72	< .05	131	< 1	< .05	< 20	16.14	< .05	< .05	19	18305	0.13	1	0.14	1.2
4216A	J-6	7.81	5	43	< .05	48	< 1	< .05	< 20	7.57	0.22	< .05	29	12439	0.6	2	0.55	1.3
4640A	J-6	7.40	4	39	< .05	212	1	< .05	< 20	8.81	< .05	< .05	27	9318	1.03	2	0.35	1
Duplicates																		
RE 4640	H-west				< .05	202	1	< .05	< 20	8.97	< .05	< .05	28	9565	1.08	2	0.34	1
RE 3505	J-6				< .05	122	< 1	< .05	< 20	10.35	< .05	< .05	29	9932	0.24	1	0.72	2.9
3509	H-west		<1															
4503	J-5		4															
4402	J-4			69														
3137	H-west			5														

Sample	Cu ppb	Fe ppb	Hg ppb	K ppb	Li ppb	Mg ppb	Mn ppb	Mo ppb	Na ppb	Ni ppb	P ppb	Pb ppb	Se ppb	Si ppb	Sr ppb	Th ppb	Ti ppb	U ppb	V ppb	Zn ppb
CCME Guideline (1999):	2-4	300	0.1	-	-	-	-	73	-	25-150	-	1-7	-	-	-	0.8	-	-	-	30
draft MWQSOG (from draft N-S report):	5-6	300	0.1	-	-	-	-	73	-	28-35	-	1.2-1.8	-	-	-	-	-	-	-	60-80
4310	2.2	< 10	< .1	1812	6	4698	1.51	9.5	3132	< .2	< 20	0.2	< .5	5759	32.91	< .05	< 10	0.8	< 1	0.9
4409	12.4	136	< .1	990	1	2103	70.53	0.4	853	4.6	78	0.5	< .5	3378	22.03	0.93	< 10	0.4	< 1	6.2
4501A	2.4	< 10	< .1	1682	3	5110	77.6	2.1	4879	0.7	< 20	< .1	< .5	4293	18.47	< .05	< 10	< .05	< 1	6.2
3510	7.6	33	< .1	1673	< 1	4001	21.68	4.7	1863	< .2	58	0.1	< .5	3202	69.32	< .05	< 10	1.34	< 1	6.8
4614A	2.4	12	< .1	1619	3	2215	13.12	3.1	3477	0.2	< 20	0.2	< .5	3081	12.07	< .05	< 10	0.1	< 1	1.6
3508	23.2	64	< .1	1799	2	2963	6.99	0.8	1022	2.9	49	0.1	< .5	2296	22.04	0.35	< 10	1.1	< 1	1.8
4218A	5.2	12	0.1	3844	8	5456	58.09	2.1	3887	1	28	0.1	< .5	3914	38.68	< .05	< 10	0.78	< 1	4.2
4501	17.2	181	< .1	1721	1	4264	37.57	2.7	6607	2.1	47	0.3	0.5	3718	30.66	0.13	< 10	0.37	< 1	2.2
4624A	1.2	< 10	< .1	2999	6	2768	11.74	2.9	1637	< .2	< 20	0.3	< .5	1859	16.75	< .05	< 10	0.34	< 1	2.4
3501	7.9	39	< .1	586	1	454	29.11	0.5	796	1	< 20	0.5	< .5	2295	8.57	0.08	< 10	0.11	< 1	4.6
3502	12.2	70	< .1	933	1	749	23.73	0.7	1104	1.1	21	0.9	< .5	3746	17.3	0.14	< 10	0.17	< 1	5.1
3505	44.4	93	< .1	867	< 1	2727	66.18	0.9	1607	2.2	36	0.2	0.6	3437	32.27	1.14	< 10	0.39	< 1	5.1
3509	1.9	18	< .1	438	< 1	253	6.72	0.2	290	0.6	< 20	0.2	< .5	474	4.47	< .05	< 10	< .05	< 1	2
4413	7.7	31	< .1	1779	< 1	1872	0.86	1	2509	< .2	< 20	0.1	< .5	1543	22.73	< .05	< 10	0.51	< 1	0.8
4416	7.3	< 10	< .1	1511	3	3139	5.63	1.2	1091	1.2	< 20	0.1	< .5	2177	21.68	< .05	< 10	0.42	< 1	1.1
3137	8.3	50	< .1	2106	1	2118	4.92	2.5	6612	0.4	< 20	0.1	0.6	4955	22.79	< .05	< 10	1.22	< 1	0.6
4414	11.2	< 10	< .1	2608	2	3422	8.73	2.6	3739	< .2	< 20	0.1	< .5	3310	35.87	< .05	< 10	1.1	< 1	13.6
4503	25.5	48	< .1	2749	2	6453	8.87	3	6281	1.1	22	0.4	< .5	3579	63.9	0.2	< 10	1.86	< 1	3.9
4504	14.5	182	< .1	2144	< 1	3191	14.92	2.3	5121	0.7	< 20	0.3	0.6	3435	32.34	0.14	< 10	0.55	< 1	2.7
Blank	0.2	< 10	< .1	< 50	< 1	< 50	0.07	< .1	< 50	< .2	< 20	0.3	< .5	12	0.05	< .05	< 10	< .05	< 1	0.8
4402	11.2	74	< .1	2396	< 1	6674	13.2	2.3	1244	< .2	32	0.2	0.5	2368	66.96	0.08	< 10	1.9	< 1	1
4216A	3	< 10	< .1	2923	5	4716	39.9	1.7	3544	1.3	21	0.1	< .5	2813	26.12	< .05	< 10	0.51	< 1	1.3
4640A	5.7	116	< .1	2049	2	4243	101.05	5.4	4726	1.5	< 20	0.2	0.7	4751	25.14	< .05	< 10	< .05	< 1	3.8
Duplicates																				
RE 4640	5.6	123	< .1	2107	3	4323	104.11	5.5	4661	2.4	39	0.2	< .5	3437	32.43	1.16	< 10	0.41	< 1	5.2
RE 3505	45.7	100	< .1	850	2	2787	68.48	1	1629	1.7	< 20	0.3	< .5	4833	25.6	< .05	< 10	< .05	< 1	4
3509																				
4503																				
4402																				
3137																				

Note: Sample 4506 did not drain sufficiently to obtain extract.
Potential exceedances of both regulatory guidelines are shaded
North-South draft "Aquatic Environment Support Document" indicates natural background concentrations of <0.1 to 33 ppb Cu and 860 to 2500 ppb Al in Wuskwatim study area

APPENDIX A3.2

SUMMARY OF QUARRY ROCK TESTING

ASSESSING ENVIRONMENTAL SENSITIVITY OF QUARRY-ROCK MATERIAL

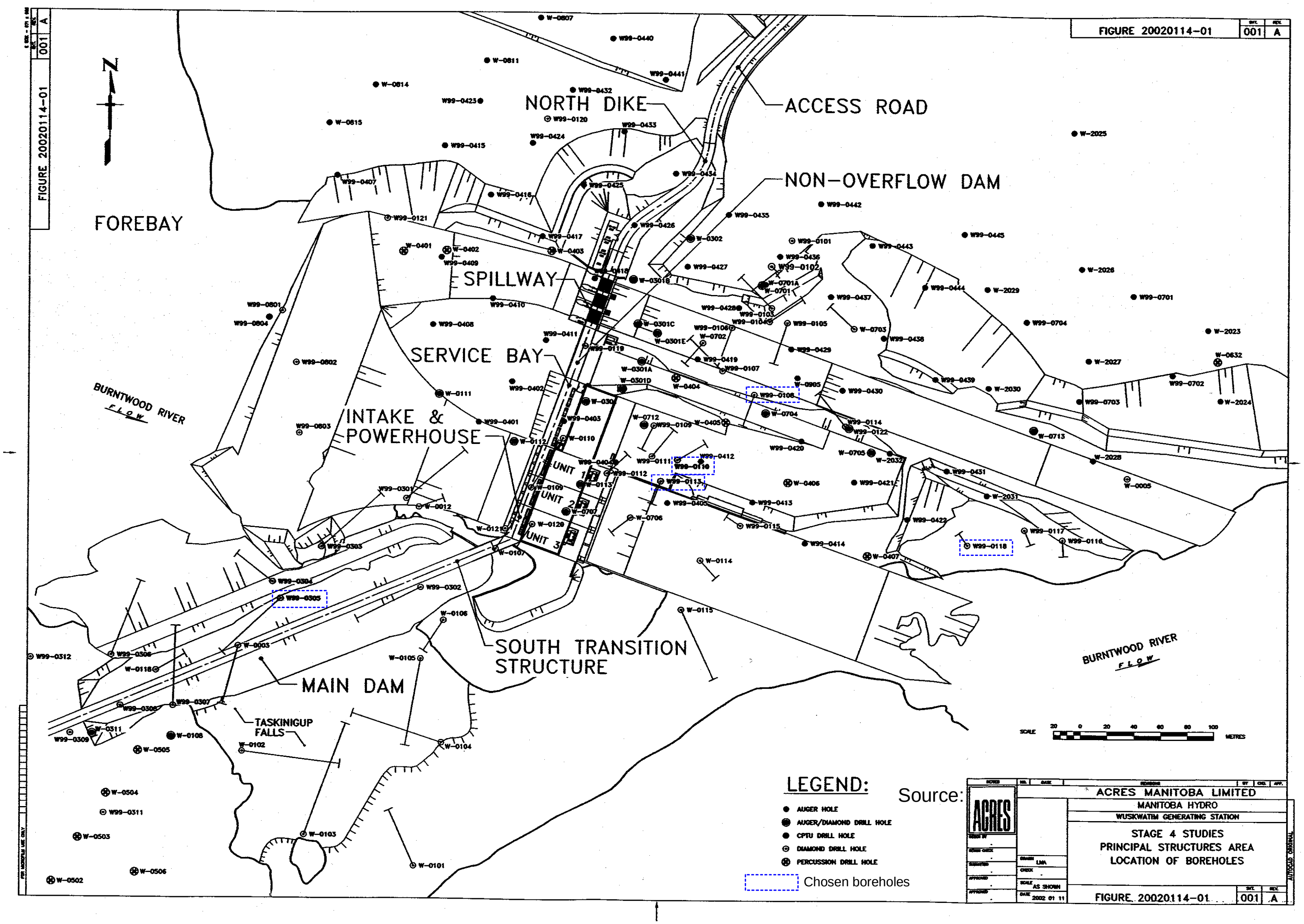
Acidic leachate is generated as a result of the oxidation of sulphur compounds (i.e., formation of sulphuric acid) once previously unexposed rock is exposed to atmospheric oxygen and as a result of bacterial action on the rock's available sulphur compounds. Depending on the nature of the acid generation, it may appear shortly after the rock is exposed to the air, or may require a number of years to appear, particularly if microbial communities generate it (MEND 1991). Acidic leachate and the release of elevated concentrations of metals can result in substantial environmental effects, particularly to aquatic environments (MEND 1991).

The aggregate deposits to the north of Wuskwatim Lake are underlain by metavolcanic rocks, potentially similar to the deposits located at INCO in Thompson, MB; at HBM&S in Flin Flon, MB; and at Lynn Lake, MB, all of which have experienced acid-generating rock problems following excavation activities (Tetr*ES* 2002). A potential therefore existed for construction in the Wuskwatim area to result in the generation of an acidic leachate and its associated potential short- and long-term environmental issues (Olinyk *pers. comm.* 2001). Accordingly, it was deemed prudent to assess the potential risk of acidic leachate generation as a result of the Project development.

Rock samples from 8 boreholes were chosen for laboratory analysis (Figures A3.2-1 and A3.2-2). The boreholes chosen and the basis for selection was as follows (Tetr*ES* 2002):

- W99-0303; W99-0110 and W99-0113 – trace sulphides visually observed in cores (recorded on borehole logs); boreholes in areas to be excavated;
- W99-0118; W99-0104 and W99-0108 – no sulphides observed in cores; boreholes located in areas to be excavated (and located away from boreholes where sulphides were located) - selected randomly; and
- W99-503 and W99-603 – no sulphides observed in cores; boreholes located in potential "quarry" areas – selected randomly.

Three continuous 5-m intervals of core from each borehole were chosen for analysis, on the basis of guidance provided by the Study Team's expert advisor, Mr. Stephen Day. Each core was halved, with half of the core retained by Manitoba Hydro (for future requirements) and the other half was shipped to B.C. Research for Acid-Base Accounting and Total Metals analysis (Tetr*ES* 2002).



wuskGS_boreholes
s\01\0221\29

Figure A3.2-1: Locations of Quarry-Rock Samples Submitted for Analysis

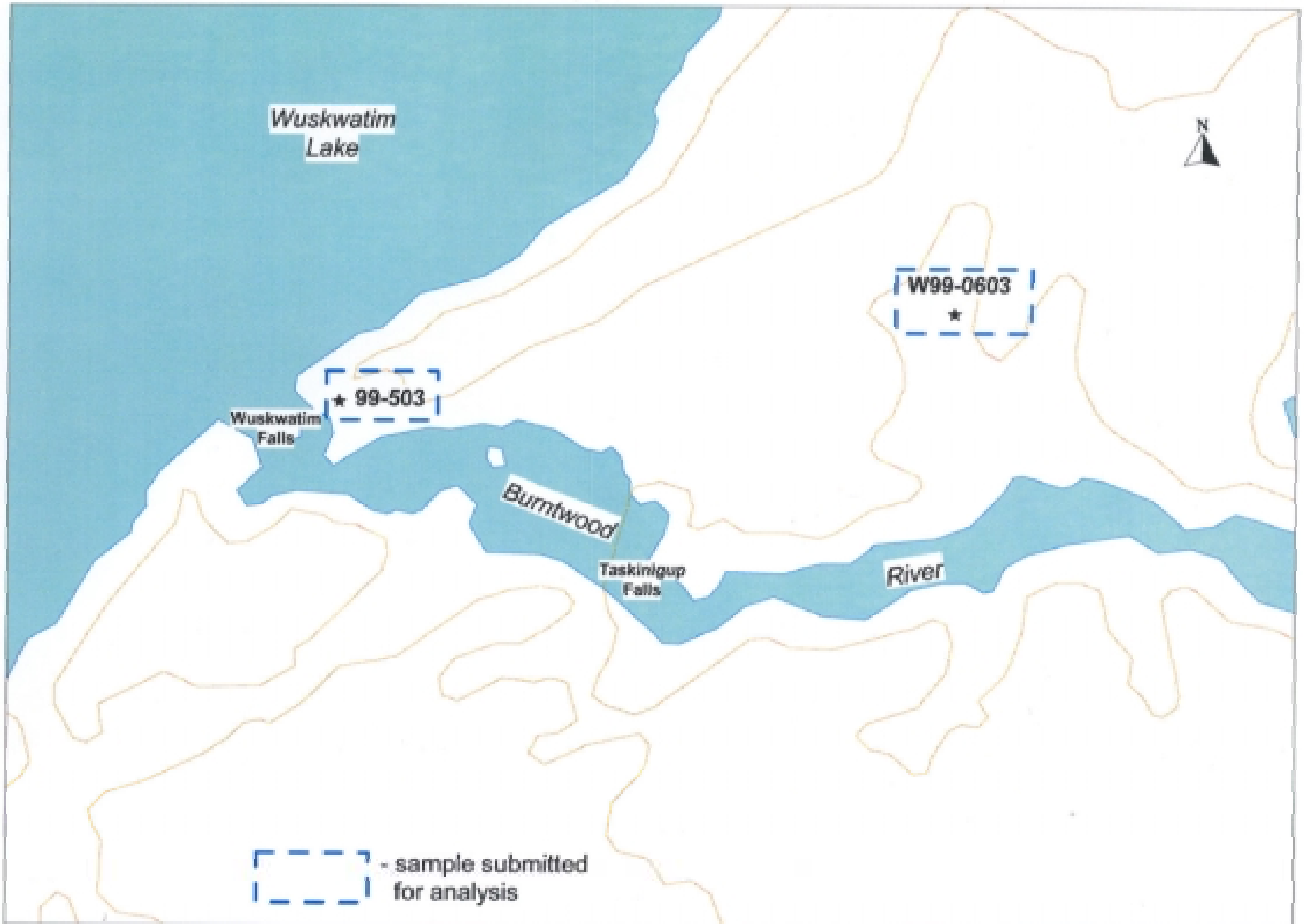


Figure A3.2-2 Locations of Other Boreholes Sampled

Acid-Base Accounting Results

The Acid-Base Accounting analytical results are shown in Table A3.2-1. A sulphur content of >0.3% generally indicates that the rock has the potential to produce an acidic leachate, however, sulphur concentrations as low as ~0.15% have been found to be acid generating (Day *pers. comm.* 2002). The analytical results indicate that Total Sulphur (in the form of sulphide, not sulphate; Table A3.2-1) is elevated in at least one 5-m interval in 5 of the 8 boreholes (Tetr*ES* 2002).

Another "indicator" of acid-generating potential is the "Neutralization Ratio" (NPR) of the rock (i.e., the Neutralization Potential/Maximum Potential Acidity; Table A3.2-1). An NPR value greater than 2 means there is negligible potential for acidic leachate generation, a value less than 1 means acidic leachate generation is almost guaranteed, and a value between 1 and 2 is a "gray zone" (Day *pers. comm.* 2002), where generation potential is uncertain. In the rock tested, the Neutralization Potential is very low (almost negligible), as shown by the low carbonate content of the rock (i.e., $CaCO_3$ Equiv.; Table A3.2-1). The NPRs calculated for each interval are shown in Table A3.2-1 and indicate that those samples with an elevated Total Sulphur concentration also have an NPR between 1 and 2 (i.e., within the "gray zone"). Based on experience elsewhere, Total Sulphur concentrations above 0.15% are a potential concern for acid generation if the neutralization potential is negligible (Day *pers. comm.* 2002). The analytical results therefore indicate that there is a potential for the generation of acidic leachate by those intervals with a Total Sulphur concentration greater than 0.15% (Tetr*ES* 2002).

Total Metals Analytical Results

The Total Metals analytical results are provided in Table A3.2-2. As previously mentioned, the generation of acidic leachate may cause the release of elevated concentrations of metals into the environment and potentially affect the environment (particularly the aquatic environment). Of particular concern would be the release of metals that are considered deleterious to the environment and/or could bioaccumulate in aquatic biota. Few substances can be truly regarded as inert, and given sufficient time could also create environmental problems. Specific metals have been identified which are known to create relatively short-term environmental effect on the receiving environment (Day *pers. comm.* 2002). Those elements believed to relate to the practical environmental influences of abandoned sulphide tailings areas include (Tetr*ES* 2002): Arsenic (As), Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb),

Table A3.2-1: Acid Base Accounting of Wuskwatim Samples Received June 27, 2002

Sample ID	Paste pH	CO_2 %	$CaCO_3$ Equiv. (Kg $CaCO_3$/ Tonne)	Total Sulphur (Wt.%)	Sulphate Sulphur (Wt.%)	Sulphide Sulphur* (Wt.%)	Maximum Potential Acidity** (MPA) (Kg $CaCO_3$/ Tonne)	Neutralization Potential (NP) (Kg $CaCO_3$/ Tonne)	Neutralization Ratio (NP/MPA)	Fizz Rating
99-104 22.26-26.00	9.5	0.03	0.7	< .02	<0.01	< .02	<0.6	9.5	15.8	none
99-104 26.00-30.13	9.3	< .01	<0.2	0.04	<0.01	0.04	1.3	9.8	6.6	none
99-104 30.13-34.27	9.4	0.04	0.9	0.04	<0.01	0.04	1.3	9.3	7.2	none
99-108 8.44-12.56	9.0	0.08	1.8	0.03	<0.01	0.03	0.9	7.3	8.1	none
99-108 25.14-29.05	9.0	0.02	0.5	0.04	<0.01	0.04	1.3	8.3	6.4	none
99-108 29.05-33.23	9.4	0.04	0.9	0.02	<0.01	0.02	0.6	8.5	14.2	none
99-110 5.17-9.12	8.9	0.09	2.0	0.16	<0.01	0.16	5.0	7.8	1.6	none
99-110 9.12-13.47	9.4	0.03	0.7	0.03	<0.01	0.03	0.9	4.3	4.8	none
99-110 13.47-17.63	9.4	0.06	1.4	0.02	<0.01	0.02	0.6	8.8	14.7	none
99-110 17.63-21.84	9.4	0.05	1.1	0.02	<0.01	0.02	0.6	9.5	15.8	none
99-113 4.07-8.53	9.0	0.03	0.7	0.06	<0.01	0.06	1.9	6.0	3.2	none
99-113 8.53-12.61	9.1	0.06	1.4	< .02	<0.01	< .02	<0.6	6.3	10.5	none
99-113 12.61-16.77	9.2	0.04	0.9	0.03	<0.01	0.03	0.9	9.3	10.3	none
99-113 16.77-21.00	9.5	0.07	1.6	0.02	<0.01	0.02	0.6	10.1	16.8	none
99-118 3.16-7.34	9.5	0.12	2.7	0.25	<0.01	0.25	7.8	15.1	1.9	none
99-118 7.34-11.34	9.5	0.11	2.5	0.18	<0.01	0.18	5.6	8.8	1.6	none
99-118 11.34-15.18	9.5	0.17	3.9	0.44	<0.01	0.44	13.8	15.3	1.1	none
99-118 15.18-19.11	9.9	0.07	1.6	0.43	<0.01	0.43	13.4	13.6	1.0	none
99-303 25.4-29.17	9.1	0.01	0.2	< .02	<0.01	< .02	<0.6	8.0	13.3	none
99-303 29.17-33.05	9.1	0.06	1.4	0.1	<0.01	0.1	3.1	7.5	2.4	none
99-303 33.05-37.05	9.4	0.02	0.5	0.02	<0.01	0.02	0.6	3.8	6.3	none
99-303 37.05-41.01	9.4	0.05	1.1	0.04	<0.01	0.04	1.3	7.3	5.6	none
99-503 6.53-9.43 EOH	9.2	0.03	0.7	0.11	<0.01	0.11	3.4	6.0	1.8	none
99-603 0.77-4.69	9.2	0.03	0.7	0.07	<0.01	0.07	2.2	6.8	3.1	none
99-603 4.69-8.89	9.3	0.02	0.5	0.13	<0.01	0.13	4.1	7.8	1.9	none

Note: Samples of concern are shaded above.

Table A3.2-2: Total Metals Analysis (by Aqua Regia Digestion with ICP-ES Finish)

SAMPLES	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U	Au	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg	Ba	Ti	B	Al	Na	K	W	Hg	Sc	Tl	Ga
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	%	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm
99-104 22.26-26.00	6.7	38.2	2.6	69	< .1	59	15.1	106	2.09	1.3	1.4	0.8	6.5	12	< .1	< .1	< .1	131	0.17	0.03	18	196	1.02	222	0.29	6	1.5	0.04	0.76	0.1	< .01	3.5	0.3	6
99-104 26.00-30.13	9.3	76	2	73	0.2	70	17.9	121	2.43	1.5	1.2	2	5.8	9	< .1	< .1	< .1	136	0.11	0.03	18	213	1.28	176	0.24	6	1.67	0.04	0.69	0.1	0.01	4.1	0.2	7
99-104 30.13-34.27	8.8	87.9	1.4	66	0.1	67	16.7	115	2.1	1.9	0.9	2.1	3.8	14	< .1	< .1	< .1	134	0.18	0.03	13	223	1.07	191	0.25	6	1.46	0.04	0.65	< .1	< .01	3.9	0.3	6
99-108 8.44-12.56	5.5	35.3	2.1	86	0.1	66	16	87	2.04	0.5	0.9	0.9	2.6	10	< .1	< .1	< .1	157	0.19	0.02	9	192	1.06	278	0.33	5	1.49	0.03	0.85	< .1	< .01	3.6	0.3	6
99-108 25.14-29.05	6.7	75.5	4.5	88	0.1	69	17.7	99	2.32	1.2	1	1.3	7.8	8	< .1	< .1	< .1	151	0.14	0.04	18	232	1.25	338	0.4	3	1.62	0.03	1.07	0.5	< .01	3.5	0.4	7
99-108 29.05-33.23	8.4	24.2	2	75	0.1	68	15.9	109	2.06	1	1.2	1.2	5	9	< .1	< .1	< .1	129	0.2	0.04	17	237	1.14	295	0.37	3	1.5	0.04	0.92	< .1	0.01	3.7	0.3	6
99-110 5.17-9.12	10.3	179	3.2	98	0.1	85	22.8	124	2.36	0.6	0.7	1.2	2.8	14	0.1	< .1	< .1	162	0.18	0.01	10	228	1.05	263	0.3	3	1.64	0.04	0.83	0.1	< .01	4.7	0.3	6
99-110 9.12-13.47	5.2	52.1	1.5	76	0.1	63	14.8	81	1.76	0.7	0.7	2.3	2.6	9	< .1	< .1	< .1	154	0.15	0.02	10	186	0.87	205	0.29	3	1.3	0.03	0.67	< .1	0.01	3.2	0.2	5
99-110 13.47-17.63	7	87.4	2.5	85	0.1	80	16.6	105	2.04	0.9	0.8	2.8	2.9	15	< .1	< .1	0.1	160	0.2	0.02	11	205	0.95	208	0.26	5	1.61	0.05	0.66	< .1	< .01	4	0.3	6
99-110 17.63-21.84	5.6	112	1.6	77	0.1	74	16	84	1.91	1	0.6	1.2	2.2	15	< .1	< .1	0.1	153	0.31	0.06	8	184	0.95	257	0.3	4	1.51	0.04	0.73	< .1	< .01	3	0.3	6
99-113 4.07-8.53	8.3	81.4	2.2	73	0.1	65	15.6	107	1.92	0.9	0.8	1.8	2.6	14	< .1	< .1	< .1	140	0.2	0.03	10	203	0.89	250	0.3	2	1.38	0.04	0.7	< .1	< .01	3.9	0.3	5
99-113 8.53-12.61	7.5	58.2	1.8	72	0.1	66	14.8	104	1.98	0.6	0.8	2.1	2.3	30	< .1	< .1	0.1	149	0.28	0.02	9	204	0.95	239	0.31	2	1.56	0.04	0.79	< .1	< .01	3.8	0.3	5
99-113 12.61-16.77	7.4	36.5	1.8	75	0.1	57	14.8	110	2	0.7	0.8	1.3	2.3	11	< .1	< .1	< .1	146	0.2	0.03	9	194	0.98	226	0.34	3	1.39	0.03	0.83	< .1	< .01	3.5	0.3	5
99-113 16.77-21.00	6.6	52.8	1.2	70	0.1	71	16.9	90	1.94	0.9	0.8	2	2.3	28	< .1	< .1	< .1	156	0.35	0.04	11	200	0.94	243	0.31	3	1.66	0.06	0.79	< .1	< .01	4	0.3	6
99-118 3.16-7.34	11	77.5	1.4	78	< .1	84	20.9	151	2.76	0.7	0.6	1.6	2.1	13	< .1	0.1	0.1	154	0.22	0.03	7	262	1.27	254	0.4	1	1.62	0.05	1.02	0.1	< .01	4.7	0.4	6
99-118 7.34-11.34	7.1	74.2	1	79	< .1	91	21.7	96	2.35	0.6	0.6	1.5	1.8	8	< .1	< .1	< .1	164	0.18	0.02	7	221	1.14	271	0.41	3	1.48	0.03	1.03	< .1	< .01	3.7	0.3	6
99-118 11.34-15.18	7.8	77.7	1.2	74	0.1	77	21.9	116	2.49	0.5	0.6	2	1.2	27	0.1	< .1	0.1	144	0.57	0.03	5	213	0.97	227	0.35	3	1.78	0.05	0.92	0.1	< .01	3.7	0.3	7
99-118 15.18-19.11	10.7	117	1.1	90	0.1	110	27.4	124	3.26	< .5	0.4	2.7	1.3	10	0.1	< .1	< .1	185	0.17	0.03	5	312	1.46	289	0.45	1	1.7	0.06	1.27	< .1	0.01	5.7	0.5	8
99-303 25.4-29.17	9	17.5	2	57	< .1	46	11.9	167	2.04	1.7	1	0.7	10.3	7	< .1	< .1	< .1	91	0.11	0.02	26	228	0.99	103	0.2	4	1.3	0.03	0.46	< .1	< .01	3.1	0.2	5
99-303 29.17-33.05	6.7	141	3.6	105	0.1	84	20	118	2.6	0.9	0.8	2.3	5.1	8	< .1	< .1	< .1	142	0.1	0.01	14	201	1.38	147	0.28	3	1.78	0.03	0.84	< .1	0.01	3.7	0.4	8
99-303 33.05-37.05	5.7	22.5	1.9	75	< .1	56	12.4	87	1.9	1.4	1.1	< .5	6.8	6	< .1	< .1	< .1	100	0.07	0.01	19	190	1.06	139	0.3	1	1.35	0.03	0.79	< .1	0.01	2.8	0.3	6
99-303 37.05-41.01	11	23	6.3	63	0.1	33	8.4	65	1.57	3	1.1	1.1	30.1	10	< .1	< .1	< .1	61	0.2	0.04	60	194	0.68	110	0.2	1	1.02	0.04	0.55	< .1	0.01	1.7	0.2	4
99-503 6.53-9.43	8.5	46.4	2	74	< .1	76	18.1	103	2.04	0.6	0.4	< .5	2.8	8	< .1	< .1	< .1	137	0.14	0.01	9	218	1.01	194	0.36	3	1.38	0.04	0.86	< .1	< .01	3.5	0.3	6
99-603 0.77-4.69	8.2	35.3	1	66	< .1	80	16.5	118	2.02	0.5	0.4	0.9	1.6	15	< .1	< .1	< .1	173	0.16	0.01	7	224	0.96	258	0.32	2	1.44	0.03	0.72	< .1	0.01	4.4	0.2	5
99-603 4.69-8.84	10.5	44	1.1	77	< .1	83	17.6	131	2.26	0.6	0.6	0.8	2	12	< .1	< .1	< .1	164	0.13	0.02	8	264	1.09	288	0.39	3	1.5	0.03	0.89	< .1	< .01	4.6	0.3	6

Note: Samples of concern are shaded above.

Manganese (Mn), Mercury (Hg), Nickel (Ni), Silver (Ag), and Zinc (Zn). These metals are typically associated with sulphide minerals.

The analytical results for those samples containing elevated Total Sulphur indicate (Table A3.2-2 and Tetr*ES* 2002):

- non-elevated Arsenic concentrations;
- non-elevated Cadmium concentrations;
- non-elevated Manganese concentrations;
- non-elevated Mercury concentrations;
- non-elevated Silver concentrations;
- slightly elevated Cobalt concentrations;
- slightly elevated Iron concentrations;
- slightly elevated Lead concentrations;
- elevated Copper concentrations;
- elevated Nickel concentrations; and
- elevated Zinc concentrations.

The elevated Total Sulphur concentrations and rock-sample NPRs indicate that acidic leachate could possibly result from the exposure to air of some of the Wuskwatim quarry rock. The elevated copper, nickel and zinc concentrations detected in those samples with elevated Total Sulphur further indicate that any generated acidic leachate (as a result of atmospheric exposure) would likely contain metals and could potentially, therefore, have an environmental effect (Tetr*ES* 2002).

Depending on the nature of the acid generation, it may appear shortly after the rock is exposed to the air, or may require a number of years to appear, particularly if microbial communities generate it. The static testing that was completed could not answer any questions regarding rates. Further testing was deemed necessary to:

- confirm the acid-generating potential of the rock;
- assess the rate of sulphur oxidation and acid generation;
- assess the rate of depletion of the neutralization potential of the rock; and
- assess the degree of metals leachability that might be expected.

Accordingly, kinetic testing, which simulates the geochemical processes of weathering, was undertaken.

Kinetic Testing

Three composite rock samples from 3 different boreholes were chosen for kinetic testing (Tetr*ES* 2003). These were W99-0110, W99-0118 and W99-603 and they were selected on the basis of the static test results (i.e., contained moderate, high and lower Total Sulphur, respectively; all had an NPR lower than 2 (based on carbonate content); and all contained trace metals – in varying concentrations). The samples further covered the two major areas of rock excavation (Figures A3.2-1 and A3.2-2).

Kinetic testing was undertaken on the 3 samples by B.C. Research for a period of 20 weeks (by which time the results had stabilized; Tetr*ES* 2003). The test design is briefly outlined in Table 3.2-3 (Tetr*ES* 2003). The individual sample results are provided in Tables A3.2-4 to A3.2-6. The results indicate that the pH of the solution released from the rock samples during the test decreased overtime, however, it did not become acidic (stabilized above 7 for all 3 samples). The results also show consistent patterns, the most significant of which is that the sulphur oxidation rate is proportional to the sulphur content of the rock sample (i.e., the sulphur-weathering rate could be estimated from the sulphur content of the sample), and that any trace metals released under the neutral pH conditions were undetectable.

On the basis of these results, rock with a sulphur content >0.3% could eventually generate an acidic leachate, however, this could take years or even decades (Day *pers. comm.* 2003). If acid generation did occur in the future from rock containing >0.3% sulphur, the runoff would probably contain metals like iron and aluminum, but metals like copper and zinc would only be released in low concentrations, based on the overall low metal concentrations in the rock samples tested (Table 3A.2-2). The test results for those samples located in areas that are to be excavated (W99-0118 is actually located outside of the Project excavation area) do not generally contain elevated Total Sulphur levels (i.e., sulphur concentrations greater than 0.3%; Tetr*ES* 2003). The distribution of Total Sulphur in all of the rock to be excavated, however, has not been tested (this would be onerous and not practical).

The greatest acidic leachate concern may be any fine rock material that is generated from Project construction that contains a concentration of Total Sulphur >0.3% (Day *pers. comm.* 2003). Fine material has greater surface area for oxidation than coarse material such as riprap. Unusable fine rock material will be generated as the rock aggregate is washed prior to its use in making concrete; the fines will settle out in the settling pond(s) in the contractor's work area on the Project site. After construction, the settling pond(s) will be decommissioned and the fine material will likely be moved into the excavated materials placement area (Volume 3 and Sikora *pers. comm.* 2003). Accordingly, it is recommended that the fine-rock material collected in the settling pond(s) be amended with crushed limestone of similar particle size to the fines to augment the natural acid-neutralizing capacity of the rock; thereby reducing the potential for acidic leachate generation in the future. A rate of 10 kg of pure limestone per tonne of rock would probably be sufficient to raise the average NPR to greater than 2.0 (Day *pers. comm.* 2003).

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Table A3.2-3: Kinetic Test Design

BCRI ID	Sample Location ID	Sample Type	Column Dimensions		Distance from Top of Column to Sample
			Diameter (cm)	Length (cm)	
HC 1	99-110 Comp	Rock	11.5	17	12
HC 2	99-118 Comp	Rock	11.5	17	12
HC 3	99-603 Comp	Rock	11.5	17	12

BCRI ID	Sample Location ID	Column Packing	Other Materials Used	Column Material	Pore Volume
		Wt. of Sample (kg)			(ml)
HC 1	99-110 Comp	1	Nytex Mesh	Plexyglass	not measured
HC 2	99-118 Comp	1	Nytex Mesh	Plexyglass	not measured
HC 3	99-603 Comp	1	Nytex Mesh	Plexyglass	not measured

BCRI ID	Sample Location ID	Total Volume of Initial Flushings	Flushing Rate/Weekly Input*	Temp.	Sampling Frequency
		(ml)		(C)	
HC 1	99-110 Comp	750	500	22-24	weekly
HC 2	99-118 Comp	750	500	22-24	weekly
HC 3	99-603 Comp	750	500	22-24	weekly

BCRI ID	Sample Location ID	Start-up date	Sampling Day	Operation Procedure	Sample Prep for Flushings
HC 1	99-110 Comp	26-Nov-02	Tuesday	Weekly Flush	Mixing
HC 2	99-118 Comp	26-Nov-02	Tuesday	Weekly Flush	Mixing
HC 3	99-603 Comp	26-Nov-02	Tuesday	Weekly Flush	Mixing

Table A3.2-4: Kinetic Test Results: Leachate Chemistry of HC - 1 (W99-0110)

Date	Accum. Weeks	Volume (ml) Input	Output	pH	Cond. (umhos/cm)	ORP (mv)	Sulfate (mg/L)	Acidity (mg CaCO3/L)	Alkalintiy (mg CaCO3/L)
26-Nov-02	0	750	620	9.03	90	224	4	#N/A	21
03-Dec-02	1	500	415	9.07	143	240	5	#N/A	#N/A
10-Dec-02	2	500	410	8.91	105	123	2	#N/A	35
17-Dec-02	3	500	370	8.37	48	258	1	#N/A	#N/A
24-Dec-02	4	500	390	8.98	103	160	6	#N/A	33
31-Dec-02	5	500	370	8.86	62	165	3	#N/A	#N/A
07-Jan-03	6	500	450	7.48	53	193	3	3	20
14-Jan-03	7	500	440	7.60	60	250	2	#N/A	#N/A
21-Jan-03	8	500	540	7.90	48	221	3	3	21
28-Jan-03	9	500	390	8.03	34	230	3	#N/A	#N/A
04-Feb-03	10	500	450	8.05	38	205	3	4	15
11-Feb-03	11	500	445	7.22	38	260	3	#N/A	#N/A
18-Feb-03	12	500	395	7.68	25	210	4	2	9
25-Feb-03	13	500	445	7.76	39	280	1	#N/A	#N/A
04-Mar-03	14	500	460	7.56	37	220	2	3	12
11-Mar-03	15	500	435	8.08	33	295	2	#N/A	#N/A
18-Mar-03	16	500	415	7.37	26	295	2	4	7
25-Mar-03	17	500	470	7.89	37	260	3	#N/A	#N/A
01-Apr-03	18	500	420	7.31	27	320	2	4	9
08-Apr-03	19	500	405	7.81	25	305	3	#N/A	#N/A
15-Apr-03	20	Terminated							

Date	Accum. Weeks	Al mg/L	As mg/L	Ba mg/L	Be mg/L	B mg/L	Cd mg/L	Ca mg/L	Cr mg/L	Co mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Li mg/L
26-Nov-02	0	0.39	-0.001	0.002	-0.001	0.06	-0.0002	0.52	-0.001	-0.001	0.003	0.11	-0.001	0.004
03-Dec-02	1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	2	0.25	0.002	-0.001	-0.001	0.11	-0.0002	0.76	-0.001	-0.001	0.006	-0.05	-0.001	0.008
17-Dec-02	3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	4	0.2	0.002	-0.001	-0.001	0.07	-0.0002	0.45	-0.001	-0.001	-0.001	-0.05	-0.001	0.007
31-Dec-02	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	6	0.25	0.002	-0.001	-0.001	0.06	-0.0002	1.03	-0.001	-0.001	-0.001	-0.05	-0.001	0.004
14-Jan-03	7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	8	0.13	0.001	-0.001	-0.001	-0.05	-0.0002	1.17	-0.001	-0.001	-0.001	-0.05	-0.001	0.007
28-Jan-03	9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	10	0.14	-0.001	-0.001	-0.001	-0.05	-0.0002	1.27	-0.001	-0.001	-0.001	-0.05	-0.001	0.006
11-Feb-03	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	12	0.17	-0.001	-0.001	-0.001	-0.05	-0.0002	0.89	-0.001	-0.001	-0.001	-0.05	-0.001	0.005
25-Feb-03	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	14	0.13	-0.001	-0.001	-0.001	-0.05	-0.0002	1.49	-0.001	-0.001	-0.001	-0.05	-0.001	0.006
11-Mar-03	15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	16	0.11	-0.001	-0.001	-0.001	-0.05	-0.0002	1.04	-0.001	-0.001	-0.001	-0.05	-0.001	0.005
25-Mar-03	17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	18	0.12	-0.001	-0.001	-0.001	-0.05	-0.0002	1.32	-0.001	-0.001	-0.001	-0.05	-0.001	0.004
08-Apr-03	19	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03	20													

Date	Accum. Weeks	Mn mg/L	Hg ug/L	Mo mg/L	Ni mg/L	PO4 mg/L	K mg/L	SiO2 mg/L	Ag mg/L	Na mg/L	Sr mg/L	Ti mg/L	V mg/L	Zn mg/L
26-Nov-02	0	0.001	-0.02	0.002	0.004	0.52	0.18	2.44	-0.0001	11.7	0.004	0.009	0.005	-0.005
03-Dec-02	1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	2	0.005	#N/A	0.0032	-0.001	0.03	0.92	0.58	-0.0001	23.1	0.008	0.003	0.005	-0.005
17-Dec-02	3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	4	0.001	#N/A	0.0012	-0.001	-0.01	0.58	1.9	-0.0001	15.3	0.004	0.003	0.003	-0.005
31-Dec-02	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	6	0.005	#N/A	-0.0005	-0.001	-0.01	0.7	2.5	-0.0001	12.8	0.007	0.004	0.003	-0.005
14-Jan-03	7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	8	0.005	#N/A	-0.0005	-0.001	-0.01	0.65	1.46	-0.0001	6.44	0.007	0.002	0.002	-0.005
28-Jan-03	9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	10	0.004	#N/A	-0.0005	-0.001	-0.01	0.53	1.69	-0.0001	5.7	0.006	0.002	0.002	-0.005
11-Feb-03	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	12	0.002	#N/A	-0.0005	-0.001	0.02	0.4	1.28	-0.0001	4.07	0.004	0.002	0.002	-0.005
25-Feb-03	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	14	0.003	#N/A	-0.0005	-0.001	-0.01	0.4	1.48	-0.0001	3.86	0.007	0.002	0.001	-0.005
11-Mar-03	15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	16	0.002	#N/A	-0.0005	-0.001	-0.01	0.32	1.18	-0.0001	2.64	0.004	-0.001	0.001	-0.005
25-Mar-03	17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	18	0.003	#N/A	-0.0005	-0.001	0.02	0.38	1.08	-0.0001	2.61	0.005	0.002	0.001	-0.005
08-Apr-03	19	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03	20													

#N/A = not tested

Table A3.2-5: Kinetic Test Results: Leachate Chemistry of HC - 2 (W99-0118)

Date	Accum.	Volume (ml)		pH	Cond.	ORP	Sulfate	Acidity	Alkalintiy
	Weeks	Input	Output		(umhos/cm)	(mv)	(mg/L)	(mg CaCO3/L)	(mg CaCO3/L)
26-Nov-02	0	750	620	8.84	72	235	7	#N/A	15
03-Dec-02	1	500	450	8.54	112	260	12	#N/A	#N/A
10-Dec-02	2	500	485	8.21	96	142	6	2	29
17-Dec-02	3	500	470	7.96	74	266	4	#N/A	#N/A
24-Dec-02	4	500	500	7.68	76	200	8	4	20
31-Dec-02	5	500	415	7.61	64	215	15	#N/A	#N/A
07-Jan-03	6	500	470	7.32	87	216	22	2	12
14-Jan-03	7	500	430	7.27	82	270	17	#N/A	#N/A
21-Jan-03	8	500	470	7.51	75	239	18	3	12
28-Jan-03	9	500	410	7.32	71	260	18	#N/A	#N/A
04-Feb-03	10	500	480	7.48	77	215	19	3	13
11-Feb-03	11	500	455	7.27	74	260	18	#N/A	#N/A
18-Feb-03	12	500	420	7.42	75	240	21	2	9
25-Feb-03	13	500	485	7.29	84	300	20	#N/A	#N/A
04-Mar-03	14	500	510	7.38	90	250	19	3	11
11-Mar-03	15	500	405	7.62	74	310	19	#N/A	#N/A
18-Mar-03	16	500	445	7.14	90	310	23	5	6
25-Mar-03	17	500	510	7.32	100	250	25	#N/A	#N/A
01-Apr-03	18	500	445	7.09	76	330	21	4	7
08-Apr-03	19	500	465	7.22	83	310	21	#N/A	#N/A
15-Apr-03	20	Terminated							

Date	Accum.	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li
	Weeks	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
26-Nov-02	0	0.11	-0.001	-0.001	-0.001	-0.05	-0.0002	1.05	-0.001	-0.001	0.001	-0.05	-0.001	0.005
03-Dec-02	1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	2	0.091	-0.001	0.001	-0.001	0.07	-0.0002	2.14	-0.001	-0.001	-0.001	-0.05	-0.001	0.015
17-Dec-02	3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	4	0.076	-0.001	0.001	-0.001	-0.05	-0.0002	3.12	-0.001	-0.001	-0.001	-0.05	-0.001	0.011
31-Dec-02	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	6	0.095	-0.001	0.002	-0.001	-0.05	-0.0002	6.54	-0.001	-0.001	-0.001	-0.05	-0.001	0.007
14-Jan-03	7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	8	0.054	-0.001	0.001	-0.001	-0.05	-0.0002	5.56	-0.001	-0.001	-0.001	-0.05	-0.001	0.011
28-Jan-03	9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	10	0.058	-0.001	0.001	-0.001	-0.05	-0.0002	6.97	-0.001	-0.001	-0.001	-0.05	-0.001	0.01
11-Feb-03	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	12	0.06	-0.001	0.001	-0.001	-0.05	-0.0002	7.63	-0.001	-0.001	-0.001	-0.05	-0.001	0.008
25-Feb-03	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	14	0.053	-0.001	0.002	-0.001	-0.05	-0.0002	8.81	-0.001	-0.001	-0.001	-0.05	-0.001	0.009
11-Mar-03	15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	16	0.041	-0.001	0.001	-0.001	-0.05	-0.0002	8.01	-0.001	-0.001	-0.001	-0.05	-0.001	0.007
25-Mar-03	17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	18	0.059	-0.001	0.001	-0.001	-0.05	-0.0002	7.44	-0.001	-0.001	-0.001	-0.05	-0.001	0.005
08-Apr-03	19	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03	20													

Date	Accum.	Mn	Hg	Mo	Ni	PO4	K	SiO2	Ag	Na	Sr	Ti	V	Zn
	Weeks	mg/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
26-Nov-02	0	0.002	-0.02	-0.0005	0.004	0.42	0.64	1.52	-0.0001	7.84	0.007	0.001	0.004	-0.005
03-Dec-02	1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	2	0.013	#N/A	0.0014	-0.001	-0.01	1.27	1.94	-0.0001	14.4	0.019	0.004	0.011	0.006
17-Dec-02	3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	4	0.013	#N/A	0.0005	-0.001	-0.01	1.11	3.58	-0.0001	5.06	0.021	0.002	0.006	-0.005
31-Dec-02	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	6	0.028	#N/A	-0.0005	-0.001	-0.01	1.3	3.37	-0.0001	4.17	0.041	0.001	0.005	-0.005
14-Jan-03	7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	8	0.023	#N/A	-0.0005	-0.001	-0.01	1.06	2.02	-0.0001	1.59	0.034	0.001	0.004	-0.005
28-Jan-03	9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	10	0.022	#N/A	-0.0005	-0.001	-0.01	0.99	2.24	-0.0001	1.26	0.037	-0.001	0.003	-0.005
11-Feb-03	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	12	0.019	#N/A	-0.0005	-0.001	0.01	0.85	1.86	-0.0001	0.84	0.039	0.001	0.003	-0.005
25-Feb-03	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	14	0.029	#N/A	-0.0005	0.001	-0.01	0.83	2.06	-0.0001	0.6	0.041	0.001	0.002	-0.005
11-Mar-03	15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	16	0.02	#N/A	-0.0005	-0.001	-0.01	0.67	1.51	-0.0001	0.49	0.036	-0.001	0.001	-0.005
25-Mar-03	17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	18	0.018	#N/A	-0.0005	-0.001	-0.01	0.71	1.41	-0.0001	0.37	0.031	0.001	0.001	-0.005
08-Apr-03	19	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03	20													

#N/A = not tested

Table A3.2-6: Kinetic Test Results: Leachate Chemistry of HC - 3 (W99-603)

Date	Accum. Weeks	Volume (ml) Input	Output	pH	Cond. (umhos/cm)	ORP (mv)	Sulfate (mg/L)	Acidity (mg CaCO3/L)	Alkalintiy (mg CaCO3/L)
26-Nov-02	0	750	605	8.33	67	254	8	#N/A	11
03-Dec-02	1	500	365	8.79	85	251	13	#N/A	#N/A
10-Dec-02	2	500	355	8.67	66	131	6	#N/A	14
17-Dec-02	3	500	355	8.57	61	241	6	#N/A	#N/A
24-Dec-02	4	500	270	8.48	57	195	5	#N/A	14
31-Dec-02	5	500	465	7.85	56	220	7	#N/A	#N/A
07-Jan-03	6	500	395	7.35	53	212	11	2	9
14-Jan-03	7	500	385	7.39	60	265	10	#N/A	#N/A
21-Jan-03	8	500	555	7.45	64	240	12	3	15
28-Jan-03	9	500	440	7.16	54	270	10	#N/A	#N/A
04-Feb-03	10	500	480	7.51	57	200	10	3	15
11-Feb-03	11	500	475	7.18	55	255	9	#N/A	#N/A
18-Feb-03	12	500	375	7.34	41	240	9	2	7
25-Feb-03	13	500	385	7.52	43	295	8	#N/A	#N/A
04-Mar-03	14	500	425	7.30	67	255	14	3	7
11-Mar-03	15	500	375	7.64	49	305	12	#N/A	#N/A
18-Mar-03	16	500	425	7.41	61	310	13	3	6
25-Mar-03	17	500	420	7.28	57	250	13	#N/A	#N/A
01-Apr-03	18	500	405	7.17	45	330	10	4	6
08-Apr-03	19	500	380	7.41	46	300	11	#N/A	#N/A
15-Apr-03	20	Terminated							

Date	Accum. Weeks	Al mg/L	As mg/L	Ba mg/L	Be mg/L	B mg/L	Cd mg/L	Ca mg/L	Cr mg/L	Co mg/L	Cu mg/L	Fe mg/L	Pb mg/L
26-Nov-02	0	0.075	-0.001	0.001	-0.001	-0.05	-0.0002	3.04	-0.001	-0.001	0.002	-0.05	-0.001
03-Dec-02	1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	2	0.12	-0.001	-0.001	-0.001	-0.05	-0.0002	3.32	-0.001	-0.001	0.001	-0.05	-0.001
17-Dec-02	3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	4	0.12	-0.001	0.001	-0.001	-0.05	-0.0002	2.55	-0.001	-0.001	-0.001	-0.05	-0.001
31-Dec-02	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	6	0.12	0.002	-0.001	-0.001	-0.05	-0.0002	4.3	-0.001	-0.001	-0.001	-0.05	-0.001
14-Jan-03	7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	8	0.046	-0.001	-0.001	-0.001	-0.05	-0.0002	5.02	-0.001	-0.001	-0.001	-0.05	-0.001
28-Jan-03	9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	10	0.086	-0.001	-0.001	-0.001	-0.05	-0.0002	5.87	-0.001	-0.001	-0.001	-0.05	-0.001
11-Feb-03	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	12	0.09	-0.001	-0.001	-0.001	-0.05	-0.0002	4.78	-0.001	-0.001	-0.001	-0.05	-0.001
25-Feb-03	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	14	0.06	-0.001	-0.001	-0.001	-0.05	-0.0002	5.98	-0.001	-0.001	-0.001	-0.05	-0.001
11-Mar-03	15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	16	0.048	-0.001	-0.001	-0.001	-0.05	-0.0002	5.38	-0.001	-0.001	-0.001	-0.05	-0.001
25-Mar-03	17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	18	0.073	-0.001	-0.001	-0.001	-0.05	-0.0002	4.67	-0.001	-0.001	-0.001	-0.05	-0.001
08-Apr-03	19	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03	20												

Date	Li mg/L	Mn mg/L	Hg ug/L	Mo mg/L	Ni mg/L	PO4 mg/L	K mg/L	SiO2 mg/L	Ag mg/L	Na mg/L	Sr mg/L	Ti mg/L	V mg/L	Zn mg/L
26-Nov-02	0.012	0.006	-0.02	-0.0005	0.006	0.73	1.5	1.12	-0.0001	3.17	0.015	-0.001	0.002	-0.005
03-Dec-02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10-Dec-02	0.021	0.013	#N/A	0.0018	0.001	0.04	2	0.37	-0.0001	5.63	0.02	0.003	0.003	-0.005
17-Dec-02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24-Dec-02	0.015	0.005	#N/A	0.001	-0.001	-0.01	1.34	1.64	-0.0001	1.67	0.012	0.002	0.003	-0.005
31-Dec-02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
07-Jan-03	0.008	0.013	#N/A	-0.0005	-0.001	-0.01	0.94	1.71	-0.0001	1.27	0.018	0.001	0.003	-0.005
14-Jan-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21-Jan-03	0.013	0.021	#N/A	-0.0005	-0.001	-0.01	0.77	1.47	-0.0001	0.65	0.021	-0.001	0.002	-0.005
28-Jan-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Feb-03	0.012	0.017	#N/A	-0.0005	-0.001	-0.01	0.91	2.08	-0.0001	0.6	0.021	0.001	0.002	-0.005
11-Feb-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Feb-03	0.008	0.008	#N/A	-0.0005	-0.001	-0.01	0.65	0.86	-0.0001	0.32	0.014	0.001	0.002	0.012
25-Feb-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04-Mar-03	0.008	0.01	#N/A	-0.0005	-0.001	-0.01	0.6	0.97	-0.0001	0.3	0.019	-0.001	0.001	-0.005
11-Mar-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18-Mar-03	0.007	0.007	#N/A	-0.0005	-0.001	-0.01	0.52	0.77	-0.0001	0.33	0.016	-0.001	-0.001	-0.005
25-Mar-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01-Apr-03	0.005	0.007	#N/A	-0.0005	-0.001	0.02	0.54	1.02	-0.0001	0.2	0.014	0.001	-0.001	-0.005
08-Apr-03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15-Apr-03														

#N/A = not tested

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4.0 WATER REGIME

4.1 INTRODUCTION

This section describes the baseline **water regime** and how the baseline environment will change with the proposed Wuskwatim Generating Station Project ("the **Project**"). Water bodies (lakes, rivers, streams, creeks, etc.) and their associated water regime are part of the physical environment which is described for the Project study area as it presently exists.

The Project is located on the Burntwood River which has been regulated by Manitoba Hydro as part of the Churchill River Diversion (**CRD**) Project since 1977. Southern Indian Lake (**SIL**) is a large reservoir from which the Churchill River is diverted into the Burntwood River via the Rat River by two control dams; Missi Falls and Notigi Control structures, in order to supply water to the **generating stations** on the lower Nelson River. Missi Falls regulates water releases into the lower Churchill River, and the Notigi **Control Structure** regulates flow into the Burntwood River (Figure 4.1-1). The CRD (and Wuskwatim Lake inflows) has been a regulated waterway for the last 25 years.

The Project will modify various characteristics of the **water regime** in a portion of the Burntwood River upstream and downstream of Taskinigup Falls which is immediately downstream of Wuskwatim Lake.

The **EIS** Guidelines require that the proponent provide a discussion of river **flows** and levels with and without the Project, as well as during the Project construction, specifically:

- *"planned, average hourly discharges at the plant"; and*
- *"under a range of flow and station operating conditions, discuss average hourly forebay **elevation**s, tailrace water elevations and water elevations at several downstream locations."*

Volume 3, Section 5.2 of the Project Description describes how the Project will operate and modify flows and **water levels**, based on the information in this section. This document describes the baseline water regime (not contained in Volume 3) and how the baseline environment will change with the Project as required by the EIS Guidelines.

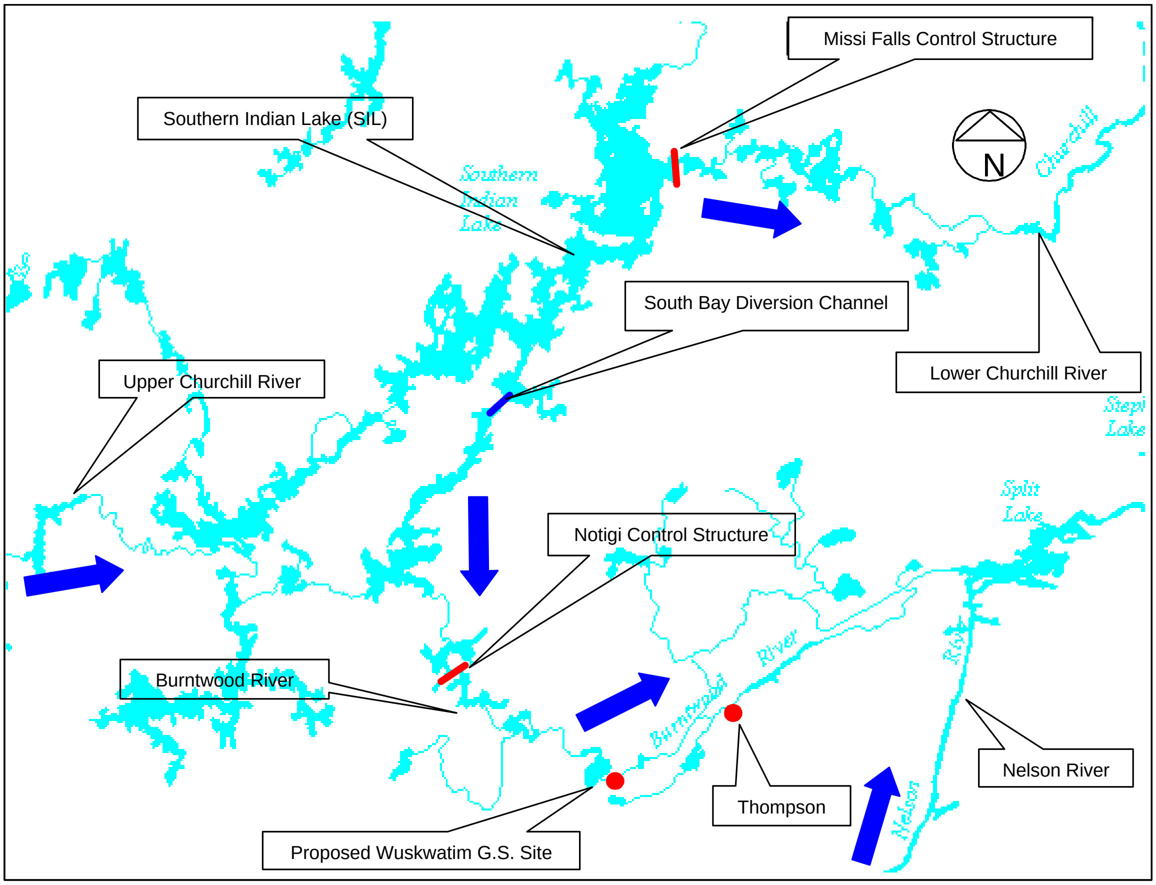


Figure 4.1-1 Churchill River Diversion

This section of the report is presented in two parts. One part pertains to the existing 25 year **post-CRD** regulated water regime. A second part pertains to a project inflow record which is a long term flow record that represents the Wuskwatim Lake inflows that are expected in the future. It is this project inflow record that will be used to assess water regime effects with and without the Project.

This section describes the flows, water levels, and river velocities with and without the Project. Products of this assessment are used to study:

- the Projects **mode of operation** (Volume 3, Section 5.2);
- the anticipated effects of the Project on the aquatic environment (Volume 5);
- the anticipated effects of the Project on the terrestrial environment (i.e. shoreline) (Volume 6);
- the anticipated effects on other aspects of physical environment, i.e., river bank **erosion** (Section 7) and sedimentation (Section 8).

4.1.1 Approach and Methodology

4.1.1.1 Overview to Approach

For over 25 years, Manitoba Hydro has collected water levels and flows at various locations along the Burntwood River, as well as additional parameters as required, for operational and planning purposes. Data collected from this program and supplemented with data requirements identified specifically for the Wuskwatim EIS have been used in assessing the effects of the Project on the water regime. The following approach was used:

- Characterize the water regime with and without the Project. Define project inflows, the boundary conditions of the Project, and the site specific components of the water regime.
- Assess whether additional data collection or creation is required to carry out these undertakings.
- Gather **hydraulic** data such as water levels, river cross sections, ice measurements and other water regime information to characterize the current water regime and to facilitate hydraulic **model** studies.
- Characterize the water regime with the Project through the application of various hydraulic models.
- Compare the water regimes with and without the Project to quantify the effects of the Project on the water regime.

The analysis of the water regime requires many hydraulic modelling tools to provide the information needed for the environmental impact assessment. The water regime that would be observed with and without the Project was characterized using a variety of open water and winter hydraulic models and engineering practices (Appendix A4.5). Various aspects of the water regime were characterized which include:

- water level and flow hydrographs;
- water level **profiles**;
- daily water level fluctuations;
- **stage-discharge relationships**;
- river velocities;
- flooded area; and,
- winter ice processes.

The approximate 25 years of flow records was used to characterize Wuskwatim Lake inflows for the existing water regime, termed the "**Existing (Post-CRD) Inflows**".

Where data was not sufficient to perform the analysis, either field studies were carried out to acquire the data (such as water level, river cross-section information) or additional "desktop" activities were undertaken to generate data needed to complete the studies (such as simulating water levels and flows).

Over the last 25 years, the existing (post-CRD) water regime has evolved because of changes in CRD operating constraints and agreements on the Burntwood River. This flow record is too short to assess system operations. For planning purposes and this EIS, Manitoba Hydro has developed a long term (86 year) **simulated flow** record of inflows to Wuskwatim Lake, termed "project inflows". This inflow record forms part of a system wide long term flow record that is also used by Manitoba Hydro for the long range planning of all new generation.

As indicated in the introduction, the study approach involved an assessment of various aspects of the water regime for two conditions:

1. Existing (post-CRD) inflows
2. Project inflows <u>with and without</u> the Project

During the different phases of construction, the effects on the water regime in the vicinity of the Project are determined using various hydraulic models.

To assess the operational effects of the Project on the water regime, project inflows were used to simulate conditions with and without the Project.

The following study results represent Manitoba Hydro's **best estimate** of the water regime with and without the Project. Manitoba Hydro has developed a good understanding of the existing (post-CRD) water regime through the collection, observation, and analysis of a considerable amount of hydraulic information on the Burntwood River over the last 25 years. It is possible that as additional data is acquired in the future, Manitoba Hydro's characterization of the water regime may need to be adjusted.

4.1.1.2 Data Sources

The following data sources were used to characterize the water regime with and without the Project:

- Hydrometric records collected by Manitoba Hydro and Water Survey of Canada including: water levels, discharges, river cross sections, winter ice information, photography, water temperatures, etc (Appendix A4.2).

- Hydraulic reports and design memoranda prepared as part of the ongoing Burntwood River development studies (Volume 3, Section 3.2). Hydraulic relationships in the form of **stage**-discharge relationships, **stage-storage curves**, and winter ice **staging factors**, etc. were developed in these studies.

- Detailed river bathymetry of the Burntwood River between Wuskwatim Falls and Taskinigup Falls was collected in 1999 as part of the engineering studies.

- Detailed river bathymetry of the Burntwood River between Taskinigup Falls and Opegano Lake was collected in 2001 as part of the environmental impact assessment.

- Detailed water regime information (i.e., **velocity** measurements, ice thicknesses, meteorological data from Environment Canada, water temperatures) required to calibrate hydraulic modelling.

All elevations included in this assessment are referenced to the Canadian Geodetic Vertical **Datum** 1928 Revision 3, 1971 local adjustment unless otherwise stated. This datum is described in Volume 3, Section 2.7. Elevations at Notigi Control Structure and Southern Indian Lake are referenced to the Notigi Construction Datum.

4.1.1.3 Water Regime Assumptions

The water regime is a complex system involving many interrelated factors. To characterize the water regime with and without the Project it is necessary to make various simplifying assumptions. The following is a list of assumptions applied in this study:

1. The CRD will continue to operate in the future as it operates today.

2. The magnitude and variability of the project inflow record is assumed to be representative of future project inflows. The effects of climate change on runoff were not considered due to the current limitations of climate change models (Section 2).

3. The characteristics of the future water regime are based on normal operations with balancing daily flows (i.e. Wuskwatim Lake: daily inflow = daily outflow) that are assumed to occur for 100% of the time. The Project Description (Volume 3, Section 5.2) describes abnormal and emergency operations and their effects on the water regime. As this assessment deals with the long term flow record, it is difficult to introduce the transient effects of abnormal and emergency operations into the project inflow record.

4. The current river morphology is assumed to be representative of the river in the future for all hydraulic studies.

5. The project inflows that consist of monthly average Wuskwatim Lake inflows are assumed to be representative of the average daily inflow for each day within the month of interest.

4.1.1.4 Project Study Area

The **study reach**, shown in Figure 4.1-2, consists of the Burntwood River from the head of Early Morning Rapids to the foot of First Rapids. The proposed Project will be located at Taskinigup Falls, which is 1.5 km downstream of the outlet of Wuskwatim Lake. The following outlines the initial studies carried out to define the hydraulic zone of influence of the Project.

Backwater modelling was carried out from the head of Early Morning Rapids to Taskinigup Falls for both the existing (post-CRD) and Project conditions. The resulting water surface profiles, shown in Figure 4.1-3, indicate that the backwater effect does not flood out Early Morning Rapids with or without the Project because of the **supercritical** flow conditions through the rapids (Appendix A4.1 contains a detailed explanation). Although an ice dam forms at the **foot** of Early Morning Rapids during the winter supercritical flow conditions continue to persist as described in Section 5. Accordingly, it was determined that the water levels upstream of Early Morning Rapids would not be affected by the Project. Therefore, the **upstream boundary** of the **hydraulic zone of influence** of the Project is located at the foot of Early Morning Rapids.

For the **reach** downstream of the Project, hydrodynamic modelling of Project operations was extended to the head of First Rapids. The modelling results indicated that the daily water level fluctuations resulting from the Project operations gradually diminish in the downstream direction as a result of dampening effects due to lake and channel **storage**. The results indicated that the daily water level fluctuations at Birch Tree Lake would not be noticeable and would be difficult to distinguish from wind generated waves. On that basis, Birch Tree Lake was identified to be the downstream boundary of the hydraulic zone of influence (Section 4.3.4.2).

4.2 EXISTING (POST-CRD) WATER REGIME

4.2.1 Existing (Post-CRD) Inflows

The Wuskwatim Lake inflow has been regulated by the CRD for the last 25 years, therefore the historic period of post-CRD flows from 1977 to 2001 was used as the existing (post-CRD) inflows.

During the operation of the CRD, the Burntwood River has been controlled under the terms and conditions of a number of licenses and agreements that include:

- The "CRD" Interim Water Power License (1973) as modified by the annual CRD **Augmented Flow Program** which began in the early 1980's and has been approved annually by the Province of Manitoba as an addendum to the Interim Water Power License. It was not until 1986 that the Augmented Flow Program fully reflected the current conditions of today's program;
- The City of Thompson Agreement (1976);
- The Nelson House Comprehensive Implementation Agreement (1996);
- The Environmental Act license (2327) for the Churchill Weir (1998).

The conditions and operating limits for the above licenses and agreements for the current operation of the Churchill-Burntwood waterway system are described as follows:

- the operating range for Southern Indian Lake is set at an upper elevation of 258.32 m (847.5 ft) ASL and a lower elevation of 256.95 m (843 ft) with a maximum **drawdown** of 1.37 m (4.5 ft) in any one year (CRD Augmented Flow Program);

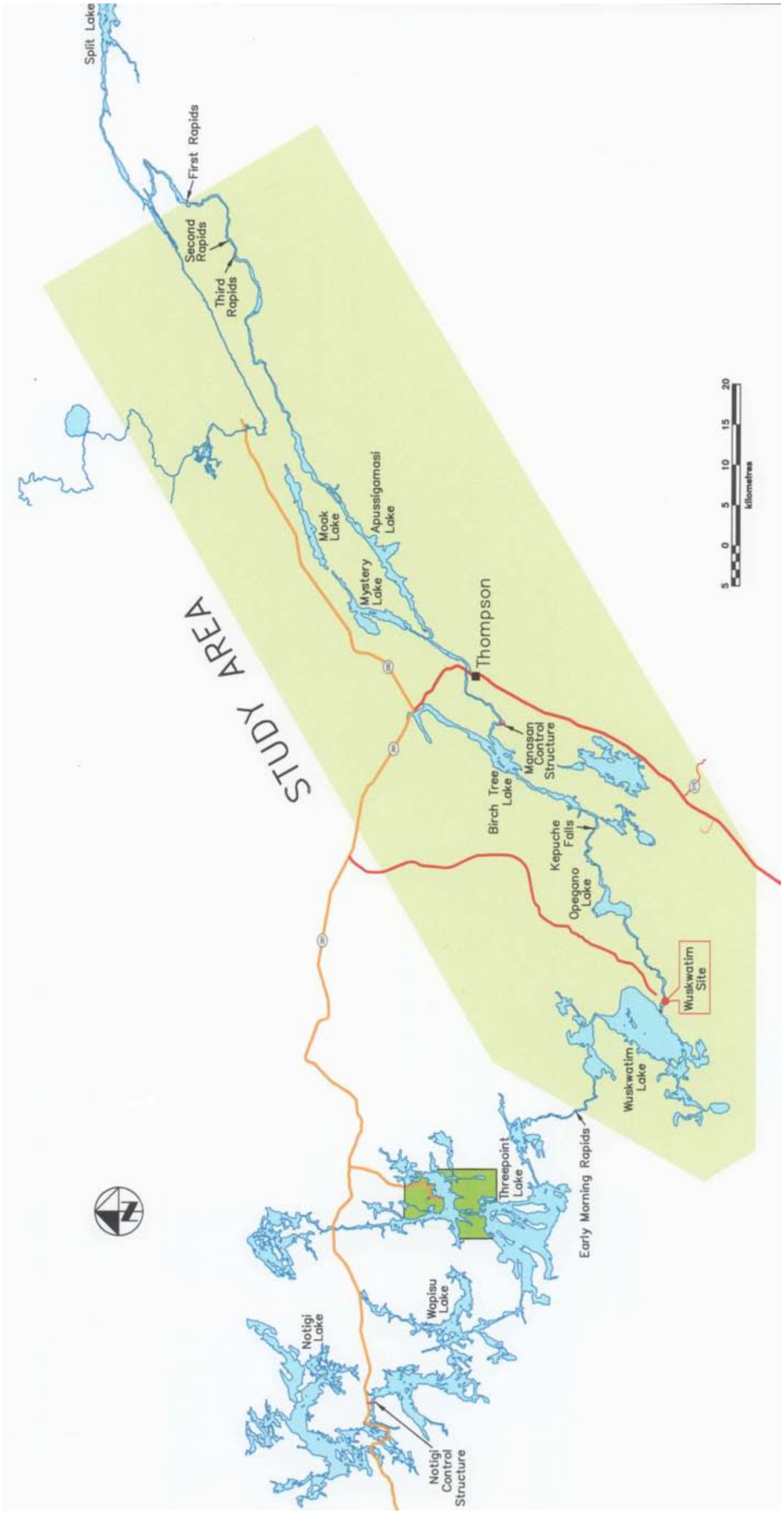


Figure 4.1-2 Project study reach

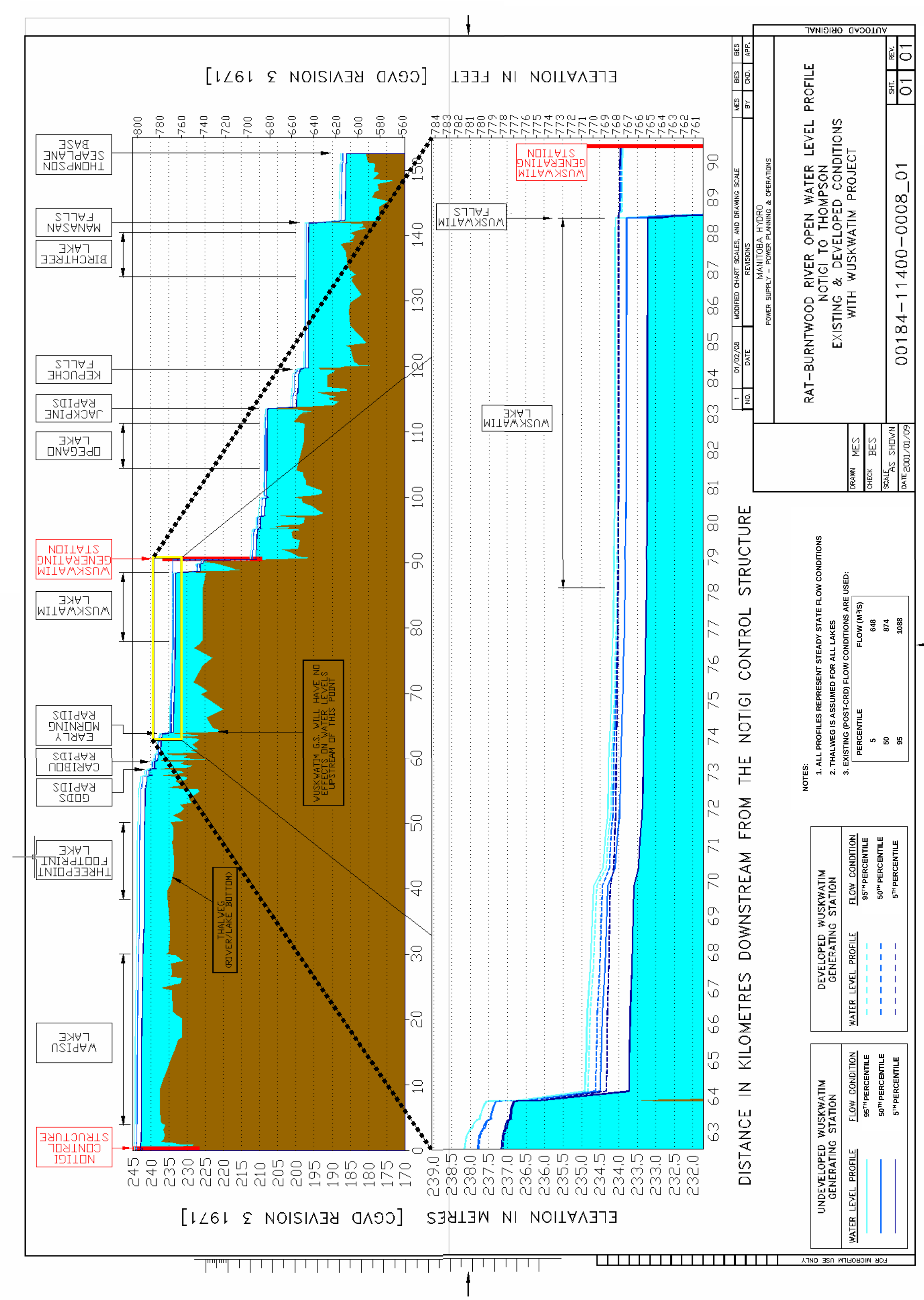
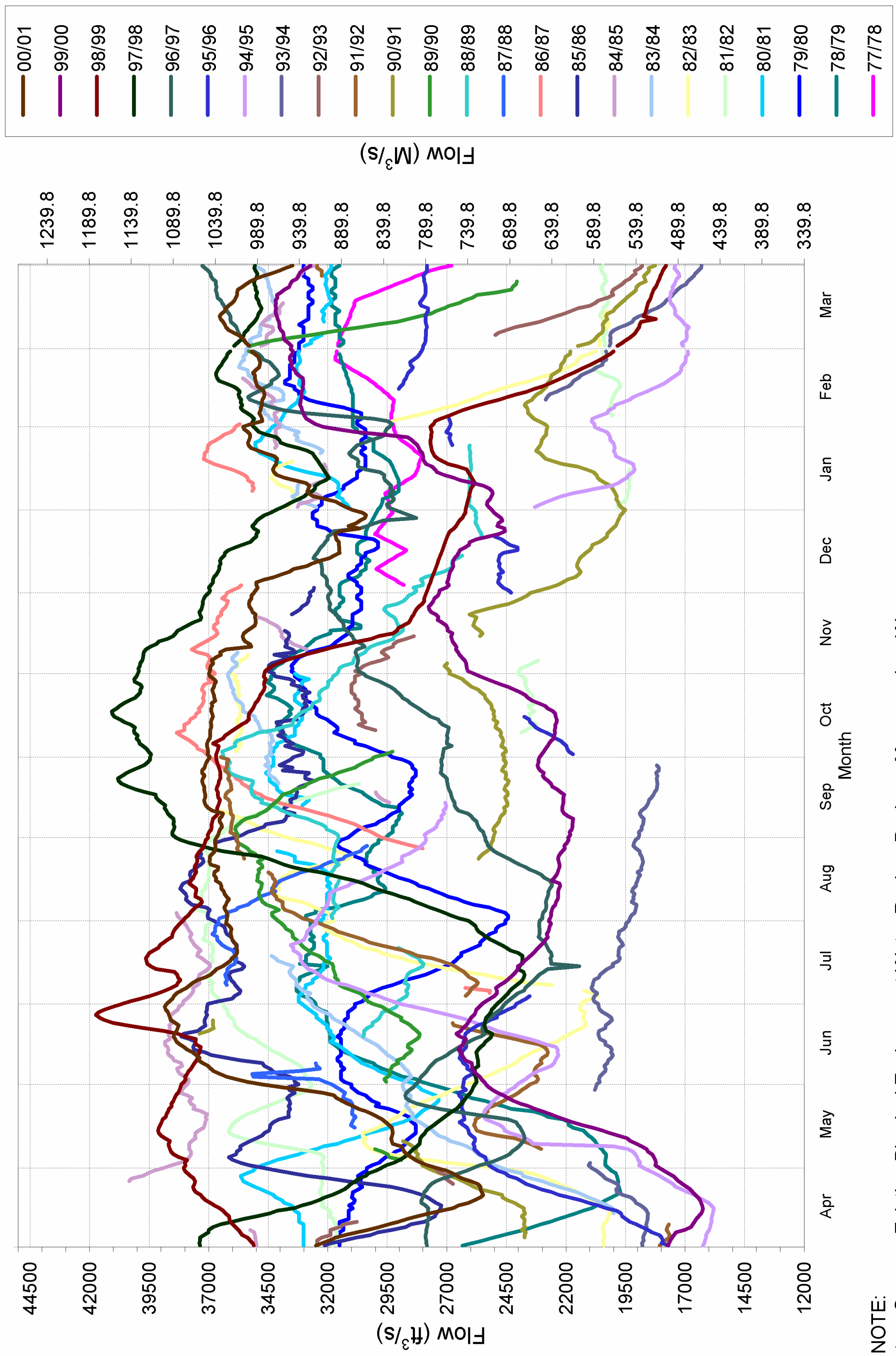


Figure 4.1-3 Open-water water-surface profiles – Burntwood River between Notigi Control structure and Thompson

- a minimum **riparian flow** release is required from Missi Control Structure of 14.16 m^3/s (500 cfs) in summer months (CRD interim license);
- a minimum winter release pattern at Missi Falls defined under the Environment Act License (2327), Churchill Water Level Enhancement Weir Project. Minimum allowable winter releases reduce from 113.2 m^3/s (4,000 ft^3/s) at the beginning of winter (November) to 42 m^3/s (1,500 ft^3/s) by mid February;
- Notigi Control Structure flow releases must not exceed 963 m^3/s (34,000 ft^3/s) in winter months and 991 m^3/s (35,000 ft^3/s) in summer months (Augmented Flow Program);
- The minimum allowable upstream reservoir level at Notigi Control Structure is 254.2 m (834 feet) (Augmented Flow Program);
- Under the Nelson House 1996 Comprehensive Implementation Agreement, Manitoba Hydro is "to exercise due diligence and take all practical, lawful, and reasonable measures" to maintain Threepoint Lake levels in the compensated range of 241.25 m (or 791.5 ft) and 243.84 m (800 ft); and
- Flows are regulated such that water levels are maintained at or below **license constraints** for the summer of 188.66 m (619 ft) at the Thompson Seaplane Base and for the winter of 189.88 m (623 ft) at the Thompson Pumphouse (City of Thompson Agreement).

Wuskwatim Lake inflows for the existing (post-CRD) period were derived from historically recorded Wuskwatim Lake water levels and an **outlet** stage discharge relationship developed for open water and winter conditions, as detailed in Appendix A4.4. Figure 4.2-1 illustrates discharge hydrographs for the existing (post-CRD) period and demonstrates the effect of the CRD regulation on the existing Wuskwatim Lake outflow regime. Figure 4.2-1 also illustrates that variability and range of flows out of Wuskwatim Lake from December 1977 to June 2001. Table 4.2-1 summarizes the existing (post-CRD) 5^{th}, 50^{th} and 95^{th} percentile inflows that have been used to generally characterize the existing water regime. See Appendix A4.4 for further details. These three inflow percentiles were chosen for aquatic assessment (Volume 5) purposes because they encompass 90 percent of all inflows. Project inflows are introduced and described in Section 4.3.1.



NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-1 Wuskwatim Lake flow hydrographs for the existing regime

Table 4.2-1
Existing (post-CRD) inflows: representative flow conditions

Discharge Condition	Discharge [m^3/s]
5^{th} percentile event	548
50^{th} percentile event	874
95^{th} percentile event	1066

4.2.2 Upstream of Project Site

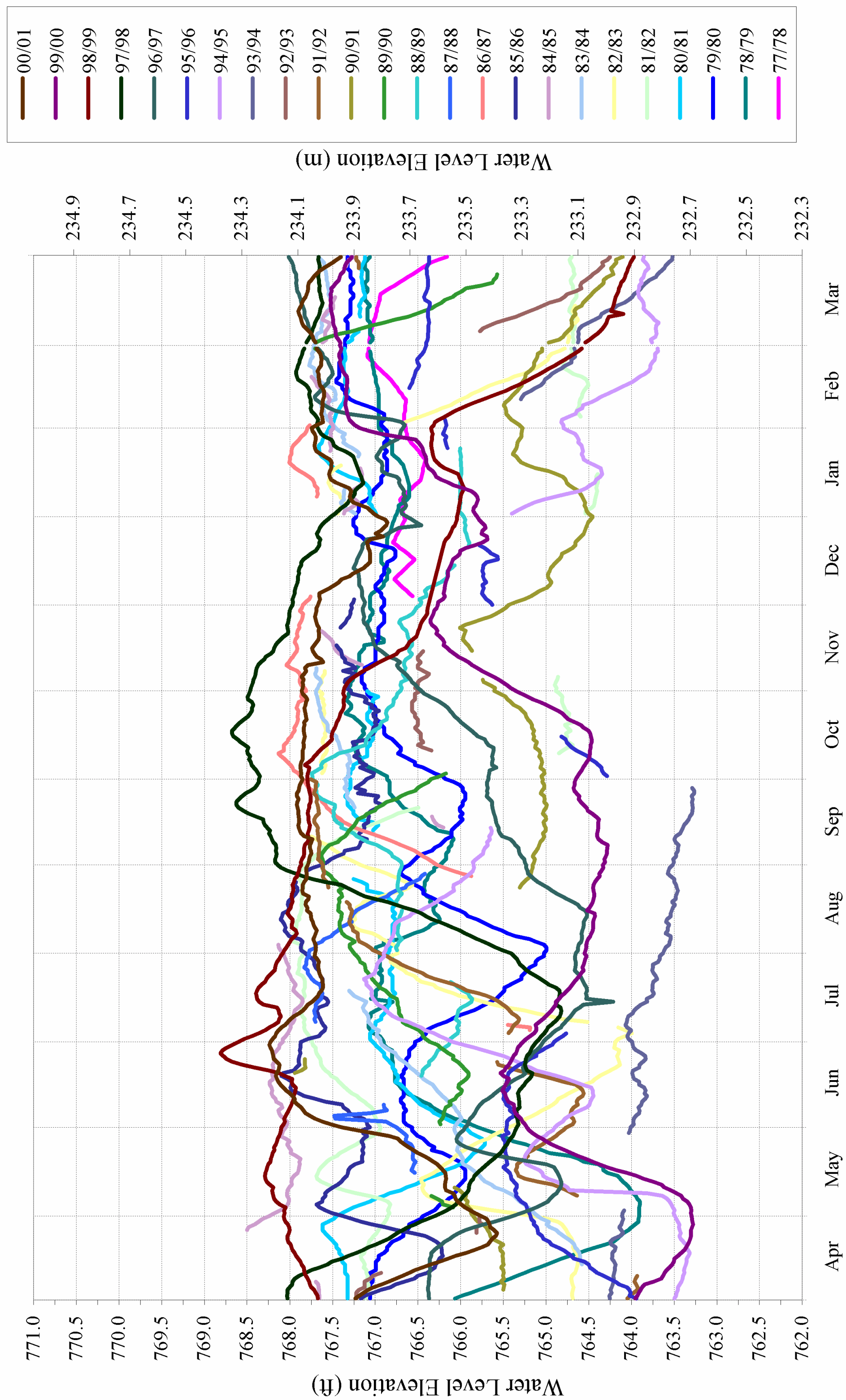
The following subsections describe the water regime characteristics from the foot of Early Morning Rapids to the site of the proposed Wuskwatim generating station. As discussed earlier in Section 4.1.1.4 Early Morning Rapids is the upstream end of the hydraulic zone of influence (Figure 4.1-2).

4.2.2.1 Stage Hydrographs

Stage **hydrograph**s for Wuskwatim Lake are shown in Figure 4.2-2 which are based on recorded water levels. The daily water level (stage) on Wuskwatim Lake has varied between 232.7 m and 234.3 m during the 1977-2001 period.

Stage hydrographs at the foot of Early Morning Rapids are shown in Figure 4.2-3. These stage hydrographs were developed by applying open water and winter stage-discharge relationships to the discharge estimate (outflows) derived from the Wuskwatim Lake levels. The stage at the foot of Early Morning Rapids has fluctuated between 233.1 m and 237.5 m during the 1977-2001 period. The much higher maximum water levels during the winter are a result of a **hanging ice dam** that forms at the foot of Early Morning Rapids (Section 5.4.1).

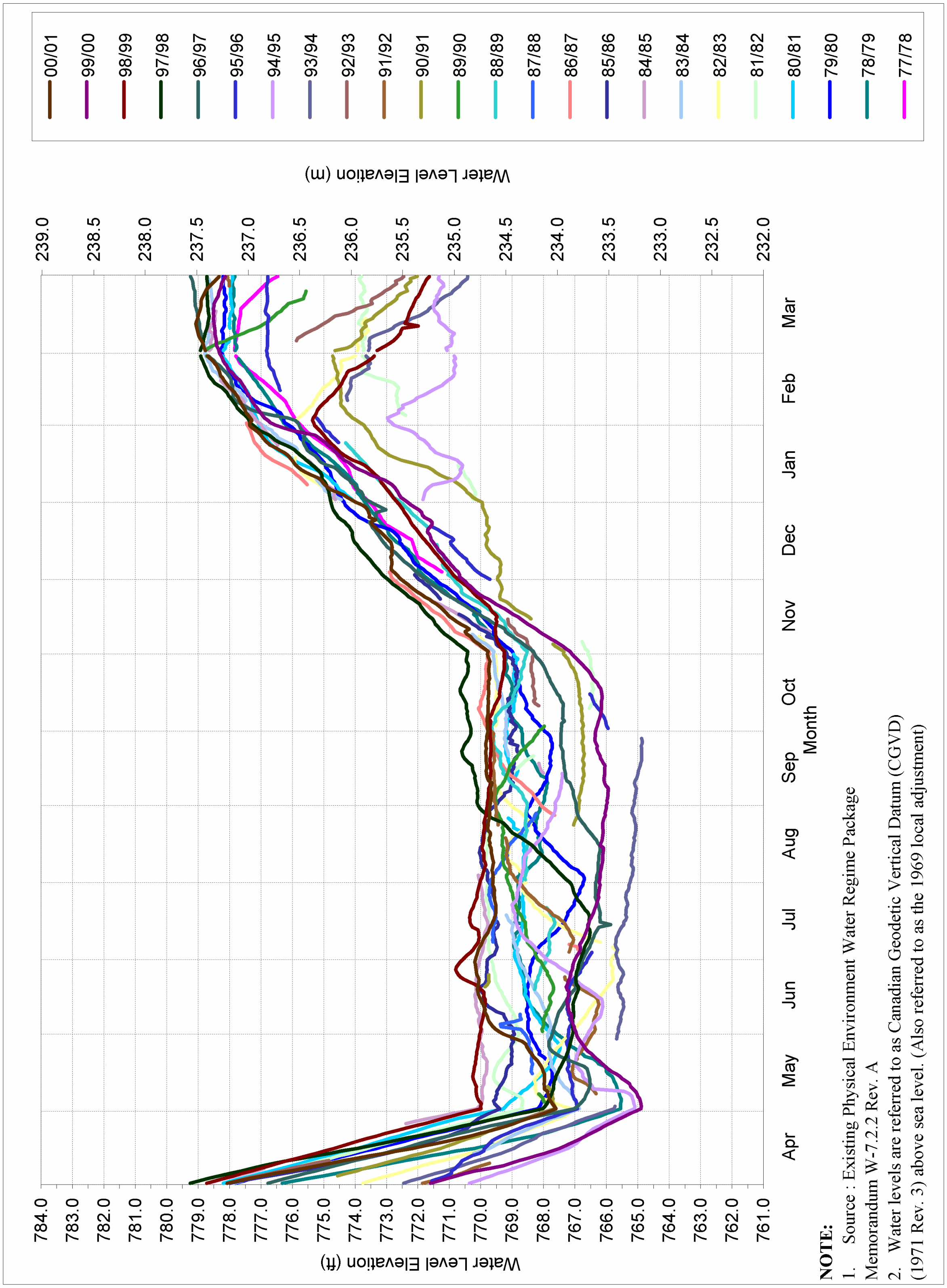
Refer to Appendix A4.4 for additional information regarding the stage hydrograph development.



NOTE:

1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-2 Wuskwatim Lake stage hydrographs for the existing regime



NOTE:

1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-3 Early Morning Rapids stage hydrographs for the existing regime

4.2.2.2 Wuskwatim Lake Stage-Storage Curve

Wuskwatim Lake, located immediately upstream of Wuskwatim Falls, has a total surface area of approximately 87.5 km^2 at a water level of 234 m. This includes all of the surrounding water bodies (e.g. Cranberry Lakes, Sesep Lake, and Wuskwatim Brook). A stage-storage curve developed for Wuskwatim Lake illustrates the storage above 229.8 m (Figure 4.2-4). The Lake has a **storage volume** of approximately 87 million m^3 between the water levels of 233.0 m and 234.0 m as illustrated in Figure 4.2-4. For further details on the development of the stage-storage curve, see Appendix A4.3. Volume 5 shows the bathymetry below 229.8 m as part of the aquatic environmental studies.

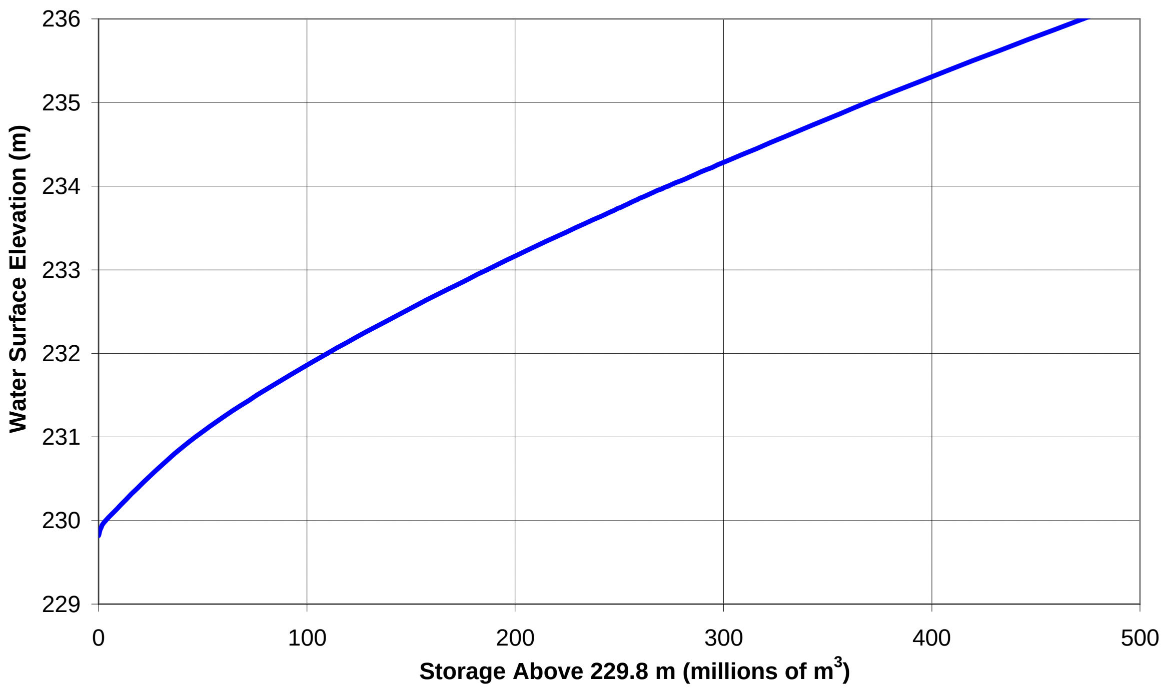


Figure 4.2-4 Wuskwatim Lake stage-storage curve

4.2.2.3 Water Surface Profiles

Open water surface profiles (for **steady-state** flow conditions) for the Early Morning Rapids to Taskinigup Falls reach were developed to support the characterization of shoreline drying and re-wetting in aquatic and terrestrial environmental studies. The open water and winter water surface profiles for the 5^{th}, 50^{th}, and 95^{th} percentile Wuskwatim Lake inflow conditions are shown in Figures 4.2-5 and 4.2-6 respectively.
Details of the open water and winter water surface profile modelling are included in Appendix A4.5 and A4.6 respectively.

Early Morning Rapids, located upstream of Wuskwatim Lake (Figure 4.2-7), has a total **head loss** of approximately 3.3 m. The water level profile downstream of Early Morning Rapids to Wuskwatim Lake has a small head loss of approximately 0.6 m for **median** flow conditions. The flow in this reach is **subcritical**, therefore this reach is backwater controlled by Wuskwatim Falls located at the outlet of Wuskwatim Lake.

Downstream of Wuskwatim Lake, a drop of approximately 7 m occurs at Wuskwatim Falls and approximately 15 m at Taskinigup Falls for median flow conditions. The water surface profile between these two sets of falls is relatively flat during open water conditions.

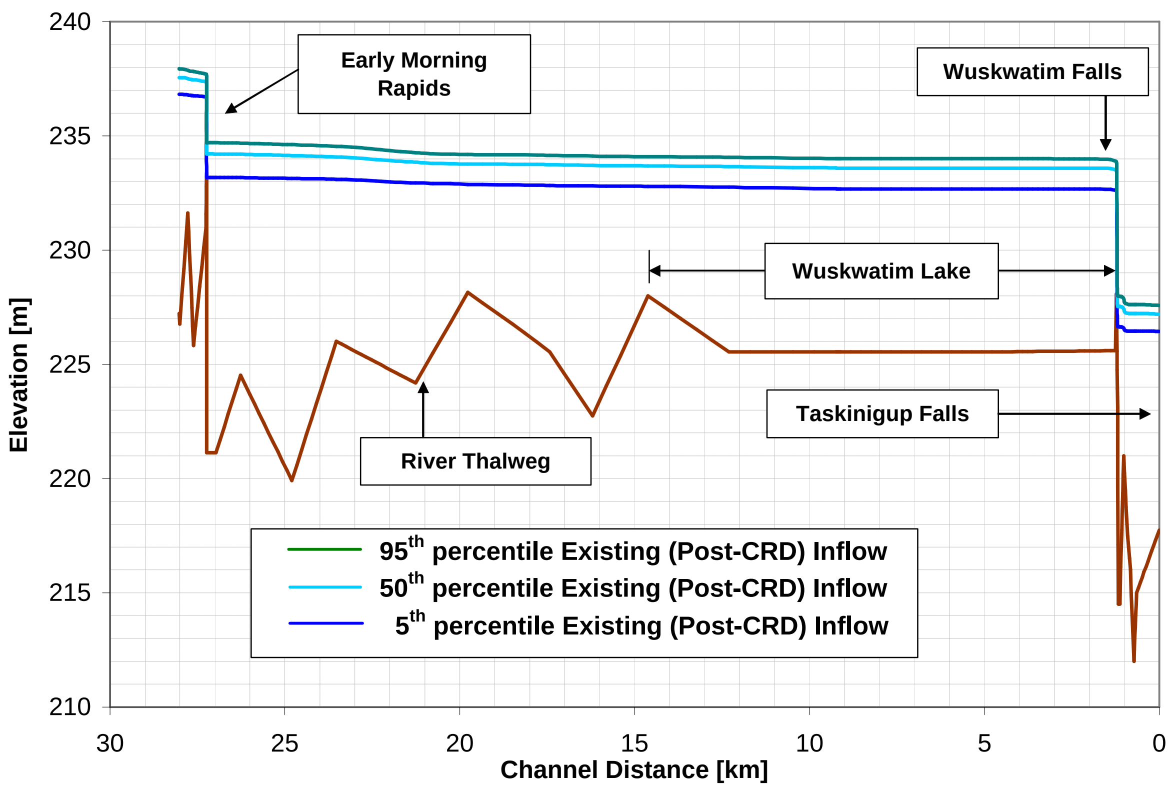


Figure 4.2-5 Open-water water-surface profiles: Early Morning Rapids - Taskinigup Falls 5th, 50th, and 95th percentile existing (post-CRD) inflows

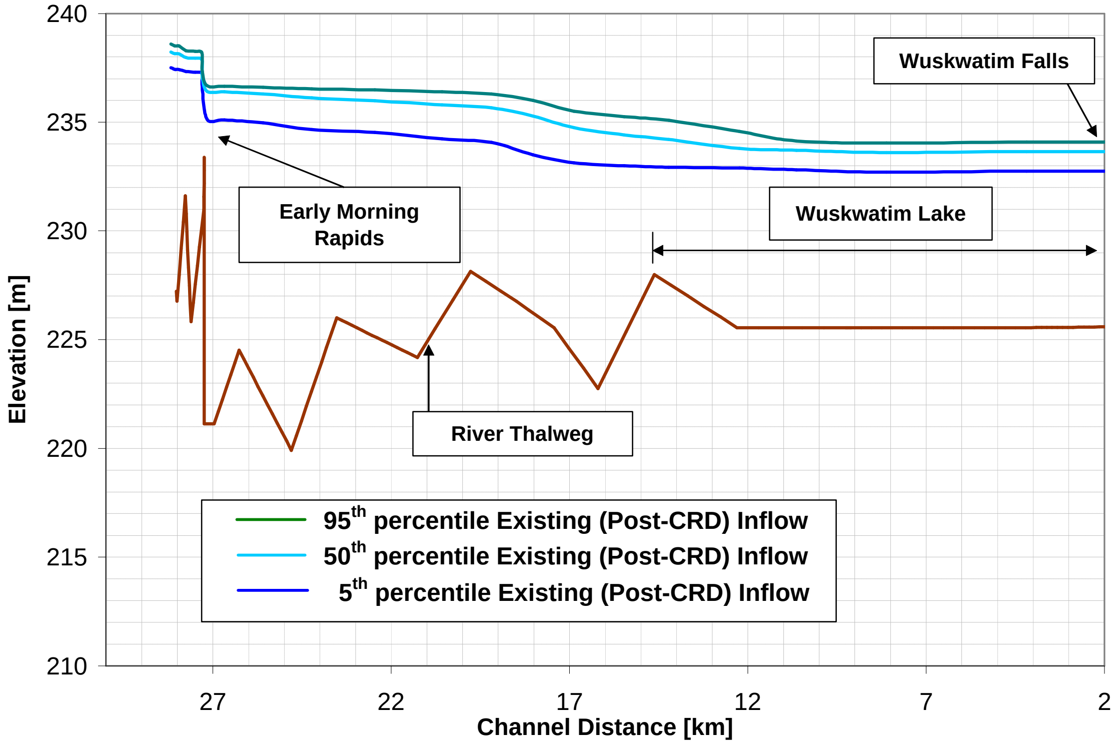


Figure 4.2-6 Winter water surface profiles: Early Morning Rapids - Taskinigup Falls 5th, 50th, and 95th percentile existing (post-CRD) inflows

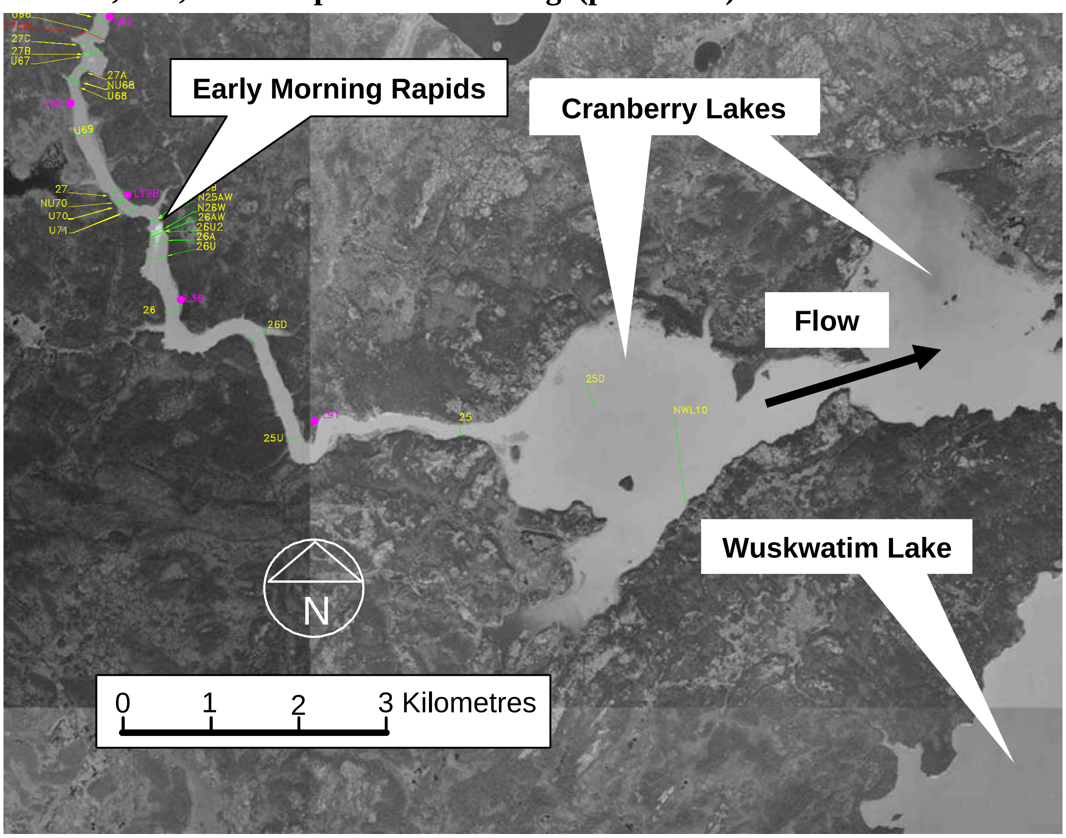


Figure 4.2-7 Location plan of Early Morning Rapids to Wuskwatim Lake.

4.2.2.4 Water Velocities in Wuskwatim Falls to Taskinigup Falls Reach

To support the aquatic environment studies (Volume 5) river velocities were developed from the foot of Wuskwatim Falls to head of Taskinigup Falls for a range of existing (post-CRD) inflow conditions (5^{th}, 50^{th}, and 95^{th} percentiles) using a three-dimensional hydraulic model (see Appendix A4.5 for details of model application). The model was run for each flow condition and river velocity distributions were extracted from a number of "horizontal slices". An example plot of a horizontal slice at elevation 225.5 m (median flow condition) is illustrated in Figure 4.2-8.

The figure indicates that velocities are less than 0.5 m/s in the bays, higher in the center of the channel (1.5 m/s), and highest velocities occur immediately downstream of Wuskwatim falls at a narrow section (3.5 m/s). The river velocities in the bays and centre channel areas range from 0.2 m/s to 0.8 m/s for the 5^{th} percentile flow condition and from 1 m/s to 2 m/s for the 95^{th} percentile flow condition. Higher velocities occur immediately downstream of Wuskwatim Falls at the narrow section (5^{th} percentile=2.0 m/s; 95^{th} percentile=3.8 m/s). For aquatic assessment purposes, the velocity distributions for the series of vertical slices were depth averaged.

Significantly higher velocities would occur through Wuskwatim Falls and are estimated to be in the range of 4 m/s to 10 m/s. Appendix A4.5 provides the velocity distributions for the 5^{th} and 95^{th} percentile flow conditions and provides details of the model setup and application.

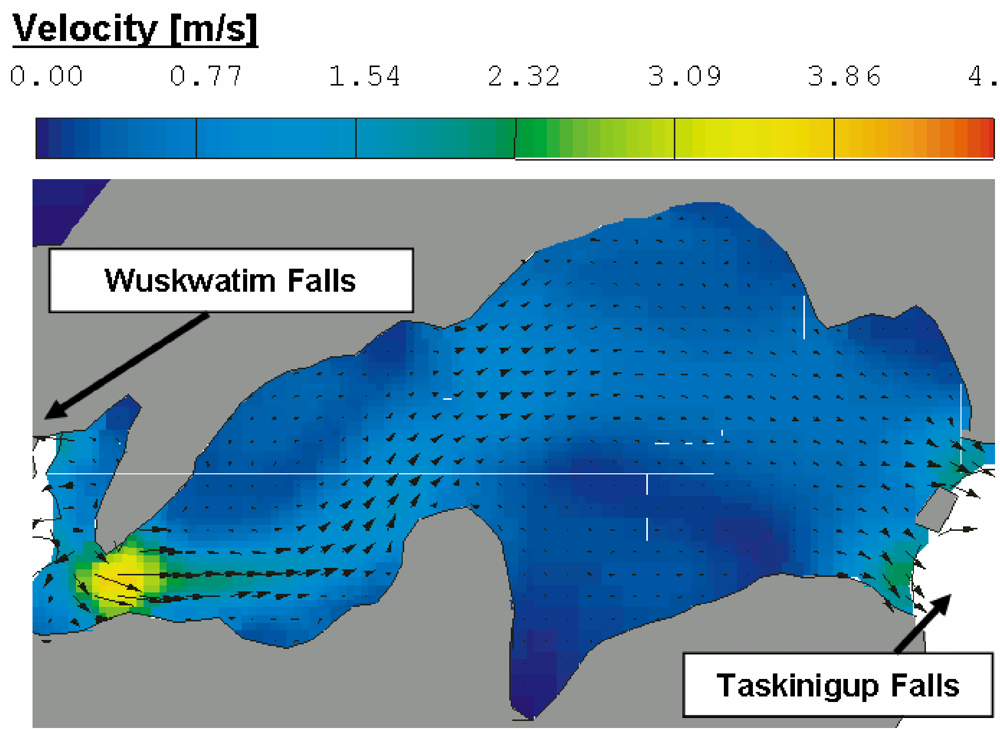


Figure 4.2-8 Velocity distribution for the Wuskwatim to Taskinigup Falls reach (50th percentile existing (post-CRD) flow at elevation 225.5 m)

4.2.3 Downstream of Project Site

Water regimes have been developed for several locations downstream of the proposed Project site from Taskinigup Falls to Birch Tree Lake to provide baseline information for assessment of the change in water regime that will result from the operation of the Project. As discussed earlier in Section 4.1.1.4 Birch Tree Lake is the downstream end of the hydraulic zone of influence (Figure 4.1-2).

4.2.3.1 Water Surface Profiles

Steady-state flow open water surface profiles in the Taskinigup Falls to First Rapids reach were developed to support the characterization of shoreline drying and re-wetting in aquatic and terrestrial environmental studies. The open water and winter water surface profiles for 5th, 50th, and 95th percentile Wuskwatim Lake inflow conditions are shown in Figures 4.2-9 and 4.2-10 respectively. Details of the open water and winter water surface profile modelling are included in Appendix A4.5 and A4.6 respectively.

The 13 km long river reach between Taskinigup Falls and Opegano Lake includes a series of smaller reaches that are relatively flat and are hydraulically controlled by three sets of rapids as illustrated in Figure 4.2-11. The water level in the 4 km of river located upstream of Opegano Lake is hydraulically controlled by the water level on Opegano lake. The water level drops approximately 3.5 m along the 13 km reach for median flow conditions. The largest set of rapids in this reach is Little Jackpine Falls, which drops roughly 1 m.

The river reach between Opegano Lake and Manasan Falls is characterized by a series of smaller reaches that are relatively flat and are hydraulically controlled by two sets of rapids, illustrated in Figure 4.2-12. Water levels on Opegano Lake are hydraulically controlled by Jackpine Falls. The water level drops 11 m along this reach with an approximate head loss of 7.8 m and 2.7 m at Jackpine Falls and Kepuche Falls for median flow conditions respectively. This reach of river also contains Birch Tree Lake, located immediately upstream of Manasan Falls. The Manasan Control Structure and Bypass Channel is located at Manasan Falls just upstream of Thompson.

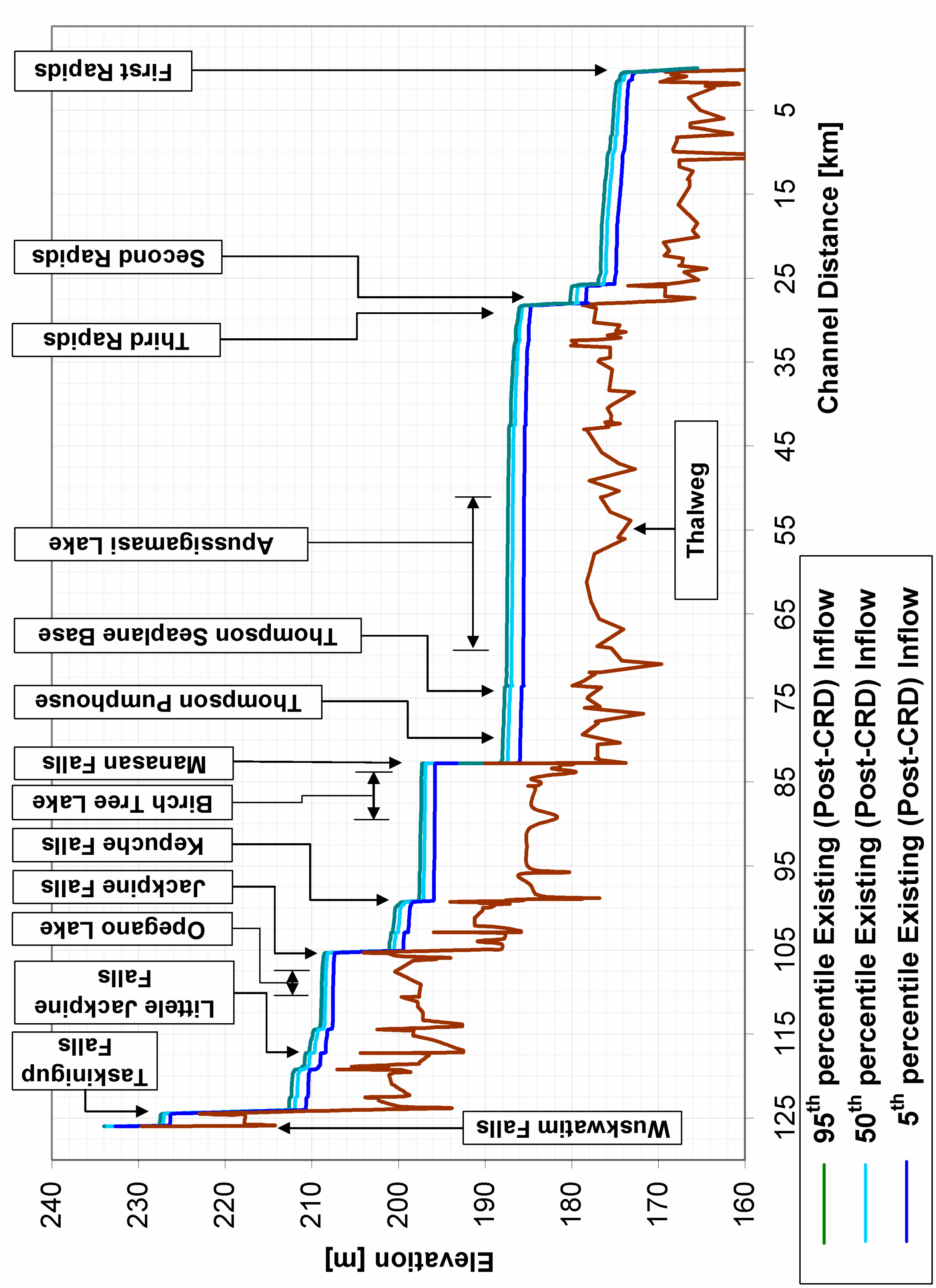


Figure 4.2-9 Wuskwatim Falls - First Rapids: open-water water-surface profiles for the 5th, 50th, and 95th percentile existing (post-CRD) flow conditions

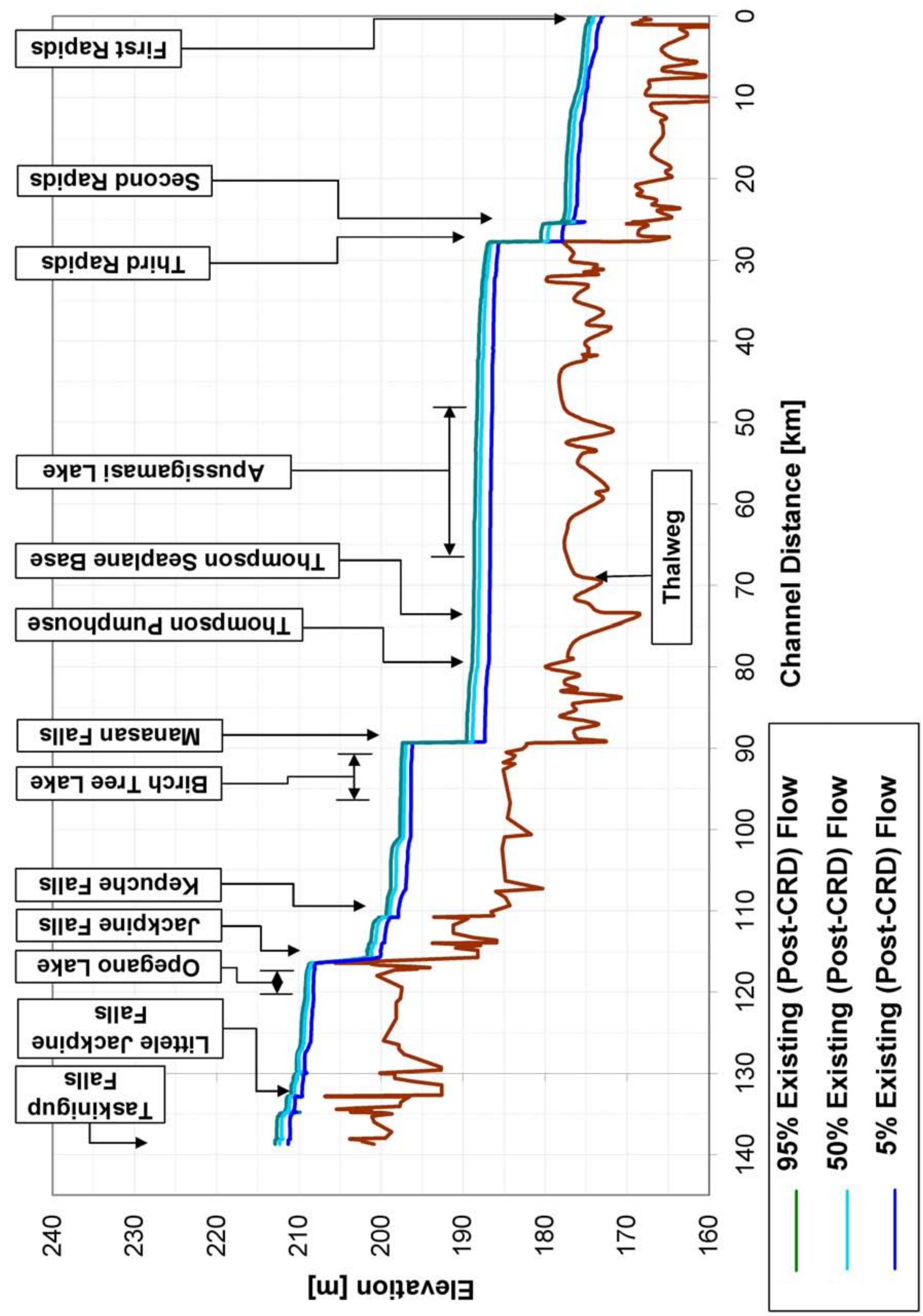


Figure 4.2-10 Wuskwatim Falls - First Rapids: winter water-surface profiles for the 5th, 50th, and 95th percentile existing (post-CRD) flow conditions

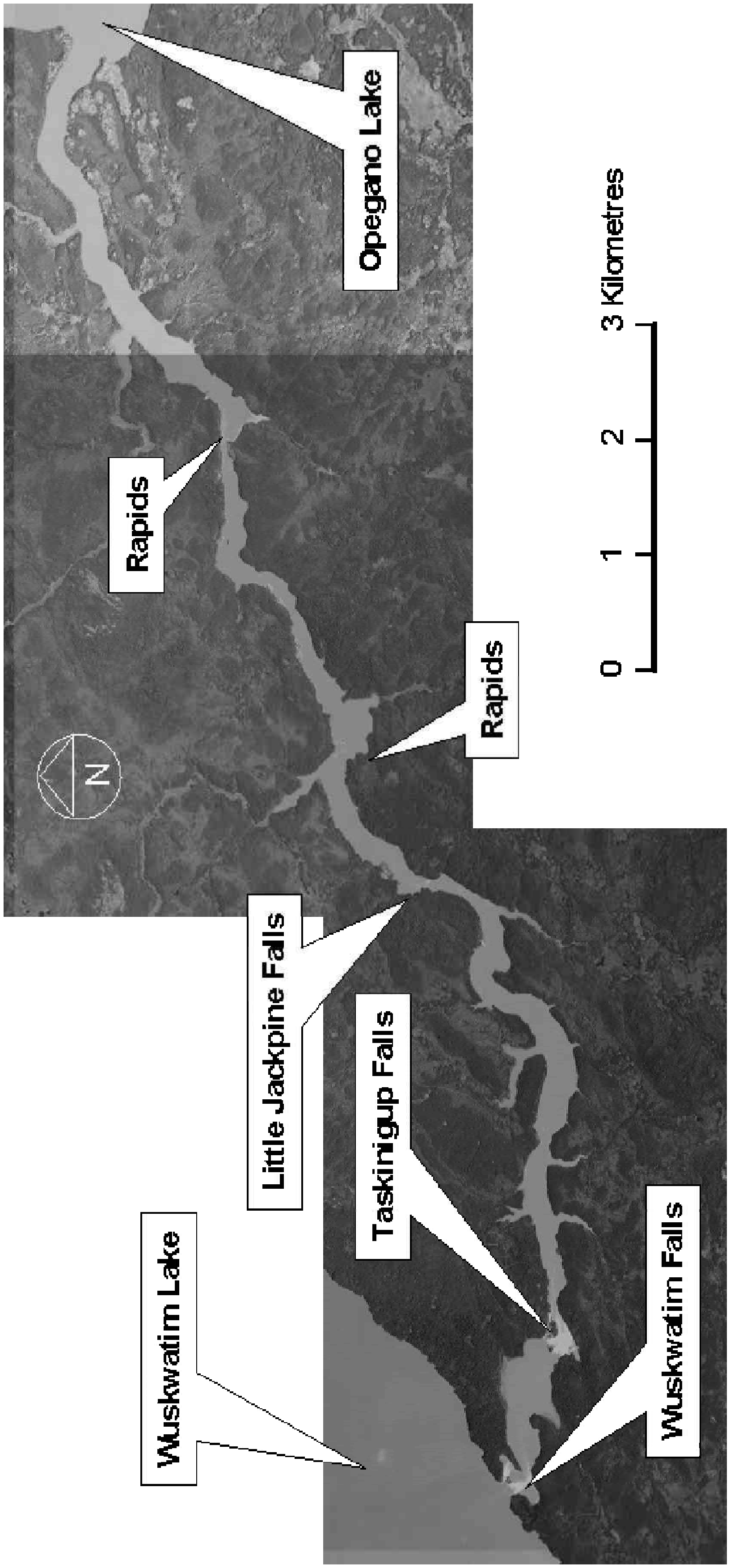


Figure 4.2-11 Burntwood River - Wuskwatim Lake to Opegano Lake location plan

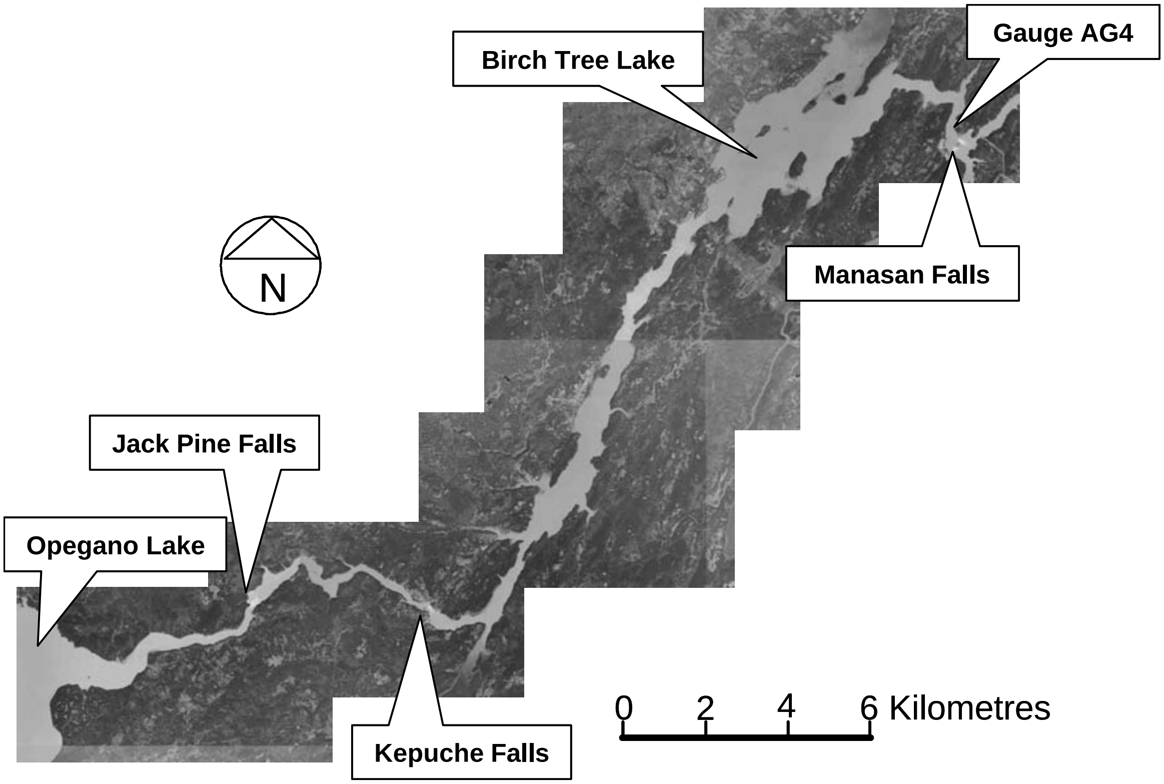


Figure 4.2-12 Opegano Lake to Manasan Falls location plan

The Manasan Falls to First Rapids reach includes a long wide section of river named Apussigamasi Lake just downstream of Thompson and a series of river reaches that are relatively flat and are hydraulically controlled by a series of rapids as illustrated in Figure 4.2-13. The water level drops approximately 33 m along this reach of river. For median flow conditions there is an approximate drop of 9.5 m across Manasan Falls, 6.6 m at Third Rapids, 3.4 m at Second Rapids and 8.2 m at First Rapids.

Open water and winter water surface profiles for steady-state flow conditions in the Taskinigup Falls to First Rapids reach were modelled for a range of existing (post-CRD) inflow conditions. The water surface profiles, shown in Figure 4.2-9 and Figure 4.3-10, were used to characterize the water levels along the reach and to support the aquatic environmental studies (Volume 5). For details regarding the modelling of the open water and winter water surface profiles refer to Appendix A4.5 and Appendix A4.6.

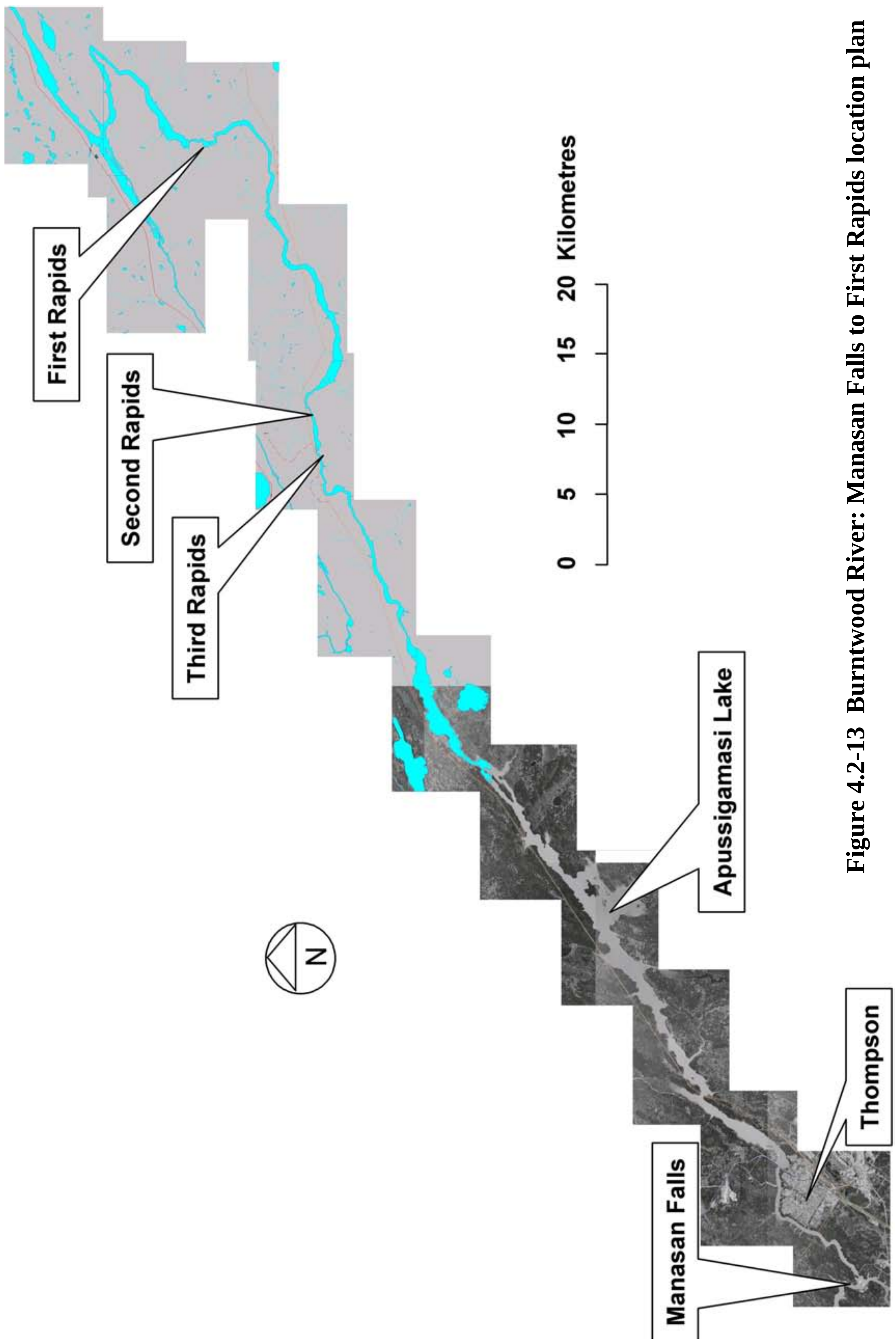


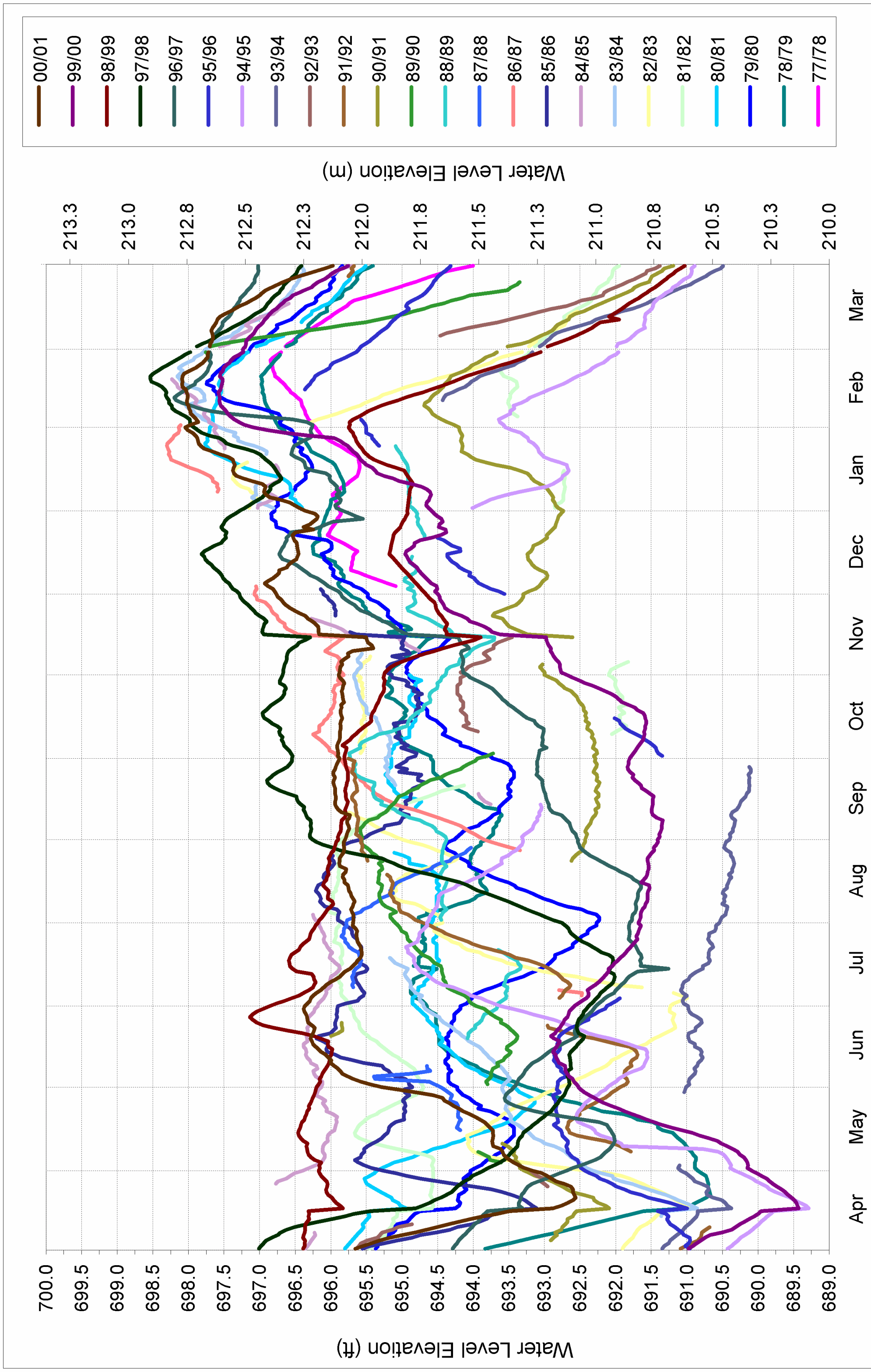
Figure 4.2-13 Burntwood River: Manasan Falls to First Rapids location plan

4.2.3.2 Stage Hydrographs

Stage hydrographs at a number of locations (listed in Table 4.2-2) within the study reach are shown in Figures 4.2-14 to 4.2-19. The stage hydrographs at Birch Tree Lake (gauge AG4), and Thompson Pumphouse are based on recorded water levels. The stage hydrographs at the foot of Taskinigup Falls and Opegano Lake were developed by applying open water and winter stage-discharge relationships to the discharge estimate derived from the Wuskwatim Lake levels in combination with the local inflows. The stage hydrographs at the inlet of Apussigamasi Lake and the head of First Rapids were developed similarly using flows recorded at the Thompson Pumphouse. For additional information, refer to Appendix A4.4. Table 4.2-2 summarizes the range of water levels at each of the locations within the study reach.

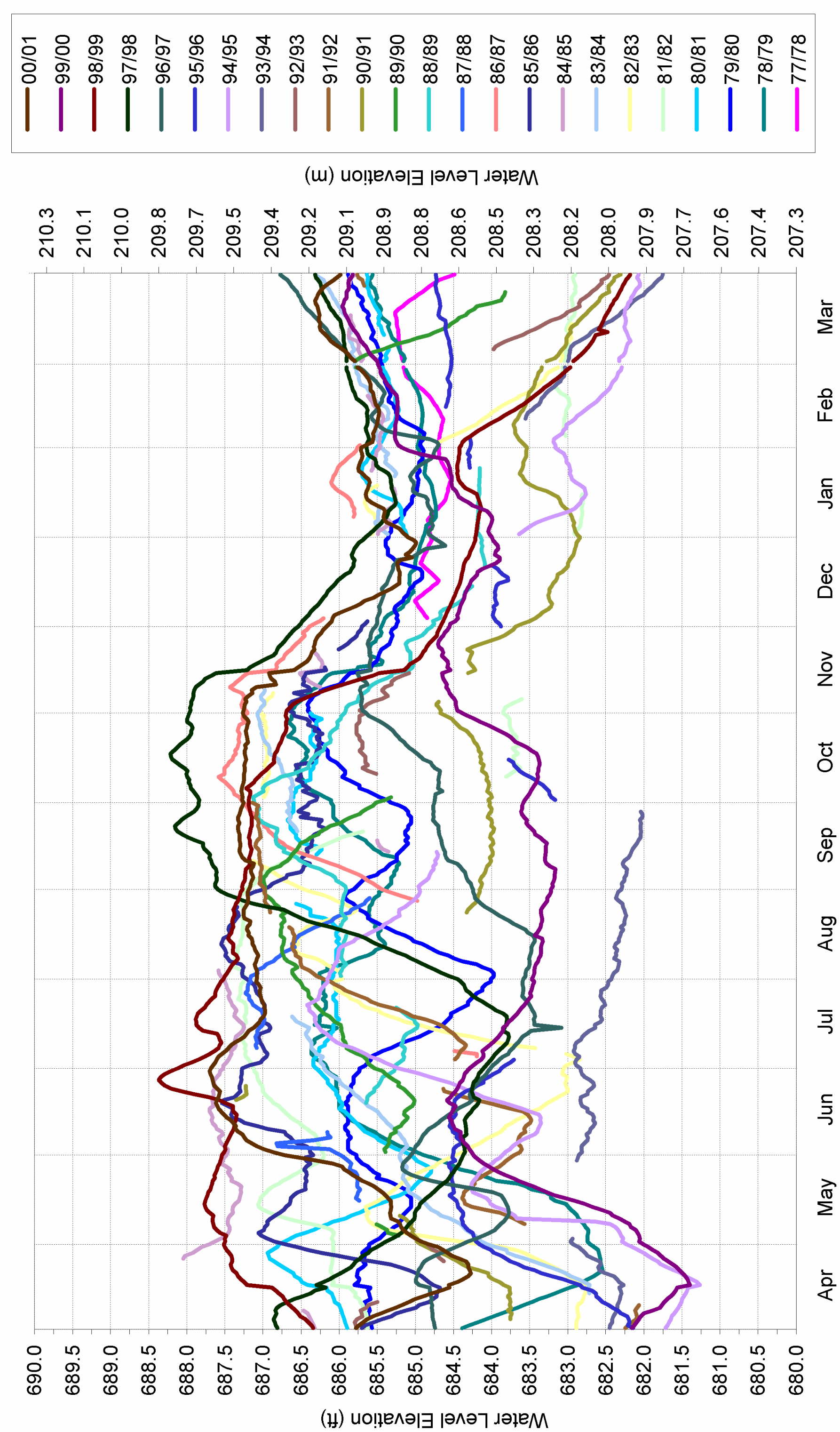
Table 4.2-2
Minimum and maximum stage during the existing (post-CRD) regime at various locations downstream of the Project

Location	Minimum		Median		Maximum	
	Open Water [m]	Winter [m]	Open Water [m]	Winter [m]	Open Water [m]	Winter [m]
Foot of Taskinigup Falls	210.34	210.18	212.48	212.92	211.66	212.07
Opegano Lake	207.50	207.79	209.22	209.01	208.55	208.55
Birch Tree Lake (Gauge AG4)	195.32	195.18	198.13	197.96	196.99	196.98
Thompson Pumphouse	185.61	185.71	188.62	189.40	187.46	188.27
Inlet of Apussigamasi Lake	185.11	185.21	188.62	188.19	186.81	186.99
Head of First Rapids	172.55	172.62	175.00	174.62	173.61	173.74



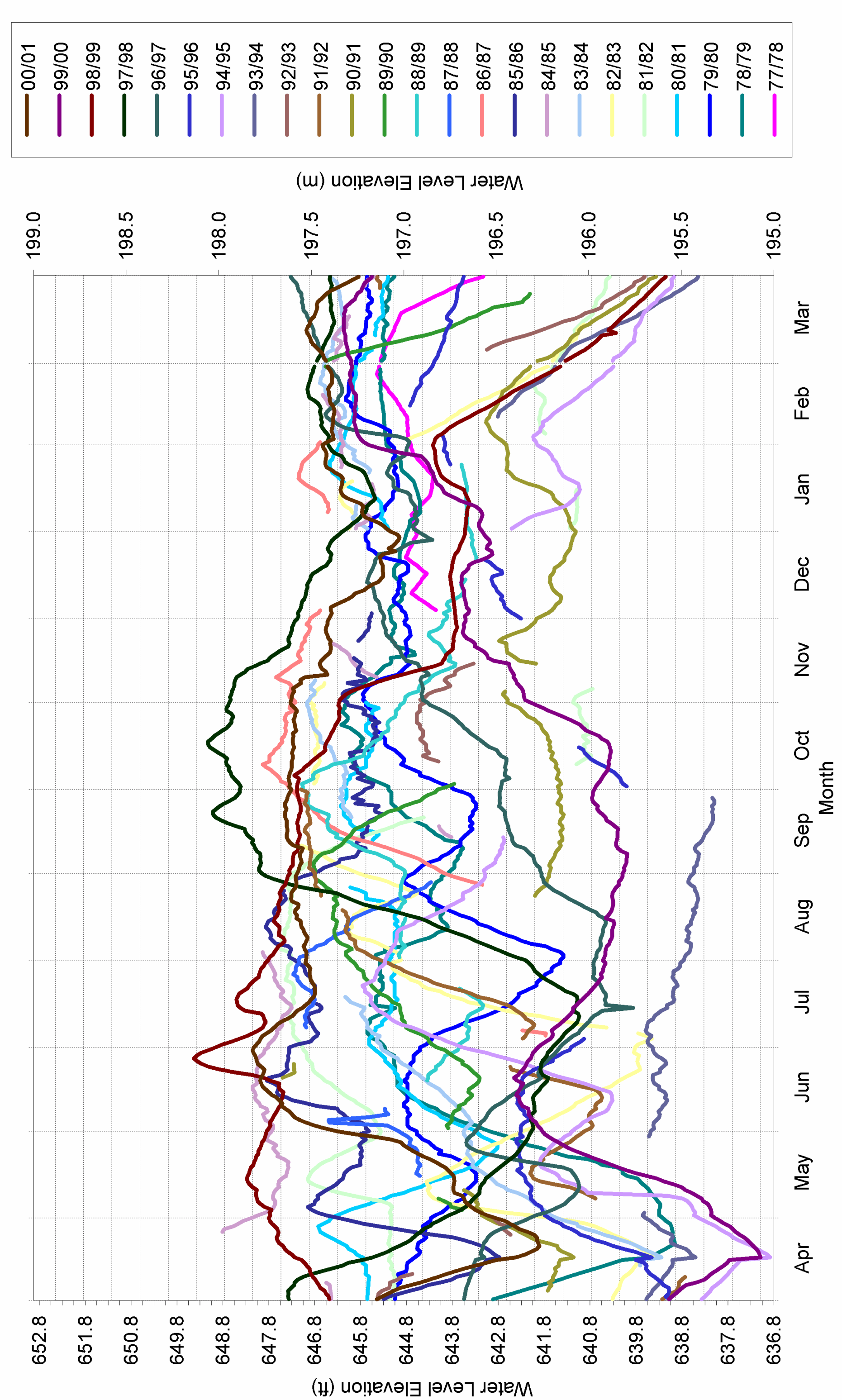
NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-14 Existing water regime stage hydrographs: foot of Taskinigup Falls



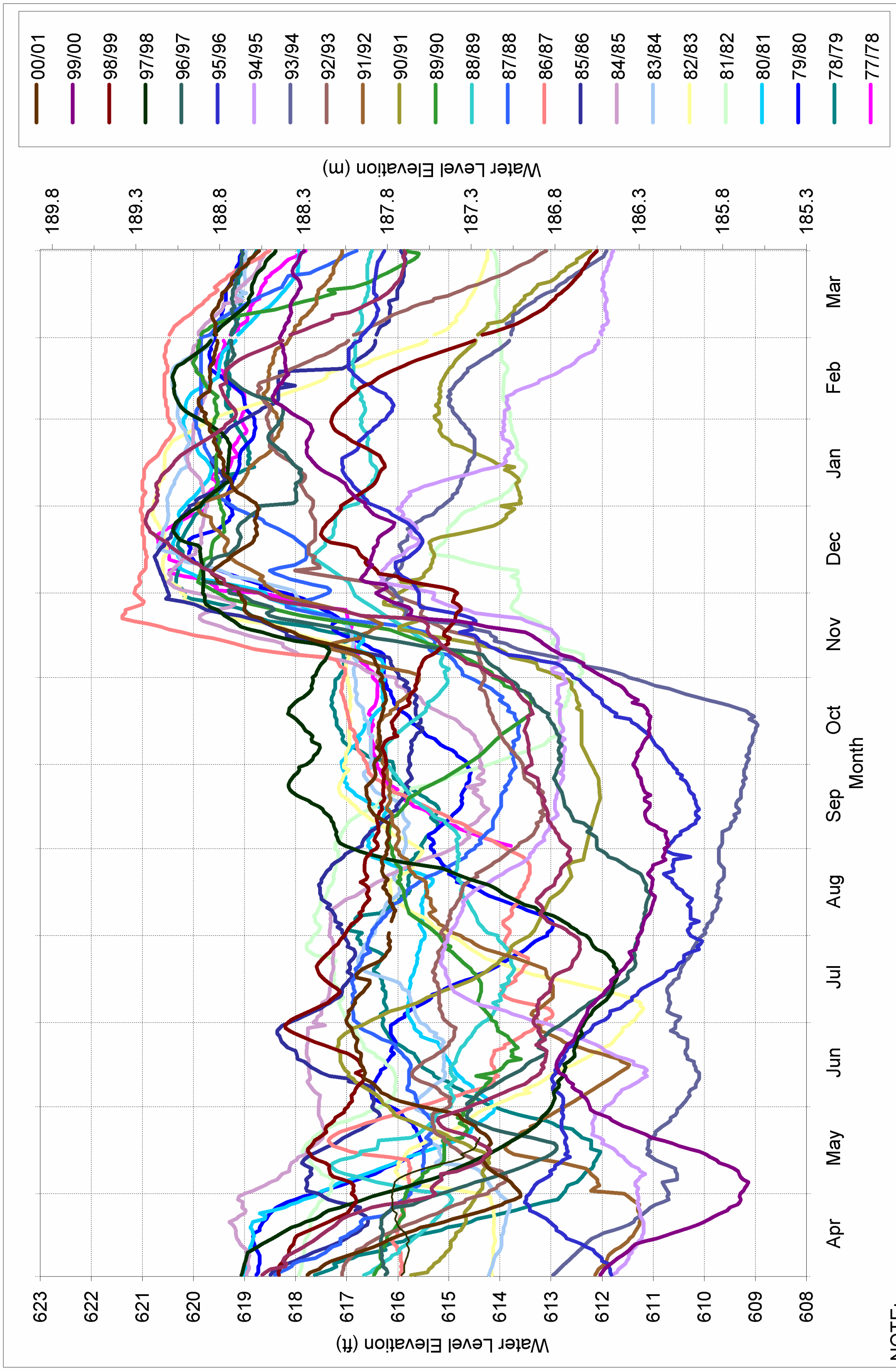
NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-15 Existing regime stage hydrographs: Opegano Lake



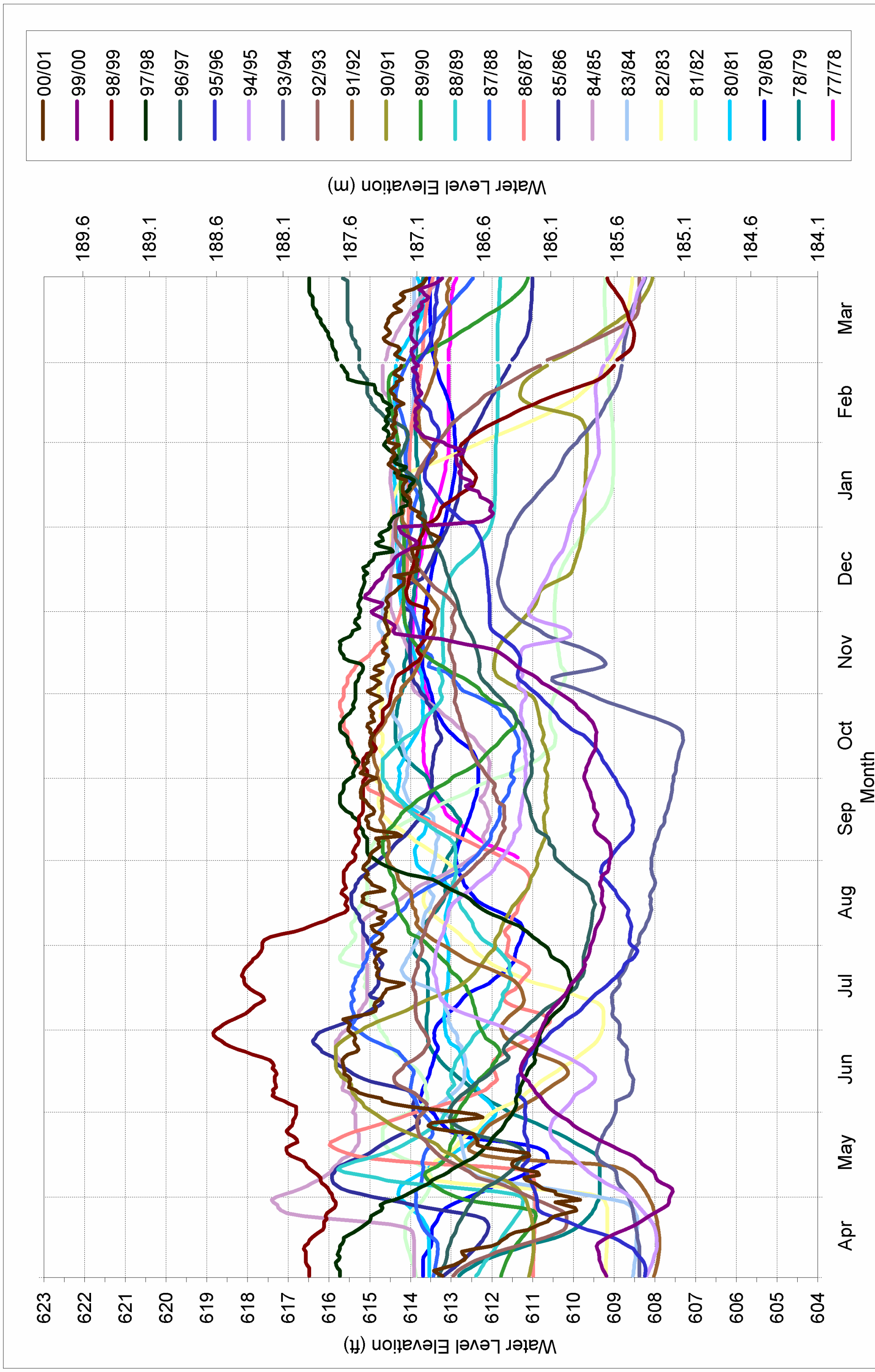
NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-16 Existing regime stage hydrographs: Birch Tree Lake (Gauge AG4)



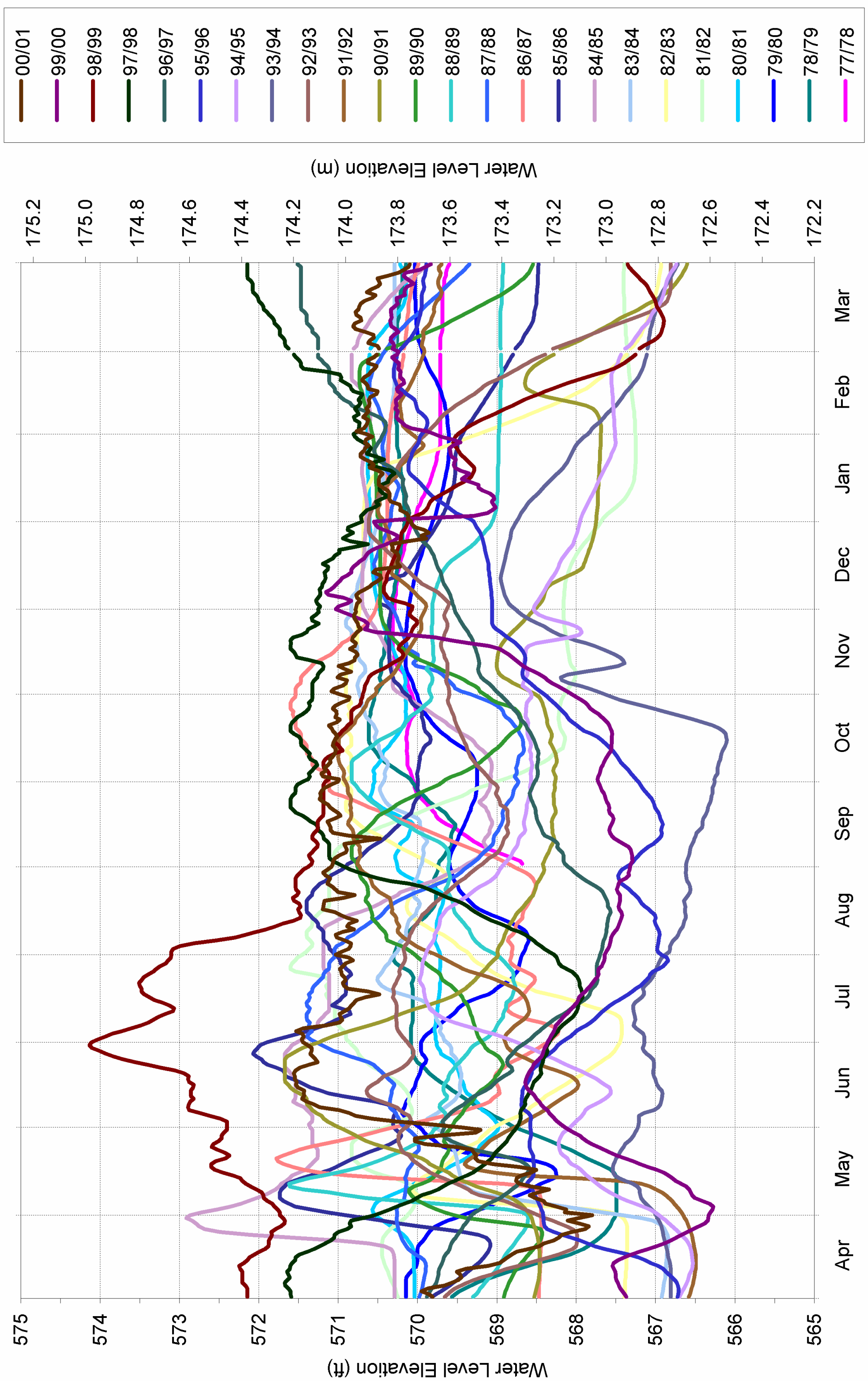
NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-17 Existing regime stage hydrographs: Thompson Pumphouse



NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-18 Existing regime stage hydrographs: Apussigamasi Lake



NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure 4.2-19 Existing regime stage hydrographs: Head of First Rapids

4.2.3.3 Water Velocities

To support the aquatic environmental and terrestrial studies (Volume 5) depth averaged velocity distributions were developed in the reach from Taskinigup Falls to the inlet of Opegano Lake for existing (post-CRD) flow conditions using a two-dimensional hydraulic model (Appendix A4.5 contains details of model application). The downstream boundary of the model application was determined during the aquatic and terrestrial environmental studies (Volume 5 and Volume 6) by reviewing the downstream extent of the water level fluctuations that would result from the Project operations.

Bathymetry could not be collected at the sets of rapids which prevented the model application at those sites. This resulted in the model being applied to three sub-reaches located between the sets of rapids. The model also includes the tributaries in those reaches of river.

Depth averaged velocity distributions for a range of existing (post-CRD) inflow conditions (5^{th}, 50^{th}, 95^{th} percentiles) were developed for the reach of river. As an illustrative example, the depth-averaged water velocities for the 50^{th} percentile case are shown in Figure 4.2-20. Appendix A4.5 provides the depth averaged water velocities for the 5^{th} and 95^{th} percentile inflow conditions. The figure show that velocities are greatest at the channel **constrictions** (in excess of 2 m/s) and within the central portions of the channel (in the range of 0.7 m/s to 1.4 m/s). The velocities at the rapids not modelled would be larger than the velocities in the river reaches that were modelled. Velocities along the shorelines and in the mouths of the tributaries are at or near 0 m/s. Appendix A4.5 contains details regarding the model application and results for the 5^{th} and 95^{th} percentile flow conditions. When comparing results for the different flow conditions, it is evident that as the flow magnitude increases, the inundated area within the mouths of the tributaries increases substantially in addition to the area inundated along the banks of the Burntwood River.

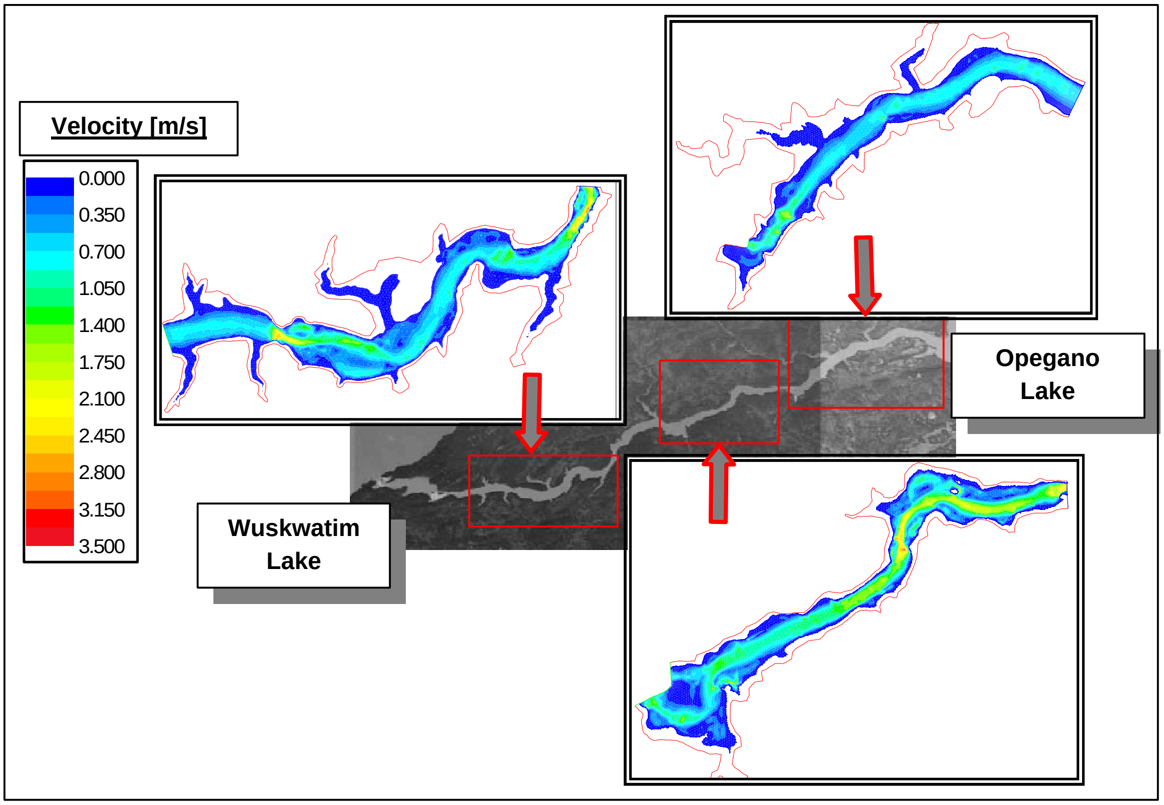


Figure 4.2-20 Taskinigup Falls – Opegano Lake: depth averaged velocities for the 50th percentile existing (post-CRD) inflow

4.2.4 Groundwater

The local area exists in the Precambrian Shield and therefore no mapping of regional **groundwater** has been carried out by the Water Branch of the Province of Manitoba. It is likely that groundwater exists in the local sand and gravel glaciofluvial deposits in the area (Section 3). During the **borrow** extraction operation there is a potential that groundwater could be drawn from the local borrow site to wash the sand prior to hauling to the Project site. This potential draw on the local groundwater would be short term in nature and groundwater levels would return to normal levels after the extraction is completed. As per regulations specified in the Manitoba *Mines and Minerals Act*, and as will be specified in the Environmental Protection Plan, servicing of vehicles would be done outside of the borrow area thereby minimizing contamination of the local groundwater.

Preliminary site inspections were carried out in the summer of 2001 to assess whether the Project may effect surrounding groundwater levels and thereby affect plant communities. The shoreline was divided into 4 broad categories: rock controlled shorelines; steep cut-banks; wetland marsh complexes and shallow cut-banks with shallow sloped backshore areas. The only shoreline that groundwater water levels were considered to be potentially at-risk was the latter category. Field investigations of the shallow cut-banks and shallow sloped backshore shorelines in 2001 indicated that the vegetation on these shorelines are not likely to be affected because of the soil type (combination of clay and silt) and the elevation and distance from the shoreline water level.

4.3 EFFECTS ASSESSMENT AND MITIGATION

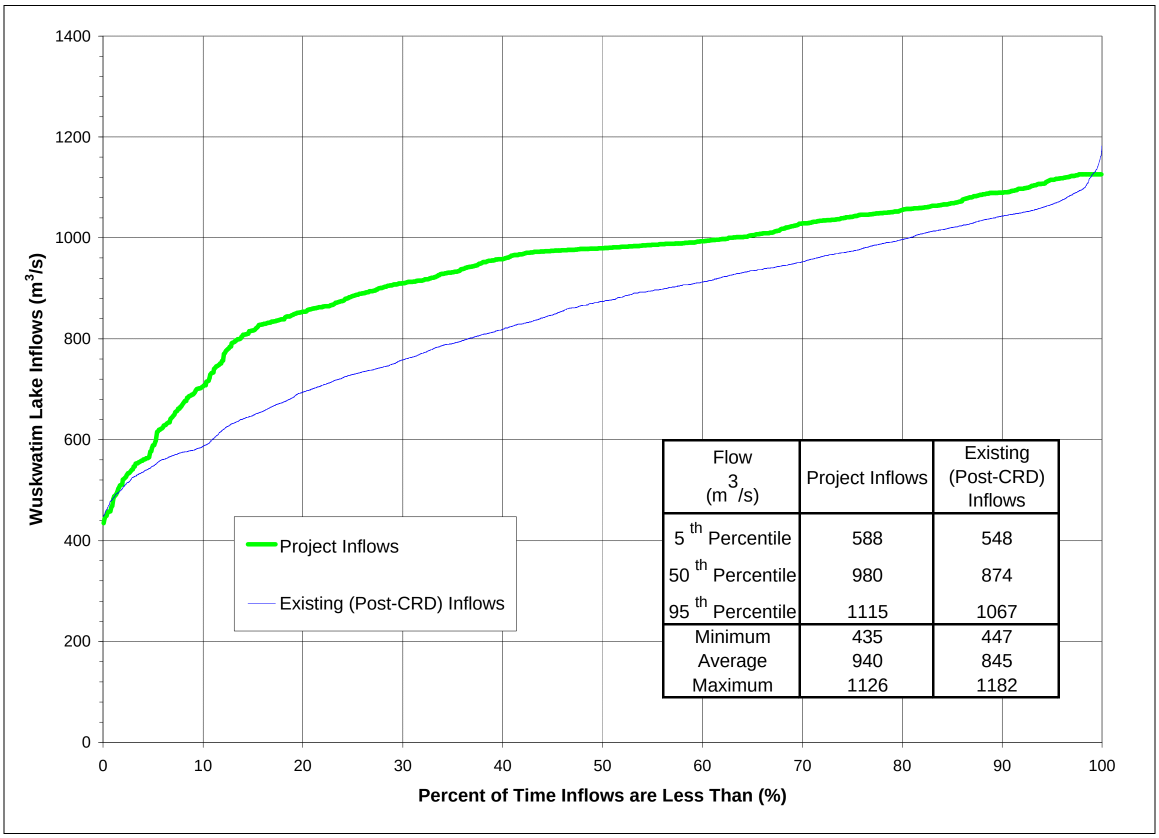
Section 4.2 described the existing (post-CRD) water regime. This section describes the derivation of the Wuskwatim Lake inflow record that was used to assess the operation of the Project and describes the water regime that would exist during these flow conditions. This section also characterizes the effects of the Project on the water regime during construction and describes the water regime that would result from normal operation of the Project.

4.3.1 Project Inflows

An important aspect in the planning, design and operation of a future hydropower site such as the Wuskwatim Generating Station is the water supply or inflow to the Project. In the engineering planning process for the Project, Manitoba Hydro has developed a "best estimate" of simulated long-term streamflow for an 86 year period. This streamflow record or what is termed "project inflow" is used in both the design and the environmental impact assessment of the Project.

In general, Manitoba Hydro has modelled project inflows into Wuskwatim Lake assuming a long term regulation of Churchill River flows at Southern Indian Lake (SIL). Missing records in the upper Churchill basin were estimated back to 1912 to reflect inflow into SIL. Downstream of SIL, Churchill River Diversion (CRD) flows reflect all existing CRD related licenses, permits, and agreements described in Section 4.2.1. In other words, the modified regulation of outflow from SIL assumes that the CRD operated under today's constraints over the entire simulated long-term record.

Figure 4.3-1 provides a comparison of flow **duration curves** for the monthly average project inflows (1912 – 1997) and the daily average existing (post-CRD) inflows (1977 – 2001) at Wuskwatim Lake. The comparison indicates that the long-term average annual flow for the period of the project inflows is approximately 100 m^3/s higher than the average (post-CRD) inflows. Maximum and minimum flows are approximately the same for both inflow periods. An analysis of streamflow records over ten year periods indicates that the streamflow during the most recent 1988 to 1997 period to be lower than the previous ten year periods (Figure 4.3-2). However, this flow period is not greatly different than a 10 year low flow period that had occurred between 1938 and 1947. The effect of today's augmented flow program (Section 4.2.1), for the period f 1978 to 1987, is evident with the average annual flow for the project inflow being approximately 30 m^3/s higher than the average (post-CRD) inflow. The operating limits of the CRD during this period were more restrictive than those assumed in the simulation utilizing current operating rules.



Flow (m^3/s)	Project Inflows	Existing (Post-CRD) Inflows
5 th Percentile	588	548
50 th Percentile	980	874
95 th Percentile	1115	1067
Minimum	435	447
Average	940	845
Maximum	1126	1182

Figure 4.3-1 A duration curve comparison of existing (post-CRD) inflows and project inflows

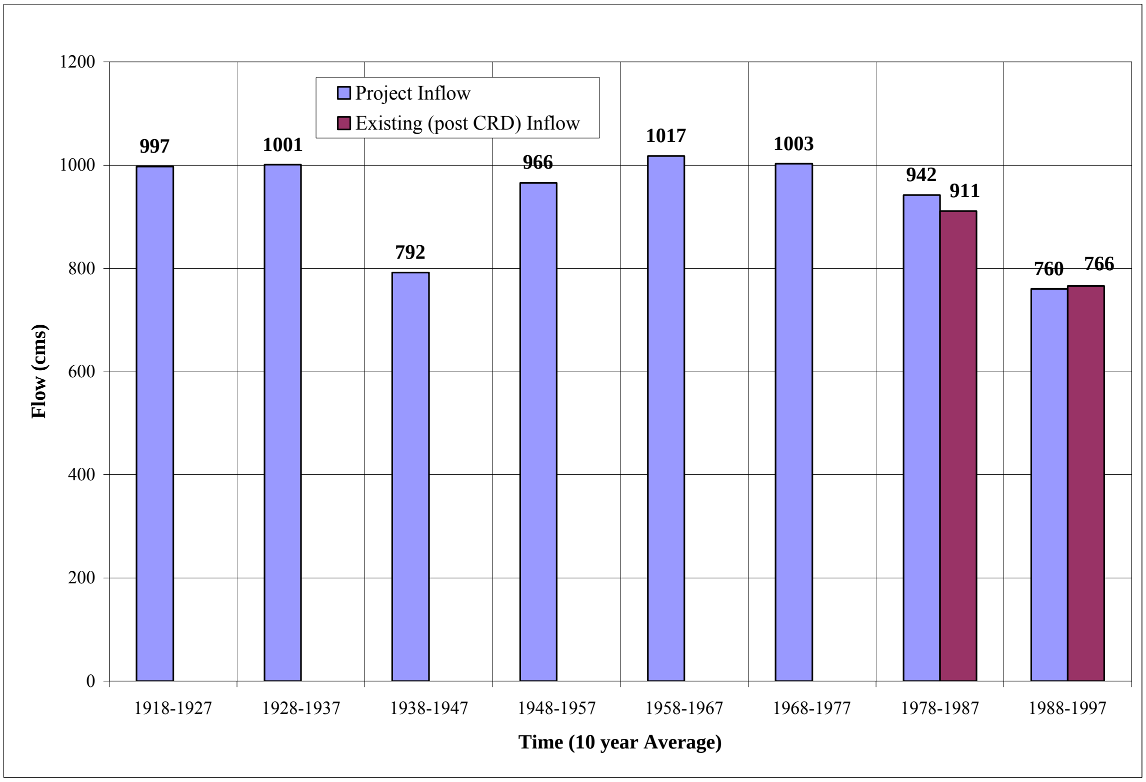


Figure 4.3-2 A histogram comparison of the project inflows and existing (post-CRD) inflows

The project inflow is judged to be the best representation of future flows. This simulated record which is longer than the existing (post-CRD) period is useful for representing the historic variability of flow. As discussed in Section 4.1.1.3 the effect of global climate change has not been factored into project inflow record due to the current limitations of climate change models (Section 2).

4.3.2 Construction

Project construction and the associated river management will be undertaken in two stages. During Stage I, construction of the **powerhous**e and **spillway** progresses in the dry behind a **cofferdam**. During Stage II the Burntwood River will be diverted through the spillway upon **closure** of the river by the main dam. Water levels immediately upstream and downstream of Taskinigup Falls will be affected by the construction of the Project. Following Stage I and Stage II diversions the **immediate forebay** and lake are impounded.

4.3.2.1 Stage I Diversion

During Stage I Diversion the powerhouse and spillway are constructed in the dry adjacent to Taskinigup Falls. This phase of construction will include a cofferdam across the south portion of Taskinigup Falls which would increase upstream stages. If the **construction design flood** of 1150 m^3/s (20 year return period) were to occur, stages would increase by as much as 0.6 m. Figure 4.3-3 illustrates the stage for other flow conditions. If the 5^{th} (548 m^3/s) and 95^{th} (1066 m^3/s) percentile flow conditions were to occur during the open-water season water levels would be expected to rise approximately 0.2 to 0.7 m. It is estimated that the winter levels immediately upstream of Taskinigup Falls would be 0.10 m higher than open water levels for the same flow conditions. Downstream stages are not expected to change.

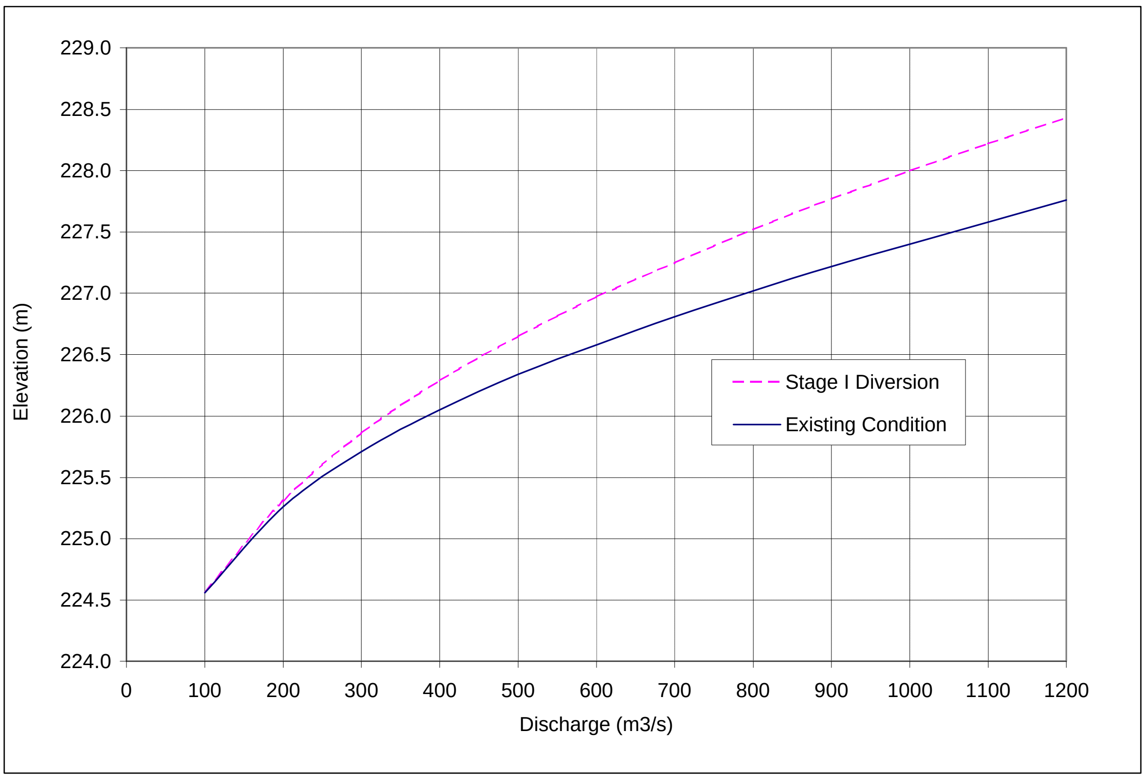


Figure 4.3-3 Stage I Diversion – Water Levels Upstream of the Stage I Cofferdam

4.3.2.2 Stage II Diversion

During Stage II Diversion, the river will be diverted through the fully open spillway to allow for river closure to occur during the construction of the main **Dam** immediately upstream of Taskinigup Falls. During river closure and the completion of the main dam, the upstream water levels are expected to increase by 0.5 to 1.0 m for the 5^{th} and 95^{th} percentile flow conditions during open water conditions and by as much as 1.3 m if the construction design flood were to occur. It is estimated that the winter levels immediately upstream of Taskinigup Falls would be similar to open water levels for the same flow conditions.

4.3.2.3 Forebay Impoundment

Following the completion of the main dam, the flow through the spillway would be regulated to impound the water in the immediate forebay and potentially raising the water to the level of Wuskwatim Lake if it is below elevation 234.0 m. The rate of water level increase in the immediate forebay area will be limited to approximately 0.5 to 1.0 m per day, which will result in **impoundment** being complete in about 7 to 14 days. Subsequently Wuskwatim Lake would be impounded to a Full Supply Level (FSL) of 234 m as the Project schedule permits.

4.3.3 Operations: Upstream Of Project Site

Operation of the Wuskwatim Generating Station will not cause changes in the operation of the CRD. Water levels and flows along the Rat and Burntwood River systems will continue to vary from year-to-year and month-to-month as they do now, except in the area between Early Morning Rapids and Opegano Lake (those areas affected by the Project), as described in the subsections below.

The Project will normally operate in a **modified run-of-river** mode, as described in Section 5.2 Volume 3, where the generating station outflows will be adjusted to alternate between efficient unit settings to obtain near "best gate" settings to produce more power during the day and less during the night. Over a 24-hour (daily) period, the amount of water entering Wuskwatim Lake will equal the amount leaving. This operation would affect water levels on a portion of the Burntwood River both upstream and downstream of the plant.

4.3.3.1 Water Levels and Variation During Normal Plant Operations

To determine the effects of the Project on the existing (post-CRD) water regime, river hydraulic studies that simulate the operation of the Project were undertaken to provide information for a comparison of the Project and existing (post-CRD) water regimes. This section describes the upstream reach and Section 4.3.4 describes the downstream reach.

During normal operations of the Project, the **reservoir** (Wuskwatim Lake) and the immediate forebay will be drawn down and re-ponded on a daily basis and returned to a level at or near a FSL of 234.0 m. Therefore, daily water level fluctuations (i.e. the maximum water level minus the minimum water level during the day of interest) at both locations would be observed. In order to characterize this water regime, river hydraulic **parameters** including water levels and water level variations were developed for open water and winter conditions using a variety of hydraulic models to support various EIS studies that include aquatic studies (Volume 5) and mode of operation studies (Volume 3).

Steady-State Flow Conditions

Open water and winter water surface profiles for steady-state existing (post-CRD) inflow conditions upstream of the Project to Early Morning Rapids are shown in Figures 4.3-4 and 4.3-5. The figures illustrate that the immediate forebay would be approximately 7 m higher than the water levels during the existing (post-CRD) flow regime. The figures also show that Wuskwatim Falls would be flooded out and the water levels upstream of Early Morning rapids would not change once the Project is in place.

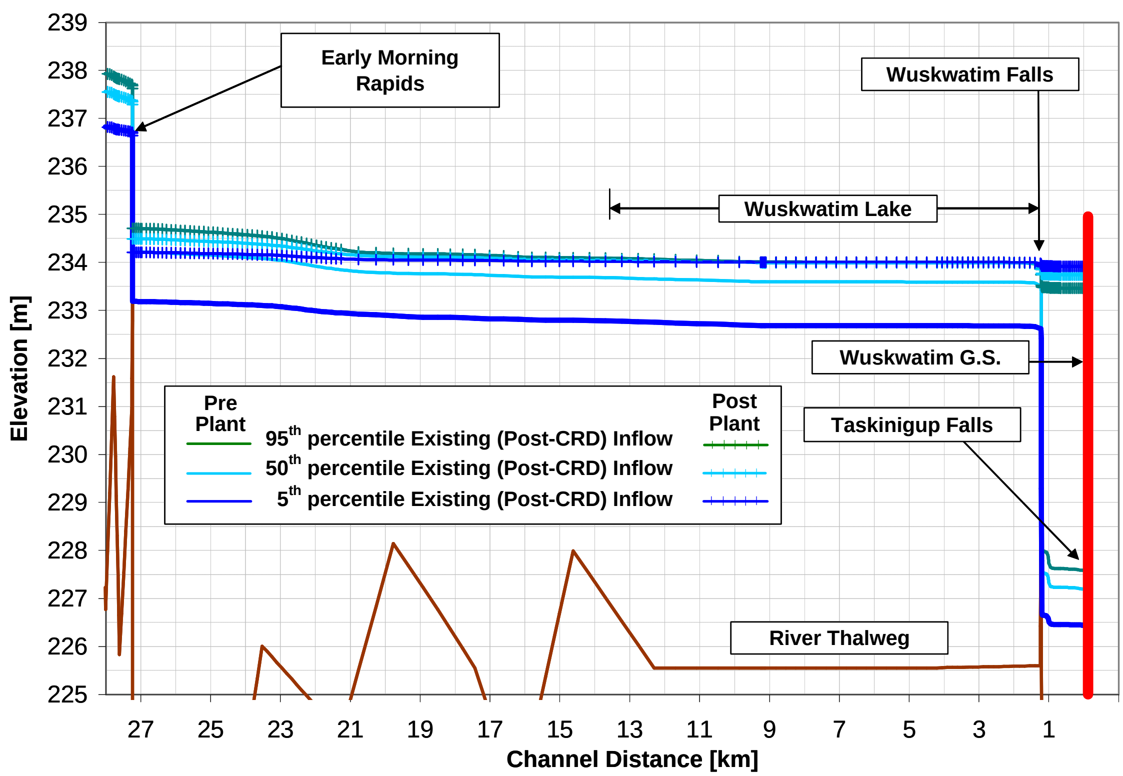


Figure 4.3-4 Open-water water-surface profiles: Early Morning Rapids – Wuskwatim GS, existing (post-CRD) water regime with and without the Project

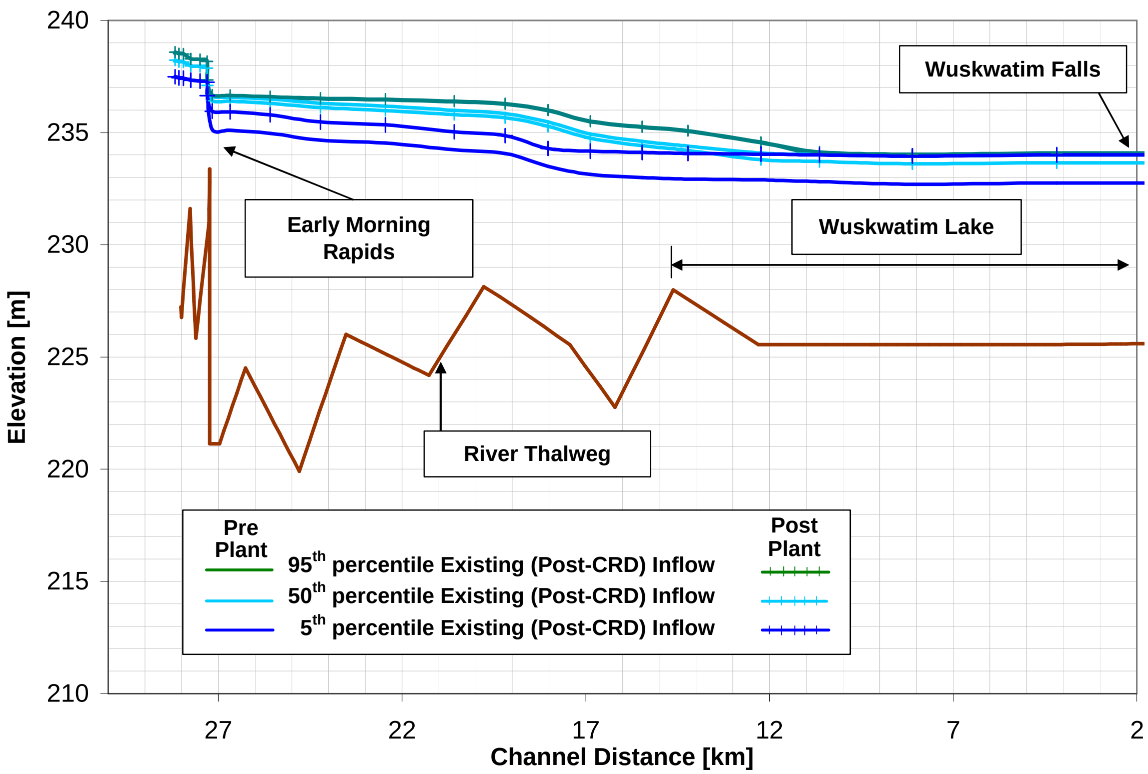


Figure 4.3-5 Winter water surface profiles: Early Morning Rapids – Wuskwatim GS, existing (post-CRD) water regime with and without the Project

Unsteady-State Flow Conditions

The majority of the time the plant operation will create unsteady flow conditions in the Early Morning Rapids to the Wuskwatim GS reach, therefore hydrodynamic modelling was undertaken in this reach to simulate these conditions. The model was used to simulate the following hydraulic characteristics of the upstream reach (Appendix A4.5 for details of the open water modelling and Appendix A4.6 for details of the winter modelling):

- routing of flow from Early Morning Rapids into Wuskwatim Lake, then into the immediate forebay, and finally through the Wuskwatim Generating Station;
- modelling the hydraulics of the river channel between Early Morning Rapids and Wuskwatim Lake, at Wuskwatim Falls and the adjacent channel excavation; and
- changes in storage in the reservoir and immediate forebay using stage-storage curves to determine the reservoir levels and stage variations.

Winter modelling was not carried out because the hydraulics during the winter are expected to be the same as during the summer, therefore results of the open water modelling are assumed to represent winter conditions.

The water levels upstream of Early Morning Rapids would not be effected by the operation of the Project because of the **supercritical flow** conditions at the rapids. Appendix A4.1 contains a detailed explanation of this hydraulic condition. Figure 4.3-6 provides the open water stage hydrographs for the 5th, 50th, and 95th percentile project inflows at the head and foot of Early Morning Rapids for Project operations. The figure illustrates that only at the 5th percentile flow condition is there a slight fluctuation in water levels at the foot of Early Morning Rapids due to the operation of the Project. This figure also indicates that there are no water level fluctuations upstream of Early Morning Rapids for all inflow conditions.

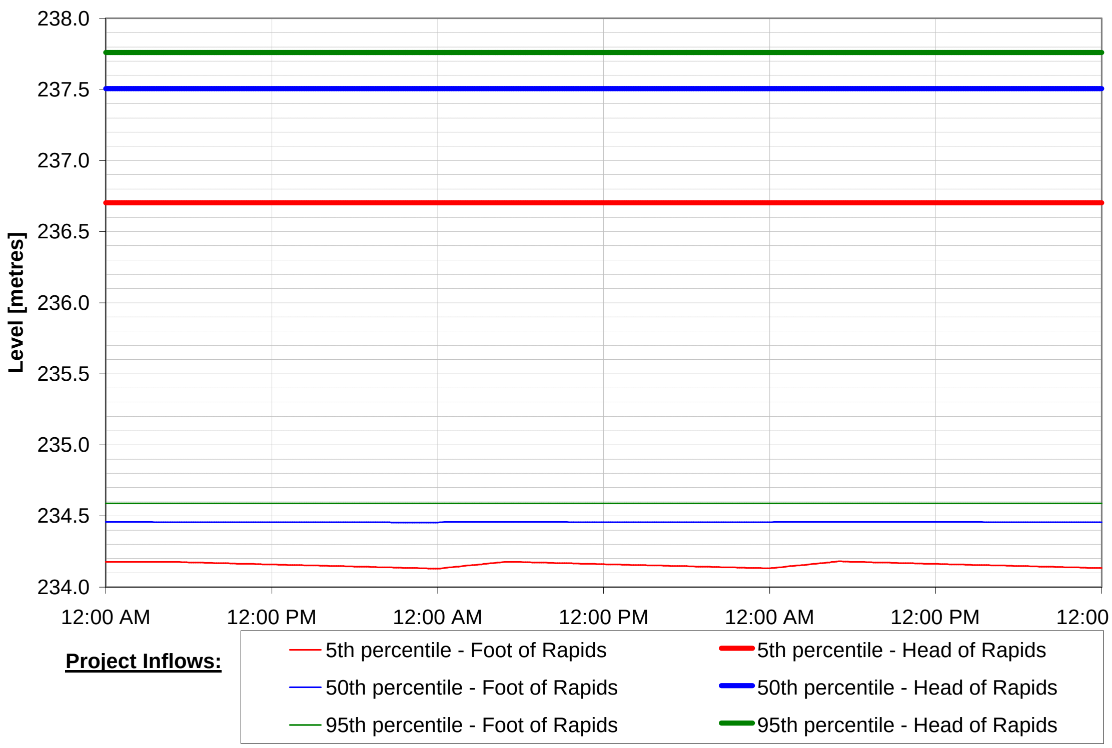


Figure 4.3-6 Example of stage variation due to the Project during the open water season for 5th, 50th, and 95th percentile flows: upstream and downstream of Early Morning Rapids

The storage in Wuskwatim Lake can support changes in outflow from the Project within a day without significant changes in the water level on Wuskwatim Lake. There is a slight elevation change (gradient) between Wuskwatim Lake and the immediate forebay. This gradient varies for different flow conditions. Figure 4.3-7 and Figure 4.3-8 illustrate that the water levels on Wuskwatim Lake and the immediate forebay would remain at or slightly below 234.0 m ASL. The elevations in the immediate forebay fluctuate over a slightly larger range than for Wuskwatim Lake. For Wuskwatim Lake the maximum daily stage fluctuation is estimated to be 0.08 m, and for the immediate forebay the fluctuation is estimated to be 0.13 m during normal operating conditions (Volume 3, Section 5.2). Figure 4.3-9 illustrates that the stage variation on Wuskwatim Lake and the immediate forebay would be 0.03 m and 0.06 m respectively for the 50th percentile inflow condition during normal operations.

During normal project operations, the water levels on Wuskwatim Lake would remain at or slightly below 234.0 m for 97.5% of the time. For the existing (post-CRD) water level regime on Wuskwatim Lake, the water level has varied between 232.64 and 234.33 m (Figure 4.2-2). Hence, the range of water level fluctuations during normal project operations would be minimal compared to the historic seasonal range and the lake levels would remain within the historical range of water levels.

Up to one metre of storage has been designated for utilization under abnormal conditions when power demand is high in either the Manitoba Hydro system or that of its neighbours and when inflows are very low. During these times, there will be increased usage of the storage to supplement inflows, drawing Wuskwatim Lake below 233.75 m and potentially as low as 233.0 m (Volume 3, Section 5.2.5.3).

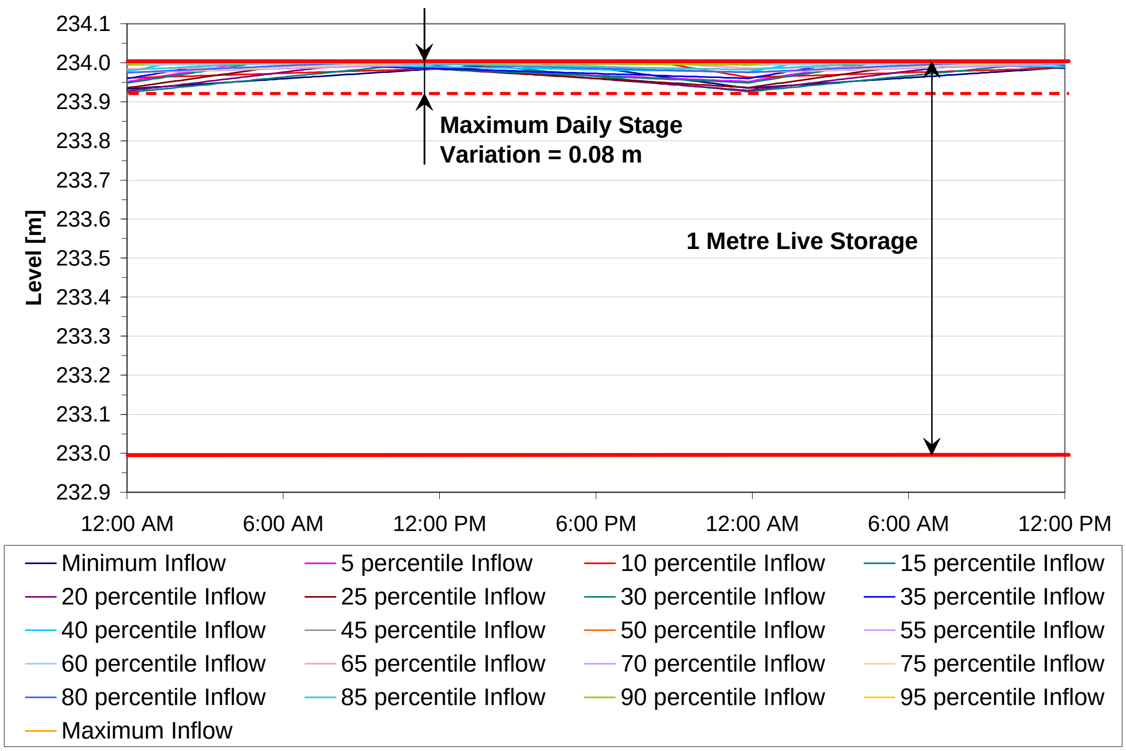


Figure 4.3-7 Stage hydrographs: Wuskwatim Lake for project inflow conditions

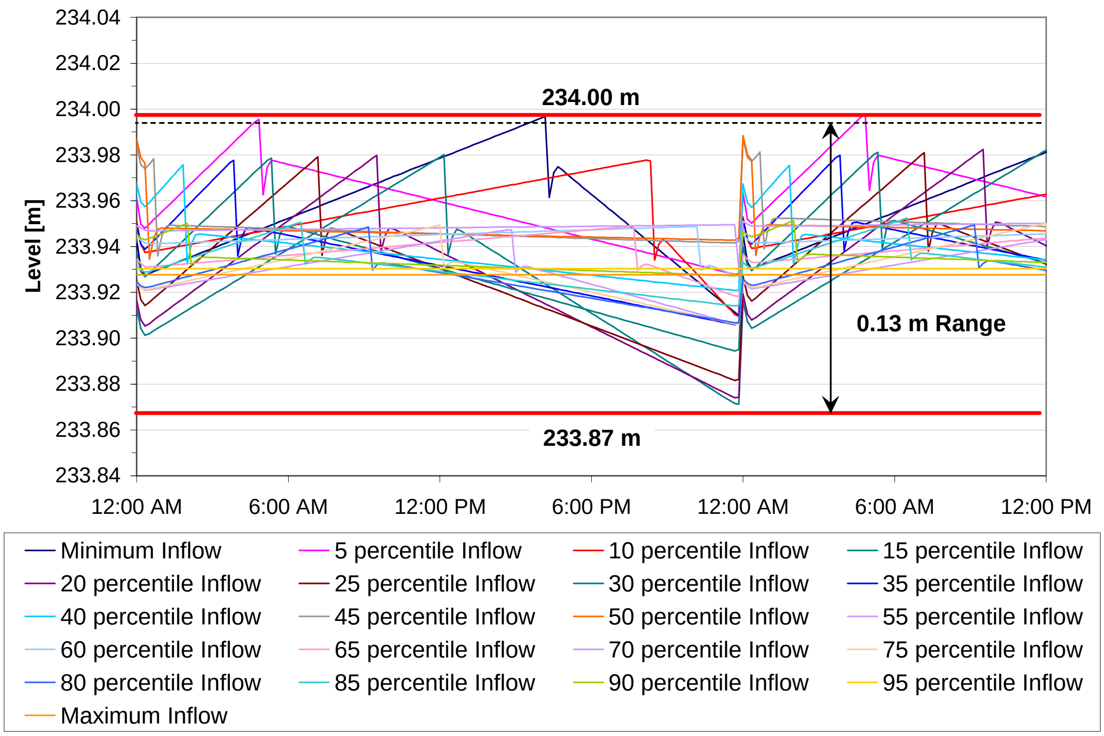


Figure 4.3-8 Stage hydrographs: immediate forebay for project inflow conditions

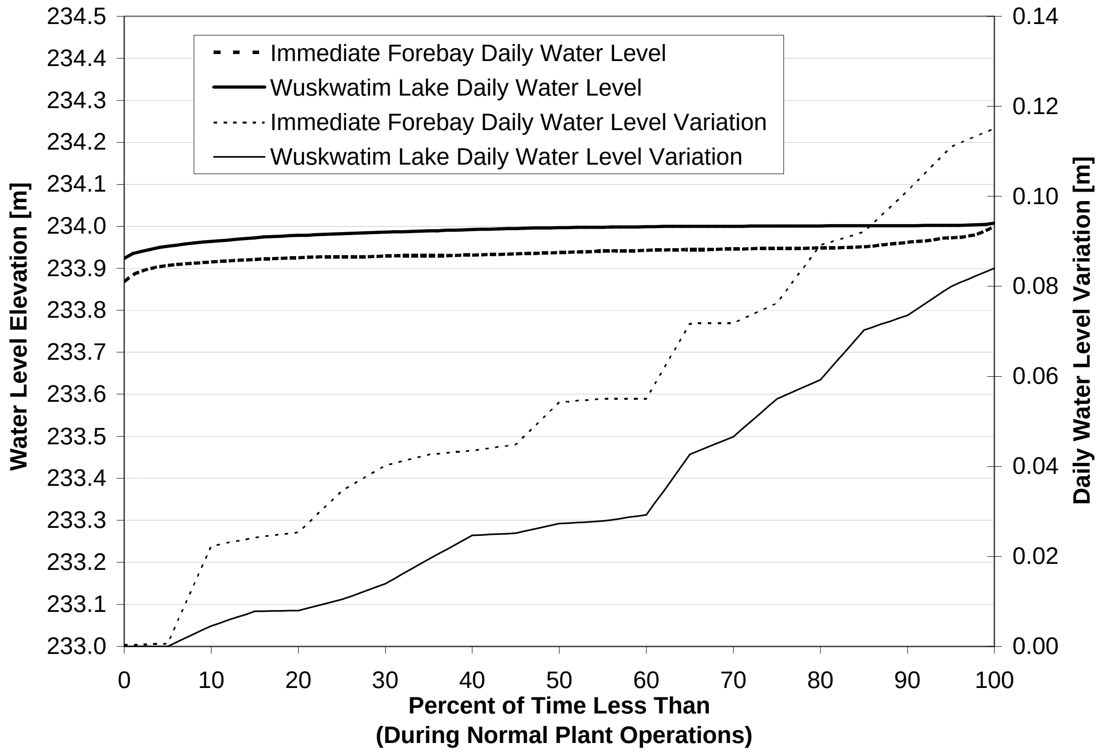


Figure 4.3-9 Stage and daily stage variation duration curves for Wuskwatim Lake and the immediate forebay for project inflow conditions

4.3.3.2 Immediate Forebay Flooded Area and Stage-Storage Curve

The reservoir created by the Project is comprised of the immediate forebay (area between Wuskwatim Falls and the Project) and Wuskwatim Lake. The reservoir is also referred to typically as the "forebay". A stage-storage curve created for Wuskwatim Lake was previously described in Section 4.2.2.2. The stage-storage curve for the immediate forebay is shown in Figure 4.3-10. See Appendix A4.3 for details of the curve development. The total storage available for the Project will be the combination of the storage in Wuskwatim Lake and the immediate forebay. Between the two water bodies the water level gradient is typically less than 0.1 m (i.e. through Wuskwatim Falls and the channel excavation).

For a full supply level of 234.0 m on Wuskwatim Lake, the flooded area in the immediate forebay from the Project is estimated to be 37 ha. The flooded area and associated calculations are shown in Figure 4.3-11.

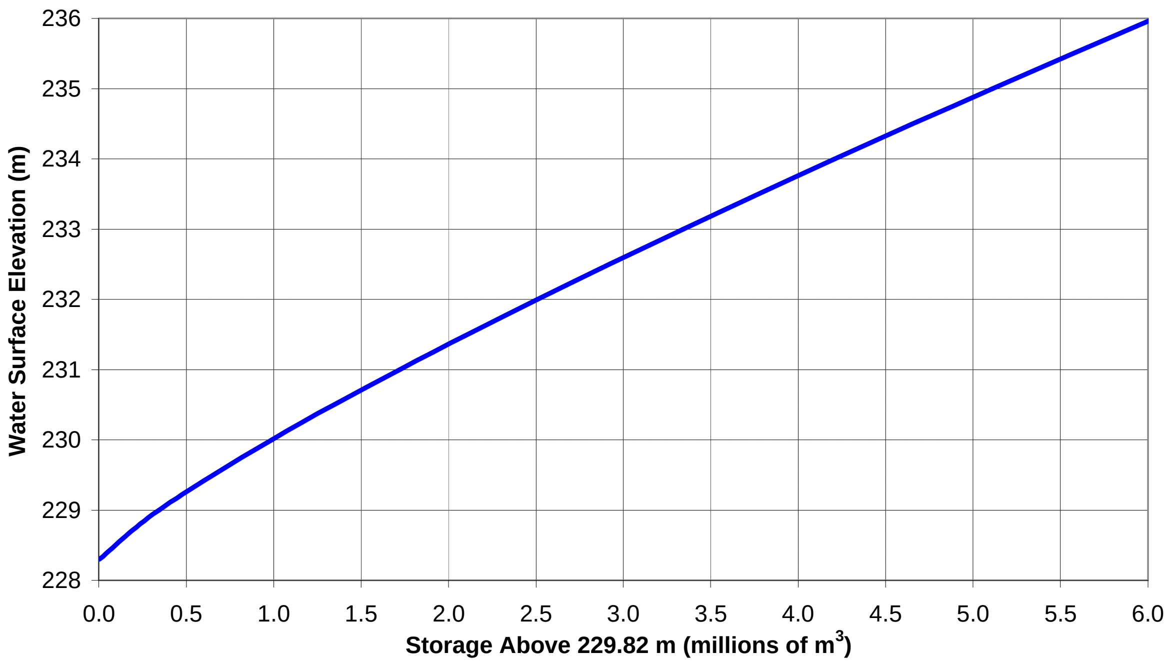
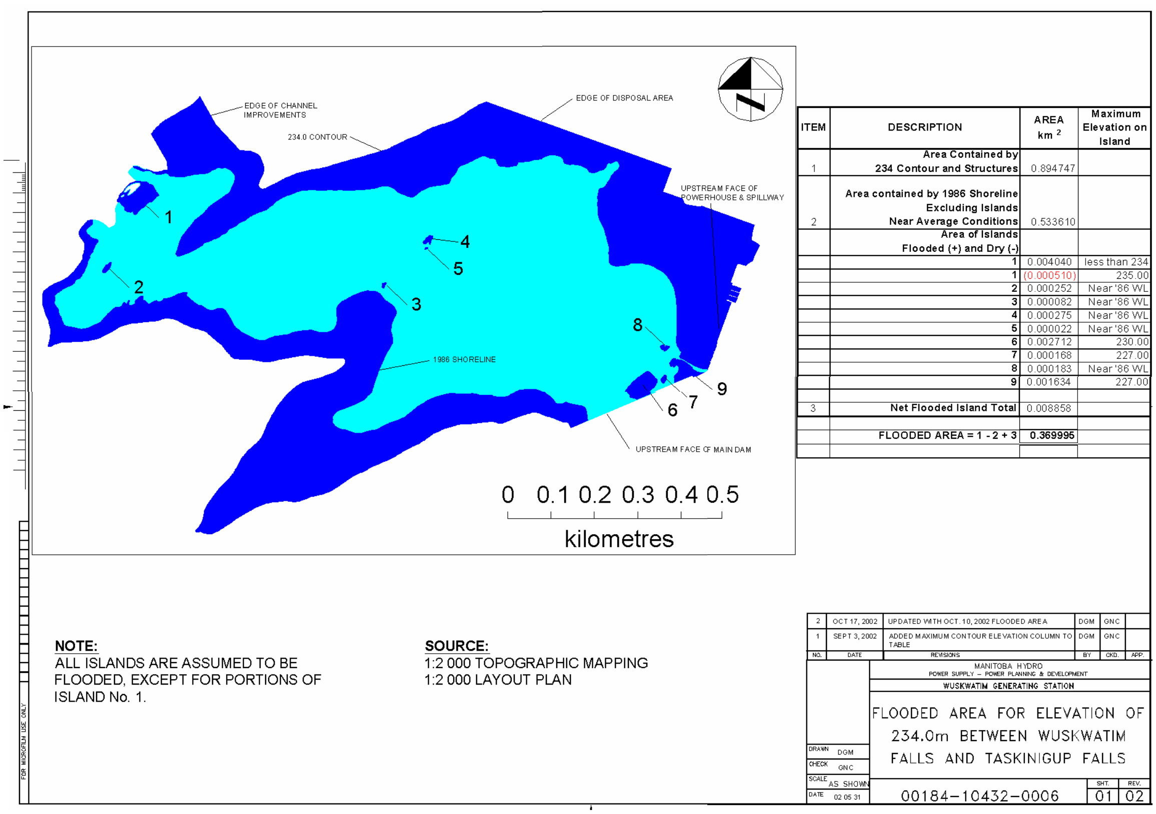


Figure 4.3-10 Immediate forebay stage-storage curve



ITEM	DESCRIPTION	AREA km 2	Maximum Elevation on Island
1	Area Contained by 234 Contour and Structures	0.894747	
2	Area contained by 1986 Shoreline Excluding Islands Near Average Conditions	0.533610	
	Area of Islands Flooded (+) and Dry (-)		
	1	0.004040	less than 234
	1	(0.000510)	235.00
	2	0.000252	Near '86 WL
	3	0.000082	Near '86 WL
	4	0.000275	Near '86 WL
	5	0.000022	Near '86 WL
	6	0.002712	230.00
	7	0.000168	227.00
	8	0.000183	Near '86 WL
	9	0.001634	227.00
3	Net Flooded Island Total	0.008858	
	FLOODED AREA = 1 - 2 + 3	0.369995	

Figure 4.3-11 Flooded area due to the Project

4.3.3.3 Water Velocities in the Immediate Forebay

To provide support for the aquatic environment studies (Volume 5) river velocities were developed from just upstream of Wuskwatim Falls to the Project site for the normal operating conditions using a three-dimensional hydraulic model (Appendix A4.5 provides details of the model application). The model was run for four outflow conditions at which the plant will operate for most of the time (one unit **best gate**, two units best gate, three units best gate and three units **full gate** flow conditions) so that river velocity distributions could be developed for a number of "horizontal slices". An example plot of a horizontal slice at elevation 233.5 m for two unit best gate operation is illustrated in Figure 4.3-12. For this case, the velocities through Wuskwatim Falls and the channel excavation are in the range of 0.5 to 0.7 m/s and the remainder of the reach is less than 0.2 m/s. For the other flow cases (one unit and three unit best gate, and three unit full gate), the velocities through Wuskwatim Falls and the channel excavation area range from 0.3 to 1.0 m/s and the remainder of the reach ranges from 0.1 to 0.3 m/s respectively. These velocities are significantly lower than for the existing (post-CRD) water velocities of 4 to 10 m/s (Section 4.2.2.4) because Wuskwatim Falls will be flooded out by the Project.

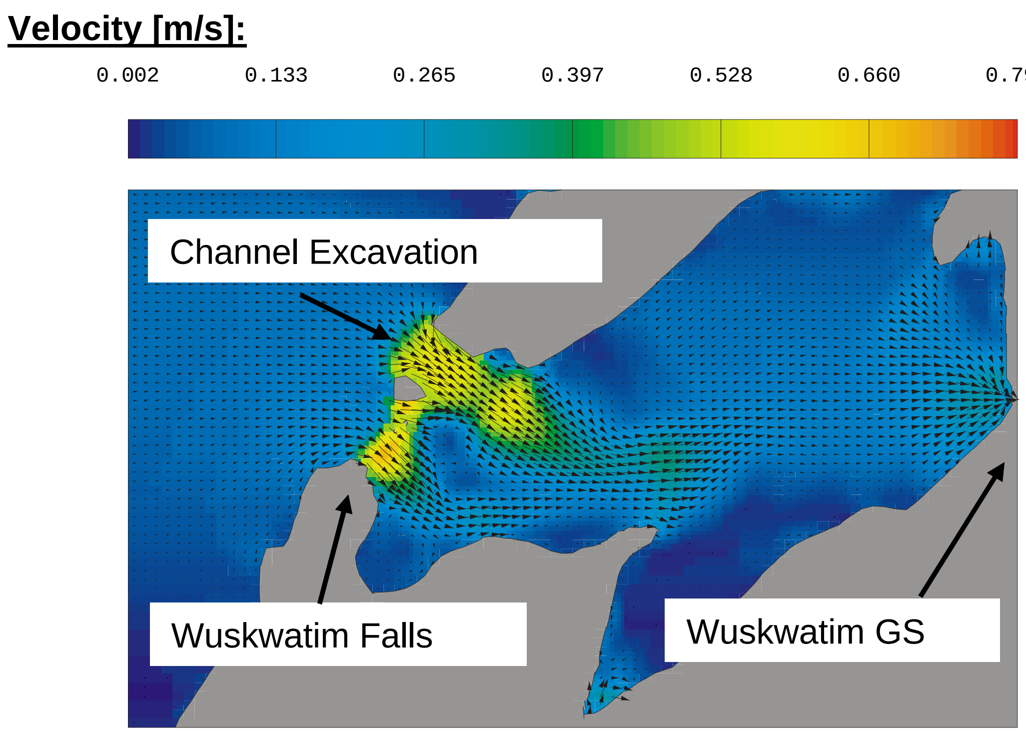


Figure 4.3-12 Velocity distribution for the Wuskwatim to Taskinigup Falls reach (2 units at best gate flow at elevation 233.5 m)

4.3.4 Operations: Downstream Of Project Site

4.3.4.1 Pre-Project Water Levels with Project Inflow Regime

In comparing the existing (post-CRD) inflow period to the long-term project inflow period, it was found that although both periods experienced similar maximum and minimum inflows, the long term average and median simulated inflows are expected to be higher than the average and median existing (post-CRD) inflows (Section 4.3.1). Therefore, future water levels along the Burntwood River would, on average, be higher with or without the Project.

To illustrate the effect of inflow on water levels without the Project, the following duration curves (Figures 4.3-13 to 4.3-18) for open water and winter conditions were developed at selected locations in the downstream reach of the hydraulic zone of influence (Refer to Appendix A4.4 for details regarding the development of the duration curves):

1. Existing (Post-CRD) Inflows: duration curve of stages experienced since 1977.
2. Project Inflows: stage duration curves for project inflow conditions without the Project.

When comparing the two stage duration curves, the long term median project inflow water levels at the **tailwater** of Taskinigup Falls (i.e. Wuskwatim Tailrace), Opegano Lake, and Birch Tree Lake are predicted to be up to 0.5 m higher than the post-CRD levels experienced to date since 1977.

To avoid later duplication of these two duration curves, a third duration curve called modified run-of-river, is also added to Figures 4.3-13 to 4.3-18. This duration curve summarizes the effects of the Project on water levels at the above locations using the project inflow record. The effect of the Project on the duration curve is discussed in the following section.

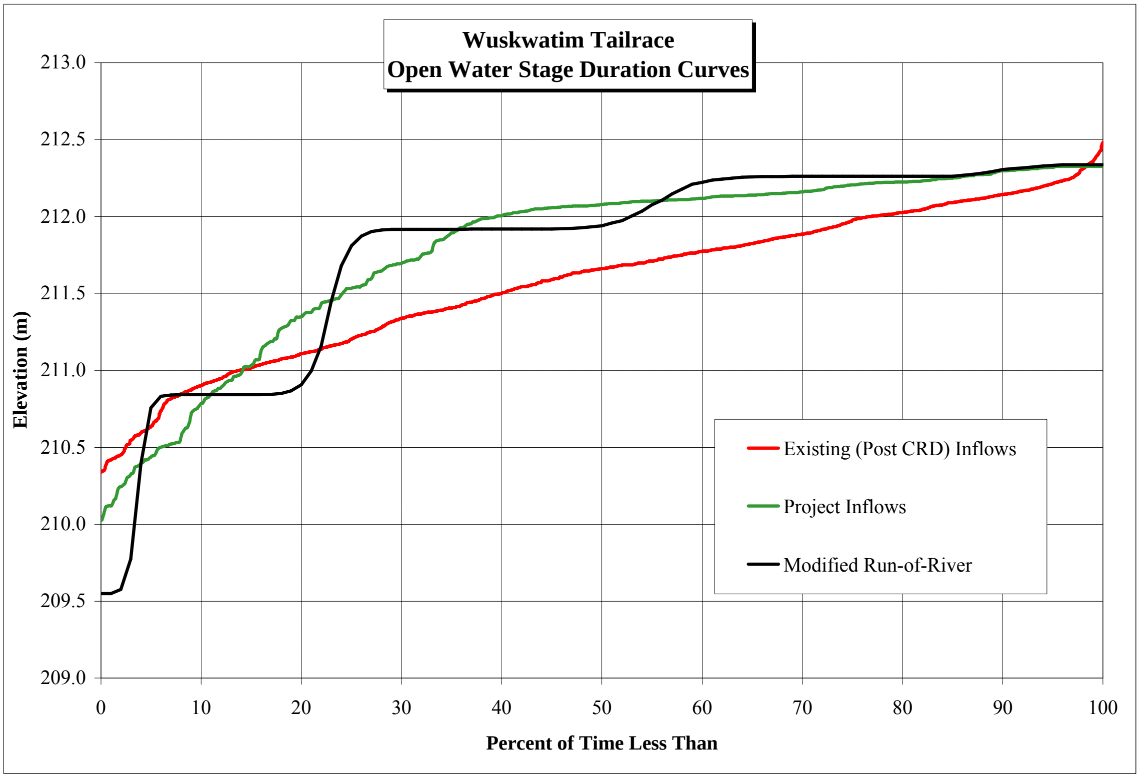


Figure 4.3-13 Wuskwatim tailrace open water stage duration curves

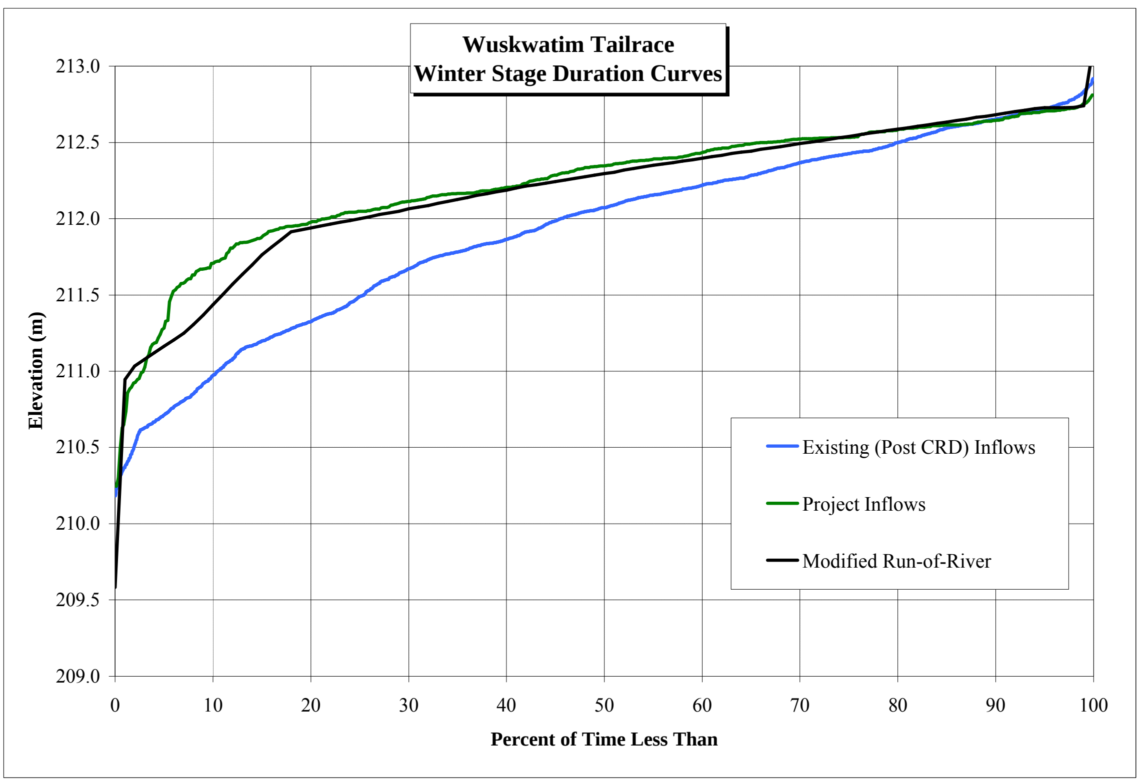


Figure 4.3-14 Wuskwatim tailrace winter stage duration curves

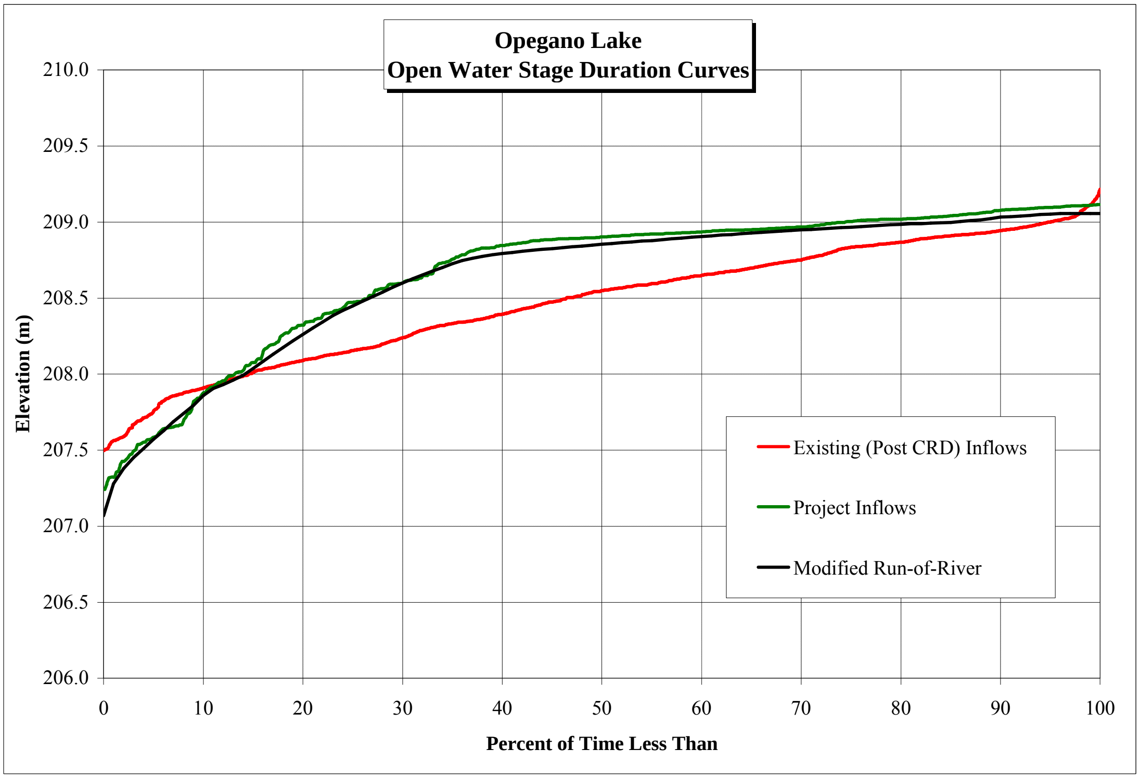


Figure 4.3-15 Opegano Lake open water stage duration curves

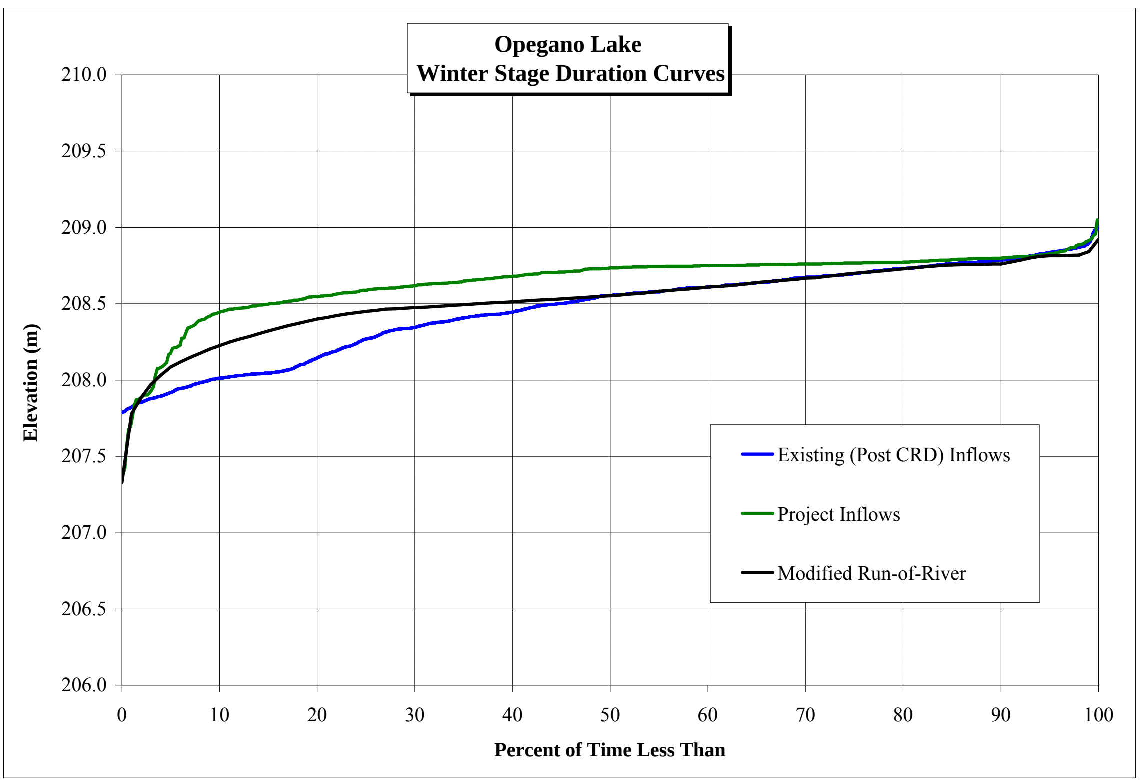


Figure 4.3-16 Opegano Lake winter stage duration curves

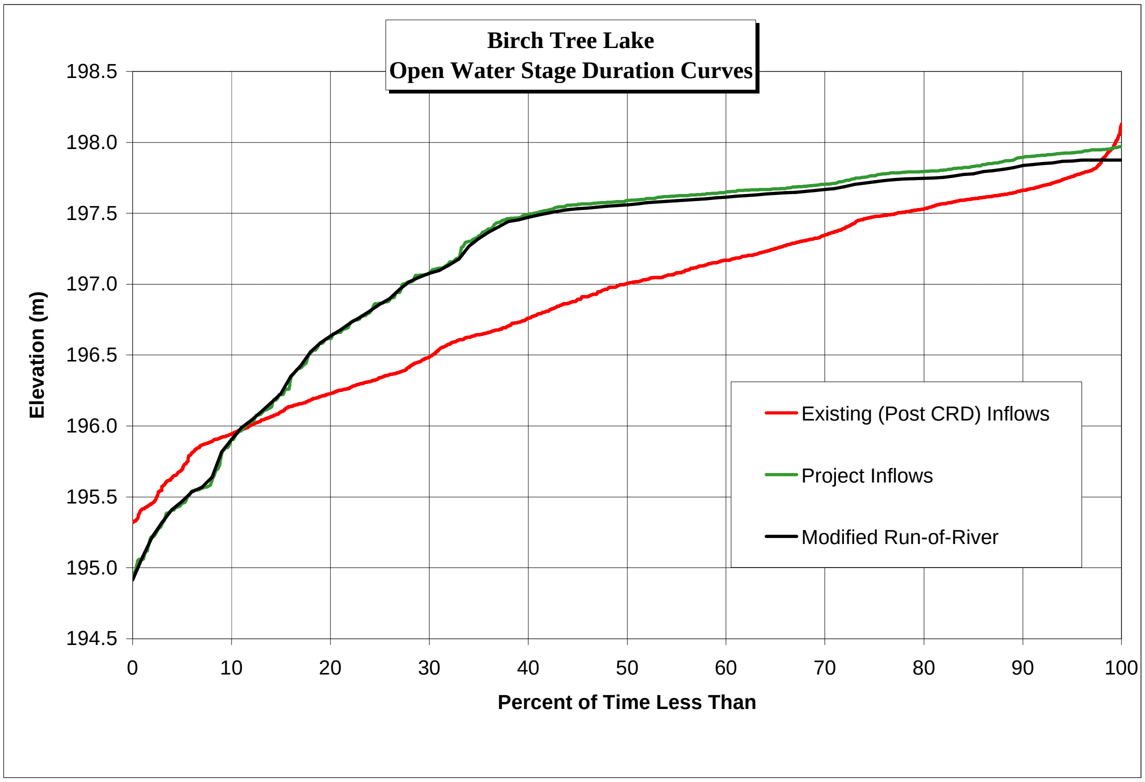


Figure 4.3-17 Birch Tree Lake open water stage duration curves

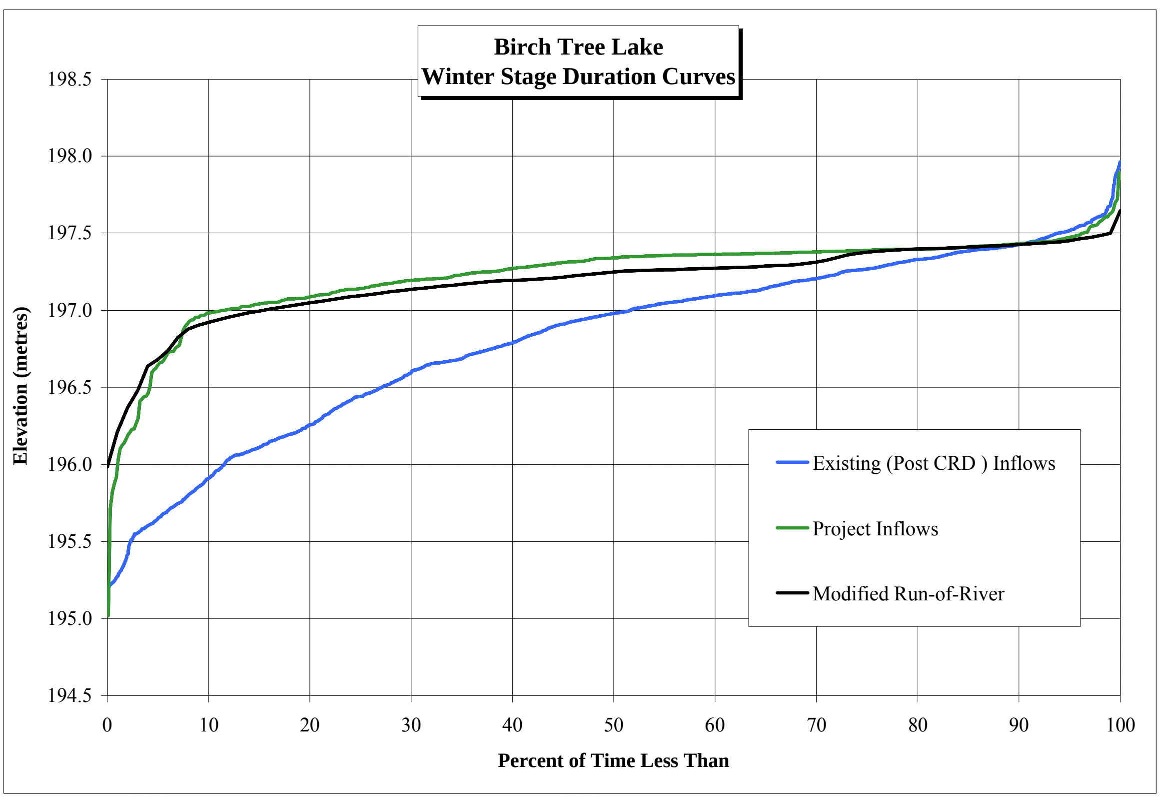


Figure 4.3-18 Birch Tree Lake winter stage duration curves

4.3.4.2 Water Levels and Fluctuations During Plant Operations

During the normal mode of operation of the Project, the outflows would vary as described in Volume 3, Section 5.2 and will affect water levels and flows on a portion of the Burntwood River downstream of the Project. As described in Volume 3, Section 5.2, there are only three target outflow settings for inflows at or below 990 m^3/s. These are 330 m^3/s (1 unit at best gate), 660 m^3/s (2 units at best gate), and 990 m^3/s (3 units at best gate). For inflows greater than 990 m^3/s there are a number of options. Figure 4.3-19 illustrates the outflow patterns for selected project inflows. For example, the 30th percentile inflow condition (912 m^3/s) results in an outflow of 660 m^3/s for approximately 330 minutes (5.5 hours) and 990 m3/s for the remainder of the day.

Steady-State Flow Conditions

Open water and winter water surface profiles for steady-state project outflow conditions were developed for the Wuskwatim **tailrace** to First Rapids reach for the four Project outflow conditions. These profiles were used to support the aquatic environmental studies (Volume 5) and terrestrial environmental studies (Volume 6) to determine the area that is intermittently wetted and dried. (Appendix A4.5 and A4.6 provides details of the modelling carried out to develop the water surface profiles).

Unsteady-State Flow Conditions

To determine the effects of the Project on the existing (post-CRD) water regime, river hydraulic studies that simulate the operation of the Project were undertaken to provide information for a comparison of the Project and existing (post-CRD) water regimes.

The process of modelling the Project water regime under **transient flow** (i.e. unsteady flow) conditions and its comparison to the existing (post-CRD) regime is similar to the process carried out in the upstream reach (Section 4.3.3.1).

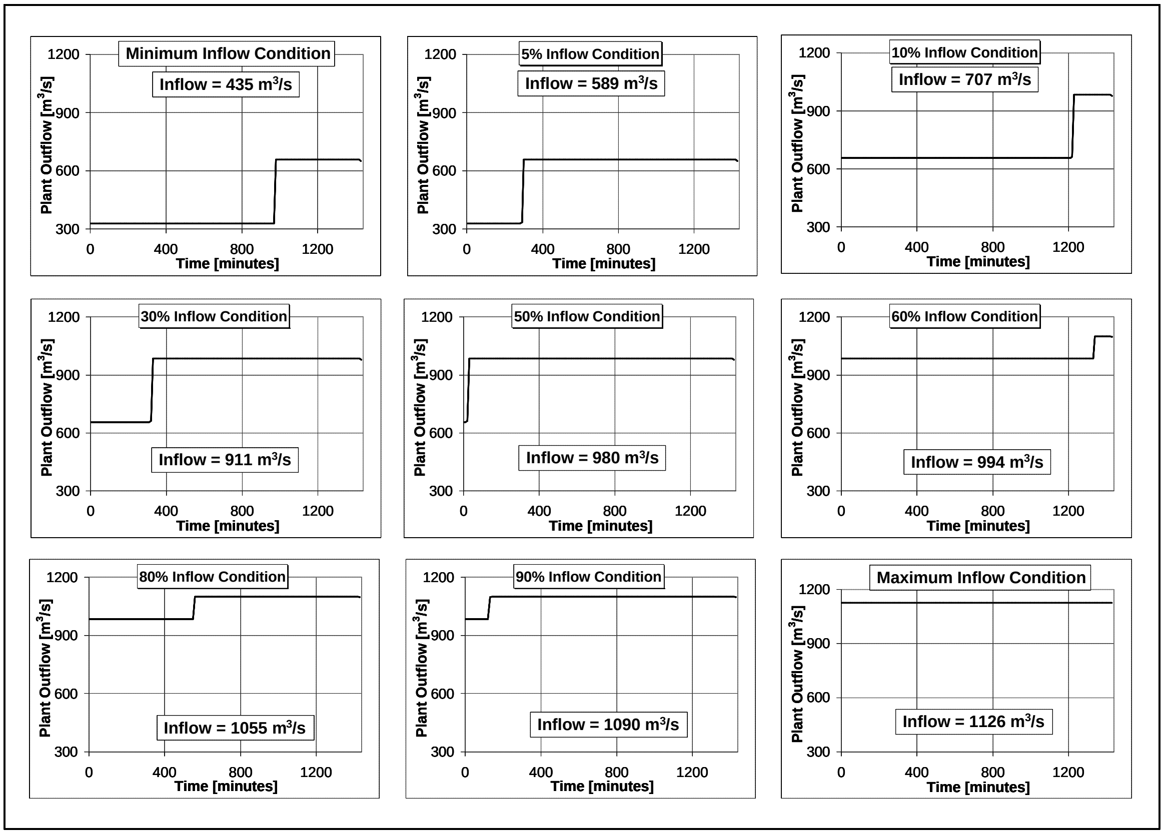


Figure 4.3-19 Project outflow hydrographs for various percentile project inflow conditions

Within the study reach, **hydrodynamic** models were used to simulate the Project outflow water regime from 1912 to 1997 using a 10 minute time step during open water and winter seasons. For each average monthly inflow, a Project outflow pattern was developed. The water regime characteristics of water levels and water level fluctuations were estimated to support various EIS studies (Volume 3 and Volume 5). The modelling is characterized by:

- routing Project outflow hydrographs along the Burntwood River through Opegano Lake, Birch Tree Lake, and Apussigamasi Lake;
- simulating river reach head losses as well as the head loss across all sets of rapids; and,
- modelling winter river ice processes.

Appendix A4.5 and A4.6 contain a detailed explanation of the hydrodynamic modelling.

As a result of the hydrodynamic modelling, a number of water regime characteristics were compiled into various forms. Observations and conclusions about the Project water regime are:

- The downstream extent of the hydraulic zone of influence will be Birch Tree Lake. Figure 4.3-20 illustrates the median and maximum open water and winter daily stage variations (i.e water level fluctuations) that will occur at a number of locations downstream of the Project. The stage variation is greatest at the Wuskwatim Tailrace, median and maximum daily stage variations are 0.42 m and 1.47 m respectively. Moving downstream the daily water level fluctuation is dampened, as described in the next paragraph, and the median and maximum daily stage variation on Birch Tree Lake are estimated to be 0.03 m and 0.14 m respectively. It is estimated that during open water conditions, wave heights for average wind conditions on Birch Tree Lake would be in the order of 0.17 m.

- The attenuation of flows by channel and lake storage dampens the daily fluctuation in water levels and flows at downstream locations. Figure 4.3-21 shows the flow hydrographs at the Wuskwatim tailrace, Opegano Lake, and Birch Tree Lake for the 15th percentile project inflow condition (817 m^3/s) . The change in the flow at the Wuskwatim tailrace occurs quickly resulting in steady flow conditions equal to the plant outflow. Moving downstream, the plant outflows are attenuated by channel and lake storage resulting in a smaller difference in the flows. The result is that at the downstream locations, the flows vary over a longer period of time and generally do not reach steady-state flow conditions prior to the project outflow pattern changing again. Figure 4.3-21 shows that the flow at Birch Tree lake would fluctuate between 807 and 825 m^3/s for the 15th percentile inflow condition whereas the flow at the Project tailrace would fluctuate between 660 and 990 m^3/s for the same condition. The 330 m^3/s flow change at Wuskwatim tailrace decreases by more than 10 times by the time the flow change reaches Birch Tree Lake. Figures 4.3-22 to 4.3-24 illustreate the stage hydrographs for selected typical project outflow patterns. For the examples shown, the water level at the Wuskwatim tailrace responds quickly and tends to stabilize whereas the water level at downstream locations respond slowly and may not stabilized due to the attenuation of flows.

- The Project will affect the duration of water levels in the river reach between the Project and Opegano Lake, and will have little effect on the duration of water levels at or downstream of Opegano Lake. Looking at the duration curves from Wuskwatim tailrace to Birch Tree Lake (Figures 4.3-13 to 4.3-18) for only the project inflow record without the Project ("Project Inflows" curve) and the project inflow with the Project ("Modified Run-of-River" curve) demonstrate the following:

  - At the Wuskwatim tailrace the outflows will consist of only a few discrete outflow settings, and the water levels will correspond to those flow conditions as evident in the open water water level duration curve (Figure 4.3-13). Therefore, the duration of water levels with the Project will not equal the duration of levels without the Project. Additionally, the minimum water level with the Project will be less than the minimum water level without the Project because the minimum plant outflow of 330 m^3/s is lower than the minimum inflow of 435 m^3/s.

  - At the Wuskwatim tailrace under winter conditions, the continuous formation of ice over the course of the winter changes the **rating curve** which results in a water level duration curve that is different than the open water condition (Figure 4.3-14).

  - In the river reach downstream of the Project, channel and lake storage attenuates flows and results in **dampened** water level fluctuations at Opegano Lake and Birch Tree Lake. As the water level fluctuation becomes smaller, the water level with the Project becomes very similar to the water level without the Project (Figures 4.3-15 to 4.3-18).

  - Under winter conditions, there is a small, consistent difference between the stage duration curves associated with the project inflows with and without the Project (for example Figure 4.3-16). This is not unexpected given that slightly different methods of analysis were utilized in simulating the water levels for each of these conditions. Given the complexity and difficulties of simulating river ice processes, the differences between the duration curves are considered to be small and within the level of accuracy expected for river ice modelling. Appendix A4.6 provides details for the river ice modelling.

In summary, the net change in water levels from the existing (post-CRD) inflow condition to the project inflow condition without the Project is greater than the net change in water levels during the project inflow condition with or without the Project.

- The daily variation in water levels caused by the Project would generally be the greatest during low Wuskwatim Lake inflows and is generally the lowest during high Wuskwatim Lake inflows. This is illustrated in Figures 4.3-25 to 4.3-27. There would be no **cycling of flows** when the Wuskwatim Lake inflow equals 1, 2, or 3 units best gate target outflow or when the inflow exceeds the 3 units full gate outflow. These situations would not result in stage variations since inflow is equal to outflow. The largest daily water level fluctuations would occur for inflows that are in the mid-range between target plant outflows (i.e. 495 m^3/s and 825 m^3/s). For example, for an inflow condition of 825 m^3/s the plant outflow would operate for 12 hours at 990 m^3/s above the inflow and then 12 hours at 660 m^3/s below the inflow. Table 4.3-1 provides the water level fluctuation as a function of Wuskatim Lake inflow.

Table 4.3-1
Maximum Daily Water Level Fluctuation
as a Function of Wuskwatim Lake Inflow

Wuskwatim Lake Inflows		Maximum Daily Water Level Fluctuations					
Flow Range	Frequency	Project Tailrace		Opegano Lake		Birch Tree Lake	
		Open Water	Winter	Open Water	Winter	Open Water	Winter
inflows greater than 1100 m^3/s	7%	0 m	0 m	0 m	0 m	0 m	0 m
inflows between 990 m^3/s and 1100 m^3/s	39%	0.34 m or 0 m *	0.42 m or 0 m *	0.14 m or 0 m *	0.12 m or 0 m *	0.03 m or 0 m *	0.05 m or 0 m *
inflows between 660 m^3/s and 990 m^3/s	47%	1.07 m	0.93 m	0.40 m	0.42 m	0.07 m	0.13 m
flow less than 660 m^3/s	7%	1.29 m	1.47 m	0.42 m	0.43 m	0.06 m	0.11 m

cf. Volume 3, Section 5.2.5 For flows greater than 990 m^3/s, and less than 1100 m^3/s plant outflow may be adjusted to match inflows resulting in no daily cycling or downstream water level changes.

- The largest downstream daily stage variations would occur infrequently. As shown in Figures 4.3-28 to 4.3-30, daily stage variations (i.e. composite) greater than 0.90 m at the Wuskwatim Tailrace, 0.20 m at Opegano Lake, and 0.05 m at Birch Tree Lake would occur less than 30% of the time.

- The daily fluctuation in water levels in Opegano Lake and downstream due to Project operation will be small relative to the weekly or monthly variation in water levels now occurring due to the operation of the CRD. The seasonal, monthly, and weekly regulation pattern of outflows from Notigi Control structure and associated changes in water levels that are now present would still occur once the Project is operated as shown in the sample year water regime Figures 4.3-31 to 4.3-33. For example, the overall shape of the stage hydrograph and variation for Birch Tree Lake (Figure 4.3-33) for the highlighted sample month is due to the operation of the CRD and amounts to approximately 0.23 m. Superimposed on top of the CRD trend is the very small daily stage variation that results from the operation of the Project. The small daily stage variation that is apparent in the first half of this example month, amounts to a daily variation of approximately 0.03 m.

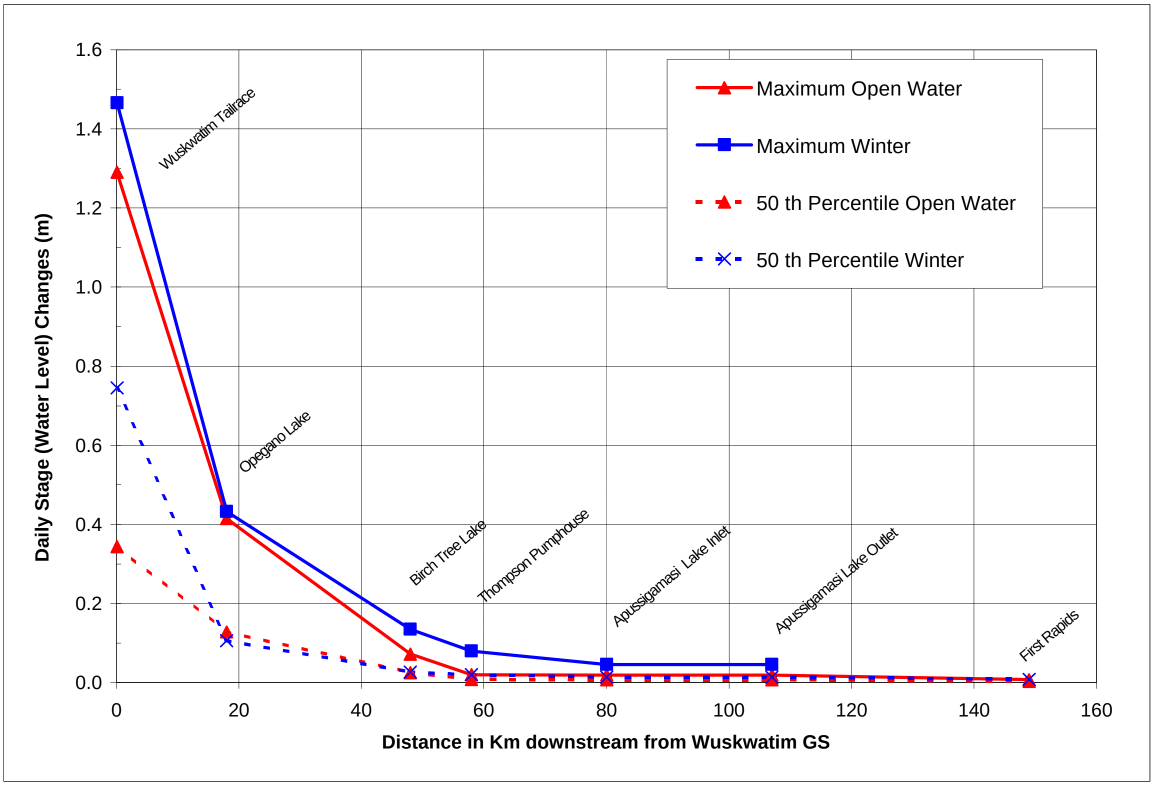


Figure 4.3-20 Typical and Maximum Downstream Stage Variation Due to Project operation for simulated flows (1912-1997)

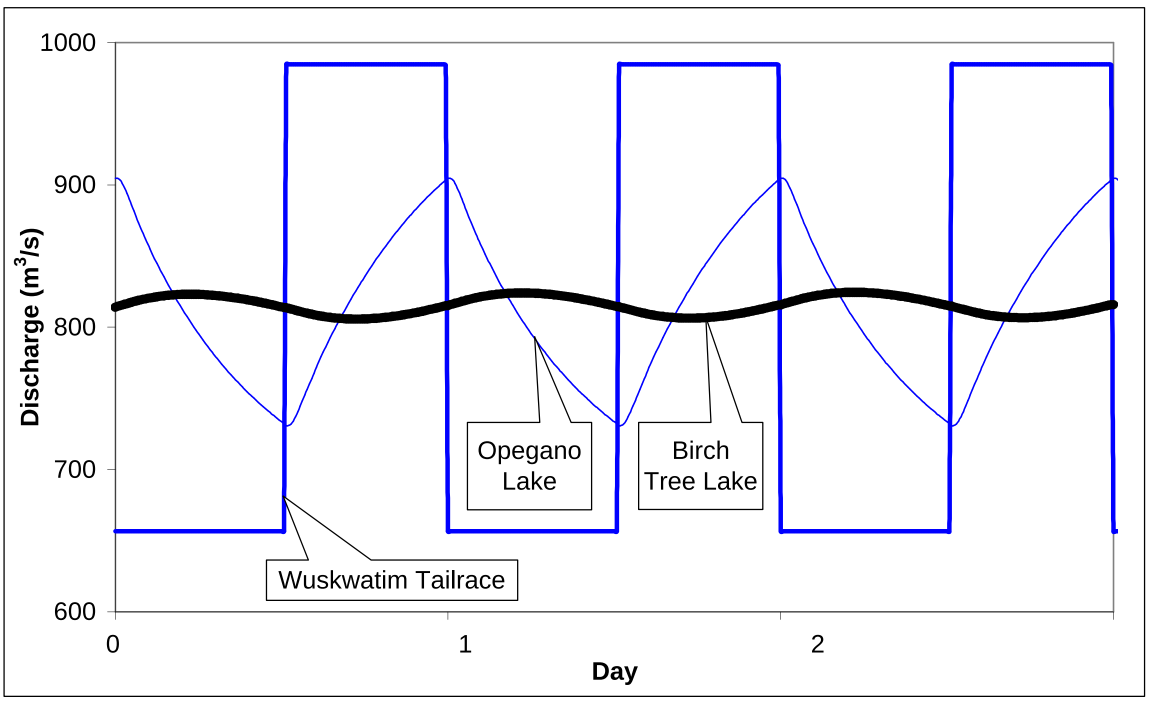


Figure 4.3-21 Flow hydrographs (15th percentile project inflow condition) at the Wuskwatim Tailrace, Opegano Lake, Birch Tree Lake

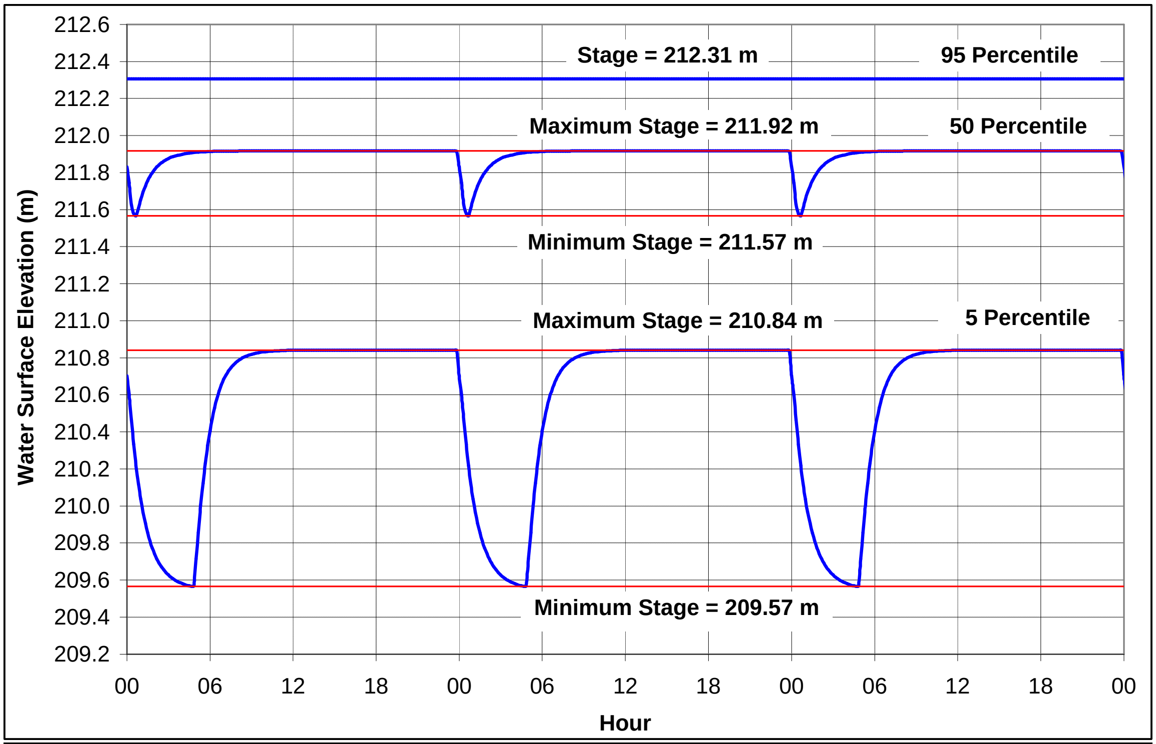


Figure 4.3-22 Wuskwatim tailrace open water stage hydrographs for 5th, 50th, and 95th percentile project inflow conditions

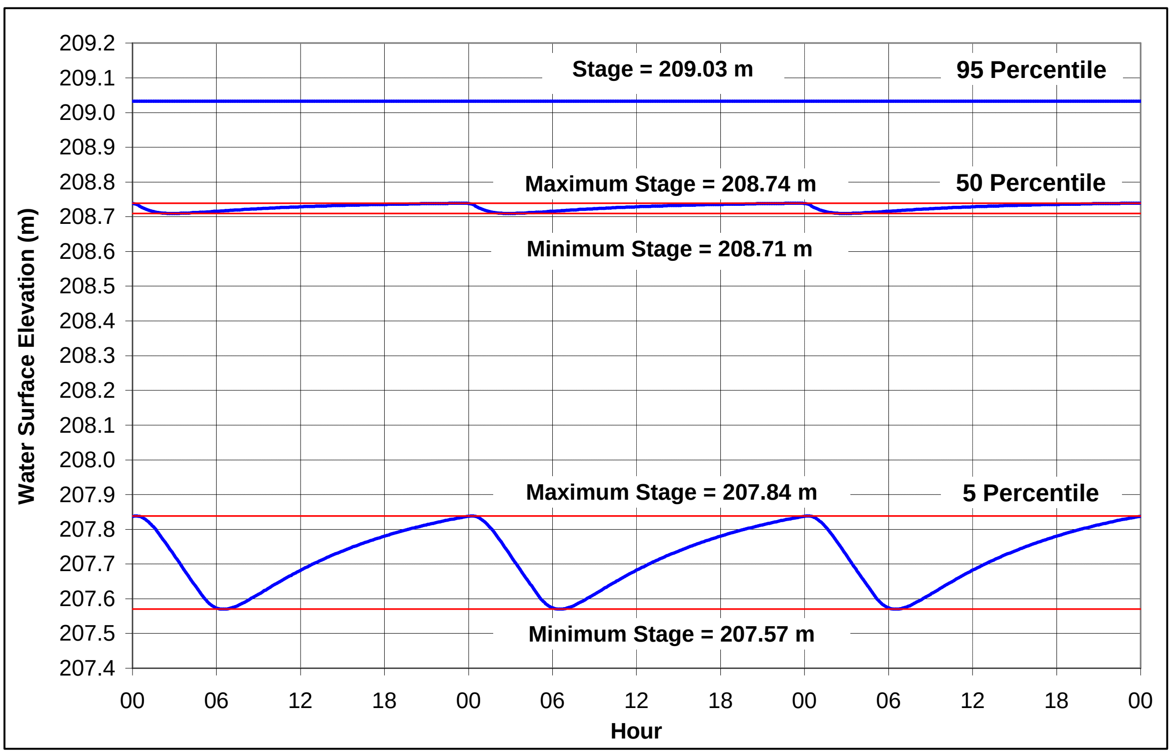


Figure 4.3-23 Opegano Lake open water stage hydrographs for 5th, 50th, and 95th percentile project inflow conditions

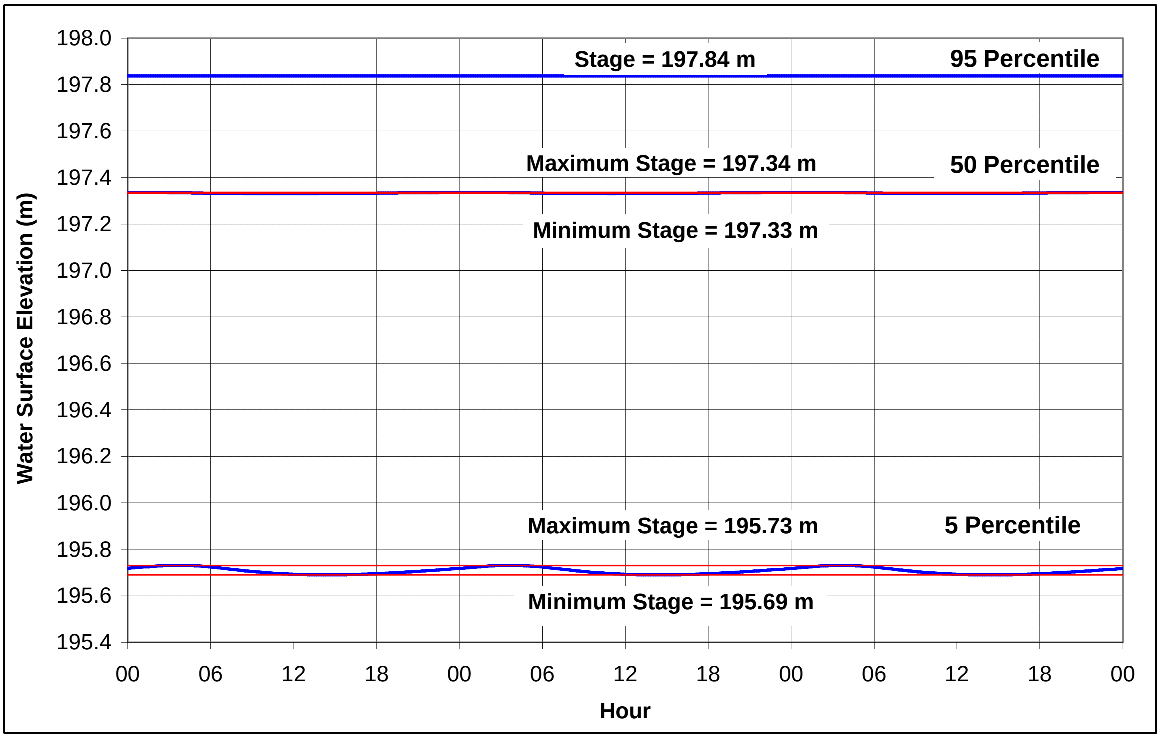


Figure 4.3-24 Birch Tree Lake open water stage hydrographs for 5th, 50th, and 95th percentile project inflow conditions

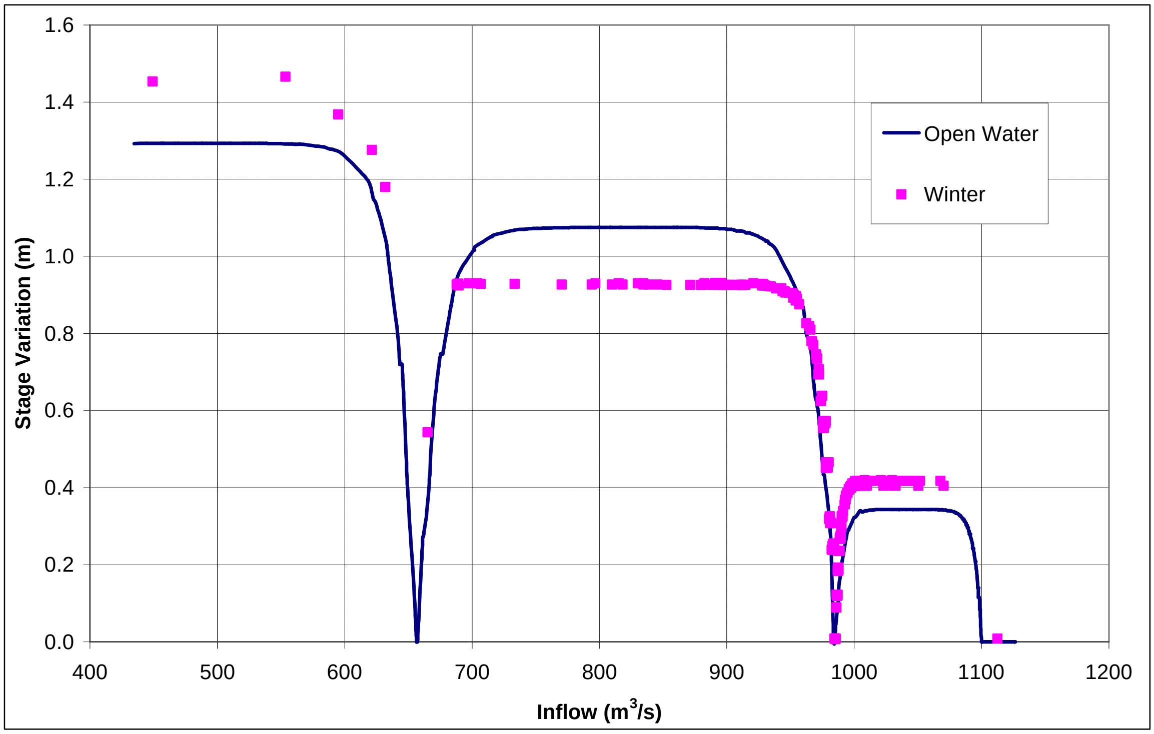


Figure 4.3-25 Wuskwatim tailrace stage variation versus Wuskwatim Lake inflow

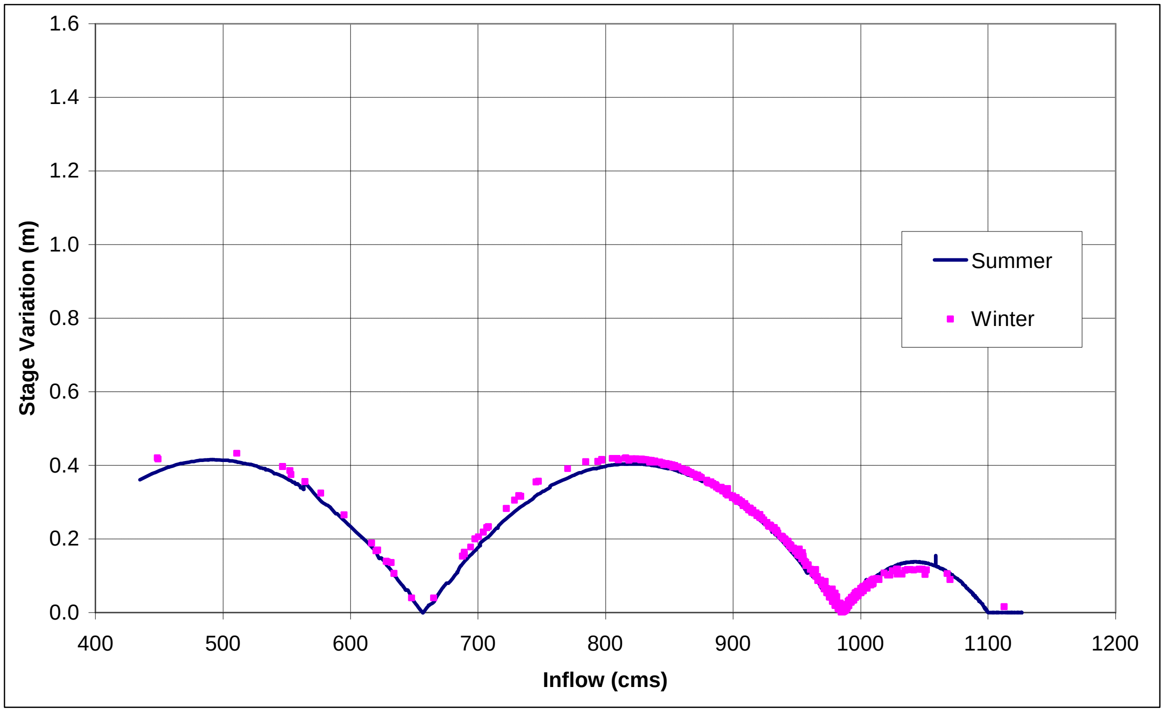


Figure 4.3-26 Opegano Lake stage variation versus Wuskwatim Lake inflow

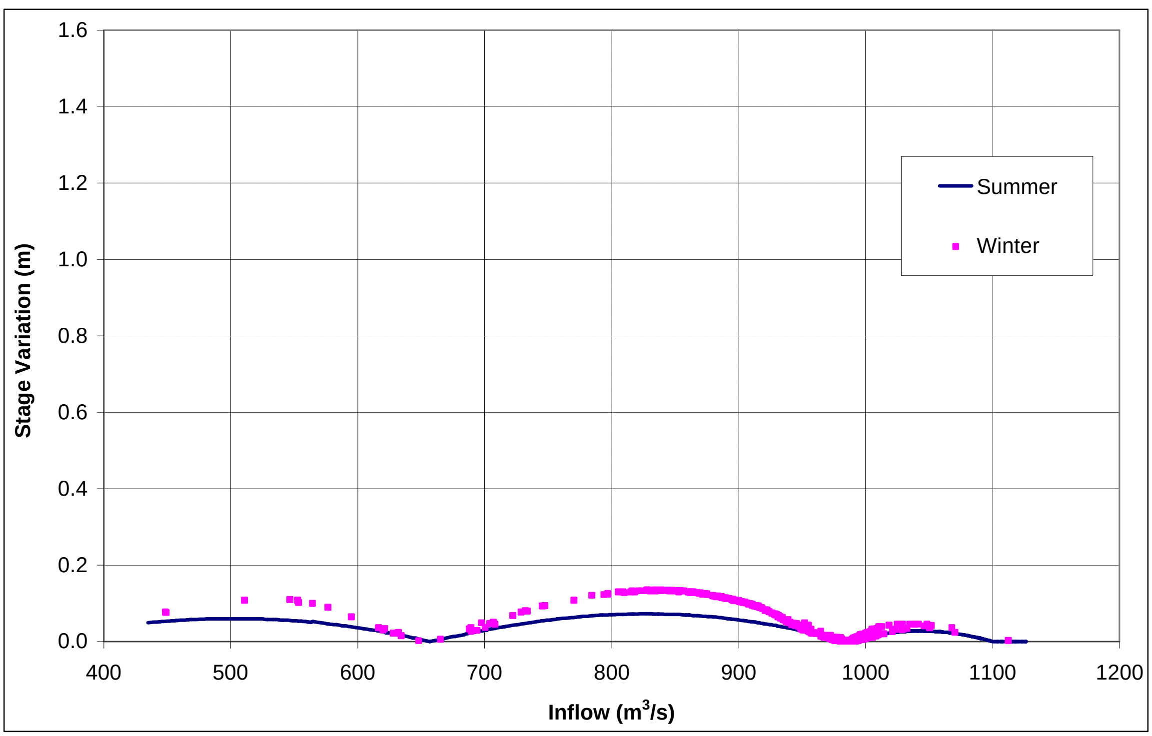


Figure 4.3-27 Birch Tree Lake stage variation versus Wuskwatim Lake inflow

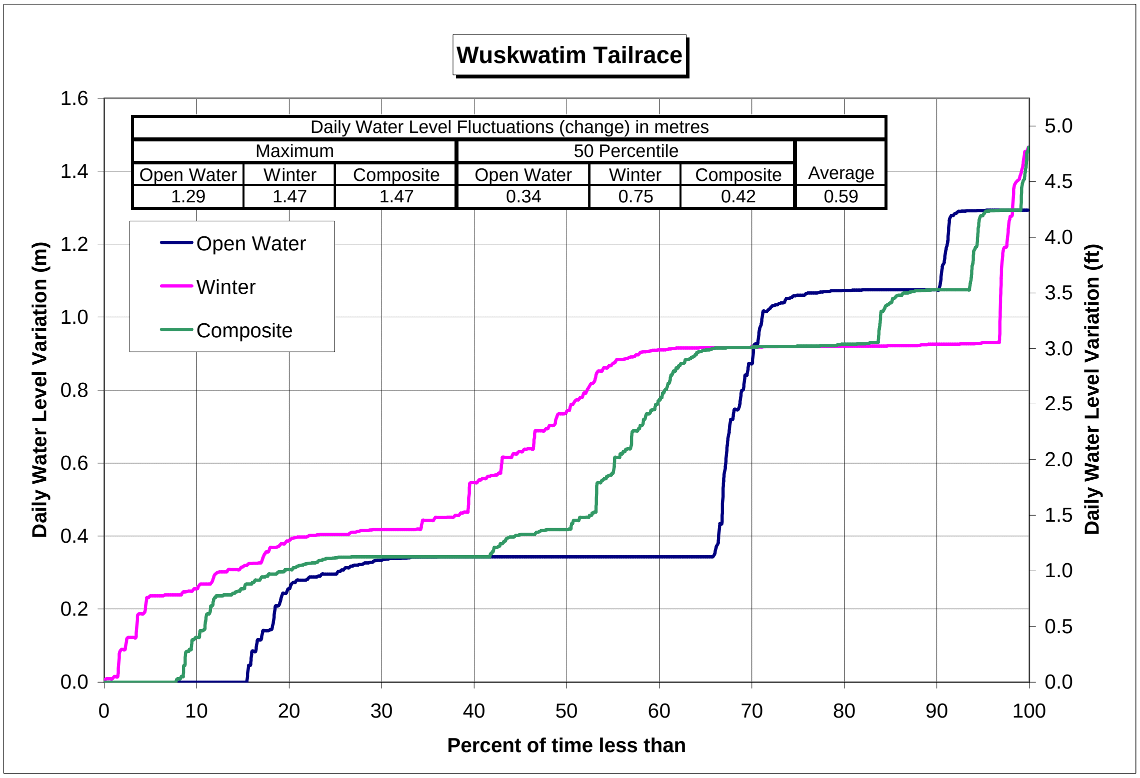


Figure 4.3-28 Wuskwatim tailrace daily stage variation duration curve

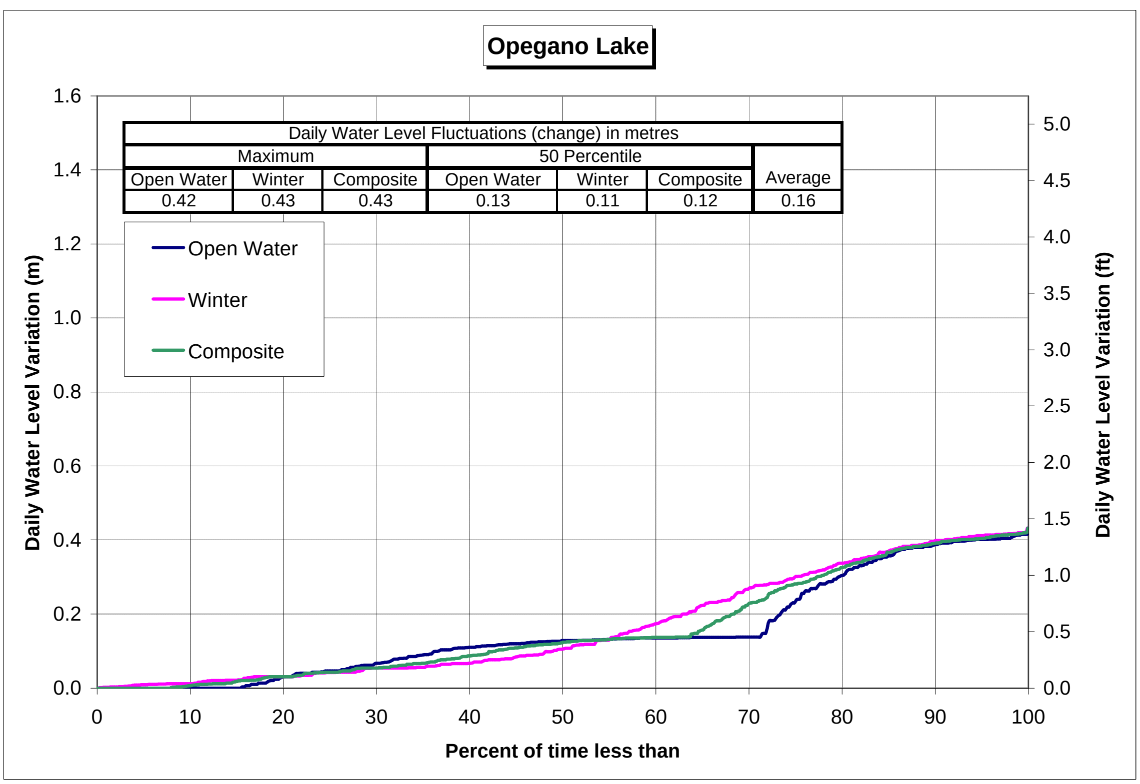


Figure 4.3-29 Opegano Lake daily stage variation duration curve

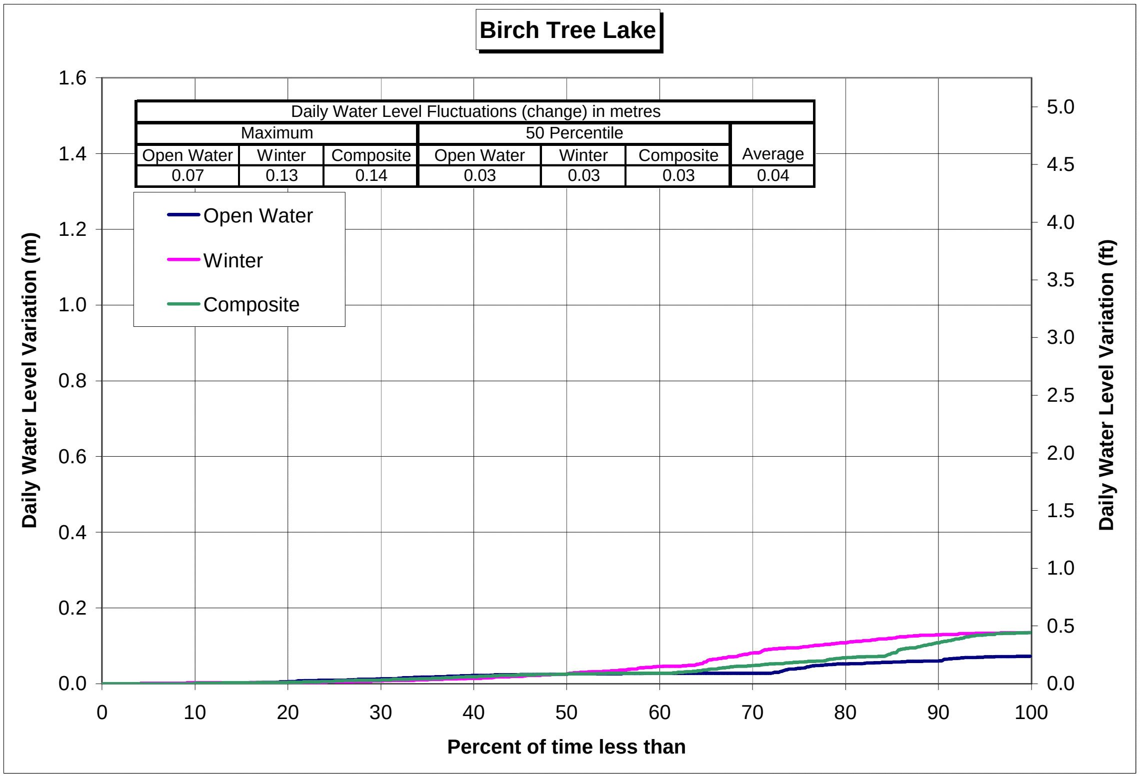


Figure 4.3-30 Birch Tree Lake daily stage variation duration curve

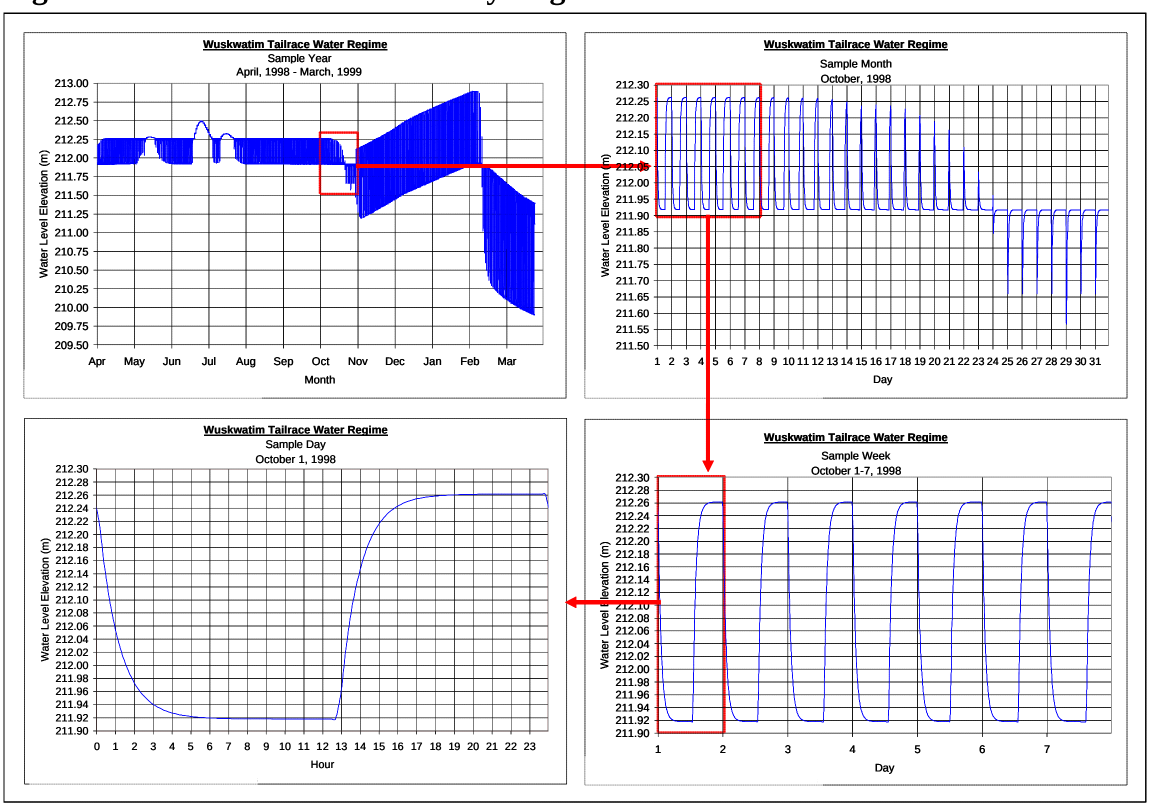


Figure 4.3-31 Stage hydrographs for 1998/1999 with the Project: Wuskwatim Tailrace

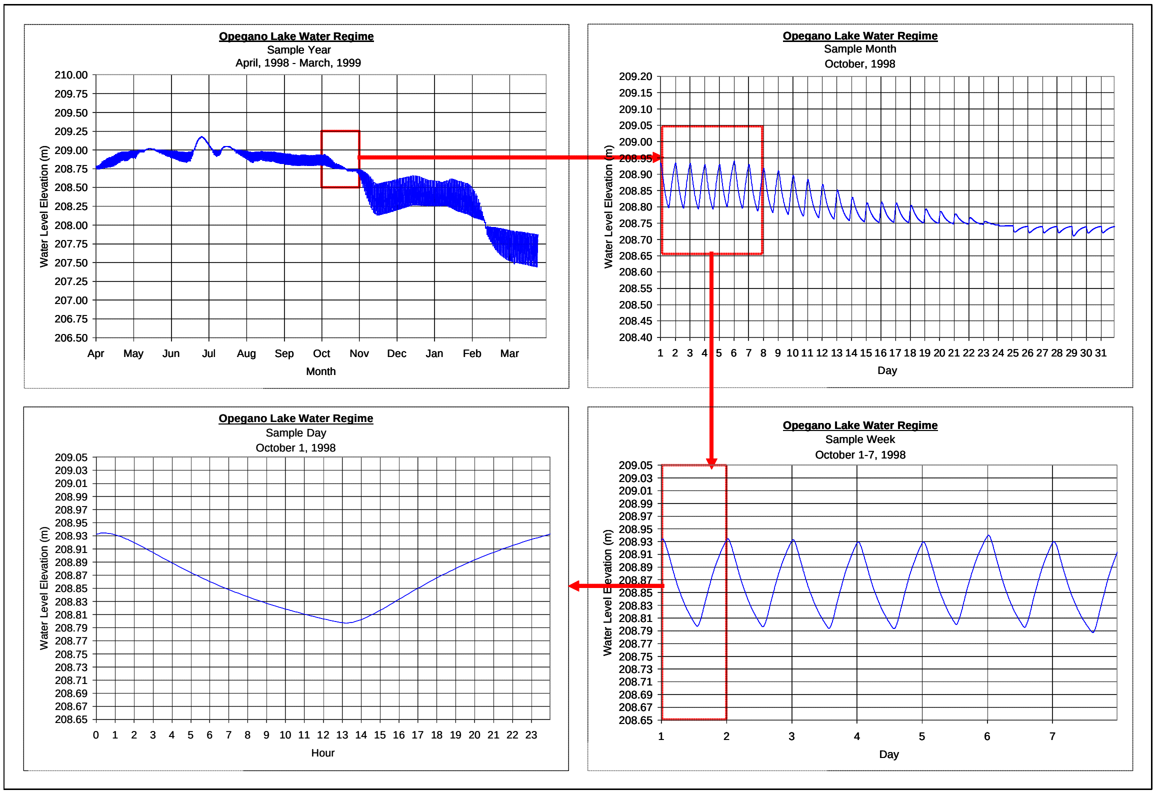


Figure 4.3-32 Stage hydrographs for 1998/1999 with the Project: Opegano Lake

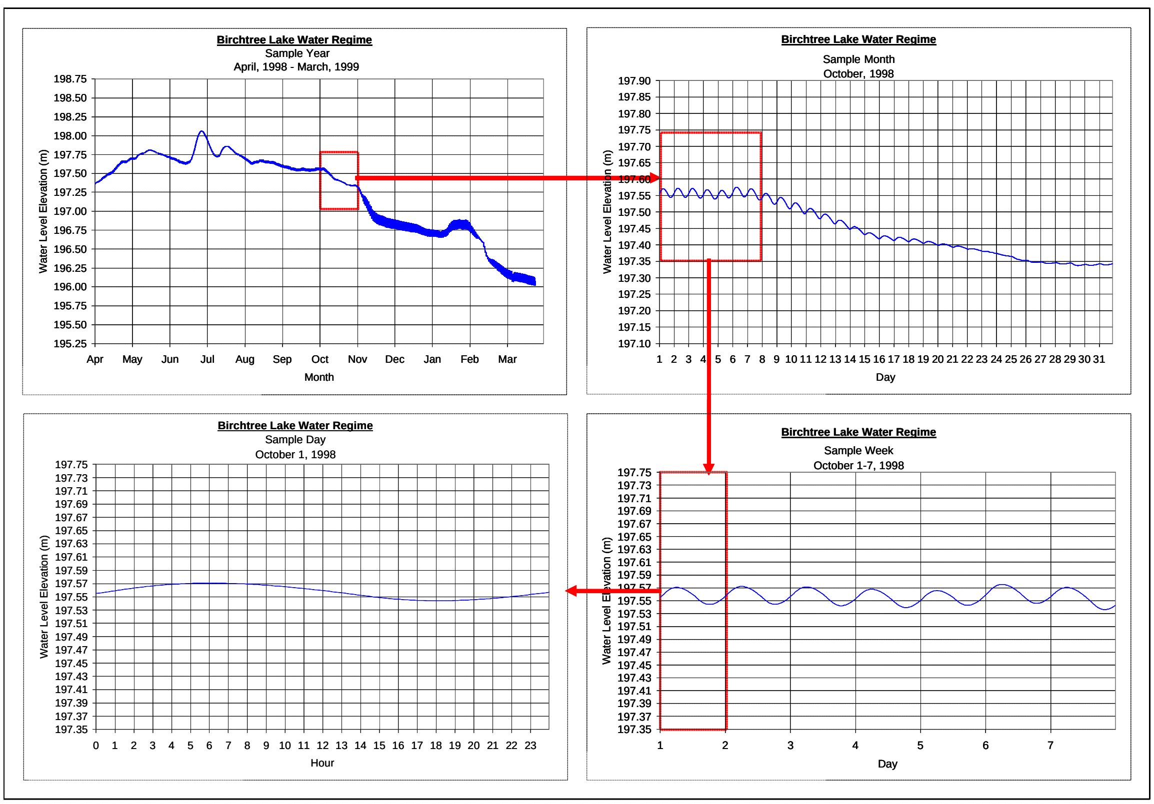


Figure 4.3-33 Stage hydrographs for 1998/1999 with the Project: Birch Tree Lake

4.3.4.3 Water Velocities for the Project Tailrace to Opegano Lake Inlet

To assist the aquatic environmental studies, a two dimensional hydraulic model was applied in the Wuskwatim Tailrace to Opegano Lake inlet reach to predict water velocities. The outflow conditions modelled were: 1 unit best gate, 2 units best gate, 3 units best gate and 3 units full gate flow conditions (Appendix A4.5). Figure 4.3-34 illustrates the resulting depth averaged water velocities for each of these four scenarios for a subreach of the study reach. It can be seen in the figure that the average velocity along the reach increases as the flow increases. For the 1 unit best gate case, main channel velocities are in the range of 0.2 m/s; for the 3 unit best gate flow case, main channel velocities are in the range of 0.8 m/s. It can also be observed that the wetted area increases with increasing flow, the majority of the wetted area occurring within the mouths of the adjoining creeks as well as along the shoreline of the Burntwood River.

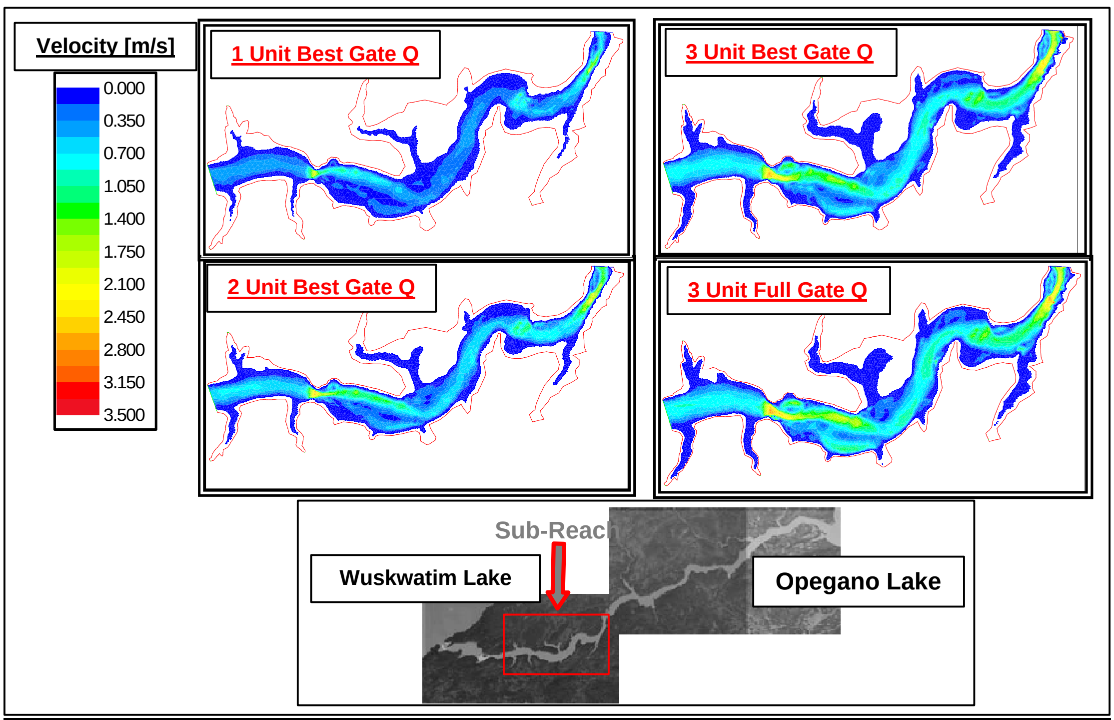


Figure 4.3-34 Taskinigup Falls – Opegano Lake: depth averaged velocities for 1, 2, 3 unit best gate flow and 3 unit full gate flow

4.4 SUMMARY OF PROJECT EFFECTS

As discussed in Section 4.3.1, the assessment of Project effects on the water regime is based on the long-term project inflow record. The use of the long-term project inflow record results in approximately on average 100 m^3/s more inflow than observed for the existing (post-CRD) inflow record, except for maximum and minimum flows which are about the same for both inflow records. This will result in future water levels being higher on average compared to the existing (post-CRD) record. Refer to Figure 4.3-13 to Figure 4.3-18.

The following summarizes the Project effects described in the previous sections:

Effects during construction:

- during Stage I Diversion, water levels during the open-water season are expected to rise approximately 0.2 to 0.7 m for the 5th and 95th percentile flow conditions respectively;
  - water levels during winter will be 0.10 m higher than during open water for the same flow conditions;
  - downstream water levels are not expected to change.
- during river closure and the completion of the main dam (Stage II Diversion), the upstream water levels during open water conditions are expected to increase by 0.5 to 1.0 m for the 5th and 95th percentile flow conditions respectively, and by as much as 1.3 m if the construction design flood were to occur.
  - water levels will be the same for both winter and open water conditions for the same flow conditions;
- groundwater may be drawn from the local burrow site to wash the sand prior to hauling. This potential draw on the local groundwater would be short term in nature and groundwater levels would return to normal levels after the extraction is completed.
  - servicing of vehicles would be done outside of the borrow area thereby minimizing contamination of the local groundwater.

Effects During Operations - Upstream of the Project Site:

- water levels in the immediate forebay area will be raised 7 m between Wuskwatim Falls and Taskinigup Falls (Figure 4.3-4);

  - velocities through Wuskwatim Falls will be reduced from a range of 4 to 10 m/s to a range of 0.5 to 0.7 m/s with impoundment (Section 4.3.3.3);
  - the water-level rise will result in the permanent flooding in the immediate forebay area of less than ½ km^2 of previously cleared land (Figure 4.3-11).
- water levels on Wuskwatim Lake will be stabilized within the existing (post-CRD) water regime at or near 234 m ASL by the construction of the channel-excavation area at Wuskwatim Falls (which improves outflow capability from Wuskwatim Lake) and the operation of the Project (Figure 4.3-7);
  - the selection of a forebay level that is within the existing (post-CRD) water regime at or near 234 m ASL results in no flooding effects in this area;
  - the selection of a forebay level that is within the existing (post-CRD) water regime also results in no backwater effects upstream of Early Morning Rapids, which defines the upstream boundary of the hydraulic zone of influence (Figure 4.3-4, Figure 4.3-6);
- daily water-level fluctuations on Wuskwatim Lake will occur and are estimated to be relatively small (i.e., typically less than 0.06 m – wind and wave effects eliminated) (Figure 4.3-7);
  - the monthly and seasonal water-level changes on Wuskwatim Lake due to CRD operation will no longer occur; and
  - very small water-level fluctuations will occur on Wuskwatim Lake and upstream to Early Morning Rapids but will not propagate further upstream (Figure 4.3-6).

<u>Effects During Operations - Downstream of the Project Site:</u>

- in the 9 km river reach from the tailwater of the Project to the set of rapids 4 km upstream of Opegano Lake, daily water-level fluctuations will occur as a result of operations (Figure 4.3-22);
  - the largest daily water-level fluctuations will occur at the tailwater (0 m to 1.5 m) and will decrease downstream because outflows are attenuated by channel storage (Figure 4.3-20);
- in the same river reach, occasional low outflows and corresponding low water levels will occur as a result of generating station operations;
  - the 330 m^3/s outflow (the 1 unit operation, which is expected to occur 3% of the time) is lower than the lowest expected inflow and results in lower downstream

water levels than what would occur without the Project (Figures 4.3-13 to 4.3-18);

- in Opegano Lake, daily water-level fluctuations, which will occur as a function of daily outflow changes (0 m^3/s to 330 m^3/s) and the duration of each outflow setting, will be dampened by the available storage in the lake (Figure 4.3-21, 4.3-23);
  - for inflows near 660 m^3/s and 990 m^3/s there would be minimal daily moderation of plant outflows and no daily water-level fluctuations in Opegano Lake (Figure 4.3-26);
  - for inflows greater than 1100 m^3/s, there will be no changes in plant outflows and no water-level fluctuations (Figure 4.3-26);
  - the largest daily water-level fluctuations on the Lake (approximately 0.4 m, which is 0.2 m above and below the water level for project inflow conditions without the Project) and all other downstream locations will occur for inflows that are near the mid-range between plant outflows (i.e. 495 m^3/s and 825 m^3/s) (Figures 4.3-26 and 4.3-27).
  - the largest daily water-level fluctuations on the Lake and all other downstream locations have a low frequency of occurrence (Figures 4.3-28 to 4.3-30).
- downstream of Opegano Lake, daily water-level fluctuations will be further dampened by the attenuation of flows by channel and lake storage (Figure 4.3-20);
  - the median water-level fluctuation will not be noticeable at Birch Tree Lake (i.e., indistinguishable from wind and wave effects);
  - under a maximum water-level fluctuation scenario, the Birch Tree Lake water-level fluctuation would be about 0.10 m in open-water conditions and 0.15 m in the winter (Figure 4.3-30) and not noticeable downstream (Figure 4.3-20) (i.e., indistinguishable from wind and wave effects). This defines the downstream boundary of the Hydraulic Zone of Influence.
- with or without the Project, the duration of water levels at Opegano Lake and downstream will not change except for the low-outflow condition described above for 1 unit operation (3% of the time) (Figures 4.3-15 to 4.3-18); and
- monthly and seasonal water-level changes due to CRD operation will continue to occur downstream of the Project (Figures 4.3-31 to 4.3-33).

4.5 REFERENCES

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MANITOBA HYDRO, 1980. Churchill River Diversion – 1979 Time Lag Study – Notigi to Thompson, System Planning Division, Hydro Development Department, 27 p.

MANITOBA HYDRO, 2002. Wuskwatim Generating Station Stage 4 Studies - Existing Physical Environment Water Regime Package, Memorandum W-7.2.2 Revision 1, Manitoba Hydro File 00184-11300-0001_00.

Appendix A4.1

REGIMES OF FLOW

Appendix A4.1 Regimes of Flow

It is important to define the hydraulic characteristics of the various aspects of river hydraulics in understanding why the stage variations on Wuskwatim Lake due to plant operations do not affect the water regime above Early Morning Rapids (Figures 4.2-6 and 4.2-7). The Burntwood River drops approximately 90 m along its course from downstream of the Notigi Control Structure to Split Lake on the Nelson River. The river reach is characterized by a series of lakes, connected by slow and fast flowing river reaches and as such, there are three distinct regimes of open channel flow (Ven Te Chow) along the river system:

Tranquil subcritical flow in a lake which is normally a deep wide water body with a large cross-sectional area where water velocity is very low;
subcritical flow in river reaches normally located between lakes and rapids where water velocity is low and is often described as tranquil and streaming;
supercritical flow in a river normally located at a set of rapids/falls or a narrow channel where water velocity is high and is defined as rapid and shooting.

To physically describe subcritical and supercritical flow in a river section, consider the case of a rock being thrown into a tranquil flowing river. To an observer standing on the shore the resulting ripples on the water surface in subcritical flow would be seen moving both upstream and downstream of the rock. If on the other hand, the rock is thrown into a set of rapids or falls, where the flow is classified as supercritical, an observer on the shore will not see a ripple moving upstream; all ripples would be washed away downstream. This means that for subcritical flow situations a change in downstream water level will also cause a change in the upstream water level. In supercritical cases, a change in downstream water level will not cause a change in the upstream water level.

If a rock is thrown into a river some distance downstream of a set of rapids, the ripples caused by the disturbance propagate both upstream and downstream. An observer on the shore will see ripples moving upstream to the foot of the rapids. As the upstream propagating ripples approach the foot of the rapids, the flow velocities are increasing due to reduced flow area and increased slope of the riverbed. A point is reached where flow becomes supercritical. Upstream beyond this point, still increasing flow velocities result in a supercritical flow zone which becomes an hydraulic barrier through which the effect of the downstream disturbance or change cannot be translated further upstream. The upstream ripples cannot move farther upstream.

The concept of subcritical flow verses supercritical flow explains how the water levels upstream of Early Morning Rapids are not affected either in the existing or the post-project water regime with Wuskwatim GS in place. Figure 4.2-7 (section 4.2.2.3), shows water level profiles between Early Morning Rapids and Wuskwatim Lake for different existing (Post-CRD) inflows with and without Wuskwatim GS in place. For both conditions, the flow velocities in the reach below Early Morning Rapids are low with little drop in water surface elevation. The flow conditions in this reach will therefore be subcritical. Any disturbance created by the fluctuating Wuskwatim forebay will travel upstream along this subcritical flow reach. Early Morning Rapids is a large set of rapids where flow velocities are very high, the bed slope is steep, and there is a large drop in elevation across the Rapids. This area will therefore be a supercritical flow zone. Any downstream disturbance will not be able to move upstream through the supercritical flow conditions at Early Morning Rapids.

The only way this disturbance can travel upstream through Early Morning Rapids is if the forebay is raised enough to physically drown out or overtop the rapids reach, such that the flow regime in the rapids reach is changed to subcritical flow. For this to occur, the forebay would have to stage to at least elevation 237m for average river flow conditions. The maximum operating Wuskwatim GS forebay is 234m.

The upstream boundary of the Hydraulic Zone of Influence has therefore been set at the foot of Early Morning Rapids.

Appendix A4.2

Churchill, Burntwood and Nelson Rivers Monitoring Program

Appendix A4.2 Churchill, Burntwood and Nelson Rivers monitoring Program

Manitoba Hydro established the Churchill, Burntwood and Nelson Rivers Monitoring Program just prior to the in-service of the Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR). The Program is managed by a Monitoring Committee whose members include representation from the Hydraulic Engineering, Mitigation, Hydropower Planning, Property, Environmental Licensing & Protection, and Geotechnical Departments of Manitoba Hydro. This program is updated annually to monitor water levels and discharges at almost 100 locations throughout the regulated system for the open water and winter season. More specifically, the program on the Burntwood River includes (see Figure 4A-2.1):

- Fifty staff gauging stations for developing open water/ice level profiles;
- River discharge measurements at 5 metering locations to measure main stem flows;
- Tributary measurements to measure local basin inflows;
- Continuous water levels at over 25 locations along the waterway recorded by automatic stage recorders and real time data collection platforms;
- A data base of about 200 cross-sections to describe river shapes for numerical modeling; and
- Reference photo & video library of various locations where visual supportive information is required to assess open water conditions, ice cover development and progression, and anchor ice formation;
- Specific ice monitoring measurements of ice dams and border ice;
- Ice and snow thickness monitoring.

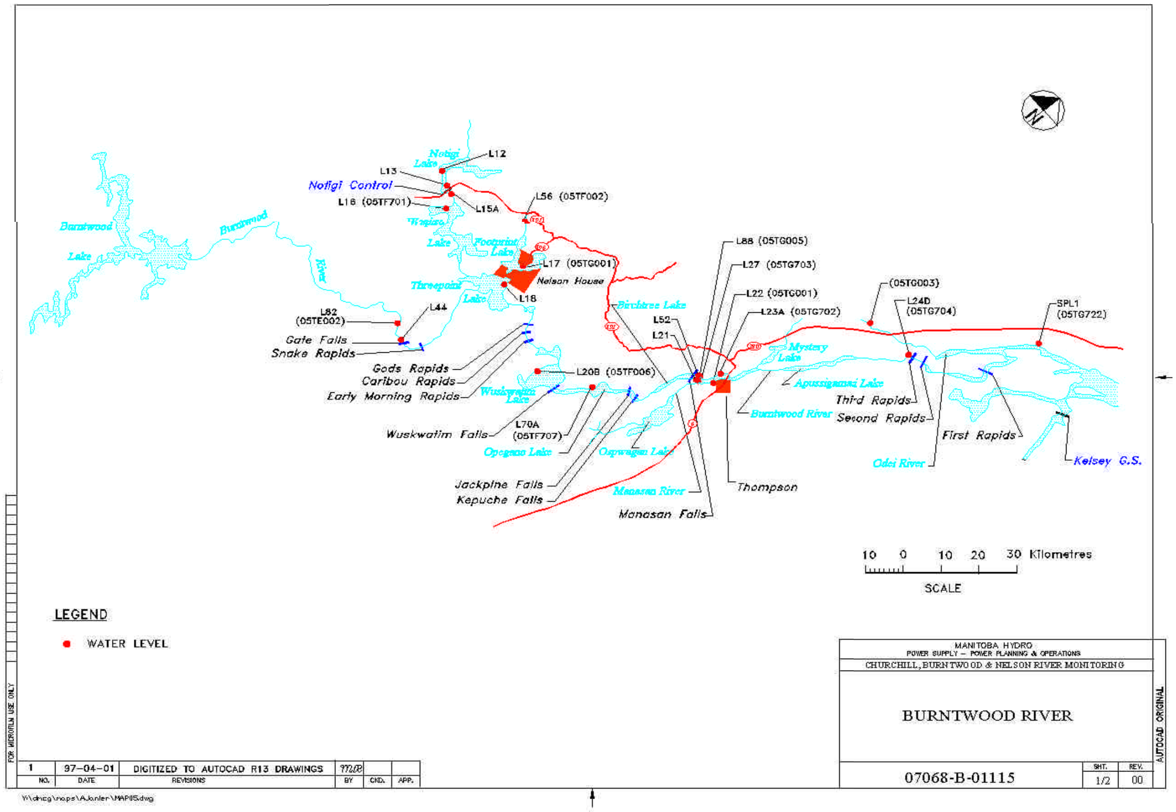


Figure A4.2-1 General Location Plan from the Monitoring Program.

Field data is collected in the Program for the purpose of:

- Operating the system with real time for the waterways regulated by Manitoba Hydro;
- Maintaining water levels & flows within license requirements set by government regulators;
- Providing water level forecasts for stakeholders affected by Manitoba Hydro's operation on these waterways;
- Documenting historical water/ice regimes for addressing environmental & mitigatory impacts of waterways regulated by Manitoba Hydro;
- Monitoring of implementation agreements on water regime with First Nations; and hydraulic analysis and assessment of the water regime in evaluating existing and new hydropower developments.

Data collected specific to the Wuskwatim and Burntwood River development studies has been used for the following:

- Update the open water hydraulics studies as described in the Stage IV Design Memo W 2.1.1 Rev 1 Updated Open Water River Hydraulics;

- Used in the development of hydraulic models as part of the Wuskwatim and Burntwood River development studies (including information collected specifically for the Environmental Impact Assessment); and
- Measured water levels and discharges were used to develop and update stage-discharge curves at specific locations in the study reach. As well, water level profiles along the river reaches were developed by measuring water levels at specified staff gauge locations with discharge measurements. River cross-sections that have been sounded throughout the study reach were used to map the channels of the river reaches.

Appendix A43: Storage –

Wuskwatim Lake & Immediate Forebay

Manitoba Hydro
Hydro Power Planning Department
Power Planning and Development Division

Wuskwatim Generating Station
Stage 4 Studies

Design Memorandum W-2.8
Revision 1 November 1, 2002

WUSKWATIM LAKE STAGE STORAGE RELATIONSHIP & FLOODED AREA

Manitoba Hydro File 00184-11400-0007_04

Prepared by MARC ST. LAURENT
Hydraulic Engineering & Operations

Reviewed by Bernard Ewthumulak
Hydraulic Engineering & Operations

Approved by Brian W. Korbaylo
Hydraulic Engineering & Operations

Noted by Per Stokke (Per Stokke) Nov 29/02
Hydropower Planning

Accepted by B.J. Osiowy (B.J. Osiowy) Jan. 22/2003
Hydropower Planning

Power Sales and Operation Division
Manitoba Hydro

MANITOBA HYDRO

INTEROFFICE MEMORANDUM

FROM B.W. Korbaylo
Hydraulic Engineering Section Head
Hydraulic Engineering & Operations

TO P. Stokke
Burntwood River Studies Engineer
Hydro Power Planning

DATE 2002 11 01

FILE 00184-11400-0007_04

SUBJECT **WUSKWATIM GENERATING STATION - STAGE 4 STUDIES**
WUSKWATIM LAKE STAGE STORAGE RELATIONSHIP & FLOODED AREA
DESIGN MEMO 2.8 REVISION 1

Attached is Revision 1 incorporating the latest revisions. All revision changes are shown in italics and deletions struck out, on separate pages for ease of reference.

B.W. Korbaylo

BES/ljm/021024-1.wpd
Att.

cc: Acres (Attn: J.L. Groeneveld)
B.J. Osiowy (Attn: G.N. Cook)

MANITOBA HYDRO
INTEROFFICE MEMORANDUM

FROM B.E. Shumilak
Hydraulic Eng. Section
Hydraulic Eng. & Ops.

TO B.W. Korbaylo
Hydraulic Eng. Section Head
Hydraulic Eng. & Ops.

DATE 2002 11 01

FILE 00184-11400_0007_04

SUBJECT **WUSKWATIM GENERATING STATION – STAGE 4 STUDIES**
WUSKWATIM LAKE STAGE STORAGE RELATIONSHIP & FLOODED AREA
DESIGN MEMO 2.8 REVISION 1

Summary

A Stage-Storage curve for Wuskwatim Lake and the immediate forebay are attached and quantify the storage above 229.82m and 228.30m respectively. A regression curve was produced using water surface areas at four different elevations under post development conditions.

The net flooded area that results from the development of the Wuskwatim GS to elevation 234.0m is 37 ha.

Stage Storage Curve - Wuskwatim Lake Reservoir

A stage-storage curve was fit to storage volumes calculated between four different elevations in the Wuskwatim Lake reservoir based on the boundary conditions shown in Figure 1. Those elevations are: 229.8m, 233.8m, 234.0m and 235.0m.

The water surface area at elevation 229.8m was extracted from a 1974 Environment Canada report [1].

Air photos with a scale of 1:20,000 were collected on September 30, 1985 at which time the existing Wuskwatim Lake level was 233.8 m. The air photos were used to develop 1:12,000 topographic mapping with a 1 meter contour interval which was used to determine areas for 233.8 m, 234.0 m and 235.0 m lake levels. The mapping grid uses a horizontal datum of NAD 1927, and a Projection of UTM Zone 14. Elevations are based

[1] "The Morphology of Rat-Burntwood Diversion Route and Lower Churchill River Lakes: Present Conditions and Post Regulation Conditions" by S.B.Brown, Fisheries and Marine Services, Environment Canada, July 1974, Appendix D in Vol.2, Technical Appendix 5, Fisheries and Limnology, Lake Winnipeg, Churchill and Nelson Rivers Study Board Report.

on CGVD 1928 (Geodetic Survey of Canada Datum - Quadrangle Sheet No. 55098, Revision No. 3 March 1971, also referred to by Manitoba Hydro as Geodetic Survey of Canada Datum 1969 Local Adjustment).

This area analysis was completed by the Surveys and Mapping Department using drawing 0184-11400-0019. Within the affected reach, polygons were defined for existing water bodies as well as islands within the water bodies. Live storage was computed for 233.8 m, 234.0 m, and 235.0 m. The spreadsheet file containing all data and resulting areas is located in R:/hydplan/storcurv/Burntriv/Wuskwatim/Wuskstor_2000r05.xls.

A regression analysis was completed to determine the new stage-storage curve. The water surface areas and storage values are listed in Table 1. The resulting equation for the stage-storage curve is:

$$\textbf{Storage} = [36.902*(\textbf{Elevation}-229.82)^{1.4}]*10^{6}$$

where:
Elevation = Wuskwatim Lake elevation [m].
Storage = Wuskwatim Lake storage above elevation 229.82m [m^3].

Table 1 - Wuskwatim Lake reservoir storage parameters.

Elevation (m)	Area (million m^2)	Incremental Storage (million m^3)	Storage (million m^3)	Source of Area Calculation
229.82	46.00	0.00	0.000	Environment Canada
233.80	83.56	257.83	257.835	Manitoba Hydro Surveys & Mapping Dept.
234.00	87.52	17.11	274.943	Manitoba Hydro Surveys & Mapping Dept.
235.00	96.08	91.80	366.743	Manitoba Hydro Surveys & Mapping Dept.

Figure 2 shows the stage-storage curve developed for Wuskwatim Lake.

Comparison of Stage-Storage Curve to Acres Stage-Storage Curve

The stage-storage curve for Wuskwatim Lake presented herein supercedes a Wuskwatim Lake stage-storage curve developed by Acres for a prior study. The following text documents a brief comparison of the two curves. The basis of the stage-storage curve developed by Acres was water surface areas calculated using the following data sets:

1) Pre-CRD photography at a lake elevation of 230.72m; and
2) 239.87m & 249.92m contours from 1:50,000 scale NTS mapping.

A regression curve was derived for the three points at 230.72m, 239.87m, and 249.92m, which resulted in a storage curve in the form of a fourth degree polynomial.

The storage data in Table 1 confirms previous surface areas and storage volumes calculated by Acres for the Wuskwatim Lake reservoir. Based on previous estimates stated in the Wuskwatim Hydraulic Design Criteria[2] the total reservoir was estimated by Acres to have a total surface area of 87 km^2 at 234.0 m (FSL) and a live storage of $87x10^6m^3$ between elevations 233 m and 234 m. The new analysis results in a total surface area of 87.52 km^2 at FSL and an incremental live storage of $86.94x10^6m^3$ between 233 m and 234 m. There is a +0.6 % difference in surface area and –0.1% difference in live storage. Figure 3 illustrates the stage-storage curve for Wuskwatim Lake and the Acres stage-storage curve.

Stage Storage Curve - Immediate Forebay

The immediate forebay is considered to be that area between Wuskwatim Falls and the Wuskwatim Generating Station axis as shown in Figure 4. The water surface area, incremental storage, and total storage at various elevations for the immediate forebay are shown in Table 2.

The water surface areas were calculated using 1:10,000 scale air photos collected on June 16, 1986. The air photos were used to develop 1:2,000 topographic mapping with a 1 meter contour interval which was used to determine water surface areas for the various elevations listed in Table 2. The mapping grid uses a horizontal datum of NAD 1927, and a Projection of UTM zone 14. Elevations are based on the Geodetic Survey of Canada Datum 1969 Local Adjustment.

The areas were determined using the latest structure arrangement including a disposal area. As shown in Table 2, the live storage between 233.0 m and 234.0 m was determined to be $0.8619x10^6m^3$. The resulting equation for the stage storage curve in the immediate forebay is:

$$\textbf{Storage} = [0.52076*(\textbf{Elevation}-228.3)^{1.2011}]*10^6$$

where:
Elevation = Wuskwatim G.S. immediate forebay elevation [m].
Storage = Wuskwatim G.S. immediate forebay storage above elevation 228.3m [m^3].

Figure 5 shows the storage curve for the immediate forebay.

[2] Wuskwatim Generating Station Stage 4 Studies Hydraulic Design Criteria memorandum W-3.3.3 Rev.C. Manitoba Hydro File 00184-06330

Table 2 - Wuskwatim G.S. Immediate Forebay Storage Parameters.

Elevation (m)	Area (million m2)	Incremental Storage (million m3)	Storage (million m3)	Source of Area Calculation
228.3	0.5921	0.0000	0.0000	Acres Ltd.
233.0	0.8296	3.3409	3.3409	Acres Ltd.
234.0	0.8942	0.8619	4.2029	Acres Ltd.
235.0	0.9315	0.9129	5.1157	Acres Ltd.

Flooded Area

The net flooded area that results from the development of the Wuskwatim GS to elevation 234.0m is 37 ha. This estimate was calculated by determining the difference between the area contained by the 234.0m contour in the immediate forebay area and the area contained by the existing shoreline shown on the 1:2,000 scale topographic base mapping. The shoreline on the base mapping is assumed to be near average conditions as the Wuskwatim Lake elevation was near average. The flooded area and the calculations are shown on drawing 00184-11400-0019, Figure 4.

Recommendations

The attached stage-storage curve for the Wuskwatim Reservoir correlates very well with past estimates. It is recommended that the attached storage-curve for the Wuskwatim Lake and Immediate Forebay be used for the current Wuskwatim Stage 4 Studies since the data points are determined using current reservoir mapping.

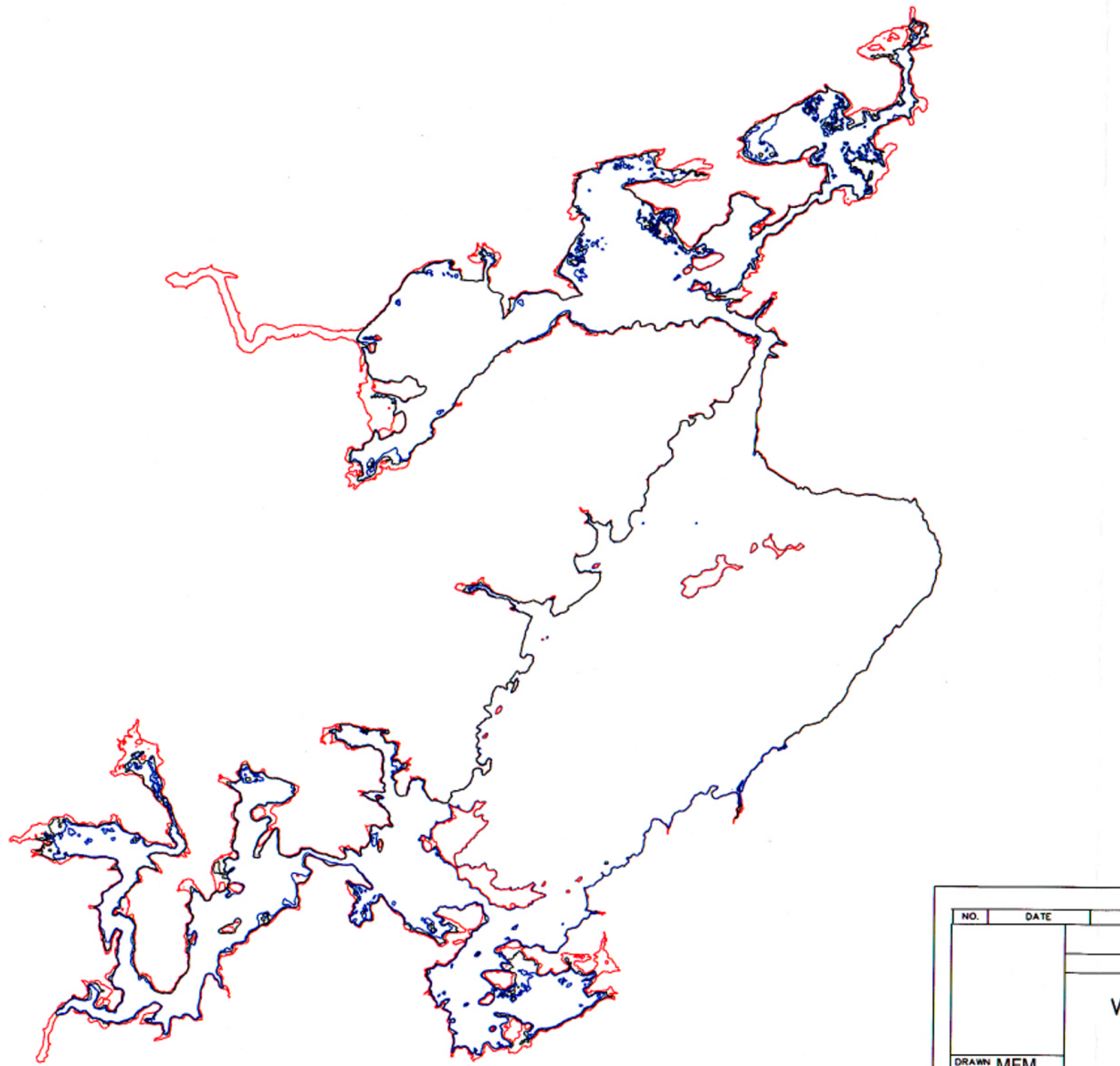
Original signed by:

B.E. Shumilak

MES/sjn/021024-1.doc

Att.

cc: Acres (Attn: J.L. Groeneveld)
B.J. Osiowy (Attn: G.N. Cook)



NOTE: BOUNDARY CONDITIONS ESTABLISHED BY SURVEYS AND MAPPING DEPT., MANITOBA HYDRO

NO.	DATE	REVISIONS	BY	CKD.	APP.

MANITOBA HYDRO
POWER SUPPLY – POWER SALES & OPERATIONS
BURNTWOOD RIVER

WUSKWATIM LAKE RESERVOIR
STAGE STORAGE CURVE
BOUNDARY CONDITIONS

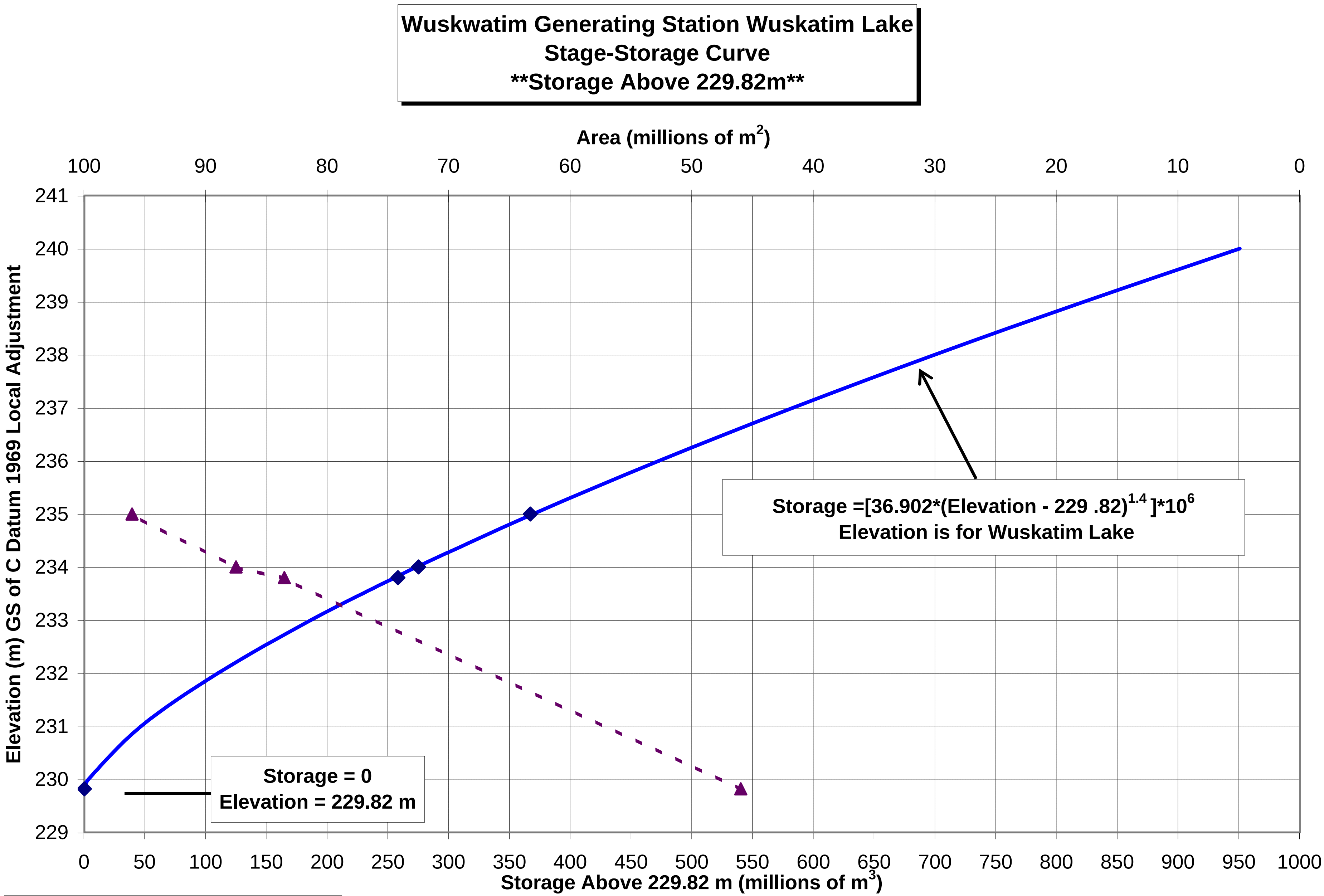
DRAWN MFM
CHECK MES
SCALE
DATE 10/02/2002

00184–11400–0019 SHT. 01 REV. 00

AUTOCAD ORIGINAL

FOR MICROFILM USE ONLY

FIGURE 1

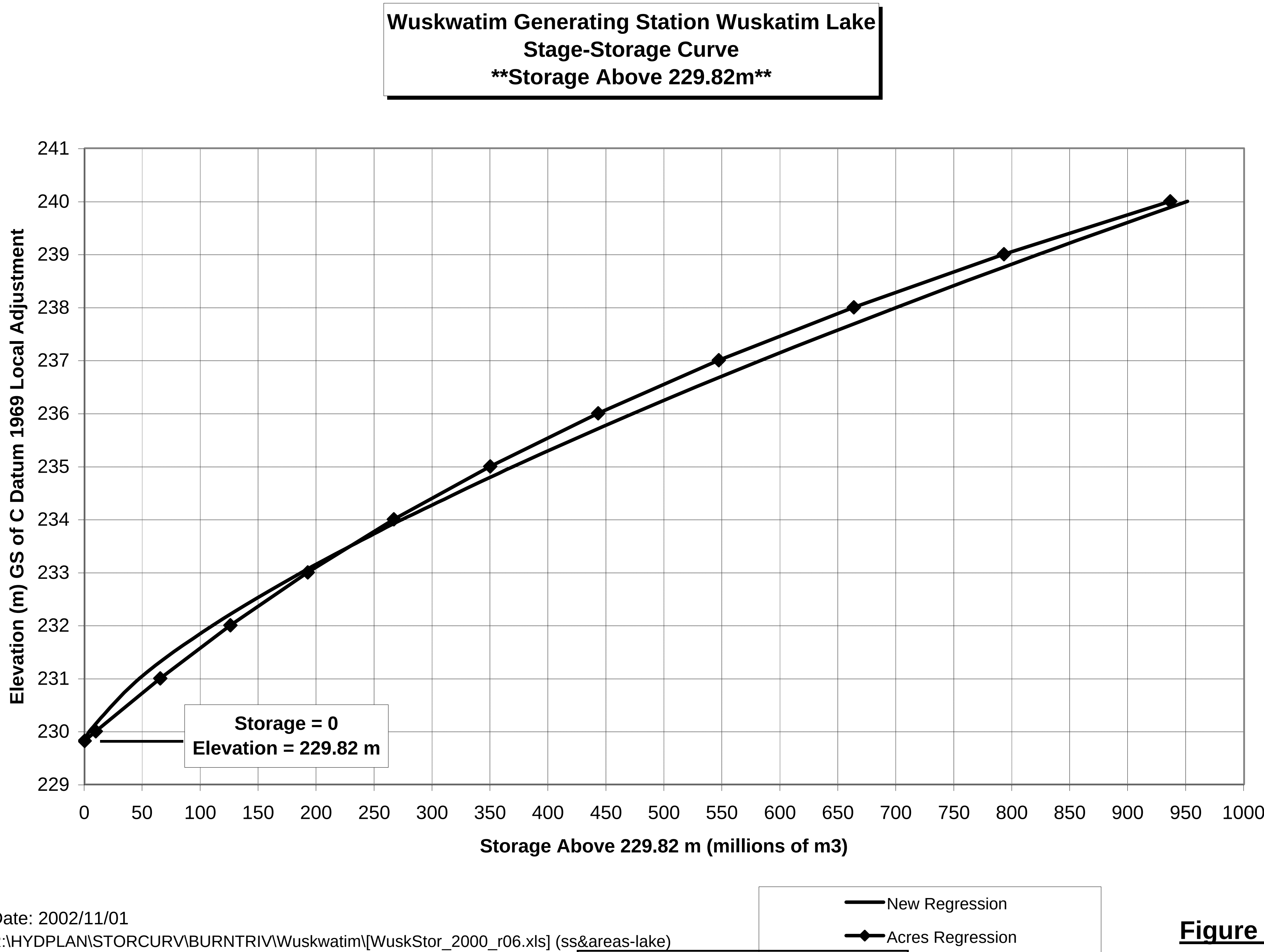


Updated Data Points (2000)
Regression-Updated Data
Updated Areas

The Updated Data Points are from file R:\Hydplan\Storcurv\Burntriv\Wuskwatim\WuskStor_2000_r05.xls; based on 1:20,000 Air Photos, collected Sept.30, 1985, NAD 1927, UTM zone 14 (October 4, 2000 Surveys & Mapping Dept., Manitoba Hydro); areas extracted from 1:12,000 scale topographic mapping.

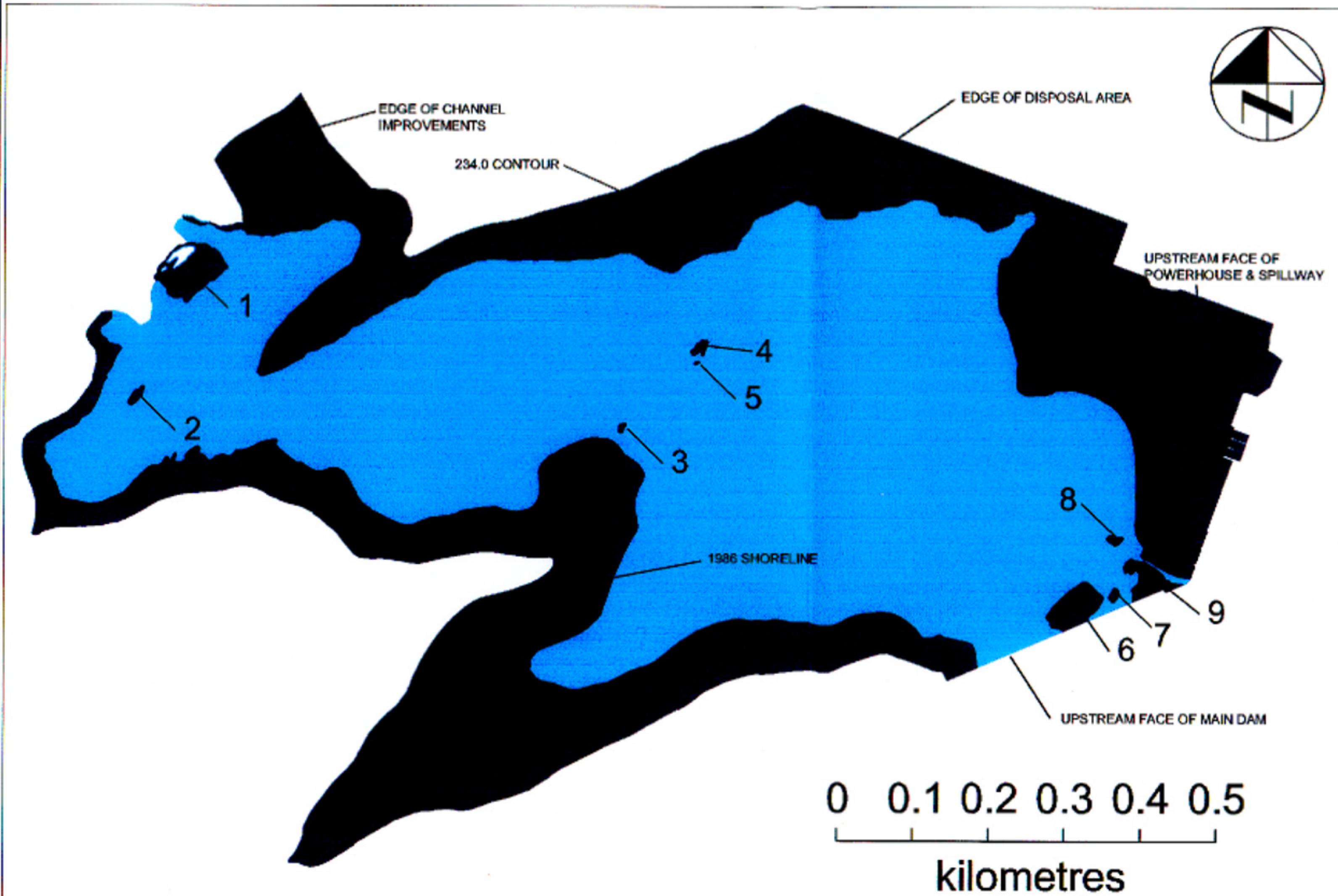
Figure 2

2002/11/01 R:\HYDPLAN\STORCURV\BURNTRIV\Wuskwatim\[WuskStor_2000_r06.xls] (ss&areas-lake)



Date: 2002/11/01
R:\HYDPLAN\STORCURV\BURNTRIV\Wuskwatim\[WuskStor_2000_r06.xls] (ss&areas-lake)

Figure 3



ITEM	DESCRIPTION	AREA km^2	Maximum Elevation on Island
1	Area Contained by 234 Contour and Structures	0.894747	
2	Area contained by 1986 Shoreline Excluding Islands Near Average Conditions	0.533610	
	Area of Islands Flooded (+) and Dry (-)		
	1	0.004040	less than 234
	1	(0.000510)	235.00
	2	0.000252	Near '86 WL
	3	0.000082	Near '86 WL
	4	0.000275	Near '86 WL
	5	0.000022	Near '86 WL
	6	0.002712	230.00
	7	0.000168	227.00
	8	0.000183	Near '86 WL
	9	0.001634	227.00
3	Net Flooded Island Total	0.008858	
	FLOODED AREA = 1 - 2 + 3	0.369995	

NOTE:
ALL ISLANDS ARE ASSUMED TO BE FLOODED, EXCEPT FOR PORTIONS OF ISLAND No. 1.

SOURCE:
1:2 000 TOPOGRAPHIC MAPPING
1:2 000 LAYOUT PLAN

NO.	DATE	REVISIONS	BY	CKD.	APP.
2	OCT 17, 2002	UPDATED WITH OCT. 10, 2002 FLOODED AREA	DGM	GNC	
1	SEPT 3, 2002	ADDED MAXIMUM CONTOUR ELEVATION COLUMN TO TABLE	DGM	GNC	

MANITOBA HYDRO
POWER SUPPLY – POWER PLANNING & DEVELOPMENT
WUSKWATIM GENERATING STATION

FLOODED AREA FOR ELEVATION OF 234.0m BETWEEN WUSKWATIM FALLS AND TASKINIGUP FALLS

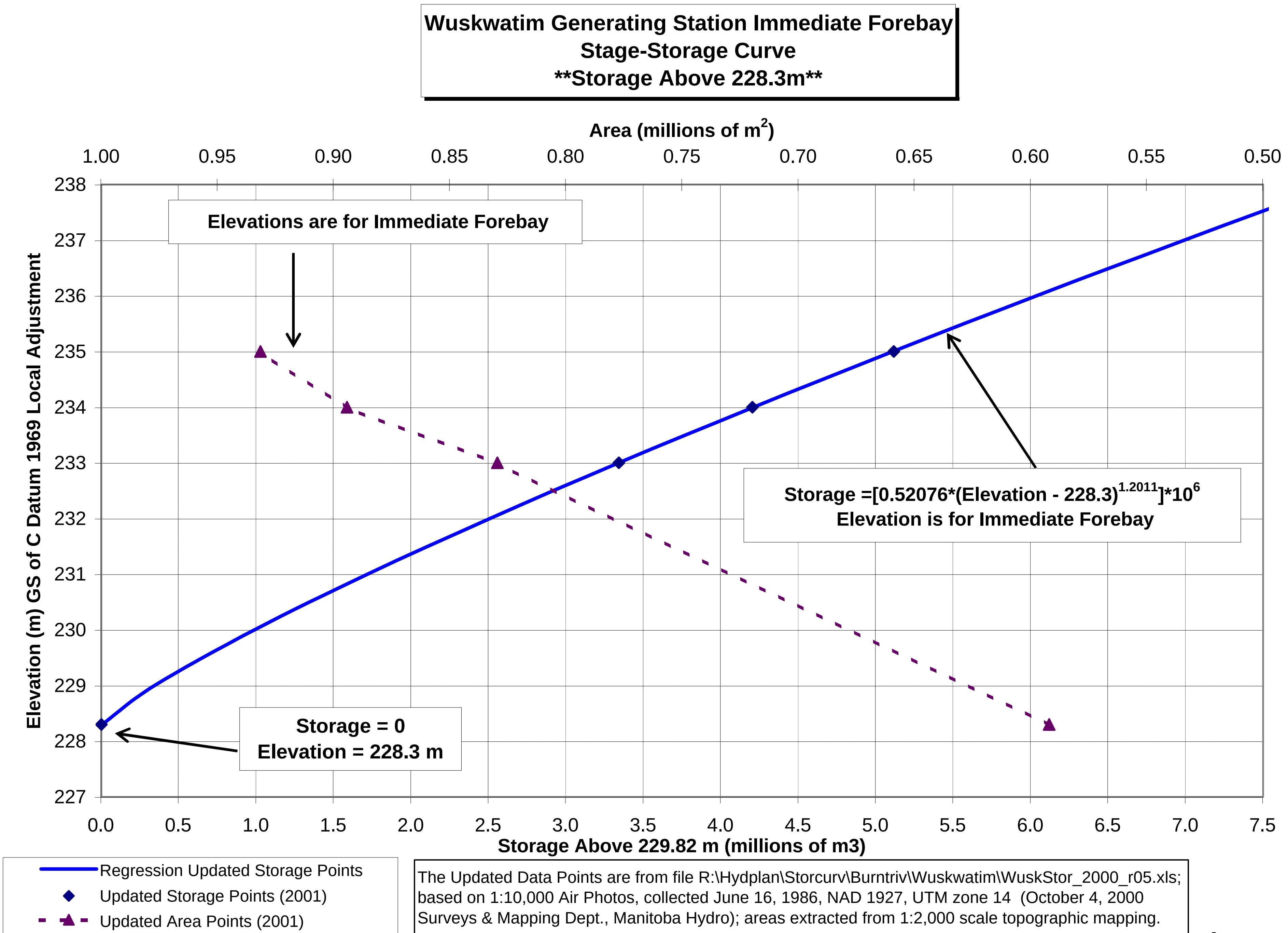
DRAWN DGM
CHECK GNC
SCALE AS SHOWN
DATE 02 05 31

00184-10432-0006 SHT. 01 REV. 02

AUTOCAD ORIGINAL

FOR MICROFILM USE ONLY

Figure 4



The Updated Data Points are from file R:\Hydplan\Storcurv\Burntriv\Wuskwatim\WuskStor_2000_r05.xls; based on 1:10,000 Air Photos, collected June 16, 1986, NAD 1927, UTM zone 14 (October 4, 2000 Surveys & Mapping Dept., Manitoba Hydro); areas extracted from 1:2,000 scale topographic mapping.

Figure 5

Date: 2002/11/01 R:\HYDPLAN\STORCURV\BURNTRIV\Wuskwatim\[WuskStor_2000_r06.xls] (ss&areas-forebay)

Appendix A4.4

Existing (Post-CRD) Flow and Water Levels

Water Levels for Project Inflow Conditions without the Project

Appendix A4.4 Existing (Post-CRD) Flow and Water Levels Water Levels for Project Inflow Conditions without the Project

A4.4 - 1.0 INTRODUCTION

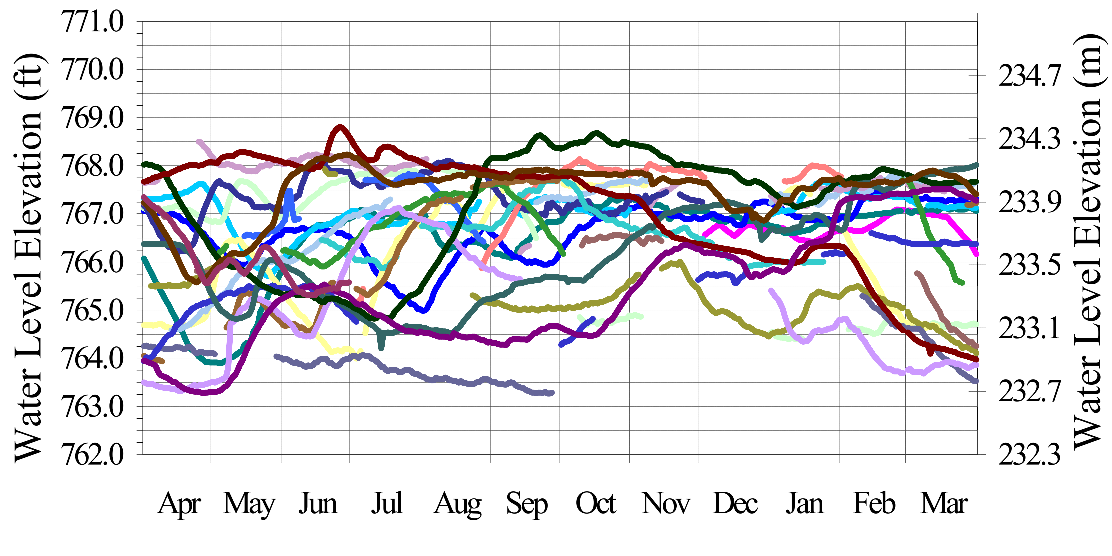
The existing (post-CRD) water regime may be described in terms of inflow and water levels conditions for the study reach (Early Morning Rapids to First Rapids) over the period of CRD operation (1977-2001). On the basis of an existing inflow data, water level hydrographs and duration curves at key study site locations in the hydraulic zone of influence were developed to describe the existing regime at these locations. Down-stream of the hydraulic zone of influence Thompson Pumphouse flow and water level data was used to develop water level hydrographs and duration curves for other sites located at Apussigamasi Lake and First Rapids.

In assessing water level conditions for the project inflow conditions without the Project, the project inflow record for the period 1912-1997 was used together with stage-discharge curves to develop water level duration curves at key sites in the hydraulic zone of influence.

A4.4 - 2.0 EXISTING FLOWS AND WATER LEVEL

A4.4 - 2.1 Existing inflow (1977-2001)

Since 1977, water levels on Wuskwatim Lake have been recorded on a daily basis as illustrated in Figure A4.4-1. In developing the existing inflow data for the Project, these observed water levels were applied to stage-discharge relationships (Figure A4.4-2) which were developed from measured water levels and flow meterings collected as part of the hydrometric monitoring program described under Appendix A4.2. Under open water conditions, the daily water level can be applied directly to the open water rating curve to obtain a daily flow value. Under winter conditions, a staging factor relationship is used to provide a transition in staging from the end of the open water season to the end of winter (Figure A4.4-3).



NOTE:

1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure A4.4-1 Wuskwatim Lake stage hydrograph

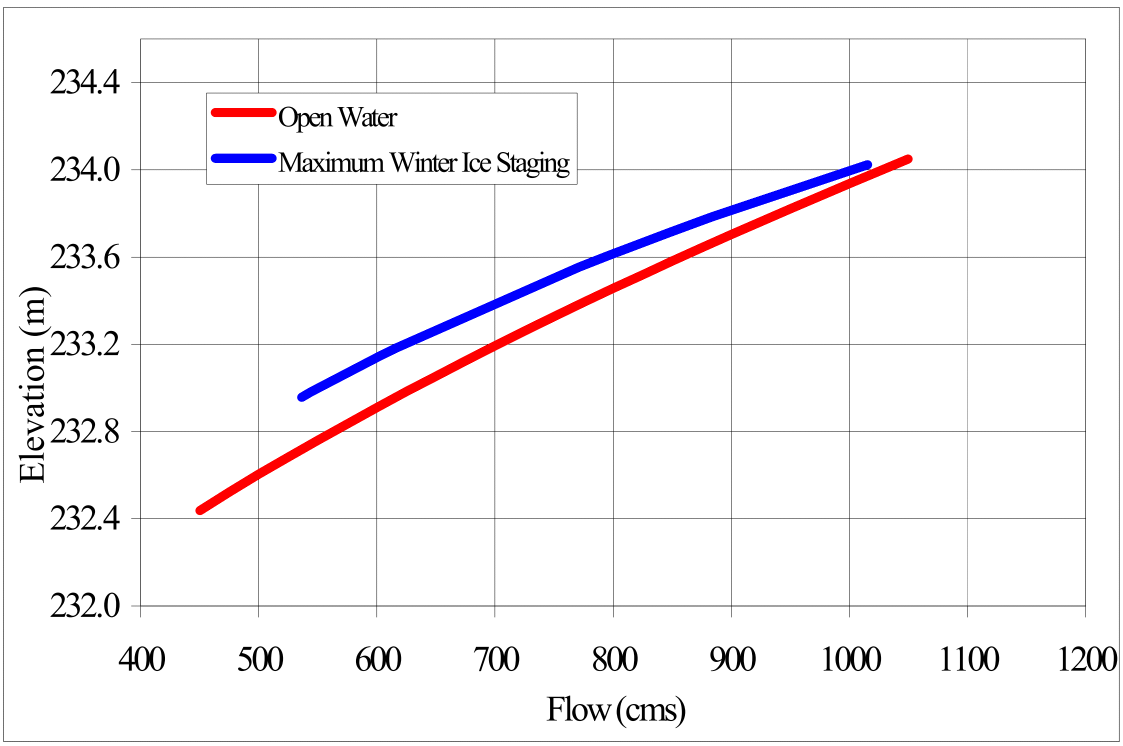


Figure A4.4-2 Wuskwatim Lake maximum winter and open water stage-discharge curves.

This factor was developed from field measurements and winter ice modelling of the Burntwood River as described in Appendix A4.6.

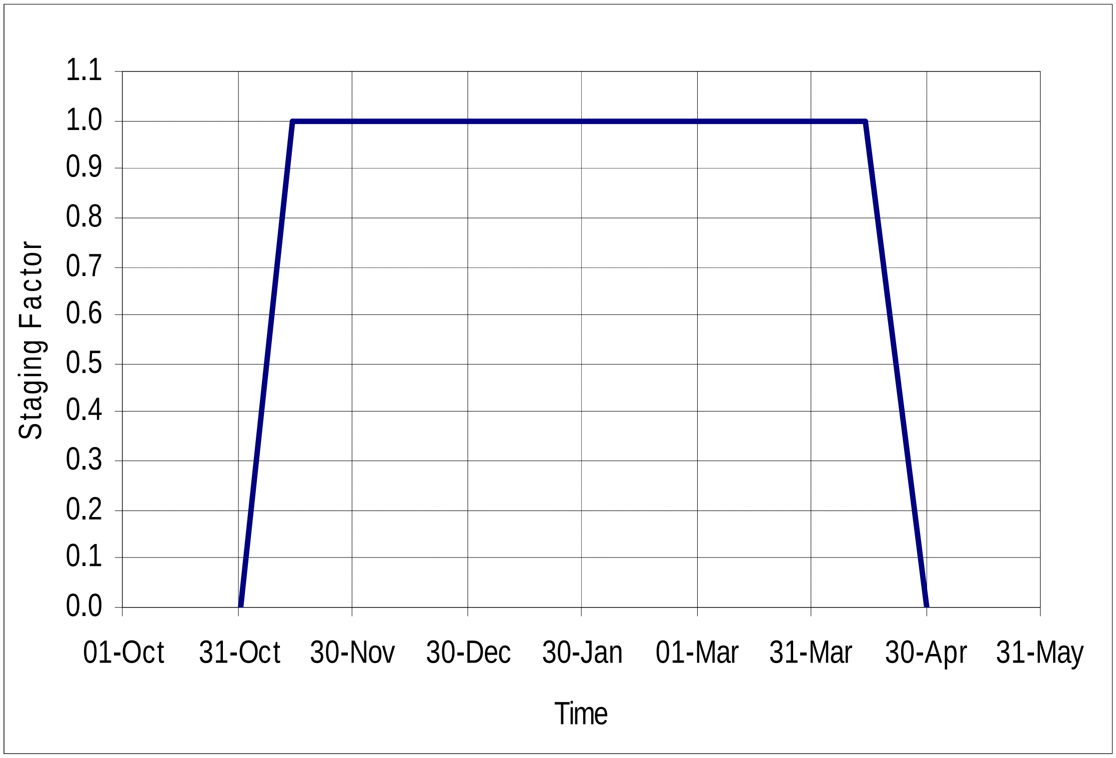


Figure A4.4-3 Wuskwatim Lake staging factor curve

Typically one would apply this staging factor as follows:

- For a given flow and date between November 01 - April 30, the difference in water level from the open water to the maximum winter staging rating curve would be adjusted by the percentile staging factor for the given date. This adjusted water level difference would then be added to the open water elevation to obtain the winter water level for that date.

Results from this approach are illustrated in the form of Wuskwatim Lake flow hydrographs for the period 1977 to 2001 (Section 4.2.1, Figure 4.2-1).

A4.4 - 2.1.1 EXISTING WATER LEVELS IN THE HYDRAULIC ZONE OF INFLUENCE

In describing the existing water regime at key locations (Early Morning Rapids, Wuskwatim GS Tailrace, Opegano Lake and Birch Tree Lake), water levels were developed in an approach similar to the one taken at Wuskwatim Lake. At these locations, stage-discharge relationships and staging factors were applied to the existing inflow record to obtain daily water levels from 1977 to 2001. The inflow record at Wuskwatim Lake was adjusted to account for local runoff at each key site. Since the local inflow files are in the range of less than 1% of the Wuskwatim Lake inflows, the flow hydrographs at each key location are essentially the same as the Wuskwatim lake inflows (Section 4.2.1, Figure 4.2-1). Stage hydrographs for these locations are shown in Section 4.2.2.1, Figures 4.2-3, and Section 4.2.3.2, Figure 4.2-14, to and 4.2-16.

Seasonal duration curves were developed from the above developed stage hydrographs at each of the above key locations (Figures A4.4-4 to A4.4-8).

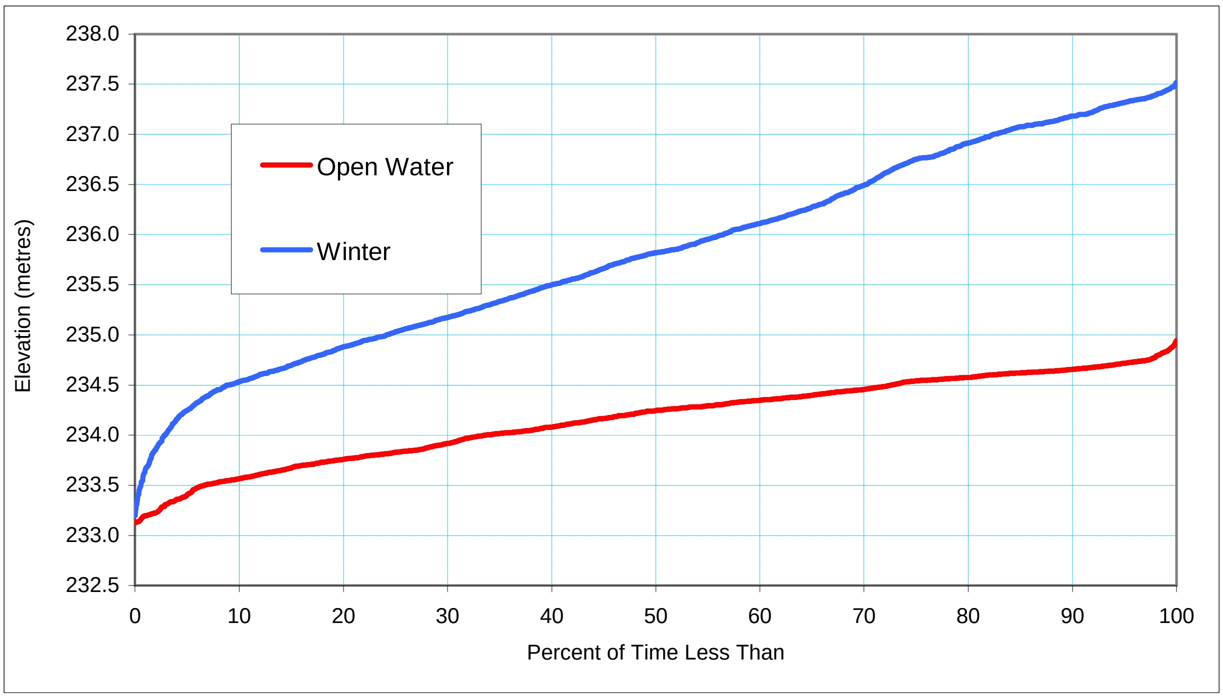


Figure A4.4-4 Early Morning Rapids stage duration curve – Existing Condition

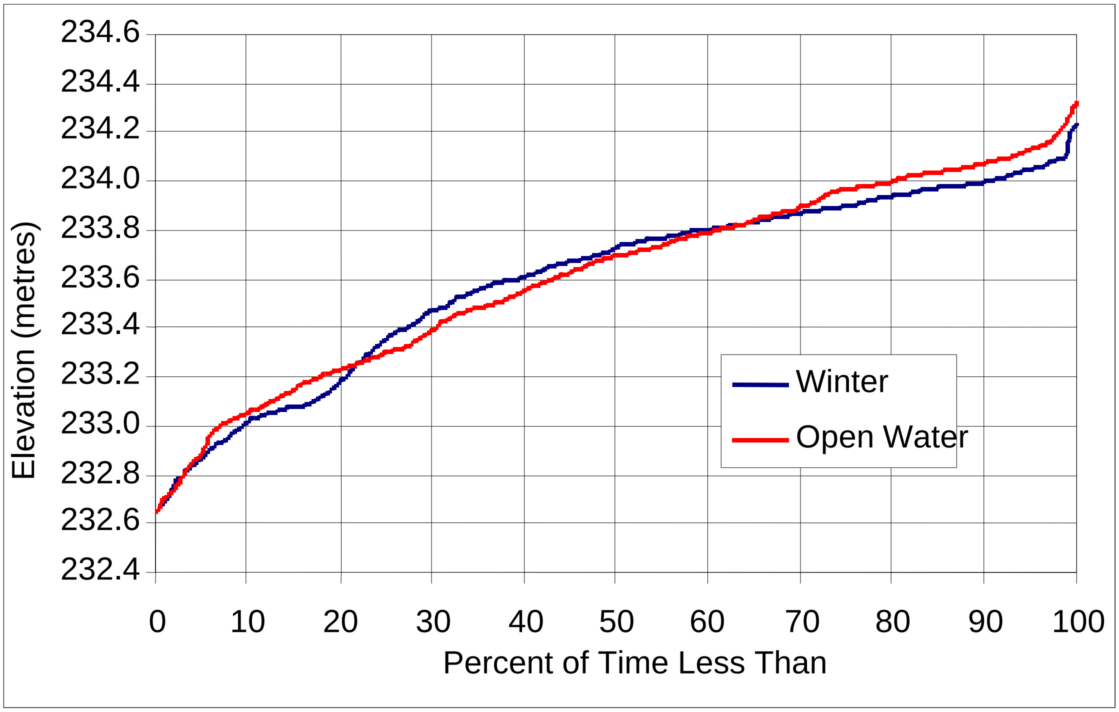


Figure A4.4-5 Wuskwatim Lake stage duration curve – Existing Condition

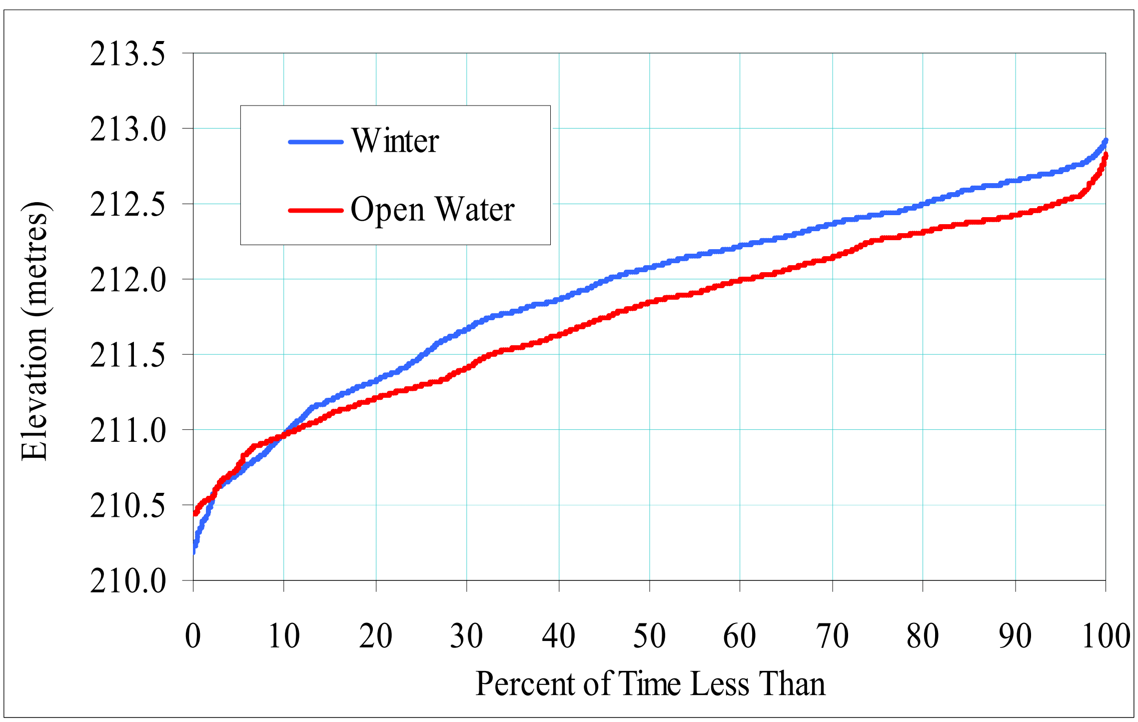


Figure A4.4-6 Foot of Taskinigup Falls (Wuskwatim GS Tailrace) - Existing Conditions

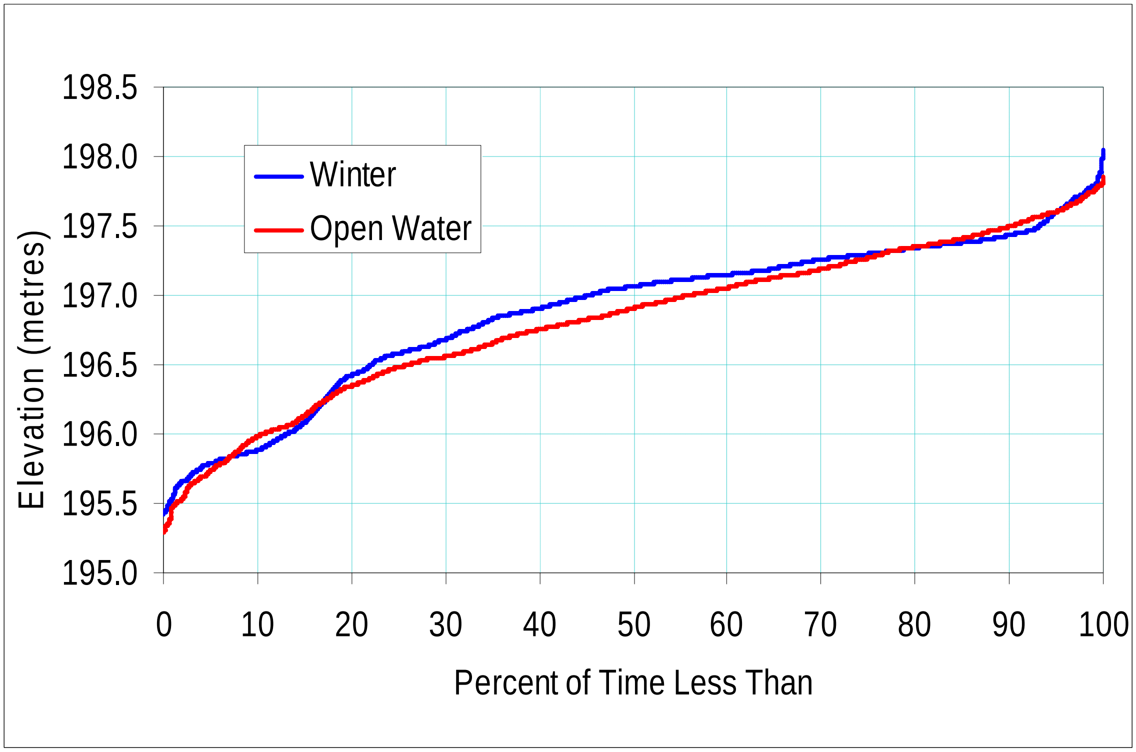


Figure A4.4-7 Opegano Lake stage duration curve - Existing Condition

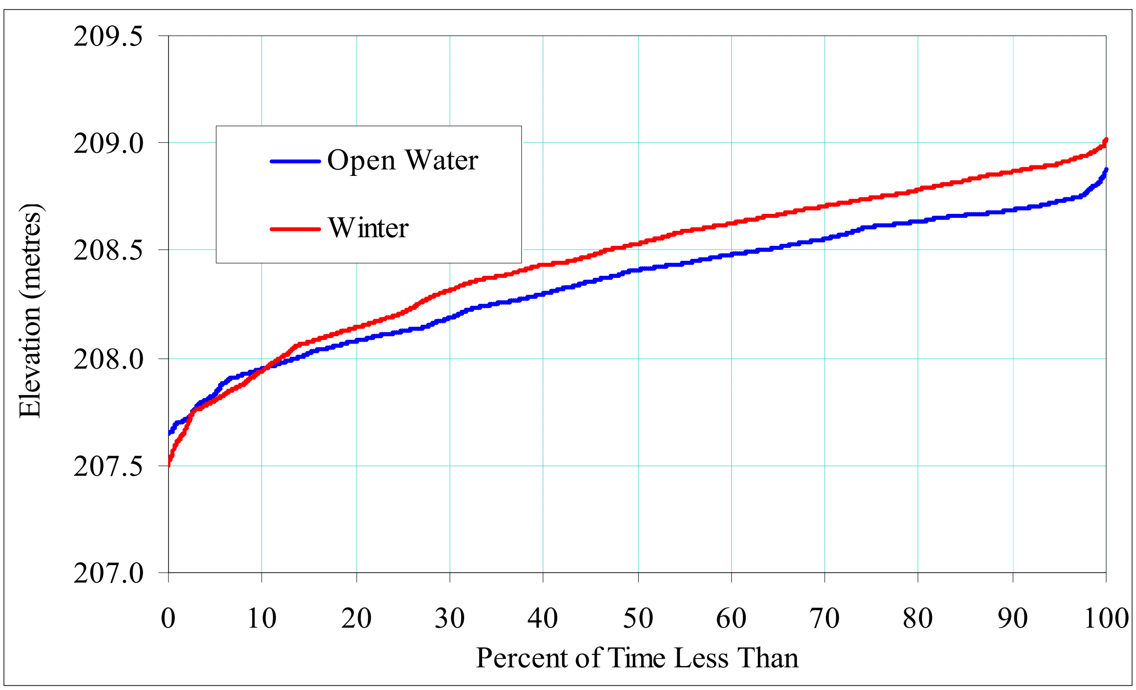
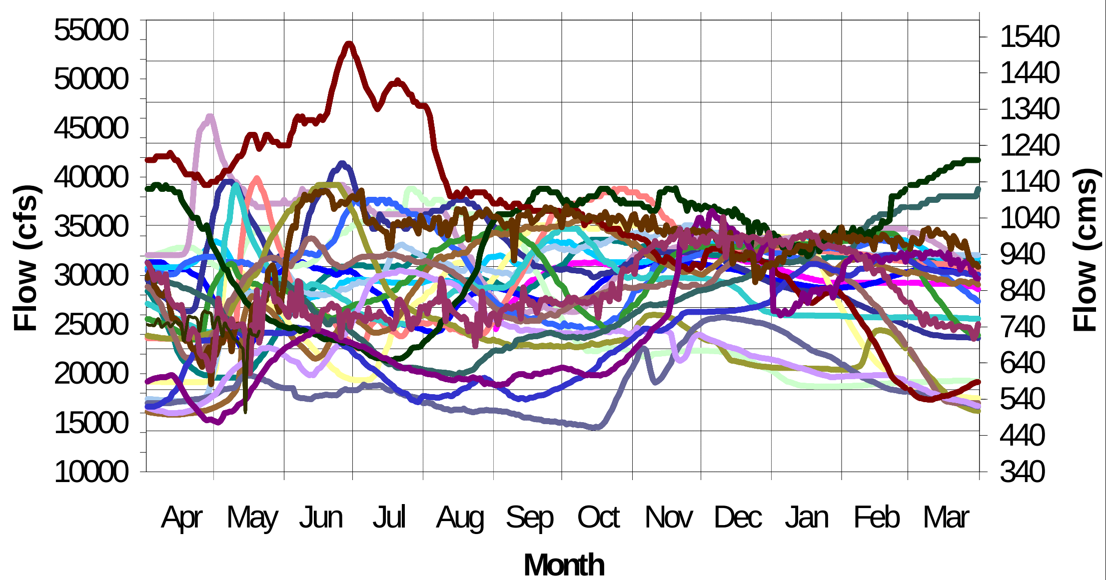


Figure A4.4-8 Birch Tree Lake stage duration curve - Existing Condition

A4.4 - 2.2 EXISTING WATER LEVELS DOWNSTREAM OF THE HYDRAULIC ZONE OF INFLUENCE

In characterizing the existing water regime at Apussigamasi Lake and First Rapids, water level hydrographs and duration curves were derived from water levels (Section 4.2.3.2 Figure 4.2-17) and flows (Figure A4.4-9) observed at the Thompson Pumphouse (Water Survey of Canada Gauge 05TG001, September 1977 to December 1999). The missing data between 1977 to 1999 and for 2000 and 2001were supplemented from Manitoba Hydro's Hydrometric data base. Both sets of flow data, Water Survey Canada and Manitoba Hydro's data were derived based on the same water level gauge located at Thompson Pumphouse.



NOTE:
1. Source : Existing Physical Environment Water Regime Package Memorandum W-7.2.2 Rev. A
2. Water levels are referred to as Canadian Geodetic Vertical Datum (CGVD) (1971 Rev. 3) above sea level. (Also referred to as the 1969 local adjustment)

Figure A4.4-9 Thompson Pumphouse flow hydrograph

As discussed in previous sections of this appendix, a similar approach was used in applying rating curves and staging factors to the Thompson Pumphouse flow record in developing stage hydrographs and duration curves at these locations. Stage hydrographs for Thompson Pumphouse, Apussigamasi Lake and First Rapids are described and shown in Section 4.2.3.2 and Figures 4.2-17 to 4.2-19.

Seasonal duration curves for existing (post CRD) conditions at these locations are shown in Figure A4.4-10 to Figure A4.4-12.

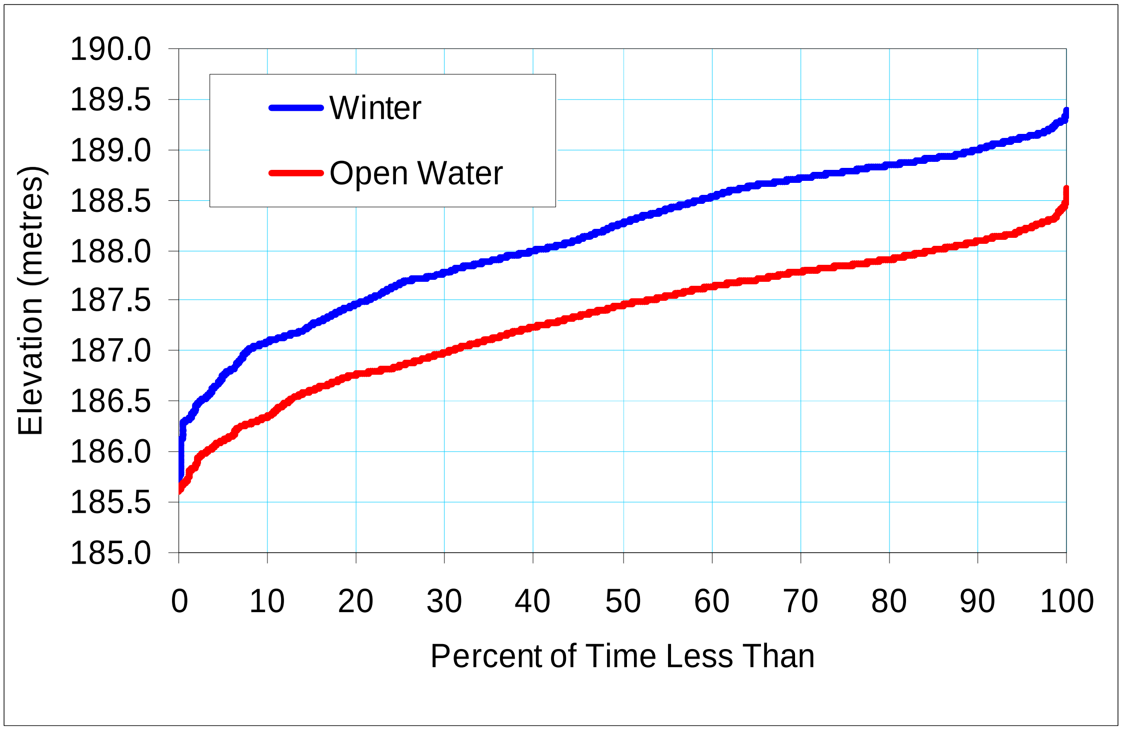


Figure A4.4-10 Thompson Pumphouse stage duration curve

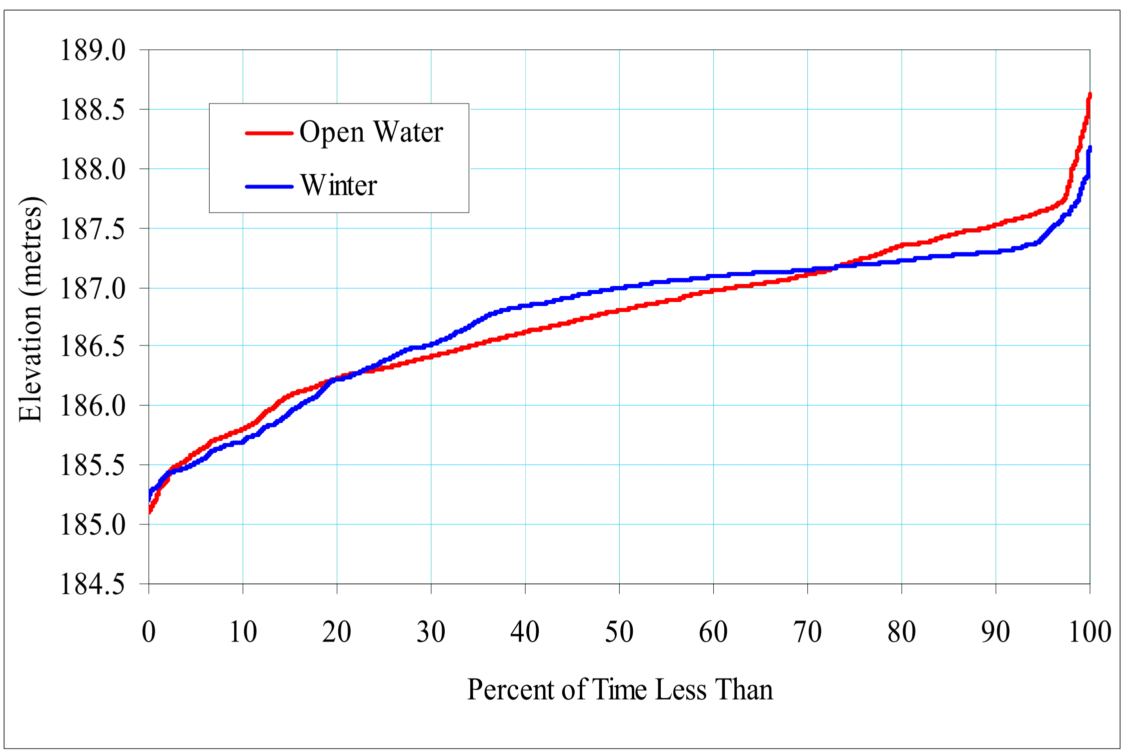


Figure A4.4-11 Apussigamasi Lake stage duration curve

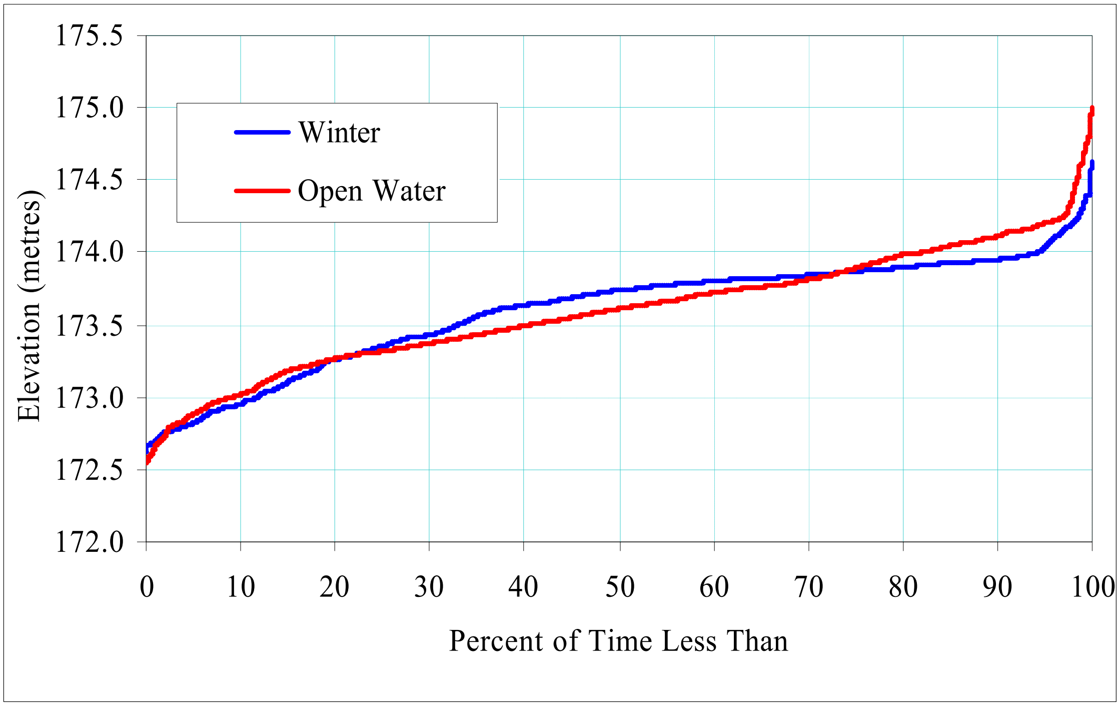


Figure A4.4-12 First Rapids stage duration curve

A4.4 - 3.0 WATER LEVELS FOR PROJECT INFLOW PERIOD WITHOUT THE PROJECT

Water level data files for the project inflow record without the Project were developed at key sites, namely Wuskwatim Lake, Wuskwatim GS tailrace, Opegano Lake and Birch Tree Lake.

Similar to the approach taken in the previous two sections, the project inflow record was adjusted to account for local basin runoff between the Project and each key site. Stage discharge curves and staging factors were applied in this case to the project inflow record to obtain water levels at key sites in the hydraulic zone of influence. Water level data files for each location were then converted into duration curves for open water and winter conditions. A comparison of seasonal stage duration curves for Wuskwatim Lake between existing and project inflows without the Project is shown in Figure A4.4-13 and Figure A4.4-14 below.

The seasonal stage duration curves at the downstream key study locations (Wuskwatim GS tailrace, Opegano Lake and Birch Tree lake) are described in Section 4.3.4.1, Figures 4.3-13 to 4.3-18.

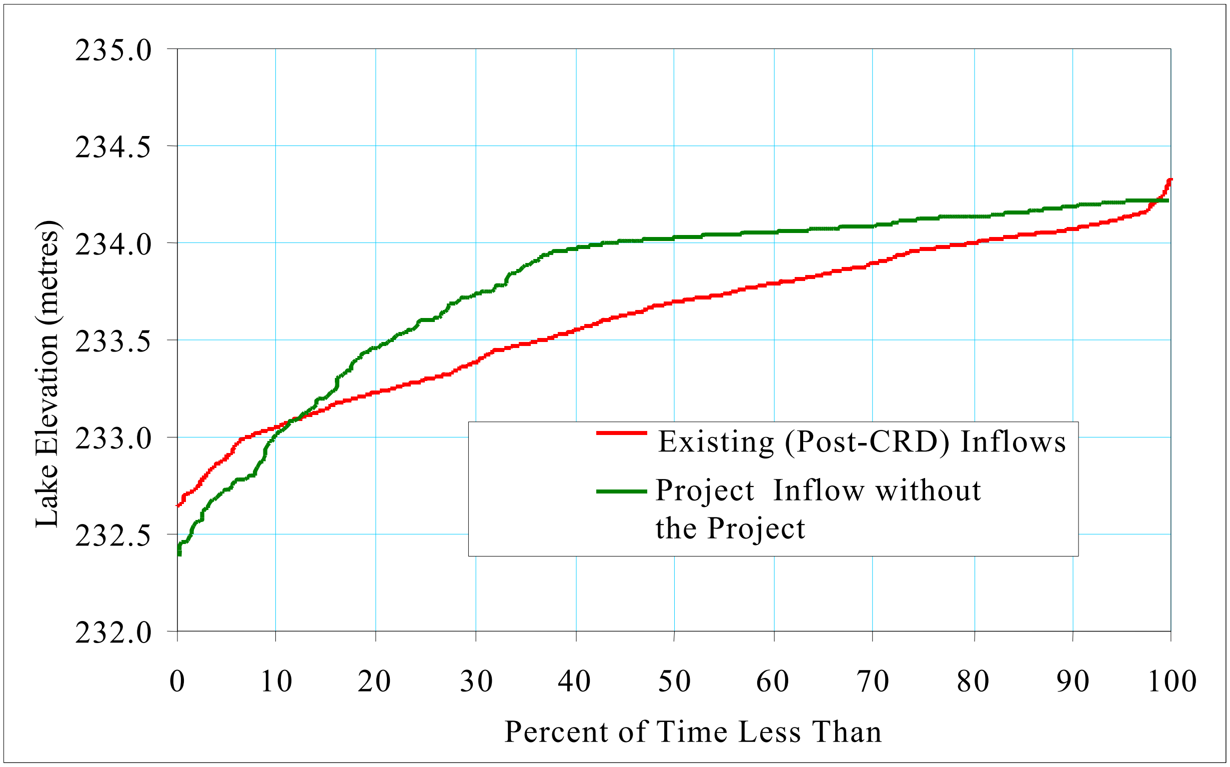


Figure A4.4-13 Wuskwatim Lake open stage duration curve

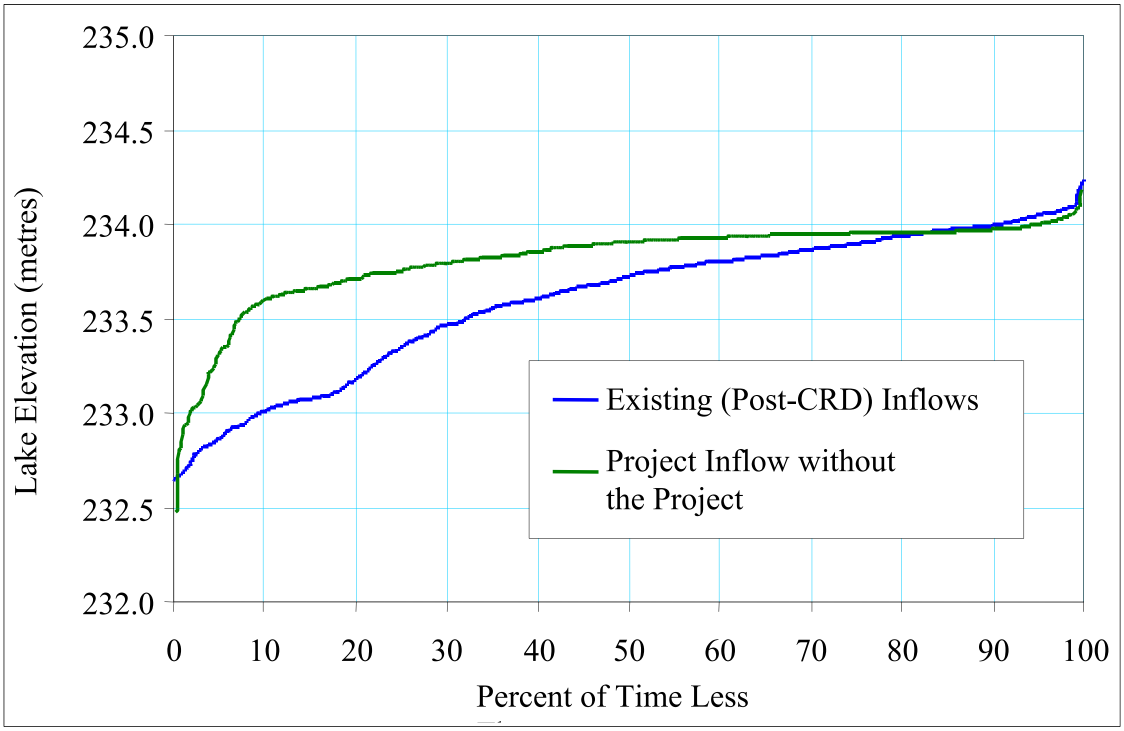


Figure A4.4-14 Wuskwatim Lake winter stage duration curve

Appendix A4.5

OPEN WATER HYDRAULIC MODELLING

APPENDIX A4.5 OPEN WATER HYDRAULIC MODELLING

A4.5 - 1.0 PURPOSE AND SCOPE

The modified run of river operation of the Project affects water levels both upstream and downstream of the plant along the Burntwood River. River hydraulic studies that simulate the operation of the Project were required to support a variety of environmental and design studies. These studies developed the magnitude and duration of water levels within the study reach from Early Morning Rapids to First Rapids (Figure 4.1-2). The effect of the Project on the water regime within the study reach was quantified by comparing water regimes with and without the Project.

During normal project operations, water levels in the immediate forebay which is the reach between the Project (Taskinigup Falls) and Wuskwatim Falls, Wuskwatim Lake and upstream to Early Morning Rapids, will fluctuate as the forebay is drawn down and re-pounded on a daily basis. Water levels in the river reach downstream of the Project tailrace will also experience daily fluctuations as a result of varying outflow from the Project. Downstream, fluctuations diminish due to river embayment and lake storage attenuation. River hydraulic parameters including water levels, water level fluctuations and river velocities for both existing (post-CRD) and Project water regimes, were developed using a variety of hydraulic models.

River hydraulic modelling was carried out to establish the hydraulic zone of influence of the Project (Volume 4 hydraulic zone of influence selection criteria), defined as the river reaches affected by the operation of the Project. These reaches extend from Early Morning Rapids to Birch Tree Lake. Separate river velocities were developed to support aquatic and terrestrial environmental studies between Wuskwatim Falls and Opegano Lake inlet (see Volume 5 for the reach selection criteria), and in the immediate forebay of the Project.

A4.5 - 2.0 MODELS AND MODELLING CALIBRATION

A4.5 - 2.1 FLOW-3D®

FLOW-3D® is a computational fluid dynamics (CFD) program developed by Flow Science Inc. It has been designed for the treatment of hydrodynamic problems in one, two and three dimensions and can accurately model problems involving free surface flows. The modeling package includes physical models such as shallow water, viscosity, cavitation, turbulence, and sediment scour, and applications include civil hydraulics and environmental engineering. This finite difference technique program is based on the fundamental laws of mass, momentum, and energy conservation, and is applicable to almost any type of flow process. This model is well suited for simulating varied and complex flow conditions, which typically occur in a variety of hydraulic design and analysis problems.

FLOW-3D® Model Setup, Calibration, Verification

FLOW-3D® was utilized for the immediate forebay of the Project since this model had already been set-up and calibrated for the Stage 4 hydraulic design studies (Wuskwatim GS Stage 4 Studies Design Memorandum W-2.9.0). Bathymetric information was collected in the immediate forebay in 1999 and used to develop a geometric grid, which became the physical representation of the river bed in the model. The model consisted of a coarse mesh (45 m) in the upstream and a very tight mesh (10m) at the plant axis.

The model was calibrated by matching water surface profiles that had been measured in this reach, for a variety of existing (post-CRD) flow conditions. The hydraulic head drop across Wuskwatim Falls and Taskinigup Falls was modelled by synthetic bathymetry, since no actual bathymetry was available at these Falls. Adjustments were made to the model parameters until to the simulated and measured water surface profiles matched.

The model was applied for the existing (post-CRD) inflow water regime and the project inflow water regime and associated immediate forebay levels to estimate velocity distributions. For the existing (post-CRD) inflow water regime, the immediate forebay level was set on the basis of 5^{th}, 50^{th} and 95^{th} percentile flows. For the post project water regime, an elevation of 233.87 m was used for all project flow conditions for 1 unit, 2 unit, 3 unit best gate operation and 3 unit full gate open operations. The FLOW-3D® program iterated the computer runs until a dynamic balance was achieved in flow and water level. Results of the FLOW-3D® analysis are provided in Section A4.5-3.2.2.

A4.5 - 2.2 HEC-RAS

The United States Army Corps of Engineers' River Analysis System (HEC-RAS) Version 3.0.1 is a one-dimensional hydraulic model which may be applied to solve steady-state flow and hydrodynamic flow problems. The steady-state flow component of the model solves the one-dimensional standard step energy equations, and is capable of modelling and optimizing split channel flow. The hydrodynamic model utilizes the St.

Venant equations of continuity and momentum for the solution of transient flow problems. The steady-state flow and hydrodynamic components are capable of modelling subcritical, critical and supercritical flow regimes.

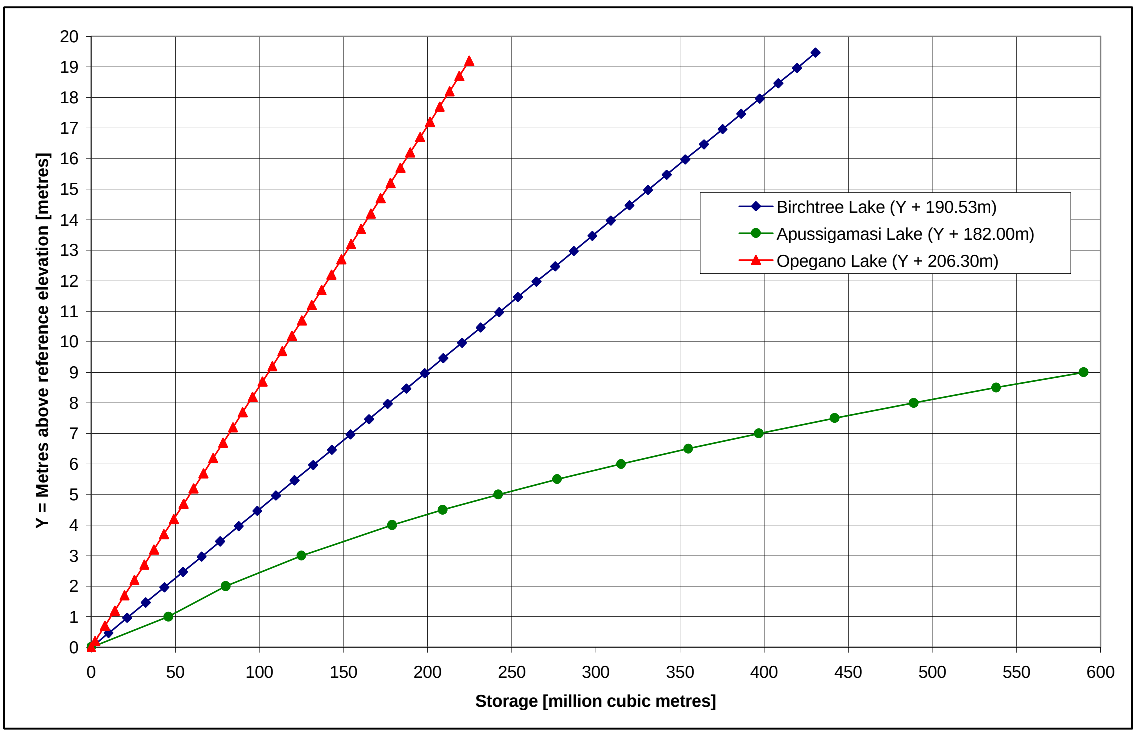
HEC-RAS Model Setup, Calibration, Verification

Steady-state backwater modelling was conducted during the Stage 4 design studies and was generally used to characterize the existing regime (Wuskwatim GS Stage 4 Studies Open Water River Hydraulics W-2.1.1). The Acres Gradient Program H01F was used in the Stage 4 design study to develop open water steady-state water surface profiles for the study reach. The H01F model uses the standard step method for open water computations, and has various useful options such as multiple channel splits, insert options for modeling geometric transitions, and expansion and contraction coefficients options. The model is capable of subcritical and supercritical flow regime. These H01F files were converted to HEC-RAS input files and recalibrated because of the hydrodynamic capabilities of HEC-RAS.

In order to effectively model the operations of the Project the model was used in two separate river reaches, the upstream reach between the head of Taskinigup Falls and the head of Early Morning Rapids and the downstream reach between the head of First Rapids and the foot of Taskinigup Falls. The model contains approximately 300 river cross sections. Some of these were collected during field surveys and others were fabricated for locations where sections could not be collected, typically rapids that act as control sections. River reach lengths were measured from topographic maps. Both the upstream and downstream models were calibrated using rating curves established at a number of water level gauges along the Burntwood River with water levels collected over the last 25 years . Steady state flow model calibration involved adjusting the fabricated cross sections at natural water level control sections so that the modelled water levels matched observed rating curves. Additionally, Manning's roughness coefficients were adjusted, ineffective flow boundaries were included and interpolated sections were added. Simulated water levels are within ± 0.2 m of the observed rating curves.

The HEC-RAS model also required setup and calibration in the hydrodynamic mode for modelling the dynamic operation and effects of the Project. The unsteady state flow modelling is fundamentally different from the steady state flow modelling as it considers water storage and models supercritical flow within internal boundaries only. Cross sections in the steady-state model for Wuskwatim Lake, the immediate forebay of the Project, Opegano Lake and Birch Tree Lake were replaced with stage storage curves (FigureA4.5-1 and Appendix A4.3). The HEC-RAS hydrodynamic model was initially calibrated and verified by routing a range of steady-state flow hydrographs and comparing the resulting water surface profiles to the observed rating curves along the CRD. For the project inflow conditions, the head loss through Wuskwatim Falls and adjacent channel excavation was modelled to simulate the drop between Wuskwatim Lake and the immediate forebay (Wuskwatim GS Stage 4 Studies Design Memorandum Channel Improvements at Wuskwatim Falls W-3.3.3). The river cross sections where supercritical flow occurs were replaced with internal boundaries that utilize weir equations. Weir coefficients and geometry were adjusted at supercritical flow locations and Manning's n was adjusted at subcritical flow locations so that simulated water levels matched observed rating curves.

As the model was intended for hydrodynamic applications, it was also necessary to calibrate and verify the model results against historically recorded stage and flow hydrographs at various locations along the river (Manitoba Hydro, 1980). The simulated water levels are within ± 0.2 m of the observed stage hydrographs.



A4.5-1 Stage-storage curves for Birch Tree Lake, Apussigamasi Lake, and Opegano Lake.

A4.5 - 2.3 RIVER2D

The River2D version 0.88 model, developed at the University of Alberta and partially funded by the Department of Fisheries and Oceans, is a two-dimensional depth averaged finite element steady state hydraulic model capable of determining fish habitat suitability indices for natural streams and rivers. The model simulates supercritical, critical, and subcritical flow regimes in addition to the wetting and drying of river banks.

The River2D model was applied to the reach between the foot of Taskinigup Falls and the inlet of Opegano Lake. It includes the Burntwood River channel as well as the creek mouths that drain into the Burntwood River along this reach. Modelling was not carried out downstream of the inlet of Opegano Lake because the stage variation that would be created by the Project is deemed to be insignificant in this reach for the aquatic studies (refer to Volume 5 for details regarding this criteria).

The two dimensional aspect of the model requires a continuous digital elevation model (DEM) of the reach including overbank elevations (hypsography) and underwater elevations (bathymetry). River cross sections were collected throughout the reach at a spacing of 50 m and bathymetry was collected parallel to the shoreline and along the centerline of the river. The bathymetry was merged with hypsography (2 m contour interval) to produce the contour map shown in Figure A4.5-2. The contour maps were converted to DEMs shown in Figure A4.5-3 and imported into River2D. Substrate information collected throughout the reach to support the aquatic studies formed the basis of the bed roughness height in the model. Bed roughness height serves a similar purpose in River2D as Manning's n serves in other hydraulic models. The bed roughness heights used in the modelling were 0.04 m for sand/gravel/clay, 0.16 m for cobble, 0.35 m for boulder, 0.03 m for bedrock, and 1.00 m for overbank areas. A River2D mesh was developed for three reaches separated by river rapids where bathymetry could not be collected due to high water velocity conditions that are unsafe for boating.

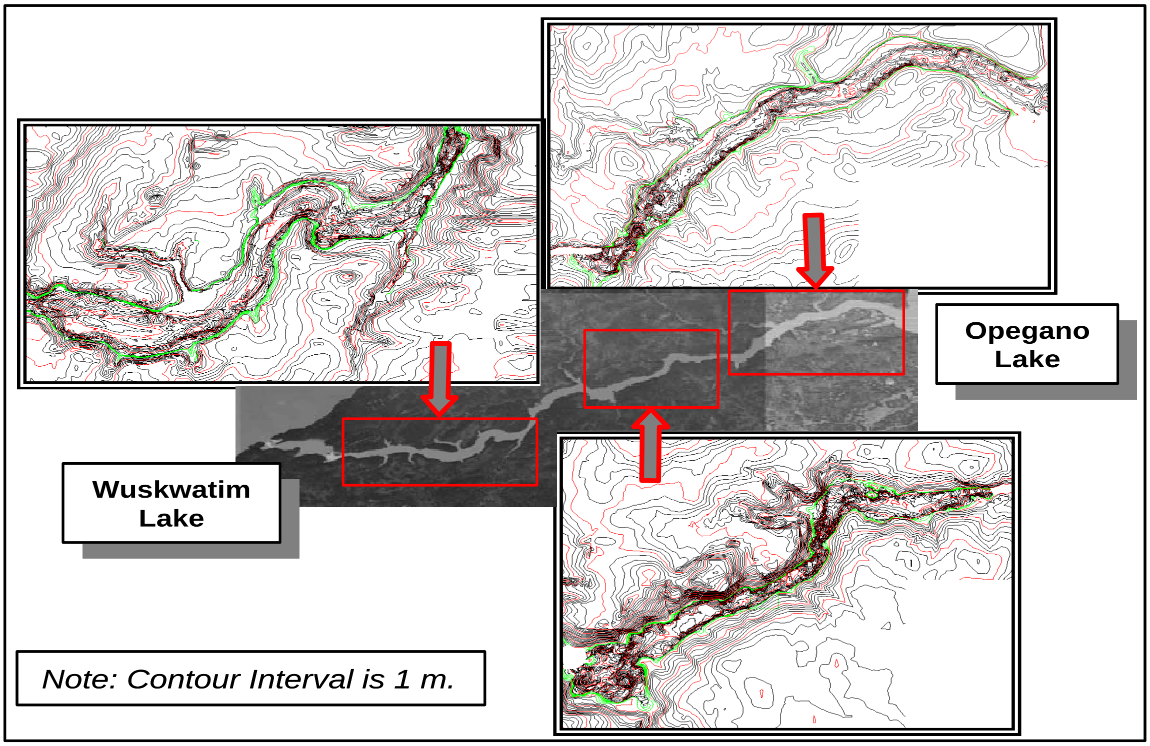


Figure A4.5-2 Taskinigup Falls – Opegano Lake: Bathymetry and hypsography at 1 m contour intervals

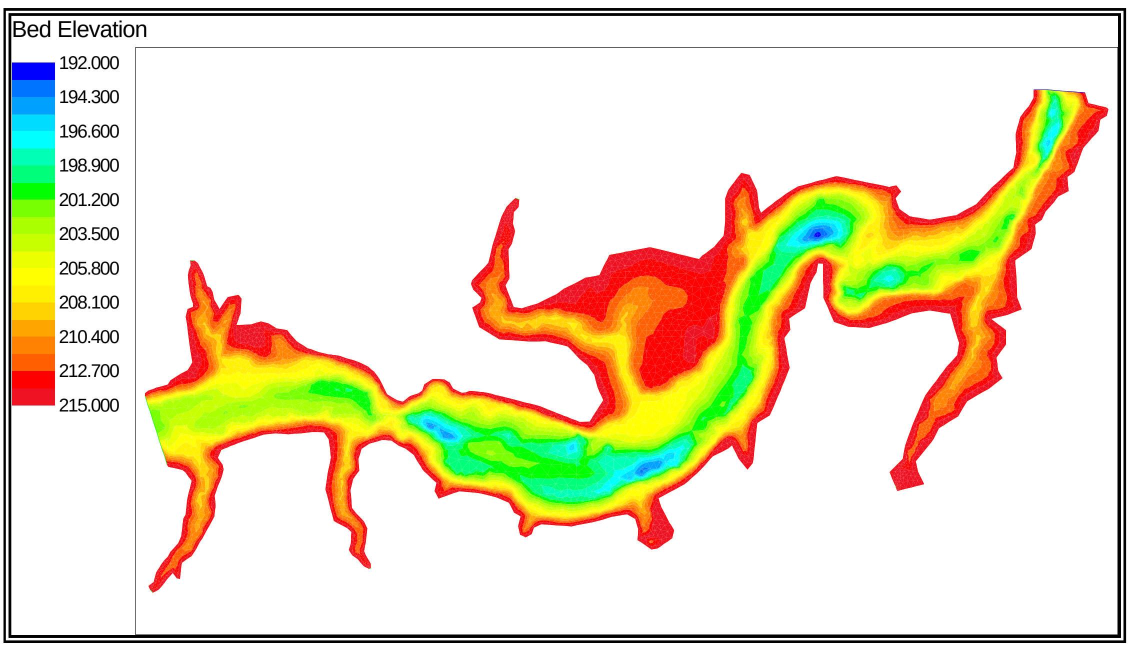


Figure A4.5-3 Taskinigup Falls – Opegano Lake: Two dimensional hydraulic modelling sample digital elevation model of river bed

A number of water levels and discharge measurements using an Acoustic Doppler Current Profiler (ADCP) were collected throughout the reach. The ADCP measurements also provided a cross section of velocities. This data was used to calibrate and verify the River2D model. Recorded water levels were used for the downstream boundary conditions, and inflow at the upstream boundary was based on an average of the ADCP discharge measurements (789 cms). Inflow from tributaries was estimated using a regional hydrologic analysis. The models were calibrated by adjusting the bed roughness height in addition to adjustments to the bed geometry so that simulated water levels matched the recorded water levels. River cross sections of velocities were extracted from the model and compared to velocities recorded with the ADCP. Simulated water levels and velocities matched the observed values well.

A4.5 - 3.0 HYDRAULIC MODELLING RESULTS

In order to characterize changes in the water regime that would result from the normal operation of the Project the various hydraulic models were applied to represent both the existing (post-CRD) inflow and project inflow conditions. Steady-state hydraulic modelling characterized existing (post-CRD) inflow conditions using 5^{th}, 50^{th} and 95^{th} percentiles inflows. These three percentiles were chosen since they encompass 90 percent of all inflows. Steady-state flow applications characterized the project inflow conditions downstream of the Project using 1, 2 and 3 unit best gate flow and 3 unit full gate open flow conditions. These were deemed to be suitable for the aquatic studies since the plant would be operating at one of these four settings for the majority of the time (Volume 5).

A4.5 - 3.1 HYDRAULIC ZONE OF INFLUENCE

The HEC-RAS model was used to establish the upstream and downstream extent of the influence from the operation of the Project, termed the hydraulic zone of influence. As discussed in Section 4.1.1.4 and Appendix A4.1, application of the HEC-RAS model in the steady-state mode established the upstream extent to be Early Morning Rapids. A hydrodynamic application downstream of the project established the downstream extent to be Birch Tree Lake.

The hydrodynamic model calculated stage variations throughout the reach from 1912 to 1997 at a 10 minute time step. Additionally the model demonstrated that the hydraulic zone of influence for the lower reach extended to Birch Tree Lake where it was estimated that the maximum daily open water stage fluctuations was on the order of 0.07 m during normal project operation (Volume 3).

A4.5 - 3.2 UPSTREAM STUDY REACH – EARLY MORNING RAPIDS TO TASKINIGUP FALLS

4.5 - 3.2.1 Steady State Flow Water Surface Profiles

Using HEC-RAS, steady state flow water surface profiles with a horizontal spacing of 20 m were developed from Early Morning Rapids to Taskinigup Falls for both existing (post-CRD) inflow conditions and project inflow conditions, as shown in 4.3.4. The water levels along this river reach were used to assist in the characterization of shoreline drying and re-wetting in the aquatic and terrestrial environmental studies (Volume 5).

4.5 - 3.2.2 River Velocities in the Immediate Forebay

As discuss in Section 4.3.3.3, numerical modelling of the existing (post-CRD) inflow river velocities in the immediate forebay of the Project was required for the aquatic and terrestrial environmental studies. Flow-3D modelling was completed for existing (post-CRD) inflows of 5^{th}, 50^{th} and 95^{th} percentiles. The corresponding downstream boundary conditions located upstream of Taskinigup Falls were water levels of 226.4 m, 227.2 m and 227.5 m respectively. Modelled velocity distributions for the 5^{th} and 95^{th} percentile flows are shown in Figures A4.5-4 and A4.5-5 respectively and the 50^{th} percentile flow figure is given in Section 4.3.3.3.

The FLOW-3D model was also applied in the immediate forebay for simulating the Project inflow conditions at a FSL of 234 m, the results shown in Figures A4.5-6 to A4.5-8.

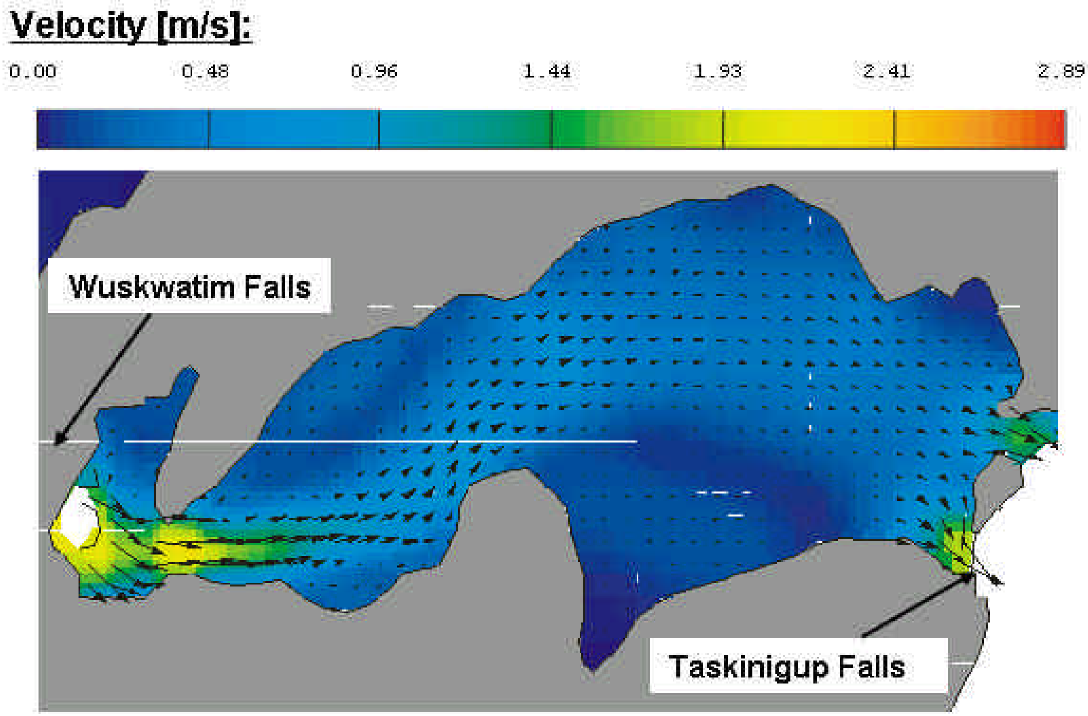


Figure A4.5-4 Wuskwatim Immediate Forebay – Velocity Distribution for 5th percentile Existing (post-CRD) Flow (548 m^3/s)

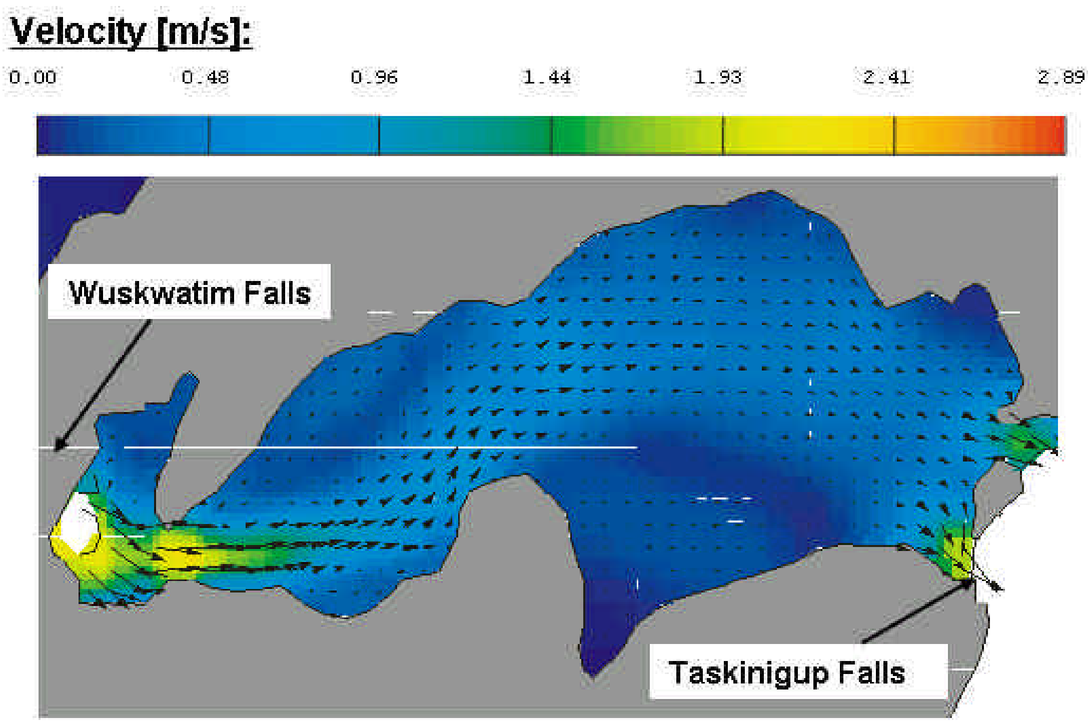


Figure A4.5-5 Wuskwatim Immediate Forebay – Velocity Distribution for 95th percentile Existing (post-CRD) Flow (1066 m^3/s)

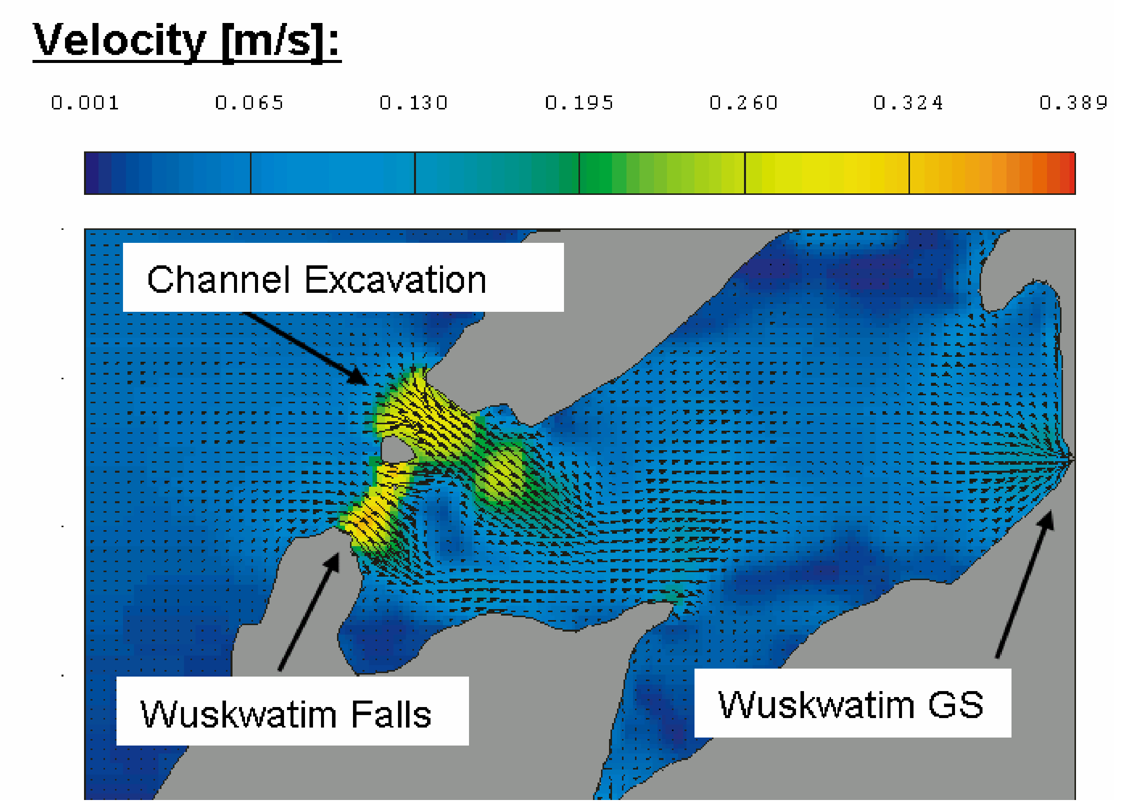


Figure A4.5-6 Wuskwatim Immediate Forebay – Velocity Distribution for 1 Unit Best Gate Project Flow (330 m^3/s)

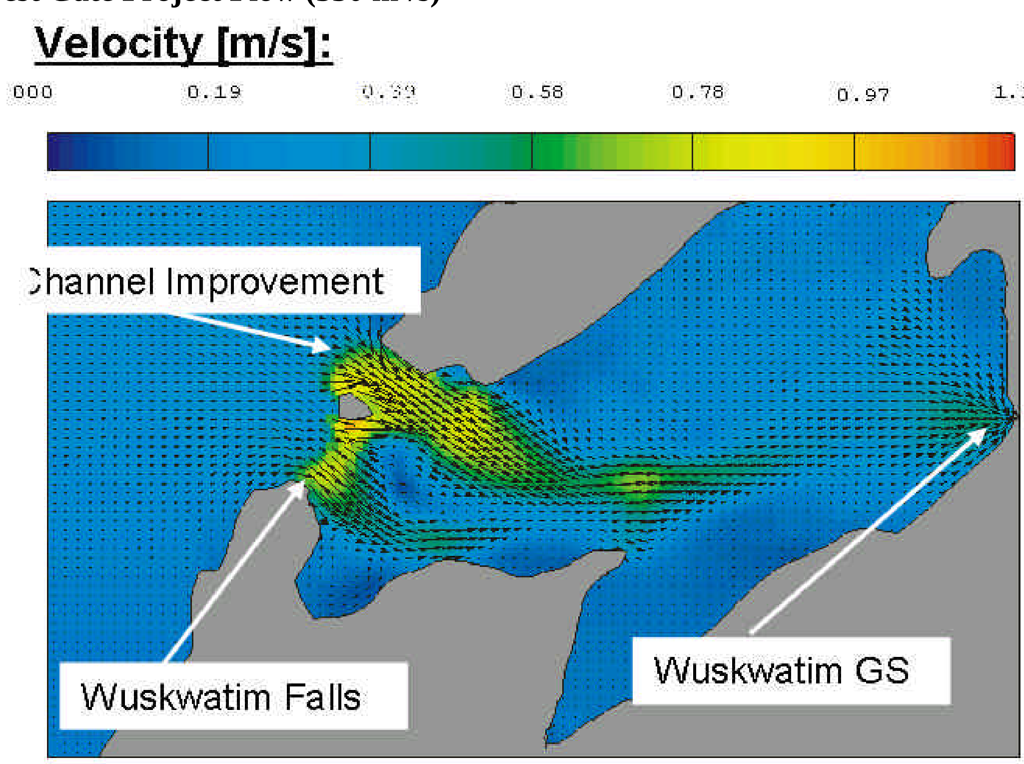


Figure A4.5-7 Wuskwatim Immediate Forebay – Velocity Distribution for 3 Units Best Gate Project Flow (990 m^3/s)

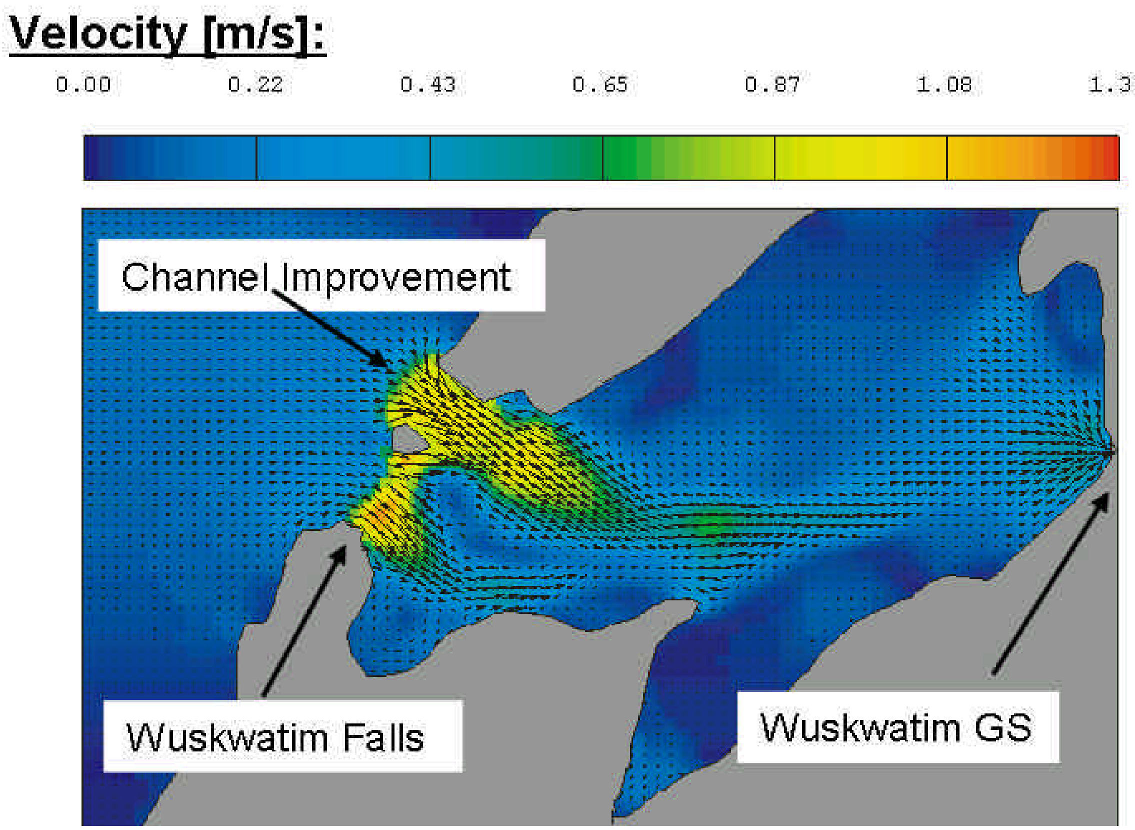


Figure A4.5-8 Wuskwatim Immediate Forebay – Velocity Distribution for 3 Units Full Gate Project Flow (1100 m^3/s)

4.5 - 3.2.3 Unsteady State Flow Water Surface Levels & Stage Variation

The one-dimensional HEC-RAS hydrodynamic model was used to simulate water levels and stage variations for the project inflow conditions in the reach from Early Morning Rapids to the immediate forebay of the Project. The results were used to determine changes in water levels as a result of the shaping mode of operation. Every 5^{th} percentile of the post project inflows (i.e. 0%, 5%,.....,95%, 100%) was simulated by applying a constant discharge hydrograph with a 10 minute time step at the upstream boundary of the model (Early Morning Rapids). A 10 minute time step hydrograph representing the corresponding regulated outflow from the Project was applied at the downstream boundary of the model. The model simulates the drawdown and reponding of both the Wuskwatim Lake and the immediate forebay in addition to water levels throughout the river reach. Stage hydrographs with a 10 minute time step were extracted at a variety of locations including the head and foot of Early Morning Rapids, Wuskwatim Lake and Wuskwatim GS immediate forebay. Daily stage variation is computed by subtracting the minimum water level during a given day from the maximum water level during the same day (Figures 4.3-7 and 4.3-8).

A4.5 - 3.3 DOWNSTREAM STUDY REACH

4.5 - 3.3.1 Steady State Flow Water Surface Profiles

Downstream of the Project site the steady state flow model was used to develop water surface profiles to support the aquatic and terrestrial environmental studies (Volume 5), where shoreline drying and re-wetting during Project operations was determined. Figure 4.2-9 in Section 4.2.3.1 shows the open water surface profiles for the 5th, 50th and 95th percentiles for existing (post-CRD) flow conditions.

4.5 - 3.3.2 River Velocities (Wuskwatim Falls – Opegano Lake)

The River2D model was applied from Taskinigup Falls to Opegano Lake for the existing (post-CRD) inflows conditions and project inflow conditions as shown in the Table A4.5-1. Depth averaged velocity grids at a 2.5 m resolution were exported from the model for each flow condition and utilized in the Aquatic Environment (Volume 5) and the River Bank Erosion Assessment (Volume 4, Section 7). The resulting depth averaged water velocities are shown in Figures 4.20 and 4.3-34 as well as Figures A4.5-9 to A4.5-12.

Table A4.5-1 River2D Modelling: Taskinigup Falls to Opegano Lake

	Discharge Condition	Discharge [cms]
Existing (post-CRD) inflows	5% Event	548
	50% Event	874
	95% Event	1066
Project inflows	1 unit best gate plant operation	328
	2 unit best gate plant operation	656
	3 unit best gate plant operation	984
	3 unit full gate plant operation	1100

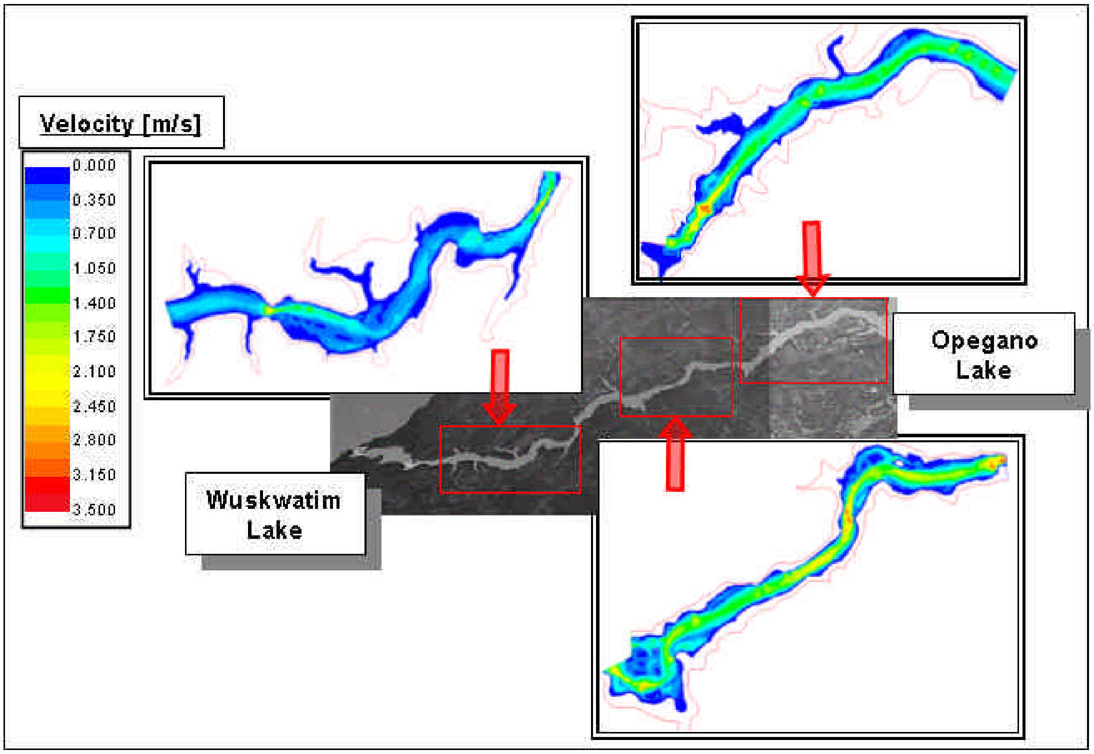


Figure A4.5-9 Taskinigup Falls – Opegano Lake: depth averaged velocities for the 5th percentile existing (post-CRD) inflow

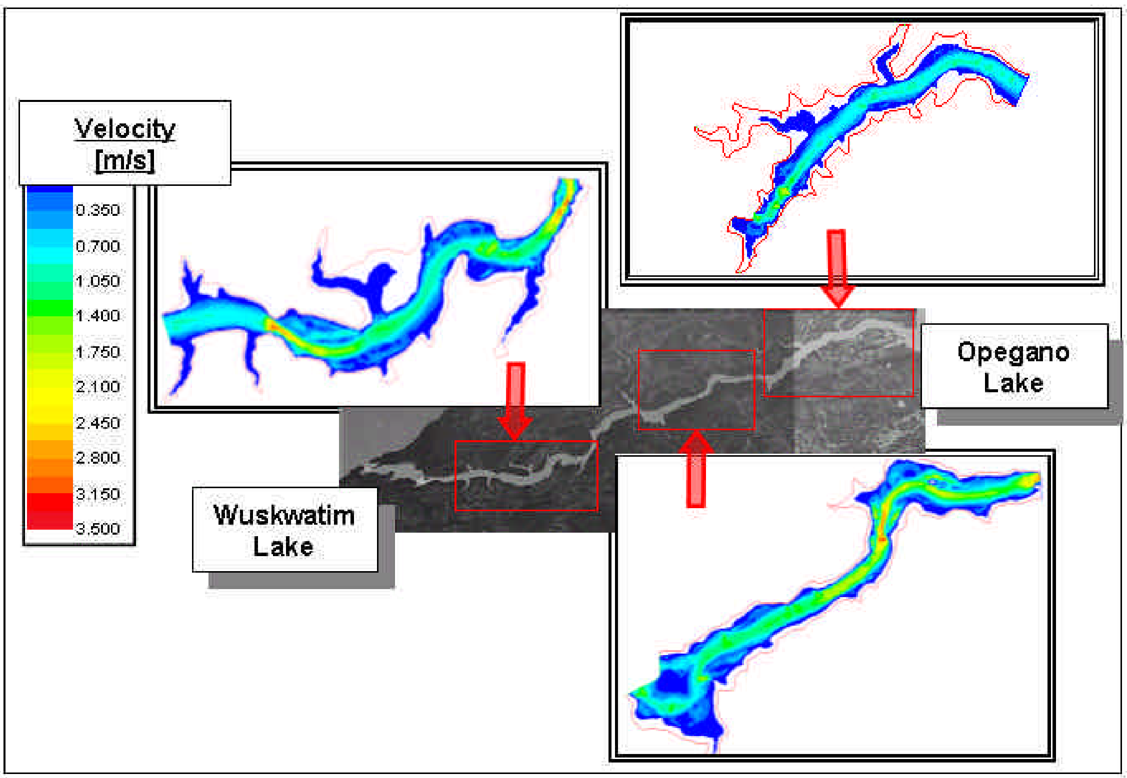


Figure A4.5-10 Taskinigup Falls – Opegano Lake: depth averaged velocities for the 95th percentile existing (post-CRD) inflow

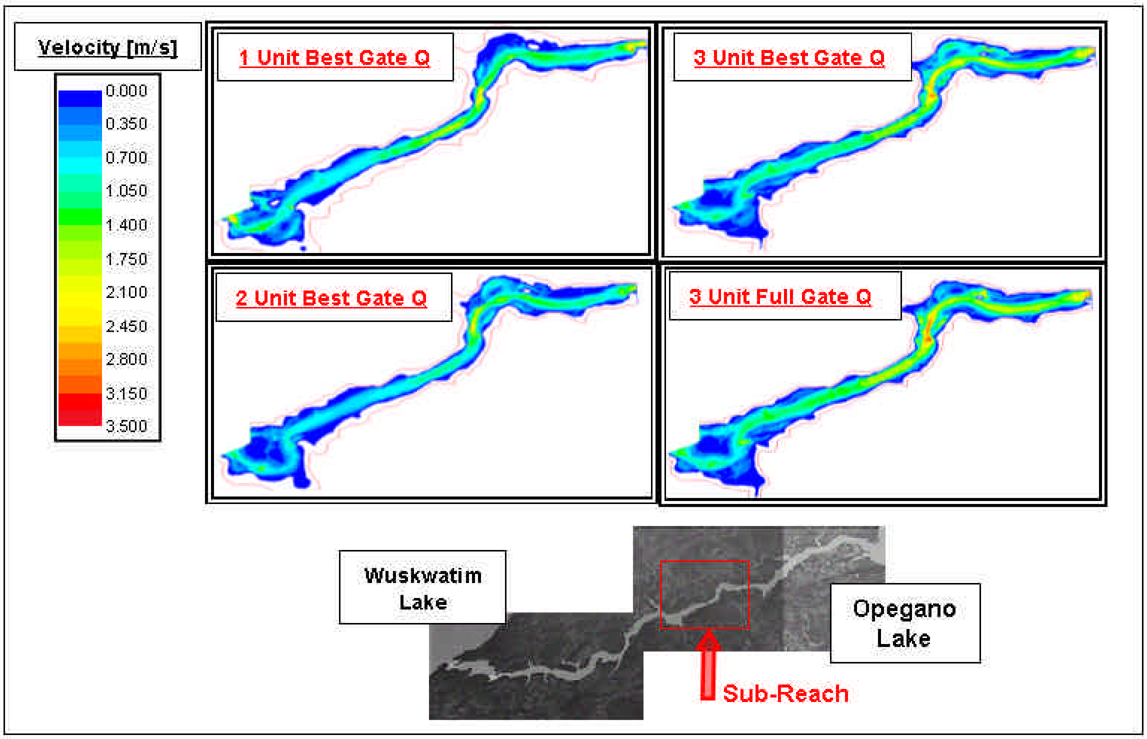


Figure A4.5-11 Sample two dimensional hydraulic modelling velocity fields for 1, 2, and 3 unit best gate flow and 3 unit full gate flow for middle subreach

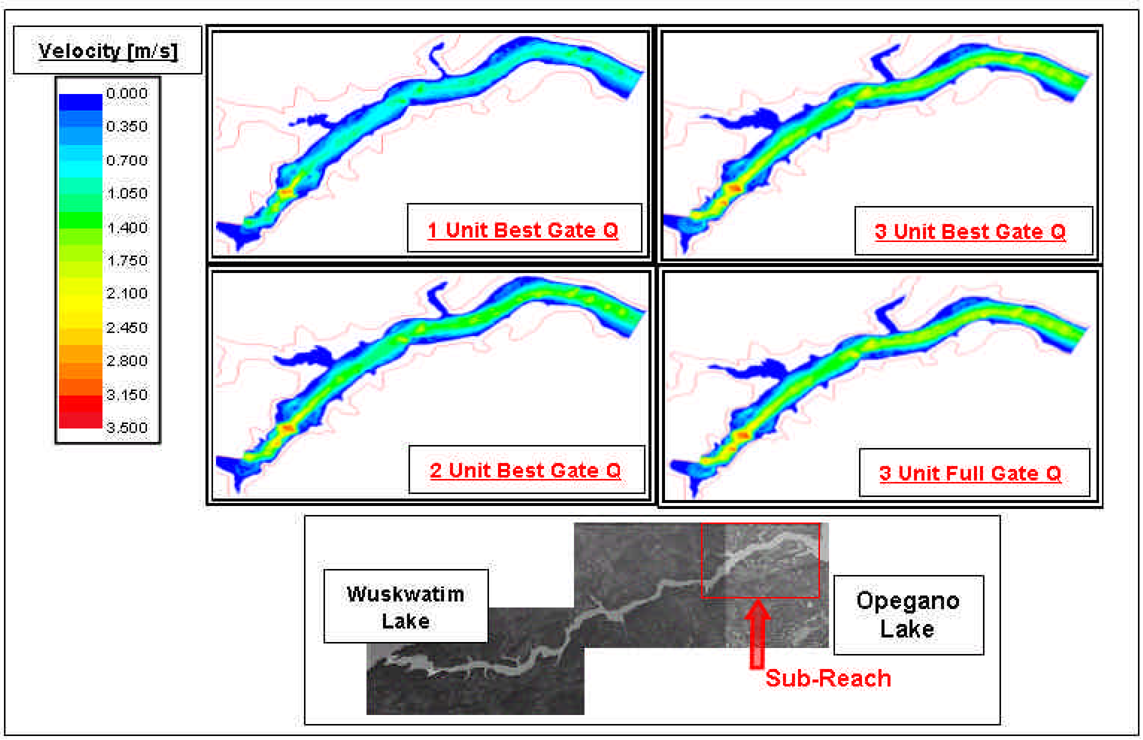


Figure A4.5-12 Sample two dimensional hydraulic modelling velocity fields for 1, 2, and 3 unit best gate flow and 3 unit full gate flow for downstream subreach

4.5 - 3.3.3 Unsteady Flow Water Surface Levels & Stage Variation

The modified run-of-river mode of operation of the Project will cause unsteady state flow conditions and stage variations along the downstream reach of the Burntwood River. The one dimensional HEC-RAS hydrodynamic model was used to simulate these hydraulic effects for project inflow conditions. The results of the hydrodynamic modelling were used to determine a number of observations and conclusions discussed in Section 4.3.4.

Hydrodynamic modelling of the downstream river reach was carried out by simulating open water conditions for the 1912 to 1997 project inflow period at a 10 minute time step. The monthly average Wuskwatim Lake inflows were assumed to represent the flow for each day within the same month. Project outflow hydrographs with a 10 minute time step which depict the modified run-of-river normal mode of operation were developed using each of the daily inflows. These hydrographs were inserted into the model as the upstream boundary condition and subsequently routed through the study reach. Samples of theses daily hydrographs are shown for selected project inflow percentiles in Figure 4.3-19, Section 4.3.4.2. Within the model, these outflow hydrographs are routed through a series of river reaches and lakes hydraulically controlled by critical control sections (rapids or falls).

Water level and flow information at 10 minute time steps were extracted at a number of selected locations including Wuskwatim tailrace (foot of Taskinigup Falls), Opegano Lake, Birch Tree Lake, Thompson Pumphouse, Apussigamasi Lake, and First Rapids. Using this information, stage hydrographs, stage duration curves, daily stage variation and duration curves were developed as described in Section A4.5-3.2.3.

Appendix A4.6

NUMERICAL MODELLING OF WINTER ICE PROCESSES ALONG THE BURNTWOOD RIVER

APPENDIX A4.6 NUMERICAL MODELLING OF WINTER ICE PROCESSES ALONG THE BURNTWOOD RIVER

A4.6 - 1.0 GENERAL

Ice processes along the Burntwood River are complex in nature. The river reach is generally characterized by a series of lakes, separated by river reaches which are hydraulically controlled by narrow constrictions and rapids. As such, there are two distinct types of ice cover formation in this northern reach of river - the formation of lake ice in low velocity areas, and the formation of Ariver ice≅ in more turbulent areas.

In order to better understand, and predict ice conditions on the river reach, sophisticated numerical models have been developed over the years. Initially, a robust and comprehensive model, ICEROUT, was developed and calibrated to represent the steady growth of the ice cover over a typical winter period. More recently, studies have been augmented with the development of a hydrodynamic ice model which is capable of dynamically routing projected daily discharge variations through the downstream reach. Each of these studies, and their associated models, is briefly described below.

A4.6 - 2.0 ESTIMATION OF WINTER WATER SURFACE PROFILES

A4.6 - 2.1 GENERAL APPROACH

As an important first step in gaining a better appreciation and understanding of the ice processes along the Burntwood River, Manitoba Hydro established a comprehensive ice monitoring program(A4.2) for this reach of river in the late seventies. The data gathered over the course of this ongoing observation program includes:

- winter water levels at a number of sites along the waterway;
- associated winter discharge meterings;
- numerous photographs and video footage of the ice conditions at various locations and stages during the winter; and
- ice thickness measurements at known ice dam locations.

As this data was gathered, a quasi "steady state" numerical model was also developed to mathematically simulate the ice processes observed in the field each year. The quasi "steady state" nature of the model meant that although it was able to simulate storage effects along a river system due to the gradual drawdown of natural lakes or reservoirs, the model was unable to dynamically route sudden flow changes through a given river reach. Rather water surface profiles were developed assuming a constant, or "steady" discharge throughout the river reach. Model development spanned a number of years, and the model was continually refined and updated based on recent ice observations. The model was Acalibrated≅ to match observed winter water surface profiles along the reach, with good success. Finally, the developed model was used to predict future ice processes under post Project conditions.

A4.6 - 2.2 ICEROUT MODEL

Numerical studies of the Burntwood River ice processes were initiated in the 1970's. The primary tool for these analyses was a sophisticated numerical model - ICEROUT. The ICEROUT model was developed specifically to simulate ice conditions on the Burntwood River. The model accounts for all of the major ice formation processes on the river, including ice generation, anchor ice formation, border ice growth, ice cover advancement, and hanging dam formation. The model has been steadily refined over the years, and is capable of simulating lake storage effects on the attenuation of a daily inflow hydrograph, but assumes steady, or constant discharges in a given river reach in computing water surface profiles.

A4.6 - 2.3 MODEL SETUP

The model was set up to represent the entire river reach, from Threepoint Lake through to the First Rapids site. This represents, in total, a river reach of some 185 km. The total drop in water surface over this reach is approximately 75 m. Cross sections for the simulation were derived directly from existing backwater datasets of the reach. In total, 77 cross sections were utilized in the reach from Threepoint Lake to Wuskwatim Lake, 94 cross sections were utilized in the reach from the Project to the Manasan ice control structure, and an additional 134 cross sections were utilized to model the reach from Manasan Falls down to First Rapids. These cross sections were surveyed as a part of earlier hydrometric surveys, and are consistent with those sections being utilized in concurrent open water studies.

Upstream boundary conditions for the model consisted of a user defined, daily discharge hydrograph. The downstream boundary for the model consisted of an observed stage discharge relationship (i.e., Wuskwatim Lake, Birch Tree Lake, or First Rapids rating curve). Daily air temperatures were also input to the model for simulation of ice generation rates.

When user defined air temperatures fall below zero degrees Celsius, the simulation of ice processes on the river reach begins including:

- the generation of frazil ice;
- the initiation of border ice growth; and

- the advancement of the ice cover by juxtaposition, and where velocities are high, the cover will stall and ice is deposited in a Ahanging ice dam≅ downstream of the high velocity area.

A4.6 - 2.4 CALIBRATION

Following its setup, the model was initially calibrated to match open water surface profiles previously derived along the river reach. After obtaining a suitable match under open water conditions, the model was configured to simulate the development of an ice cover on the downstream reach. Ice parameters for the model were adjusted as required to achieve a consistent match with observed maximum water surface profiles along the reach for a number of past winters. Observed profiles have been surveyed by Manitoba Hydro over the past number of years, providing an excellent data base of information for calibration. The calibration was successful, and a good match was obtained for all winter simulations. Figure A4.6-1 illustrates a sample water surface profile for the reach of river between Threepoint Lake and Wuskwatim Lake. Figure A4.6-2 illustrates a sample match obtained for the reach between Taskinigup Falls and Manasan Falls.

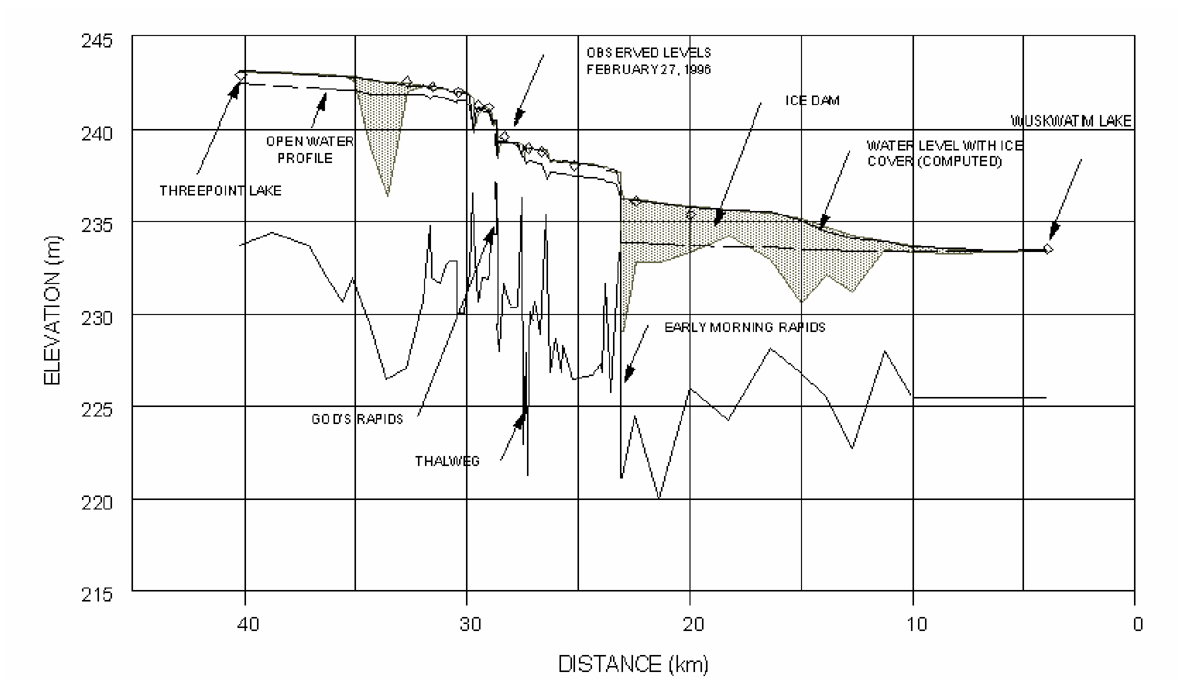


Figure A4.6-1 Sample Winter Calibration: Threepoint Lake to Wuskwatim Reach (February, 1996).

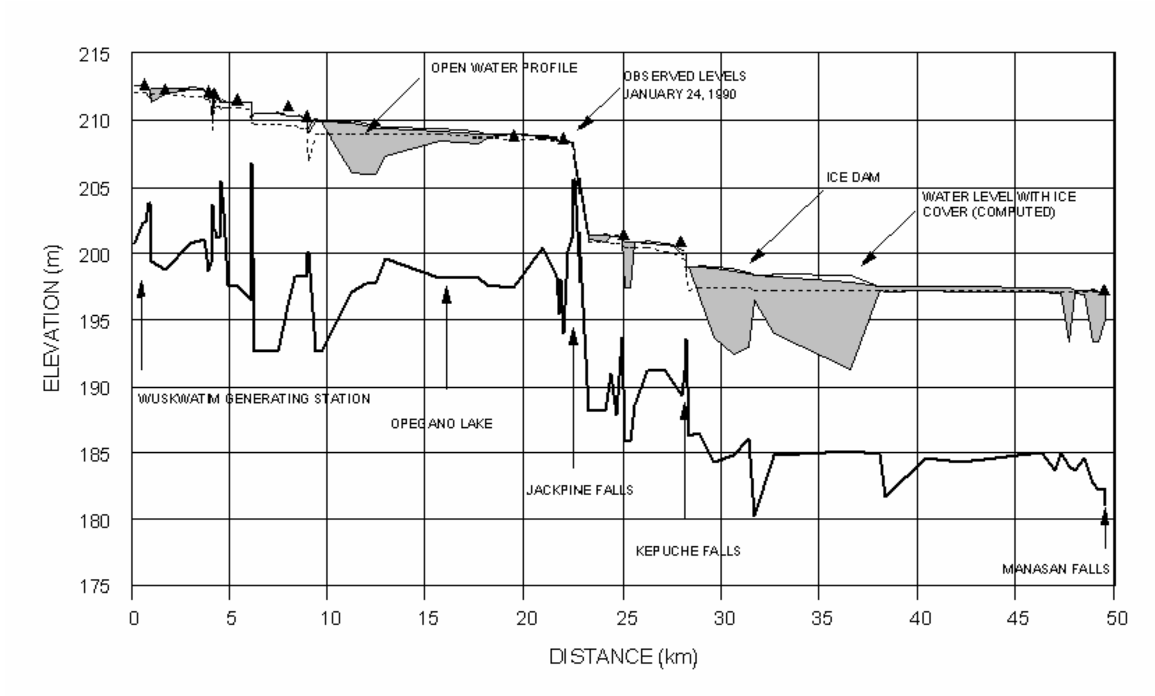


Figure A4.6-2 Sample Winter Calibration: Taskinigup Falls to Manasan Falls Reach.

A4.6 - 2.5 RESULTS

Following the model=s successful calibration under both open water and winter conditions, it was utilized to evaluate maximum winter water surface profiles along both the upstream and downstream reaches under a variety of winter conditions. These maximum water surface profiles were developed based on the actual air temperatures experienced during the 1978/79 winter season. This temperature sequence represents one of the most extreme thermographs in recent history in terms of cumulative degree days of freezing.

Profiles were assessed under both existing inflow conditions, and under anticipated project inflow conditions. Figure A4.6-3 summarizes predicted water surface profiles along the reach between Threepoint Lake and Wuskwatim Lake under existing conditions, for Burntwood River flows of 548 m^3/s, 874 m^3/s, and 1066 m^3/s. These flows correspond to the 5 percentile, 50 percentile, and 95 percentile flows respectively under existing conditions. Figure A4.6-4 summarizes predicted water surface profiles for the reach between Taskinigup Falls and the Manasan Falls ice control structure for the same flows.

The profiles shown in Figures A4.6-1 and A4.6-2 represent the maximum water surface profiles anticipated over a given winter for the respective flow. However, in reality, staging due to ice formation/accumulation is a gradual process, starting generally at the onset of winter and reaching a peak at some time in the latter part of the winter. Likewise, during the spring, water levels gradually fall once again to reach open water conditions as the ice cover melts and deteriorates. In order to account for this annual pattern, monthly “staging factors” were extracted from the model results, and refined where possible using temporal data along the reach. These staging factors were utilized by others in subsequent hydraulic models. Figure A4.6-5 represents a typical staging relationship along the reach, this one for the Wuskwatim tailrace area.

Figure A4.6-6 summarizes predicted water surface profiles along the reach between Threepoint Lake and Wuskwatim Lake under post-project conditions for Burntwood River flows of 548 m^3/s, 874 m^3/s, and 1066 m^3/s. These flows correspond to the 5 percentile, 50 percentile, and 95 percentile monthly inflows to Wuskwatim Lake. The Project was assumed to be operated so as to maintain a level on Wuskwatim Lake of elevation 234.0 m under all flow conditions. Figure A4.6-7 summarizes predicted water surface profiles for the reach between Taskinigup Falls and the Manasan Falls ice control structure for flows of 328 m^3/s, (one unit at best gate), 656 m^3/s (two units at best gate), 984 m^3/s (three units at best gate), and 1100 m^3/s (three units at full gate discharge). These represent typical flows associated with the operation of the Project.

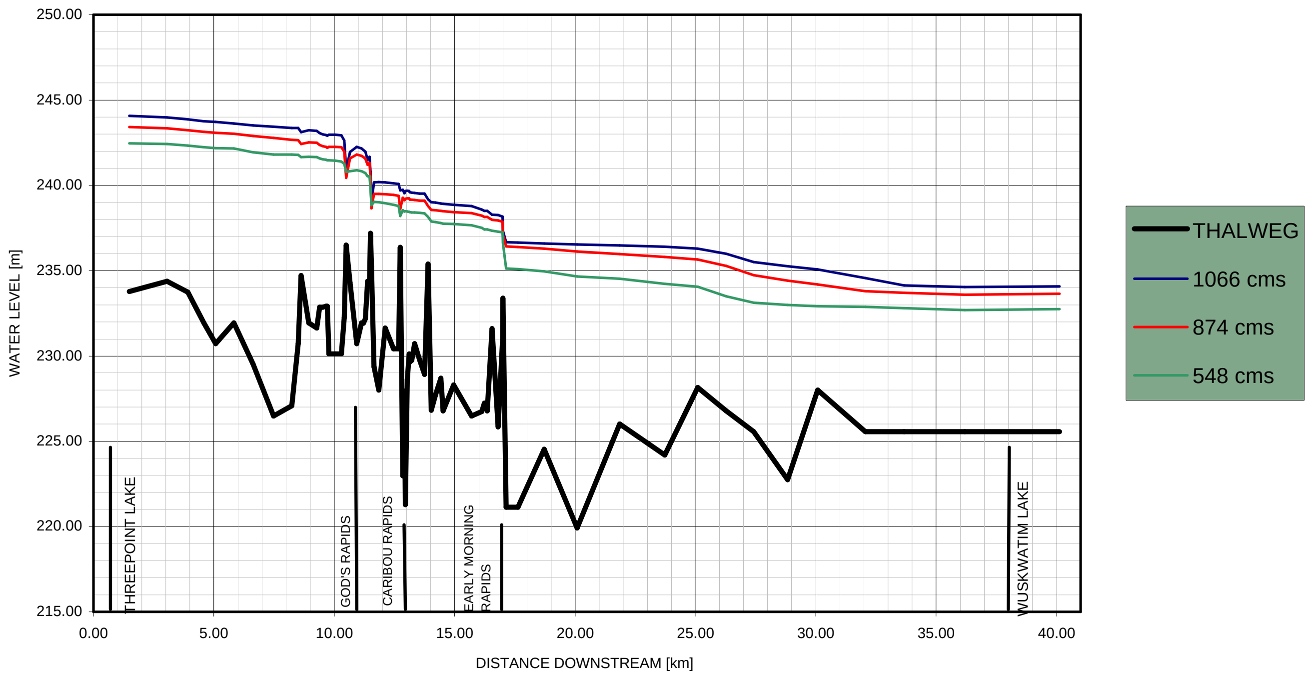


Figure A4.6-3 Maximum Winter Water Surface Profiles - Threepoint Lake to Wuskwatim Reach Under Existing Inflow Conditions.

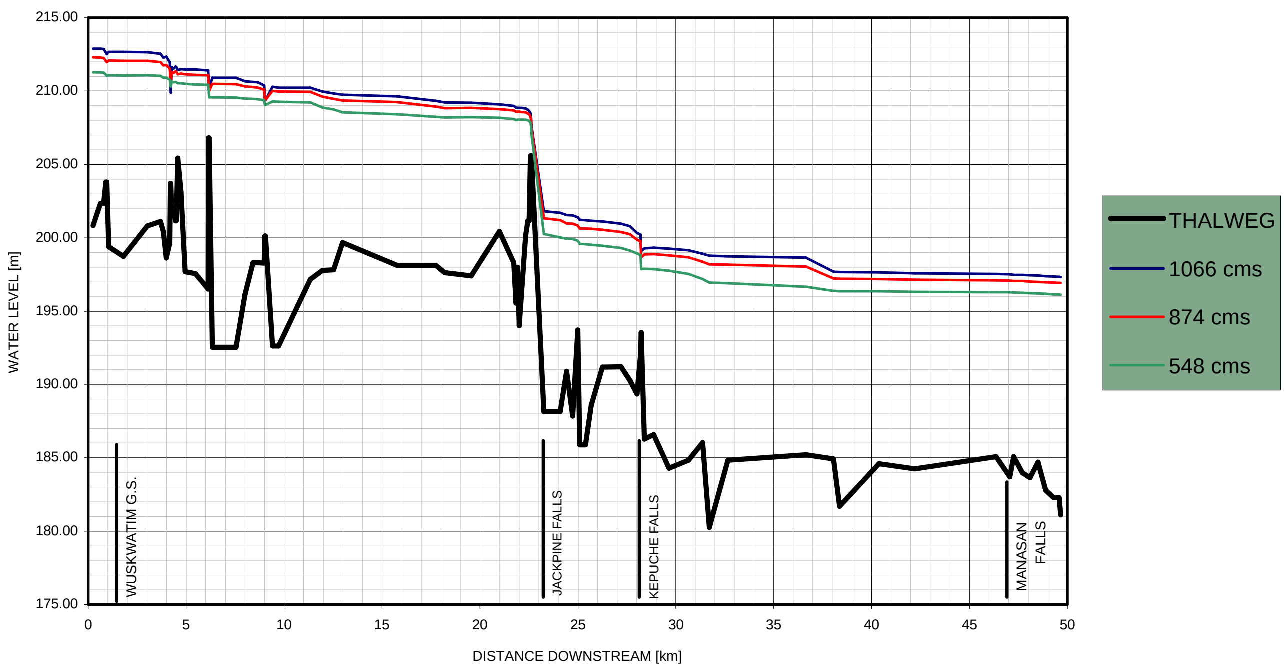


Figure A4.6-4 Maximum Winter Water Surface Profiles - Taskinigup Falls to Manasan Falls Reach Under Existing Inflow Conditions

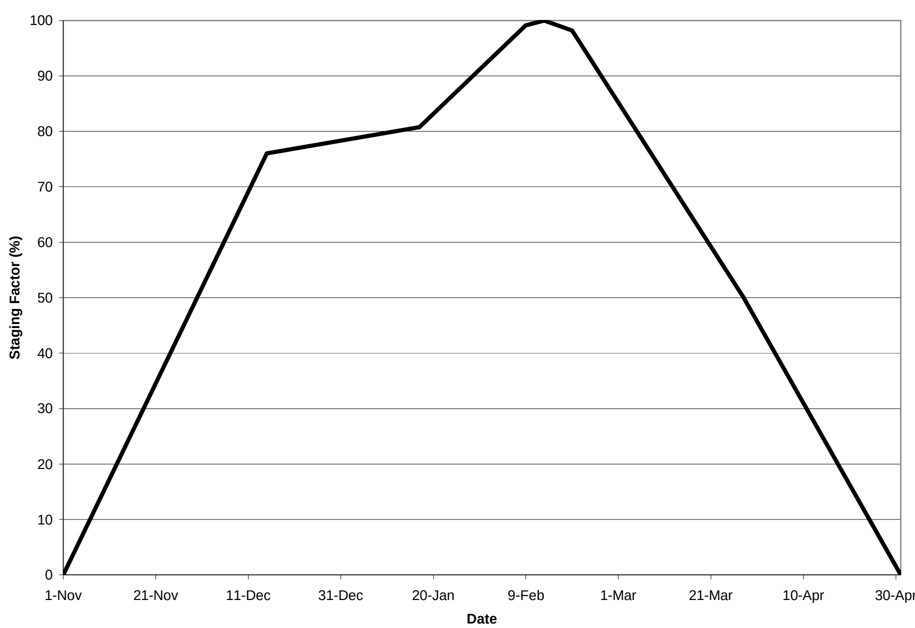


Figure A4.6-5 Typical Staging Pattern: Wuskwatim Tailrace Area.

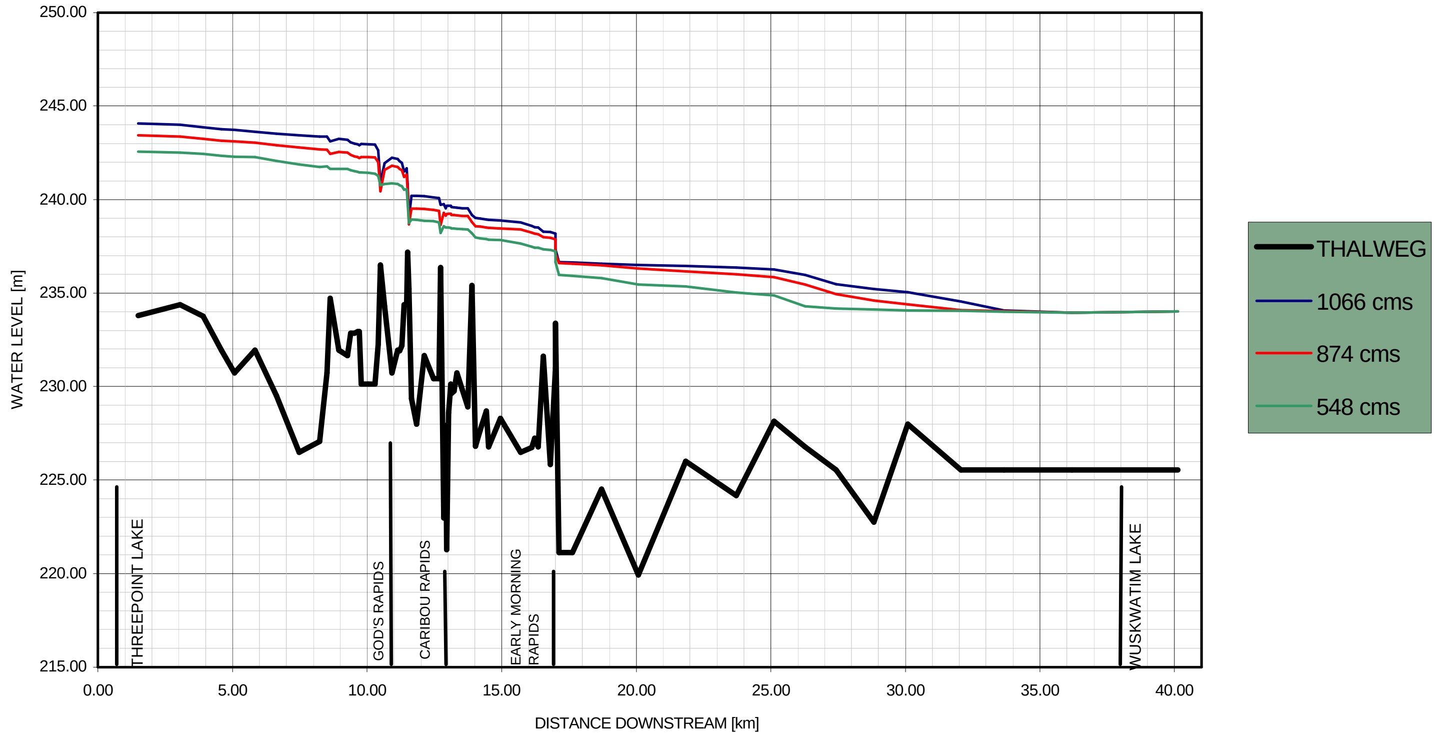


Figure A4.6-6 Maximum Winter Water Surface Profiles - Threepoint Lake to Wuskwatim Reach - Project Inflow Conditions.

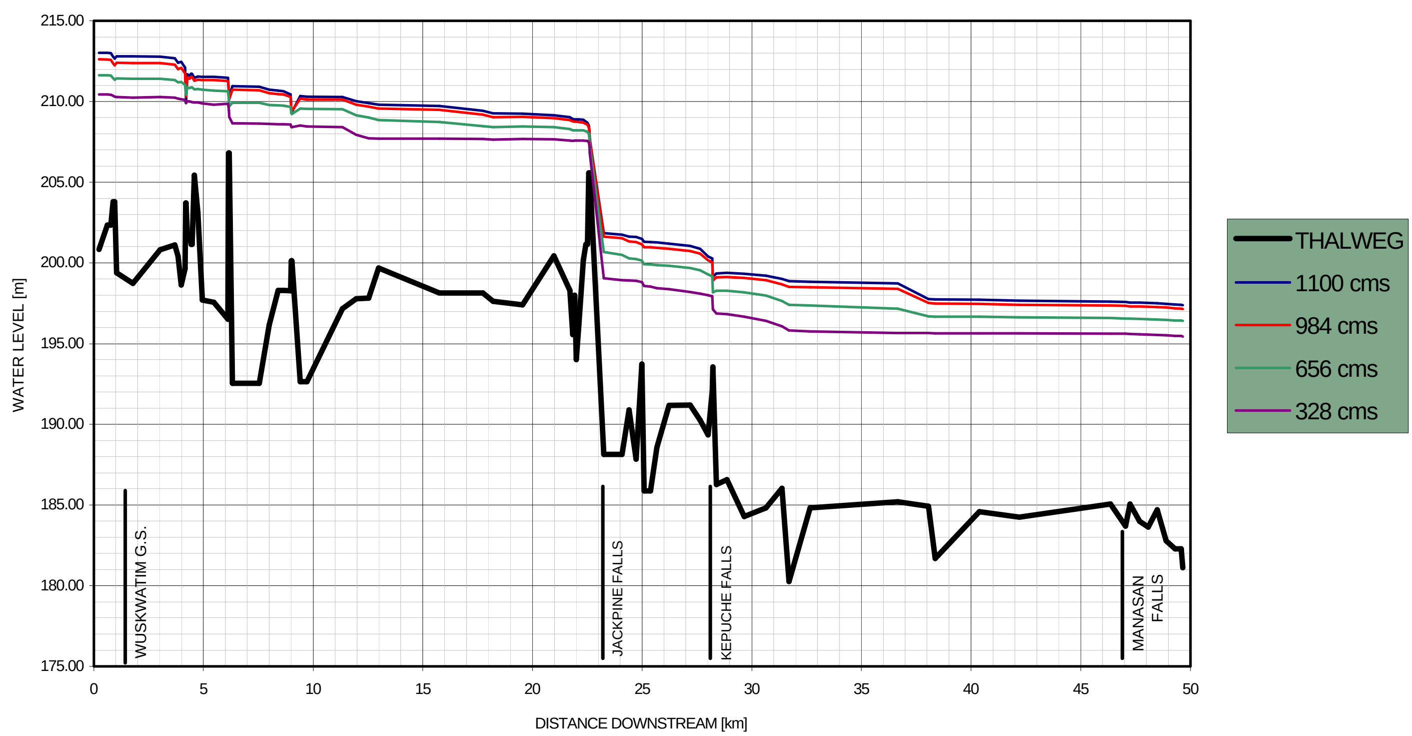


Figure A4.6-7 Maximum Winter Water Surface Profiles - Taskinigup Falls to Manasan Falls Reach - Project Inflow Conditions

A4.6 - 3.0 DYNAMIC MODELLING

A4.6 - 3.1 GENERAL

The Project will operate under a modified run-of-river condition in which the forebay is drawn down and reponded on a daily basis. That is, plant discharges will vary on a daily basis resulting in daily water level fluctuations downstream of the plant. In order to predict the magnitude of variation at downstream locations under winter conditions, the ICEDYN computer model was setup, calibrated, and run to simulate 86 years of daily plant operation.

A4.6 - 3.2 ICEDYN MODEL

The ICEDYN model is a powerful ice simulation model, derived from the earlier ICESIM model developed for use on the Nelson River. Like its predecessor, the ICEDYN model is fully capable of simulating typical ice formation processes, including ice generation, deposition, advancement, shoving and thickening. However, in addition, the program is capable of routing river flows in a fully dynamic mode. It does so through a solution of the St. Venant equations of unsteady fluid flow. For this study, the model was also refined to represent staging due to anchor ice along a river reach - an important addition given the predominance of anchor ice accumulations along the Burntwood River.

A4.6 - 3.3 MODEL SETUP

Like ICEROUT, the ICEDYN model was set up to represent the entire river reach, from the Wuskwatim tailrace down through to the First Rapids site. Cross sections for the simulation were derived directly from existing backwater datasets of the reach. In total, 94 cross sections were utilized in the reach from the Project to the Manasan ice control structure, and an additional 135 cross sections were utilized to model the reach from Manasan Falls down to First Rapids. These cross sections were surveyed as a part of earlier hydrometric surveys.

Following its initial setup, the model was calibrated to match open water rating curves previously derived at a number of specific locations along the river reach using an open water backwater model. After obtaining a suitable match under open water conditions, the model was then configured to simulate the development of an ice cover on the downstream reach, and compared to results obtained in earlier ICEROUT simulations under a constant winter flow condition. Ice parameters for the model were selected based on earlier parameter sets identified in analyses undertaken with the ICEROUT model, and adjusted as necessary to match earlier ICEROUT results. Overall the match was reasonably good. However, given the complexity of ice conditions in the reach, and slight variations in model algorithms, some minor differences between the two models were noted in areas of significant ice accumulation, such as Opegano Lake. This is not unexpected, and generally amounted to only a few tenths of a meter.

The upstream boundary condition for the model consisted of a user defined flow hydrograph, which represents projected Wuskwatim plant outflows under a modified run-of-river mode of operation. These outflows were based upon the project inflow record for a simulated long term period from 1912 to 1997 (Section 4.3.1) Utilizing these predicted monthly flows, Manitoba Hydro generated a flow file representing the daily variation in outflows resulting from a modified run-of-river mode of operation. These outflows were based on a 10 minute time step.

The downstream boundary condition for each model consisted of a known stage/discharge relationship. Air temperature sequences utilized in the model for this long term simulation were based on average winter temperatures, derived from an analysis of meteorological data collected at the Thompson airport. The simulation was conducted based on a ten minute time step for the entire 86 year record. Each run proceeded from October 1 in year Y-1 , through to completion in April of year Y.

The model was adjusted to simulate the effects of anchor ice at a number of locations along the reach. This adjustment included the addition of a user defined anchor ice pattern, input by the user, and derived based on past experience and observations.

A4.6 - 3.4 RESULTS

Following its setup, the ICEDYN model was used to simulate daily plant operation, and the resulting impact on downstream water levels as the ice cover forms each winter. The results of the 86 years of simulation were summarized on a series of plots depicting the frequency of stage variation magnitude at specific sites along the river reach. Anticipated stage variation at the Wuskwatim Tailrace, Opegano Lake, and Birch Tree Lake are illustrated in Figures 4.3-28,29,30,Section 4.3.4.2.

As shown in the figures, under winter operating conditions the water level and flow effects resulting from the daily operation of Wuskwatim GS are diminished as they reach Opegano Lake, and eventually Birch Tree Lake. The maximum stage variation occurs in the Wuskwatim tailrace, while variations in the level of Opegano Lake are considerably reduced.

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5.0 ICE PROCESSES

5.1 INTRODUCTION

Developing a good understanding of **ice processes** is an important part of any Hydro Power Planning study for a development located within a northern climate. Ice processes along the Burntwood River were studied to:

- understand current ice processes along the water way;
- predict future ice process associated with change in water regime associated with the Project and its operation;
- estimate winter water levels associated the Project operation;
- assist in development of construction management strategies;
- provide input into power and energy calculations; and
- provide input into environmental studies.

Ice processes have been studied in detail for the past 30 years along the Burntwood River. These studies have included the development of i) a comprehensive field observation program, and ii) detailed **numerical models**, which have been successfully used to simulate the complex ice conditions along the river (Appendix A4.6). The following sections summarize the existing ice regime of the Burntwood River (which includes the Wuskwatim Lake area) and how the current ice regime is expected to change as a result of Project construction and operation.

5.2 APPROACH AND METHODS

To understand and document ice formation processes on the Burntwood River system, a comprehensive **hydrometric monitoring program** (Appendix A4.2) was established, with data collected during the winter months from November through to March. The winter portion of the program was initiated in the early 1970's. Data collected each winter as part of the hydrometric monitoring program includes:

- photographic records of ice cover development;
- periodic observations of ice cover progression and anchor ice formation along the reach;
- surveyed measurements of the length and thickness of developing ice dams;

- border ice measurements
- measurements of ice and snow depth;
- flow metering;
- water level measurements; and
- temperature records.

Based on this information, detailed **numerical ice models** were developed and **calibrated** to simulate the formation of the ice cover and its growth throughout the winter (Crippen Acres 1987; Acres Manitoba 2003, Appendix A4.6). Using actual daily temperature and flow data, the models were calibrated to match observed field conditions. Once calibrated, the model was used to assess how the nature of the ice cover may vary depending on the severity of the winter air temperatures, and winter flow scenarios. Data from the hydrometric monitoring program and ice model has been used to assess current ice formation processes along the Burntwood River (Section 5.4), and has been used to predict potential changes to these processes as a result of the Project (Sections 5.5 to 5.7).

5.3 OVERVIEW OF ICE PROCESSES

In a typical northern river, an ice cover will begin to form with the onset of cool winter temperatures. The nature of the cover will vary with location and water velocity, but generally can be described as either a smooth "lake ice" or a rougher more dynamic "river ice". Lake ice usually forms in areas of very low velocity, such as lakes, or deep, slow-moving river sections. It forms when cold air temperatures cool the water surface to freezing at the beginning of the winter. This type of ice cover forms very quickly, often within the span of a single night, and grows steadily in thickness with time. The thickness of lake ice is primarily governed by air temperature and the depth of snow cover on the ice. If the snow cover becomes excessively deep, it can weigh the ice cover down causing it to sink below the water surface. This can cause cracks to form in the ice, allowing water to flood over the ice surface creating "slush" on the lake. Cracks can also form in an ice cover due to thermal contraction of the ice.

River ice forms in more swiftly moving sections of a river, and the nature of the ice cover will be significantly different from lake ice. In these areas, the ice cover will evolve based on four basic processes, as itemized below, and as described in more detail below:

- ice generation (frazil);
- ice front progression and formation of hanging ice dams;
- border ice formation; and

- anchor ice formation.

Ice generation (production) takes place in the moving open water sections of a river reach. With the onset of winter, water temperatures within the river begin to fall, and eventually drop to near freezing. When the temperature drops below freezing, small ice crystals begin to form throughout the water depth. These small crystals, known as **frazil ice**, resemble fine snow crystals and are fairly adhesive in nature, and attach to solid objects and each other. They gather together (or **agglomerate**), and eventually rise to the surface to form ice pans. These pans drift along the water surface, and in turn join together forming larger ice sheets.

Where ice pans and ice sheets encounter an existing ice cover, such as at a lake, they begin to accumulate, and the cover begins to advance upstream. The upstream end of an advancing ice cover is called the **ice front**. If flow velocities at the ice front are low enough, the ice cover will continue to advance upstream through the accumulation of these sheets and pans - a process known as juxtaposition. However, if the advancing cover reaches a section of high velocity, the cover “stalls”, and the ice pans begin to be drawn down under the cover and accumulate there. This formation is referred to as a hanging ice dam, and creates a restriction in the flow area which can result in a substantial rise in water level as the ice cover grows and thickens progressively over the winter. Figure 5.3-1 illustrates a typical hanging ice dam formation.

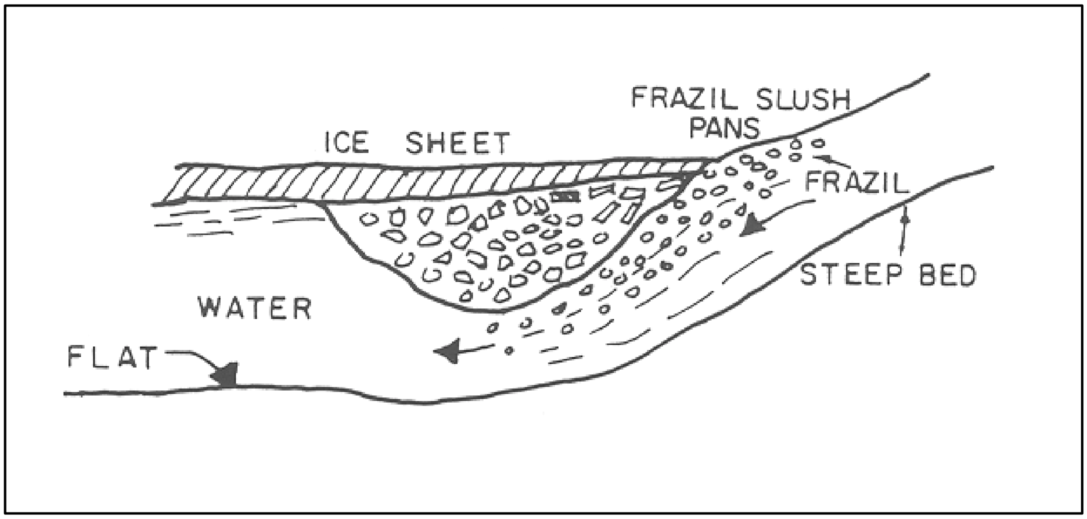

Figure 5.3-1. Typical hanging ice dam

Border ice forms along the shoreline of a river, where velocities are low. The overall process by which border ice forms is similar to that described for lake ice. Lateral growth rates are sometimes augmented as drifting ice pans attach to the shorefast ice. Throughout the winter, border ice will continue to grow by these processes, gradually reducing the area of open water. In particularly low velocity locations, the border ice forming along each shore may eventually grow together, creating an ice bridge and hence an ice front against which drifting ice floes can begin to accumulate. The extent of border ice formation is governed by the flow velocity, river geometry, and winter temperatures. Figure 5.3-2 illustrates a typical border ice growth formation.

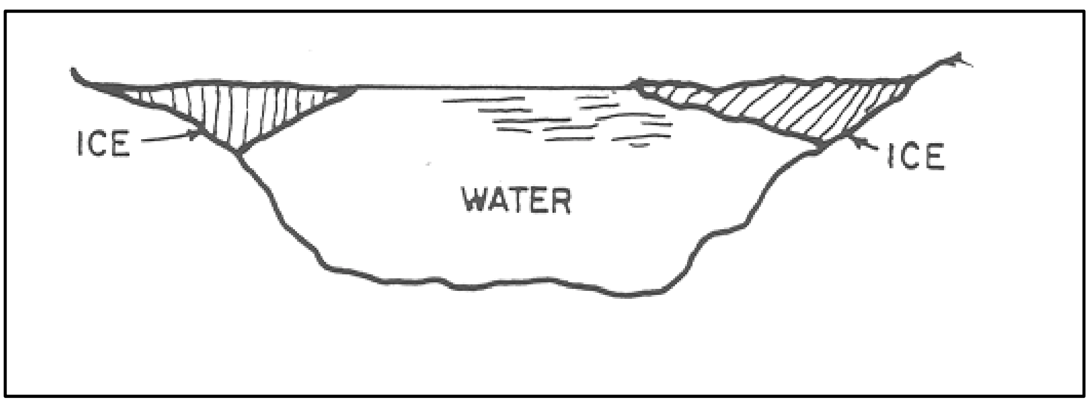

Figure 5.3-2. Typical border ice growth.

Anchor ice typically forms on the river bed at locations that are shallow and flowing rapidly, such as at the "brink" of a set of rapids or a waterfall. At these locations, the turbulent, high velocity flow causes mixing of the newly formed frazil ice. The frazil ice comes into contact with solid objects on the riverbed, such as rock, and attaches to the material. As this ice mass slowly grows, it begins to constrict or block the river channel, and can result in a substantial rise in upstream water levels. Figure 5.3-3 illustrates a typical anchor ice accumulation.

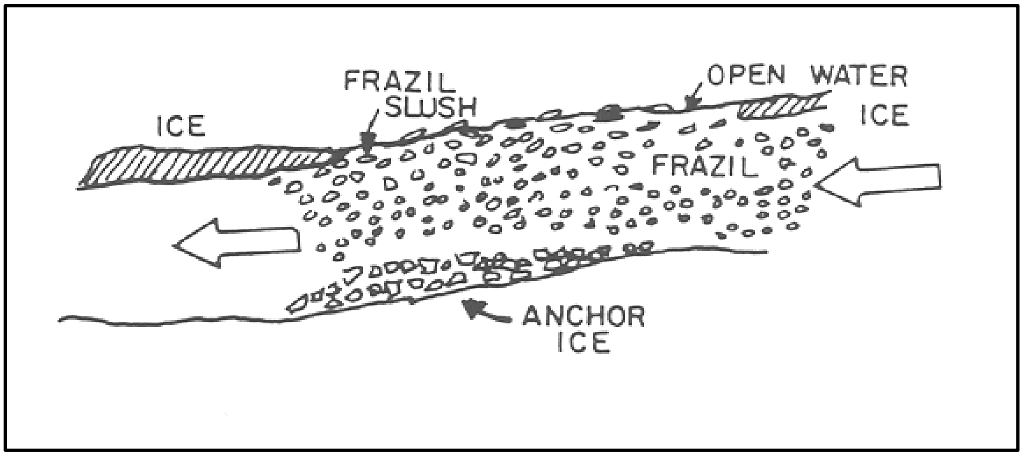

Figure 5.3-3. Typical anchor ice accumulation.

5.4 EXISTING ENVIRONMENT

The Rat-Burntwood River drops approximately 90 m along its course between the Notigi Control Structure and its downstream confluence with the larger Nelson River at Split Lake. The river reach is characterized by a series of lakes, separated by river reaches that are **hydraulically controlled** by narrow constrictions and rapids sections. (Figure 4.1-1)

Ice formation on the Burntwood River is a relatively complex process, and has been studied for many years (Section 5.2). In this section, ice processes are described for the reach of the Burntwood river between Threepoint Lake and Birch Tree Lake. This reach of river is predominantly within the zone of influence of the Project.

5.4.1 Ice Formation on CRD

As described in Section 5.4, the Burntwood River waterway is comprised of a number of lakes separated by river reaches that are hydraulically controlled by narrow constrictions and rapids. Therefore, the present winter regime consists of fast flowing river reaches, which remain ice free, and connecting lakes or slow velocity reaches which freeze over early in the winter. Each year, a competent ice cover quickly forms on major lakes in this reach, including Wapisu Lake, Threepoint Lake, Wuskwatim Lake, Opegano Lake, and Birch Tree Lake. Other sections of the river remain open, and produce large volumes of frazil ice, which either accumulates on the leading edge of the downstream ice cover, resulting in advancement of the cover upstream, or deposits under the cover forming a hanging ice dam.

Major ice processes observed along the river, from Threepoint Lake to the Manasan Falls site, are briefly described under the two sub-reaches below:

Threepoint Lake to Wuskwatim Lake

- Each year, a competent ice cover quickly forms on most of Threepoint Lake.
- The river reach between the Threepoint Lake outlet and God's Rapids generally remains open, but exhibits heavy border ice growth. The formation of this border ice slowly reduces the open water area as winter progresses. Under cold winters and/or low diversion discharges, this border ice growth has sometimes completely closed across the river.
- The river reach between God's Rapids and Early Morning Rapids, shown in Figure 5.4-1, remains open throughout the winter period, generating large volumes of frazil ice. This ice collects in a large hanging ice dam at the foot of Early Morning Rapids, causing upstream water levels to increase significantly in this area. The size of this ice dam will vary with the severity of a given winter season - long cold winters produce larger, thicker ice dams. In addition, the frazil laden water causes anchor ice to build up at three locations along the reach: God's Rapids, Upper Caribou Rapids, and Early Morning Rapids. Photographs of each of these anchor ice locations are shown in Figures 5.4-2, 5.4-3, and 5.4-4 respectively. As the anchor ice accumulates over the winter, flow capacity at these locations is restricted, and results in increased water levels upstream of each site. The growth of anchor ice at God's Rapids causes winter staging of Threepoint Lake and Footprint Lake levels. The ice dam forming at the foot of Early Morning Rapids typically results in an increase in the water level at the foot of the rapids of up to 3 m. However, even with this stage increase, the ice dam is unable to drown out the control at Early Morning Rapids or advance any further upstream. Water levels on Threepoint Lake are not affected by the formation of this ice dam, but are controlled by anchor ice growth at God's Rapids and ice cover formation between Threepoint Lake and God's Rapids.
- Wuskwatim Lake (including Cranberry Lakes) forms a strong, competent ice cover each winter.

- The ice processes along this reach were numerically modelled (Appendix A4.6), and the results of a typical simulation are presented in Figure 5.4-5. This figure illustrates a typical winter water surface profile along this reach of river, and represents conditions in the reach during February of 1996, when Burntwood River flows were estimated to be approximately 795 m^3/s. Also shown on the plot for comparison is the corresponding water surface profile under open water conditions, and a number of the observed water levels along the reach. The close match obtained between observed and computed water levels demonstrates the ability of the numerical model to represent ice conditions along the reach. Also shown on the figure is the large ice dam forming at the base of Early Morning Rapids. Note the water levels staging at God's Rapids that cause the higher water levels on Threepoint Lake in the winter.

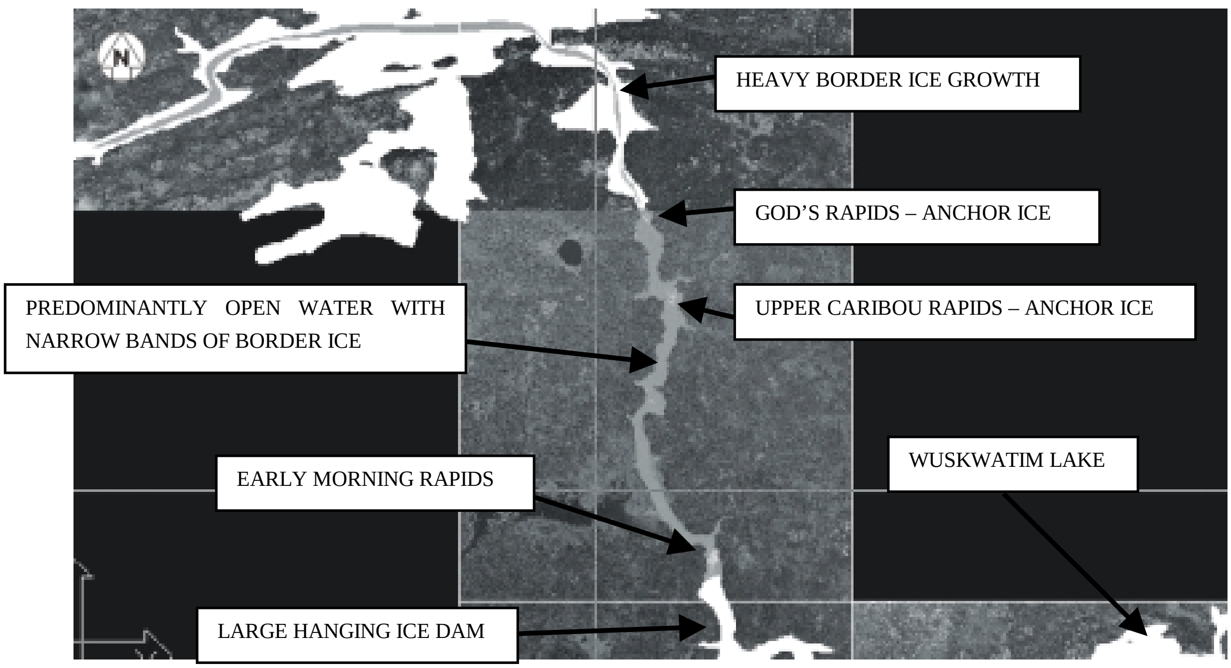

Figure 5.4-1. Ice processes from Threepoint Lake to Wuskwatim Lake.

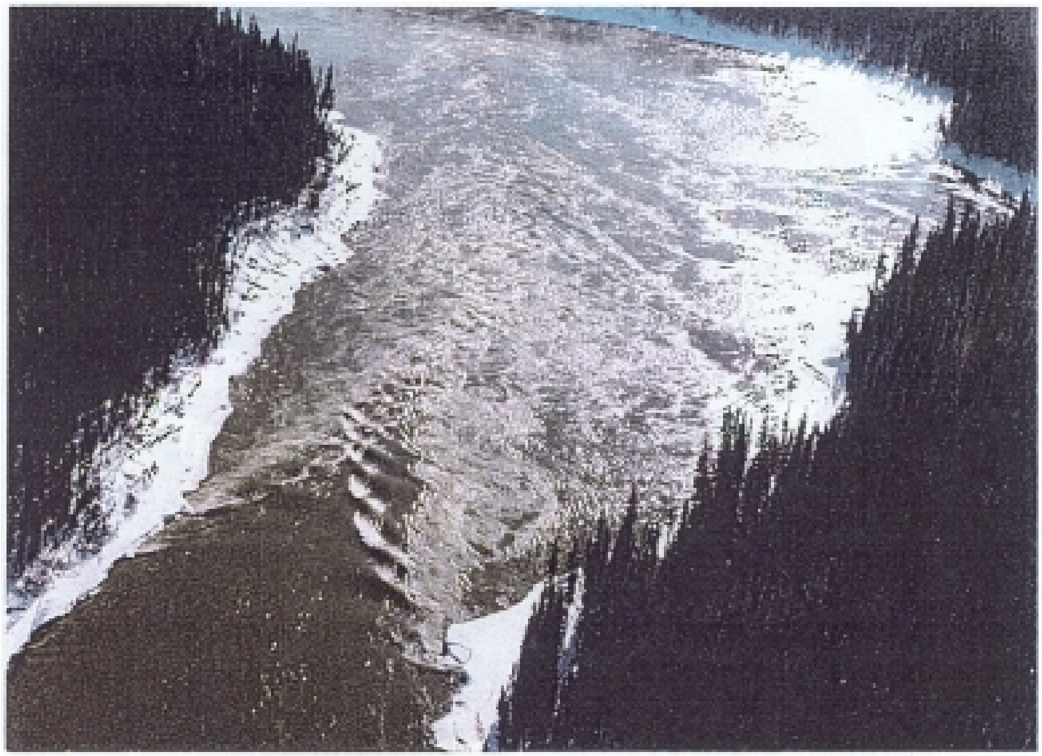

Figure 5.4-2. Site photograph: God's Rapids.

Figure 5.4-3. Site photograph: Upper Caribou Rapids.

Figure 5.4-4. Site photograph: Early Morning Rapids.

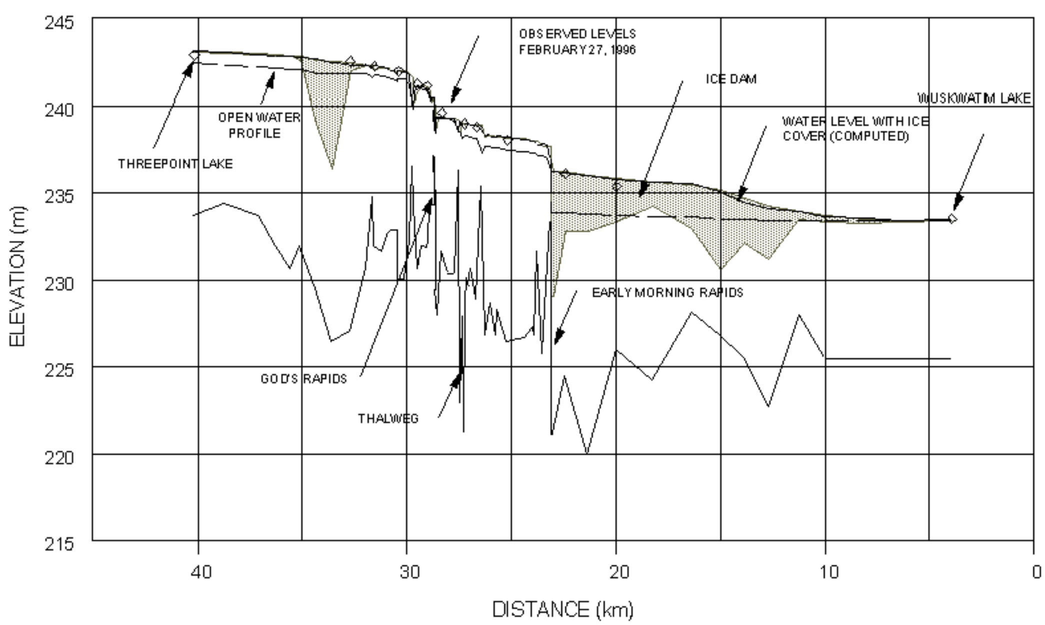

Figure 5.4-5. Water surface profile: winter flow of 795 m^3/s. (Appendix A4.6).

Wuskwatim Lake to Manasan Falls

- Each year, a competent (or strong) lake ice cover quickly forms on major lakes in this reach - specifically on Wuskwatim Lake, Opegano Lake, and Birch Tree Lake.
- As shown in Figure 5.4-6, the river remains predominantly open in the reach between Wuskwatim Falls and Opegano Lake, with varying extents of border ice formation along this reach. During especially cold winters, and/or low diversion flows, there are some low velocity locations along this reach that may close and form a short, poor quality ice cover.

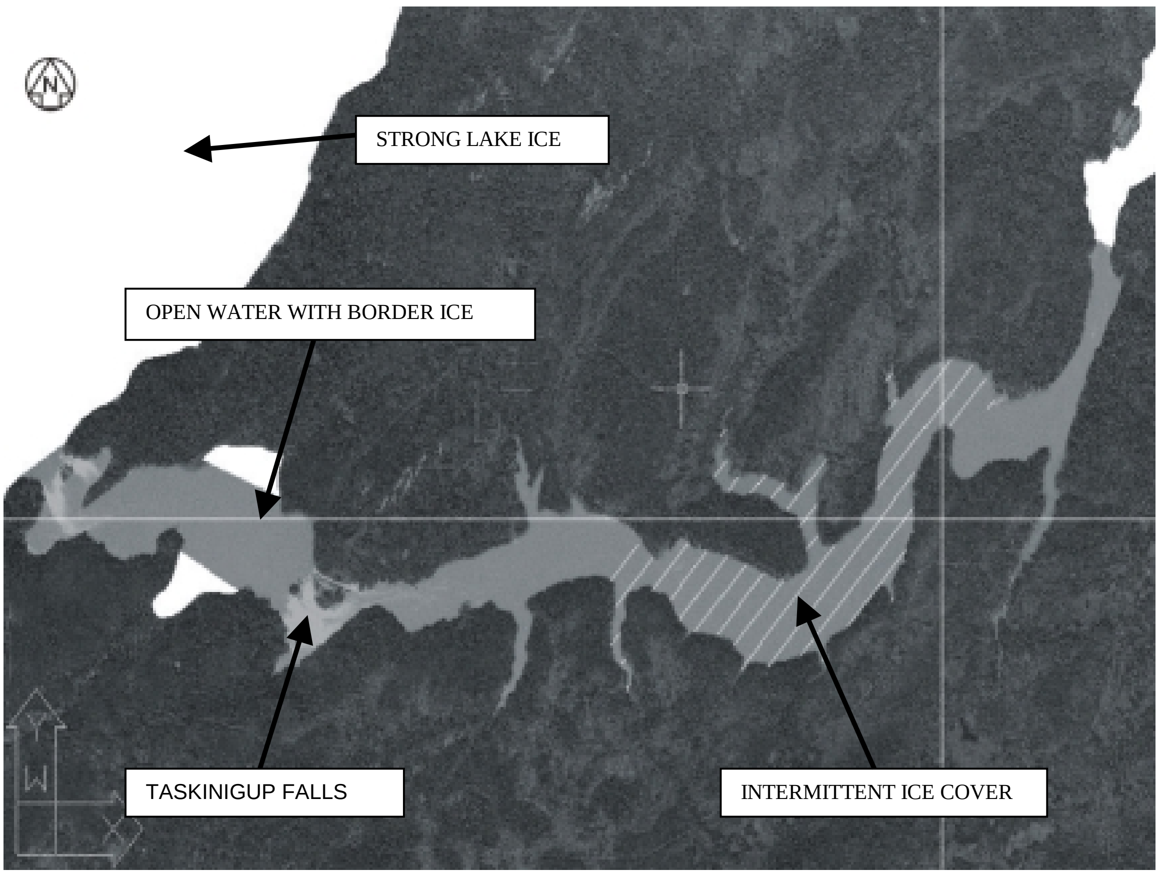

Figure 5.4-6. Ice processes downstream of Wuskwatim Lake.

- The reach of open water upstream of Opegano Lake generates significant volumes of frazil ice that is swept downstream (Figure 5.4-7). This ice is deposited as a large hanging ice dam that forms at the inlet to and through Opegano Lake each year. Although the size of the ice dam will vary from year to year depending on the severity of the winter, the local increase in water level at the hanging dam site is not severe enough to affect tailwater levels at the site of the proposed Wuskwatim Generating Station. However, as shown later in Figure 5.4-9 below, this hanging dam is of a considerable size, and may be over 5 m thick in some locations. The size of this dam can affect the amount of staging on Opegano Lake, particularly at the upstream end of the lake.

- Anchor ice has been observed to form at a number of locations along this reach, in particular at shallow sections near Little Jackpine Rapids, at Cross Section 20EW, located approximately 1 km downstream of Little Jackpine Rapids, at Jackpine Falls, and at Kepuche Falls. The anchor ice accumulations at both Little Jackpine Rapids and Cross Section 20 EW are the primary source for the increase in tailwater level experienced at the Wuskwatim site during the course of the winter.

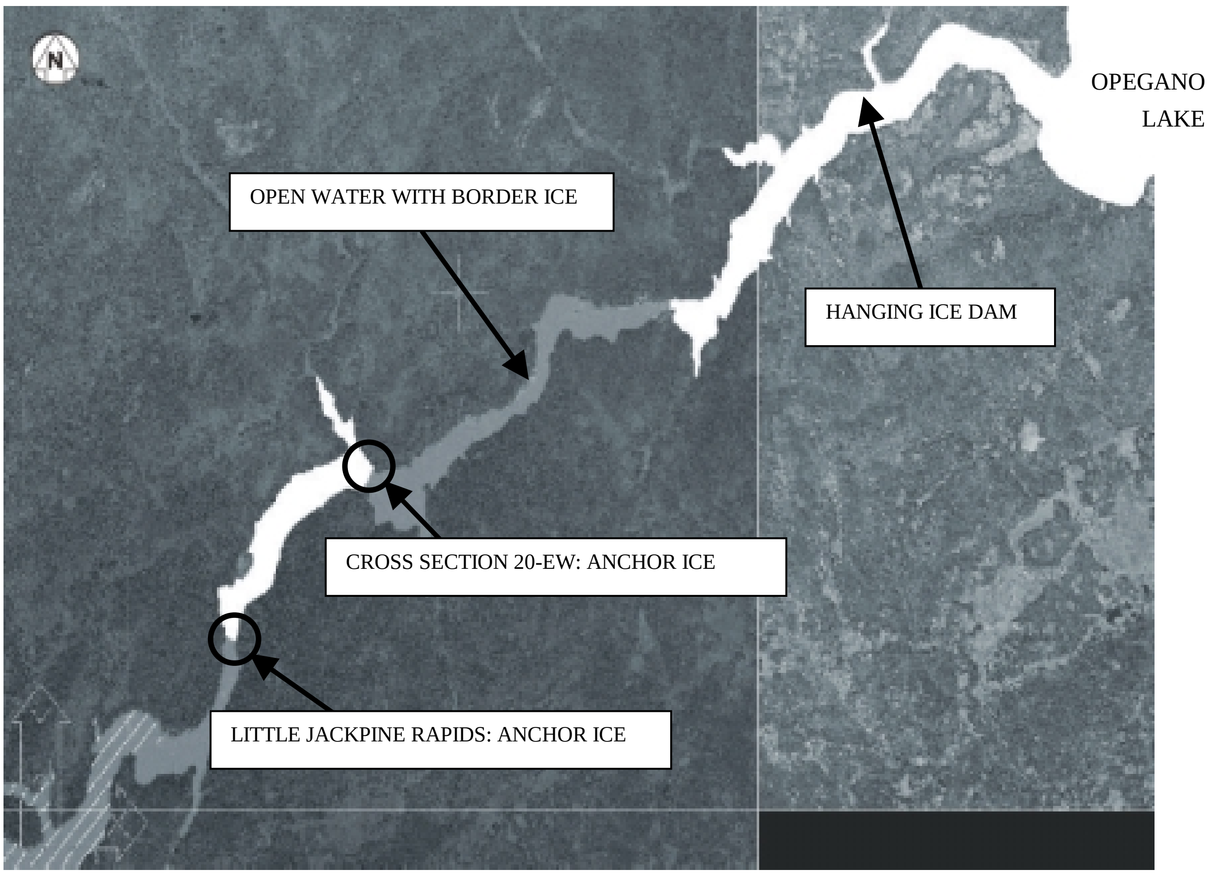

Figure 5.4-7. Ice processes upstream of Opegano Lake.

- As shown in Figure 5.4-8, the reach of river from the outlet of Opegano Lake to Kepuche Falls typically remains open for most of the winter, producing large volumes of frazil ice. This ice is deposited in an ice dam which forms immediately downstream of Kepuche Falls. The formation of this dam can result in local water level increases of 1 to 2 m, depending on the severity of the winter. The river reach from Kepuche Falls through Birch Tree lake, to the Manasan Falls ice control structure forms a solid ice cover relatively quickly each winter.

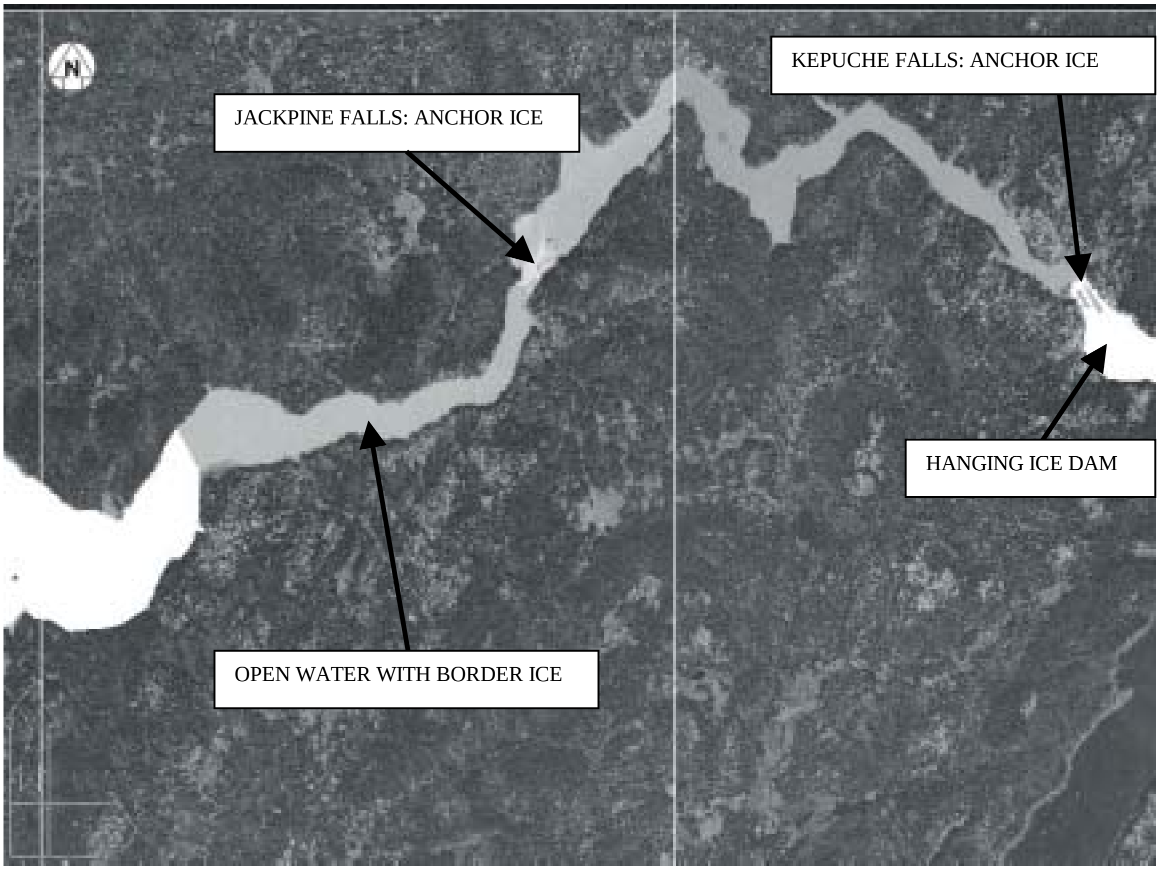

Figure 5.4-8. Ice processes from Opegano Lake to Kepuche Falls.

- The ice processes along this reach were numerically modelled (Appendix A4.6), and the results of a typical simulation are presented in Figure 5.4-9. This figure illustrates a typical winter water surface profile along this reach of river, and represents conditions in the reach during January of 1990, when Burntwood River flows were estimated to be approximately 950 m^3/s. Observed water levels along the reach are also shown for comparison, along with the corresponding water surface profile under open water conditions. The close match obtained between observed and computed water levels demonstrates the ability of the numerical model to represent ice conditions along the reach.

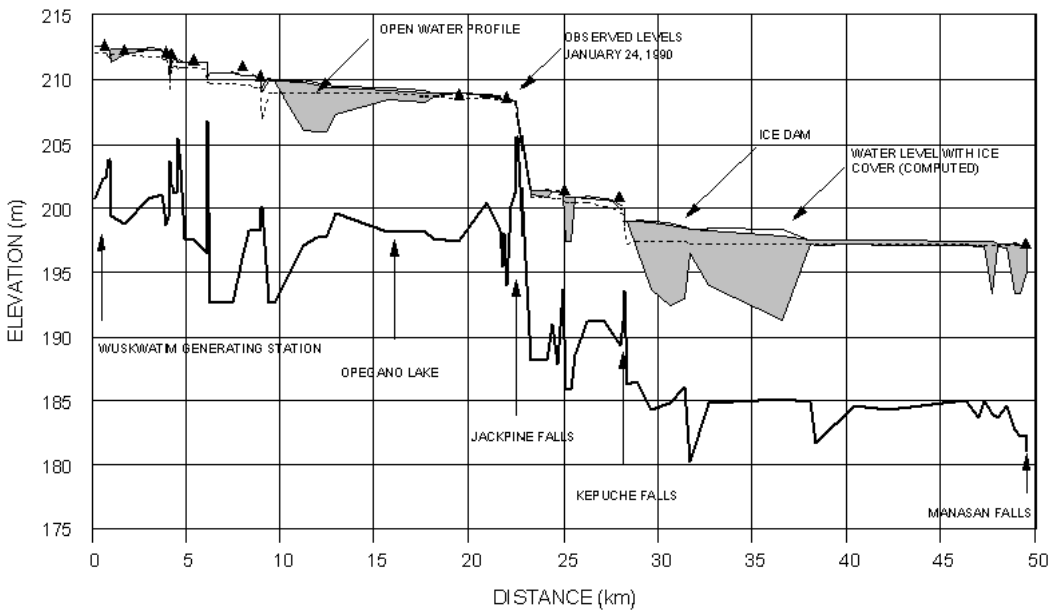

Figure 5.4-9. Water surface profile: winter flow of 950 m^3/s.

5.4.2 NCN Ice Issues

The concern over winter ice conditions has been expressed in several of the northern First Nation communities. Ice conditions such as thin ice, slush ice and hanging ice (air gaps between the bottom ice layer and the water surface) have been identified as specific areas of concern, along with open water conditions and incomplete freezing of the surrounding creeks. All these conditions restrict access to valuable resource sites, resulting in increased travel times and significant safety hazards (Remnant *et al*. 2002). A heavy snow cover can sometimes cause slush ice conditions, as was previously discussed in Section 5.3.

Over the years Manitoba Hydro has worked collaboratively with many northern First Nation communities to maintain safe ice trails including NCN. In 1996, Nelson House activities were formally codified in the 1996 NFA Implementation Agreement. Article 2.7 of this agreement outlines the safety measures that Manitoba Hydro shall implement or continue; the specific relevant articles that relate to ice safety are outlined below. Hydro funds these activities and uses local contractors or resource users to implement:

- annual preparation, marking and maintenance of ice crossings and main trails on the ice in the locations detailed in Figure 5.4-10;

- monitoring the safety of ice crossings when reasonably required in the winter period;
- posting notices with respect to changing ice conditions and vehicle load limits on any ice crossing;
- conducting annual public meetings to provide information to Members on safe use of ice crossings; and
- removal of debris at shoreline locations where winter ice trails intersect the shoreline and a hazard to access exists.

As part of a general opinion survey conducted between July 30 and September 28 in 2001, respondents were asked to assess the safety measures Manitoba Hydro has implemented to deal with the ice issue. In total 175 band members were polled. The issue of protecting navigation and safety was assigned the highest grade on a scale of importance by 93 percent of respondents (Dimark and Intergroup 2000). Three separate measures were defined for respondents to comment on:

- preparing and maintaining ice crossing and trails;
- monitoring ice safety; and
- providing notices on ice conditions and load limits.

Respondents were asked to grade each measure as being “effective”, “somewhat effective”, “not effective” or “don’t know”. Approximately 60 percent of respondents gave all three measures an “effective” grade, while approximately 10 percent felt these measures were not being implemented successfully.

5.5 EFFECTS ASSESSMENT AND MITIGATION

During construction of the Project, and following it’s completion, ice processes in the affected reach of the Burntwood River will, for the most part, remain unchanged from the existing condition. The following sections provide more detail on anticipated effects both during construction and operation.

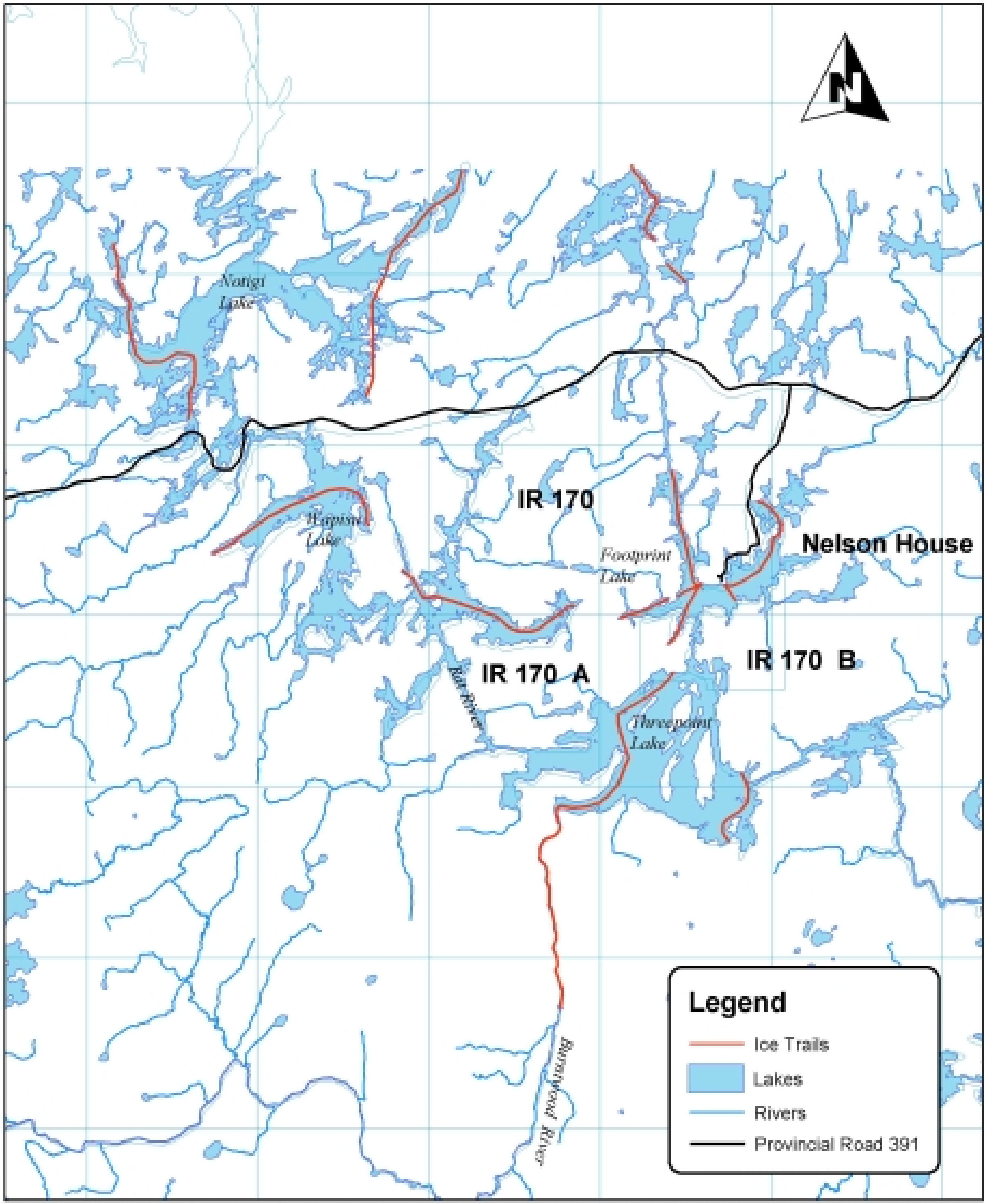

Figure 5.4-10. Ice trails funded by Manitoba Hydro under NCN 1996 NFA Implementation Agreement.

5.5.1 Construction

The construction and **river management** of the project will be undertaken in two major stages (Volume 3, Section 4). In the first, **Stage I Diversion**, river flows will remain in the natural river channel while the Project's primary concrete structures are constructed on the north bank. The construction of the upstream Stage I Cofferdam will result in a small increase (approximately 0.7 m) in water level in the reach between Wuskwatim Falls and Taskinigup Falls, but this will not effect natural ice processes in the reach. Likewise, in the downstream reach, ice processes will be unchanged from existing conditions.

During the second phase of construction, **Stage II Diversion**, the river will be closed and all flows will be diverted through the completed Spillway, as the Project's main dam is constructed. The main dam will be completed prior to the onset of winter, and the intermediate forebay between Wuskwatim Falls and Taskinigup Falls will be impounded in the fall to it's FSL. The spillway will then be used to divert the river during one full winter as the powerhouse is completed. During this time, water levels along the reach between Wuskwatim Falls and Taskinigup Falls will be approximately 7 m higher than what presently occurs, velocities will be low (Section 4), and a stable ice cover will form over most of this reach, with the exception of the river reach in the immediate vicinity of Wuskwatim Falls. Ice processes in the downstream reach will be unchanged from existing conditions.

5.5.2 Operation

Following completion of the Wuskwatim Generating Station, ice processes in the hydraulic zone of influence of the Burntwood River will, for the most part, remain unchanged. CRD Hydrometric Monitoring studies will continue during the operation of the facility, to gather additional data on these post-development ice conditions. The following sections describe the potential future ice regime.

5.5.2.1 Upstream of Wuskwatim Lake

Winter water levels on Threepoint Lake will be unaffected by the operation of the Wuskwatim GS. Anchor ice will continue to form at God's Rapids, Caribou Falls and Early Morning Rapids, and a hanging ice dam will continue to form at the base of Early Morning Rapids. However, this hanging dam will not be appreciably different in size or nature following construction of the Wuskwatim GS. The ice dam will be unable to **drown out the control** at Early Morning Rapids or advance any further upstream. Therefore, Early Morning Rapids forms the upstream limit of the hydraulic zone of influence for the Wuskwatim reservoir, even under low flow conditions. Figure 5.5-1 illustrates the anticipated water surface profile along this reach during winter for both pre and post project conditions. Shown for comparison are both the pre and post-Project development profiles for a relatively low flow of 548 m^3/s, representing the 5 percentile inflow based on the historical water regime. As seen in the Figure, under the post-Project condition with Wuskwatim Lake near el. 234.0 m, water surface levels between Early Morning Rapids and Wuskwatim Lake (Wuskwatim Lake included) with the Project will be higher than without the Project by approximately 1 m. However, water surface profiles are identical upstream of Early Morning Rapids for both conditions, illustrating the natural control exhibited by Early Morning Rapids, Caribou Falls, and God's Rapids. Note that at higher flows, Wuskwatim Lake would actually be higher naturally, and the difference shown between the pre- and post-Project profiles in Figure 5.5-1 would actually decrease.

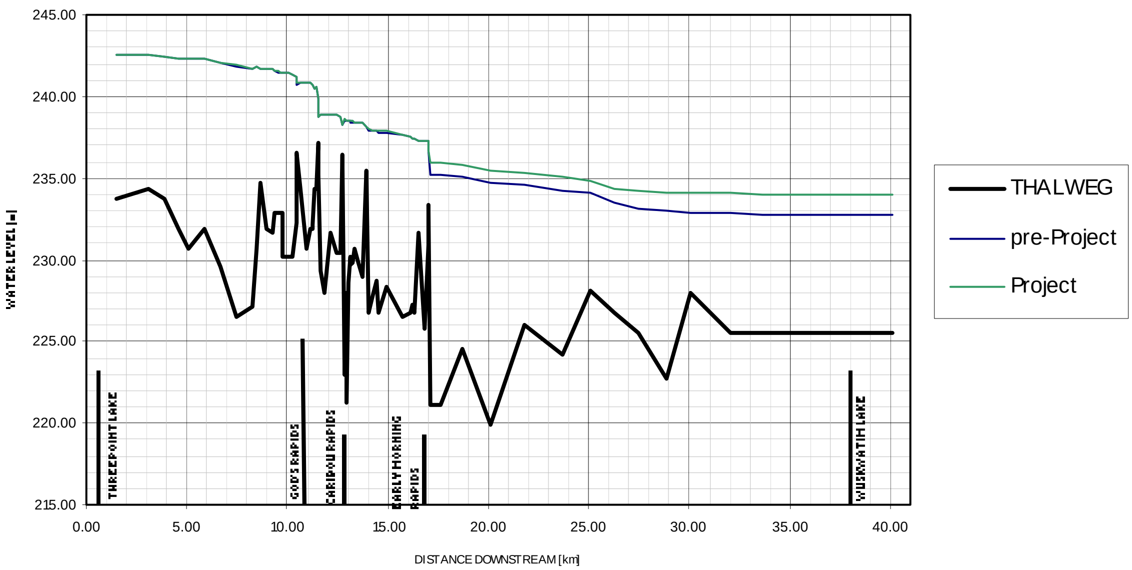

Figure 5.5-1. Pre-Project and Project winter water surface profile upstream of the Project site (flow of 548 m3/s)

5.5.2.2 Wuskwatim Lake

Under existing conditions, Wuskwatim Lake develops a solid ice cover each winter season, and this will also be the case following completion of the Wuskwatim Generation Project. Wuskwatim Lake water levels will be slightly higher than present winter levels as the project will stabilize Wuskwatim Lake at el. 234.0 m. A partial ice cover is anticipated to form over the short reach between the Wuskwatim Generation Project and Wuskwatim Falls. However, the site of the present Wuskwatim Falls and the proposed channel improvement excavation area will likely remain open over the winter season, due to the slightly higher flow velocities in these areas.

5.5.2.3 Downstream of The Project

Winter ice conditions currently experienced downstream of the Project are naturally variable, and as discussed in Section 5.4, depend on factors such as the magnitude of CRD flows, air temperature, and water temperature. With the operation of the Wuskwatim Generation Project, areas that currently remain open during the winter season are anticipated to remain open, and areas where an ice cover currently forms are anticipated to continue to form an ice cover. Locations of anchor ice accumulation are not anticipated to change. A large hanging ice dam will continue to form at the upstream end of Opegano Lake, and downstream of Kepuche Falls. These dams, however, will not affect tailwater levels at the Project site. Tailwater levels in the winter will be affected, as they are under the existing condition, by anchor ice buildup at Little Jackpine Rapids and Cross Section 20EW.

The operation of the Wuskwatim Generation Project as described in Volume 3 (Section 5) will result in daily flow fluctuations that could vary daily between 0 and 330 m^3/s (Section 4). These flow and water level fluctuations may lead to the cyclic breakage of some border ice growth in the reach between the Wuskwatim Generation Project and Opegano Lake but beyond that there is no change expected.

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6.0 WUSKWATIM LAKE EROSION

6.1 INTRODUCTION

Shore erosion is a natural process in lakes and reservoirs. Effects include recession of erodible banks, **nearshore downcutting**, deposition of eroded shorezone material in shallow nearshore and deeper offshore areas and transport of suspended sediment to lakes and downstream areas. A study has been undertaken to:

- assess ongoing shore erosion processes and **bank-recession rates** under existing conditions in Wuskwatim Lake;
- predict future bank-recession rates under existing conditions; and
- predict likely changes that may result from construction of the Project.

Products of this assessment are projected future shorelines in Wuskwatim Lake with and without the Project for 5, 25 and 100 years after the proposed in-service date of 2009 for the Project. The study also estimates the land area and volume of shoreline material that will be eroded over these time periods with and without the Project. Information from this study will be used in a terrestrial studies (Volume 6), and other physical environment studies: sedimentation and woody debris.

The study area for this assessment is shown in Figure 6.1-1. The study covers the Wuskwatim Lake shoreline and the surrounding lake shorelines of Cranberry Lake, Sesep Lake, and Wuskwatim Brook and the south arm of Wuskwatim Lake - an area collectively referred to as Wuskwatim Lake.

6.2 APPROACH AND METHODS

6.2.1 Overview to Approach

Shore erosion is a complex natural process involving many interrelated factors that may act alone or in combination (Section 6.3.1), including the following:

- variable wind and wave energy conditions;
- fluctuating lake levels;
- shoreline geometry in plan view and profile;

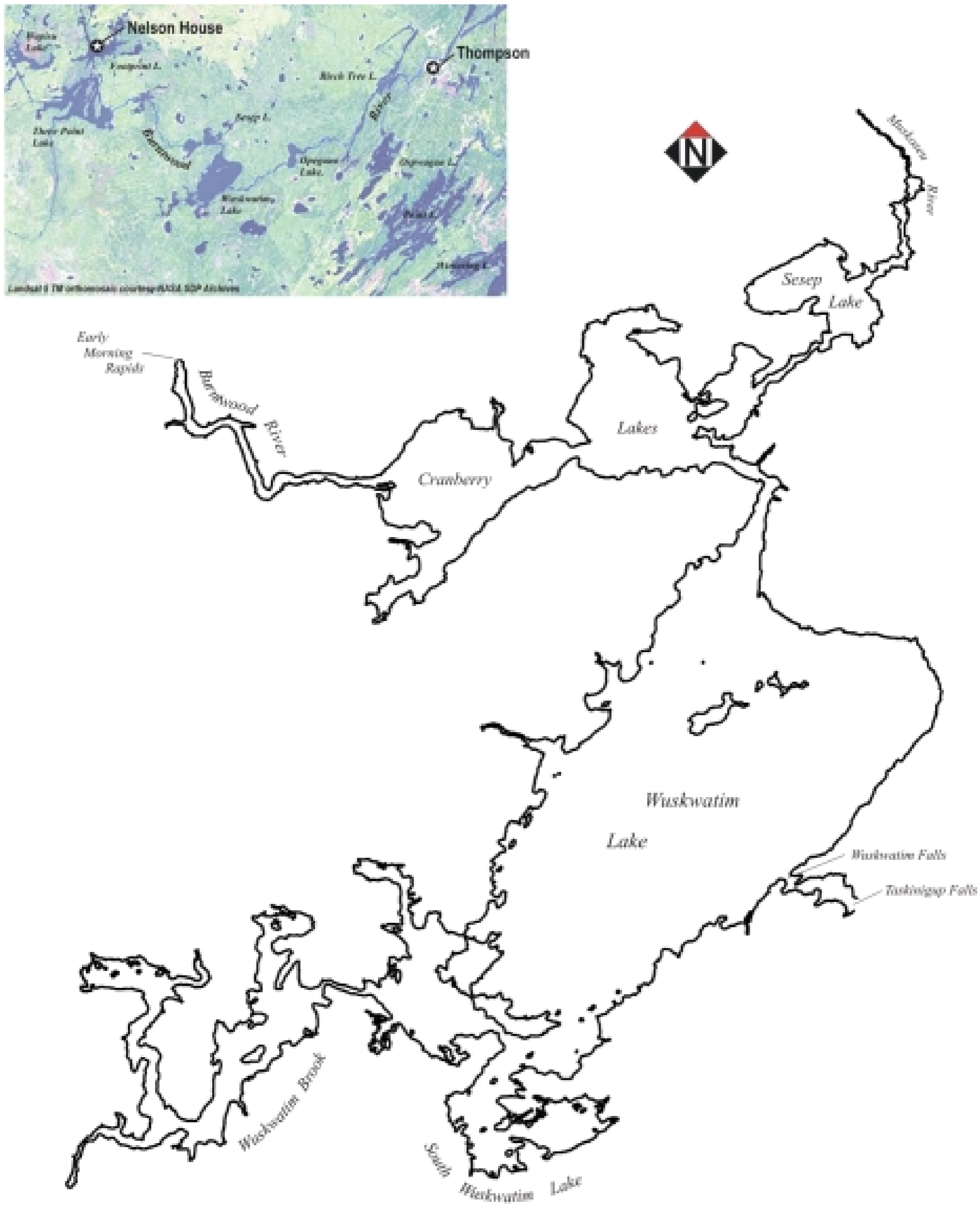

Figure 6.1-1. Location of Wuskwatim Lake and environs shoreline areas

- variable **bedrock** exposure around the shoreline;
- **permafrost** conditions;
- the presence of shoreline debris and other obstructions to incoming wave energy; and
- episodic bank failures.

These factors influence bank-recession rates under current conditions and in the future with or without the Project. Moreover, predictability of **temporal** and spatial changes in these factors over short to long time periods (i.e., 5 to 100 years) also varies. As a result of these difficulties, the approach taken was to base projection of future changes in shore erosion on past bank-recession rates measured under field conditions that are believed to be representative of future conditions with and without the Project.

Modelling studies estimate future bank-recession rates, land area loss and eroded bank material volumes based on field observations, historical erosion measurements and an understanding of erosion processes. Wind climate and the estimate of elevation of the clay/silt-bedrock interface around the shoreline are important factors in model projections. Reasonable effort has been made to accurately characterize these and other factors from available information (including other concurrent EIS studies) and current knowledge of erosion processes.

Model results reported here are considered to represent a conservative estimate of changes due to erosion under existing and post-project conditions. Actual recession distances at specific locations and times may vary from projected values if there are future changes in wind and storm conditions, in the degree of bedrock exposure along the shoreline, and perhaps other unforeseen factors.

The general approach used to assess shoreline erosion has three main components:

- classification of shorezone terrain conditions;
- estimating future bank-recession rates for different shoreline types, wave energy settings and time periods; and
- mapping projected bank recession lines in a geographic information system (**GIS**).

The following section provides the details to the above components.

6.2.2 Details to Approach

6.2.2.1 Shoreline Classification Methodology

A prerequisite to characterizing erosional conditions around Wuskwatim Lake with and without the Project is classification of the shorezone with respect to surficial materials, wave energy, bank height and erosion processes. Four main shoreline types were identified. These are:

- shorelines with erodible glaciolacustrine clay and silt banks;
- banks with **glaciolacustrine** clay and silt overlying non-erodible bedrock;
- non-erodible bedrock shorelines; and
- non-eroding **fen** and marsh dominated shorelines.

Glaciolacustrine shorelines were further subdivided into low gradient shorelines where little or no erosion is apparent, and shorelines with eroding banks. Shorelines with clay and silt overlying bedrock were divided into three categories (low, medium and high) depending on the elevation of the clay/silt-bedrock contact as discussed below.

In addition to shoreline types, the existing erosion condition was inferred from the available low-level helicopter video coverage. Erosion condition was mapped as being active, partially stabilized or non-eroding. Erosion conditions in the Wuskwatim Brook area were inferred from airphoto interpretation because helicopter video coverage was not available in this area. Bank height was mapped as low (<1 m), moderate (1-3 m) and high (>3 m). Low gradient shores are those with gently sloping nearshore slopes and no eroding bank.

Currently, Wuskwatim Lake varies between elevation 233 and 234.3 m for the most part. With the Project, water levels are expected to stabilize in the 233.75 to 234.0 m range, with a typical daily fluctuation of 0.06 m (Volume 3, Section 5.2). The clay/silt-bedrock contact elevations of low (l), medium (m) and high (h) were defined based on the current variation in water levels and the proposed future water level. That is, the “low” category has a bedrock contact of approximately 233.5 m, “moderate” at ~ 234 m, and “high” greater than ~234 m.

The Wuskwatim Lake shoreline was initially classified from interpretation of 1985 1:20,000 airphotos (JDMA 1993). For the present study, the 1993 shoreline classification was reviewed and the classification updated using 1999 and 2001 low-level shoreline video coverage, augmented by interpretation of 1985 and 1998 stereoscopic airphotos, and shoreline field data acquired in 2000 (Section 6.2.3). Since the FSL for the Project will be within the existing water level range, the same shoreline classification described above applies with and without the Project.

Another component of shoreline classification relates to the degree of exposure different shoreline types have to wave action or "wave energy". According to the *Glossary of Geology* (1972), wave energy is the capacity of a wave system (all waves reaching the shoreline) to do work. In the case of shoreline erosion, it refers to the ability of waves to remove sediment from the bank and nearshore slope. Wave energy is primarily a function of the wave height and wave period, which in turn are a function of wind velocity and fetch length (i.e., the length of open water over which the wind blows). Total wave energy reaching a point on the shore depends on the exposure a shoreline has to waves approaching from different directions. Deepwater wave energy refers to the energy of waves in relatively deep water. Effective wave energy is the wave energy reaching the shore and accounts for partial dissipation of deepwater wave energy in shallow water.

Deepwater wave energy at representative locations in Wuskwatim Lake was calculated by JDMA (1993). Wave energy was calculated using monthly average wind frequencies and velocities in up to seven fetch directions oriented in 22.5˚ intervals from the shore-normal fetch direction (i.e., the fetch direction that is perpendicular to the shoreline tangent at the point of calculation). The 22.5˚ interval is based on the halfway distance to the next compass interval. For example, winds measured from the east (E), i.e., 90˚, are actually measured over an interval +/- 12.25˚ from this bearing, which extends from halfway between ENE and E to halfway between E and ESE. Shorelines that are fully exposed to open water are subjected to wave energy from seven 22.5˚ fetch directions. Partially protected bays are exposed to waves approaching from fewer than seven 22.5˚ fetch directions.

Wave hindcasting charts from USCE (1977) were used to estimate the effective height and period of waves for different combinations of wind velocity and fetch length, and a standard wave energy equation (USCE, 1977) was used to calculate wave energies. Wind data recorded by Environment Canada at the Thompson, Manitoba, weather station was the source of wind frequency information because of its long term record. In 1997, a wind station was established at Wuskwatim Lake as part of Manitoba Hydro’s water level instrumentation data collection platform (DCP) for the lake. Calculated deepwater wave energies are subdivided into low, moderate and high categories according to the following criteria:

Low: ~ 10,000 tonne-metre/year/metre of shoreline;
Moderate: ~ 25,000 tonne-metre/year/metre of shoreline; and
High: ~ 40,000 tonne-metre/year/metre of shoreline.

6.2.2.2 Projected Bank Erosion Rates

Projected erosion rates with and without the Project are used to:

- map projected future bank positions for different time periods with and without the Project; and,
- calculate estimated eroded land areas and eroded bank material volumes.

The following methods were used to map projected future bank positions and to calculate eroded land areas and material volumes.

Projected future bank recession lines (with and without the Project) are based on expected long-term average bank-recession rates plus a 50% variability buffer determined from a statistical analysis of historical erosion rates measured in Wuskwatim Lake (Section 6.3.4). This is done so that projected bank recession lines represent the likely maximum extent of bank recession along the shoreline. Actual future bank recession is not expected to reach this maximum extent at most locations because of the natural variability in bank recession from point to point. Even so, it is impossible to predict where the maximum amount of bank recession will occur within a given shoreline reach, and where lesser amounts of bank recession will occur. The position of projected

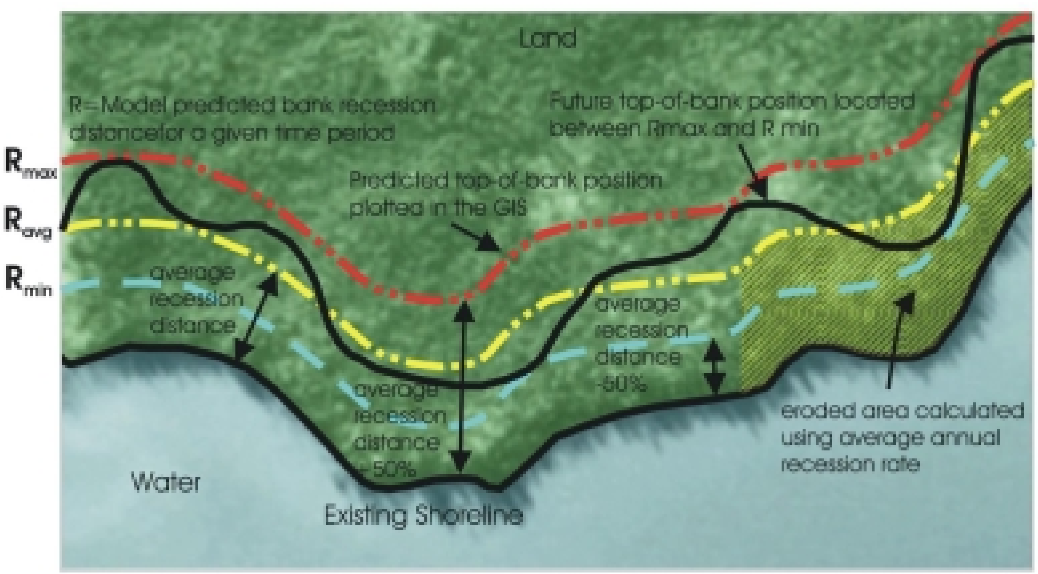

Figure 6.2-1. Schematic shorezone plan view illustrating the variability of shorebank recession and related terminology.

bank recession lines in relation to anticipated variability in bank recession along the shoreline is illustrated in Figure 6.2-1). A more conservative estimate of land area loss due to erosion can be estimated from the position of the projected future bank recession lines.

Calculation of eroded land areas and material volumes for Wuskwatim Lake are based on average annual bank-recession rates, also illustrated in Figure 6.2-1. In making eroded land area estimates, average annual bank-recession rates are used because, on average, as much of the shoreline will experience below average recession as will experience above average recession. Therefore, average annual rates without a **variability buffer** yield more realistic estimates of eroded land area than average annual rates with a variability buffer, as were used to plot maximum bank recession distances described above. Eroded bank material volumes are calculated as the product of eroded area and the bank height recorded for each shoreline unit. Estimated bank heights include a thin cover of organic material. Volume of eroded mineral soil is estimated by subtracting the volume of organic material, which is calculated as the product of eroded area and an estimated average organic layer thickness.

The following three sub-sections outline the approach used to determine appropriate future erosion rates for existing and post-project conditions.

Historical Wuskwatim Lake Erosion Data

The earliest erosion monitoring stations in Wuskwatim Lake were established by Manitoba Hydro in 1981. Two stations, designated EP2 and EP2A, were located on a small island in the northeast part of Wuskwatim Lake (Section 6.4.2.1). These stations were destroyed when the islands eroded away in 1984. A third station, designated AG3a, was located near Wuskwatim Falls. Erosion at this site had stabilized against bedrock by June 1987. The location of AG3a is also discussed in Section 6.4.2.1. In addition to these datasets, JDMA (1993) made airphoto measurements of pre-CRD and post-CRD bank-recession rates in Wuskwatim Lake for the periods 1950-1972 and 1978-1985, respectively.

In 1989, Manitoba Hydro re-established its erosion monitoring network in Wuskwatim Lake by developing five new sites distributed around the lake (ERP 1, 2, 3, 4, 5 Section 6.3.4). In 1992/93 the monitoring network was further expanded to include all of the currently monitored 15 sites discussed in Section 6.3.4. Monitoring sites established from 1989 on consist of a centreline profile as well as right and left offset profiles. In the initial years of monitoring (i.e., post 1989), data were collected annually. This has now been changed to a bi-annual collection frequency (Manitoba Hydro, 2001). The assessment of current condition erosion rates carried out in this study was based on data collected from 1989 to August 2000 (Manitoba Hydro 2001), which was the last report available during the time period of this study. Manitoba Hydro's erosion monitoring reports summarize measured bank recession distances and field observations.

Post-1989 Manitoba Hydro data were used to help estimate future erosion rates under current conditions at other locations around Wuskwatim Lake. Data from earlier monitoring sites (EP2, EP2A and AG3a) have been used to help estimate erosion rates in the 1980s and, together with post-CRD erosion rates measured from 1978 and 1985 airphotos, are used to help estimate bank-recession rates after the Project is in operation.

Future Bank-Recession Rates Under Existing Conditions

Future bank-recession rates under existing conditions were projected from an analysis of bank-recession rates measured in Wuskwatim Lake from 1989 to 2000, combined with shoreline classification information and wave energy conditions for each shoreline unit. Projected recession rates are used to plot future bank recession lines around Wuskwatim Lake with and without the Project for 0-5, 6-25 and 26-100 year periods following the proposed in-service date of 2009. In addition, current condition bank-recession rates were estimated for a model test period that extended from 1985-1998, and for estimating bank recession distances from 1998 to the in-service date of 2009. The model test period from 1985-1998 was used to confirm that model projections based on selected bank-recession rates for different shoreline types and wave energy conditions matched bank positions visible in the 1998 **digital orthoimages**. Appropriate bank-recession rates were then selected for each terrain unit and wave energy category for the 1998-2009 period and for 0-5, 6-25 and 26-100 year periods following the proposed in-service date of 2009.

Assumptions used to estimate future bank-recession rates under current conditions are summarized in Section 6.2.4. While these bank-recession rates provide a useful guide for projecting likely future bank positions and shoreline loss, it is noted that actual bank-recession rates and distances are a function of several interrelated factors that may act alone or in combination. These factors include:

- wind velocity, direction, duration and timing;
- lake level fluctuations;
- the presence of temporary obstructions to wave attack, such as woody shoreline debris;

- periodic failure of the banks resulting in rapid bank recession over short time periods;
- permafrost conditions;
- accumulation of failed bank material that may limit further bank recession until the failed material is removed by wave action; and
- changes in bedrock elevation in a landward direction from the existing shoreline.

As a result of the many factors that cause variation in bank-recession rates, projection of annual bank-recession rates over longer time periods (>10 years) tends to be more reliable than projection of short-term rates. For this reason, average annual bank-recession rates based on an 11-year record (1989-2000) were used to assess future erosion in this study.

Projected Bank-Recession Rates with the Project in Place

Post-project bank-recession rates are estimated from historical bank recession data from the 1980s and from 1978-1985 airphoto measurements. Bank recession measurements in Wuskwatim Lake from the early 1980s were significantly higher than present average rates because fewer sites had eroded back to bedrock to that time (i.e., the reservoir was younger - 10 to 15 years old). A discussion on how erosion rates in new reservoirs change over time is found later in Section 6.3.2. With the Project, water levels will be held at higher levels within the current operating range. Therefore, the initial post-project erosion condition is seen as being similar to a "newer" reservoir condition. Information from past erosion modelling studies in Wuskwatim Lake and data from other lakes and reservoirs are also used to support assessment of future bank-recession rates under post-project conditions (see details in Section 6.4.2). An important consideration in assessing future post-project bank-recession rates is identification of shoreline reaches that will change from being bedrock controlled at low water levels under current conditions to erodible silty clay banks under post-project conditions as discussed later in Section 6.4.3.

6.2.2.3 Applying GIS Software to Map Shoreline Erosion

MicroImages TNTmips v6.70 geographic information system (GIS) software was used to help generate projected bank recession lines around Wuskwatim Lake, and to calculate eroded land area and the volume of eroded material. Calculations were performed for specified time periods under existing and post-project conditions, based on shoreline classification data and corresponding bank-recession rates. Projected annual bank-recession rates were applied to each shoreline unit defined by material type, wave energy and bank height. To plot bank recession distances for different shoreline types under current conditions, the calculations were applied to time periods 1985-1998, 1998-2009, 2009-2014, 2014-2034 and 2034-2109. Projected post-project recession lines were plotted for time periods 2009-2014, 2014-2034 and 2034-2109.

The GIS-based bank recession model was calibrated using bank-recession rates selected for different shoreline types to "predict" future top-of-bank recession from 1985 to 1998. The selected bank-recession rates used to plot future bank recession lines were based on average annual erosion rates measured at the erosion monitoring sites plus 50% to account for natural variability, rounded to the nearest tenth of a metre. In shoreline types where no monitoring data are available, bank-recession rates were either interpolated or extrapolated based on measured rates at other monitoring sites, guided by erosion modelling studies by JDMA (1993), and by experience in other lakes and reservoirs.

Using the 1985 shoreline position as a starting point, the GIS model was run to determine a model-predicted 1998 top-of-bank position. A visual comparison of the GIS model-predicted bank recession distance for the 1985-1998 period, to the actual 1998 top-of-bank position visible on the Wuskwatim Lake digital orthoimage (DOI) was made to assess the reliability of the GIS-based model and the selected bank-recession rates. The comparison showed a close correspondence between the model-predicted 1998 bank position and the maximum landward recession of the bank as seen on the 1998 DOI for the different shoreline types and wave energy settings, at those locations where the shore receded the maximum amount. In other areas the orthoimage indicated that the banks receded less than the maximum amount "predicted" by the model. This is consistent with the discussion in the previous section (Section 6.2.2.2) in that the actual recession is likely to be less than the projected maximum amount at a number of locations due to the use of higher than average recession rates to plot future bank recession lines (i.e., average plus 50% variability factor; see also, Figure 6.2-1).

Following verification, the GIS model was run for 1998-2009, 2009-2014, 2014-2034 and 2034-2109 time periods using bank-recession rates assigned to different combinations of bank material and wave energy for the current conditions. The model was then run for 2009-2014, 2014-2034 and 2034-2109 time periods using projected post-project bank-recession rates. Recession lines calculated for current and post-project conditions were then plotted in a GIS to assess incremental Project effects. These include changes in total bank recession distance for each shoreline type and wave energy combination, as well as changes in eroded land area and sediment volume.

6.2.3 Data Sources

The following data sources were used to classify the Wuskwatim Lake shoreline and to determine suitable bank-recession rates to predict future changes in shore erosion:

- Data from Manitoba Hydro's Wuskwatim Lake erosion monitoring sites (Manitoba Hydro, 2001).
- Environment Canada wind data from the Thompson, Manitoba, weather station.
- Results of previous office and field studies carried out by JDMA to define shoreline materials, erosion conditions and erosion processes in Wuskwatim Lake and other northern Manitoba lakes, as well as pre- and post-CRD airphoto-measured bank-recession rates (JDMA 1993, 1998). These reports also include references to Kellerhals (1988) and earlier Manitoba Hydro studies on lakes and rivers along the Churchill River Diversion.
- Manitoba Hydro helicopter video acquired on September 22, 1999, lake level ~233.0 m. This video coverage was used to classify the main Wuskwatim Lake shoreline.
- North/South Consultants video coverage acquired on August 24 and 27, 2001, lake level ~ 233.3 m. This video coverage was used to classify the island shorelines in the north part of Wuskwatim Lake and Sesep Lake and Cranberry Lake shorelines.
- Shoreline information documented by Tetr*ES* Consultants based on boat-based field mapping carried out on June 2-6, 2000, lake level ~ 234.0 m (Section 9.2 and 9.3.3.1).
- 1998 1:60,000 stereoscopic airphotos.
- 1985 1:20,000 stereoscopic airphotos.

6.2.4 Erosion Modelling Assumptions

Since shore erosion processes are complex, involving many interrelated factors, some necessarily simplifying assumptions are required to make quantitative estimates of future changes in erosion under current and post-project conditions. Following is a list of modelling assumptions applied in this study.

1. The main cause of shoreline erosion is wind-generated wave action (Reid *et al*., 1988).

2. Historical erosion rates in Wuskwatim Lake for different time periods, shoreline types and wave energy settings are a reliable guide for estimating future rates.

3. Wuskwatim Lake is currently in an intermediate stage of erosion following implementation of the Churchill River Diversion and further reduction of erosion rates to 2109, while unknown, are likely to be relatively small (Section 6.3.2). As a result, current average annual erosion rates in silty clay banks are applied to 2109 under existing conditions. Where silty clay banks overlie low bedrock, current erosion rates are reduced by 25% under existing conditions for the 1998 to 2109 period to account for some anticipated shoreline stabilization against bedrock in these shoreline areas. The implication of these conservative assumptions is that the estimate of future erosion over the 100-year timeframe is likely overestimated in some locations.

4. Under current conditions, projected bank-recession rates for silty clay banks overlying moderately high bedrock shorelines are reduced to zero for the 1998 to 2109 period because the clay/silt-bedrock contact is generally above the maximum lake level. It is anticipated that local bank failures will stabilize over time.

   Under post-project conditions a relatively low bank-recession rate is assumed for silty clay banks overlying moderately high bedrock. The bank-recession rate in these shorelines is reduced to zero for the 2034-2109 period (i.e., after 25 years).

5. Bank recession in low gradient shorelines (LC_{lg}, BC_{lg} and FN), and bedrock-controlled shorelines (LC/BR_h, BR_h and BR) are expected to be zero throughout the 1985 to 2109 period for current and post-project conditions.

6. Initial post-project erosion rates in silty clay banks and in silty clay banks overlying low bedrock are expected to be similar to bank-recession rates measured in the early to mid 1980s in Wuskwatim Lake, which are similar to current short-term bank-recession rates when water levels are at 234 m.

7. Initial post-project erosion rates in silty clay banks and in silty clay banks overlying low bedrock are expected to decrease to current rates over the first 25 years of the Project. This assumption is based on the observed reduction in erosion rates in

Wuskwatim Lake following implementation of the CRD from 1976 to present (see Section 6.3.2).

8. The shoreline classification established from 1999 and 2001 video data has been applied to the entire modelling period for current conditions (1985-2109) and post-project conditions (2009-2109). While this assumption is believed to be accurate for most shoreline types, it is likely that some silty clay over low bedrock shorelines will stabilize against bedrock during these time periods. The difficulty in modelling is to predict when and where some of these shorelines will stabilize without doing extensive exploratory boreholes or geophysical surveys along the shoreline. Shoreline stabilization against bedrock has been partly compensated for in the erosion projections under current conditions by reducing erosion rates in silty clay over low bedrock shores by 25% from current levels. Under post-project conditions bank-recession rates estimated for the first 5 years are reduced substantially in the 6-25 year period and again in the 26-100 year period. Even so, shoreline recession estimates in these shorelines are likely conservative, both for the current condition and post-development projections. Regular re-classification of the shoreline and updating of model projections every 10 years would be beneficial to reduce uncertainty associated with future changes in shoreline type.

9. Comparable assumptions have been applied to assessment of bank-recession rates under current and post-project conditions. Therefore, projected changes in erosion under these two scenarios are thought to be reliable in a relative sense, even though absolute changes may differ from those that have been projected.

6.3 EXISTING ENVIRONMENT

6.3.1 Overview of Lakeshore Erosion Processes

Lakeshore erosion is defined here as the “loss of sediment from the shore area of a lake or reservoir.” The erosion zone is defined as extending in a lakeward direction from the top-of-bank to a point on the underwater slope below minimum water level elevation. Shore erosion is caused by several interacting processes:

- wave erosion of the bank toe;
- beach flattening and downcutting of the nearshore slope by wave action;
- **mass-wasting** of the shore bank due to weathering and slope failure mechanisms;
- removal of failed bank material by wave action; and

- offshore and alongshore transport of eroded sediment.

The above processes and terminology are illustrated in Figure 6.3-1.

In lakes and reservoirs, wave action during the open water season and mass-wasting of banks cause ongoing evolution and modification of the shorezone profile, including bank recession. These processes result in progressive flattening and downcutting of the beach slope and related landward recession of the bank toe and bank slope. Bank recession tends to be cyclic over time, reflecting the effect of changing water levels, variable wave energy conditions including periodic storm events, and local obstructions to wave attack.

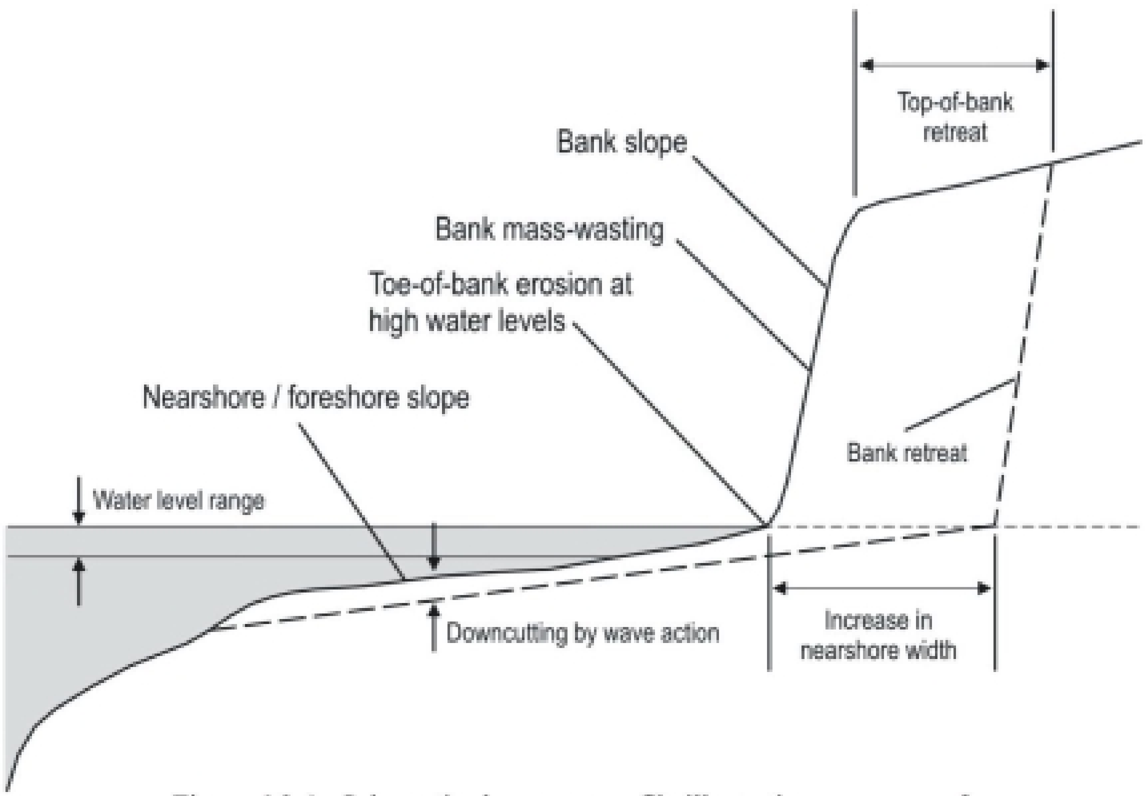

Figure 6.3-1. Schematic shorezone profile illustrating processes of nearshore downcutting and toe-of-bank erosion.

Figures 6.3-2 and 6.3-3 illustrate erosion processes during periods of high and low water levels in clay and silt shorelines and shorelines where clay and silt overlies bedrock. When water levels are high enough to reach the bank toe, wave erosion at the bank toe dominates the shore erosion process. Over steepening of the bank due to toe erosion commonly causes accompanying topple and slumping failure of the upper bank slope which results in rapid short-term top-of-bank recession.

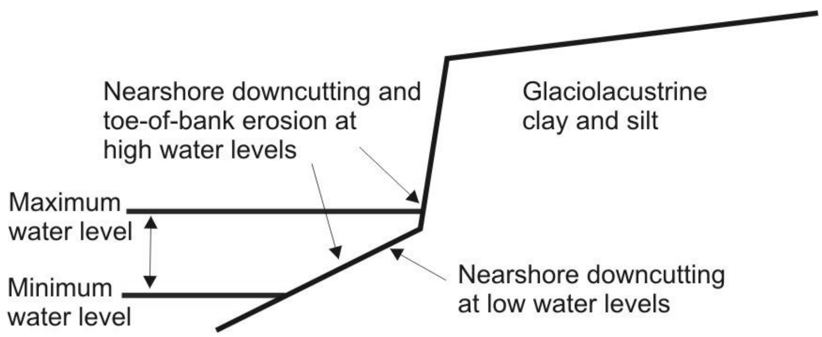

Figure 6.3-2. Schematic illustrating erosion processes in clay/silt shorelines at low and high water levels.

When water levels are low, weathered bank material shed by mass-wasting accumulates at the toe-of-bank, temporarily above the reach of incoming waves. The dominant wave erosion process at times of low water level is progressive downcutting and flattening of the beach slope due to dissipation of wave energy across the nearshore slope. Washing by waves reworks coarser sediment accumulated on the beach surface. Figure 6.3-4 shows evidence of nearshore downcutting in Jenpeg Forebay. For those shores where bedrock is exposed at lower water elevations no nearshore downcutting occurs, as illustrated in Figure 6.3-3.

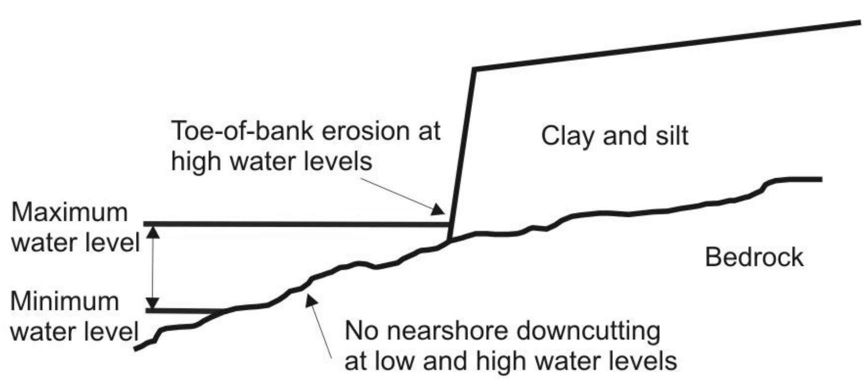

Figure 6.3-3. Schematic illustrating erosion processes in shorelines where clay/silt overlies bedrock, for high and low water level conditions.

Figure 6.3-4. Tree roots ("spiders") exposed by nearshore downcutting in Jenpeg Forebay. Photograph taken in October 2001.

High water levels following a period of low water level result in removal of the disintegrating toppled bank material. If high water levels are sustained, removal of failed bank material is followed by toe-of-bank erosion and continued erosion of the nearshore slope. As water levels drop again, weathered and sloughed bank material begins to accumulate at the bank toe again; and remains there until the next rise in water level and incursion of waves.

6.3.2 Erosion Processes in New Reservoirs

To help estimate future long-term bank-recession rates in lakes and reservoirs, shore erosion is visualized to occur in three stages representing early, intermediate, and advanced stages of shorezone evolution (Figure 6.3-5).

An early, or initial, stage occurs when waves wash and erode previously non-flooded slopes around new reservoirs, and where water levels are raised in existing lakes and reservoirs. This was the situation in Wuskwatim Lake following construction of the Churchill River Diversion (CRD) when water levels rose approximately 3 m. Initially, a narrow beach slope forms, backed by an adjoining bank. During this early stage, erosion of the toe-of-bank and bank mass-wasting dominate the shore erosion process. Airphoto measurements by JDMA (1993) indicate that pre-CRD erosion rates in Wuskwatim Lake were in the range of 0-2 m/yr, depending on shoreline type and wave energy exposure, with an overall average of 0.7 m/yr. Current bank-recession rates at Wuskwatim Lake

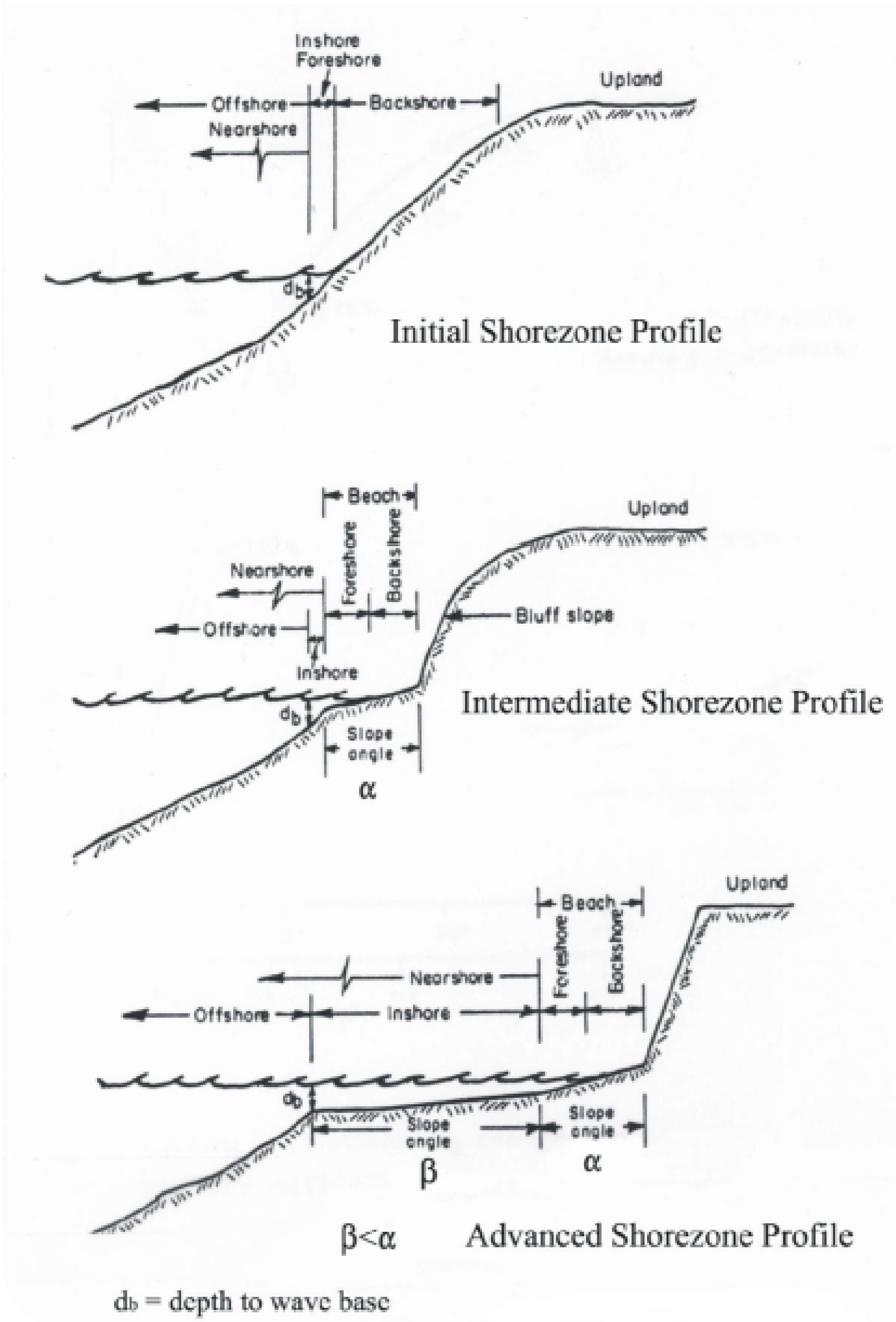

Figure 6.3-5. Diagram representing initial, intermediate, and advanced stages of erosion in lake and reservoirs.

erosion monitoring stations average 0.6 m/yr (Section 6.3.4), suggesting that current rates are approaching long-term pre-CRD rates.

Post-CRD rates in Wuskwatim Lake, measured from 1978 and 1985 airphotos, range from 0-5 m/yr, with an overall average of 2.0 m/yr (Section 6.4.2.1). In high wave energy settings, rates measured by JDMA (1993) for the period 1978-1985 were mostly in the range from 1-3 m/yr.

As erosion continues into an intermediate stage, nearshore slopes widen, and the banks may heighten. The evolving bank height depends on topography of the pre-erosion shorezone. During this intermediate stage, nearshore downcutting becomes increasingly important, although toe-of-bank erosion and bank mass-wasting may still be significant. With continued erosion, nearshore slopes become wider and flatter, and nearshore downcutting begins to dominate the erosion process. Bank recession continues, usually at a lower rate, driven by nearshore downcutting, and by removal of failed bank material and toe-of-bank erosion during periods of high water level.

Reaching an advanced stage of shoreline evolution is uncommon around relatively young (less than 50 year old) reservoirs. Examples of advanced or mature shorezones occur around large lakes such as Lake Winnipeg and the Great Lakes (Brown & Baird, 1980; Nairn, 1992), as shown in Figure 6.3-6, and ocean coasts. Even in these relatively advanced shorezones, banks continue to recede and are subject to high erosion rates during episodical storm events.

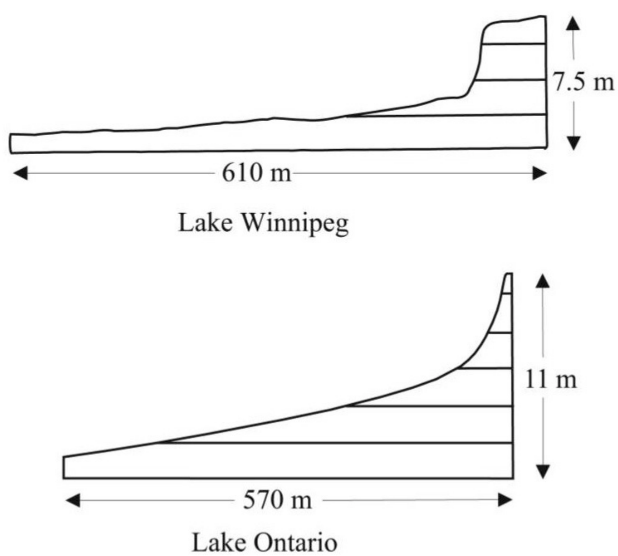

Figure 6.3-6. Advanced shorezone profiles in Lake Winnipeg and Lake Ontario

Recession of erodible banks is generally most rapid during the early stages of reservoir development, progressively decreasing in intermediate and advanced stages (Figure 6.3-7). Post-CRD Wuskwatim Lake is believed to be in an intermediate stage of shoreline evolution at present, with erosion rates approaching long-term rates observed in other lakes and reservoirs. The duration of each erosion stage (and associated changes in bank-recession rate, bank height, bank slope, nearshore width, and slope angle) depends on the susceptibility of shorezone materials to wave erosion, long-term and short-term wave energy conditions, changes in water level and the frequency of storms.

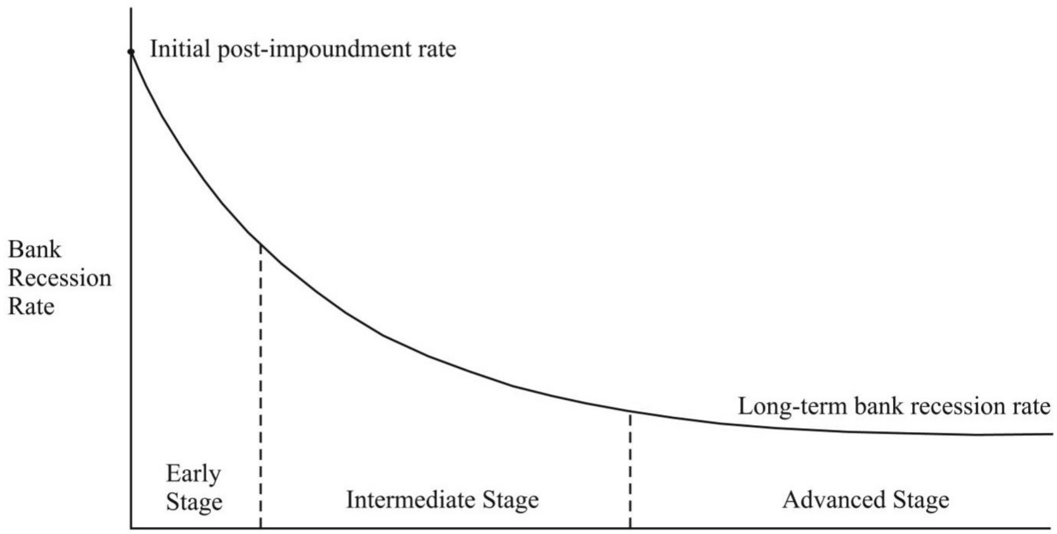

Figure 6.3-7. Conceptual diagram illustrating the progressive decrease in bank recession rates in early, intermediate, and advanced shorezones.

Additional references on shore erosion processes include Reid (1984), Newbury and McCullough (1984), Mollard (1986), Reid *et al*. (1988), Penner *et al*. (1992), Penner (1993), Davidson-Arnott *et al*. (1999), Davidson-Arnott and Ollerhead (1995), Amin and Davidson-Arnott (1995), Penner and Boals (2000) and Penner (2002).

6.3.3 Shoreline Types and Erosion Susceptibility

6.3.3.1 General

As with other physical environment parameters such as debris and sedimentation, shore erosion processes continue to evolve under post-CRD conditions. Therefore, a complete assessment of the existing environment with respect to erosion and shoreline morphology must include a description of the present situation as well as an assessment of how the environment is expected to change in the future even if the Project is not developed. This evolving environment is the baseline to assess change resulting from the Project.

Existing erosion conditions in Wuskwatim Lake represent a relatively short-term view of a long-term ongoing dynamic process that began when the lake first formed following draining of Glacial Lake Agassiz in early postglacial time. Completion of the Churchill River Diversion (CRD) in 1977 lead to a rise in Wuskwatim Lake water levels of approximately 3 m, and a related increase in bank-recession rates around the shoreline. Since then, bank-recession rates have decreased as the lake evolved to an intermediate stage of shoreline evolution as discussed in Section 6.3.2. While bank-recession rates may continue to decrease depending on shoreline bank materials, shorezone profile geometry, wave energy, water level fluctuations, and other factors, current bank-recession rates are believed to be approaching long-term rates observed in other lakes and reservoirs.

6.3.3.2 Shoreline Bank Materials

The following shoreline classification was used to map the Wuskwatim Lake shorelines, and are discussed in detail below. These shoreline classifications are also summarized in Table 6.3-1 in terms of their erosion susceptibility.

Table 6.3-1
Shoreline classification units and erosion susceptibility

Shoreline Classification Unit	Description	Bedrock Contact Elevation*	Erosion Susceptibility	Figure (Photo) Reference
LC	silty clay shorelines with banks ranging from 0.5 to >3 m locally	< 233 m	high	Figs. 6.3-8 & 6.3-9
LC_{lg}, BC_{lg}	low-gradient silty clay shorelines with no eroded bank and no apparent bank erosion. BC_{lg} shorelines may have shallow bedrock below silty clay	Below 233 m	very low to non-erodible	Fig. 6.3-10
LC/BR_l, BC	silty clay banks overlying low bedrock	~233.5m in main part of Wuskwatim Lake; ~233.8m in Cranberry and Sesep Lakes	low at lake levels < 233 m; high at lake levels > 233.5 m	Figs. 6.3-11 & 6.3-12
LC/BR_m	silty clay banks overlying moderately high bedrock	234 m in main part of Wuskwatim Lake; ~234.3 m in Cranberry and Sesep Lakes	low to very low	Fig. 6.3-13
LC/BR_h	silty clay banks overlying high bedrock	> 234 m	non-erodible	
BR, BR_h	bedrock banks	> 233 m	non-erodible	
FN	fen and marsh dominated shorelines	N/A	very low to non-erodible	Figs. 6.3-14 & 6.3-15

* Bedrock contact elevation was estimated from analysis of shoreline video coverage. LC/BR_l, LC/BR_m and LC/BR_h correspond to bedrock contact elevations approximately 0.5, 1.0 and >1.0 m, respectively, above the water level visible in the available video coverage. In 1999 video coverage of the main part of Wuskwatim Lake the water level was 233 m. In 2001 video coverage of Cranberry and Sesep lakes the water level was 233.3 m.

LC - Fine-grained (silt and clay) glaciolacustrine sediments in shoreline banks ranging in height from approximately 0.5 m to > 3 m locally. In LC shores, glaciolacustrine sediments extend below the water level visible in the 1999 video coverage (water level ~233.0 m). No bedrock is apparent in these areas (Figures 6.3-8 and 6.3-9). The erosional process for these shorelines is illustrated in Figure 6.3-2.

Figure 6.3-8. An eroding clay/silt shoreline and nearshore woody debris, southeast shoreline of Wuskwatim Lake. September 9-11. Lake Level ~234.0 m.

This shoreline type is most susceptible to erosion under existing conditions because erodible sediments are exposed to wave action throughout the entire water level range for the lake. However, erosion rates are somewhat lower during periods when lake levels are below approximately 233.5 m because a higher percentage of wave energy is dissipated across the nearshore slope rather than at the toe-of-bank. Conversely, erosion rates are higher during periods of relatively high lake level (lake levels ~233.5 to 234.3 m) because the wave energy reaching the toe-of-bank is greater. The most severe erosion conditions occur when high winds coincide with periods of high lake levels.

Figure 6.3-9. Eroding clay/silt bank, southeast shoreline of Wuskwatim Lake September 9-11, 1991. Lake level ~234.0 m

LC_{lg} - Low gradient glaciolacustrine shores with no eroded bank (Figure 6.3-10). These areas are subject to periodic flooding under fluctuating water levels, but little or no bank recession is apparent.

Figure 6.3-10. Low gradient glaciolacustrine clay/silt (LC_{lg}) and fen and marsh shorelines in Cranberry Lakes. June 2, 2000. Lake level ~234.0 m (Photograph courtesy TetrES Consultants.)

Under existing conditions, gently sloping nearshore areas are periodically flooded when water levels rise from low levels of approximately 233.0 m to a maximum level of about 234.3 m. However, negligible erosion and bank recession occurs in these areas.

LC/BR$_l$ - Fine-grained (clay and silt) glaciolacustrine sediments overlying bedrock with the clay/silt-bedrock contact at a relatively low elevation (~ 233.5 m in the main part of Wuskwatim Lake) (Figures 6.3-11 and 6.3-12). The erosional process for these shorelines is illustrated in Figure 6.3-3.

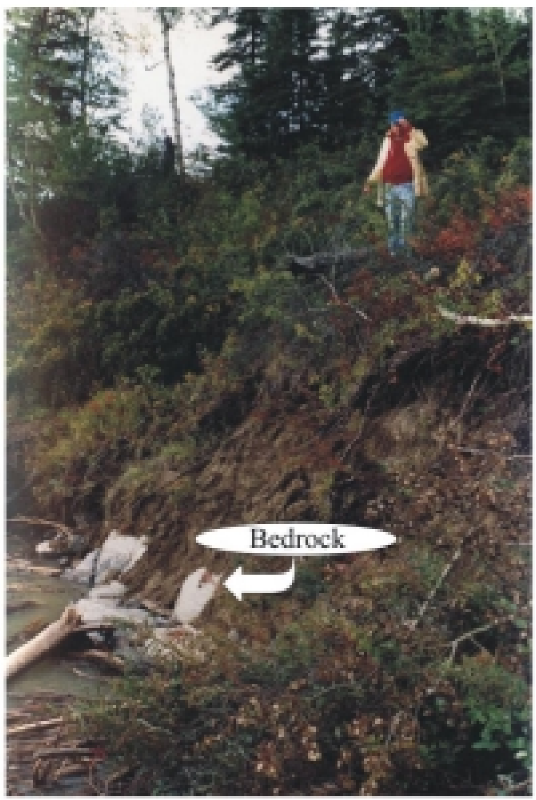

Figure 6.3-11. Eroding bank with clay/silt overlying bedrock (LC/BR$_l$), north shoreline of Wuskwatim Lake. September 9-11, 1991. Lake level ~234.0 m.

Under existing conditions, negligible erosion occurs when water levels are below approximately 233.5 m because non-erodible bedrock is present below this elevation. However, when water levels are above 233.5 m, waves reach the toe of erodible clay and silt banks, eroding the fine-grained sediment and causing increased bank-recession rates.

Figure 6.3-12. Glaciolacustrine clay/silt bank overlying bedrock with a low clay/silt-bedrock contact (LC/BR$_l$). Wuskwatim Lake. June 2, 2000. Lake level ~234.0 m. Bedrock is exposed along the shoreline at low lake levels (i.e., lake levels below ~233.6 m). (Photograph courtesy TetrES Consultants.)

LC/BR$_m$ - Fine-grained (clay and silt) glaciolacustrine sediments overlying bedrock with the clay/silt-bedrock contact the clay/silt-bedrock contact approximately 0.5 to 1.0 m above the water level in the 1999 and 2001 video (i.e., ~ 234 m in the main part of Wuskwatim Lake) (Figure 6.3-13).

Figure 6.3-13. Glaciolacustrine clay/silt bank overlying bedrock with a moderately high clay/silt-bedrock contact (LC/BR$_m$). Wuskwatim Lake. June 2, 2000. Lake level ~234.0 m. (Photograph courtesy TetrES Consultants.)

These shorelines are largely bedrock controlled at low and high water levels (233.0 to 234.3 m) under existing conditions. Exceptions are local occurrences of low bedrock where overlying clay and silt banks may be subjected to erosion at high water levels. Local sloughing of unconsolidated clay and silt banks may occur in these isolated low bedrock areas.

LC/BR$_h$ - Fine-grained (clay and silt) glaciolacustrine sediments overlying bedrock with the clay/silt-bedrock contact greater than approximately 1 m above the water level in the 1999 and 2001 video (i.e., >~ 234 m in the main part of Wuskwatim Lake).

These shorelines are bedrock controlled under existing conditions because non-erodible bedrock extends well above the maximum lake level. Negligible wave-induced bank recession occurs in these areas under existing conditions.

BR, BR$_h$ - Relatively high and steep non-erodible bedrock slopes in the shorezone area. No wave induced bank recession occurs in these areas under existing conditions.

FN - Low gradient fen and marsh-dominated shores in shallow low-lying flooded areas. These areas typically show little or no evidence of bank recession under existing conditions, but are subject to periodic flooding under fluctuating water levels (Figures 6.3-14 and 6.3-15).

Figure 6.3-14. Fen and marsh shoreline in Cranberry Lakes, June 2, 2000. Lake level ~234.0 m (Photograph courtesy TetrES Consultants)

Figure 6.3-15. Fen and marsh dominated shoreline in Wuskwatim Lake, Sept 9-11, 1991. Lake level ~234.0 metres

BC - Airphoto-mapped bedrock-cored terrain with fine-grained glaciolacustrine sediments overlying bedrock. This shoreline type is restricted to a few short reaches in the Wuskwatim Brook area that are not covered by the available 1999 and 2001 shoreline video coverage. BC areas were mapped from airphoto interpretation and are comparable to the LC/BR_l unit mapped from video in the main part of Wuskwatim Lake. That is, BC shorelines are bedrock controlled at water levels below about 233.5 m. Erosion of clay and silt banks overlying bedrock occurs at water levels above approximately 233.5 m.

BC_{lg} - Low gradient bedrock-cored shores. BC_{lg} shores are subject to periodic flooding under fluctuating water levels but little or no erosion and bank recession is expected.

Permafrost - No extensive borehole testing has been carried out around the shorelines of Wuskwatim Lake to determine whether permafrost exists. Twelve test pits dug in low-lying areas around Wuskwatim Lake did not encounter permafrost (Terraform 2000), nor did airphoto and video interpretation of the shoreline show any large-scale bank failures like those typically attributed to permafrost thaw. These results suggest that extensive permafrost is not likely present around the shorelines.

The percentage of shoreline length characterized by each shoreline type is listed in Table 6.3-2.

Table 6.3-2

Percentage of shoreline types around Wuskwatim Lake*

Shore Type	Shoreline Length (km)	% of Total Shoreline Length	Erosion Susceptibility					
			Moderate to Highly Erodible	Percentage of Shoreline	Very Low Erodibility	% of Shoreline	Non-Eroding	% of Shoreline
LC	27.2	10.7	√					
LC/BR_l and BC	44.7	17.7	√	28.4				
LC/BR_m	15.3	6.0			√	6.0		
LC_{lg}; BC_{lg}	74.2	29.3					√	
FN	89.2	35.3					√	
LC/BR_h;BR_h;BR	2.5	1.0					√	65.6
Total	**253.1**	**100.0**						

* The distribution of shoreline types around the main part of Wuskwatim Lake is summarized in Appendix A6.1.

Table 6.3-2 shows the percentage of the Wuskwatim Lake shorelines that have moderate to high susceptibility to erosion, very low susceptibility to erosion and no susceptibility to erosion. Moderate to highly erodible shorelines consist of clay and silt banks (LC) and clay and silt banks overlying bedrock where the clay/silt-bedrock contact is below approximately 233.5 m elevation (LC/BR_l and BC). These erodible shorelines make up 28.7% of the shoreline length. Of the erodible banks, 10.7 % are LC shorelines that are expected to experience continued long-term erosion under existing fluctuating water level conditions**. LC/BR_l and BC shorelines make up 17.7 % of the shoreline. Some LC/BR_l and BC shorelines may eventually stabilize where the buried bedrock elevation increases in a landward direction from the shoreline. The majority of the eroding shorelines are located in the main part of Wuskwatim Lake** (Figure 6.3-16).

Non-eroding shorelines include low gradient shores (LC_{lg} and BC_{lg}), fen and marsh dominated shores (FN) and bedrock-controlled shorelines (LC/BR_h, BR_h and BR). Non-eroding shorelines make up 65.6 % of the total shoreline length.

Shorelines characterized by clay and silt banks overlying bedrock with a moderately high clay/silt-bedrock contact (LC/BR_m) have a very low erosion susceptibility. These shorelines make up 6.0% of the total shoreline length.

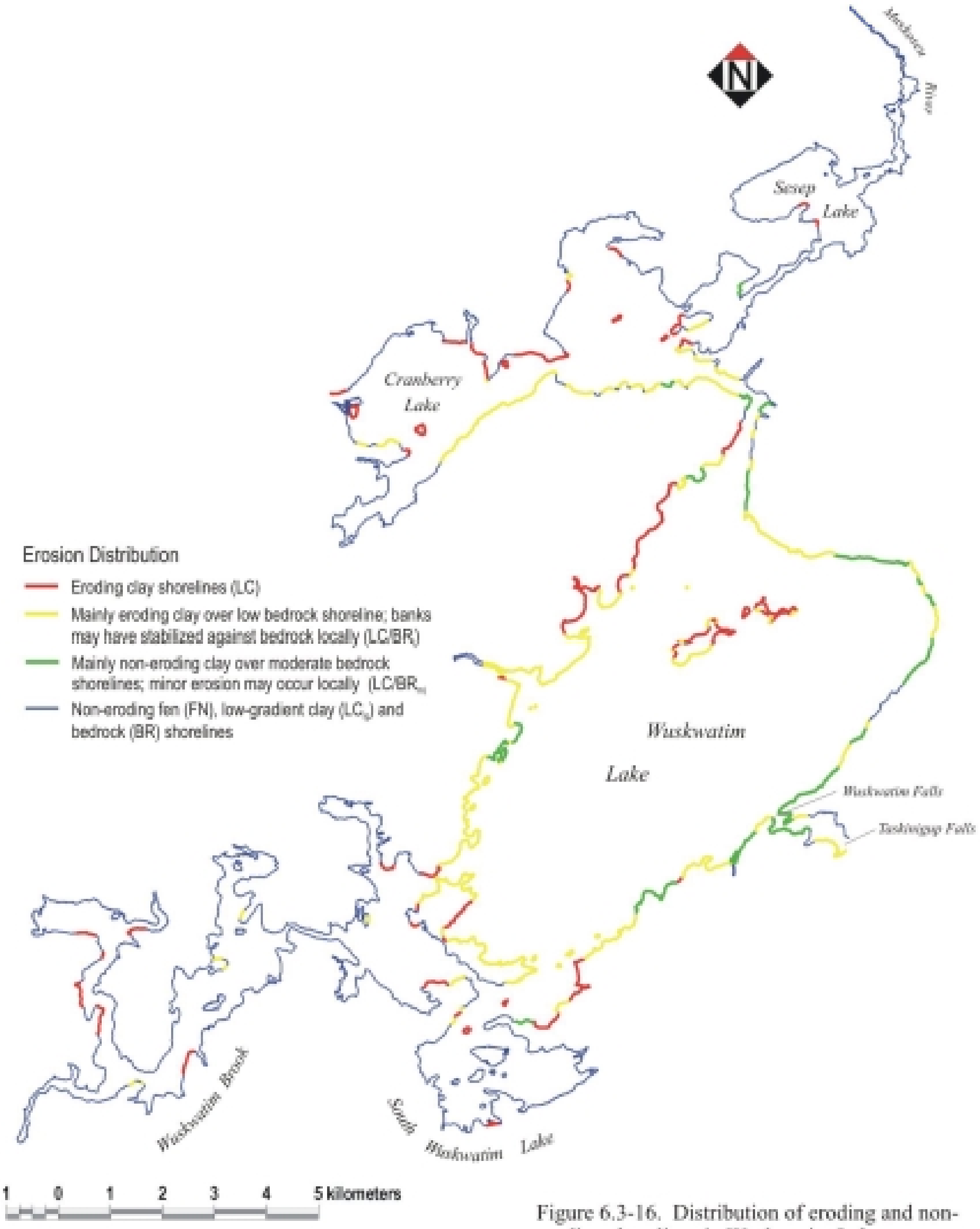

Figure 6.3-16. Distribution of eroding and non-eroding shorelines in Wuskwatim Lake

In addition to shoreline types, the existing erosion condition was also inferred from the available video coverage. Erosion condition was mapped as being active, partially stabilized or non-eroding. Figure 6.3-17 is a map showing erosion condition around Wuskwatim Lake. The percentage of active, partially stabilized and non-eroding shores is summarized in Table 6.3-3. As might be expected, the distribution of shoreline types shown in Table 6.3-2 corresponds closely to the distribution of active, partially stabilized and non-eroding shores summarized in Table 6.3-3.

Figure 6.3-17. Distribution of active, partially stabilized, and non-eroding shorelines mapped from low-level helicopter video.

A comparison of the above two methods of shoreline characterization is shown in Table 6.3-4. Active and partially stabilized shorelines were noted along approximately 30.5% of the shoreline, compared to 28.4% of the shore that is mapped as LC, LC/BR_l and BC. Inactive (non-eroding) shorelines are present along the remaining 69.5% of the shoreline, compared to 71.6% of the shore mapped as LC/BR_m, LC/BR_h, BR_h, BR, LC_{lg}, BC_{lg} and FN. While the overall correlation between the two methods is good, local exceptions might occur where: 1) the bedrock elevation in LC/BR_m shores is lower than 234 m; or 2) the bedrock elevation in LC/BR_l shores is higher than 233.5 m.

Table 6.3-3

Distribution of existing erosion conditions around Wuskwatim Lake

Erosion Condition	Shoreline Length (km)	% of Shoreline Length
Active	53.5	21.1
Active to partially stabilized	4.3	1.7
Partially stabilized	19.5	7.7
Inactive	175.8*	69.5
Total	**253.1**	**100.0**

*erosion condition of 120.8 km of shoreline in Wuskwatim Brook area was inferred from stereoscopic airphotos because helicopter video footage was unavailable during the time period of this study.

Table 6.3-4

Comparison of existing erosion condition and shoreline type around Wuskwatim Lake

Erosion Condition	Percentage Shoreline Length	Percentage Shoreline Length	Shoreline Type
Active, active to partially stabilized, partially stabilized	30.5	28.4	LC, LC/BR_l and BC
Inactive	69.5	71.6	LC/BR_m, LC/BR_h, BR_h, BR, LC_{lg}, BC_{lg} and FN
Totals	**100.0**	**100.0**	

6.3.3.3 Wave Energy

Wind generated waves are the dominant erosion causing factor in lakes and reservoirs (Reid *et al.* 1988). Figure 6.3-18 shows dominant wind directions measured at Wuskwatim Lake during open water periods from 13 September 1997 to 31 October 2001. The histogram in Figure 6.3-19 shows the percentage of time that winds blew at speeds ranging from 0 to 90 km/hr during this same period.

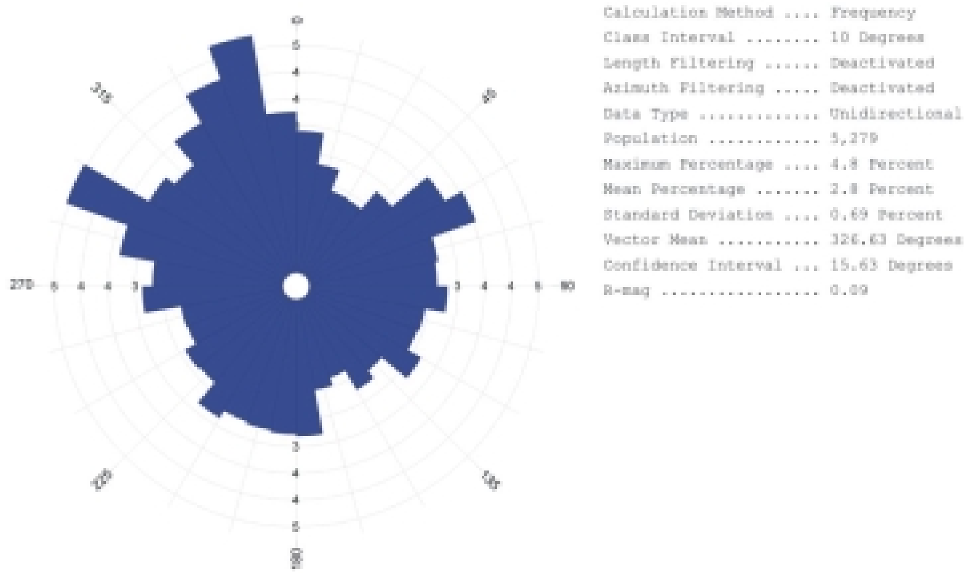

Figure 6.3-18. Dominant wind directions at Wuskwatim Lake during open water seasons from 13 September 1997 to 31 October 2001

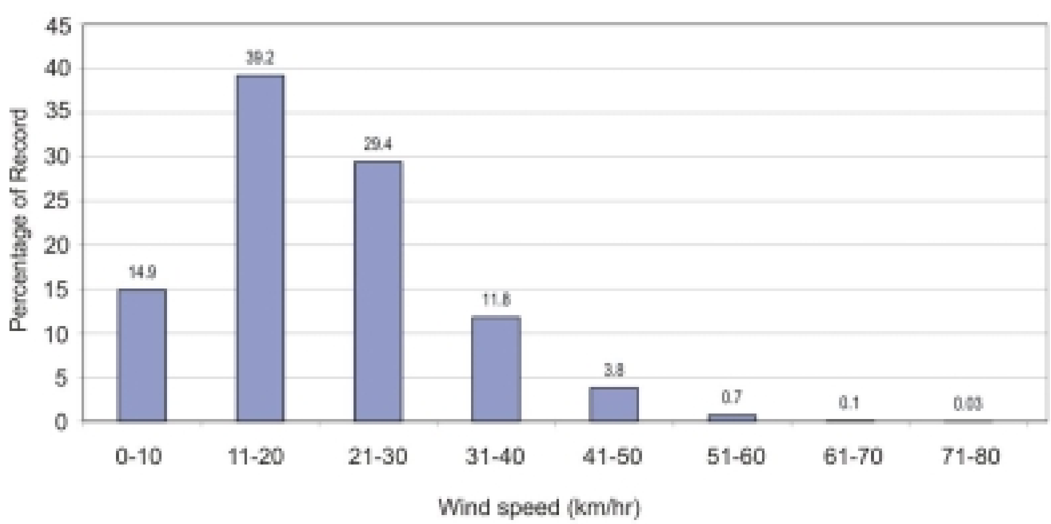

Figure 6.3-19. Frequency of wind speeds at Wuskwatim Lake during open water season (May 15 - Oct. 31) from 13 September 1997 to 31 October 2001 (wind data record maximum wind gusts in 3 hour periods)

The distribution of wave energy in Wuskwatim Lake is shown in Table 6.3-5 and Figure 6.3-20. **Seventy-eight (78.1) percent of the shoreline is exposed to relatively low wave energy**, while 11.0% of the shoreline is exposed to moderate wave energy. High wave energy is present over 10.9% of the shoreline length. While there is a relatively low percentage of moderate to high wave energy shorelines for the entire Wuskwatim

Figure 6.3-20. Wave energy distribution map of Wuskatim Lake.

Lake**, the majority of moderate to high wave energy shorelines are located in the main part of Wuskwatim Lake. This is also the area where the majority of eroding shorelines are located** (see Figure 6.3-16).

Table 6.3-5

Wave energy distribution around Wuskwatim Lake

Wave Energy	Shoreline Length (km)	% of Shoreline Length
Low	197.6	78.1
Moderate	27.8	11.0
High	27.7	10.9
Total	**253.1**	**100.0**

The wave base depth is the maximum depth that wave energy reaches below the water surface. Negligible nearshore erosion occurs below the maximum wave base depth and thicker deposits of nearshore sediment accumulate where water depths are greater than the wave base depth. The maximum wave base depth in Wuskwatim Lake has been estimated to assist others in assessing the effects of shore erosion on nearshore sedimentation conditions.

Wave base depth is a function of wave height and wave length. These wave properties, in turn, are a function of wind speed and effective fetch length. Following the procedure outlined in USCE (1977), maximum wave base depths in Wuskwatim Lake have been estimated for wind speeds of 50, 60 and 70 km/hr and fetch lengths of 4, 4.5 and 10 km, as shown in Table 6.3-6. These fetch lengths are parallel to dominant wind directions blowing toward the southwest, southeast and south shorelines of Wuskwatim Lake.

Table 6.3-6
Estimated maximum wave base depth along the southeast, southwest and south shorelines of Wuskwatim Lake

Shoreline Location in Wuskwatim Lake	Fetch Length Parallel to the Dominant Wind Direction (km)	Lake Width Normal to the Fetch Direction (km)	Effective Fetch Length (km)	Estimated Wave Base Depth (m)		
				Wind speed 50 km/h	Wind speed 60 km/h	Wind speed 70 km/h
SE Shore	4.5	10.0	4.5	0.9	1.0	1.2
S Shore	10.1	5.0	6.7	1.1	1.3	1.6
SW Shore	4.0	6.3	4.0	0.8	1.0	1.2

6.3.4 Analyzing Recent Erosion Rates Measured in Wuskwatim Lake

Average annual recession rates calculated from erosion data collected from 1989-2000, and published by Manitoba Hydro (2001), are summarized in Table 6.3-7. These data are used to estimate erosion rates under current conditions. Erosion rates measured from 1978-1985 airphotos and erosion monitoring data acquired in the early to mid 1980s are used to estimate initial post-project erosion rates in erodible shoreline types. Locations of recently monitored erosion monitoring sites are shown in Figure 6.3-21. An example of monitoring profiles at one of these sites is shown in Figure 6.3-22. The maximum single year recession distances recorded by Manitoba Hydro (2001) are also listed in Table 6.3-7 for each erosion monitoring profile location. Inspection of the erosion rates in Table 6.3-7 shows the natural variability in average annual bank-recession rates for a given station (i.e., centre, and right and left offsets) and for different locations around the lake. Variability in the period in which the maximum annual recession rate occurred is also recorded in Table 6.3-7, as are the shoreline classification and wave energy exposure (see Sections 6.3.3.2 and 6.3.3.3). Examination of Table 6.3-7 indicates that the erosion monitoring sites provide data for the two main erodible shoreline types - namely, shores with clay and silt banks (LC), and shores with clay and silt banks overlying low bedrock (LC/BR_l) described in Section 6.3.3.2.

Table 6.3-8 summarizes the erosion rate statistics for LC and LC/BR_l shores for low, moderate, and high wave energy settings based on information contained in Table 6.3-7.

The coefficient of variation (V), shown in Table 6.3-8, characterizes the degree of variability in average bank-recession rates. Based on data from LC/BR_l and LC shorelines in high wave energy settings, which represent 35 of 44 profile locations, the natural variability in bank-recession rates is in the order of 50 to 60%. That is, annual bank-recession rates at a given location may range from 50 to 60% above or below average values. Additional information on calculation of the coefficient of variability is presented in Appendix A6.2.

In addition to variability in long-term average annual bank-recession rates, the data collected from the erosion monitoring sites exhibits considerable year-to-year variability in bank-recession rates. Maximum single-year recession rates at Wuskwatim Lake erosion monitoring sites exceed average annual recession rates by an average of 3 times. This characteristic, while incorporated in the coefficient of variation, warrants mentioning because short-term bank-recession rates may, from time to time, exceed long-term average annual rates by a significant amount.

Table 6.3-7

Summary of average annual bank-recession rates and maximum annual recession rates from 1989-2000 at Manitoba Hydro's Wuskwatim Lake erosion monitoring sites

Wuskwatim Lake Erosion Monitoring Site	Wave Energy Exposure (high/moderate/low)	Shoreline Classification	Record Period	Average Annual Recession Rate (m/yr)	Maximum Annual Recession Distance (m)	Period in Which Maximum Occurred	Max Annual Rec./ Ave. Annual Rec. Rate
ERP#1 - C/L	H	LC/BRI	1989-2000	0.35	1.22	1992-1993	3.2
ERP#1 - Left			1993-1998	1.00	1.52	1994-1995	1.5
ERP#1 - Right			1993-1998	0.86	3.05	1993-1994	3.5
ERP#2 - C/L	H	LC/BRI	1989-2000	1.50	2.59	1992-1993	1.7
ERP#2 - Left			1993-2000	0.65	1.30	1996-1998	2.0
ERP#2 - Right			1993-2000	0.60	1.22	1993-1994	2.0
ERP#2A - C/L	H	LC/BRI	1992-2000	0.54	1.52	1992-1993	2.8
ERP#2A - Left			1992-2000	0.27	0.61	1992-1993 and 1996-1998	2.3
ERP#2A - Right			1992-2000	0.23	0.61	1993-1994	2.7
ERP#2B - C/L	H	LC/BRI	1992-2000	0.42	2.44	1992-1993	5.8
ERP#2B - Left			1992-2000	0.38	0.91	1995-1996	2.4
ERP#2B - Right			1992-2000	0.08	0.31	1992-1993 and 1995-1996	3.9
ERP#2C - C/L	H	LC/BRI	1992-2000	0.75	1.82	1992-1993	2.4
ERP#2C - Left			1992-2000	0.39	1.22	1995-1996	3.1
ERP#2C - Right			1992-2000	0.59	1.95	1998-2000	3.3
ERP#3 - C/L	M	LC	1989-2000	0.66	1.22	1989-1991 and 1995-1996	1.8
ERP#3 - Left			1993-2000	0.62	2.44	1994-1995	3.9
ERP#3 - Right			1993-2000	0.60	1.74	1996-1998	2.9
ERP#4 - C/L	H	LC/BRI	1989-2000	0.99	5.13	1996-1998	5.2
ERP#4 - Left			1993-2000	0.55	0.97	1998-2000	1.8
ERP#4 - Right			1993-2000	0.12	0.31	1993-1994	2.6
ERP#4A - C/L	L	LC/BRI	1992-2000	0.18	0.61	1992-1993	3.4
ERP#4A - Left			1992-2000	0.00			
ERP#4A - Right			1992-2000	0.16	0.61	1995-1996	3.8
ERP#5 - C/L	H	LC/BRI	1989-2000	0.86	5.18	1992-1993	6.0
ERP#5 - Left			1992-2000	0.48	1.05	1998-2000	2.2
ERP#5 - Right			1992-2000	0.96	2.09	1996-1998	2.2
ERP#5A - C/L	H	LC	1992-2000	0.42	0.92	1994-1995	2.2
ERP#5A - Left			1992-2000	1.21	2.84	1996-1998	2.3
ERP#5A - Right			1992-2000	0.33	1.52	1994-1995	4.6
ERP#5B - C/L	H	LC	1992-2000	0.63	2.32	1993-1994	3.7
ERP#5B - Left			1992-2000	1.46	2.09	1996-1998	1.4
ERP#5B - Right			1992-2000	0.73	2.74	1994-1995	3.8
ERP#5C - C/L	H	LC/BRI	1992-2000	0.21	0.59	1996-1998	2.8
ERP#5C - Left			1992-2000	0.64	2.40	1998-2000	3.8
ERP#5C - Right			1992-2000	1.04	3.05	1994-1995	2.9
ERP#6A - C/L	H	LC/BRI	1992-2000	0.53	1.52	1992-1993	2.9
ERP#6A - Left			1992-2000	0.27	2.12	1993-1994	7.9
ERP#6A - Right			1992-2000	0.51	1.52	1993-1994	3.0
ERP#7D - C/L	H	LC/BRI	1992-2000	0.84	2.18	1996-1998	2.6
ERP#7D - Left			1992-2000	0.26	0.92	1993-1994	3.5
ERP#7D - Right			1992-2000	0.97	1.83	1993-1994	1.9
ERP#8A - C/L	M	LC	1992-2000	0.43	1.07	1993-1994	2.5
ERP#8A - Left			1992-2000	0.81	1.70	1996-1998	2.1
ERP#8A - Right			1992-2000	0.28	1.12	1996-1998	4.0
Averages				**0.59**	**1.7**		**3.1**

Figure 6.3-21. Location of Manitoba Hydro's Wuskwatim Lake erosion monitoring sites. Average annual bank recession rates at right, centre and left profile lines are shown in m/yr.

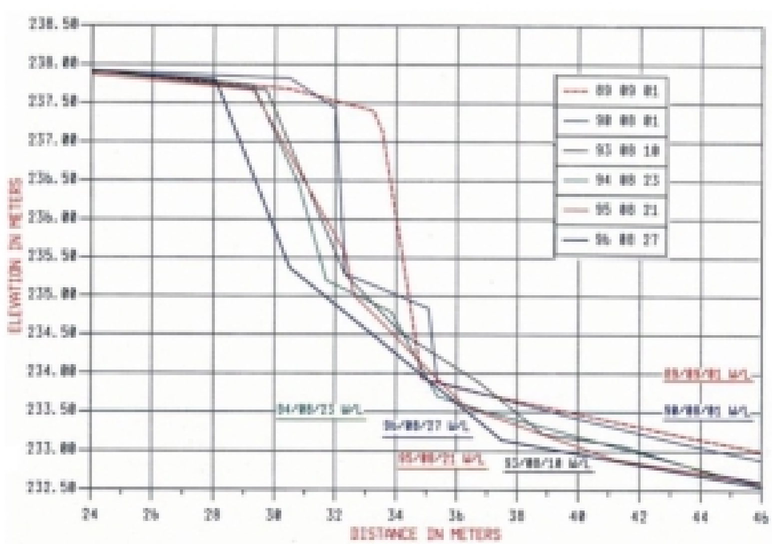

Figure 6.3-22. Example of surveyed shorezone profiles from one Manitoba Hydro Wuskwatim Lake monitoring site (ERP-3).

Table 6.3-8

Summary of average annual bank-recession rates and maximum annual recession rates at Manitoba Hydro's Wuskwatim Lake erosion monitoring sites

LC/BR$_I$ shorelines

Wave Energy Exposure.	Number of Profiles	Average Annual Recession Rate (m/yr)	Standard Deviation	Coefficient of Variation	Maximum Annual Recession Rate (m/yr)	Averaged Max. Single Year Recession Distance Divided by the avg. annual Recession Rate	Bank-recession rate Used in Model Calculations for 1985-1998
High	29*	0.56	0.29	52%	1.04	3.18	1.00
Moderate	0	no sites					0.60
Low	3	0.11	0.10	91%	0.18	3.60	0.25
* site ERP#2-C/L rejected on basis of extreme deviates calculation at a 5% level of significance							

LC shorelines

Wave Energy Exposure.	Number of Profiles	Average Annual Recession Rate (m/yr)	Standard Deviation	Coefficient of Variation	Maximum Annual Recession Rate (m/yr)	Averaged Max. Single Year Recession Distance Divided by the avg. annual Recession Rate	Bank-recession rate Used in Model Calculations for 1985-1998
High	6	0.80	0.45	56%	1.46	3.00	1.50
Moderate	6	0.57	0.19	33%	0.81	2.88	1.00
Low	0	no sites					0.50

6.3.5 Projected Future Erosion Rates With No Development

As indicated in the introduction of Section 6.3.3.1, defining the existing environment includes assessing the extent of erosion that is likely to occur even if the Project does not proceed. However, as discussed previously, the erosion rates used to calculate future bank recession distances are different from rates used to estimate eroded land areas and eroded bank material volumes, as discussed in Section 6.2.2.2.

Plotting future bank recession lines is based on the expected long-term average bank-recession rates, plus a 50% variability factor. This rate is used to determine the potential maximum extent of shoreline erosion at any given location. Actual future bank erosion is not expected to reach the likely maximum extent at most locations because of the natural variability from point to point, but at some points along the shoreline it probably will. Using a higher than average rate is appropriate for determining setback distances because it is not known where the maximum erosion will occur (and where it will not).

Calculations of land area and volume of material eroded are based on average annual bank-recession rates because these rates provide a more realistic estimate of overall erosion in terms of land area and bank material loss for the entire lake. Therefore, these rates are used by others to assess environmental effects related to lake sedimentation and water quality. A more conservative approach was used to assess terrestrial habitat loss (i.e., estimating losses of unusual habitat types in areas that might potentially experience higher than average erosion rates) (Volume 6, Section 5). For the terrestrial analysis, land area loss was estimated using average erosion rates plus a 50% variability factor. Land area losses estimated in this way are presented in Appendix A6.3. The two approaches differ in the time scale in which land area may be lost. In the terrestrial assessment, the loss of land is estimated to occur sooner than when estimated using the average erosion rate assessment.

Table 6.3-9 shows the recession rates used to map future bank recession lines. Table 6.3-10 shows the recession rates used to calculate eroded land area and sediment volume loss. These tables show various rates for different shoreline types and wave energy environments around Wuskwatim Lake.

To compare future shoreline changes under existing conditions to anticipated post-project bank-recession rates, future bank positions for existing conditions have been estimated for 5, 25 and 100 years following the proposed Project in-service date of 2009. This corresponds to time periods 2009-2014, 2014-2034 and 2034-2109.

Projected bank-recession rates for 1998 onwards, as listed in Tables 6.3-9 and 6.3-10, are based on field survey data from Manitoba Hydro's erosion monitoring stations located around the Wuskwatim Lake shoreline (summarized in Tables 6.3-7 and 6.3-8 and discussed in Section 6.3.4), combined with information about shoreline materials derived from airphoto interpretation and analysis of video coverage. Related information on the derivation of projected bank-recession rates is presented Appendix A6.4.

Table 6.3-9

Projected bank-recession rates used to map future bank recession lines in Wuskwatim Lake without the Project

Shoreline Type	Existing Bank-recession rates (m/yr) (Table 6.3-8			Projected Bank-Recession Rates (m/yr)											
	1985-1998			1998-2009			2009-2014			2014-2034			2034-2109		
	Wave Energy			Wave Energy			Wave Energy			Wave Energy			Wave Energy		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
LC_{lg}, BC_{lg},FN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC, BC	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
LC/BR_l, BC	0.25	0.60	1.00	0.20	0.50	0.75	0.20	0.50	0.75	0.20	0.50	0.75	0.20	0.50	0.75
LC/BR_m	0.10	0.20	0.30	0	0	0	0	0	0	0	0	0	0	0	0
LC/BR_h, BR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: recession rates used to estimate future bank recession lines are based on average rates plus a 50% variability buffer; Legend: Wave Energy Categories: Low (L); Moderate (M), High (H) (Section 6.3.3.3)

Table 6.3-10

Projected average annual bank-recession rates used to calculate eroded land area and sediment volume in Wuskwatim Lake without the Project

Shoreline Type	Existing Bank-recession rates (m/yr) (Table 6.3-8)			Projected Bank-Recession Rates (m/yr)											
	1985-1998			1998-2009			2009-2014			2014-2034			2034-2109		
	Wave Energy			Wave Energy			Wave Energy			Wave Energy			Wave Energy		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC, BC	0.35	0.65	1.00	0.35	0.65	1.00	0.35	0.65	1.00	0.35	0.65	1.00	0.35	0.65	1.00
LC/BR_l, BC	0.15	0.40	0.65	0.15	0.35	0.50	0.15	0.35	0.50	0.15	0.35	0.50	0.15	0.35	0.50
LC/BR_m	0.07	0.15	0.20	0	0	0	0	0	0	0	0	0	0	0	0
LC/BR_h, BR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: average recession rates are used to estimate future land area and sediment volume added to the lake. Legend: Wave Energy Categories: Low (L); Moderate (M), High (H) (Section 6.3.3.3)

6.3.6 Modelling Future Bank Recession Lines With No Development

Figure 6.3-23 shows the location of projected bank positions for 1998, 2009, 2014, 2034 and 2109 without the Project. These lines represent the maximum likely bank recession for each classified shoreline unit.

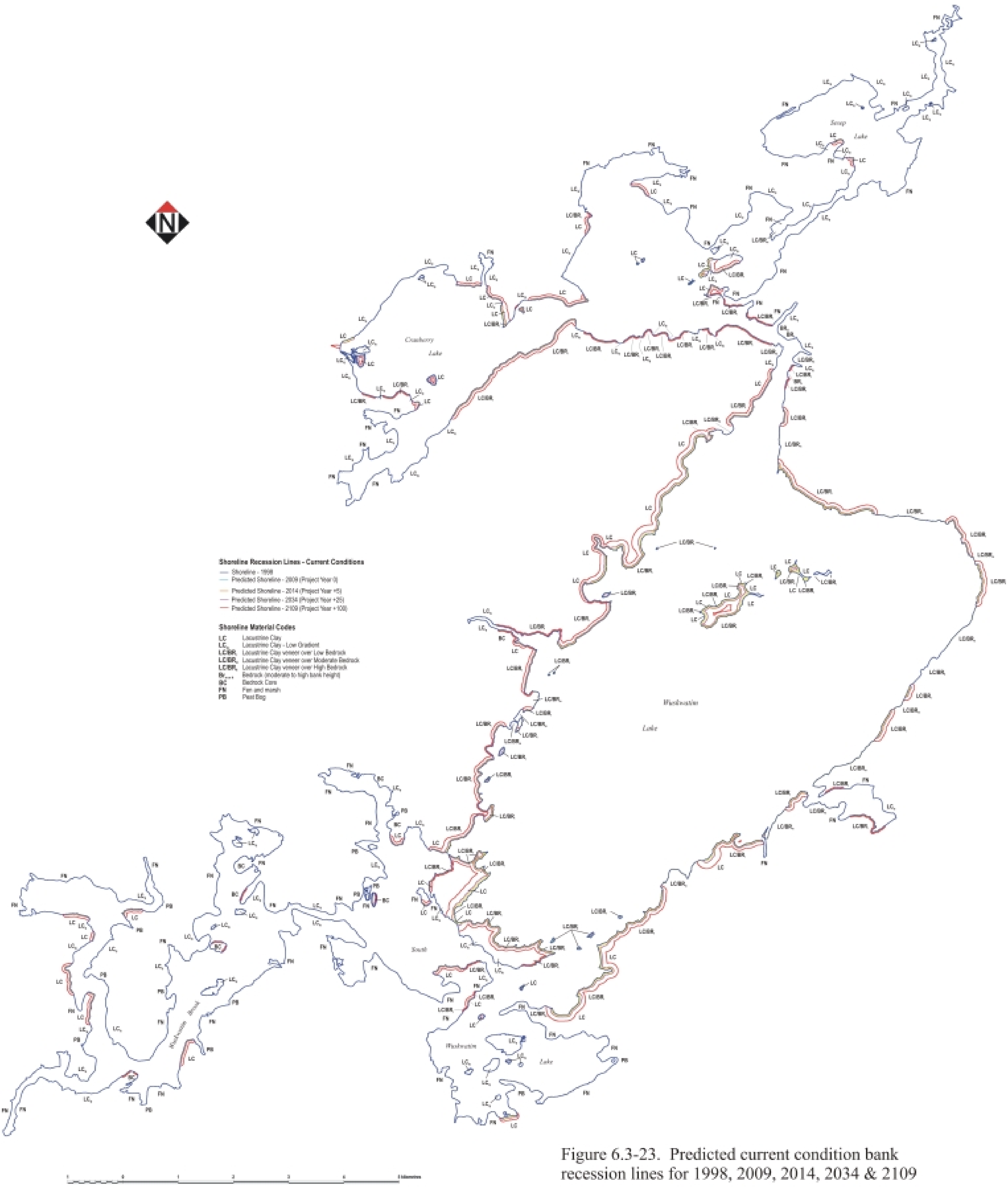

Figure 6.3-23. Predicted current condition bank recession lines for 1998, 2009, 2014, 2034 & 2109

Table 6.3-11 shows the total estimated land area lost due to erosion and the annual rate of land area loss for the five time periods modelled. The rate of land area loss decreases from approximately 3.2 ha/yr for 1985 to 1998 to approximately 2.7 ha/yr for the last period modelled from 2034 to 2109. The reduction in erosion rate is a result of stabilization of LC/BR_m shorelines and an anticipated slight reduction in bank-recession rates in LC/BR_l shorelines after 1998 (see Table 6.3-9).

Table 6.3-11

Projected land area eroded from around Wuskwatim Lake shorelines without the Project

	Average Land Area Eroded*	
Time Period	Area Eroded During Time Period (ha)	Area Eroded Annually (ha/yr)
1985-1998	41	3.2
1998-2009	32	2.9
2009-2014	14	2.8
2014-2034	56	2.8
2034-2109	204	2.7

* Land area eroded based on average erosion rates plus a 50% variability factor are presented in Appendix A6.3.

Table 6.3-12 shows the estimated volume of mineral and organic sediment eroded from around the Wuskwatim Lake shoreline assuming an average organic layer thickness of 0.3 m. The assumed organic layer thickness is based on limited field observation. Projected land areas and sediment volumes eroded around the main part of Wuskwatim Lake are summarized in Appendix A6.1.

Table 6.3-12

Projected volume of sediment eroded from the Wuskwatim Lake shoreline without the Project

Year	Total volume eroded (x 10^5 m^3)	Estimated volume of organics (assumed average thickness = 0.3m) (x 10^5 m^3)	Estimated volume of mineral sediment eroded (x 10^5 m^3)
1985-1998	7.8	1.2	6.6
1998-2009	5.8	1.0	4.8
2009-2014	2.6	0.4	2.2
2014-2034	10.3	1.7	8.6
2034-2109	38.3	6.1	32.2

Immediate Forebay Area

Under existing conditions, Wuskwatim Falls form a natural control for Wuskwatim Lake outflows. Downstream of Wuskwatim Falls, a short reach of channel conveys Burntwood River flows to Taskinigup Falls. Under the existing environment, flow conditions in this short reach of channel are in the high range of velocities observed in other reaches of the Burntwood River. Average flow velocities in the reach are typically in the order of 1 to 1.5 m/s, except in the local vicinity of Wuskwatim Falls and the approach to Taskinigup Falls where much higher velocities occur. The reach generally remains open during the winter, with a band of border ice forming on each bank.

Under present conditions the shores along this reach consist of alternating reaches of erodible clay and silt banks and banks where clay and silt overlies bedrock. Erosion along the majority of the north and south shores is relatively minor at present. Local exceptions to minor erosion observed elsewhere are active bank failures at the head ends of two small bays located immediately below Wuskwatim Falls. One bay is located on the north shore and the other on the south shore (Figure 6.3-24). These failures are likely due to undercutting of the banks as a result of the strong back eddies that form below Wuskwatim Falls

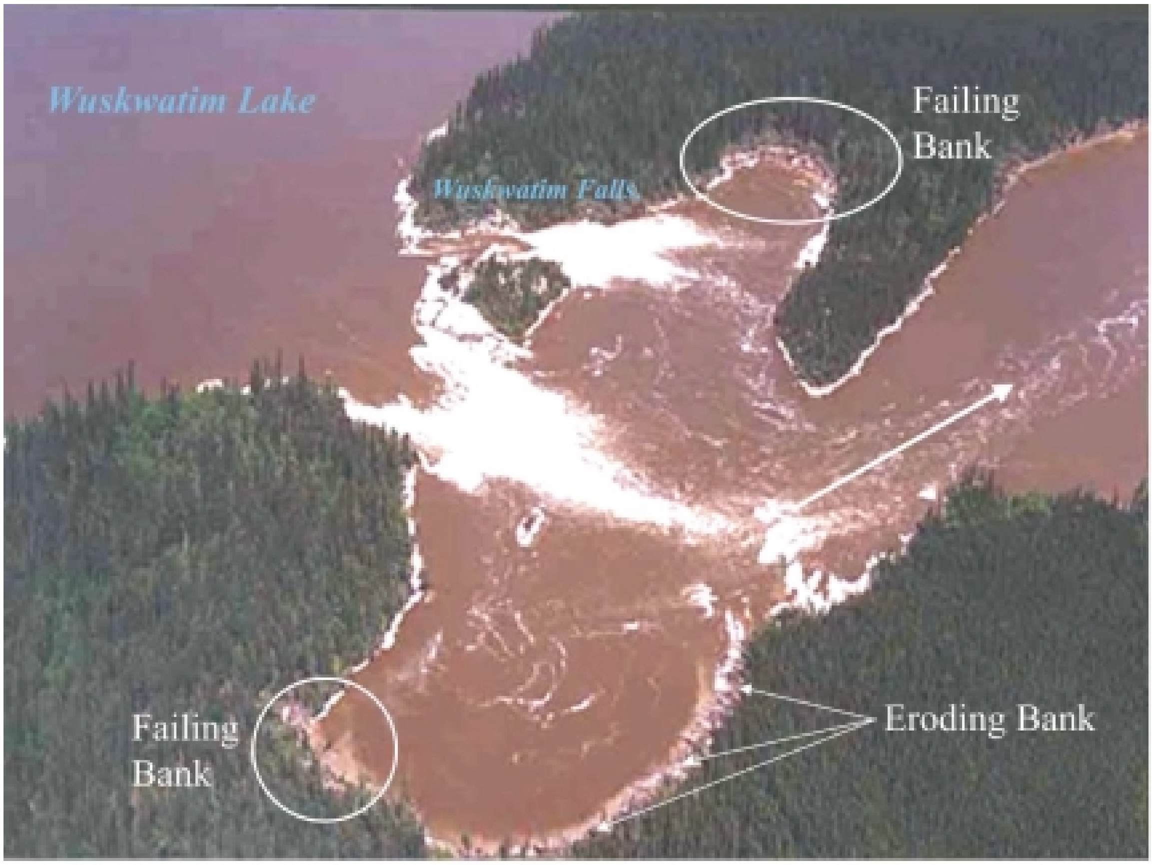

Figure 6.3-24. Oblique aerial photograph showing the location of failing and eroding banks below Wuskwatim Falls. View looking towards the north.

6.4 EFFECTS AND MITIGATION

This section describes the change expected in shore erosion processes and effects with construction of the proposed Wuskwatim Generation Project.

6.4.1 Construction

During both Stage I and II diversion, the riverbanks in the upstream reach between Wuskwatim Falls and Taskinigup Falls will be exposed to slightly higher water levels of approximately 0.2 to 0.3 m, and potentially up to 0.5 to 1.0 m under a high flow event or in winter conditions. This short-term rise in water level might result in some minor river bank erosion between Wuskwatim and Taskinigup falls during construction prior to full impoundment. There will be no change in upstream water levels during construction and therefore no change in erosion in the main part of Wuskwatim Lake is anticipated during construction.

Near the end of construction (October 2008) water levels between Wuskwatim Falls and Taskinigup Falls will rise by up to 7 m, to 234 m elevation as a result of **forebay** impoundment. As a result, shorelines in this immediate forebay area will become part of the Wuskwatim Lake shoreline. Changes in erosion in the immediate forebay area with impoundment are addressed in Section 6.4.2.2.

6.4.2 Operation

6.4.2.1 Anticipated Changes in Erosion Rates

In terms of shore erosion, the main difference between existing conditions and post-project conditions is a change from the current pattern of lake level variations to a relatively constant level that will be maintained under post-project conditions. Under existing conditions, lake levels fluctuate between approximately 233.0 m and 234.3 m most of the time, with an average lake level of about 233.6 m. Following the proposed development, the lake level will be stabilized at or near the 234.0 m FSL elevation. Since the lake level after development will remain within the existing operating range, the existing condition shoreline classification presented in Section 6.3.3.2 will apply under post-project conditions as well.

The susceptibility of some shoreline types to erosion will change as a result of the lake being held relatively constant at the upper end of its current range. Shorelines most affected are clay and silt banks (LC) and clay and silt banks overlying relatively low bedrock (LC/BR_l). Post-project erosion conditions in these shoreline types will be much like that experienced when the lake level is relatively high (i.e., ~234 m) under existing conditions.

In clay and silt (LC) shorelines, maximum initial post-project bank-recession rates are expected to be comparable to bank-recession rates that were measured in Wuskwatim Lake mainly in the early to mid 1980s. That is, rates that are less than initial post-CRD rates but higher than current rates, which are believed to be approaching long-term stable rates (Section 6.3.2). Figure 6.4-1 shows airphoto-measured bank-recession rates in Wuskwatim Lake for the period 1978-1985 and a number of short-term bank-recession rates measured between 1981 and 1988. Data presented in Figure 6.4-1 indicates that the overall average bank-recession rate measured from 1978-1985 is 2.0 m/yr. These rates were measured in mostly moderate and high wave energy settings in the main part of Wuskwatim Lake. The average bank-recession rate at high wave energy sites located on the east and south shores of Wuskwatim Lake is 2.2 m/yr. The recession rate at moderate wave energy sites located on the west shore is 1.7 m/yr.

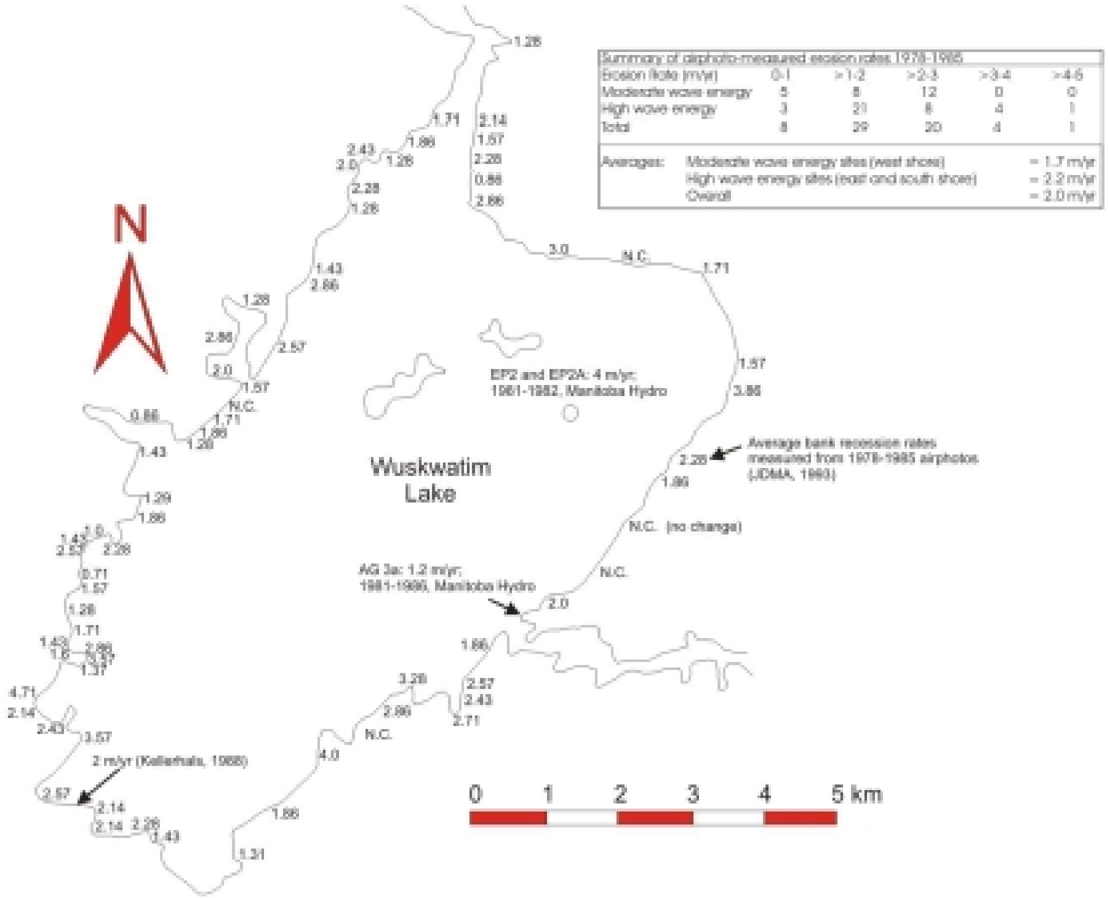

Figure 6.4-1. Average bank recession rates in Wuskwatim Lake measured from 1978-1985 airphotos (JDMA, 1993) and at three erosion monitoring sites in the 1980s.

Since the airphoto measurement period begins in 1978 and ends in 1985, the data spans a period in which erosion rates were likely higher immediately after CRD to the mid-1980s when erosion rates had likely declined from initial post-CRD rates. Therefore, it seems reasonable to expect that initial post-project erosion rates will be lower than the average rate measured from 1978-1985. How much lower is not known. For model calculation purposes, an initial average post-project rate of 1.5 m/yr has been assumed for silt and clay banks exposed to high wave energy. The same initial post-project erosion rate has been assumed for banks where silt and clay overlies low bedrock because the 234 m water level is initially above the clay/silt-bedrock contact in these areas.

The assumptions made here are consistent with erosion model calculations by JDMA (1993). Those calculations suggested initial erosion rates of approximately 2 m/yr in high wave energy settings for so-called "**high-head**" reservoir conditions being proposed at that time (Figure 6.4-2).

Initial erosion rates with the Project as presently proposed are expected to be lower than for high-head conditions contemplated by Manitoba Hydro in the early 1990s. This is because the Project will modify an existing shoreline whereas the high-head scenario would have created a new shoreline with less wave energy dissipation in the nearshore zone. Bank-recession rates from other lakes and reservoirs are summarized in Table 6.4-1 for comparison to projected rates in Wuskwatim Lake.

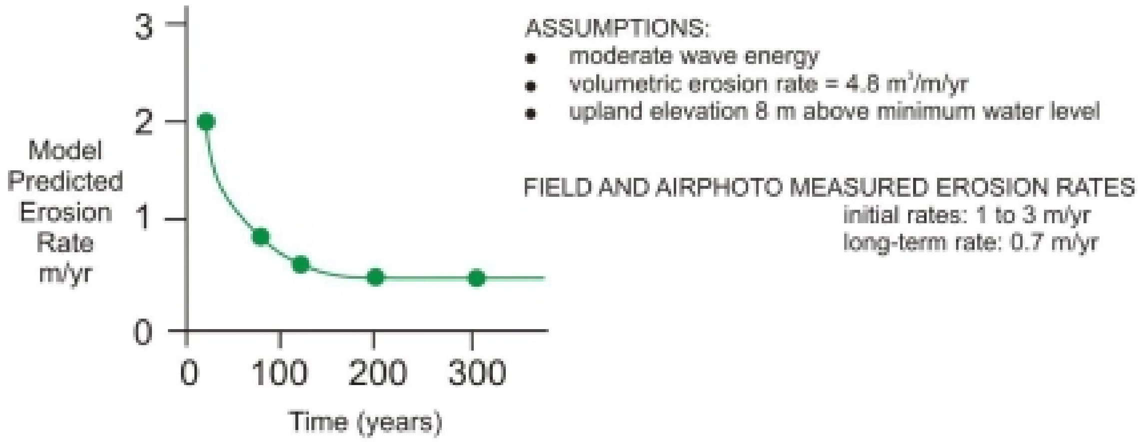

Figure 6.4-2. Model predicted erosion rate versus time curve for "high head" conditions proposed for Wuskwatim Lake in the early 1990s (JDMA, 1993)

Using historical erosion data from Wuskwatim Lake, and supported by data from other lakes and reservoirs in Table 6.4-1, projected average annual post-project bank-recession rates were developed for 0-5, 6-25 and 26-100 year periods after development. Rates used to plot future bank recession lines are shown in Table 6.4-2. These recession rates are based on anticipated average annual bank-recession rates plus a 50% variability buffer, similar to the methodology used for the no-development scenario (Section 6.3.5).

Table 6.4-3 shows projected post-project bank-recession rates used to estimate eroded land areas and eroded bank material volumes. These rates are based on average annual bank-recession rates (Section 6.3.5).

Table 6.4-1

Summary of historical bank-recession rates in western Canadian lakes and reservoirs

Name of water body	Typical average bank-recession rates (m/yr)
Avonlea Reservoir, SK (Penner *et al*. 1992)	0.25 to 1.5
Lake Diefenbaker, SK (Penner *et al*. 1992)	1 to 3
Lake of the Prairies, MB (Penner *et al.* 1992)	0.5 to 1.5
Sipiwesk Lake, MB (Southwest basin) (JDMA, 1993)	0.3 to 1 (long-term pre-Kelsey generating station)
J.D. Mollard and Associates data from 20 lakes and reservoirs	0.25 to 1 (small water bodies) 0.5 to 3 (large water bodies)
Penner et al (1975) data from 9 lakes and reservoirs	0.25 to 1.5

Table 6.4-2

Projected bank-recession rates used to plot future bank recession lines in Wuskwatim Lake* with the Project

	Projected Average Annual Bank-recession rate (m/yr)								
Shoreline Type	2009-2014			2014-2034			2034-2109		
	Wave Energy			Wave Energy			Wave Energy		
	L	M	H	L	M	H	L	M	H
LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
LC, BC	0.75	1.50	2.00	0.60	1.25	1.75	0.50	1.00	1.50
LC/BR_l, BC	0.75	1.50	2.00	0.25	0.60	1.00	0.20	0.50	0.75
LC/BR_m	0.20	0.40	0.60	0.10	0.20	0.30	0	0	0
LC/BR_h, BR	0	0	0	0	0	0	0	0	0

Legend: Wave Energy Categories: Low (L); Moderate (M), High (H) (Section 6.3.3.3)
* These rates were also used to assess terrestrial habitat loss in Volume 6, Section 5.

Table 6.4-3

Projected bank-recession rates used to calculate eroded land area and eroded material volume with the Project

	Projected Average Annual Bank-recession rate (m/yr)								
Shoreline Type	**2009-2014**			**2014-2034**			**2034-2109**		
	Wave Energy			**Wave Energy**			**Wave Energy**		
	L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
LC, BC	0.50	1.00	1.50	0.40	0.85	1.20	0.35	0.65	1.00
LC/BR_{l}, BC	0.50	1.00	1.50	0.15	0.40	0.65	0.15	0.35	0.50
LC/BR_{m}	0.15	0.25	0.40	0.07	0.15	0.20	0	0	0
LC/BR_{h}, BR	0	0	0	0	0	0	0	0	0

Legend: Wave Energy Categories: Low (L); Moderate (M), High (H) (Section 6.3.3.3)

As previously indicated, it is expected that with the Project, erosion rates in clay and silt (LC) shorelines will increase to levels that are comparable to erosion rates measured in Wuskwatim Lake in the mid to late 1980s, and then decline over time. Average erosion rates for clay and silt shorelines in high wave-energy environments from Table 6.4-3 are graphically depicted in Figure 6.4-3. Figure 6.4-3 shows an initial increase in erosion rates in the first 5 years, a decline in the next 20 years and a further decline to pre-project levels after 25 years. The rates are shown as "steps" for modelling purposes. The estimated initial post-CRD bank-recession rate of 3 m/yr is based mainly on modelling and airphoto studies carried out by JDMA (1993) and in part on bank-recession rates

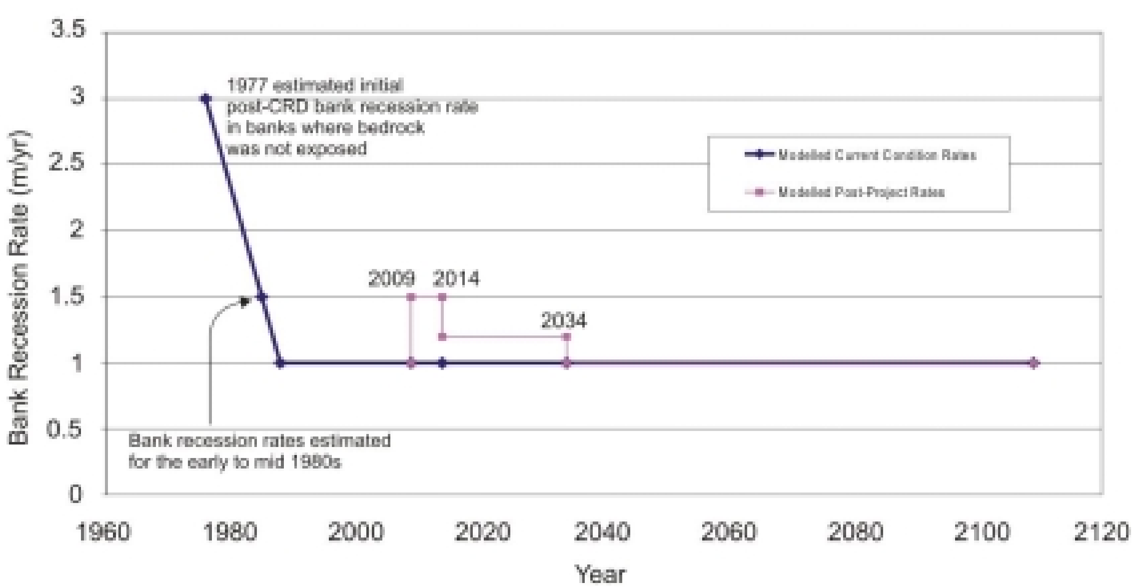

Figure 6.4-3. Predicted change in average bank recession rates in clay and silt shorelines exposed to high wave energy - Wuskwatim Lake.

observed in other northern Manitoba lakes and reservoirs under comparable conditions. A constant long-term erosion rate has been assumed for modelling purposes. However, based on pre-CRD airphoto measured recession rates in Wuskwatim Lake, as well as long-term rates observed in other lakes and reservoirs, long-term rates may decline slightly below modelled rates in the future.

In shorelines where clay and silt banks overlie low bedrock (LC/BR_l), post-project lake levels are sufficiently high that in-coming waves will reach the toe of erodible banks (Figure 6.3-3). As a result, maximum initial post-project bank-recession rates in these shorelines are expected to be comparable to initial post-project bank-recession rates in LC shorelines. Long-term (i.e., >25 years after the Project) bank-recession rates are expected to return to values observed under existing conditions in LC/BR_l shorelines. It is anticipated that erosion rates during the 6 to 25 year post-project period will be at a level between anticipated initial and long-term post-project rates. The change in erosion rates for LC/BR_l shorelines in high wave energy environments is depicted in Figure 6.4-4.

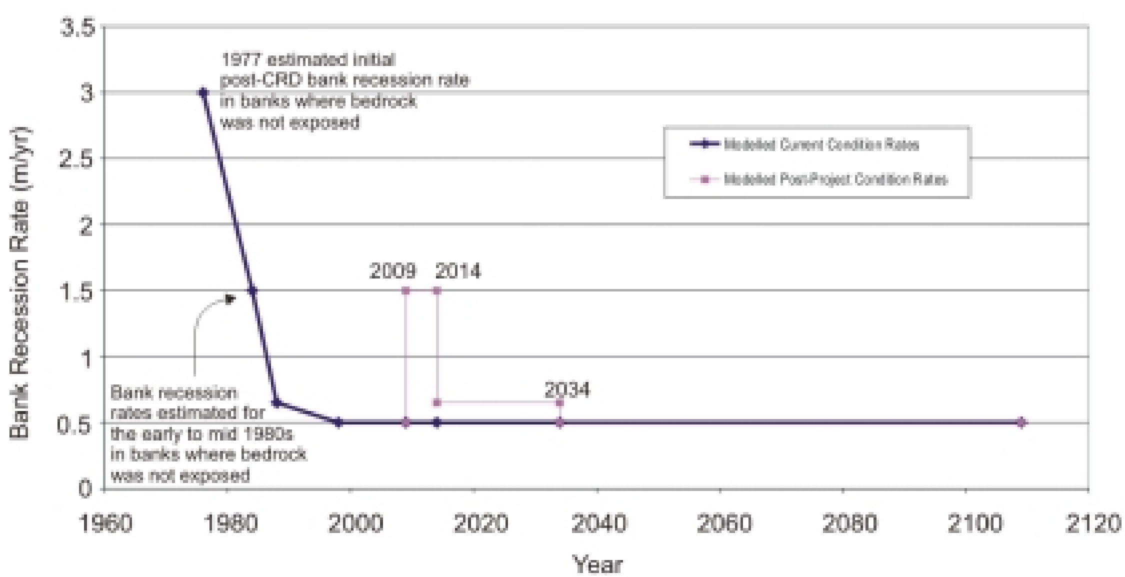

Figure 6.4-4. Predicted change in average bank recession rates in shorelines where clay and silt overlies low bedrock exposed to high wave energy - Wuskwatim Lake

In clay and silt shorelines where the bedrock contact is near the 234.0 m elevation (i.e., LC/BR_m) it is anticipated that there would be a slight initial increase in bank-recession rates. Under post-project conditions, the bedrock-**drift** contact is expected to be above the 234.0 m lake level in most locations in LC/BR_m shorelines. However, discontinuous local bank recession due to local erosion and failure of clay and silt banks is anticipated where the bedrock surface is near or slightly below 234.0 m. The frequency of local bank failures is expected to decrease over time, with only rare and isolated occurrences in the 25 to 100 year time frame after the Project. It is impossible to predict where and when such local failures might occur within LC/BR_m shoreline reaches. Therefore, a low bank-recession rate has been applied to LC/BR_m shorelines for the first 25 years after the Project, reducing to zero after 25 years.

6.4.2.2 Immediate Forebay Area

In the immediate forebay area, the Project will cause a rise in water levels of up to 7 m, to 234 m elevation. Throughout most of this area landward shoreline migration due to initial flooding will be in the order of 20 to 75 m, depending on the gradient of the flooded slopes. In local gently sloping areas, flooding will extend farther inland, up to a maximum of approximately 300m in a creek bed on the south shore. Post-project wave energy in the immediate forebay area will be low owing to relatively short open water fetches and low-angle nearshore slopes.

North Shore

The majority of the north shore is unlikely to experience erosion due to placement of rock material at or near the shoreline associated with the north dyke, excavated material placement area and the construction of an access road to the channel excavation area, which will be built to elevation 234 m (Volume 3, Section 4).

South Shore

With the rise in water levels to 234 m, a new shoreline will form in erodible clay and silt materials along most of the south shore. An exception is a 535 m-long reach that will consist of non-eroding low-gradient clay or fen and marsh shoreline in a flooded creek bed. The remainder of the south shoreline is classified as eroding clay and silt materials (LC) exposed to low energy. Future post-project bank recession lines and estimates of eroded land area and sediment volumes were calculated using the same procedure as was done for shoreline areas in the main part of the lake and connected water bodies.

6.4.3 Summary of Changes in Shoreline Erosion With and Without the Project

Wuskwatim Lake has a variety of shoreline types from non-eroding fen, marsh and bedrock shorelines to eroding silty clay banks and silty clay banks overlying low bedrock shores. The later two categories are considered highly erodible. Within the entire Wuskwatim Lake waterbody (including Sesep and Cranberry lakes) approximately 30% of the shoreline is considered erodible, however within the main part of Wuskwatim Lake, eroding shorelines represent nearly 75% of that shoreline. Of the 75% of the shoreline that is considered erodible in the main part of Wuskwatim Lake, approximately 50% of the shoreline is exposed to high wave-energy due to prevailing wind direction and/or exposure to long open water stretches. The high wave-energy shorelines are located on the eastern and southern sides of the lake and will have higher average annual rates of erosion in the range of 0.65 to 1.0 m/yr depending on shoreline type. Shorelines located in moderate wave-energy environments (i.e., westerly shorelines) will have erosion rates that are approximately 2/3 of the above rates.

With the Project, water levels will be stabilized near the upper end of their historical post-CRD range. This will result in an accelerated rate of erosion in the short to medium term (0-25 years) for those shorelines that are erodible. The following summarizes anticipated changes in erosion rates, bank recession distances and eroded shore area and bank material volume with and without the Project.

6.4.3.1 Erosion Rates

Table 6.4-4 summarizes the erosion rates used for modelling future erosion with and without the Project. Sections 6.3.5 and Section 6.4.2.1 provide the derivation of these rates. Average annual erosion rates shown in Table 6.4-4 were used to calculate shore area loss and eroded volume of material. Figure 6.4-3 shows graphically the change in erosion rates for clay and silt shorelines (in a high-wave energy environment) following the Project. This figure indicates that for these shorelines, erosion rates will initially increase to 1.5 m/yr in the first 5 years, and then decrease in the following 6 to 25 years, returning to long-term rates after 25 years. Similarly Figure 6.4-4 shows the change in erosion rates for clay and silt shorelines overlying low bedrock in high wave energy environments.

6.4.3.2 Shoreline Recession

Table 6.4-5 summarizes the cumulative change in bank recession distances that are estimated for different shoreline types and wave energy conditions around Wuskwatim Lake for the various time periods modelled, i.e., 5, 25 and 100 years post-project based on post-project rates shown in Table 6.4-4. Table 6.4-5 indicates that for highly erodible shorelines, i.e., silty clay shorelines (LC) located in a high wave energy environment, the cumulative bank recession after the Project in 2109 would be 106.5 m, on average, versus 100 m without the Project. Shorelines located in lower wave energy settings will erode less, as will shorelines with less erodible materials rates, i.e., silty clay overlying bedrock (LC/BR_l).

Table 6.4-4

Summary of average erosion rates used for modelling various time periods with and without the Project

With vs without the Project		Average Bank Erosion Rates for Various Time Periods (m/yr)								
	Shoreline Type	0 - 5 Years (2009-2014)			6 -25 Years (2014-2034)			26 - 100 Years (2035-2109)		
		Wave Energy			Wave Energy			Wave Energy		
		L	M	H	L	M	H	L	M	H
Without Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
With Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
Without Project	LC	0.35	0.65	1.00	0.35	0.65	1.00	0.35	0.65	1.00
With Project	LC	0.50	1.00	1.50	0.40	0.85	1.20	0.35	0.65	1.00
Without Project	LC/BR_l	0.15	0.35	0.50	0.15	0.35	0.50	0.15	0.35	0.50
With Project	LC/BR_l	0.50	1.00	1.50	0.15	0.40	0.65	0.15	0.35	0.50
Without Project	LC/BR_m	0	0	0	0	0	0	0	0	0
With Project	LC/BR_m	0.15	0.25	0.40	0.07	0.15	0.20	0	0	0
Without Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0
With Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0

Legend: Wave Energy Categories: Low (L); Moderate (M), High (H); Table based on average bank-recession rates, shown in Tables 6.3-10 and 6.4-3

Table 6.4-5

Projected cumulative bank recession distances 5, 25 and 100 years after the proposed Wuskwatim development in-service date of 2009 with and without the Project

Without vs with the Project		Projected Cumulative Bank Recession Distances (m)								
	Shoreline Type	5 Years (2009-2014)			25 Years (2009-2034)			100 Years (2009-2109)		
		Wave Energy			Wave Energy			Wave Energy		
		L	M	H	L	M	H	L	M	H
Without Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
With Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
Without Project	LC	1.8	3.3	5.0	8.8	16.3	25.0	35.1	65.1	100.0
With Project	LC	2.5	5.0	7.5	10.5	22.0	31.5	36.8	70.8	106.5
Without Project	LC/BR_l	0.8	1.8	2.5	3.8	8.8	12.5	15.1	35.1	50.0
With Project	LC/BR_l	2.5	5.0	7.5	5.5	13.0	20.5	16.8	39.3	58.0
Without Project	LC/BR_m	0	0	0	0	0	0	0	0	0
With Project	LC/BR_m	0.8	1.3	2.0	2.2	4.3	6.0	2.2	4.3	6.0
Without Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0
With Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0

Legend: Same as Table 6.4-5; Table based on average bank-recession rates shown in Tables 6.4-4

Figure 6.4-5 shows the position of projected bank recession lines in Wuskwatim Lake for 2014 (5 years after the Project), 2034 (25 years after the Project) and for 2109 (100 years after the Project). Figure 6.4-6 shows the incremental change in 5, 25 and 100-year bank recession positions with and without the Project. Projected future bank recession lines around the entire lake shoreline for current conditions and post-development conditions were used to estimate land area and volume of material loss to erosion. These lines can be viewed in more detail in Manitoba Hydro's geographic information system, as can the recession lines based on higher rates of erosion (average plus 50% variability factor that were used for establishing setback lines and for the terrestrial assessment studies, see Section 6.3.5).

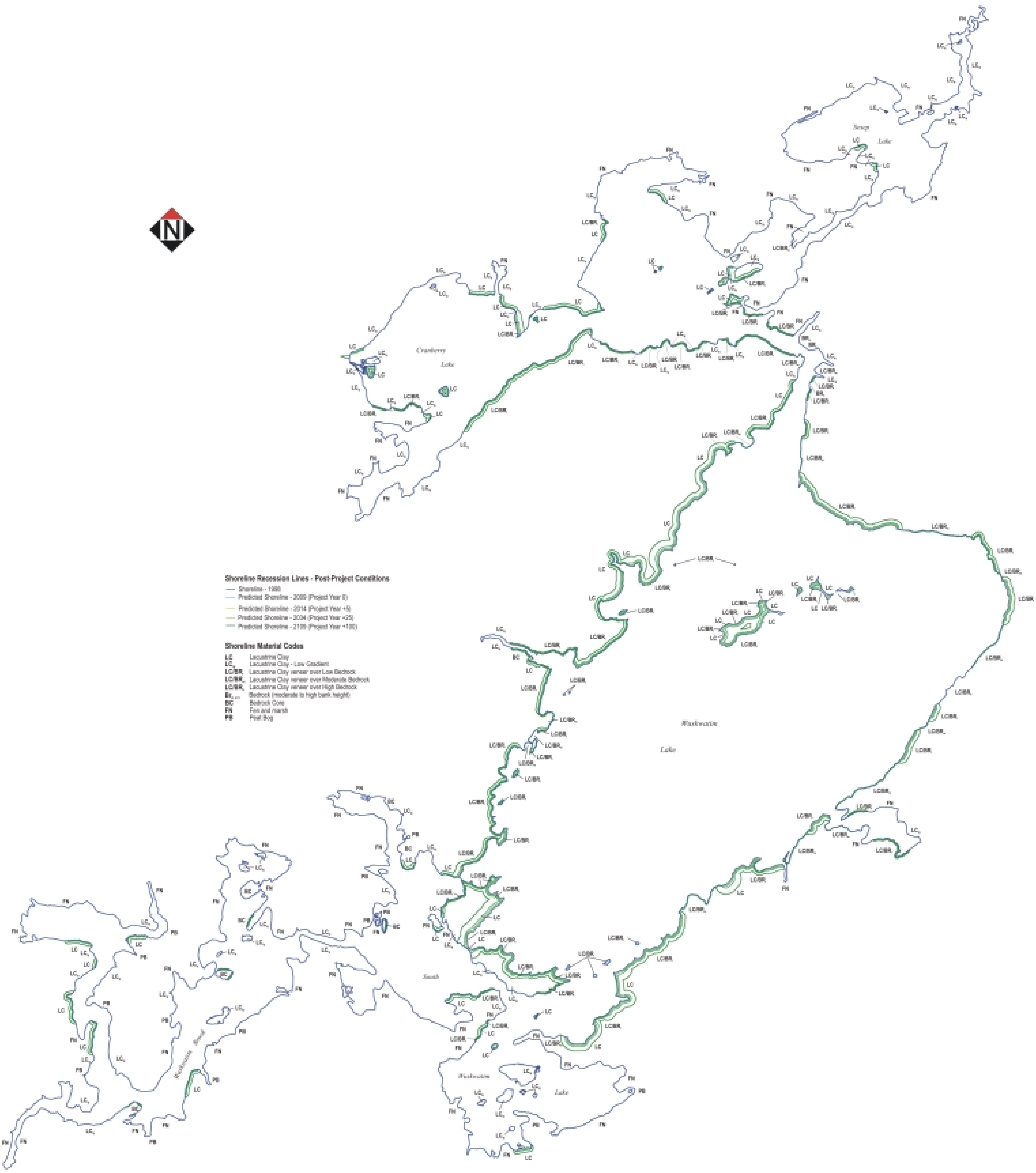

Figure 6.4-5. Predicted post-project bank recession lines for 1998, 2009, 2014, 2034 & 2109

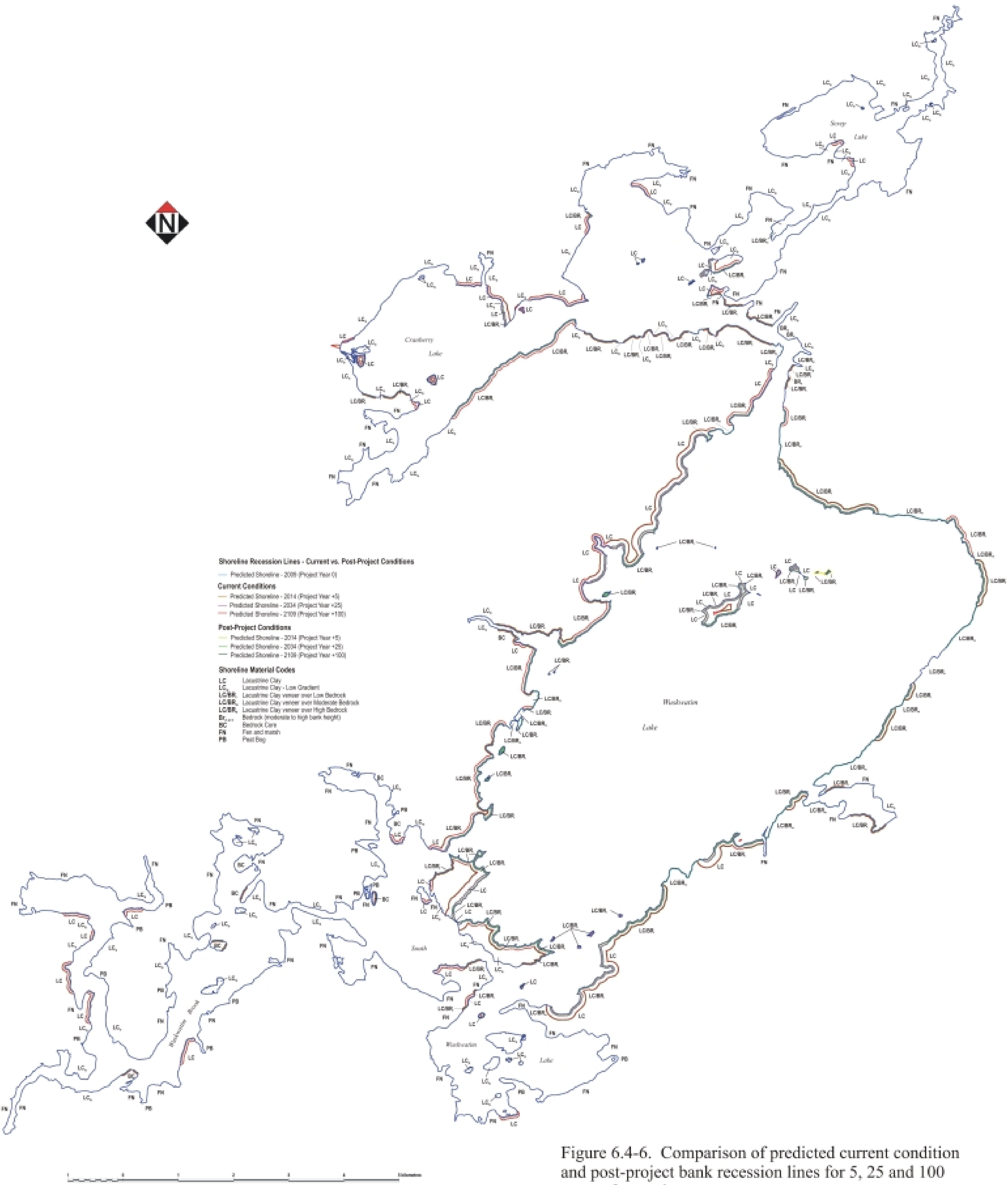

Figure 6.4-6. Comparison of predicted current condition and post-project bank recession lines for 5, 25 and 100 years after project

6.4.3.3 Shoreline Area and Volume

Table 6.4-6 provides a summary of the land area loss based on GIS mapping of Wuskwatim Lake shorelines using average erosion rates. This table provides a summary for the two pre-project modelling periods and the three post-project modelling periods, as well as calculated annual rates. With the Project the initial loss rate calculated on an annual basis is about 7.8 ha/yr during the first five years. This figure does not include loss of land due to initial post-project flooding. During the 6 to 25 year period, the rate of land loss with the Project is about 3.7 ha/yr. During the 26 to 100 year period, the rate of land area loss under post-project conditions is anticipated to be approximately the same as under existing conditions (i.e., about 2.8 ha/yr).

Table 6.4-6

Comparison of the projected land area eroded with and without the Project*

Modelled Time Periods	Incremental Area Eroded Without the Project (ha)	Incremental Area Eroded With the Project (ha)	Average Annual Area Eroded Without the Project (ha/yr)	Average Annual Area Eroded With the Project (ha/yr)
1985-1998	41	N/A	3.2	N/A
1998-2009	32	N/A	2.9	N/A
2009-2014	14	39	2.8	7.8
2014-2034	56	73	2.8	3.7
2034-2109	204	209	2.7	2.8

*Table based on average bank-recession rates, shown in Table 6.4-4. Land areas calculated using average plus 50% variability erosion rates are presented in Appendix A6.3.

Table 6.4-7 summarizes the estimated volume of mineral and organic sediment that will be eroded from the Wuskwatim Lake shoreline under existing and post-project conditions. The volume of organic sediment is based on an assumed average organic layer thickness of 0.3m. During the first five years of the Project it is estimated that the volumetric erosion rate in Wuskwatim Lake will be approximately 1.1 x 10^5 m^3/yr. This rate is expected to decrease to about 0.6 x 10^5 m^3/yr for the 6 to 25 year period and then to about 0.4 x 10^5 m^3/yr for the 26 to 100 year period. After 25 years the volumetric erosion rate is expected to be the approximately the same as it would have been without the Project. The effect of shoreline erosion on sedimentation in Wuskwatim Lake is discussed later in Section 8 – Sedimentation.

Table 6.4-7

Projected volume of mineral and organic sediment eroded from the Wuskwatim Lake* shoreline with and without the Project

Year	Total estimated volume of sediment eroded (x 10^5 m^3)		Estimated volume of organic sediment eroded (assuming an organic layer thickness of 0.3m) (x 10^5 m^3)		Estimated volume of mineral sediment eroded			
					Over Time Period (10^5 m^3)		Annual Basis (10^5 m^3/yr)	
	Without Project	With Project	Without Project	With Project	Without Project	With Project	Without Project	With Project
1985-1998	7.8	N/A	1.2	N/A	6.6	N/A	0.5	N/A
1998-2009	5.8	N/A	1.0	N/A	4.8	N/A	0.4	N/A
2009-2014	2.6	6.6	0.4	1.1	2.2	5.5	0.4	1.1
2014-2034	10.3	13.6	1.7	2.2	8.6	11.4	0.4	0.6
2034-2109	38.3	39.9	6.1	6.3	32.2	33.6	0.4	0.4

Table based on average bank-recession rates, shown in Tables 6.4-4

Projected mineral and sediment volumes eroded from the main part of Wuskwatim Lake are summarized in Appendix A6.1.

6.4.4 Summary of Effects

The effect of the Project will be to stabilize water levels near the upper end of the current operating regime. This will result in a short-term acceleration in the ongoing shore erosion that is now occurring on Wuskwatim Lake. The increase in erosion will be highest initially and decline over time to zero at the end of 25 years. Since incremental changes in erosion are declining over a moderate time frame (25 years), effects on the physical environment are considered moderate as well. The potential implications to the aquatic and terrestrial environments are discussed in Volumes 5 and 6.

Specific erosion aspects of the Project are summarized below.

- Thirty percent (30%) of the entire Wuskwatim Lake shorelines (including back bays and surrounding lakes) are considered moderate to highly erodible. In the main part of Wuskwatim Lake, erodible shorelines make up 75% of that shoreline.

- Little change in bank-recession rates is anticipated in the remaining 70% of the shoreline.

- Over a 25-year period, silty-clay shorelines on the eastern and southern shores of Wuskwatim Lake, which have more frequent high wind and wave energy events, are projected to recede about 32 m, compared to 25 m without the Project on average. Silty-clay shorelines overlying shallow bedrock in high wave energy settings will recede, on average, 21 m versus 13 m without the Project. The erodible shorelines on the west side of the lake, which have less exposure to higher winds and wave energy are expected to recede an average of about two thirds of the above rates.

- With the Project, land area loss to erosion will increase from 70 ha to 112 ha over a 25-year period.

- After an initial 25-year period, bank-recession rates in eroding shorelines are expected to be the same as they would be under existing conditions.

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Appendix A6.1 Summary Of Erosion Analysis for Main Part Of Wuskwatim Lake

Summary of shoreline types and predicted eroded land area and sediment volume for current and post-project conditions for the main part of Wuskwatim Lake (excludes shorelines in Cranberry Lake, Sesep Lake, Wuskwatim Brook and the south basin of Wuskwatim Lake).

Table A6.1-1

Length of shoreline types in the main part of Wuskwatim Lake

Shore Type	Length of Shoreline (km)				Percentage of Shoreline Length (%)
	Low Wave Energy	Moderate Wave Energy	High Wave Energy	Total Length (km)	
LC	1.7	6.8	3.0	11.5	20.6
LC/BR_l and BC	4.6	10.5	14.8	29.9	53.6
LC/BR_m	1.1	1.4	8.8	11.3	20.3
LC_{lg}; BC_{lg}	1.5	0	0	1.5	2.7
FN	0.5	0	0	0.5	0.9
LC/BR_h;BR_h;BR	0	0	1.1	1.1	2.0
Totals	**9.4**	**18.7**	**27.7**	**55.8**	**100.0**

Table A6.1-2

Predicted land area eroded around the shoreline of the main part of Wuskwatim Lake

Year	Predicted Land Area Eroded Under Current Conditions (ha)	Predicted Land Area Eroded Under Post-Project Conditions (ha)
2009-2014	9	23
2014-2034	36	49
2034-2109	136	136

Table A6.1-3

Predicted volume of mineral and organic soil sediment eroded from the shoreline of the main part of Wuskwatim Lake under current and post-project conditions

Year	Current Conditions			Post-Project Conditions		
	Total Eroded Volume (x 10^5 m^3)	Organic Material Eroded * (x 10^5 m^3)	Mineral Soil Eroded (x 10^5 m^3)	Total Eroded Volume (x 10^5 m^3)	Organic Material Eroded * (x 10^5 m^3)	Mineral Soil Eroded (x 10^5 m^3)
2009-2014	1.9	0.3	1.6	4.9	0.7	4.2
2014-2034	7.7	1.1	6.6	10.4	1.5	8.9
2034-2109	29.0	4.1	24.9	29.0	4.1	24.9

* assuming an average organic layer thickness of 0.3 m.

Appendix A6.2 Discussion of Variability Between Erosion Rates and Variability Factor

Estimating potential errors and variability in predicted Wuskwatim Lake bank-recession rates and long-term bank positions.

Predicted future bank positions around Wuskwatim Lake represent conservative estimates based on average annual bank-recession rates measured at Manitoba Hydro's erosion monitoring sites located in Wuskwatim Lake plus a 50% variability factor. At monitored sites, bank-recession rates vary locally around the lake. This appendix provides a summary of factors that contribute to variability in bank-recession rates.

The main factors causing variability in predicted erosion rates and bank recession distances are summarized in Equation 1, below:

Equation 1

Total potential variability =

1) natural variability in erosion rates under present day wave energy and shoreline terrain conditions

+

2) systematic and random map and digital data set errors

+

3) variability in future long-term wave energy climate and shoreline terrain conditions.

1) Natural variability in long-term erosion rates under present day wave energy and shoreline terrain conditions can be estimated based on the variability observed in recorded erosion rates at Manitoba Hydro's Wuskwatim Lake erosion monitoring sites (Section 6.3.4).

2) Systematic and random errors associated with map projection errors, GIS data layer accuracy and digital orthoimage (DOI) accuracy are additive to the anticipated natural variability in erosion rates.
3) Variability in future long-term wave energy and shoreline terrain conditions are difficult to predict. Storm frequency, severity of high wind events, dominant wind directions during storms and timing of storms with respect to the open water season are some of the factors that could result in changes to future bank-recession rates. Also, changes in shoreline terrain conditions, especially the percentage and location of bedrock-controlled shores, may alter future recession rates in local areas.

Even though long-term wave energy and shoreline conditions are important factors, it is difficult to accurately predict changes that might occur over the next 100 years, especially with respect to wave energy as it relates to potential climate change effects. There are also practical limitations to the amount of field investigation that might be carried out to map bedrock surface elevations around the shoreline and back from the present shoreline a distance of 100 metres or more.

In terms of shoreline materials, the predicted recession lines are thought to represent conservative estimates because, if anything, the percentage of bedrock-controlled shoreline is likely to increase over time.

The coefficient of variation (V) characterizes the degree of variability in average bank-recession rates. It is a function of the average annualized recession rate (r_m) and the standard deviation(s), as shown in the following equation:

$$V = (s/r_m)\ x(100\%)$$

A summary of the coefficient of variability for erosion data from Manitoba Hydro's Wuskwatim Lake erosion monitoring sites is shown in Table 6.3-7 in Section 6.3.4 of this report.

Average bank-recession rates at erosion monitoring sites, and variability ranges based on coefficients of variation of 50% and 60%, are shown in Table A6.2-1 for LC and LC/BR_l shores. Corresponding bank-recession rates used to predict future bank positions are also shown in Table A6.2-1. Note that there are no monitoring profiles located in LC shores in low wave energy settings. Therefore, bank-recession rates for the categories have been estimated by interpolation and LC/BR_l shores in moderate wave energy settings.

Table A6.2-1

Average bank-recession rates (m/yr), variability ranges for coefficients of variation of 50% and 60%, and long-term bank-recession rates used to predict future bank positions for the 1985 to 1998 period under existing conditions

	V = 50%			V = 60%			Bank-Recession Rates Used To Predict Future Bank Positions For 1985-1998 Under Existing Conditions		
Wave Energy	L	M	H	L	M	H	L	M	H
LC	0.3+/-0.15	0.6+/-0.3	0.8+/-0.4	0.3+/-0.2	0.6+/-0.4	0.8+/-0.5	0.50	1.00	1.50
LC/BR$_I$	0.1+/-0.05	0.4+/-0.2	0.6+/-0.3	0.1+/-0.06	0.4+/-0.25	0.6+/-0.4	0.25	0.60	1.00

Note that the coefficient of variation does not account for systematic and random map and digital data set errors, or for variability due to future changes in wind and storm activity and shoreline terrain conditions, especially increased length of bedrock-controlled shorelines.

Appendix A6.3 Comparison Table Between Erosion Area and Variability Factor

To allow comparisons between eroded areas in the terrestrial assessment and eroded areas shown in Table 6.4-6, the following tables have been included to show erosion rates and eroded land area calculations based on average erosion rates plus a 50% variability factor, as discussed in Section 6.3.5.

Table A6.3-1

Summary of average plus 50% variability erosion rates with and without the Project

With vs. without the project		Average Plus 50% Bank Erosion Rates for Various Time Periods (m/yr)								
	Shoreline Type	0 - 5 Years (2009-2014)			6 -25 Years (2014-2034)			26 - 100 Years (2035-2109)		
		Wave Energy			Wave Energy			Wave Energy		
		L	M	H	L	M	H	L	M	H
Without Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
With Project	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
Without Project	LC	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
With Project	LC	0.75	1.50	2.00	0.60	1.25	1.75	0.50	1.00	1.50
Without Project	LC/BR_l	0.20	0.50	0.75	0.20	0.50	0.75	0.20	0.50	0.75
With Project	LC/BR_l	0.75	1.50	2.00	0.25	0.60	1.00	0.20	0.50	0.75
Without Project	LC/BR_m	0	0	0	0	0	0	0	0	0
With Project	LC/BR_m	0.20	0.40	0.60	0.10	0.20	0.30	0	0	0
Without Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0
With Project	LC/BR_h, BR	0	0	0	0	0	0	0	0	0

Legend: Wave Energy Categories: Low (L); Moderate (M), High (H)
Table based on bank-recession rates shown in Tables 6.3-9 and 6.4-2

Table A6.3-2

Comparison of the projected land area eroded with and without the Project calculated using average erosion rates plus a 50% variability factor

Modelled Time Periods	Incremental Area Eroded Without the Project (ha)	Incremental Area Eroded With the Project (ha)	Average Annual Area Eroded Without the Project (ha/yr)	Average Annual Area Eroded With the Project (ha/yr)
1985-1998	63	N/A	4.8	N/A
1998-2009	46	N/A	4.2	N/A
2009-2014	21	54	4.2	10.8
2014-2034	82	109	4.1	5.5
2034-2109	298	306	4.0	4.1

*Table based on bank-recession rates shown in Table 6.4-2.

Appendix A6.4 Supporting Table For Derivation of Projected Bank Recession Rates

Supporting Material for Derivation of Projected Bank-recession rates for Existing and Post -Project Conditions.

Table A6.4 -1

Comparison of predicted bank-recession rates used for modelling various time periods with and without the Project

Current Condition vs. Post-development Condition		Average Bank Erosion Rates for Various Time Periods (m/yr)								
	Shoreline Type	0 - 5 Years (2009-2014)			6 -25 Years (2014-2034)			26 - 100 Years (2035-2109)		
		Wave Energy			Wave Energy			Wave Energy		
		L	M	H	L	M	H	L	M	H
Current condition	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
Post-development	LC_{lg}, BC_{lg}, FN	0	0	0	0	0	0	0	0	0
Current condition	LC, BC*	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
Post-development	LC, BC*	0.75	1.50	2.00	0.60	1.25	1.75	0.50	1.00	1.50
Current condition	LC/BR_l	0.25	0.60	1.00	0.25	0.60	1.00	0.20	0.50	0.75
Post-development	LC/BR_l	0.75	1.50	2.00	0.25	0.60	1.00	0.20	0.50	0.75
Current condition	LC/BR_m	0.10	0.20	0.30	0.10	0.20	0.30	0	0	0
Post-development	LC/BR_m	0.20	0.40	0.60	0.20	.040	0.60	0	0	0
Current condition	LC/BR_h, BR	0	0	0	0	0	0	0	0	0
Post-development	LC/BR_h, BR	0	0	0	0	0	0	0	0	0

Legend: Wave Energy Categories: Low (L); Moderate (M), High (H)

Table A6.4-1 Legend

BC* - In BC areas LC erosion rates are used for 0 to 7 years and LC/BR_l rates are used thereafter
EC - existing conditions
PD - post development conditions
L: low wave energy; M: moderate wave energy; H: high wave energy
Pink - Erosion rates based on data from Manitoba Hydro's Wuskwatim Lake erosion monitoring stations.
Green - Initial post-project development rates based on early post-CRD erosion data and erosion model estimates.
Blue - Intermediate level erosion rates estimated for the 6- to 25-year period are based on measured long-term rates and initial post-CRD rates.
Red - LC/BR_l erosion rates in the 6- to 25-year period are based on erosion data Manitoba Hydro's Wuskwatim Lake erosion-monitoring stations located in LC/BR_l areas. These rates are expected to apply to current conditions and post-project development conditions for the 6- to 25-year time period.
Yellow - LC/BR_l erosion rates in the 26- to 100-year period are based on a 25% reduction in erosion rates over current rates. This is based on the expectation that over time, erosion at 234.0 m elevation will encounter bedrock at an increasing number of locations.
White - In LC/BR_m areas, erosion rates are based on the expectation that some local bank recession will occur due to bank sloughing, with a slight increase during the first 25 years post-project. The frequency of bank failures is expected to decrease over time.

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7.0 RIVERINE EROSION

7.1 INTRODUCTION

The objective of this assessment is to evaluate the potential effects of the Generation Project on riverine erosion processes in the river reach downstream of the site. Any changes to riverine **erosion** could potentially change sedimentation or **Total Suspended Sediment (TSS)** concentrations in the downstream river and lakes discussed in Section 8 (Sedimentation).

As discussed in Volume 3 (Section 5.2.5.1) the Generation Project will be able to operate over a wide range of inflow conditions, however there is a narrow set of outflow settings at which the turbines can operate most efficiently (Figure 5.2-2, Volume 3). To accomplish this the Generation Project outflows will therefore be adjusted to alternate between efficient unit settings to obtain near "best gate" settings as much as possible (Figure 5.2-4, Volume 3) such that outflows are balanced with inflows on a daily basis. As a result of the daily plant cycling, downstream water levels will fluctuate. The largest fluctuation would occur at the Wuskwatim tailrace with water levels varying by up to 1.3 m during open water conditions depending on flow conditions (Volume 3, Table 5.2-2). These fluctuations will attenuate moving downstream by the available channel and lake storage. At Opegano Lake the maximum daily lake fluctuation would be 0.4 m, however for approximately 70 % of the time the fluctuation would be 0.1 m or less (Figure 4.3-20). As discussed in Section 4.3.5 the maximum water level change at Opegano Lake results for inflows that are midway between the target outflow settings and result in a water level change of about 0.2 m above and below the average daily flow without the Project. Since the majority of the Project related water level changes at Opegano Lake are within the range of wave-induced water level changes it is considered to be the downstream boundary of this assessment.

This assessment focuses on the river reach between the tailrace and Opegano Lake, principally the 9 km riverine stretch from the tailrace to the set of rapids 4 km upstream of Opegano Lake (below this set of rapids the water levels in the river reach are hydraulically controlled by Opegano Lake Section 4.2.2.3) where the largest of the Project operation water level fluctuations will occur. The objective of this assessment is to determine whether or not the daily water level fluctuations in this section of the river will increase existing bank erosion rates and sediment concentrations.

Construction of the Project (i.e., cofferdam construction and removal and river management activities [Volume 4, Section 4.6.8]) will result in erosion of some of the cofferdam material, which will result in a temporary increase in Total Suspended Solids (TSS) in the river (Section 7.5.1). Also during operation of the Project, anticipated effects due to erosion of the downstream banks will be minimal. Since the process that causes the elevated TSS levels is an erosional process, it is discussed in this section. Further discussion of the TSS levels relative to existing sedimentation levels is discussed in Section 8 (Sedimentation).

7.2 ENVIRONMENTAL INFLUENCES

Bank erosion accompanying **channel migration**, widening, or **downcutting**, is often initiated by **scour** and undermining of the toe of the bank, rather than by direct erosion of the slope. As the toe is undercut and the slope steepens, the bank recedes to regain its **angle of repose**, either by gradual unraveling, in **granular** materials, or by intermittent slumping, in **cohesive** materials. Where the banks contain **permafrost**, thawing may also play a role. Failure of the bank toe may not be apparent from above-water inspection. Other factors such as loss of vegetation, thawing of permafrost, or surface waves may affect mainly the upper levels of the bank. In general, riverine erosion can arise from a number of causes, and these are described in Appendix A7.1.

Given an understanding of the Project and its effects on downstream flow it is likely that only the last three factors in Appendix A7.1 could potentially change bank erosion processes, that is:

- hanging ice dams;
- increases in river flows or reduced sediment inputs; and
- rapid lowering of water levels adjacent to the river banks.

As discussed in Section 5.5.2.3 of this volume, it is not anticipated that there would be any changes to the downstream ice regime as a result of the project. Where ice dams occur now, they will continue to form, and will be of a similar size and nature.

7.3 APPROACH AND METHODOLOGY

In the general case where river flows are significantly altered by engineering works, at least two approaches can usually be considered for estimating consequent bank erosion. Natural river channels in erodible materials tend to have an average width that is adjusted to their "dominant" or channel-forming discharge. In terms of flood frequency, this discharge is usually around the 2-year annual maximum, which for the Burntwood River is approximately 1100 m^3/s. Therefore, one approach to estimating erosion potential is to estimate the effect of the Project's flow alterations on the **dominant discharge** and then, using empirical width-discharge relationships, to predict the ultimate change in width. This "regime" approach cannot predict rates of width increase, only the ultimate equilibrium width. A natural channel is said to be in dynamic equilibrium (or 'in regime') if the channel dimensions (depth, width and channel slope, etc) remain unchanged over a long period of time. If disturbed, a natural channel will adjust its dimensions to balance the changed environment. Channel adjustments may be rapid and significant in the short term if the disturbance is severe. It should be noted that *localized* erosion and/or deposition might occur even when a channel is in a state of dynamic equilibrium. As long as the erosion/deposition activities remain on a small scale and the overall channel dimensions are not altered, the channel will remain in dynamic equilibrium.

Another approach to estimating erosion potential is based on **sediment transport theory** and associated **numerical modeling**. It involves comparing the capability of the "with and without" the Project flows to erode and transport bed and bank sediments. This approach is theoretically attractive because it seems to allow the estimation of rates of change, but it presents great practical difficulties, especially where the channel boundaries involve fine silt and clay materials. Prediction of sediment transport rates from channel hydraulics is mainly applicable to granular materials, and even then is subject to a wide range of uncertainty.

There seems to be no firm basis for quantitative prediction of changes in river bank erosion that might be caused by the Project. The regime approach is somewhat difficult to apply because of the relatively small changes in discharge patterns. The sediment transport approach is considered inapplicable because the greater part of the eroded sediment consists of very fine materials (silt and clay sizes) that are transported downstream in suspension. Both present and potential future concentrations of these fine materials are extremely small compared to the capacity of the flow for suspended transport.

However, a qualitative assessment was developed on the basis of a careful review of available data and past study results, and an assessment of this information in association with basic principles of regime theory.

7.4 EXISTING ENVIRONMENT

Flows. Post-CRD, annual means have mostly ranged from about 800 to 1000 m^3/s, and annual maxima from about 1000 to 1300 m^3/s.

Planform, widths and velocities. A range of empirical regime equations have been developed to predict the geometry of dynamically stable **alluvial** channels (Lacey 1929-1930; Hey and Thorne, 1986). Channels which require little maintenance are said to be "in regime", meaning that they convey the imposed water and sediment loads in a state of dynamic equilibrium, with width, depth, and slope gently varying about some long-term average. Ideally, regime equations developed for the specific river system being studied should be applied to ensure reliable predictions, however, these types of equations have not been specifically developed for the Burntwood River and, therefore, accepted channel geometry-discharge relationships developed elsewhere were used as an initial assessment. The predictions should be regarded as estimates and should only be viewed as an initial assessment because regime equations developed elsewhere may not be strictly applicable to the study reach.

In general, it has been found that channel dimensions follow the Power Law and can be expressed as:

$$W = a\, Q_b^{\alpha}$$
$$D = b\, Q_b^{\beta}$$
$$S = c\, Q_b^{\gamma}$$

Where W is the top width of the channel, D is the average depth, S is the slope and Q_b is the channel forming discharge or dominant discharge. Determination of the channel forming discharge is often very difficult and highly subjective. It has been found that the channel forming discharge can be defined to be the peak flood flow with an annual recurrence interval of approximately 2 years. The coefficients, a, b, c, α, β and γ are empirical parameters.

Both the Lacey (1929-30) and Hey and Thorne (1986) regime equations were used in this prediction. Based on the results of flood frequency analysis, the 1:2 year flood peak at the Wuskwatim site was estimated to be 1100 m^3/s. Based on the regime equations, the predicted stable channel width on the Burntwood River is estimated to be 150 m, which compares reasonably well to the existing average width of 160 m from Taskinigup Falls to Opegano Lake. This would appear to indicate that the reach is near a state of dynamic equilibrium. Extensive additional/incremental erosion would not be expected unless a very large change in the flow regime was experienced, although localized erosion might still exist.

The Burntwood River in this reach has a slightly **sinuous**, irregular **planform**, with widths ranging from about 100 m to 330 m. Since a "regime" width for a self-formed alluvial channel subjected to the post-CRD flow regime would be in the order of 150 m, many reaches could be classed as over-wide in terms of channel equilibrium. Other reaches, generally bounded by **bedrock**, are narrower than 150 m.

Depth average velocity distribution modelling (Section 4), shows that in the wider reaches, most of the discharge is contained in a sinuous central stream with velocities mostly in the range of 0.7 to 1.4 m/s. In areas outside this central stream, velocities are at or near zero and account for quite a small proportion of the discharge. In the narrower reaches of the river, where the overall width is around 100 m, the central stream occupies the entire width and midstream velocities reach 2.0 m/s or greater.

An interim report by Mollard (2002) classified river banks and shoreline bluffs between the Wuskwatim Project site and the outlet of Opegano Lake, and highlighted existing erosion conditions and estimated existing shore recession rates. Information for the river was based mainly on low-level video coverage of September 2001 and on a comparison of airphotos of 1985 and 1998. Maps based on airphoto-mosaics showed inferred rates of bank erosion over this period. The study indicated that, generally, 13-year-average rates of post-CRD river bank recession vary locally from zero to just under 1.0 m/yr, with a spatial average of approximately 0.2 m/yr. In some lengths only one bank shows recession, while in other locations both banks are noted to be eroding. Bank heights are classified descriptively, but actual heights are not given.

On the basis of low-level helicopter video footage, Mollard (2002) classified shoreline zones according to their type, height, and observed erosion condition. Figure 7.4-1 illustrates a sample illustration prepared as a part of these studies, indicating bank classifications in the reach immediately downstream of Taskinigup Falls. A description of the terminology found in the legend of Figure 7.4-1 is given in Appendix A7.2.

Based on air photo analysis (1985 compared to 1998), Mollard (2002) also calculated erosion rates over the 13 year period. Figure 7.4-2 illustrates a sample plot summarizing historical erosion (recession) magnitudes in the same location as Figure 7.4-1 over the period from 1985 to 1998. The results of this erosion assessment are summarized in

Appendix A7.3 by erosion condition in Tables A7.3-1 and by shoreline type in Table A7.3-2 for both the river reach section and Opegano Lake.

The following observations can be made from the information:

- between Taskinigup Falls and the eastern outlet of Opegano Lake, 72% of the total length is classified as **river bank**, with the remaining 28% classified as a lake shoreline **bluff**;
- river bank heights are generally low (1 m or less);
- bank heights associated with shoreline bluffs are typically moderate (between 1 and 3 m high);
- approximately 45% of the total length is viewed as eroding to some degree, and the rest is described as "**water-washed**";
- over substantial lengths - even in wider reaches - some recession is occurring on both banks simultaneously;
- except for a few specific riverbank locations, recession varies for the most part from 0 to <1.0 m/yr, with a spatial average of 0.2 m/yr; and
- bank materials are generally classified as fine-grained **glaciolacustrine sediments**

In some areas, bank recession is occurring in "over-wide" reaches where bank velocities are very low, and it seems unlikely to result from normal **fluvial** processes such as occur in more regular types of river channel with systematically shifting planforms (e.g., meandering alluvial rivers). Depending on the degree of exposure to wind, this may occur in some areas as a surficial response to wave action, while in others it may be a response to the thawing of permafrost. However, as discussed earlier, it must be recognized that even a river reach approaching a regime condition will continue to exhibit local geometric changes associated with erosion and deposition. Although the system may eventually reach a dynamic equilibrium, it will always be changing.

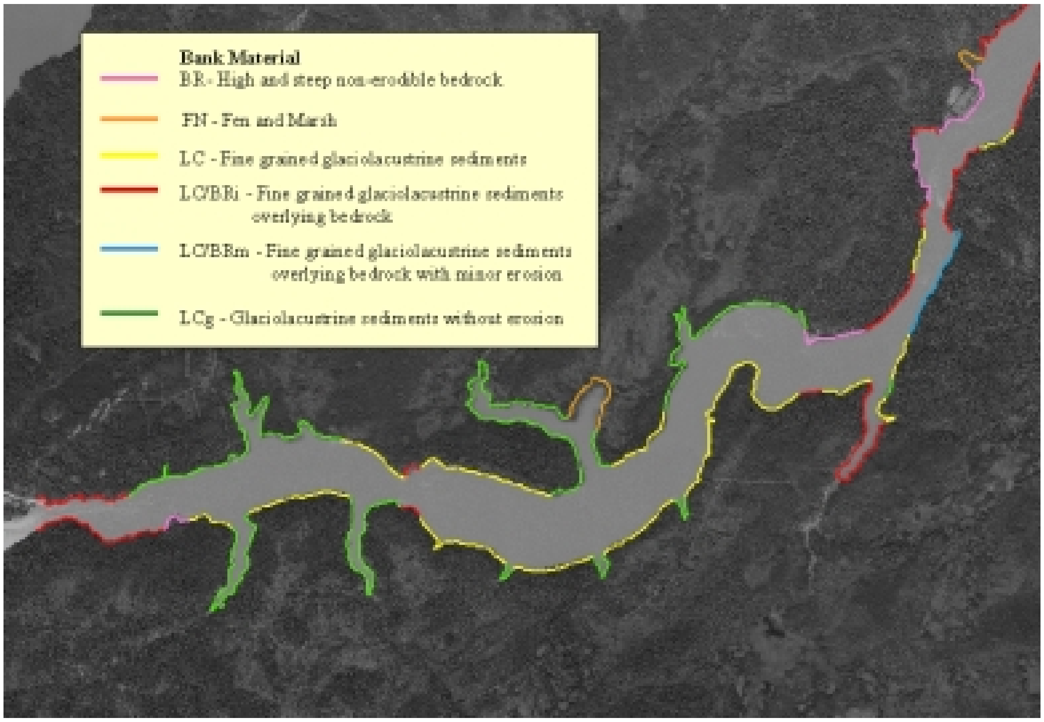

Figure 7.4-1. Typical shoreline classification : immediately downstream of Taskinigup Falls.

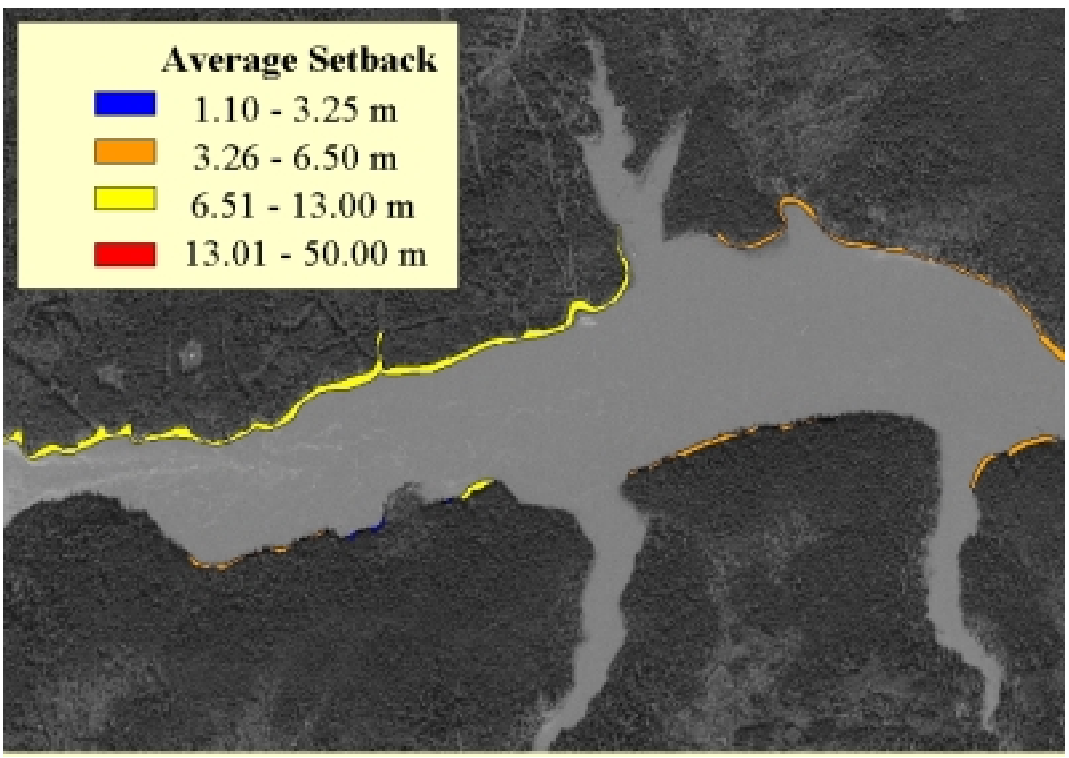

Figure 7.4-2. Typical shoreline recession between 1985 and 1998: immediately downstream of Taskinigup Falls.

Figure 7-4.3 illustrates an envelope of typical grain size distribution curves associated with this material, as derived from geotechnical site investigations of the area. A review of this data indicates that the majority of the material is in the silt and clay fraction.

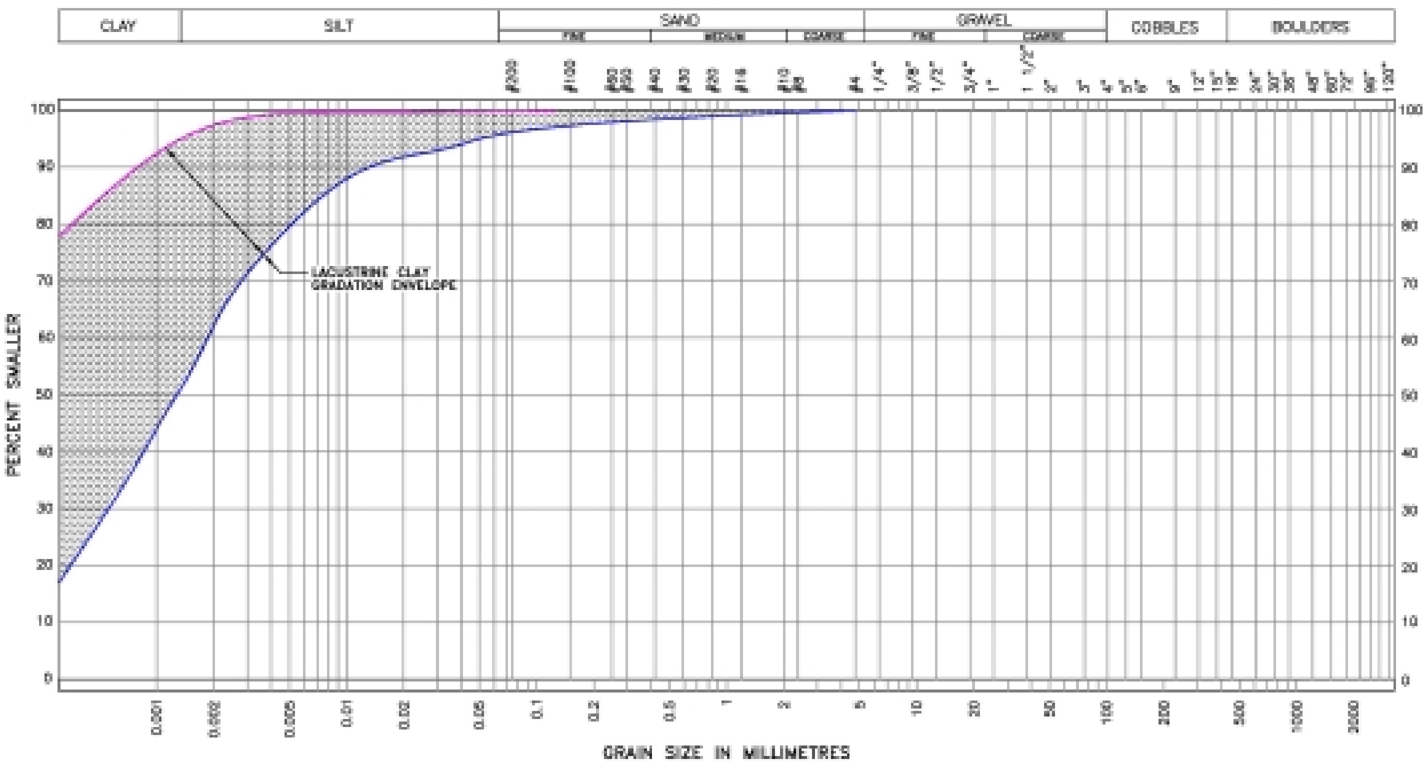

Figure 7.4-3. Grain size distribution for typical bank material.

In certain areas, localized river-bank erosion may have been exacerbated due to the formation of large hanging ice dams (Figure 5.4-7) during the winter period. This is particularly evident at the inlet to Opegano Lake. At this location, the ice front typically stalls due to high flow velocities, and ice accumulates in a large hanging ice dam in the downstream river reach. The presence of this hanging ice dam restricts flows through the channel, causes local water levels to rise, and as the main channel becomes increasingly congested with ice, flow may be diverted along one of the riverbanks and thus result in bank erosion.

7.5 EFFECTS ASSESSMENT AND MITIGATION

7.5.1 Construction

During the construction of the Wuskwatim Generation Project there will be no expected changes to the daily flow patterns on the CRD and therefore no expected changes to overall riverine erosion processes in the reach of the river between the Wuskwatim site and Opegano Lake. However, there will be changes to water levels in the reach between Wuskwatim Falls and Taskinigup Falls as a result of river management techniques as discussed below.

As discussed in the Project Description (Volume 3, Section 4.6.8) construction of the Wuskwatim project will be accomplished through a two-stage **river management** scheme. During Stage I, cofferdams will be placed in the Burntwood River both upstream and downstream of Taskinigup Falls. The primary structures will be constructed within the confines of these cofferdams, and the river will continue to flow through the southern portion of the Burntwood River and over Taskinigup Falls. Once these primary structures are sufficiently complete, the Stage I cofferdams/plugs will be removed, the spillway gates will be opened, and the Stage II upstream cofferdam will be constructed and advanced across the head of Taskinigup Falls. This action will cause the flow to be directed/diverted through the **spillway (Stage II Diversion)**. This is the beginning of **Stage II Diversion**. Following the opening of the spillway, a rockfill cofferdam will be advanced across the head of Taskinigup Falls, effectively closing the river and diverting all flow through the spillway structure. This will allow the main dam to be constructed in the dry behind the protection of the Stage II cofferdam. Once the river has been completely closed, and flow diverted through the spillway, the Stage II downstream cofferdam will be constructed to facilitate final excavation of the **powerhouse** tailrace channel.

This river management strategy has been carefully planned to minimize anticipated erosion impacts during construction. However, there are a number of activities, which may expose river flows to additional sources of erodible material during the construction of the plant (Acres 2003). These activities are described below.

7.5.1.1 Material Losses During Cofferdam Construction

Cofferdam construction will involve the placement of various materials within the river channel, ranging from Class C **rockfill** to Class A **impervious fill**. Each cofferdam will be constructed in a manner such that the amount of material that may be lost and carried downstream by the river flow will be minimized. Initially, rockfill will be end dumped from the top of the existing fill along the advancing face of the cofferdam. Following this, both the granular fill and impervious fill will be dumped on top of the existing fill, and then bulldozed into the water such that the material enters the water as a sliding mass, making it more resistant to erosion/dispersion. Given this method of construction, potential sources of erodible material which could increase the total suspended solids (TSS) during this activity include: fine material contained in the rockfill, silt contained in the granular fill, the loss of a certain amount of the any silt and clay which comprises the impervious fill, and the suspension of some riverbed material, due to construction of the cofferdam. Any increase in TSS level due to the potential suspension of these fine materials will only occur during the times that the work would actually be underway, and will quickly decrease after any stoppage in the work. The temporary increase in TSS level is expected to be 25 mg/L or less during this activity. Construction of the various cofferdams would proceed during two separate periods, totaling approximately 15 weeks.

7.5.1.2 Material Losses During Cofferdam Removal

Following completion of the powerhouse and spillway, the cofferdam structures will be removed. These structures will be removed as much as possible in the dry in relatively low velocity water, minimizing the potential for entrainment and suspension of fine materials into the flow stream. Removal in the wet of the Stage I upstream and downstream cofferdams, and the Stage II downstream cofferdam will be accomplished by the use of a backhoe and dragline. The potential for loss of material during excavation in the wet is difficult to accurately quantify, but it will result in a small increase in TSS level (1 mg/L or less) for the duration of the removal activities (approximately 12 weeks). Likewise, removal of the rock plugs at the entrance to the Wuskwatim Falls channel excavation area, and the exit of the spillway tailrace area are expected to result in a small, temporary increase in TSS levels of 14 mg/L or less.

7.5.1.3 Wuskwatim Falls to Taskinigup Falls Reach

During both Stage I and II Diversion, the riverbanks in the upstream reach between Wuskwatim Falls and Taskinigup Falls will be subjected to water levels which will be, on average, 0.6 m higher than those occurring under existing conditions in the reach. This will expose more bank material in this area to higher velocity river flows, and could lead to a minor increase in erosion in some areas prior to impoundment. This increase is estimated to be 4 mg/L or less. This would include an area of the south shore of the river immediately upstream of Taskinigup Falls, which forms the closure site for the Stage II Cofferdam. Riprap or rock filled **gabions** may be placed in this area in order to mitigate against possible erosion of the bank during river closure.

7.5.1.4 Riverbed Upstream of Spillway Approach Channel

Operation of the spillway at the commencement of Stage II Diversion will result in some potential erosion of the natural river channel and Stage I **Cofferdam remnant** in the area of the approach channel. The riverbed material at this location consists of medium to high plasticity clays or silty clays. At the onset of Stage II Diversion, this area will be exposed to higher velocities than have occurred under existing conditions, and this may lead to some erosion, depending on the *in situ* resistance of the natural material in this area. Preliminary estimates, based on the most probable anticipated strength of the materials, indicate erosion of the upstream riverbed may cause initial increases in the TSS level of approximately 14 mg/L. This value is slightly less than that quoted in Volume 1, and has been reduced based on additional work undertaken since Volume 1 was published. This level would reach a peak shortly after the spillway gates are raised, and then would reduce with time. It should be noted that this initial increase may range from negligible to approximately 100 mg/L, depending on the strength of the river bed material. Further field tests are planned during the construction period to more confidently establish the overall resistance of this material, and should it (the riverbed material) prove to be weaker than anticipated, mitigative measures will be explored to minimize potential erosion in this area. This would likely include the placement of a layer of suitable **armour stone** over susceptible areas to prevent erosion. Following impoundment, velocities in this approach area will be minimal for all but the most extreme flow cases, and therefore erosion will not be an ongoing concern.

Exposed overburden within the excavated portion of the approach channel (both bed and banks) will be protected with riprap, and therefore should be resistant to fluvial erosion.

7.5.1.5 Stage II Downstream Cofferdam

Following completion of the Powerhouse, and its associated tailrace channel, the protective downstream cofferdam will be removed to elevation 203 m. Any fill below this removal elevation would be left in place, and may be subject to erosion as a result of subsequent powerhouse outflows. However, the erosion volume would be relatively small and this local reach would quickly reach a stable configuration following powerhouse operation.

7.5.2 Operation

As discussed in the Introduction (Section 7.1), the operation of the Project will result in a change in the outflow patterns relative to inflows. A duration curve of Project inflows and outflow is shown in Figure 5.2-7 (Volume 3). The outflow duration is a step curve that illustrates the various potential outflow settings for the plant. This curve also shows that the outflows are in the same flow range as the inflows (except a small percentage of one unit outflows). As discussed in Section 7.3 an assessment of what this change to outflow means to riverine erosion processes must be assessed in a qualitative way due to limitations of the regime approach and the sediment transport approach. The following points can be made about the Project operation.

- Downstream of the plant, there will be no change in the overall sequence or regime of daily flows, and therefore no effective change in the channel-forming or “dominant” discharge. Therefore, there should be no overall tendency for additional channel widening beyond present rates.

- Bank recession rates are controlled by the high end of the flow range, roughly 900 to 1100 m^3/s. In this range, projected changes in the durations of hourly flows are relatively trivial. It seems unlikely that small changes in hourly discharge frequencies could have significant effects on bank recession rates.

- The only other hydrologic change of potential significance is the fluctuation of hourly water levels. As discussed in Section 7.1 water levels in the tailrace may vary up to 1.3 m during the openwater season and dampen out slightly in the 9 km river section before the last rapids before Opegano Lake. Relative to present water depths in the order of 10 m, this fluctuation in water levels represents a sizeable change. From a geotechnical perspective the daily (i.e., short duration) nature of the water level fluctuations and the relatively impervious nature of the banks, it is unlikely that the fluctuating water levels will adversely influence the **phreatic surface** within the river bank, therefore the potential for an increase in bank failure due to negatively impacted **pore pressures** is also therefore low.

Taking account of these points, it is considered that any increase in riverbank erosion rates, if any, is likely to be very small.

7.6 REFERENCES

J.D. MOLLARD AND ASSOCIATES 2002. Classification of upstream and downstream river banks and lake shoreline bluffs and measurement of river bank and lake shoreline bluff recession from 1985 to 1998 - Wuskwatim Lake Physical Environmental Studies, Interim Report #1 - Version 2.

HEY AND THORNE (1986). “Stable Channels with Mobile Gravel Beds”, Journal of Hydraulic Engineering, American society of Engineers, Vol 112, No. 8, pp 671-689.

ACRES, 2003. Cofferdam and Riverbed Erosion During Construction, Memorandum W-2.9.1, Rev 0, Wuskwatim Generating Station Stage 4 Studies, May, 2003.

LACEY (1929-30). Stable Channels in Alluvium, Vol 229, Part 1, pp 259-292.

Appendix A7.1 Causes of Riverine Erosion

In general, riverine erosion can arise from a number of causes including the following.

- Valley widening and/or deepening as part of ongoing geological processes, which can cause erosion of river banks in contact with valley walls.
- River channel shifting, such as **meander** migration. In this case, erosion on one bank is normally offset by **accretion** on the opposite bank; average widths remaining unchanged.
- Channel widening with erosion of both banks. The most common cause is increased flood flows as a result of diversions, deforestation, urbanization, etc. Increased inputs of bed sediment may also produce general widening, accompanied by deposition of in-channel bars and islands.
- Reduced resistance to erosion. For example, removal of riparian vegetation or thawing of permafrost.
- Local macro-turbulence and flow disturbances due to structures such as bridge abutments, weirs, jetties, etc.
- Waves due to wind or passage of vessels.
- Local scour caused by the formation of significant hanging **ice dams** in a reach. The accumulation of ice in these dams may result in a restriction in conveyance capacity for the channel, and the redirection of flows against erodible river banks.
- Downcutting (degradation) of the river bed, leading to undermining of bank slopes. Downcutting may result from geological processes, ice dam formations, or from man-made changes that involve increased river flows or reduced inputs of bed sediment.
- Rapid lowering of water levels adjacent to saturated clay banks causing slope failure.

Appendix A7.2 Riverbank Classification

River Bank And Lake Shoreline Bluff Classification Legend	
Water Body Type	
R	River
L	Lake
River Bank Or Lake Shoreline Bluff Material	
Symbol	Description
LC	Fine-grained (silt and clay) glaciolacustrine sediments in banks and bluffs ranging in height from approximately 0.5 m to > 3m locally. Glaciolacustrine sediments extend below the water level visible in the video coverage. No bedrock is apparent in these areas.
LC_{lg}	Low gradient glaciolacustrine shores with no eroded bank or bluff. These areas are subject to periodic flooding under fluctuating water levels, but little or no bank recession is apparent.
LC/BR_{l}	Fine-grained glaciolacustrine sediments overlying bedrock. The drift/bedrock contact is ~ 0.5 m above water level in the video coverage. Erosion of clay and silt banks and bluffs is evident.
LC/BR_{m}	Fine-grained glaciolacustrine sediments overlying bedrock. The drift/bedrock contact is ~ 0.5 to 1.0 m above the water level in the video coverage. Minor erosion of clay and silt banks and bluffs is evident in some locations.
LC/BR_{h}	Fine-grained glaciolacustrine sediments overlying bedrock. The drift/bedrock contact is >1.0 m above the water level in the video coverage. No erosion of clay and silt banks and bluffs is evident.
BR, BR_{h}	Relatively high and steep non-erodible bedrock slopes in river and lake shorezone areas.
FN	Low gradient fen and marsh dominated shores in shallow low-lying flooded areas. These areas typically show little or no evidence of bank recession but are subject to periodic flooding under fluctuating water levels.
Bank And Bluff Height	
L	Low height (~< 1 m)
M	Moderate height (~ 1-3 m)
H	High height (~ > 3 m)
Erosion Condition Inferred From Video Coverage	
W	Water washed and/or ice scoured river banks and lake shorelines with relatively minor river bank or lake shoreline bluff recession inferred.
M	Minor recession of river banks and lake shoreline bluffs inferred.
I	Intermediate recession of river banks and lake shoreline bluffs inferred.
S	Severe recession of river banks or lake shoreline bluffs inferred.
Other Conditions	
Sl	Slumping banks

Appendix A7.3 Shoreline Classification Taskinigup to outlet of Opegano Lake

Table A7.3-1.

Average bank and bluff recession rates for different erosion conditions: Taskinigup Falls to the east outlet of Opegano Lake.

River Banks			Lake Shorelines		
Erosion Condition	Length of Shoreline (m)	Average Rate of Bank Recession from 1985 to 1998 (m/yr)	Erosion Condition	Length of Shoreline (m)	Average Rate of Shoreline Recession from 1985 to 1998 (m/yr)
W - water washed	26,079	0.07	W – water washed	2,157	0.34
M – minor	7,259	0.19	M – minor	2,375	0.30
I - intermediate	11,003	0.38	I - intermediate	1,916	0.58
S- severe	1,955	0.98	S- severe	4,536	0.49
Unclassified	1,414	0.50	Unclassified	7,509	0

Table A7.3-2.

Average bank and bluff recession rates for different river bank and lake shoreline bluff materials: Taskinigup Falls to the east outlet of Opegano Lake

River Banks			Lake Shorelines		
Bank Material	Length of Shoreline (m)	Average Rate of Bank Recession from 1985 to 1998 (m/yr)	Shoreline Bluff Material	Length of Shoreline (m)	Average Rate of Shoreline Recession from 1985 to 1998 (m/yr)
LC	21,823	0.30	LC	8,477	0.47
LC_{lg}	12,070	0.18	LC_{lg}	9,474	0.08
LC/BR_l	6,121	0.16	LC/BR_l	350	0.44
LC/BR_m	1,494	0.11	LC/BR_m	192	0
LC/BR_h	0	-	LC/BR_h	0	-
BR, BR_h	3,711	0	BR, BR_h	0	-
FN	2,491	0	FN	0	-

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8.0 SEDIMENTATION

8.1 OBJECTIVE AND BACKGROUND

Sedimentation and **Total Suspended Solids (TSS)** in the water column are the end results of several processes including lake- and riverine-erosion and sediment transport processes. As in other lakes, inflowing rivers with sediment loads and localized erosional processes within Wuskwatim Lake are predominantly responsible for the existing sedimentation processes and rates.

This section reviews the existing sediment loads and sedimentation processes in the Wuskwatim Generation Project area (Section 8.3) and evaluates the potential effects of lake-erosion changes (Section 6.4.3) and "in-river" activities (Section 7.5.1) associated with constructing and operating the Project on existing sedimentation in Wuskwatim Lake (Section 8.4). This section also evaluates the potential for the transport of sediments downstream of the Project via the Burntwood River.

8.2 APPROACH AND METHODOLOGY

To assess the effects of the Project on the sediment regime of the affected water bodies, the following steps were undertaken:

- All relevant past reports and studies were collected and reviewed. This includes documents by Hecky and McCullough (1984) and McCullough (1987) on shoreline erosion processes observed along South Indian Lake, and a report by Williamson and Ralley (1993) documenting water chemistry changes on the Burntwood River following the Churchill River Diversion (CRD) were particularly useful in advancing the understanding of erosion and sedimentation/TSS changes within affected waterbodies.
- All relevant data collected over the past few summers was gathered and analyzed. This included **sediment trap** data and data on TSS collected over the past 3 years at various locations along the Burntwood River, as discussed in Section 8.3.1.
- Finally, a **sediment budget** model was created for Wuskwatim Lake. The sediment budget model developed and used reflects the limited data available. The model was then used to estimate sediment changes with and without the Project.

The following sections provide further detail on each of these steps.

8.3 EXISTING ENVIRONMENT

8.3.1 Summary of Relevant Reports and Data

8.3.1.1 Southern Indian Lake Shoreline Erosion Study

McCullough (1987) performed a study of nearshore sedimentation processes at Southern Indian Lake following its impoundment. This study was based on fieldwork carried out in 1983. In his study, McCullough measured the ratio of sediment eroded from the shorezone to the sediment deposited in the nearshore zone. For actively eroding clay shorelines, McCullough (1987) noted that on average 54% (range of 28% to 74 %) of eroded sediment was deposited in the **nearshore** area, while 46% was carried farther offshore. Major nearshore deposits typically formed narrow lenses, thickening quickly from the shoreward apex to a maximum at 10 to 50 m from shore, and tapering gradually to a few centimeters thickness by 100 to 150 m offshore. In stabilizing shorezones (i.e., shorezones where bedrock underlying erodible clay and silt banks becomes exposed over time), only 13% of the eroded sediment was deposited in the nearshore zone.

Erodible sediments around the Wuskwatim Lake shorezone are similar to those in SIL, both consisting of clay and silt that was originally deposited as glaciolacustrine sediments in glacial Lake Agassiz. While SIL has had significant erosion of permafrost shorelines and therefore large inputs of sediment, it is felt that the overall dispersion of sediment should be similar within Wuskwatim Lake. Therefore, a deposition of 50 percent in the nearshore zone and 50 percent in the deepwater portion of the lake was assumed in developing the sediment budget model for Wuskwatim Lake.

8.3.1.2 Summary of Water-Chemistry Changes Following Hydroelectric Development in Northern Manitoba, Canada

Williamson and Ralley (1993) summarized the results of an ongoing monitoring program established by the Provincial Government to collect water-quality data to assess effects associated with hydroelectric development. Of key interest to the Wuskwatim study is an analysis of TSS data collected on the Burntwood River at Thompson, both prior to and following the Churchill River Diversion (CRD). This monitoring station represents the longest continuous record of suspended sediment data in the Burntwood River downstream of Threepoint Lake. Additional data collected since 1993 were also obtained from the author and used in this assessment.

The results of this monitoring program are summarized in Table A8.1-1 (Appendix A8.1). The Williamson and Ralley (1993) data indicates that during and just after the commissioning of the CRD in 1977, average TSS levels in the river rose to approximately 20 mg/L and then returned back to pre-CRD levels of 13 mg/L in the 1987 to 1992 reporting period; approximately 10 years after CRD. Additional data collected by Manitoba Conservation from 1992 through to 2002 (Williamson *pers. comm.* 2003) show average TSS levels appear to have stabilized at a concentration of approximately 13 mg/L. While TSS concentrations have returned to pre-CRD conditions, total sediment loads have increased about 8 times (Manitoba Hydro 1996) due to the increased volume of water flowing down the CRD. While the total TSS load carried by the river has increased as a result of the increase in flows, the TSS concentrations indicate that the system has adjusted relatively quickly to the water-regime change that resulted from CRD. This is consistent with the decrease in shoreline erosion rates that occurred a number of years following CRD, as discussed in Section 6.4.2.1.

Given that most of the sediment is derived from lake and riverine erosion of silt/clay shorelines and that the coarser portion tends to re-deposit in the lake, it appears likely that suspended sediment exiting Wuskwatim Lake and entering the Burntwood River is mostly fine silt and clay with some organic matter. Such material remains in suspension and requires very long settling times in calm water. In flowing water, in the absence of salt or some other coagulant, the suspended material will remain in suspension and will only settle out in large calm bodies of water. Figure 7.4-3 shows the typical grain-size distribution for the silty clay shores around Wuskwatim Lake.

8.3.1.3 Recent TSS Data

As part of this EIS, TSS data was collected in the Burntwood River during the summer of 1999, 2000, and 2001 (Table A8.2-1, Appendix A8.2). In particular, a number of samples were collected upstream, within, and downstream of Wuskwatim Lake. As discussed below the three years represent a range of flow and water level conditions (i.e., low, medium and high water levels). It is noteworthy that Wuskwatim Lake levels in 2000 were primarily at elevation 234 m **ASL**, which is the proposed full-supply level of the Wuskwatim Generation Project. The locations of the various collection points are shown in Figure A8.2-1.

On Wuskwatim Lake, the 3 years sampled represent a range of flow conditions and water levels, as follows:

- In 1999, flows were about 700 m^3/s and Wuskwatim Lake levels were in the 233.0 to 233.2 m range. For this case average TSS levels at the inlet to the lake were approximately 11mg/L, while TSS levels in the lake varied between 3 and 10 mg/L, with an average near 7 mg/L.

- In the year 2000, river flows were approximately 1,000 m^3/s and lake levels were at or slightly above elevation 234 m (the proposed Project forebay level). For this case average TSS levels at the inlet to the lake were higher, at approximately 14 mg/L, while TSS levels in the lake varied between 7 and 21 mg/L, with an average near 13 mg/L. Also associated with the TSS data in Table A8.2-1 are wind speeds from the Wuskwatim DCP station for the day of, and the four preceding days, the TSS data measurement. It appears from this data that there is a correlation with wind data and elevated TSS levels caused by shoreline erosion.
- In 2001, river flows were approximately 820 m^3/s which are near existing average flow conditions (Figure 4.3-1), and Wuskwatim Lake levels varied between 233.3 to 233.5 m. For this case average TSS levels at the inlet to the lake were approximately 10.5 mg/L, while TSS levels in the lake varied between 2 and 24 mg/L, with an average near 9.6 mg/L.

An examination of Table A8.2-1 shows data collected for Wuskwatim Lake (2 stations), Taskinigup Falls, and Opegano Lake in the year 2001 indicates that the TSS data for all three stations are approximately the same. This means there is a negligible additional contribution to TSS levels from the river reach section, that the two stations in Wuskwatim Lake can be used as a surrogate of sediment outflows from the lake and that all 3 years of data can be used to compute an average of sediment outflows along with sediment inflows into Wuskwatim Lake. The data can be summarized as follows:

- Upstream: mean = 11.8 mg/L, standard deviation = 3.7 mg/L
- Downstream: mean = 9.3 mg/L, standard deviation = 3.8 mg/L

While the data sets are rather small to permit reliable statistical inferences, the difference in means is not significant at the 5% confidence level (the usual standard for acceptance), it is significant at the 10% level. Therefore the difference was accepted as real, thus indicating a reduction of inflowing sediment that could be attributable to deposition in the lake.

8.3.1.4 Recent Sediment Trap and Sediment Core Data

In addition to the TSS data summarized above, a lake-bottom core was taken near the middle of the lake in 2000 at the location shown in Figure 8.3-1 (North/South, unpublished data). Analysis of this core indicates average pre- and post-CRD sedimentation rates of approximately 0.16 and 0.32 g/cm^2/yr. This would imply, on average, a doubling of the sedimentation rate in the lake following implementation of the

CRD in 1977. However, similar to the trends exhibited in TSS data collected at Thompson after diversion, previously discussed, and the observed reduction in lake shoreline erosion rates (Section 6.4.2.1), it is likely that sedimentation rates in the early post-CRD period initially exceeded this average value (0.32 cm^2/yr), but have since decreased to lower values.

Sediment trap data was collected in 2000 and 2001 at several sites in Wuskwatim Lake as shown in Figure 8.3-1. Table A8.3-1 and Table A8.3-2 summarize the results of this data for the 2 years, respectively. The data indicates nearshore sedimentation rates in 2001 to be approximately 0.48 g/cm^2/yr based on an average of six nearshore collection sites. Nearshore sedimentation rates in 2000, in which Wuskwatim Lake levels were at or near the proposed full supply level of the Wuskwatim Generation Project for a good portion of the year, were higher, at 0.74 g/cm^2/yr.

Figure 8.3-1. Location of sediment-trap measurements (North/South *pers. comm.* 2003).

A number of the observation sites in the centre of Wuskwatim Lake (i.e. sites 4 and 5) were lost through the study and data was only collected at Site 6. For Site 6, the sedimentation rate in 2000 was 1.19 $g/cm^2/yr$. It is uncertain how representative this single site is of the total deepwater deposition area.

8.3.2 Sediment Budget for Wuskwatim Lake

As in any typical lake, sediment sources for Wuskwatim Lake include the inflowing sediment load of the Burntwood River (at the inlet to the lake), and material contributed through localized erosion of the lake shoreline. These shoreline erosion processes and the anticipated quantities are described in detail in Appendix A6.1. Sediment loads contributed by small tributary streams entering Wuskwatim Lake are likely small, and will be the same both with and without the Project. Given these considerations, they have not been included in the present analysis.

A preliminary sediment budget for existing post-CRD conditions was estimated for the main part of Wuskwatim Lake based on the TSS data collected from 1999 to 2001, Hecky and McCullough's earlier (1984) observations on Southern Indian Lake, and the estimated volume of material resulting from existing erosion of the Wuskwatim Lake shoreline. This sediment budget is summarized pictorially in Figure 8.3-2. An average of the 3 years of data shows that the TSS levels entering into the Wuskwatim Lake are approximately 12 mg/L and the TSS levels leaving Wuskwatim Lake are approximately 9 to 10 mg/L, indicating sediment deposition is currently occurring within Wuskwatim Lake. Using a post-CRD average annual inflow to Wuskwatim Lake of 845 m^3/s (Figure 4.3-1), it is calculated that approximately 57,000 tonnes/year of sediment are currently being deposited within the main part of Wuskwatim Lake, based on an inflow minus outflow **sediment balance** only. This estimation does not account for any additional localized erosion occurring within Wuskwatim Lake.

Based on existing shoreline erosion conditions in the main part of Wuskwatim Lake it is estimated that approximately 1,900,000 m^3/yr of material will erode in the first 5 years following Project completion, i.e., 2009 to 2014 (Table A6.1-3) or 38,000 m^3/yr. Based on an estimated material density of 1.2 t/m^3, this volume converts to a mass quantity of approximately 45,600 tonnes/yr.

As described earlier, data collected from Southern Indian Lake in the early 1980s indicates that 50% to 80% of the material eroded from shorelines is deposited in a zone near the eroding shoreline, approximately in the first 150 to 300 m from shore ("nearshore" area; Section 8.3.1).

The remaining portion of the eroded material becomes part of the solids suspended in the water further out in the lake, where it either settles out (deepwater deposition) or is carried downstream. In terms of the potential transport of shoreline-erosion sediment into deep water and its potential fate afterwards, again, measurements in Southern Indian Lake indicate that deepwater transport and deposition could range from a low of 20% up to 50% (Section 8.3.1). Accordingly, it is conservatively estimated that 22,800 tonnes/yr are currently being deposited in the nearshore area around the eroding shorelines of Wuskwatim Lake and the other 50% or 22,800 tonnes/yr is being transported out into the deepwater section of the Lake where it will join with the other suspended material and be deposited in the water. Therefore, in combination with the 57,000 tonnes/yr from the inflow-outflow sediment balance (see above), the total deepwater deposition within Wuskwatim Lake is estimated to be 79,800 tonnes/yr (Figure 8.3-2).

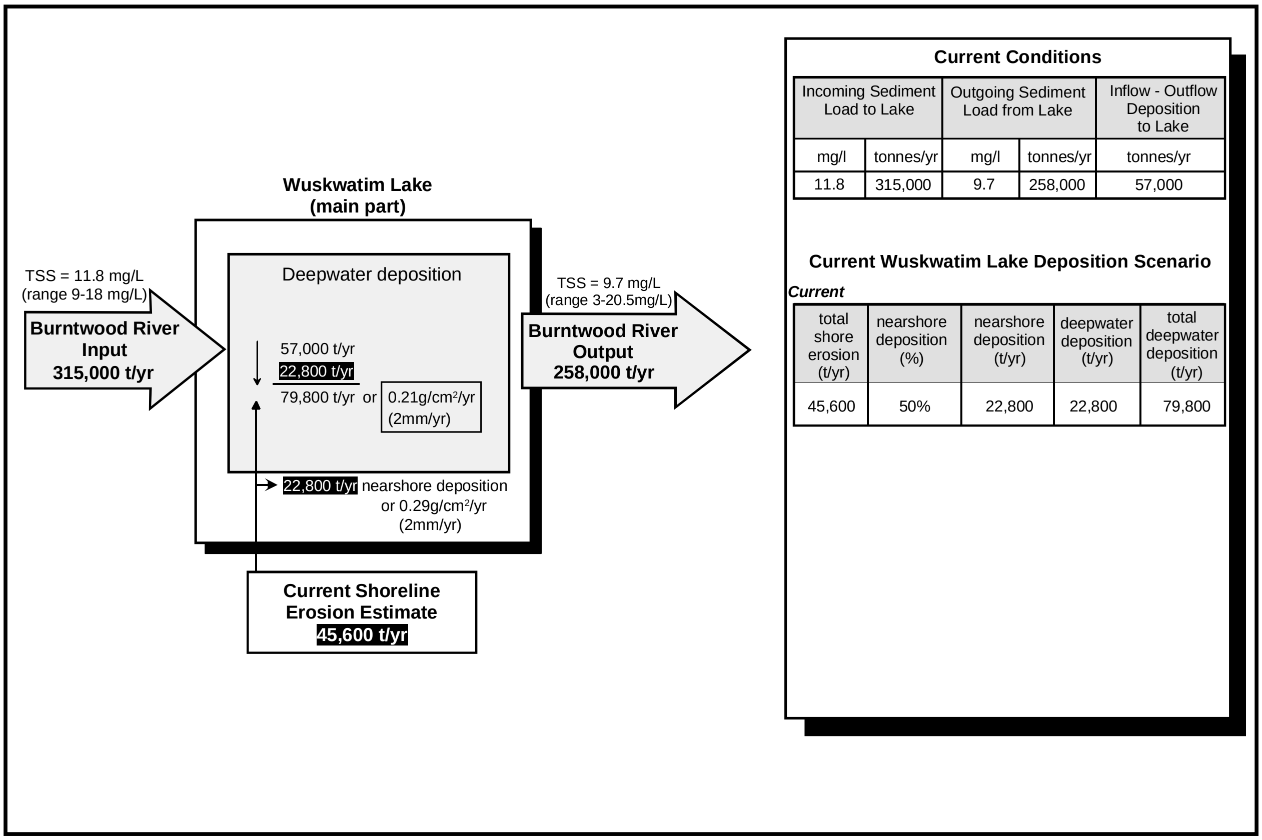

Figure 8.3-2. Existing Condition: Sedimentation Estimates for Wuskwatim Lake.

In terms of deposition rates, potential nearshore deposition has been estimated to be approximately 0.29 g/cm^2/yr (based on 52.6 km of eroding shoreline along the main part of Wuskwatim Lake, and an average deposition width of 150 m; Section 6 and Table A6.1-1). Deepwater deposition has been estimated to be approximately 0.21 g/cm^2/yr (based on an estimate of effective lake area in the main part of Wuskwatim Lake of 38 km^2; Penner *pers. comm.* 2002).

8.3.2.1 Comparison with Sediment Core and Trap Data

The predicted sediment budget rate of 0.21 $g/cm^2/yr$ derived in Figure 8.3-2 is in the range of the sediment core sample collected in 2000 (0.32 $g/cm^2/yr$; Section 8.3.1.4). The predicted sediment budget of 0.21 $g/cm^2/yr$ is not, however, in the range of the sediment-trap datum of 1.19 $g/cm^2/yr$. As discussed in Section 8.3.1.4, this sediment trap datum may not be representative of the entire deepwater portion of the lake.

Additional sediment trap data was collected in 2000 and 2001. Of particular interest to this assessment was the data collected in 2001, given that flow conditions and water levels in 2001 represented average or typical values for the existing environment. This data was collected at several sites in Wuskwatim Lake, and showed average nearshore deposition rates in 2001 of approximately 0.48 $g/cm^2/yr$. The deposition rates estimated in Figure 8.3-2 are only about 60% of observed rates. Assuming the eroded sediment volumes estimated in Section 6 are correct, and that this trend is typical for the main lake shoreline, this would imply that up to 80% of the eroded sediments may be depositing within the nearshore zone. This is consistent with some of Hecky and McCullough's (1984) earlier observations, in which up to 80 percent of eroded sediment volumes were estimated to be deposited within the nearshore zone on SIL (Section 8.3.1).

8.3.3 Summary of Downstream Conditions

As indicated in Section 7.4, the weighted average rate of river-bank recession between the Project site (Taskinigup Falls) and Opegano Lake was approximately 0.2 m/yr over the ten year period from 1985 to 1995. Assuming a density of 1.2 t/m^3, and an average bank height of 5 m, the mass of eroded sediment entering the river would be about 58,000 tonnes/yr, which converts to a river sediment concentration of about 2.2 mg/L assuming nothing settles out – a relatively small value, and well within the natural variability of the river. This small incremental value was confirmed by TSS measurements taken in the summer of 2001 (Appendix A8.2). Based on the measurements taken, there were no discernable increases in TSS levels between samples taken at Taskinigup Falls and those taken at Opegano Lake.

8.4 EFFECTS ASSESSMENT AND MITIGATION

8.4.1 Construction

During construction, there will be no changes in upstream water levels on Wuskwatim Lake and therefore no changes in erosion/sedimentation rates in the lake are expected.

As discussed in Section 7.4.1, there are a number of short-term construction activities, which may result in a temporary increase in the downstream TSS levels. However, during cofferdam construction and removal, best construction practices will be adopted which will minimize the overall potential for fine-grained sediments to be entrained in the flow. This would include placement of the granular and impervious fill by bulldozing from the top of the slope such that the material enters the water as a sliding mass, making it more resistant to erosion and dispersion. It is estimated that cofferdam construction would result in a temporary increase in TSS level of 25 mg/L or less during this activity and would take approximately 15 weeks in total over two separate periods. Cofferdam removal would occur as much as possible in the dry and then removal of remaining material in the wet. During cofferdam removal it is expected that there would be a small increase in TSS level (5 mg/L or less) for the duration of the removal activities (approximately 12 weeks). Table A8.4-1 provides a breakdown of the expected TSS levels during the various cofferdam construction and removal activities.

As also discussed in Section 7.4.1 there is potential for increased bed erosion in the approach channel leading to the **spillway** during **Stage II** river diversion, which could result in an initial increase of TSS of 14 mg/L (range negligible to 100 mg/L, Table A8.4-1). However, as indicated in Section 7.4.1, additional testing is planned to address uncertainties in the strength of this natural riverbed material and, if necessary, armour stone will be placed in vulnerable areas to minimize erosion (and subsequent sediment transport) effects. The results of these riverbed investigations and any proposed mitigative strategies will be discussed with the regulators prior to implementation.

8.4.2 Operation

8.4.2.1 Wuskwatim Lake

First Five Years

The Wuskwatim Project will result in a generally stable water level in Wuskwatim Lake at or near elevation 234 m, which is within the upper range of the current water level variations. This is expected to result in conditions, and TSS levels, similar to those experienced in 2000, and summarized in Table 8.3-2. During the summer of 2000, TSS levels within Wuskwatim Lake were observed to vary between 7 and 21 mg/L, with a calculated average of approximately 13 mg/L. TSS measurements at the inlet to the lake were higher, at 14.3 mg/L, indicating the lake continues to act as a sediment sink for incoming sediment loads. The recorded data for 2000 includes the effects of wind events, one of which was up to 46 km/h in magnitude. These TSS levels may vary from year to year dependent on the number, magnitude and direction of the wind events, but the conditions observed in 2000 provide a reasonable representation of the post-Project conditions for the first five years following construction.

A preliminary sediment budget was also prepared for this initial post Project condition. It is estimated that an incremental increase in erosion in the main part of Wuskwatim Lake of about 72,000 tonnes/yr will occur in the first 5 years after the Project as a result of the lake levels being near their historic maximum levels on a sustained basis. It should be noted that this estimated incremental increase of 72,000 tonnes in shoreline erosion is likely similar to what occurred in the year 2000. For the initial assessment of effects, it was assumed that this incremental increase in erosion would not result in a change in sediment outflow - that is, that all sediment would be re-deposited within Wuskwatim Lake. The results of this sediment budget are summarized in Figure 8.4-1. As shown in the figure, using the estimated existing 50/50 split with respect to nearshore/deepwater deposition (McCullough 1987), 36,000 tonnes/yr would be added to the nearshore area of the lake and a similar amount added to the deepwater area for deposition.

Sediment deposition in the nearshore area is estimated to be in the range of 0.74 g/cm^2/yr or approximately 6 mm/yr, a 2.5 times increase in deposition rate in the first 5 years, based on the same method described previously (Figure 8.4-1). Note that this compares quite well with average deposition rates established in the nearshore zone based on sediment trap data collected in 2000 (approximately 0.74 g/cm^2/yr). As a result of the Project, areas near the shore where erosion is currently occurring are anticipated to have more frequent wind/wave-induced erosion events in the first 5 years of operations and therefore more days of elevated TSS levels.

The sediment balance for existing conditions, outlined above, suggests that very little of the shoreline erosion material exits from the lake as suspended sediment. As a sensitivity test, a second scenario was considered in which it was assumed 50% of the deepwater component would remain in suspension, and be transported downstream. This scenario is summarized in Figure 8.4-2. As shown in the figure, under this case, TSS levels in the outgoing flow would rise by less than 1 mg/L, which is unlikely to be detectable, given the range of existing variation. Under this scenario, with a portion of the lake eroding

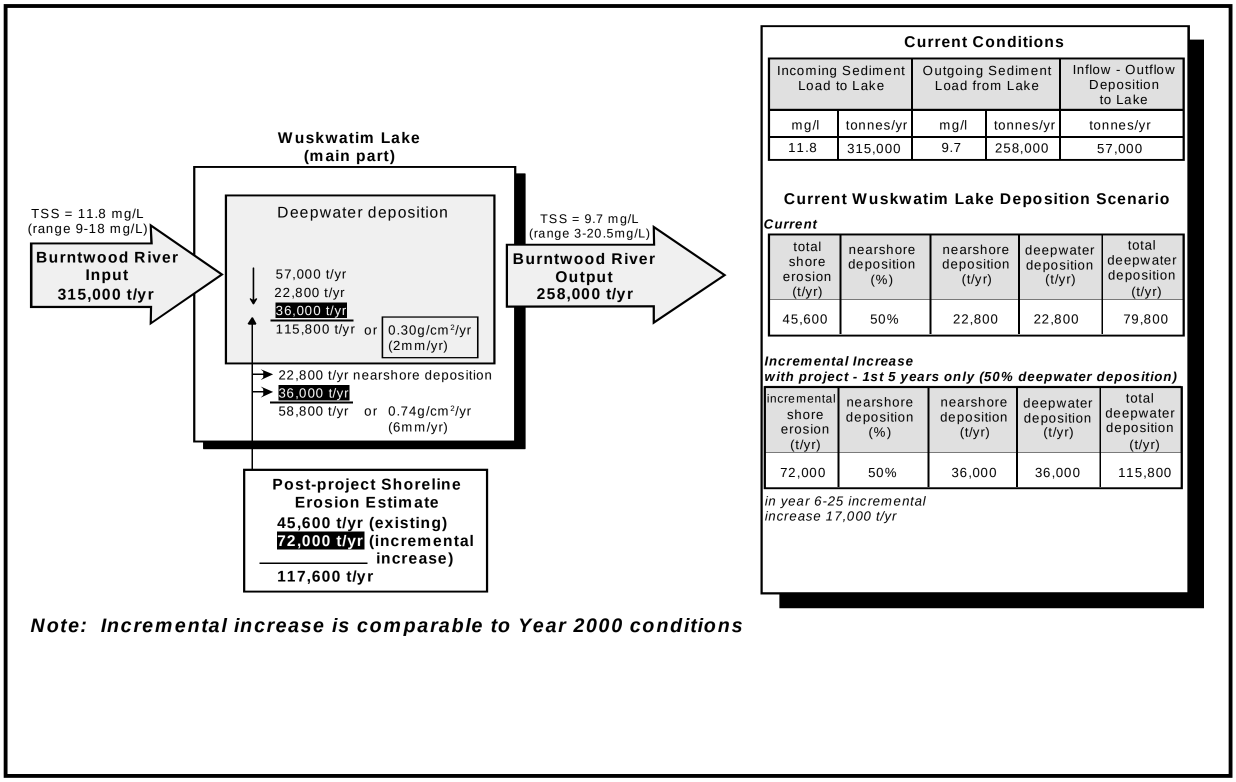

Figure 8.4-1. Predicted Sedimentation Estimates: First 5 Years Post-Project (assuming no change in outflow sediment).

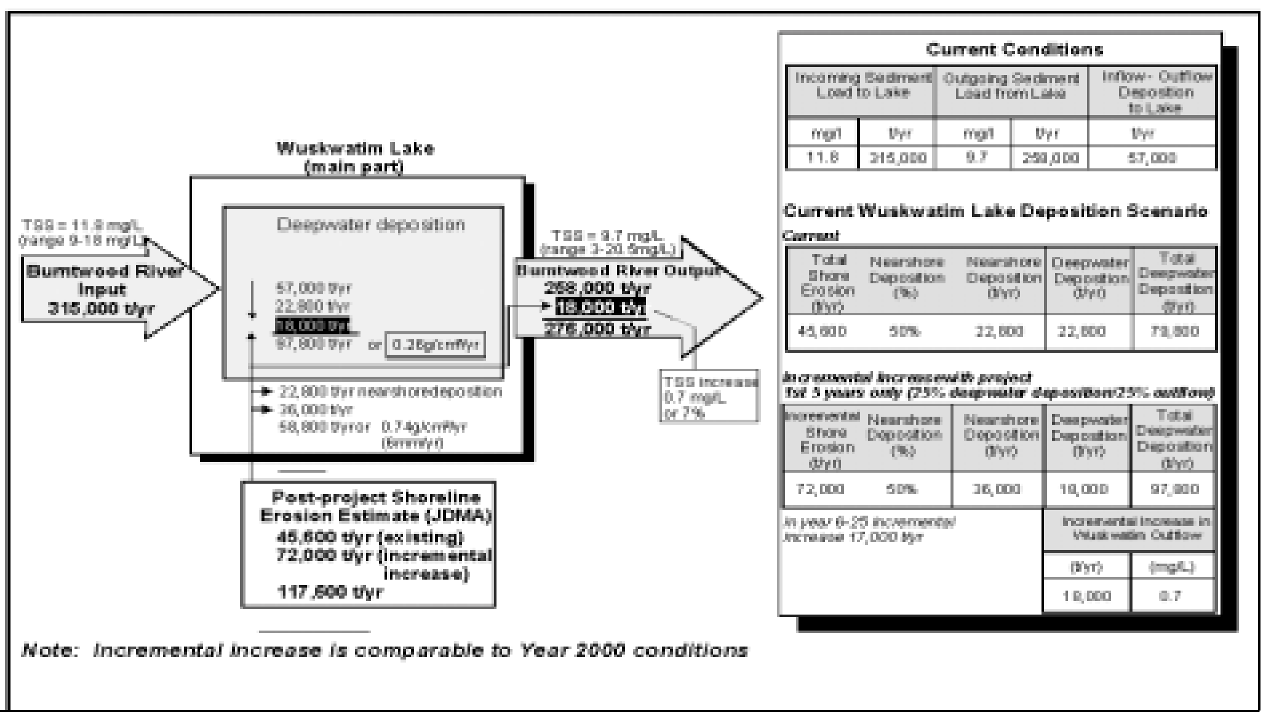

Figure 8.4-2. Predicted Sedimentation Estimates: First 5 years Post-Project (assumes 25% sediment outflow from Wuskwatim Lake).

sediment being transported downstream, the deepwater deposition in the lake would reduce from 0.30 g/cm^2/yr down to 0.26 g/cm^2/yr.

Years 5 to 25

It is expected that the estimated large increases in sedimentation in the nearshore and the estimated minor increase in deepwater areas (within the main part of Wuskwatim Lake) will decrease significantly after the first 5 years of the Project (Figure 8.4-3) and return, in the following 20 years, to background levels. The effects of sedimentation are expected to decline over a moderate timeframe.

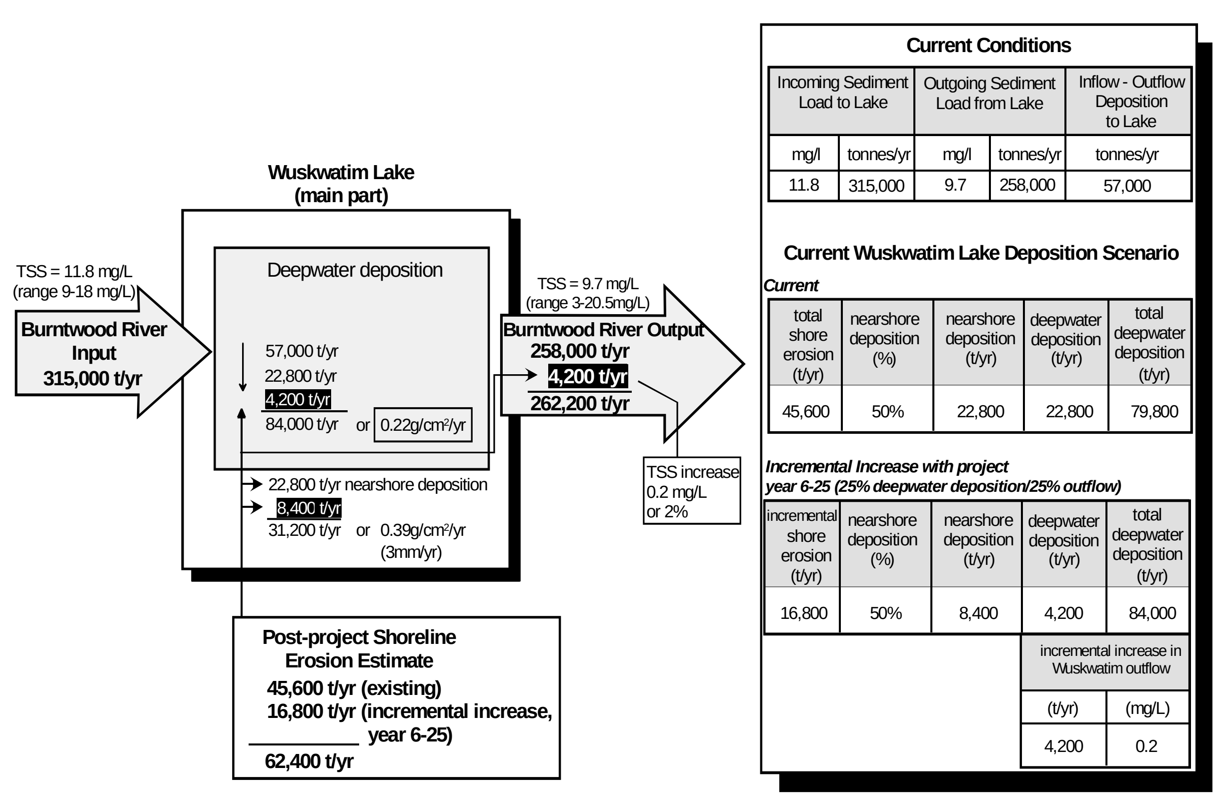

Figure 8.4-3. Predicted Sedimentation Estimates: Years 6 to 25 Post-Project (assumes 25% sediment outflow from Wuskwatim Lake).

8.4.3 Downstream Reach

As indicated in Section 7, any increase in river sediment derived from river bank erosion - as a result of Wuskwatim Project normal operation is expected to be very small, and is judged to be undetectable given the observed variation in TSS values.

8.5 REFERENCES

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Appendix A8.1 - TSS Data for the Burntwood River at Thompson

Williamson and Ralley (1993) summarized the results of an ongoing monitoring program established by the Provincial Government on water quality impacts associated with hydroelectric development. Of key interest to the Wuskwatim study is an analysis of TSS data collected on the Burntwood River at Thompson, both prior to and following the Churchill River Diversion (CRD). The results of this monitoring program are summarized in Table A8.1-1. Summary below is supplemented with information provided by Williamson (2003).

Table A8.1-1

Summary of average TSS levels at Thompson, Manitoba for various periods

Period	Description	Average TSS Level (mg/L)	Range in TSS Levels (mg/L)
1967 – 1976	Represents pre-CRD condition	13.9	<5 – 44
1977-1984	Represents early CRD condition	20.0	<5 – 385
1987-1992	Represents 10 to 15 years post-CRD	13.0	<5 – 25
1992-2003	Represents current conditions	13.5	<5 – 31
1999	Data for 1999	23	18 - 28
2000	Data for 2000	16	5 - 31
2001	Data for 2001 (one measurement)	9	N/A

Appendix A8.2 - Available TSS Data: Wuskwatim and Opegano Lake

Table A8.2-1

Analysis of Total Suspended Solids, water level, and wind data for Wuskwatim Lake

Date	Water Level: Wusk. Lake	SITE TSS (mg/L)							Wind Data (km/h)			
		LBR C	WuL A	WuL B	WuL Avg.	TF	OL-A	OL-B	Day - 1	Day - 2	Day - 3	Day - 4
2-Jun-99	233.256	9	10	5	**7.5**				17.9	11.1	12.6	18.7
26-Jun-99	233.279	17	7	9	**8**				18.6	28.8	26.6	24.5
19-Aug-99	233.003	9	3	3	**3**				20.3	13.8	17.2	24.7
29-Sep-99	233.07	10	7	9	**8**				18.4	15.0	19.8	21.2
1999 Average		**11.3**	**6.8**	**6.5**	**6.6**							
14-Jun-00	234.109	13	13	19	**16**				21.7 (58^0)	27.6 (119^0)	35.5 (119^0)	46.1 (81^0)
24-Jul-00	233.976	18	7	7	**7**				18.4	19.7	10.0	15.9
15-Aug-00	234.03							<5				
20-Aug-00	234.02						<5					
18-Sep-00	234.056	12	8	21	**14.5**				14.0 (28^0)	26.2 (26^0)	24.4 (24^0)	18.2 (306^0)
24-Sep-00	234.06						13	15				
2000 Average		**14.3**	**9.3**	**15.7**	**12.5**		**9**	**10**				
28-Mar-01	233.88							8				
30-May-01	233.48	16	17	24	**20.5**	24			22.0 (169^0)	22.8 (101^0)	29.7 (48^0)	10.4
31-May-01	233.46						14	14				
16-Jul-01	233.311	7	5	3	**4**	6			20.4	23.4	12.5	23.0
17-Jul-01	233.98						6	7				
23-Aug-01	233.34	10	7	6	**6.5**	6			14.5	23.4	22.7	22.5
26-Aug-01	233.34						10	9				
27-Sep-01	233.51	9	2	13	**7.5**	10			16.5 (151^0)	11.9 (182^0)	25.7 (206^0)	23.2
30-Sep-01	233.51						8	9				
2001 Average		**10.5**	**7.75**	**11.5**	**9.625**	**11.5**	**9.5**	**9.4**				

Source: North/South pers. comm. 2002 and Manitoba Hydro Wuskwatim DCP data (2002)

Notes:

1) See Figure A8.2-1 for location of measurement points
2) Highlighted wind data includes reference to prevailing wind conditions for those sample periods exhibiting high TSS measurements and/or dissimilar values for sites **WuL A** and **WuL B**.

Appendix A8.2 cont'd

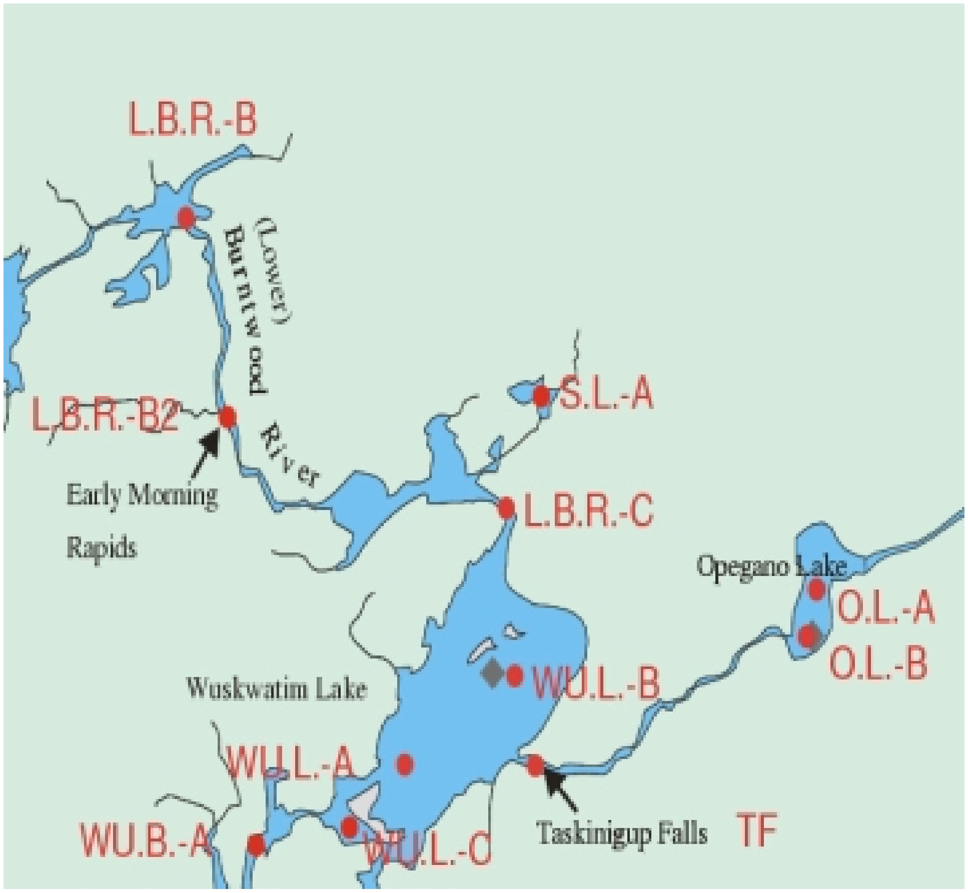

Figure A8.2-1. Location of TSS measurements (Source: North/South *pers. comm.* 2002).

Appendix A8.3 - Available Sediment Trap Data: Wuskwatim Lake

Table A8.3-1
Sediment trap data – Wuskwatim Lake 2000

Sample Number	Standard Trap Set Time (365 days)	Total Dry Weight (g)	Inorganic Dry Weight (g)	Organic Weight (g)	Sand* Weight (g)	Silt/Clay Weight (g)	Sediment Deposition Rate (g/cm^2/year)
1	365	39.58	37.60	1.98	0.02	37.59	0.73
2	365	43.59	41.20	2.38	0.35	40.85	0.80
3	365	35.45	33.04	2.41	0.03	33.01	0.65
6	365	64.80	61.37	3.43	0.09	61.28	1.19
7	365	45.11	42.42	2.68	0.07	42.35	0.83
8	365	42.15	40.48	1.67	0.01	40.47	0.78
9	365	38.57	36.40	2.17	0.27	36.13	0.71
10	365	32.15	29.51	2.64	0.03	29.48	0.59
Average of all sites							0.78
Average of Nearshore Sites (1,2,3,7,8, 9, and 10)							0.73
Deepwater sites (6)							1.19

1) There were no gravel particles identified in any of the samples.
2) Traps initially set on August 19, 1999 and retrieved July 22/23, 2000
3) Results have been standardized for a 365 day year
4) Location of traps shown in Figure 8.3-2
5) Reference (North/South, unpublished data)

Table A8.3-2
Sediment trap data – Wuskwatim Lake 2001

Sample Number	Standard Trap Set Time (365 days)	Total Dry Weight (g)	Inorganic Dry Weight (g)	Organic Weight (g)	Sand* Weight (g)	Silt/Clay Weight (g)	Sediment Deposition Rate (g/cm^2/year)
1	365	23.32	22.12	1.20	0.03	22.09	0.43
2	365	30.94	29.39	1.55	0.02	29.37	0.57
3	365	30.69	28.87	1.82	0.04	28.83	0.57
6	365	52.01	49.30	2.71	0.04	49.26	0.96
7	365	36.19	34.34	1.85	0.03	34.30	0.67
8	365	20.85	19.77	1.08	0.02	19.75	0.38
10	365	19.53	17.55	1.97	0.03	17.53	0.36
Average of all sites							0.56
Average of Nearshore Sites (1,2,3,7,8, and 10)							0.49
Deepwater sites (6)							0.96

1) There were no gravel particles identified in any of the samples.
2) Traps initially set on July 22/23, 2000 and retrieved on May 29, 2001
3) Trap 6 was retrieved on August 26, 2001.
4) Results have been standardized for a 365 day year
5) Location of traps shown in Figure 8.3-2

Appendix A8.3 cont'd

Figure A8.3-1. Location of Sediment Trap Measurements (Source: North/South *pers. comm.* 2003).

Appendix A8.4 – Estimated Increases in TSS Levels During Construction

Table A8.4-1

Summary of estimated increases in TSS in the Burntwood River during construction of the Wuskwatim Project

Location/Time Period	Description	Estimated Increase in TSS (mg/L)[1] Most Probable[2]	Range
Cofferdam Construction			
(i) Stage I Upstream Cofferdam	Loss of Cofferdam Fill	7	3 to 9
	Re-suspension of riverbed deposits	10	4 to 15
(ii) Stage I Downstream Cofferdam	Loss of Cofferdam Fill	<1	<1 to 1
	Re-suspension of riverbed deposits	15	6 to 22
(iii) Stage II Upstream Cofferdam - section placed in the wet	Loss of Cofferdam Fill	11	6 to 13
(iv) StageI I Downstream Cofferdam	Loss of Cofferdam Fill	9	4 to 14
Cofferdam Removal			
(i) Stage I Upstream Cofferdam [3]		1	1 to 1
(ii) Stage I Downstream Cofferdam	Removed in the dry	N/A	
(iii) Stage II Upstream Cofferdam	No removal required	N/A	
(iv) Stage II Downstream Cofferdam [3]		1	1 to 1
(v) Spillway Discharge Channel Rock Plug		5	2 to 7
(vi) Wuskwatim Falls Channel Excavation Rock Plug		10	4 to 14
South River Bank Adjacent to Taskinigup Falls during Stage I Diversion	Erosion of lacustrine clays	3	1 to 4
Stage II Downstream Cofferdam Remnant – Initial Powerhouse Operation	Erosion of the cofferdam remnant	3 decreasing to 2	1 to 30
River Banks between Wuskwatim Falls and Taskinigup Falls during Stage I and Stage II Diversion	Erosion of lacustrine clays	1	1 to 1
Area Near Upstream End of Spillway Approach Channel during Stage II Diversion	Erosion of riverbed and remnant of the Stage I Upstream Cofferdam, erosion gradually decreases during Stage II Diversion	14 decreasing to 6	1 to 100 1 to 9

(1) Estimated increases in TSS assume dispersion of the solids uniformly throughout the entire flow.

(2) Base Case is for a constant flow of 940 m^3/s (average annual flow), with the lacustrine clays having a critical shear stress of 1 Pa and a Parthenaides Coefficient of 10^{-4} $kg/m^2/s$.

(3) Increases in TSS due to cofferdam removal in the wet are very low due to the slow rate of removal of the fill (50 m^3/h).

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9.0 WOODY DEBRIS

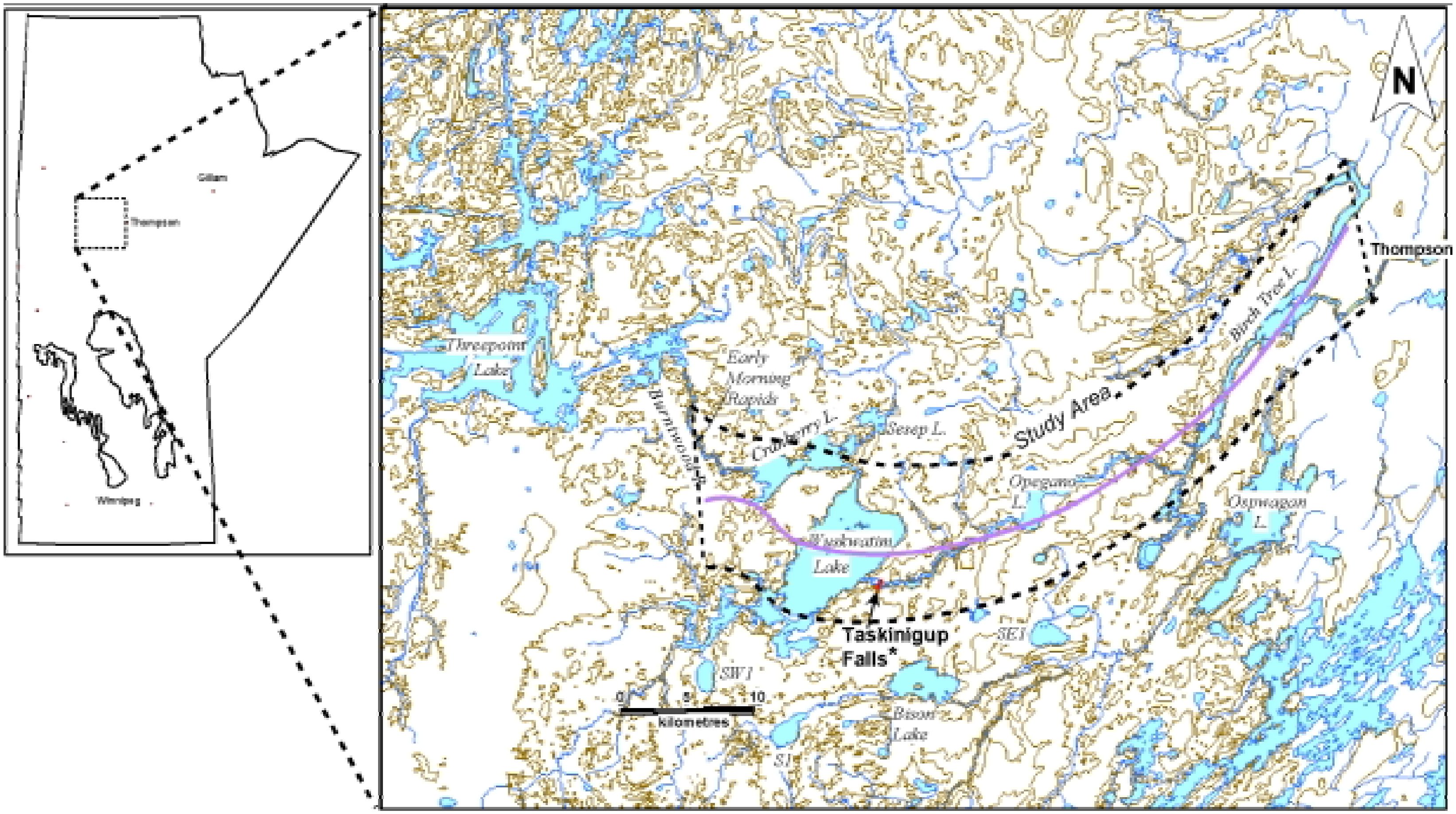
9.1 INTRODUCTION

The overall purpose of this section is to characterize and quantify where practicable, the existing debris situation and predict how this might change with the proposed Project. Along with quantifying the current debris levels, relevant historical CRD information was reviewed to gain insights on the current debris environment.

The proposed Wuskwatim Generation Station is located within Manitoba Hydro's previously built Churchill River Diversion (CRD) Project area. The opening of the CRD in late 1976 resulted in significant physical changes to the CRD system (MacLaren/InterGroup 1984). Some of the physical changes were immediate, such as flow increasing by approximately 8-fold from 100 m^3/s to 850 m^3/s (Manitoba Hydro 1996), which caused Wuskwatim Lake levels to rise about 3 m. Other physical changes associated with the new water regime have resulted in more gradual changes over time such as development of new shorelines, shoreline erosion, debris generation and sedimentation.

The study area for this assessment encompasses the section of the CRD from Early Morning Rapids to Birch Tree Lake (Figure 9.1-1). The major focus of the assessment is on the Wuskwatim Lake environs, as this is the area where the majority of debris effects from the Wuskwatim Project will be experienced.

Debris in this study, and in the context of Manitoba hydroelectric developments, is defined as "woody or other organic material that impedes desired uses of a waterway. Debris can be either fixed (trees or tree parts that remain rooted) or loose (either floating freely or deposited on a shoreline)" (Manitoba Hydro 2000). There are a number of sources for debris entering the water. Natural occurring phenomena such as floods and eroding banks can add debris to waterways over time. Forestry operations in some locales can also contribute debris through the water transport of logs or forest cutting too close to the riparian edge. In northern Manitoba, the main source of debris along waterways used by Manitoba Hydro originates from areas that were not cleared or only partially cleared prior to Project-related flooding (Manitoba Hydro 2000). Establishment of new shorelines as a result of Project flooding and new water regimes, as described in Section 6.3, will also contribute additional debris loads to waterways over and above natural levels.



* - Proposed Generating Station Site

Figure 9.1-1 Debris Study Area

9.2 APPROACH AND METHODOLOGY

The debris environment on Wuskwatim Lake and the CRD is dynamic and is evolving from the induced water-level change in the mid 1970's. To understand the current and evolving debris environment and how it might change requires an understanding of how it arrived in this state. To do this, information was collected from a variety of sources including reports and personal communications, followed by a synthesis of this information. This analysis is discussed in Section 9.3.2.

A variety of methods were used to characterize the current debris environment for the study area, i.e., Wuskwatim Lake and downstream lakes and rivers. The methods included boat and/or helicopter surveys, which were done during the May to September 2000 and 2001 field season.

Boat-based surveys were used on Wuskwatim Lake and the surrounding lakes of Cranberry, Sesep, Wuskwatim Brook as well as on Opegano Lake. Helicopter-based surveys occurred at all other sites within the study area that were not sampled by boat. A description of the methods and timing is discussed below.

9.2.1 Boat Based Debris Survey

For Wuskwatim Lake a boat-based debris survey was carried out between June 2 and 6, 2000 during relatively calm days. From the boat observations were made using binoculars from stops located about every kilometre along the shoreline from an offshore position of approximately 50-100 m. At each observation stop, an assessment was made of the 500 m of shoreline and offshore waters on either side of each observation point. Photographs and notes were taken describing:

- the type and relative density of debris along the shorelines;
- shoreline type (i.e., rocky, clay etc.) and slope; and
- vegetation present near the shore – dominant canopy cover and, where visible, understory species.

The location of the Wuskwatim debris observation points is shown in Figure 9.2-1.

Between June 10 and 12, 2001, a similar boat based survey occurred on Opegano Lake, and along 1.5 to 2 km reaches of the Burntwood River upstream and downstream of Opegano Lake.

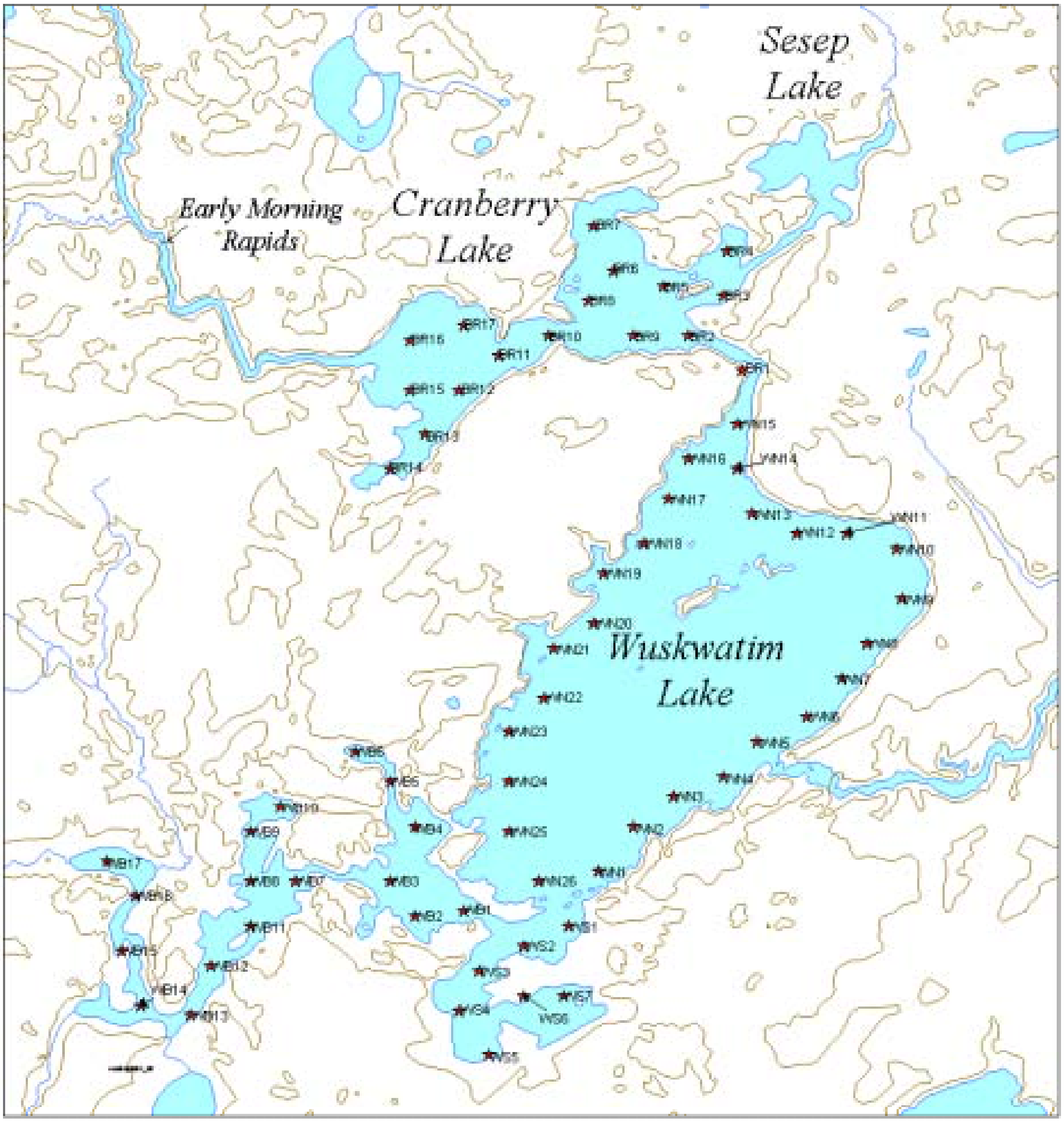


Figure 9.2-1. Wuskwatim Lake debris mapping

9.2.2 Helicopter Surveys

Video camcording by helicopter was also carried out on September 19 and 20, 2001. The video coverage extended from Birch Tree Lake to Wuskwatim Falls, with selective recordings occurring between Wuskwatim Lake and Early Morning Rapids (where information was not recorded during the boat-based survey in 2000, e.g. Sesep Lake). Video coverage of Opegano Lake consisted of a complete pass along the edge of the lake, while coverage of the river sections and Birch Tree Lake consisted of a single pass with video coverage of mostly the northwest shore of the river with scattered coverage of the southeast shore.

9.2.3 Ground-Truthing Surveys

Between September 17 and 19, 2001, shoreline ground-truthing surveys were carried out at 9 sites around Wuskwatim Lake out to quantify the previous years visual archiving of debris by boat (Section 9.2.1). This survey was designed to provide a baseline for the standard descriptions of debris density. As described in Appendix A9.1, the 2001 ground-truthing surveys involved measuring debris within a 50 metre transect using 3 different techniques and comparing the results to the previous year's visual description of debris density, i.e. low, medium and high. The three techniques used in the 2001 survey included a:

- linear transect method - at each site debris was measured at 1 metre intervals along a 50 metre tape that was placed parallel to the shore and through the centre of either the rafted or beached debris. Any debris that either touched the tape or passed beneath the tape was counted. The counted debris was divided into 4 groupings based on the diameter of the debris;
- quadrat method – at each 10 metre stop along the above mentioned tape all debris contained within or passed through a 1 m square area, centred on the 10 metre stop point was counted. Again all debris counted within the 1 m^2 was classified into the above 4 categories; and
- visual assessment of the amount of debris contained within the 50 m transect was also done.

9.2.4 Roving Boat Surveys

In 2001, roving boat surveys were carried out on Wuskwatim Lake along a set course and the GPS location of floating debris, either freely floating logs or deadheads observed were noted along the boat course. Surveys were done three times over the course of the summer Figure 9.2-2 (Appendix A9.2). The total boat route length was approximately 47 kilometres. To track floating-debris movements, debris was marked with orange flagging tape to allow re-identification during subsequent boat surveys. However, it was observed that on subsequent trips the flagging tape was lost due to weathering or bird tampering.

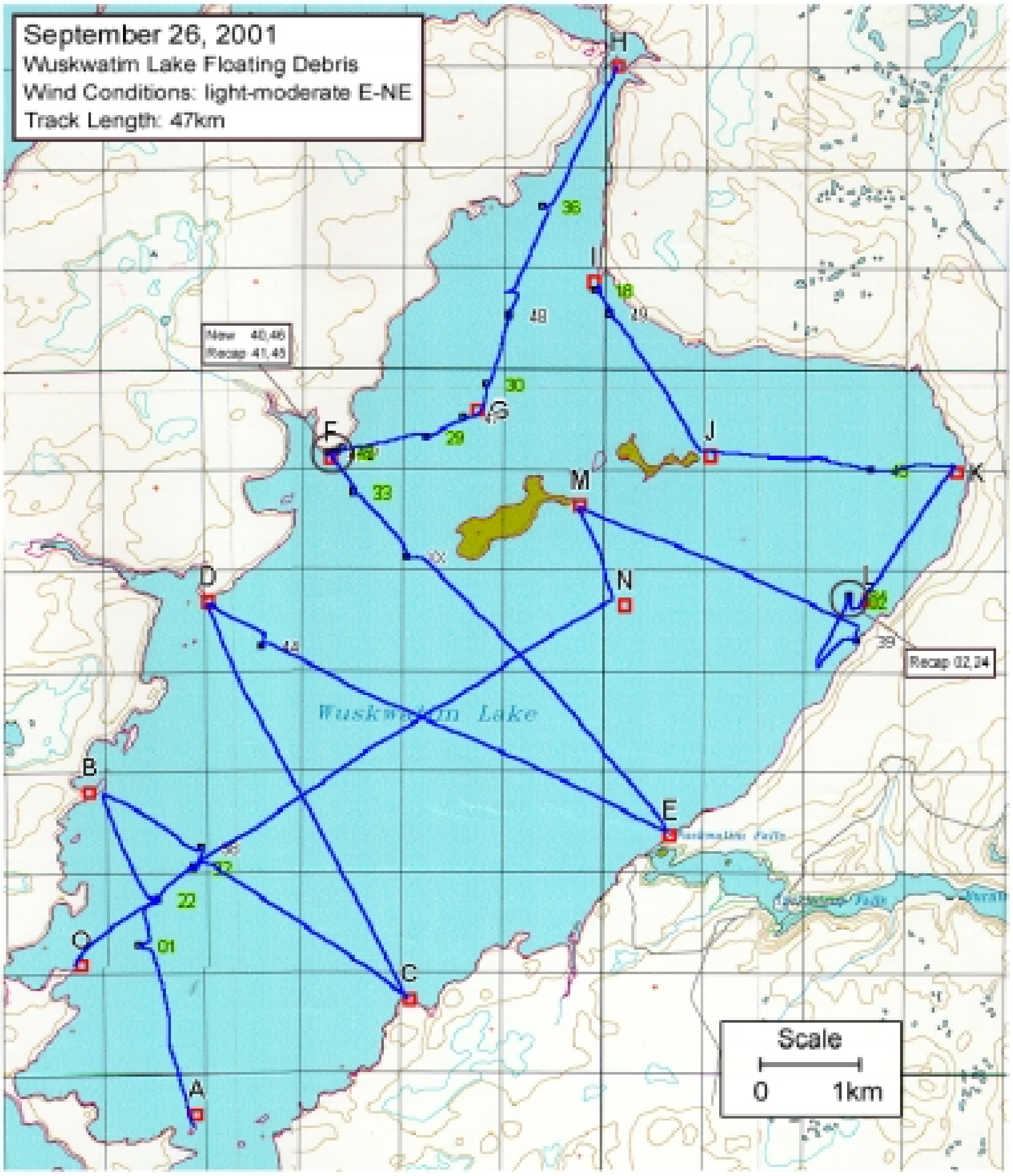


Figure 9.2-2. September 2001 boat survey route and debris positions.

The ability to view floating debris depends on the sampling methods used. From the helicopter, floating logs are relatively easy to observe over a relatively wide area of the water body as the entire length of the log is observed floating on the surface. From a boat the observer needs to be relatively close to a floating log to observe it. While deadheads are very difficult to observe from the air since only the tip of the log is typically observed, they are more easily observable from a boat, but again the observer needs to be very close.

9.3 ENVIRONMENTAL SETTING

Debris and other physical environment parameters such as erosion and sedimentation continue to evolve as a result of the CRD, i.e., it is not static. Therefore, the existing environment with respect to debris, reflects not only the present situation but also how this environment will change in the future if no Project was developed. This evolving environment is the baseline to assess the change resulting from the proposed Wuskwatim Project.

9.3.1 Debris-related Issues

The Nisichawayasihk Cree Nation and Manitoba Hydro (2001) Joint Study Program outlines some of the concerns and issues with debris as it relates to the Project.
NCN views debris as an issue with respect to:

- boating safety;
- potential adverse effects on fishing due to increased effort to clean nets and damage to equipment;
- difficulties in access to and from the water; and
- aesthetics.

Other issues raised by study team members include:

- increased boater-related debris issues;
  - currently, Wuskwatim Lake is accessible either by floatplane or by boat by portaging around Early Morning Rapids. Once road access is created in order to build the generation station, there is the potential of increased boat usage of the lake.
- potential remobilization of the currently stranded debris that is above the average water line;
  - with the proposed Project, water levels will be kept relatively constant at the upper end of the historical lake range.

The NCN and MH (2001) Joint Study Program has suggested that there are perceived issues related to the potential effects that debris may have on fish and wildlife, such as debris affecting fish spawning grounds and debris limiting access to nesting areas by waterfowl and wildlife accessing the water. The identification of any debris-related environmental sensitivities associated with the existing environment will not be discussed in this section, but will be discussed by wildlife and aquatic specialists in the Terrestrial and Aquatics Supporting Volumes. These documents will also discuss the incremental effect that debris from the proposed Wuskwatim Project will have on the aquatic and terrestrial environment.

Manitoba Hydro is currently in the process of carrying out a system-wide inventory of debris, to identify and priorize debris management across the northern hydroelectric generation system as part of their new Debris Management Program (DMP) (Manitoba Hydro 2000). Therefore any actions to address concerns with the existing debris will be addressed by the corporate DMP. This section will discuss how the Wuskwatim Generation Station Project may change the existing debris environment partially with respect to navigation, access and aesthetics.

9.3.2 Effects of CRD on Current Debris Environment

The current CRD debris environment (in which Wuskwatim Lake is located) is a product of pre-CRD clearing practices (Figure A9.3-1), water-regime change as a result of the CRD project and subsequent post-CRD physical changes (e.g., erosion, etc.), occurring along the waterways.

With the CRD project, flows on the Rat-Burntwood system increased approximately 8-fold from 100 m^3/s to 850 m^3/s (Manitoba Hydro 1996), and created considerable physical "impacts" along the diversion route (MacLaren/InterGroup 1984). With the increased flows, Wuskwatim Lake rose about 3 m increasing the surface area of the lake from 46 km^2 to 84 km^2 (Appendix A4.3). The majority of the aerial expansion of Wuskwatim Lake occurred in the peripheral lakes, i.e., Wuskwatim Brook, Sesep and Cranberry lakes (Figure A9.3-2). Within the main part of Wuskwatim Lake, there was very little change in aerial extent of the lake post CRD.

The CRD resulted in the flooding of approximately 550 km^2 of land of which about 14% was cleared prior to diversion. For those impounded trees not cleared prior to the diversion it was anticipated that most of them would be felled by ice action within 10 years except in well-protected bays (UMA 1973). In northern Quebec impoundments, a similar ice effect has been observed. Ice action accompanied with a winter drawdown has been extremely effective in removing dead standing trees (Société d'énergie de la Baie James 1988). Flyovers of the area now indicated that standing trees generally only exist in the back bays along tributary streams or in the small bays (embayments) alongside the Burntwood River. For the back-bay areas, it appears that a combination of factors such as having protected areas and shallow areas where the ice cover can potentially freeze to the bottom, as well as the lack of shoreline erosion due to the low gradient shorelines and low wave-energy environment (Section 6) are likely reasons why these areas still have standing dead trees approximately 25 years after the CRD.

It was anticipated that there would be an extensive floating-debris issue as a result of the diversion. To address this issue Manitoba Hydro initiated a substantial debris management program from 1976 to the mid 80's (Manitoba Hydro 1999). By the mid 1980's, the volume of floating debris had decreased such that there was no longer a need for the some of the collection booms and the majority of them were decommissioned. Figure A9.3-3 shows an example of debris collected in the Manasan boom just upstream of Thompson in a typical year. According to Manitoba Hydro staff, the amount of debris collected by the boom varied from year to year depending on preceding hydraulic conditions.

While some of the floating debris was intercepted through the extensive debris management program described above, the majority of the debris was not captured. UMA (1973) in their "impact assessment" of the CRD predicted that the currents in the river sections of the CRD would carry the majority of the floating debris downstream where it would likely deposit along the shores of the downstream lakes. Due to the nature of the river currents, the majority of the debris would have been deposited in the main part of the lake and not in the off-current back-bay areas.

The last contributing factor to debris in the CRD system is the acceleration of shoreline erosion (Section 6) as the new shorelines adapt to a higher water regime. This additional erosion has resulted in additional trees being added to the waterway over time.

9.3.3 Debris Characterization

Woody debris on waterbodies exists in several different forms. Previous classifications of woody debris have found that debris can be classified into 6 broad categories, including:

- **beached woody debris** is debris that is found at or above the average water level along the shore (Figures 9.3-1 and 9.3-2). The location of the photographs is shown in Figure 9.2-1;
- **standing dead trees** are flooded trees that are still standing trees but no longer alive, as shown in Figure 9.3-2;
- **rafted woody debris** is floating debris that is interlocked and "rafted" together. This debris can either be rafted next to the shoreline but not on the shoreline because of the existing quantity of beached woody debris or lack of a shoreline beach, or it can be a mat of debris that becomes entangled amongst the leading edge of standing dead trees (Figure 9.3-3). For the most part, this rafted woody debris is relatively stationary and tends not to move about on the reservoir due to wind or wave action;
- **floating woody debris** can exist in two forms. The first type is the occasional floating log that is being moved by wind and wave action in a lake or by currents in a river. The other type of floating woody debris floats loosely near the shore, but is not entangled amongst other debris, as with rafted debris;
- **leaning trees** are trees along the shoreline that are tipping towards the water due to shoreline erosion of their root structure. In most cases, leaning trees will eventually enter the water after the shoreline in which they sit on has eroded (Figure 9.3-4); and
- **submerged/deadheads** are trees that are in the water but are not mobile. Typically, deadheads have one end floating just at the surface while the other end is either on the bottom substrate or embedded into it. Submerged logs are those below the surface and can occasionally be seen in areas of clear shallow water or when there is a low water level condition. This study did not attempt to map submerged logs, but did carry out deadhead studies.

Except for standing and rafted woody debris, the debris classifications would be found on most natural water bodies (i.e., lakes and rivers) although in much smaller amounts as compared to impounded reservoirs or within waterbodies affected by diversions such as the CRD. Standing dead trees are often associated with beaver floods of creeks.

The debris was also classified into the following three densities categories: low, medium and high based on a visual inspection.

Figure 9.3-1 Example of Low-Density Beached Debris Along Bedrock Shore Northeast End of Wuskwatim Lake

Figure 9.3-2 Example of Standing and Rafted Debris - West Portion of Wuskwatim Brook

Note: Site is WN2 (see Figure 9.2-1)

Figure 9.3-3 Example of Beached / Rafted Debris - South End of Wuskwatim Lake

Note: Site is WS1 (see Figure 9.2-1)

Figure 9.3-4 Example of Leaning Trees at South End of Wuskwatim Lake

Subsequent ground-truthing surveys in 2001 (described in Section 9.2.3 and Appendix A9.1) found that the visualization technique of quantifying the volume of debris within a 50-metre grid produced more consistent results (relative to the other techniques described in Section 9.2.3) when compared with the previous years classification of low, medium and high debris categories, and yielded:

- **low-density debris:** a density of 0.1 m^3 or less per metre of shoreline;
- **medium-density debris:** a density of about 0.6 m^3 per metre of shoreline (range 0.3 to 1 m^3); and
- **high-density debris:** a density of >2 m^3 per metre of shoreline (range equal to and greater than 2 m^3).

For comparison purposes, debris densities in a "natural" lake would likely be in the zero to very-low category, i.e., below the range used to describe impounded reservoirs and waterbodies affected by diversions like the CRD (Section 9.1).

9.3.3.1 Wuskwatim Lake Debris Mapping

Results of the Wuskwatim debris survey and environs are summarized in Appendix A9.4 (Table A9.4-1) and graphically depicted in Figure 9.3-5. When the debris surveys were being carried out on Wuskwatim Lake in early June 2000 the lake level was at 234 m. This was opportunistic because it provided an opportunity to view the debris condition on the lake as well as the silty/clay bedrock contact elevation (Section 6) at the same elevation that would occur with the Wuskwatim Project (i.e., 234 m). The following observation can be made from examination of Figure 9.3-5 and Table A9.4-1:

- **In the main part of Wuskwatim Lake**:
  - the predominant debris type is beached debris in low to medium densities;
  - debris concentrations are the highest in the southern portions of the lake where there are combinations of beached, rafted and floating debris in low to medium densities for each debris type. These areas are also associated with actively eroding banks, as described in Table A9.4-1 (see Figure 4.2-1 for reference to locations WN1 and WN24 to WN26); and
  - in the upper portion of Wuskwatim Lake, rafted debris is noted sporadically in low to moderate densities.

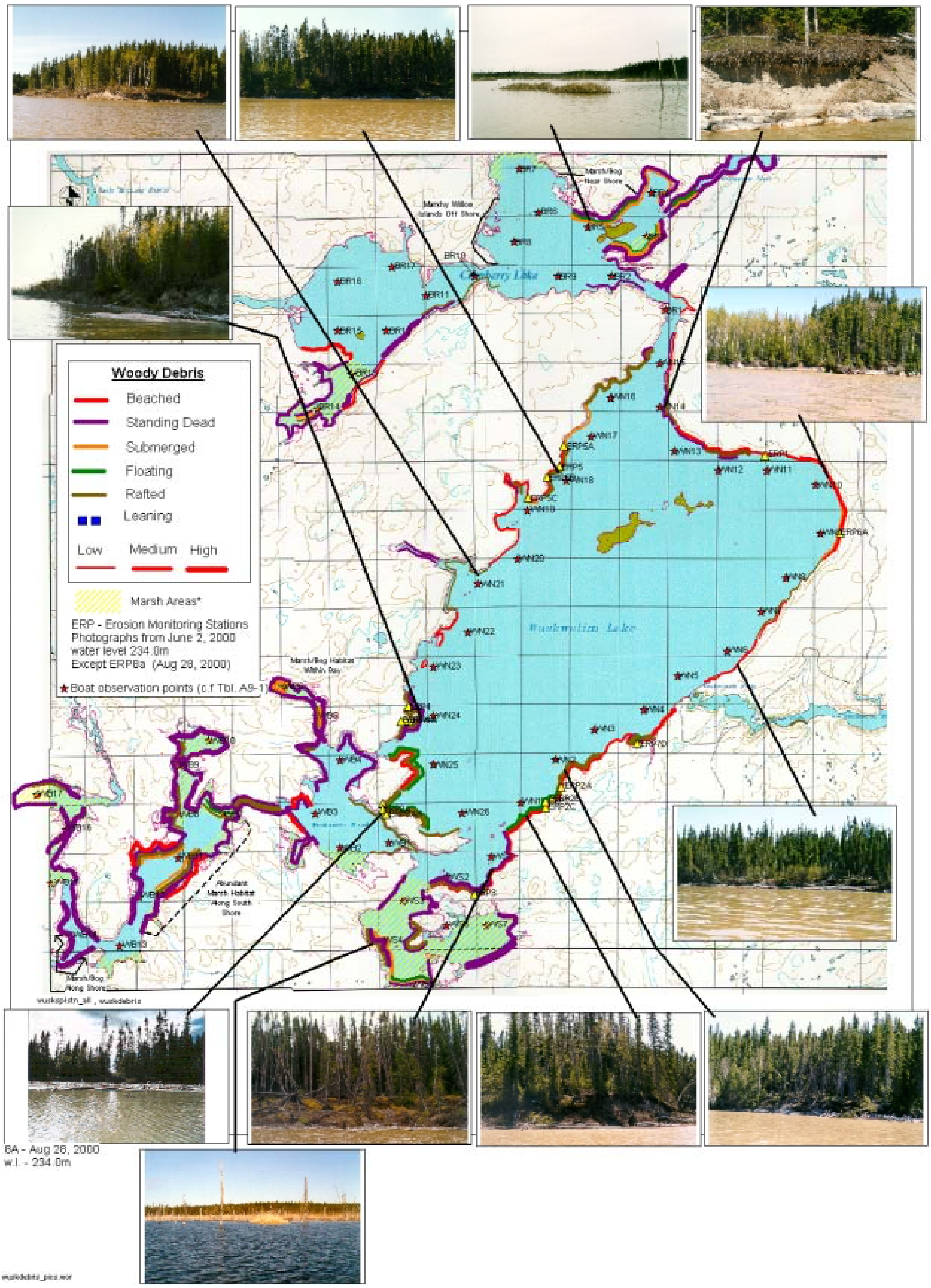


Figure 9.3-5 Wuskwatim Lake Debris Mapping

- **In Wuskwatim Brook, southern arm of Wuskwatim Lake, Cranberry Lake and Sesep Lake**:
  - the most common debris types are standing dead trees in moderate-to-high densities, along with moderately dense rafted and submerged debris; and
  - these areas have very low amounts of beached debris due to the presence of standing dead trees, which prevent the debris from being washed up on shore due to wind and wave action.

- **Between Early Morning Rapids and Cranberry Lake on the Burntwood River:**
  - very low amounts of beached debris are observed.

9.3.3.2 Debris Mapping Downstream of Wuskwatim Falls

Between Wuskwatim Falls and Thompson, waterbodies affected by the CRD are mostly associated with river habitat (i.e. Burntwood River) and two lakes, Opegano and Birch Tree lakes. A description of the surveys undertaken in this section of the CRD is described in Section 9.2. The results of boat based and helicopter-based investigations from 2001 are illustrated in Figure 9.3-6, which covers the entire study area from Early Morning Rapids to Birch Tree Lake. Figure 9.3-7 and Table A9.4-2 show the debris mapping for Opegano Lake. Summaries of these surveys are described below.

Along the Burntwood River, beached debris is located along the edges of the channel either on the banks or in shallow water depending on water-level conditions (which are flow dependent). Densities are typically low, particularly between Wuskwatim Falls and Opegano Lake and vary between moderate to heavy density between Opegano and Birch Tree lakes. In the small bays (or embayments) off the river, there are a variety of debris types including beached, floating and standing dead. Densities in these areas vary from medium to high. There is the potential that the current or ice action may pick up some of the shoreline debris and move it downstream, but given that debris is along the edge of the river, the majority of the debris will likely remain in place.

During this and other flyovers very low amounts of "floating" debris were observed in the major current area of the river.

Birch Tree Lake contains high to very high densities of beached, standing dead and submerged debris. The majority of the shorelines are low relief. Difficulties with boating through the waters and fouling of nets have been reported by several study team members, including local resources users, in 2000 and 2001. It was indicated that care had to be taken in setting nets due to the presence of submerged debris, particularly near shore. LWCNRSB (1975) indicated that prior to CRD, Birch Tree Lake was noted for its

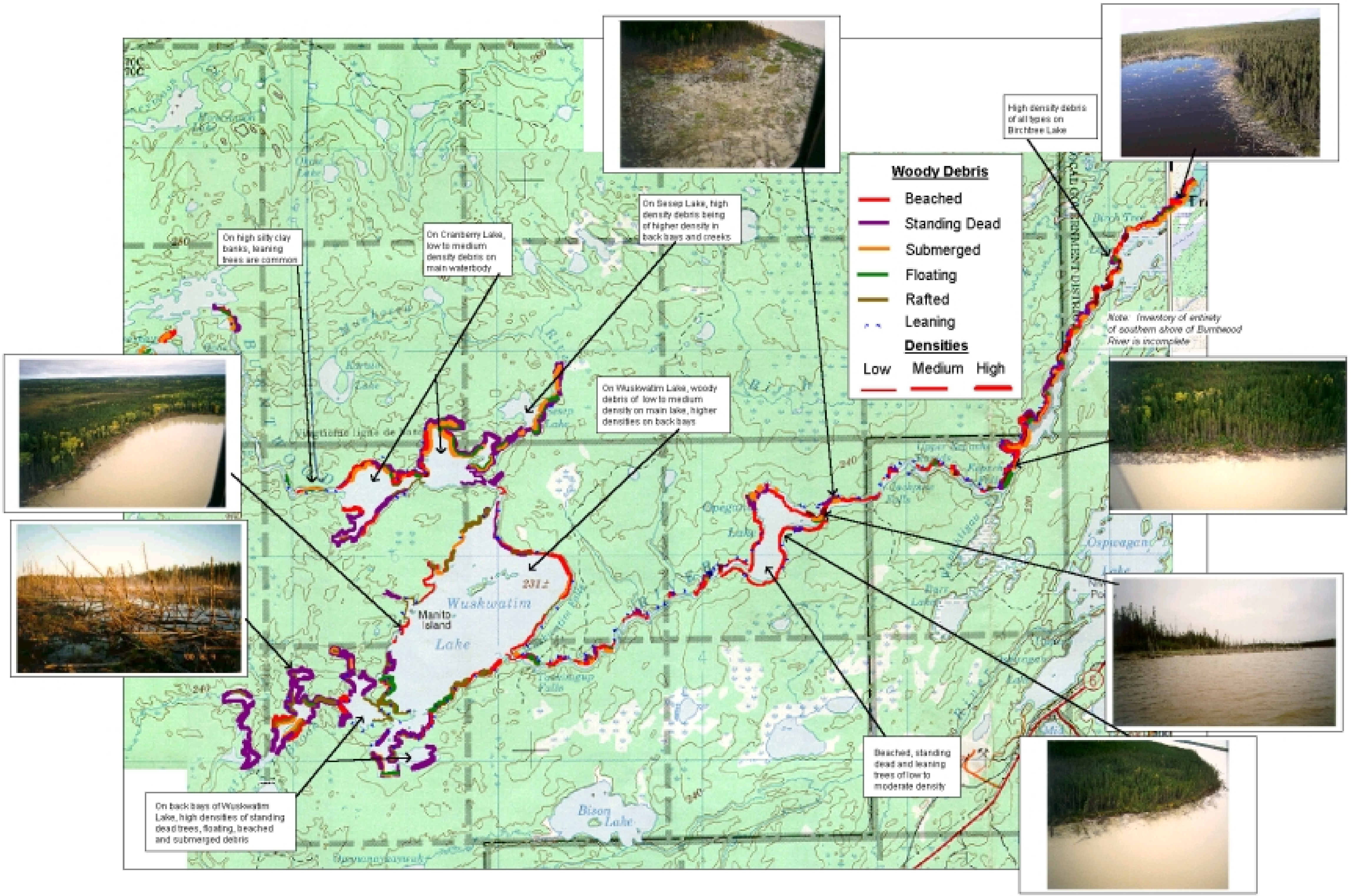
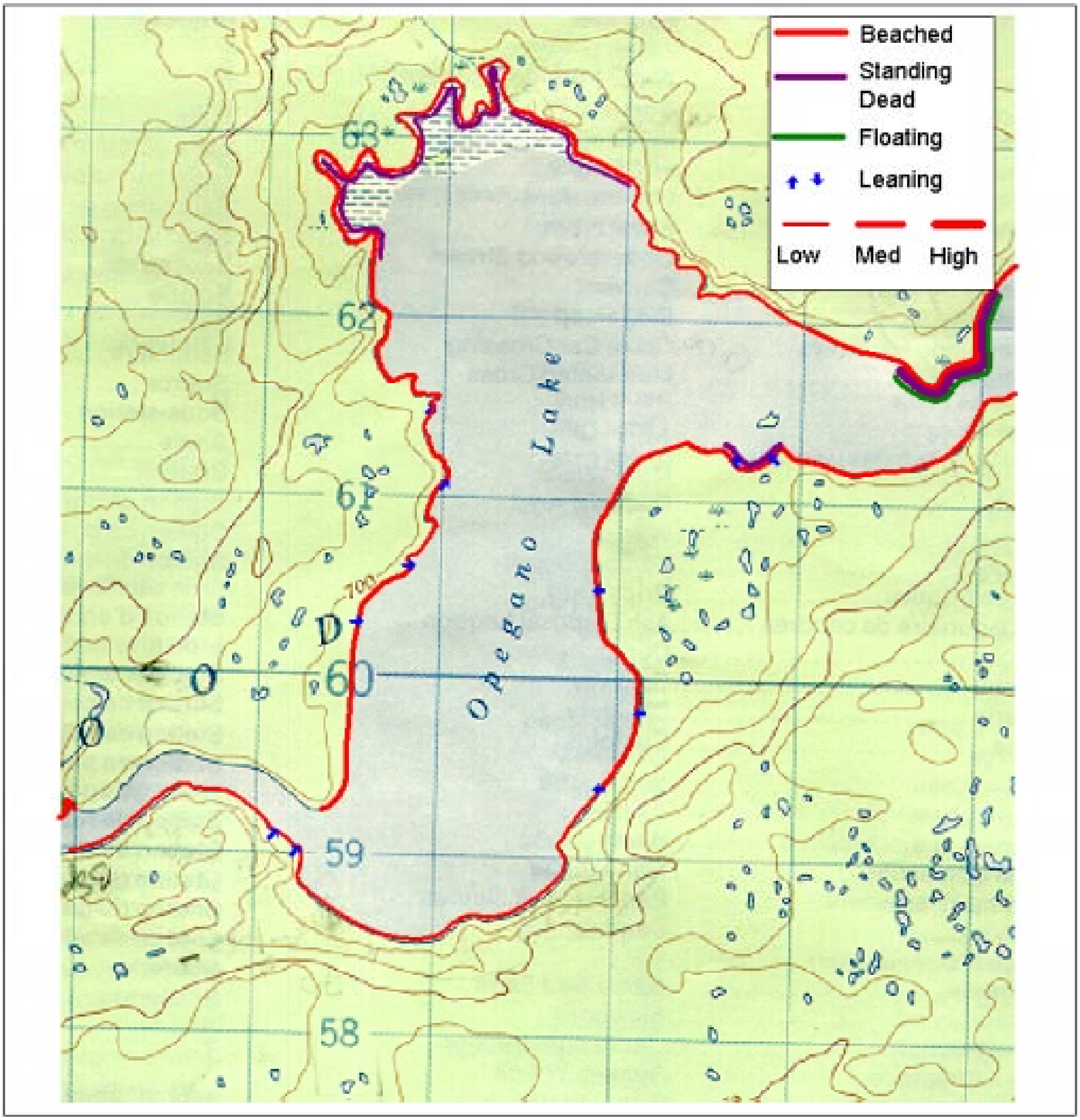


Figure 9.3-6. Wuskwatim Lake to Birch Tree Lake debris mapping.



Refer to Table A9.2-2 for boat stop data

Figure 9.3-7 Opegano Lake Debris Mapping low-relief shorelines. Therefore this lake is similar to the shallow back bays areas of Wuskwatim Lake. The lack of ice action in Birch Tree Lake due to its shallowness is the likely reason large amounts of debris remain around the edge of this lake along with the back flooding of Birch Tree Brook (UMA 1973).

Debris around Opegano Lake was primarily composed of low to moderate beached debris with scattered areas of standing, leaning and submerged trees. Study Team members noted that boating and netting on Opegano Lake was generally not as difficult as on Birch Tree Lake, although there were some locations where shore access to areas for netting were not available due to debris, e.g., northern end of Opegano Lake.

9.3.3.3 Wuskwatim Lake Floating Debris Investigations

Results of the roving boat surveys in 2001 (Section 9.2.4) on Wuskwatim Lake indicated that the majority of the observed floating debris was deadheads, with limited mobility and not freely floating logs. Boat survey results from September 26, 2001 (Figure 9.2-2) relative to the two previous trips in 2001 showed that the majority of the debris is found in relatively the same location as previous surveys indicating the lack of mobility of most of the deadheads. The low number of freely floating logs is consistent with the observations of only occasional logs during boat-based surveys and flyovers of the lake in 2000 and 2001.

The low amounts of floating debris observed on Wuskwatim Lake may have been due to the fact that boat surveys were made following extended windy periods where any floating debris would be pushed to shore by wind and wave action. It is not certain that even in calm periods that there would be significant quantities of loosely floating debris. The year 2000 boat-based debris quantification surveys, as described in Section 9.2.1 that were done during relatively calm periods on the lake and floating debris was not observed coming off from shore.

Other study consultants have also made observation of debris caught in their gill nets. The general observations were that the woody debris was mostly composed of small quantities of small sticks. It was also noted that there was very little change in woody debris collected in the nets in the past few years. From discussions with the local fishers that assisted in the field studies, in the first few years of the CRD, there was extensive fouling of nets by logs and trees. The reduction in floating debris over the years generally corresponds with Manitoba Hydro's initial post-CRD debris management experience (Section 9.3.2).

9.3.4 Wuskwatim Lake Erosion and Debris Inputs

As discussed in the Erosion section of this document (Section 6) the main part of Wuskwatim Lake is in a moderate to high wave-energy environment and portions of these shorelines are erodible; particularly the silty-clay shorelines or silty-clay shorelines with a bedrock contact below elevation 234 m. The backshore areas of Wuskwatim Lake have low gradient slopes and are also in a low wave-energy environment and therefore are not erosion sensitive (Section 6). As the shorelines in the main part of Wuskwatim Lake continue to erode they will continue to add new debris to the water over time (Sections 9.1 and 9.3.2).

With respect to shoreline development, the field data shown in Table A9.4-1 indicates that the bedrock shorelines in the main part of Wuskwatim Lake are beginning to become exposed indicating that shorelines are beginning to stabilize. A calculation of the percentage of bedrock visible at each observation stop shown in Table A9.4-1 indicates that approximately 50% of the east shore, 20% of the west shore and 0% of the south shore has exposed bedrock. These estimates are consistent with the shoreline typing that has been shown in Section 6 where 49% of the east side was either bedrock or silty/clay over bedrock (i.e., LC/BR_m and LC/BR_h Section 6.3.3.2), similarly 15% on the west shore and 0% on the south shore (Penner *pers. comm.* 2002).

As discussed in Section 2.3.2.3, the prevailing winds during the open water season (May through to October) are as follows: in May the winds are from the NE, in June they shift to E and from July through to October they are from the W. In Section 6.2.2.1, a calculation of the wave-energy environment has been made for Wuskwatim Lake. Wave energy is a calculation of wind speed from 7 compass directions and over-water fetch distance. Figure 6.3-20 (Section 6) illustrates that the east and south sides of Wuskwatim Lake are in a high wave-energy environment and the majority of the west side is in a moderate wave-energy environment. The approximate equal amount of debris on both sides of the lake is a result of moderating a high wave-energy shoreline on the east side with only 50% of the shoreline being silty clay (remainder are bedrock controlled and non-eroding), versus the west side shoreline in a moderate wave-energy environment (for the most part) with 80% of the shoreline being silty clay.

As identified in Section 9.3.3.1, the area with the most actively eroding shoreline is the southern portion of the lake, sites WN1, WN24, WN25 and WN26 (Table A9.4-1). These sites have silty-clay shorelines, no visible bedrock control, are in a high wave-energy environment and are exposed to north winds with a fetch length of 10 km. Because of the active erosion that is occurring, new trees are being continually added to the water. Figure 9.3-4 shows the presence of a combination of both rafted and floating debris of medium density in this area.

An examination of Manitoba Hydro's erosional monitoring site #8 located between WN25 and WN26 (Figure 9.3-5), shows the presence of high density rafted and floating debris. The erosion at this site with its debris is comparable to the erosion that is occurring at other sites in the absence of large amounts of debris (Section 6, Table 6.3-7).

9.3.5 Predicted Future Debris Levels with no Development

The following discussion will mainly focus on predicted debris levels in the main part of Wuskwatim Lake. Debris changes on the back bays of Wuskwatim Lake (i.e., Wuskwatim Brook, Sesep Lake, etc.) and downstream on the Burntwood River where major shoreline erosion changes are not expected to occur will only be briefly discussed. The reason for the focus on the main part of Wuskwatim Lake is because this is the area of moderate and high erosion (Section 6) and the main area of debris generation and deposition as discussed previously in Section 9.3.2.

As discussed in Section 9.3.2, in the first few years following the opening of the CRD floating debris levels were quite high. By the mid 1980's, floating debris levels had declined appreciably such that Manitoba Hydro discontinued their extensive debris program on the CRD; barges, tugs and booms were decommissioned. Now 25 years later, helicopter flyovers of the CRD indicate very low levels of freely floating debris. Even with these low levels of visible debris as noted in Section 9.3.2, there still is considerable year-to-year variation in the amount of debris caught in the Manasan boom (up to 4 times normal in a high flow year, Boe *pers. comm.* 2000). Based on these observations this represents the normal variation of floating debris in the system and it is likely that this will continue in the future.

As also discussed in Section 9.3.2, the majority of floating debris moving downstream through the CRD ultimately becomes deposited around the shorelines of the downstream lakes. As discussed in that section, there are a number of debris sources, the felled trees pre-CRD, ice removal of dead standing trees and shoreline erosion, which have all added additional debris to the shorelines of the main water bodies, such as Wuskwatim. While there are no historical shoreline debris inventories for Wuskwatim Lake, it does not appear from examination of the current debris environment that there is a large amount of accumulated debris around the main part of Wuskwatim Lake (Section 9.3.3.1).

Local fisherman, with knowledge of the CRD when it was initially commissioned, indicated that a large amount of floating debris was observed in the early years. They further indicated that there is now the presence of submerged debris at the bottom of the lake. As documented below, there is evidence elsewhere of debris becoming water logged and sinking to the bottom over time. Dewatering of the Jenpeg forebay in the spring of 2001 showed evidence of considerable amount of water logged wood on the bottom of the reservoir. In NW Ontario, up until the mid 1980's, pulp logs were commonly transported to the mills in Fort Frances and Kenora using log booms. In the Fort Frances area, it is local common knowledge that a boom full of red and white pines is now on the lake bottom after being left in the water too long (Thomas *pers. comm.* 2003). Sonar soundings in the immediate forebay of Grand Rapids GS indicate large amounts of sunken logs in the immediate forebay of the generating station. Hydro Quebec, with their Phase 1 James Bay project, estimated that, over time, over 50% of the debris generated would water log and be lost (Société d'énergie de la Baie James 1988). As stated in Section 9.3.3, no underwater studies were undertaken in this phase of debris studies. Given some of the difficulties encountered trying to quantify the visible rafted debris around the shorelines of Wuskwatim Lake, quantifying submerged debris for the entire shoreline would have been extremely difficult (Appendix A9.1). Given that there are declining rates in shoreline erosion (as discussed in Section 6), declining rates in floating debris (as discussed previously), and a portion of the existing debris is water logging and also becoming submerged, it is expected that the quantities of visible near-shore debris will also decline over time.

The photograph of Manitoba Hydro's erosion monitoring site (ERP Site 8A) shown in Figure 9.3-5, and the photographs of other shoreline debris in Figure 9.3-5, show debris that has been in the water for extended periods of time (i.e., debris has lost its bark and branches and has bleached to a whitish-grey colour). New trees that are added to the water will have their branches and root structure still intact and because of this will be relatively immobile as compared to existing debris that has already lost its branches and root ball. Accordingly, it is expected that any new woody debris will be relatively immobile along the shoreline for a period of time.

The deadheads that are currently present on the lake and on the river will likely remain in place unless there is a program to remove them to improve boater safety.

In the back bays of Wuskwatim Lake it is expected that over the next 25 years there will be a decrease in standing trees as the trees rot at the waterline and eventually fall over. These fallen trees will likely float for a while and become rafted amongst the other debris. Over time this and previously rafted debris will sink if there is sufficient depth, otherwise the debris will remain exposed.

On the Burntwood River section of the CRD system, ice action and river currents have probably moved the most easily removable debris. As noted earlier in this section, there still is variability in floating debris amounts being captured each year; the overall amount relative to the initial CRD years is quite small. While ice action under breakup conditions and river currents could continue to move some of the beached debris along the shorelines, the majority of the beached debris is in shallow waters along the edge and will likely remain in place for a long period of time (i.e., the next 25-50 years). Debris in the embayments, as discussed in Section 9.3.3.2, will reduce over time due to the same forces described above for the back bays of Wuskwatim Lake.

9.4 EFFECTS ASSESSMENT AND MITIGATION

This section will describe how the proposed Wuskwatim Generation Station is expected to change the debris situation as it exists today and how it would be expected to evolve with the Project.

9.4.1 Construction

Very modest water-level staging is expected between Wuskwatim Falls and Taskinigup Falls as a result of Project construction as discussed in Section 4.3.2. This water-level change is not expected to change the current local debris environment due to low levels of existing debris present (Section 9.3.3.2). The Project will not affect debris generation or accumulation upstream on Wuskwatim Lake or downstream of Taskinigup Falls.

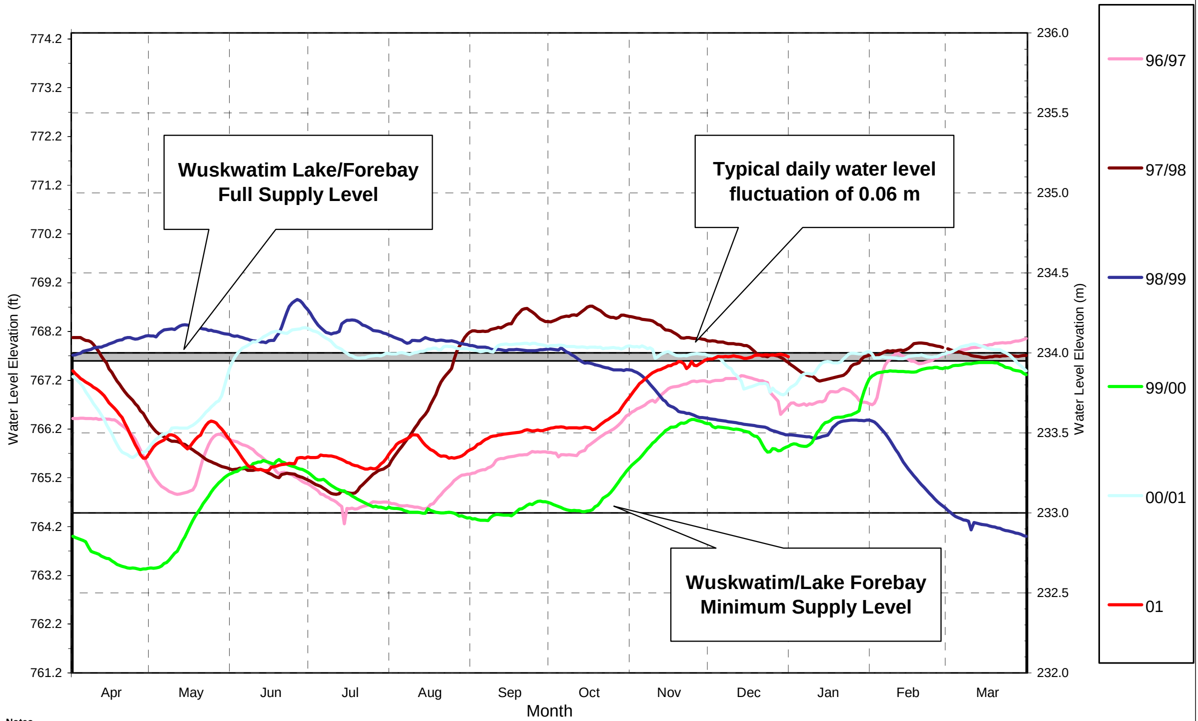
It is possible that recreational use of Wuskwatim Lake will increase during Project construction. If required, Manitoba Hydro will place a boat patrol on the lake.

During construction, the effects of woody debris on the physical environment are considered to be small, short-term, localized in nature and capable of being mitigated. The potential implications of debris on the aquatic and terrestrial environments are discussed in Volumes 5 and 6, respectively.

9.4.2 Operation

The completion of the Wuskwatim Generating Station will result in the flooding of less than ½ km^2 (about 37 ha) of land between Wuskwatim Falls and Taskinigup Falls, called the immediate forebay (Volume 3, Section 3.3). To mitigate the short-term increase in debris levels and the aesthetic issues resulting from this flooding, this area will be cleared prior to impoundment. Current plans call for clearing to be done in stages. The initial clearing would occur before the placement of the Stage I cofferdam (which will cause water levels to rise in this section of the river; Section 4.3.2) and a final clearing just before final impoundment (Volume 3, Section 4.2).

During Project operation, Wuskwatim Lake levels will be kept relatively constant at or near elevation 234 m, which is at the upper end of its historical post-CRD water regime. Historically the lake has varied between elevation 232.6 m and 234.3 m (Section 4.2.2.1). As shown in Figure 9.4-1, water levels in the past 5 years have been near or above the 234 m level (i.e., 234.2 to 234.3) for extended periods of time. Note that with the Project there will be channel excavation at the outlet of Wuskwatim Lake that will increase its flow capacity and allow for maintaining of the 234 m elevation on the forebay even under higher flow conditions.



Notes

-Source: Manitoba Hydro (Raw Data)
-Conversion: 1 foot = 0.3048 metres
-Period of Record: Apr 1996 to Dec 2001

-Water levels are referred to Canadian Geodetic Vertical Datum (CGVD), 1971 Rev. 3) above sea level.
-The historical water level elevation data is discontinuous for most years from 1977-1996. In some cases there are fewer than 20 data points for an entire year.
-Data is presented in terms of a 'water year' (Apr 1 to Mar 31) as opposed to a 'calendar year' (Jan 1 to Dec 31)

Source: Manitoba Hydro

Wuskwatim Lake Water Levels 1996 to 2001
Figure 9.4-1

Based on ongoing field studies on the lake during the summers of 2000 and 2001, it is not expected that there will be a noticeable increase in floating debris on Wuskwatim Lake over existing conditions as a result of keeping the lake at 234 m (Section 9.3.3.3). In 2000, the lake was at or just above elevation 234 m, while in 2001 the water level varied between elevation 233.3 and 233.5 m for most of the summer (Figure 9.4-1). During those two years Study Team members did not observe a noticeable change in floating debris levels on the lake.

With Wuskwatim Lake water levels being kept constant at or near 234 m with the Project, it is predicted there will be a short-term increase in the ongoing erosion of the erodible shorelines (i.e., silt clay banks and silt-clay banks overlying shallow bedrock) that is occurring on Wuskwatim Lake (Section 6.4.2). (Note that the initial erosion predicted with the Project is likely similar to the erosion that occurred on the lake in the year 2000 without the Project.) The erosion process is described in Section 6.3.1, and basically involves an undercutting of the toe of slope, a failure of the bank and a mass-wasting of the material at the base of the slope. In the mass-wasting phase, any live trees that are associated with the bank failure would be added to the water as debris. As discussed in Section 6.4.2, the majority of the erosion that is now occurring is in the main part of the lake due to the long open stretches of water. With the Project, the incremental increase in erosion would also occur in this area.

As discussed in the erosion section (Section 6.4.3.3 and shown in Table 6.4-6), Wuskwatim Lake shorelines are currently eroding at the rate of 2.9 ha/yr, with the majority of this erosion occurring in the main part of Wuskwatim Lake. With the Project, it is expected that shoreline erosion would increase to 7.8 ha/yr in the first 5 years and then decrease to about 3.7 ha/yr during the 6 to 25 year period following the Project. After 25 years, shoreline loss would be back to the same rate under existing conditions (i.e., 2.9 ha/yr).

Using the GIS-based erosion mapping (for example Figure 6.4-6), a forestry resource inventory (FRI) mapping has been overlain to calculate the number of trees that would be added to the lake over the three time periods being considered (i.e., 2009 to 2014, 2014 to 2034 and 2034 to 2109), with and without the Project (Volume 6, Table 5.2-13). This table shows the average annual stems (trees) for the three time periods being considered. For the 2009 to 2014 time period, it is estimated that approximately 5,200 trees per year would be added as a result of ongoing erosion without the Project. With the Project, it is estimated that an additional 5,600 trees per year could be added as the incremental effect of the Project Table 5.2-13. The tree count given in the Table 5.2-13 represents productive forest stands (i.e., cutting classes 3, 4 and 5). As indicated in the footnote to Table 5.2-13 cutting classes 0, 1 and 2 were not included as the stem-density data is limited and unreliable for these stand types. Inclusion of these stands would increase the total tree count. The erosion mapping that was used in the terrestrial section (Volume 6) is based on above average erosion estimates (Section 6.3.5). To convert the terrestrial estimates to be representative of average erosion rates for the whole lake requires reducing the terrestrial estimates to 65% of the original estimate. Applying this factor over the 72 km of eroding shoreline (Table 6.3-2) yields about 50 trees/km being added per year without the Project, and 104 trees/km being added per year with the Project (first 5 years).

In the following 2014 to 2034 (i.e., 6 to 25 year) time period, erosion rates decline to about 30% above existing rates on an area basis due to reduced erosion rates as shown in Figure 6.4-3 and Figure 6.4-4. Using this 30% increase over normal it is estimated that the (Class 3 and above) trees being added with the Project would be about 65 trees/km with the Project, and 50 trees/km without the Project. This is different than the estimates shown in Table 5.2-13 (Volume 6), which shows the erosion areas with and without the Project being about the same. While some of the differences can be explained from differences in the use and generation of the GPS information (Penner and Zimmer *pers. comm.* 2003) and potentially how the FRI mapping overlays on the erosion mapping, a thorough analysis has not been done to explain all discrepancies. It is felt that 65 trees/km with the Project and 50 trees/km without the Project represents a reasonable estimate of the 2014 to 2034 time frame.

While the assessment of trees being added to the lake represents a reasonable estimate of the process, dividing this by the length of eroding shoreline averages out the actual debris inputs per shoreline type. If the live tree inputs could have been applied over the two types of eroding shorelines and the two different wave-energy environments within Wuskwatim Lake then a more reasonable estimate of the likely debris input per shoreline type could be made. Given the averaging process, it is probable that the tree count per km will be underestimated in the highly erodible areas in the south and likely over-estimated for the western shorelines of the lake that are not in a high wave-energy environment.

Overall, the application of the FRI mapping to the erosion mapping provides an indication of the range of trees that could be put into the lake with and without the Project. Based on the above information it is predicted that there will likely be a short-term (5 years) increase in trees being added (as debris) in areas that are actively eroding. After 5 years, the Project-related debris would be slightly above the long-term ongoing debris input process and likely not measurable. Relative to the existing debris along the shoreline the increase in incremental debris amounts in eroding areas is considered insignificant.

No change in debris density or mobility is expected in the back bays around Wuskwatim Lake because of the low erosion potential of these shorelines and the fact that these areas are located in low wave energy environments.

During Project operation, downstream water levels will fluctuate as a result of daily plant cycling (Section 4.3.5). The largest fluctuation would occur at the Wuskwatim tailrace with water levels varying by up to 1.3 m during open water conditions depending on flow conditions (Table 4.3-1). These fluctuations will attenuate, moving downstream by the available channel and lake storage. At Opegano Lake the maximum daily lake fluctuation could be 0.4 m, but for approximately 70% of the time fluctuations would be 0.1 m or less (Figure 4.3-20). As discussed in Section 4.3.5, the maximum fluctuation in Opegano Lake is a result of a set of mid-range plant outflow settings that result in the water-level change being about 0.2 m above and below the daily average normal flow (i.e., flow without the Project). A daily water-level fluctuation ranging from 0.1 to 0.2 m is in the range of wave-induced water-level changes and therefore not seen as a change to the existing water regime and not expected to result in the mobilization of additional debris.

It is not felt that the water level changes of 1.1 m to 1.3 m in the tailrace (from a 1-unit flow change) would cause a significant amount of the shoreline debris to be mobilized for a number of reasons. The channel in this section of the river is well defined, and a water level change of 1.3 m only exposes a portion of the bank (Section 8). Two dimensional flow modeling (discussed in Section 4.2.3.3 and illustrated in Figure 4.2-19) indicates that the velocities near the shore are negligible, therefore it is expected that when the water level increases this will not cause a significant amount of debris movement. If debris did mobilize from Project operations, it would be short-term as the debris in this river section adapted to the new water regime. If debris becomes re-mobilized it will likely move downstream and redeposit in Opegano Lake, similar to previous discussed river-channel debris movement (Section 9.3.2). The effect of Project operations and unit cycling on mobilizing downstream channel debris is considered to be small, short-term and localized.

To summarize, the incremental effects of the Wuskwatim Project on existing debris include:

- no significant change to Wuskwatim Lake debris mobility over existing variability;
- no expected change to downstream debris mobility over existing variability;
- no expected change to downstream shoreline debris accumulation; and

- small, localized and short-term increase to Wuskwatim Lake shoreline debris accumulation.

With respect to the issues raised in Section 9.3.1:

- boater safety – no significant change, if required Hydro's Debris Management Program (DMP) will deal with improving boater safety on the lake;
- adverse effect on fishing – no change anticipated with the Project;
- access difficulties to and from the water – no change with the Project, existing impediments would be dealt through Hydro's DMP as required; and
- aesthetics – no discernable change changes to aesthetics relating to debris with the Project.

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9.5.1 Literature Cited

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THOMAS, JIM. Landscape architect with Hildermann Thomas Frank Cram. Telephone conversation on April 12, 2003 with Grant Mohr of Tetr*ES* Consultants Inc.

APPENDIX A9.1

GROUND-TRUTHING SURVEYS TO QUANTIFY WUSKWATIM DEBRIS DENSITIES IN 2001

A9.1 GROUND-TRUTHING SURVEYS

INTRODUCTION

This report outlines the various ground-truthing surveys that were carried out to quantify the densities of the low, medium and high beached and rafted debris fields that were visually described from the previous summer's (i.e., year 2000) debris surveys (Section 9.2). The definition of beached and rafted debris corresponds to descriptions used in the main part of this report (i.e., Section 9.3.3). Beached debris is defined as debris at or above the average water level, while rafted debris is floating debris that is interlocked next to the shoreline in this case.

This report outlines the various quantification methods tested, and summarizes the data collected from the test sites and a discussion of the applicability of the various methods.

APPROACH AND DATA COLLECTED

The 2000 boat survey and additional mapping conducted in 2001 of the debris fields located on Wuskwatim Lake provides a catalogue of the baseline status with respect to debris occurrence. Ground based field survey were conducted (September 17 to 19, 2001) to provide additional information with respect to quantifying the volume of wood present in a number of identified debris fields.

The ground-truthing surveys concentrated on quantifying beached and rafted debris fields due to the anticipated difficulties in accessing and surveying standing dead and submerged debris fields. Survey plots were selected while in the field based on representative shorelines of the various types of beached debris identified by the aerial survey. A total of nine sites were surveyed between September 17 and 19, 2001 (Figures A9.1-1 to A9.1-10).

The surveys were conducted by placing a 50-metre tape along the approximate centreline of the beached or the rafted debris field, parallel to the contour of the shoreline or the debris field. The debris abundance was characterized using three methods:

- linear method - for each one-metre segment along the tape, any debris that either touched the tape or passed directly under the tape was counted. The counted debris was divided into four size classes based on approximate diameter;

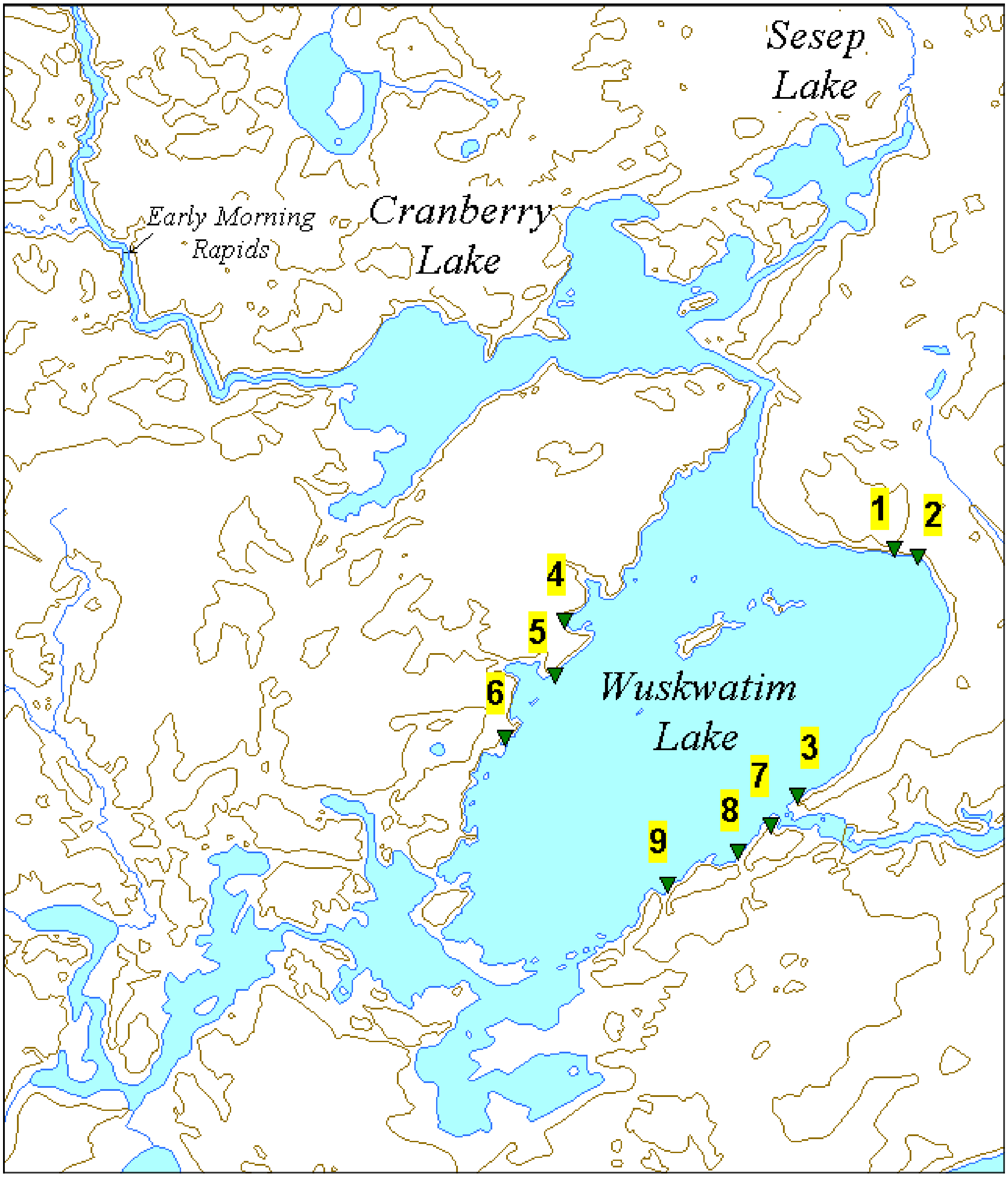


Figure A9.1-1. Wuskwatim Lake shoreline debris study sites. September 2001.

Site 1; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-2

Site 2; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-3

Site 3; September, 2001
Wuskwatim Lake Debris
Characterization

Figure A9.1-4

Site 4; September, 2001
Wuskwatim Lake Debris
Characterization

Figure A9.1-5

Site 5; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-6

Site 6; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-7

Site 7; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-8

Site 8; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-9

Site 9; September, 2001
Wuskwatim Lake Debris Characterization

Figure A9.1-10

Note: Poplar tree marked at location 55° 35.11" by 98° 28.90"

Marked Tree
Near Site #2

Figure A9.1-11

quadrat method - at 10-metre intervals along the tape, all debris contained within or passed through a one metre square area (quadrat centred on the 10 metre mark) was counted. The counted debris was divided into four size classes based on approximate diameter; and

- visual method - the width of the debris field and the volume of wood present in the 50 metre transect was visually estimated, along with a categorization of the debris from light to heavy density according to methods used in the previous year (Section 9.2) in the main report.

At six of the sites, debris was marked with colour-coded spray paint to allow possible future tracking with respect to debris movement in the area. An popular tree trunk (Figure A9.1-11) at Site #2 was also marked with orange and blue paint so that the mark would be visible from the water (marking was about two metres off the ground) and the distance from the lakeside of the tree trunk to the top of bank (9.27 metres) and water edge (16.32 metres) measured.

ANALYSIS OF DEBRIS QUANTIFICATION METHODS

Table A9.1-1 summarized the results of the field survey with respect to estimated or calculated debris volumes at the study sites and compared to the debris density ranking system used for the surveys, as follows:

- The visual estimate for low density debris of 0.1 m^3 per m of shoreline (Table A9.1-1) corresponded to the calculated volumes using the linear transect survey method, however the debris volumes present calculated using the quadrat methodogy generally estimated debris volumes at three to four times the visually estimated level.

- The visual estimates of the medium density debris varied from 0.3 to 1 m^3 per m of shoreline (Table A9.1-1). Both transect and quadrat methods corresponded poorly to the visual estimates. In particular, Site 8 (low-medium density) and Site 1 (medium-high density) surveys yielded similar debris volume estimates. The quadrat methods also yielded volume estimates which were generally four to five times the transect method results.

- The quadrat method, at high-density debris fields, yielded volume estimates approximately three times higher than the transect method, although the transect method and the visual method results were comparable.

Overall, the debris survey found that low-density beach and rafted debris fields contain less than 0.5 m^3 of debris per metre of shoreline (the visual and transect methods suggested debris densities of about 0.1 m^3 per metre of shoreline). The survey results demonstrated that medium class debris fields contained between 0.2 and 4.9 m^3 per metre of shoreline, for an overall average of about 1.5 m^3 per metre of shoreline. High-density debris fields consistently contained two or more m^3 per metre of shoreline.

Based on the above survey results, the estimated debris present in the various debris classes observed during the survey was assumed to be within the following estimated density levels;

- low density debris fields at 0.1 m^3 per metre of shoreline;
- medium density debris fields at 1 m^3 per metre of shoreline; and
- high-density debris fields at over 2 m^3 per metre of shoreline.

The above debris constants were back-tested against debris clearing programs on the Jenpeg Forebay in 2000. In that year, all the debris piles were counted and estimates made of the volume of wood collected along 30 km of shoreline that was classified as heavy density. The Jenpeg calculation was made to estimate biomass volumes. A comparison of the Wuskwatim classification of “heavy debris” versus the Jenpeg classification found that the Wuskwatim estimate of volume was approximately 20% higher than the actual measured volume of the cleared debris piles. Given the considerable variability in the observed medium and high-density debris fields, a 20 % variance is acceptable for the purposes of debris management planning. Site-specific assessments may still be required for large high-density debris fields and for standing dead and submerged debris fields.

RECOMMENDATIONS

The methods employed in this survey illustrated the difficulties, which are encountered when attempting to estimate shoreline debris volumes. The transect and the quadrat methods used were limited by the fact that debris is not randomly distributed across the shoreline, but is relatively uniformly stacked with the logs running parallel to the shoreline. To attempt to accommodate this limitation, future ground-truthing surveys could evaluate the effectiveness of using short two metre transects applied perpendicular too and at regular intervals along the primary transect as a means of quantifying the stacked debris parallel to the shoreline.

While the overall debris densities on Wuskwatim Lake were generally low to medium, two observed areas of high-density debris fields should be evaluated and considered for possible remedial action:

- Site 2 contained a large rafted debris field which may have been blocking aquatic and terrestrial access to a small stream mouth in the area; and
- Site 9 contained a high density of beached debris and some standing dead covering up a small marshland found along a sandy beach. The site may have value, either in terms of the potentially rehabilitated marshland or as a recreational area.

For the purposes of debris management planning, the stated debris densities section should provide debris volume estimates for beached and rafted debris with sufficient accuracy for use in debris management planning.

TABLE A9.1-1

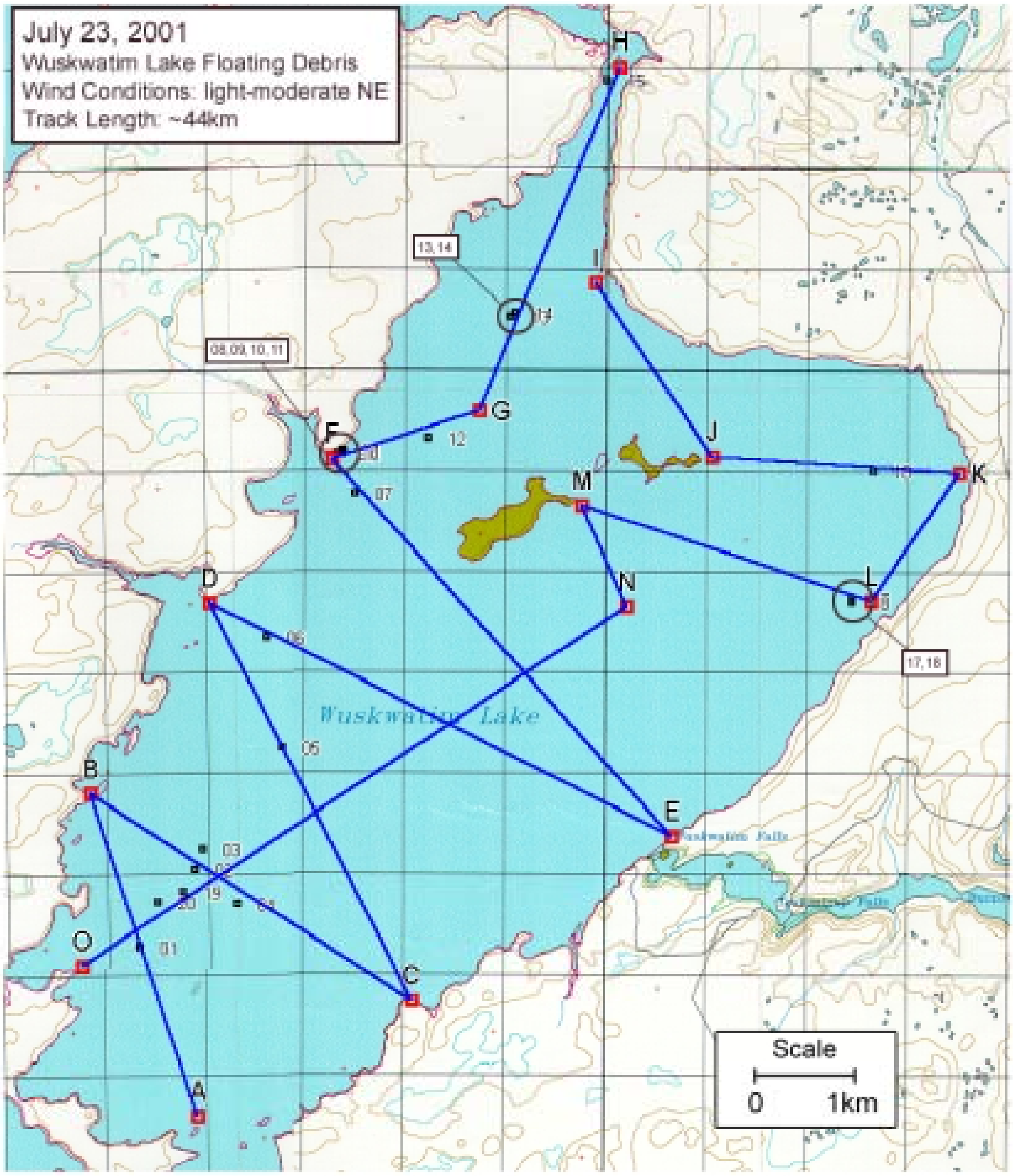
SHORELINE DEBRIS SUMMARY FOR WUSKWATIM LAKE

Site Number	Type	Linear Method[1]				Quadrat Method[2]				Visual Method[3]	
		Small (<1 cm dia)	Medium (<10 cm dia)	Large (<20 cm dia)	Very large (>20 cm dia)	Small (<1 cm dia)	Medium (<10 cm dia)	Large (<20 cm dia)	Very large (>20 cm dia)	Debris Density	Debris volume (m^3) per 50 m
1	Beached	34	61	38	81	13	15	4	39	medium high	50
2	Rafted	15	64	129	102	1	22	18	27	high	100
3	Beached	142	184	130	95	25	64	22	25	medium	30
4	Rafted	18	60	53	51	1	10	28	15	low medium	20
5	Beached	15	6	2	29	13	1	2	7	low	5 to 10
6	Beached	26	15	6	31	0	0	0	6	low	5
7	Beached	7	3	9	23	4	3	9	7	low	3 to 5
8	Beached	2	21	48	31	2	8	21	13	low medium	15
9	Beached	2	96	196	98	3	38	55	23	high	100’s

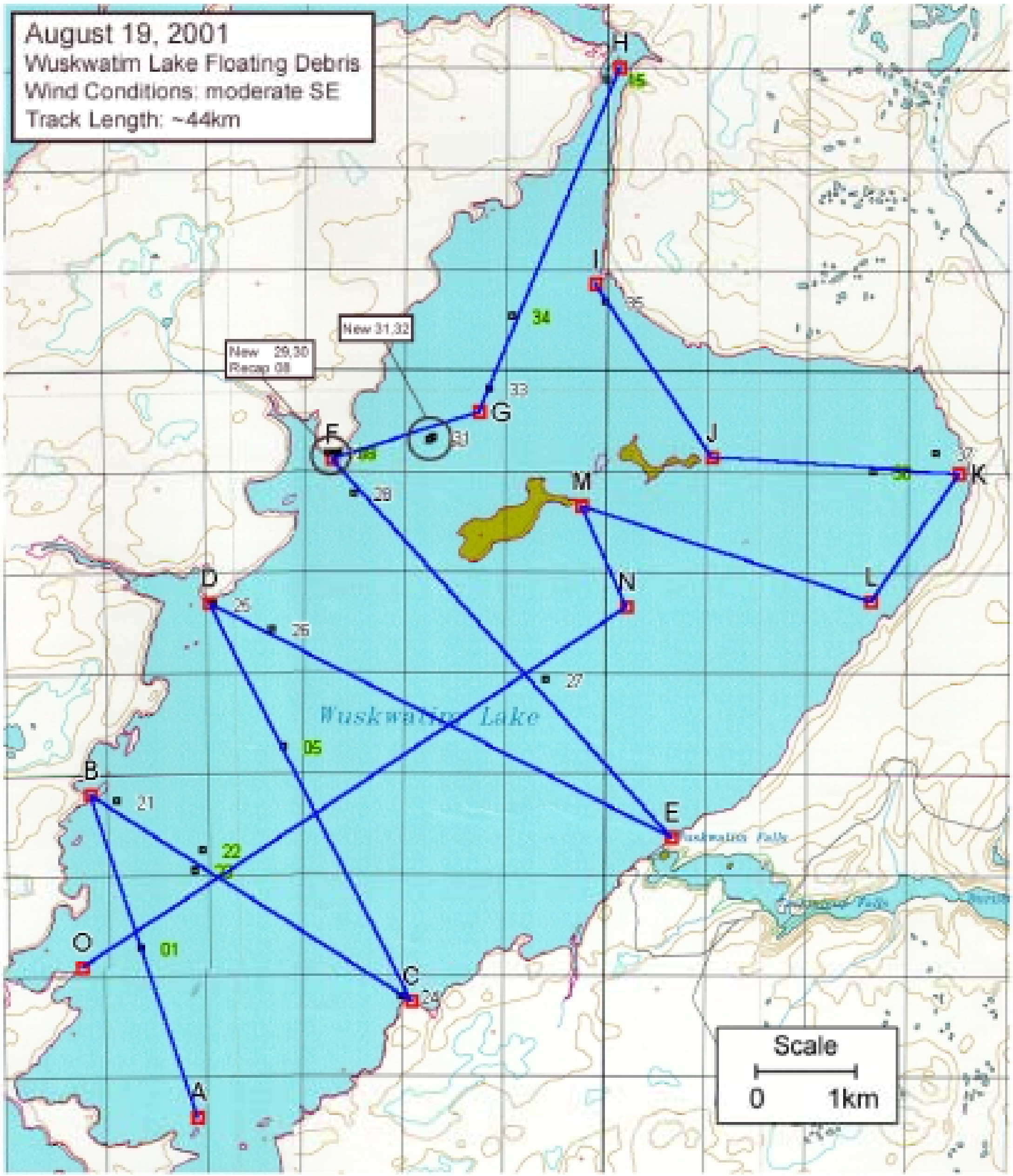
1) Debris Counts on or under transect (# per 50 m).
2) Debris Counts (total # per m^2)
3) Visual Method

APPENDIX A9.2

BOAT ROUTE DEBRIS SURVEYS

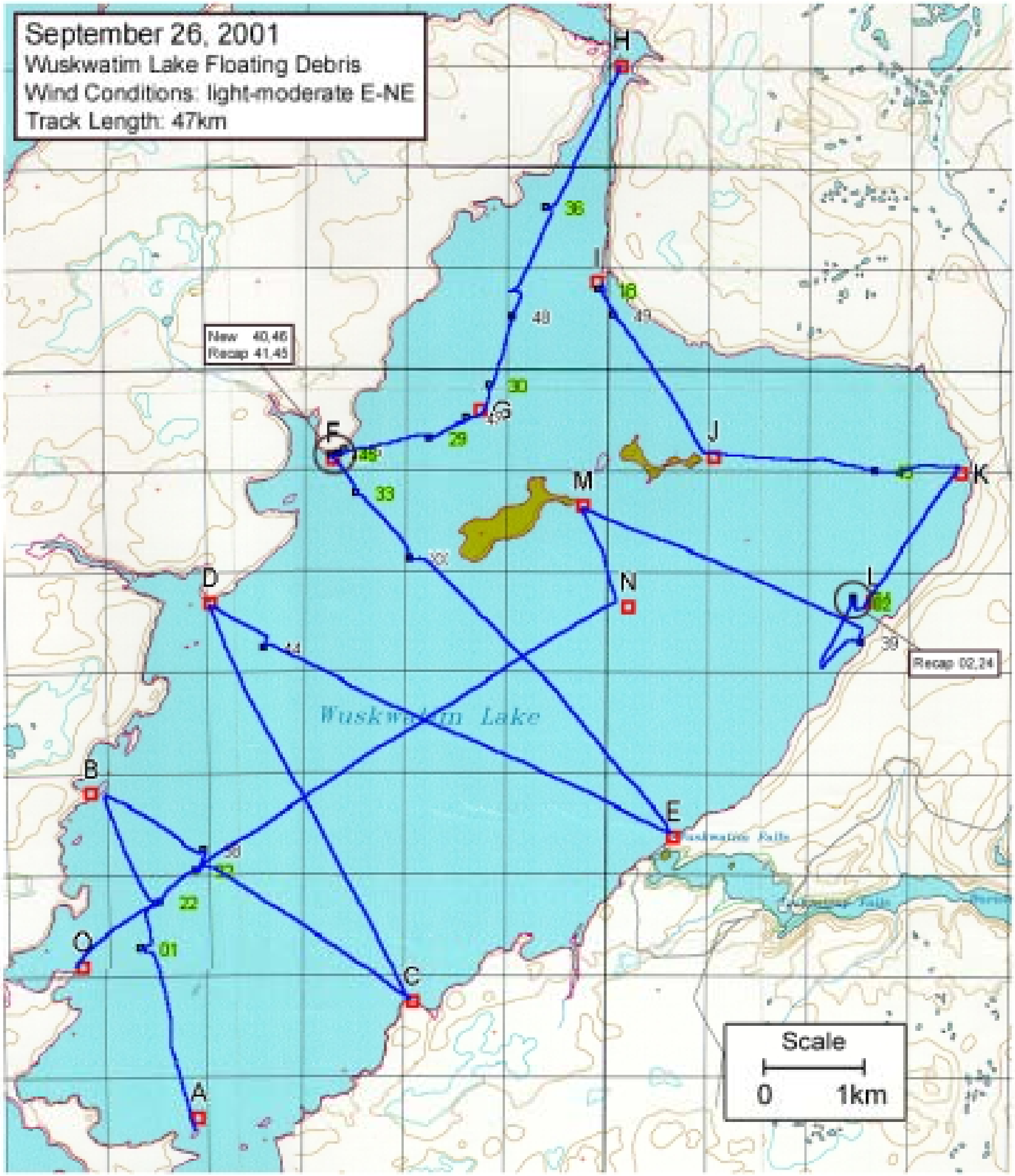


July 2001 Boat Survey
Route and Debris Positions
Figure A9.2-1



August 2001 Boat Survey Route and Debris Positions

Figure A9.2-2

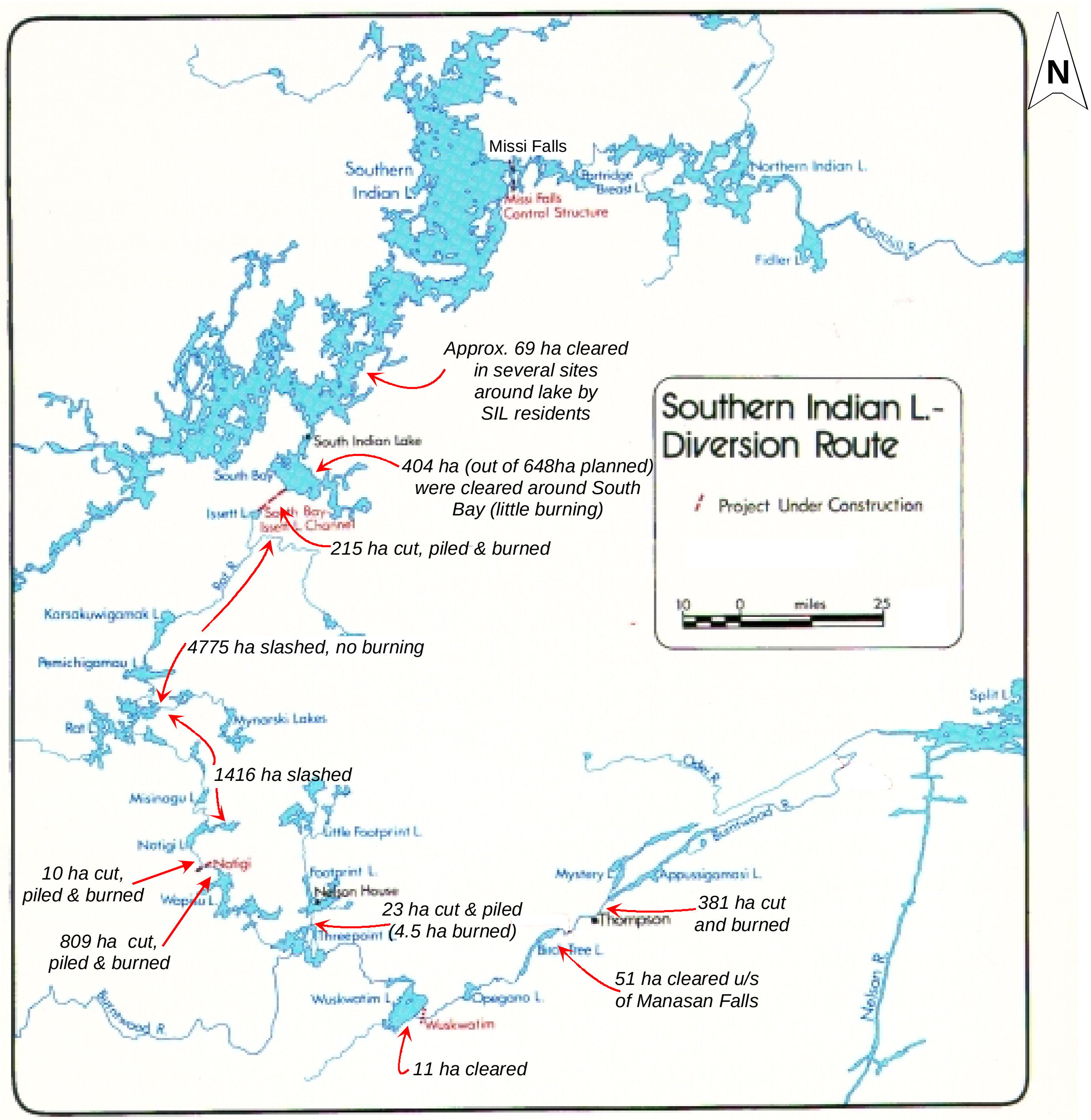


September 2001 Boat Survey Route and Debris Positions

Figure A9.2-3

APPENDIX A9.3

MISCELLANEOUS MAPS & PHOTOGRAPHS



Source: Manitoba Hydro files

Figure A9.3-1
Overall Clearing Along CRD
Prior to Impoundement

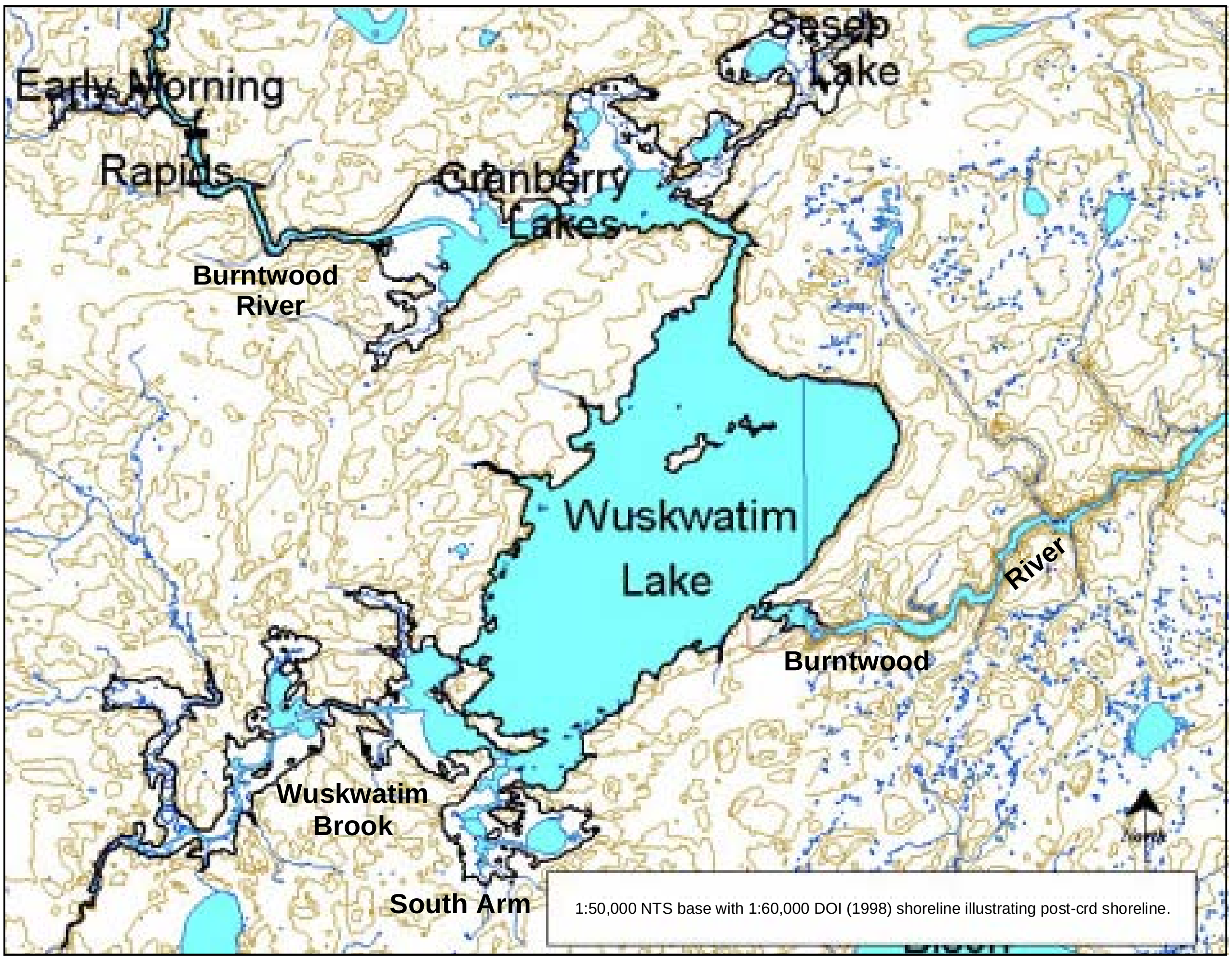


Figure A9.3-2
Aerial extent of lakes in the
Wuskwatim Area (Pre and Post CRD)

Photo taken July 1, 2002
Photo represents typical debris collection in an average year

Figure A9.3-3
Photo of Debris Caught in Manasan Ice Boom
Upstream of Thompson in July 2002

APPENDIX A9.4

DEBRIS SURVEY TABLES FOR WUSKWATIM AND OPEGANO LAKE

TABLE A9.4-1

DESCRIPTION OF DEBRIS AND SHORELINE HABITAT ALONG WUSKWATIM LAKE IN JUNE 2000

Locale*	UTM Co-ordinates		Date (2000)	Debris: Debris Type	Debris: Debris Density	Shoreline: Substrate Type	Shoreline: % Substrate Type	Shoreline: Bank Height	Shoreline: Slope°	Shoreline: Aspect	Dominant Plant Community	Comments
WN1	6153000N	527000E	June 2	b	h	clay**	100%	h	60-90	W	BS (95% of tree species)-(TA-JP)/BS-willow-alder-(WS) with 30-50% understory cover/lichen-moss	High clay bank will be actively eroding but somewhat protected by beached debris. Note: rafted debris is along shoreline, but could become mobile.
				l	m			h	60-90 to W			
				f	m			h	60-90 to W			
WN2	6153900N	527700E	June 2	r	l/m	clay	40%		70-90		Shore= 10% young spruce/fir + TA. Bank is BS (70%)-BF (10%)- poplar.	Almost down to bedrock; anticipate erosion will continue for at least 10-20 years. Leaning trees at points, with high risk leaning falling in on clay bank area.
				b	l/m	bedrock	60%					
				l	m							
WN3	6154500N	528500E	June 2	b	l	clay	50%	h	70-90	E	Diverse mixed wood. Bank edge is WS (60%)-poplar (20%)-BF (10%)-BS(10%): "young trees" <3m ht. Mature BS(80%)-TA more than 10m from shore	Low risk erosion area overall except in 100 m strech to N where clay bank > 3m & terrraced with 90% bank. Occassional "spiders" (tree root masses) present.
				l	vl	bedrock	50%	l				

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			Date (2000)	Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope^{o}	Aspect		
WN4	6154900N	529500E	June 2	b	m	clay	20%	m	60-90	NE	A) Shore: 10% young spruce/fir + TA. Bank: 70% BS-BF (10)-poplar. Shore edge: JP (70%)-BS (20%)-TA (10%)- BF (2%)- WB (2%)	
				l	l	bedrock	80%					
				r	vh						B) Inland= 90% BS	Low area may be affected by rising water, debris trapped. WS -poplar lining bay.
				b	l	clay	95%	h	45-90		C) 130^{o} to south - BS (90%) closed	BS forest on clay bank to SW. Bay with abundant debris. Beached debris is 220^{o} to SW, with little/none to W at point.
				sub	l/m	bedrock	5%					
				sd	l/m							
				f/r	h							
WN5	6155600N	530200E	June 2	b	vl	clay	90%	h	60-90		A) SW of Falls: BS (80%)-TA (10-20%) in small stands up to the edge; B) North of Falls: BF (90%)-WS (10%)-WB (2%) with 50% crown cover/fir with dense cover/lichen	Wuskwatim falls: directly S is clay bank that extends for >300m. "Island" in the middle has bedrock 1 m high.
						bedrock	10%					
WN6	6156100N	531200E	June 2	b	vl/l	bedrock	80%	vl	45		BS (95%) closed to shore with some willow edge and occasional young poplar, BF (5%)	Looking E: Very little to no erosion potential. Have seen only occasional logs floating on lake & few deadheads (submerged).
				l	l	clay	20%		45-90			

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			Date (2000)	Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WN7	6156900N	531900E	June 2	b/r	vl	bedrock	100%	h	90		<10m shore: BF (60%)- WS (20%)- TA (5%)- BS (5%)- WB (1%)-BP (5%)-JP (10%)	Debris rafted to shore.
				l	vl							
WN8	6157600N	532400E	June 2	r	vl	bedrock	80%		60-90		Shore: alder along the rocks. Within 20 m shore: WS (70%)-TA (15%)- BS (10%)-w. birch (5%).	Debris rafted on rocks.
				l	few	clay	20%		60-90			
WN9	6158500N	533100E	June 2	sub	vl	clay	60%		60-90		A) Shore edge: alder/willow along slope with young poplar & WB along edge. B) Bank: Closed & mature WS (70%)-JP (15%)-BS (10%)-TA (5%).	Low flooding effect on clay bank visible - some erosion.
				b	m	bedrock	40%		60-90			
				l	vl							
WN10	6159500N	533000E	June 2	b	m	bedrock	50%	l/m	90		TA (50%)-BF (20%)-WS (25%)-JP (5%)	Low-moderate risk of erosion in clay areas. Bays are slowly being formed, but the shore is close to bedrock in clay areas, ie., bedrock becoming exposed.
						clay	50%		45-90			

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris: Debris Type	Debris: Debris Density	Shoreline: Substrate Type	Shoreline: % Substrate Type	Shoreline: Bank Height	Shoreline: Slope°	Shoreline: Aspect	Dominant Plant Community	Comments
WN11	6159800N	532000E	June 2	b	l/m	bedrock	100%	m	45-50		WS (50%)- BP (45%)	100% bedrock up to 1-2 ft over-lain by humus/clay. Raised water levels could come over rocks and assist in undercutting soil so more trees fall in. Bedrock may not be far back.
				l	l							
WN12	6159800N	531000E	June 2	b/r	m	clay	95%		80-90	S	WS (50%)-TA (40%)-BP (2)-WB (2) with 50%crown cover	
				sd	vl	bedrock	5%					
WN13	6160200N	530100E	June 2	b	l-m	clay-silt	80%	h		S	WS (85%)-TA (10%)	Two kingfisher holes in bank. 9 standing dead stumps are in a 20 X 30 m section.
				sd	l	bedrock	20%	l				
WN14	6161100N	529800E	June 2	r	l	clay	50%	h		W	WS (85%) -TA (5%)-JP (2%)-BS (5%)	
				sd	l	bedrock	50%	h				
				l	vl							
WN15	6162000N	529800E	June 2	b	vl	bedrock	90%	h		E & W & SW	A) To East - 1. shore edge: alder-willow. 2. Bank: WS (90%)-BS (5%)-TA (5%) with 50% cover; B) To West 1. shore edge: alder-willow-WS; 2. Bank: WS (90%)-TA (30%)-JP (30%)-BF (10%)	Cranberry Lake Directly North. Creek with standing dead, looking W. Looking N: bedrock is exposed for about 90% of reach.
				sd	vl	clay	10%	h				
				l	vl			h				
WN16	6161300N	528800E	June 2	r	m	clay	50%	vh		E	WS (40%)- BF (10%), BS (20%)-TA (30%)-JP (5%)	Looking NNW: Clay banks very high, very erodable.
				l	vl	bedrock	50%	vh		E		
				l	vl							

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris: Debris Type	Debris: Debris Density	Shoreline: Substrate Type	Shoreline: % Substrate Type	Shoreline: Bank Height	Shoreline: Slope°	Shoreline: Aspect	Dominant Plant Community	Comments
WN17	6160500N	528400E	June 2	sub	l	clay	100%	h	45-50	E & NE	A) Slope= WS (60%)-BP (20%)-TA (10%). B) High bank= 100% BS	Debris: occasional dead heads.
Gull Island	6159600N	528750E	June 2	b	vl						WS/willow	Gull Island (6160000N 529000E): WS/willow has been flooded before acording to Ron (colony is about 2m above water level)
WN18	6159600N	527900E	June 2	r/b	l/m	clay	60%	h		E	BS (80%)-TA (15%)-BF (5%)	
						bedrock	40%			E		
WN20	6158000N	526900E	June 2	b	vl	clay-silt	90%	l	90	E	70% WS-JP (15%)- TA (15%)/red osier dogwood-birch-BF/lichen-grass	Bedrock overlain by clay/sand.
						bedrock	10%					
WN21	6157500N	526100E	June 2	r	vl	clay	100%	h	60-90	S	A) Shore edge has poplar-birch; B) Bank: BS (80%)- poplar (TA) 10%- birch (2)	
				l	m							
WN22	6156500N	525900E	June 2	r/b	l	clay	50%	h	90	E	JP (50%)-WS (10%)-WB (10%)	Island of low-med bedrock overlain by clay. Clay banks being eroded on S side (high clay).
				l	vl	bedrock	50%					
WN23	6155800N	525200E	June 2			clay	80%	m-h				Hydro "structure" - meter station. Island very susceptible to erosion on ends- has bedrock in middle. North and south ends may slump off when water rises, i.e., is suseptable to erosion from wind action.
						bedrock	20%	l				

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WN24	6154800N	525200E	June 2	l		clay	80%	h		NE	WS (60%)-JP (20%)-TA (20%)	Bank susceptible to erosion. Inside bay- high sandy clay banks at 90°. Stumps and rafted debris along shore.
				sd	m	bedrock	20%	l				
				r	m							
WN25	6153800N	525200E	June 2	l	h	clay	100%	h		E	BS (90%)-TA (10%)	Looking south down the shore: High clay bank actively eroding within 200 m from the point. Leaning trees are falling into water.
				f	l/m							
				r	l/m							
				b	l/m							
WN26	6152800N	525800E	June 2	f	m/h	clay	95%	h	45-60	NE	A) Mainline - BS (60%)-TA (40%)/willow-alder edge; B) Island - JP-poplar	JP-poplar Island has high clay bank and may be more quickly eroded if water rises. Island is 100 X 30 m in size. Banks terraced and about 3m high. Very actively eroding shore with big trees falling in - high risk area for more trees falling in with raised water levels.
				r	m/h		5%	l				
WS1	6151900N	526400E	June 3	l	l/m	clay	100%	h	45-60	NW	100% BS	Standing dead are stumps - stumps in creek.
				b	vl							
				sd	m							

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			**Date (2000)**	**Debris Type**	**Debris Density**	**Substrate Type**	**% Substrate Type**	**Bank Height**	**Slope°**	**Aspect**		
WS2	6151500N	525500E	June 3	b	m	clay	10%	h	60-90	N	BS (80%)- JP (10%)-TA (10%)	Floating bog to the south of here. Eroding area here. Debris mod-dense standing dead near tip of land to south. Mod/dense standing dead with rafted debris 200 m from shore. Lots of standing dead & rafted debris off shore between WS2 & WS3. 60-90° slope where bank is high.
				r	h/vh	clay	30%	m				
				sd	m/h	clay	60%	l	60-90 where high			
WS3	6151000N	524600E	June 3	sd	m	clay / organic	100%	vl/l		NW & SE	BS (100%) within 100-200 m of shore with poplar in the distance. Bay with 50% cattail marsh broken up in small (5 X 2m) raised patches.	Shore low (<1ft) along edges. Floating bog; bog has dominantly leatherleaf & cattail edge- would be duck nesting habitat

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WS4	6150200N	524200E	June 3	r	m/h	clay / organic	100%	low		NE & SW	BS (95%)-JP (<5%)-TA (<5%)	Debris with low standing dead stumps. Shore - marshy/organic (50%). **Note: leave standing dead (has avian value)**. High water will affect this marsh- will cut it back. Area has good duck nesting area. Note: came in and anchored for an hour & recorded all wildlife seen & heard. 2m high beaver lodge. 50% cattail marsh, very healthy with occasional floating bogs. Cattail marsh 2 ft deep with hard substrate here.
				sub	m							
				sd	m/h			low				
WS5	6149300N	524800E	June 3	sd	l/m	organic	100%	vl/l		N	Cattail border. Young spruce-JP	Looking S. - lots of standing dead.
WS6	6150000N	525500E	June 3			organic		l		N & S	BS (50%)-TA (50%) directly south of stop; BS (90%)-TA (5%) to the SE (along WST1), and BS (80%)-TA (20%) about 300m to SE	Marshes anchored here.
WS7	6150500N	526300E	June 3							W	Lots of floating cattail (100%) marshes. BS (90%)-TA (10%) to E & BS (50%)-TA (50%) further E.	Transect WST2 was conducted near 0526193 6150681N

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			Date (2000)	Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WB1	6152200N	524300E	June 3	r	vl	clay		m/h		S	BS (95%)-JP (5%)-TA (5%)	Near camp. Erodable if winds from right direction.
WB2	6152100N	523300E	June 3	l	m	clay		m	90	NW	From 140° to 230° is a spruce-TA mixedwood that extends for 1km or more with cattail margin (5m wide). Marsh not as developed as other side since exposed & not in sheltered bay. Lots of stands of cattail have drifted in this area.	En route to WB2, on the south side, are clay undercut banks about 1-2m high. High risk to being undercut (possibly lower risk if water levels high & constant?). Points to S & E appear to have eroded away since CRD (by as much as 200m or more). Low lying organic soil (0 m) that appears to rise about 10m or more back from shore. Dense standing dead off shore extending around the bay. Lots of cattail marshes floated in (about 20% cover out here & >50% along shore).
WB3	6152800N	522800E	June 3	sd	h/vh					E	BS (95%)-TA (5%) marshy edge 1-2 m	Low area along shore & throughout to south. Dense to very dense SD along shore for about 5m or more.
				b	m							
				l	vl							
WB4	6153900N	523300E	June 3	sd	m	clay		m/h		E & W	BS (100%) with TA in isolated stands in bay - approx. 100 m inland	Standing dead moderate around shore. Debris: SD 100% moderate along bay shore to north. Bank height is 50% m & 50% h.
				sd	m	clay		m		S		Bay to North: Bay is to 0 - 60° N, low risk but land rises abruptly.

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WB5	6154800N	522800E	June 3	sd	h	clay	100%	m	30-45	E & W	A) To SW: BS (100%) shore edge, with BS (80%)-TA (20%) upland (Pict# 18); B) To NE: BS (100%) shore edge, with BS (70%)-TA (20%)-JP(8%)-WhSp (2%) upland (Pict# 17)	In channel to east & west, land rises steeply 30-45°. Dense SD extending 5m out from BS shore. Organic low shore with occasional isolated marsh of cattail.
				r	l							
				sub	l/m							
WB6	6155400N	522100E	June 3	sd	m/h	organic					A) Several floating and anchored cattail marshes (3x2m to 10x3m in size); B) low BS (100%) shore for 10-20m; C) Upland of BS (60%)-TA (40%)-(LA); D) Willow/sedge creek with BS-LA	Organic shore with marsh. Low BS shore; to N is cattail marsh & willow/sedge creek
				r	m							
WB7	6152800N	520900E	June 3	sd	m/h	organic		l	20-45		A) Large floating cattail marsh (100x5m in size); B) marsh edge for 2m; C) inland is BS (90%)-TA (10%)	En route through the channel. Low organic shore with thin marshy edge.
				sub	m							
				f/r	m/h							

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			Date (2000)	Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
WB8	6152800N	520000E	June 3	sd	h/vh	organic	100%	l	30-45	E & W	To West: A) Floating cattail marshes (at least 2, 10x2m in size); B) 1-2m marsh edge C) BS (100%) and low along shore to SW; D) BS (60%)-TA (20%)-JP (10%) to W along shore; E) BS (70%)-TA (30%) on upland. To East: BS (80%)-TA (15%)-JP (5%)	Shoreline to W and peninsula to east. To the SW is cattail marsh, BS shore, and BS-TA upland
				l	l							
				r	l							
WB9	6153800N	520000E	June 3	sd	m	clay / organic	100%			E & W	Shore to West: A) 2m marsh edge B) willow thicket in 1 stand; C) to SW; D) BS (80%)-TA (10%)-JP (5%)-LA (5%). To East: low BS (100%) along shore	To the E is 2m of SD along BS forest edge to E. To the W is SD, willow thicket and BS-TA-JP-LA forest
				sd	h						Island with BS (100%)	SD in a 1m band around island
WB10	6154300N	520600E	June 3	sd	d				45-50	S, N & W	A) Several (29) floating cattail marshes (mean=30x3m in size, with largest one 50x10m in size); B) WS (50%)-TA (50%)	To the E is a large floating cattail bog.
WB11	6151900N	520000E	June 3	sd	m	organic				NW	A) Large marsh to S; B) Shore of 1m of grass-marsh margin with 3m standing dead; C) TA (40%)-WS (30%)-JP (20%)-BS (10%) on slope.	Looking E to WS-JP-TA-BS shore. Slope is very low at shore, rising as move inland.
				b/r	m							
				sub	l							

TABLE A9.4-1 (cont'd)

	UTM Co-ordinates			Debris		Shoreline					Dominant Plant Community	Comments
Locale*			**Date (2000)**	**Debris Type**	**Debris Density**	**Substrate Type**	**% Substrate Type**	**Bank Height**	**Slope°**	**Aspect**		
WB12	6151100N	519200E	June 3	sd	m	clay / organic				N & S	To South: A) Numerous (>5) small marshy bogs (about 5x2m in size) with at least 3 very large floating bogs; B) 5m marsh edge with standing dead; C) WS (60%)-TA (30%)-JP (5%)-BS (5%). To North: WS (60%)-TA (30%)-JP (10%)	Shore rises quickly to the east and less quickly to west.
WB13	6150100N	518800E	June 3							N	Floating bog in "bay" to south, with shore of BS (60%)-TA (30%) mixedwood in small stands and dense bog birch-willow (<2m tall). To north: JP (50%)-WS (30%)-TA (10%) along shore edge	
WB14	6150300N	517800E	June 3	sd	m	clay		m/h		SW & NE	To South: BS (70%)-TA (20%) with a marsh edge. To North: TA (80%)-WS (20%)	
WB15	6151400N	517400E	June 3	sd	m/h			h	60	E & W	To South: A) Numerous (>3) medium-large marshy bogs; B) Spruce (60%)-TA (30%); To North: BS (85%)-TA (5%)-JP (5%)-LA (5%). To East: TA (90%)-WS-BS. To North: WS (60%)-TA (30%)-JP (10%)	Floating bog to west. Shore is low-medium slope at lake edge and rises sharply to 60°.
WB16	6152500N	517700E	June 3	sd	h	clay	100%	l		E & W	Marsh edge (1m) with shore of BS (60%)-TA (20%)-LA (15%)-JP (5%)	Low erosion risk here and to west. Standing dead in 5m band along shore
WB17	6153200N	517100E	June 3	sd	m					N & S	North: Large marsh (anchored into substrate) with 50% cover with a shoreline of BS (80%)-TA (20%)	Several small islands and floating bogs and marshes. Standing dead in a 5m band to the N and S; including along a 30m wide channel.
				r	l							

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
BR1	6163100N	529900E	June 6	sd	m			l			BS (60%)-JP (20%)-TA (20%)/standing dead/sedge. Following a creek. There are areas of BS(90%)-JP(10%)-TA(1%) and along the shoreline to opening of larger bay are several low, wet spots of BS(10%)-JP(20%)-TA(20%).	BR1 with high bedrock and BS-TA-JP;standing dead at mouth of creek
BR2	6163800N	528800E	June 6	sd	l	clay		l/m			WS (50%)-TA (50%)/willow-alder/grass-litter.	standing dead trees present
BR3	6164600N	529500E	June 6	sd	h						BS (70%)-JP (20%)-tamarack (10%). There is cattail marsh, with 50% cover, comprised of numerous small stands off-shore.	50% cattail marsh. Several small cattail marshes are separated from shore by a 10-30m wide band of standing dead along riparian edge.
				f	vl							
				sub	l/m							
BR4	6165500N	529600E	June 6	sd	m						TA (50%)-BS (30%)-WS (20%)-(JP) in most of plot and BS (80%)-JP (20%) in eastern portion. Cattail marsh with 50% cover extends several metres out from shore for entire stop.	
				sub	l							
BR5	6164800N	528300E	June 6	sd	m						JP (50%)-TA (50%) with 30% cover.	Floating bog. Off-shore are 2 large stands of moderate standing dead, and two stands of cattail and standing dead, with a band of standing dead along shore.
				sub	l/m							
				f	l							

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
BR6	6165100N	527300E	June 6	sd	m	clay	100%	h			BS high on shore, intermixed with cattail marsh having moderate standing dead along shore. BS growing on island off-shore.	Occassional floating debris between stops 5 & 6.
				f	l							
BR7	6166000N	526900E	June 6								Similar to above	
BR8	6164500N	526800E	June 6	sd	m						WS (60%)-JP (30%)-TA (10%) along shore with 5-10m wide band of standing dead. Marshy willow islands off-shore. The western half of the plot is TA(60)-JP(30)-WS(10)-(TL-BS)/alder-willow	The northern bay in here used to be all marsh prior to CRD. Standing dead is about 5-10m wide along the shore.
				sub	l							
BR9	6163800N	527700E	June 6									
BR10	6163800N	526000E	June 6	r	vl	clay-silt	100%	m/h			WS (40%)-TA (40%)-JP (20%)/alder thicket with a small stand of TA (100%).	Medium-high clay-silt bank.

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris Type	Debris Density	Shoreline Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect	Dominant Plant Community	Comments
BR11	6163400N	525000E	June 6	sd	l	clay	100%	m		S	TA (60%)-JP (30%)-BS (20%)-WS (10%)/alder-poplar/grass. Standing dead stumps immediately off-shore for a small portion of stop. Some trees falling in, but appears to be fairly stable shore with lots of alder along edge; some undercutting of medium clay bank.	Not eroding very fast, but some trees falling in
				r	l/m							
				l	l							
BR12	6162700N	524200E	June 6	sd	vh	clay	80%	l/m			TA (50%)-JP (30%)-BS (20%), with a 50x150m stand of BS(80%)-JP(20%).	Very dense standing dead immediately off-shore. Low-medium clay bank (80% of shore) and bedrock (20%).
						bedrock	20%	l/m				
BR13	6161800N	523500E	June 6	sd	vl/vh			l			BS (50%)-TA (40%)-JP (10%) & low TA along shore. Cattail stand off-shore has dense sd.	Standing dead as a band of dead trees along shore, with one area to the SW where a clump of very dense standing dead occur and high density in cattail marsh. Very high density (vhd) standing dead (sd) along western half of water edge and immediately off-shore, with a vhd-sd clump in center of plot. Low clay bank with low density beached debris.
				b	l							

TABLE A9.4-1 (cont'd)

Locale*	UTM Co-ordinates		Date (2000)	Debris		Shoreline					Dominant Plant Community	Comments
				Debris Type	Debris Density	Substrate Type	% Substrate Type	Bank Height	Slope°	Aspect		
BR14	6161100N	522800E	June 6								TA (60%)-JP (30%)-BF (10%) forest of young age. Off-shore are at least 3 large stands of sedge-birch-willow (perhaps floating bogs).	Sedge-birch-willow floating bogs;
BR15	6162700N	523200E	June 6	b	m	clay		h			TA (50%)-JP (30%)-WS (15%)-BS (5%), with young poplar along shore. High clay-silt bank. Eroding bank at mouth of river. Moderate beached debris on island off-shore.	Eroding bank at mouth of river. Beached debris on island.
BR16	6163700N	523200E	July 29	sd / f	h / m							

Note: measurements are approximated

Codes: Plants: Black Spruce = BS, White Spruce = WS, Jack Pine = JP, Trembling Aspen = TA, Tamarack = TL, Balsam Fir = BF, Balsam Poplar = BP, White Birch = WB

Debris Type: b = beached, l = leaning, f = floating, r = rafted, sub = submerged, sd = standing dead

Debris Density: vh = very high, h = high, m = moderate, l = low, vl = very low

Bank Height: l = <1m, m = 1-2m, h = >2m

*Refer to Figure 9.2-1 for boat-based shoreline survey stop locations

** Substrate not inspected on land (observed from boat), "clay" may be "silt" or mix of highly erodable substrate that appears to be clay from a distance

S:\0221A2911 Wusk Gen Stn\Wusk Debris\Debris-Shoreline Data2

TABLE A9.4-2

DESCRIPTION OF DEBRIS AND SHORELINE HABITAT ALONG OPEGANO LAKE AND THE BURNTWOOD RIVER IN JUNE 2001

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
OP1	0542681	6161875	0542628	6162242	10/6/01	beached	Med-low	100	Clay / Silt-Bedrock	80-20	<15°		Spruce mixedwood		Bedrock is on NW point of bay. From camp, headed N on W shore.
OP2	0542628	6162242	0542583	6162560	10/6/01	Beached	Med-low	100	Clay / Silt	100	ca.15°		Spruce dominated mixedwood		
OP3	0542583	6162560	0542800	6163000	10/6/01	standing-beached	Med-low	50 – 50			<15°		Mixedwood behind alder on shore	Sedges and partly submerged willow/alder	
OP4	0542800	6163000	0542864	6163342	10/6/01	standing-beached	Low	50 – 50			<15°		Spruce and spruce mixedwood	Alder/cattail marsh & some standing dead (patchy)	

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
OP5	0542864	6163342	0543270	6163400	10/6/01	beached/ standing	Low / Med-low	50 / 50			<10°		young spruce mixedwood shoreline	Band of sedges along shore about 1m wide	A strip of med. High standing dead at E542300, N6163300 for ca.100m
OP6	0543270	6163400	0543950	6163000	10/6/01	Standing/ beached	Low / Med-low	30 / 70	Organic	100	15-30°		young BS dominant		Active erosion somewhat protected by light debris
OP7	0543950	6163000	0544400	6162370	10/6/01	beached	Low	100	Clay / Silt-Rock	50-50	20-30°		Spruce mixedwood		
BR1	0544400	6162370	0545200	6162100	10/6/01	beached	Low	100	Clay / Silt-Bedrock	90-10	35°		WS-JP dominant, more mature		med low debris from E545014, N6162188 to E545200, N6162100. High eroding clay bank. Main shore 3-5m above water
BR2	0545200	6162100	0545428	6162040	10/6/01	beached	Med-low	100	Clay / Silt	100	low		Very young BS		

BR3	0545428	6162040	0545966	6162380	10/6/01	standing/ beached/ floating	High / Med-high / Med-low	50 / 40 / 10			low		young to medium age BS	Band of sedges along shore about 1m wide	Heading E along shore. Many ducks here. Picture at E545800, N6162065	

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
BR4	0545966	6162380	0547080	6162466	10/6/01	beached	Med-low	100	Clay / Silt	100	10-20°		Med. Age BS and young BS at shore. Some mixedwood		Shoreline eroding where not protected by beached debris
BR5	0547080	6162466	0546633	6162364	10/6/01	beached	Low	100	Clay / Silt	100	20°		Alder shore with low density mixedwood		picture at E547080, N6162466
BR6	0546633	6162364	0546210	6162206	10/6/01	standing/ rafted	High / Med-high	50 - 50			low		Shoreline with alder and some sedge. BS behind.		
BR7	0546210	6162206	0544365	6161562	10/6/01	standing/ beached	Low / Med-low	10 - 90	Clay / Silt	100	low		young to medium age BS right to eroding bank		Cut Bank 1.5-3m above water & flat shore beyond. E0544864, N6161501 to E0544590, N6161500 is a bay with med st. dead, med-low beached & low leaning debris. Hydro bench mark at E544487, N6161514
OP8	0544365	6161562	0543820	6160763	10/6/01	Beached	Med-low	100				2.5m	BS to shore edge		Heading S on E side. Picture at Eo543948, N6161310 looking W. Active erosion & slumping

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
OP9	0543820	6160763	0543952	6159727	10/6/01	leaning / beached	Low / Med-low	10 - 90	Clay / Silt	100	15-20^o		young BS dominant		Picture at E0544085, N6160267. Active erosion on cutbank ca. 0.5-2m above water.
OP10	0543952	6159727	0543620	6159312	10/6/01	Beached/ leaning	Low	50 - 50	Bedrock	100	30-35^o		young BS and BS mixedwood with alder shoreline		
OP11	0543620	6159312	0543661	6159117	10/6/01	Beached	Low	100	Clay / Silt	100		1-2m			Actively eroding banks
OP12	0543661	6159117	0543035	6158831	10/6/01	Beached	Low	100	High Bedrock	100					Bedrock bank is 2-3m above water.
OP13	0543035	6158831	0542271	6159060	10/6/01	Beached	Low	100	Clay / Silt	100		0.5-2m	Mixedwood right up to shoreline		Clay bank slumping in some places. S end of Opegano Lake

OP14	0542271	6159060	0542281	6159162	10/6/01	Beached	Low	100	Clay / Silt	100		<5m	Aspen forest on clay bank		High eroding clay bank 5m high in places

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
OP15	0542281	6159162	0542266	6159221	10/6/01				Bedrock	100	steep		Aspen forest on penninsula		
BR8	0542266	6159221	0542105	6159339	10/6/01	leaning / beached	Low	50 / 50	Clay / Silt	100	20-30o		Varies between Aspen or Coniferous dominant mixedwood		Eroding clay bank. Forest is 4-5m above water in placesMoving along S shore of Burntwood towards rapids at E539300, N6158000
BR9	0542105	6159339	0540690	6159122	10/6/01	beached	Low	100	Clay / Silt	100	$<10^{o}$		Mixedwood forest		Low clay bank. Picture at E542062, N6159382
BR10	0540690	6159122	0539834	6158400	10/6/01	beached	Med-low	100	Clay / Silt	100	$<10^{o}$		Mixedwood forest		Crossed to N side of river at E539999, N6158339
BR11	0539834	6158400	0540682	6159356	10/6/01	beached	Low	100	Clay / Silt	100	15-20o		Spruce forest		Clay bank slumping

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
BR12	0540682	6159356	0542272	6159460	10/6/01		Minimal		Clay / Silt	100	25°				Bank height ca. 0.5-2m, occasional slumping. Bay at E540913, N6159517 with low beached debris and med-low debris at bay mouth on W side
OP16	0542272	6159460	0542905	6160904	10/6/01	beached	Med-low	100	Clay / Silt	100		2-4m	Spruce mixedwood forest		Eroding clay bank with slumping and leaning trees. Heading N along W shore
OP17	0542905	6160904	0542924	9160991	10/6/01	Beached/ leaning	Low		Bedrock	100	25°				behind bedrock, shoreline becomes clay
OP18	0542924	9160991	0543004	6161407	10/6/01	Beached/ leaning	Med-low		Clay / Silt	100	20o		Coniferous mixedwood forest		Clay bank is 2-3.5m high.
OP19	0543004	6161407	0542900	6161571	10/6/01	Beached	Med-low	100	Clay / Silt	100		4-5m			Slumping clay bank 4-5m above water

TABLE A9.4-2 (cont'd)

Locale	Start Location (UTM)		End Location (UTM)		Date (2001)	DEBRIS			SHORELINE TYPE				Dominant Vegetation		Comments
	Easting	Northing	Easting	Northing		Type	Density	Type %	Substrate Type	% Substrate Type	Slope (Degrees)	Height	Shoreline	Aquatic	
OP20	0542900	6161571	0542900	6161776	10/6/01	beached/ leaning	Low		Clay / Silt-Bedrock						Bedrock shoreline varies with clay bank
OP21	0542900	6161776	0542792	6161889	10/6/01	Beached	Med-low	100	Clay / Silt	100		2m			High slumping clay bank

10.0 RESIDUAL EFFECTS

10.1 CLIMATE

The Project will not result in significant emissions relative to other forms of electricity production. The net impact of the Project will be a significant reduction in global GHG emissions (Section 2.4.2.2). The electricity produced by Wuskwatim will displace GHG-intensive natural gas and coal-fired resources, predominantly outside of Manitoba. Assuming the Project displaces only the most efficient combined cycle natural gas generation, the average GHG emission reduction due to Wuskwatim is expected to be greater than 750,000 tonnes of CO_2 emissions per year. In addition to GHG emission reductions there would also be global emission reductions in nitrogen oxides, sulfur oxides, mercury and particulates. Therefore the Project will have a net positive residual effect on global GHG emissions.

10.2 PHYSIOGRAPHY, GEOLOGY AND SOILS

The resulting final footprint of the Wuskwatim Generating Station on the physical landscape (both land and river bottom) will create an unavoidable, long-term, localized effect on the physical environment (Sections 3.4.1.8). The Project will also result in the unavoidable loss of Taskinigup and Wuskwatim Falls (Section 3.4.2). The significance of these residual effects to the aquatic, terrestrial, and socioeconomic environments and resource use is discussed in Volumes 5 through 8.

10.3 WATER REGIME

In the "immediate forebay" between Wuskwatim and Taskinigup Falls, water levels will be raised to 234 m ASL elevation (an increase of about 7 m in this upstream area), which will result in the flooding of less than ½ km^2 (about 37 ha) of previously cleared land. With respect to the physical environment, the residual effects are considered to be unavoidable, long-term, large in magnitude, and localized (Section 4.3.5). The potential residual implications of these residual effects to the aquatic and terrestrial environment are discussed in Volumes 5 and 6.

The residual effect of daily flow and water-level changes as a result of the Project on the reservoir of Wuskwatim Lake and downstream river channels are considered to be long-term, localized, and small to moderate in magnitude with respect to the physical environment (Section 4.3.5). The potential residual implications to aquatic and terrestrial habitats and biota are discussed in Volumes 5 and 6.

10.4 ICE PROCESSES

There will be no measurable changes to ice processes and therefore no residual effects as a result of the Project (Section 5.5.2).

10.5 WUSKWATIM LAKE EROSION

The Project will result in a short-term, moderate increase in bank-recession rates of erodible shores in localized areas that will decline to existing levels over the moderate term (i.e., <25 years; Section 6.4.4). This will result in a moderate increase in total land area and volume of material being eroded around Wuskwatim Lake over the next 25 years. The potential residual implications to aquatic and terrestrial environments are discussed in Volumes 5 and 6.

10.6 RIVERINE EROSION

No change in channel-forming flows is predicted and therefore riverbank-erosion during Project operations is not expected to have a residual effect on the physical environment (Section 7.5.2).

10.7 SEDIMENTATION

It is expected that the estimated large increases in sedimentation in the nearshore and the estimated minor increase in sedimentation in deepwater areas (within the main part of Wuskwatim Lake) will decrease significantly after the first 5 years of the Project and return, in the following 20 years, to background levels; consistent with the Wuskwatim Lake shoreline-erosion predictions (Section 8.4.2). The effects of sediment deposition are expected to decline over a moderate time frame. The potential residual implications of these changes in sedimentation on the aquatic environment are discussed in Volume 5.

10.8 WOODY DEBRIS

The Project will result in a small incremental increase in debris accumulation on those localized Wuskwatim shores where active erosion and debris accumulation is now occurring (Section 9.4.2). The potential residual implications to the aquatic and terrestrial environments and resource use are discussed in Volumes 5 through 7.

11.0 CUMULATIVE EFFECTS

The effects of the Project were assessed in combination with the effects of other projects that have or will be carried out, which potentially could affect the physical environment (land, water or air). One project that has already been completed in the area is the Churchill River Diversion (CRD). For the purposes of this assessment, the CRD has been considered the baseline condition and is therefore not considered as part of this Cumulative Effects Assessment. Other known or potentially foreseeable projects that could affect the physical landscape include other hydroelectric generation and transmission projects (i.e., Wuskwatim Transmission Project, Gull/Keeyask Generation Project or the Conawapa Generation Project, and Notigi Generation Project) and any other industrial projects (e.g., Tolko Forestry activities).

The Wuskwatim Transmission Project will be developed in the vicinity of, and concurrently with, the Project (i.e., it overlaps in space and time). This Transmission Project, however, is not anticipated to interact with the effects of the Project on the physical environment (e.g., erosion, sedimentation, etc.).

Construction of the Gull/Keeyask and Conawapa Generation Projects, if developed, could overlap or be sequential in time, but would not overlap in space, with the construction of the Wuskwatim Generation Project. The Gull/Keeyask and Conawapa projects would be located on the Nelson River (downstream of where the Burntwood River enters the Nelson River). The Wuskwatim Project will not change the overall CRD water regime. Accordingly, it will not affect the operation of a potential downstream Gull/Keeysask or Conawapa Project if they are constructed. As well, these potential projects would not interact with the physical environment effects of the Project as documented in the preceding sections.

A potential Notigi Generation Project would be located adjacent to the Notigi Control Structure upstream of the Wuskwatim Project. The potential Notigi generating station would operate similar to the Wuskwatim Project (i.e., there would be no change to the current daily or seasonal flow patterns on the CRD) and therefore it would not interact with the effects of the Project on the physical environment.

If Tolko winter-road building and harvesting activities are pursued south of the Burntwood River, this would overlap in space and time with the Project. If Tolko activity in this area did proceed, forest cutting would be required to abide by a 30-m buffer around waterbodies and would, therefore, not affect current or projected Wuskwatim Lake shoreline-erosion estimates.

In terms of global greenhouse gas emissions, the net effect of the Project will be a significant reduction in global GHG emissions (Section 10.1). The cumulative effect of Tolko's forestry activities would not influence this significant net GHG benefit. The cumulative effect of other potential hydro projects such as Notigi, Gull Rapids and Conawapa, if they are undertaken, would not affect the GHG benefit from the Project and would be expected to result in further significant reductions to global GHG emissions.

On this basis, no negative cumulative effects are anticipated with respect to changes in the physical environment and the combination of these potential developments with the Wuskwatim Generation Project.

12.0 ENVIRONMENTAL FOLLOW-UP AND MONITORING

This section provides an overview of the monitoring activities to occur during Project construction and operation in order to verify predictions, resolve uncertainties and generally track changes to the physical environment as a result of the Project. This program has been reviewed and agreed to by both Manitoba Hydro and NCN at a conceptual level. Going forward, the Environmental/Engineering Consultants, Manitoba Hydro and NCN will work out the details regarding monitoring design (e.g., equipment used, parameters measured, methods and reporting mechanisms, etc.)**.**

12.1 CLIMATE

12.1.1 Monitoring Future Weather Patterns and Climate Extremes

Manitoba Hydro will monitor changes in the regional climate of the Wuskwatim Generation Project area using climate information that includes measurements of temperature, precipitation and wind speed provided by the Meteorological Service of Canada. In addition, Manitoba Hydro will monitor research work from the scientific community in the area of global climate change to assess the degree at which climate change is occurring in the Wuskwatim Generation Project area.

A significant challenge to the scientific community will be to determine the degree to which global climate is changing due to anthropogenic (man-made) causes such as increased greenhouse gas concentrations in the atmosphere as opposed to natural causes such as volcanic and solar activity. Manitoba Hydro will continue to monitor the capability of Global Climate Models (GCMs) and regional climate models from the perspective of being able to duplicate climate change within the current climate regime. Work is ongoing with the International Institute for Sustainable Development to investigate and report on the current status of GCMs and GCM scenarios and provide information about further developments in global climate models and regional climate models.

When GCMs have been developed to the point where they can be calibrated to predict current climate regimes, they can be used with confidence to predict future climate trends and may potentially be useful in predicting the frequency and magnitude of extreme events in the Wuskwatim Generation Project area (e.g. severe storms, wind events, ice storms).

12.1.2 Research on Historic Hydrologic Extremes

Manitoba Hydro continues to be involved in a number of research initiatives in order to assess extremes in climate and particularly streamflow, which may have occurred in past centuries, prior to the current period of record. Information from a number of research initiatives underway suggest that both extreme flood and drought events may have occurred in the past were far greater in magnitude and severity than the most extreme hydrologic events recorded over the past 100 years. This research involves investigating a number of techniques to infer past hydrologic extremes using proxy data such as tree-rings and lake sediments. Research in this area will continue.

12.1.3 Monitoring Future Weather Patterns and Climate Extremes

GCMs at present do not specifically model future climate extremes (e.g. extreme heat waves or cold snaps, wind events, rainfall events, tornadoes, ice storms, etc.) or future changes in seasonal weather patterns (warmer winters, earlier break-up of rivers, etc.). A greater incidence of climate extremes would not only affect hydro operations but could also have an impact on the environment in the Wuskwatim resource area. Conversely, a major shift in seasonal weather patterns could also have significant environmental impacts. Manitoba Hydro will continue to follow the developments in meteorological forecasting and regional climate modeling and their ability to address these issues.

12.2 PHYSIOGRAPHY, GEOLOGY AND SOILS

Following construction, the geology of the newly exposed rock faces will be mapped. During operations, sites proposed for **rehabilitation** will be monitored to determine the success of natural revegetation for the purposes of safety (i.e., erosion prevention) and aesthetics. Erodible soils along the access road to site, as well as the general Wuskwatim site, will also be monitored to determine whether additional slope protection is required.

12.3 WATER REGIME

From the perspective of energy production, Manitoba Hydro will record forebay elevation, tailrace elevation and flow through the Wuskwatim Site. Additionally, Manitoba Hydro currently records water levels on the three lakes (Wuskwatim Lake, Opegano Lake and Birch Tree Lake) through the use of Data Collection Platforms (DCPs). Manitoba Hydro will also add tailrace water-level recording to the information it currently collects in the local vicinity.

12.4 ICE PROCESSES

Periodic ice and water-temperature monitoring upstream and downstream of the Project site will be carried out for safety purposes and to maintain efficient flows.

12.5 WUSKWATIM LAKE EROSION

Follow-up monitoring and analysis related to shoreline-erosion processes and effects in Wuskwatim Lake, to periodically update GIS model input parameters and re-calibrate erosion model estimates, would likely include the following:

- continuing to monitor bank recession at the Manitoba Hydro erosion-monitoring sites;
- analyzing wind data from Manitoba Hydro's Wuskwatim Lake weather-monitoring site, combined with water-level data and bank-recession rate data from the erosion monitoring sites, to better model factors causing variability in bank recession rates;
- reclassifying the shoreline shortly before impoundment and making necessary adjustments to the GIS database and erosion-model estimates;
- reclassifying the shoreline at regular intervals (e.g., every 10 years) after impoundment, as required; and
- analyzing and monitoring debris conditions, erosion rates, and wind and water-level data to better understand the relationship between debris conditions and bank recession rates.

12.6 RIVERINE EROSION

As discussed in Section 7.5.1, further field tests are planned in the early stages of construction to better assess the strength of *in-situ* bed material upstream of the Stage I Cofferdam.

It is estimated that future impacts on downstream erosion processes, related to the construction and operation of the Wuskwatim Generation Project, will be minimal, however, it would be useful to establish a monitoring program downstream bank erosion in the reach between Taskinigup Falls and Opegano Lake to gather additional baseline data on the existing condition and rate of erosion of banks in this area. This program should be continued upon completion of the Wuskwatim Project to compare and identify any impacts on these historical erosion rates.

12.7 SEDIMENTATION

Follow-up monitoring and analysis related to sedimentation and TSS processes would likely include the following:

- the implementation of a long-term sediment-monitoring program to develop site-specific sediment-deposition characteristics for the lake, and to monitor deposition in other downstream lakes such as Opegano and Birch Tree Lakes;
- the expansion of the TSS monitoring program (both temporally and spatially) to better understand the variation in TSS data and to correlate the wind data already collected at the Wuskwatim DCP (on the west side of the lake); and
- the continuation of the collection of sediment plate data including re-establishment of deep-water sites on Wuskwatim Lake.

12.8 WOODY DEBRIS

Shoreline debris survey as described in Volume 4, Section 9.2 will be carried out shortly before impoundment to determine whether there are any substantial changes in shoreline debris (e.g., a change from light to moderate debris).

13.0 COMPLETE GLOSSARY OF TERMS

AC Alternating Current - is the oscillating (back and forth) flow of electrical current, whereas the DC (Direct Current) is the unidirectional continuous flow of electrical. The AC current form of electricity is the common household form. DC current form of electricity is the form provided by a battery.

accretion the process of growth or enlargement by gradual build up.

acid rain rain that has a high acidity because of the presence of sulphur or nitrogen oxides (both created from burning coal and other fossil fuels) in the atmosphere.

agglomerate to gather into a ball, mass, or cluster.

aggregate sand, gravel, slag or crushed stone; used for mixing with a cementing material to form concrete mortar or plaster, or used alone as in graded fill.

alluvial pertaining to or composed of alluvium; clay, silt, sand, gravel, or similar detrital material deposited by running water.

anchor ice ice which sometimes forms about stones and other objects at the bottom of running or other water, and is thus attached or anchored to the ground; typically forms on the river bed at locations that are shallow and flowing rapidly, such as at the “brink” of a set of rapids or a waterfall - at these locations, the turbulent, high velocity flow causes mixing of the newly formed frazil ice and supercooling of the riverbed material. The frazil ice that comes into contact with the river bed attaches itself to the material on the river bottom. As this ice mass slowly grows, it begins to constrict or block the river channel, and can result in a substantial rise in upstream water levels; can form during the coldest winter months and be eroded during the latter warmer winter months.

angle of repose for any given granular material the steepest angle to the horizontal at which a heaped surface will stand in an equilibrium condition.

ASL elevation Above Sea Level, elevations are referenced to Geodetic Survey of Canada, Canadian Geodetic Vertical Datum 1928, 1971 Local Adjustment.

armour stone large, heavy rocks placed over a fine material to protect it from scour or erosion.

Augmented Flow Program annual amendment to the Churchill River Diversion 1973 Interim Water License, which provides additional flexibility in the operation of the CRD.

azimuth direction, in degrees, referenced to true north.

backflooding intentionally flooding the work area behind a cofferdam to minimize erosion during cofferdam removal.

background amount of pollutants present in the environment owing to natural sources.

backwater refers to the backing up of water behind a dam or natural barrier. This effect will not extend upstream through rapids or falls in which flow is supercritical (Appendix A4.1).

bank-recession rates quantity, amount, or degree of the shore or bank retreat by progressive erosion.

bedload sediment material transported by rolling, sliding and saltating (i.e., bounce, jump, or hop) motions along the bed.

bedrock solid rock that underlies soil and the regolith or that is exposed at the surface.

Belt elongated region where a specific condition is found.

best estimate suggests that the result is not exact. Specifically to the Project, a number of factors can affect the accuracy of the hydraulic information. These factors include the amount of field data collected, measurement errors in field data, calibration of measurement equipment, numerical models and the exactness of modeling parameters used in hydraulic models. Therefore in many situations, it is extremely difficult to quantify the accuracy of a result and Engineering judgment and experience must be used to assess how representative the hydraulic information is.

best-gate setting wicket gate setting at which a hydraulic turbine operates most efficiently. The wicket gates are the main flow control to the turbine.

biomass total mass of living matter in a given unit area.

bog wetland ecosystem characterized by an accumulation of peat, acid conditions and a plant community dominated by *Sphagnum* moss.

bluff a high steep bank.

boreal forest needle-leaved evergreen or coniferous forest bordering sub-polar regions.

border ice forms along the shoreline of a river, where velocities are low; formation similar to that of lake ice; reduces the area of open water; in particularly low velocity locations, the border ice forming along each shore may eventually grow together, creating an ice bridge and hence an ice front against which drifting ice sheets can begin to accumulate; extent of border ice formation governed by flow velocity, river geometry, and winter temperatures.

borrow areas or borrow 'sites' or 'pits'; areas were materials (e.g. gravel, sand, silt, clay) are excavated for use.

boundary location that indicates a limit or extent.

Brunisols soils of the Brunisolic order have sufficient development to exclude the soils from the Regosolic order, but lack the degrees or kinds of horizon development specified for soils of the other orders. The central concept of the order is that of soils formed under forest and having brownish coloured Bm horizons and/or various colours with both Ae horizons and B horizons having slight accumulations of either clay, or amorphous Al and Fe compounds, or both.

C Celsius; scale for measuring temperature; convert Celsius to Fahrenheit: multiply degrees in C by 9/5 and add 32.

CRD Churchill River Diversion; involved constructing a control structure at the outlet of Southern Indian Lake to divert a large portion of the Churchill River down the Rat/Burntwood Rivers into the lower Nelson River at Split Lake to enhance power production at the Kettle, Long Spruce and Limestone operating stations.

calcareous composed of or containing or resembling calcium carbonate or calcite or chalk.

calibrated process by which parameters in numerical or physical models are adjusted until they consistently replicate or simulate historical observations.

capacity factor ratio of average load of a plant or machine, to its maximum capacity rating.

channel excavation excavation of a channel to improve the conveyance or carrying capability of an existing natural river reach, or local channel constriction.

channel-forming flow flow that defines the characteristics of the channel; typically it is the flood flow that has a return period of once every two years.

channel migration slow lateral movement of a meandering river channel due to erosion and deposition.

clayey clays interspersed with silt, loam and/ or sand.

closure event during the construction stages of a hydro power project, where rock-filled cofferdams are extended into the river until the flow down the natural river channel is halted. During this process, flow is being diverted through the completed spillway. River closure is generally the initial step in the construction of the main dam.

cofferdam temporary barrier, usually an earthen dyke, constructed around a work site in a river, so the work site can be de-watered or the water level controlled. See dam.

cofferdam remnant residual earthfill material remaining in the river or lake after breaching and removal of the cofferdam structure.

cohesive sediment material of very small sizes for which cohesive bonds between particles (i.e., intermolecular forces) are significant and affect the material properties.

commissioned with reference to a hydro generating station: testing of generating equipment and upon satisfactory completion, releasing for commercial service.

concrete aggregate crushed rock or gravel of varying size used in the production of concrete. Aggregate is mixed with sand, cement, and water and other additives to produce concrete.

constriction relative narrowing, a restriction in a river channel.

construction design flood river flow that is used in the design of temporary structures such as cofferdams during the construction of a hydro power plant. The flow value is higher than the average flow and is therefore considered a flood event. The magnitude of the construction design flood, acceptable in engineering practise, is a 1:20 event (expressed in terms of probability of exceedance per year). It is used to establish crest heights for temporary cofferdams and for planning river closure designs.

control structure type of structure designed to control the outflow from a waterbody (e.g., Missi Falls control structure, Notigi control structure). It is usually a gated structure.

CRD Churchill River Diversion; involved the construction of the following structures:

- the Missi Falls Control Structure at the outlet of Southern Indian Lake (SIL) to control and pond Churchill River inflows;
- the excavation of South bay channel for diverting SIL flows into the Rat/Burntwood Rivers:
- the Notigi Control Structure to control diverted flows into the Rat/Burntwood Rivers.

The CRD allows the diversion of a large portion of the Churchill River down the Rat/Burntwood Rivers into the lower Nelson River at Split Lake to enhance power production at the Kettle, Long Spruce and Limestone operating stations.

cross sections the shape of a river cut transversely (perpendicular) to its length, sometimes called a transverse section.

Cryosols soils of the Crysolic order are formed in either mineral or organic materials that have permafrost either within 1 m of the surface or within 2 m if the pedon has been strongly crysturbated laterally within the active layer, as indicated by disrupted, mixed or broken horizons. They have a mean annual temperature of less than or equal to 0 degrees Celsius.

crystalline consisting of or containing or of the nature of crystals; general term applied to metamorphic or igneous rocks formed by the process of crystallization from solid or liquid precursors.

cumulative impact the impact on the environment which results from the effects of a project when combined with those of other past, existing and imminent projects and activities.

cycling of flows systematic change in powerhouse flow over a period of time to derive the best benefit from the incoming flows and available forebay storage.

dam barrier built across a river that obstructs the flow of water. A barrier built across a watercourse to impound or divert water. A barrier that obstructs, directs, retards, or stores the flow of water. Usually built across a stream. A structure built to hold back a flow of water.

dampened to reduce amplitude (of oscillations or waves). In the case of a river reach, water levels are dampened as a result of channel and lake storage.

database collection of organized data, especially for rapid search and retrieval (as by a computer).

datum any level surface taken as a plane of reference from which to measure elevations.

decommission to take out of active use (typically involves the dismantling and removal of the original structure(s) and associated facilities).

dominant discharge for an unregulated, natural flow, the dominant discharge is usually the bank-full or 1:2 year annual peak discharge.

downcutting vertical deepening of a channel.

drawdown lowering of a reservoir's water level; process of depleting a reservoir. The difference between two water levels in a reservoir. The amount of water drawn from a reservoir.

drowned out the submergence of a set of rapids within a channel such that critical flow conditions no longer exist at that section.

duration curve cumulative distribution function based on a sample of data, to indicate frequency of exceedance. A curve that shows how often an event is expected to be exceeded.

dyke embankment, usually constructed to prevent flooding of low lying areas and thus limit the extent of flooding.

dynamic equilibrium when two (or more) processes occur at the same rate so that no net change occurs.

Dystric Brunisols acid Brunisols (see definition for Brunisol above) that lack a well-developed mineral organic surface horizon; occur widely, usually on parent materials of low base status and typically under forest vegetation.

EIS Environmental Impact Statement; an assessment designed to identify, predict, interpret and communicate information about the impact of a proposed action on the natural and human environment.

elevation height of a point above a plane of reference. Generally refers to the height above sea level. See datum.

embayment relatively small bay, adjacent to and joined to a river channel, which can temporarily store water during rising flows and provide additional flow into the river during falling flow.

EnvPP Environmental Protection Plan; a "user-friendly" guide for the contractor that includes: information such as a brief project description; updated construction schedule; summary identifying environmental sensitivities and mitigative actions; listing of all federal, provincial or municipal approvals, licenses, or permits that are required for the project; a description of general corporate practices and specific mitigating actions for the various construction activities; emergency response plans, training and information; and environmental / engineering monitoring plans and reporting protocols.

erosion wearing away of the Earth's surface by the action of water, wind, current, etc.

existing flows refers to flows (or water levels) that have occurred since the final commissioning of the Churchill River Diversion (CRD), see post-CRD. Flow record used in study goes from Sept. 1977 to June 2001.

felsic term applied to an igneous rock having an abundance of light-coloured minerals.

fen low-lying wet land with grassy vegetation; usually is a transition zone between land and water.

Fibrisols organic soils that are composed largely of relatively undecomposed fibric organic material. They occur extensively in peat deposits dominated by *Sphagnum* mosses.

fill natural soils that are manually or mechanically placed. Soil or loose rock used to raise a grade.

floating ice pan agglomeration of frazil ice, or slush ice, into frazil pans and larger ice sheets. Slush ice, if on the surface long enough, will form a continuous ice sheet over a porous mass of frazil sheets. This ice sheet is known as a frazil pan. As these pans move, they bump and grind, and become somewhat circular in shape. These pans may then freeze together to produce larger ice sheets, typically in slow moving reaches where the contacting pans have had time to freeze together.

flow motion characteristic of fluids (liquids or gases); any uninterrupted stream or discharge.

fluvial produced by the action of a stream.

foliated layered structure produced by deformation; flattening and arrangement of constituent mineral grains by metamorphism.

footprint the surface area occupied by a structure or activity.

forebay see reservoir.

fossil fuels fuel consisting of the remains of organisms preserved in rocks in the earth's crust with high carbon and hydrogen content; includes coal, petroleum and natural gas.

frazil ice fine spicular or ground ice (slush), derived from the French word for cinders, which this variety of ice most resembles. When first formed, frazil is colloidal and is not visible in the water. Frazil crystals are discoid in shape, with diameters that are typically smaller than 1 mm. Frazil crystals tend to stick to objects and each other. After forming, frazil crystals continue to grow and agglomerate, initially into small clusters, and then into larger flocs. See floating ice pan.

fugitive transient, fleeting.

full-gate setting fully open wicket gate setting at which the hydraulic turbine produces maximum power.

gabions a basket or cage filled with earth or rocks and used in building a support or abutment, or for protection against erosion or scour.

generating station complex of structures used in the production of electricity. A hydroelectric generating station would include the powerhouse, spillway, dam(s) and transitions structures.

Geologic Province large region characterized by similar geologic history and development.

geology study of the plant Earth – the materials of which it is made, the processes that act on these materials, the products formed, and the history of the plant and its life forms since its origin.

glaciolacustrine sediments sediments pertaining to, derived from, or deposited in glacial lakes; especially said of landforms and deposits such as varved sediments.

granular fill fill material including sand and gravel.

groin rock-fill structure extending out into a river or lake from the bank or shore. Used to protect the bank from erosion.

GW (Gigawatt) one billion watts (1,000,000,000 watts) of electricity.

GWh Gigawatt hour.

gneiss(es) coarse-grained, banded rocks that formed during high-grade regional metamorphism; the banding is a result of the separation of dark- and light-coloured minerals.

Gleysols an order of soils developed under wet conditions and permanent or periodic reduction. They occur under a wide range of climatic conditions; Gleysolic soils may or may not have a thin Ah horizon over mottled gray or brownish gleyed material. They may have up to 40 cm of mixed peat or 60 cm of fibric moss peat on the surface.

granoblastic textural term referring to a mosaic of equidimensional anhedral (no regular crystal shape) grains in metamorphic rocks.

Gray Luvisol these Luvisolic (see Luvisol definition below) soils usually have L, F, and H horizons (duff layer) and may or may not have a degraded, organic enriched A horizon. They typically occur under boreal or mixed forest vegetation and in forest-grassland transition zones under a wide range of climatic conditions.

Greenhouse Gas gases (e.g. methane, carbon dioxide, CFC's) emitted from a variety of sources and processes, said to contribute to global warming by trapping heat between the earth and the atmosphere.

greywacke texturally and mineralogically immature sandstones that contain more than 15% clay minerals.

groundwater portion of sub-surface water that is below the water table, in the zone of saturation.

ha hectares; a metric unit of square measure equal to 10,000 square metres or 2.471 acres.

hanging ice dam partial blockage formed on a water body by the buildup or deposition of ice. An ice dam typically forms below a set of falls or rapids, as a result of accumulated frazil ice that typically forms on an upstream open water river reach.

head loss energy lost from a flowing fluid due to friction, transitions, bends, etc.

heterogeneous consisting of dissimilar components.

High Boreal Ecoclimatic Region subdivision in the Canadian Ecological Land Classification System hierarchy, which divides Canada's natural landscapes into 15 terrestrial Ecozones, which are then subdivided into 45 Ecoprovinces, 177 Ecoregions and 5,428 Ecodistricts.

high-grade metamorphism metamorphism accomplished under conditions of high temperature and pressure.

high-head generating station design that has a high forebay elevation compared to other options.

Humic partly or wholly decomposed vegetable matter; Humic Gleysol soils have a dark-coloured (organic enriched) A horizon. They may have up to 40 cm of mixed peat or 60 cm of fibric moss peat on the surface.

hydraulics having to do with the mechanical properties of water in motion and the application of these properties in engineering; relating to water in motion.

hydraulically controlled in open channel flow, the cross-section where critical flow conditions take place.

hydraulic zone of influence reach of river beyond which water levels and fluctuations from the operation of the Project are not noticeable.

hydrodynamic term used to describe hydraulic models which can be used to assess unsteady or transient flow conditions in a reach of river.

hydrometric hydraulic-related data that is collected in the field and used for assessing the hydraulic characteristics of a river or stream. The data collected includes flow (discharge) measurements, water level measurements at locations along the reach, sounded cross-sections, ice and snow measurements, etc. For more information, see Appendix A4.2 Hydrometric Program.

hydrometric monitoring program systematic field survey set up to gather data on the flows and water levels at various points along a river system.

hydroelectric electricity produced by converting the energy of falling water into electrical energy (i.e. at a hydro generating station).

ice dam partial blockage formed on a water body by the buildup or deposition of ice.

ice cover progression advancement of an ice cover by juxtaposition of individual ice pans.

ice front the most upstream limit of a competent ice cover.

ice generation the production of ice on a water body as air temperatures drop below zero degrees Celsius.

ice processes the natural processes by which an ice cover will initiate and evolve over a winter period.

immediate forebay reservoir area immediately upstream of a dam. The immediate forebay for the Project lies between Wuskwatim Falls and Taskinigup Falls.

impervious fill fill that has low permeability (usually clay) and used in an embankment structure to reduce leakage through the dam. It can also be used as a liner of a pond or lagoon to prevent leakage into the surrounding area.

impoundment body of water confined by a dam or other structure; body of water created by a dam. See forebay.

incremental small addition or increase.

inflow amount of water that flows into a body of water or a reservoir, expressed in units of m^3/s.

infrastructure basic features needed for the operation or construction of a system (e.g. access road, construction camp, construction power, batch plant, etc.).

in situ in place; undisturbed.

interlobate ridge long raised strip of sand or gravel formed along the general line of contact or zone of overlap between two former glaciers or ice lobes.

intrusive applied to a body of rock, usually igneous, that has emplaced within pre-existing rocks.

km kilometres.

lacustrine of, pertaining to, or inhabiting lakes.

leachate solution of material leached or dissolved out from a solid.

leachability cause (a liquid) to leach or percolate; create a leachate.

levelized (lifecycle emissions) average emission over the entire lifecycle of the resource expressed per unit of energy delivered (e.g. tonnes CO_2/GWh). This is equivalent to the lifecycle emissions divided by total energy delivered over the resource's life. Lifecycle emissions include not just those emission released through the operation of a resource but also those emitted due to the construction, manufacture of material and components and net emission arising from landscape changes.

license constraints limits to which the operation of a hydro power facility is required to adhere to, which have been established by appropriate government regulators.

low-head generating station design that has a low forebay elevation compared to other options.

Luvisols soils of the Luvisolic order generally have light-coloured, eluvial horizons and have illuvial B horizons in which silicate clay has been accumulated. These soils develop characteristically in well to imperfectly drained sites, in sandy loam to clay, base saturated parent material under forest vegetation in subhumid to humid, mild to very cold climates.

LWR Lake Winnipeg Regulation allows the regulation of Lake Winnipeg water levels to enhance power production on the lower Nelson River. Constructed in the early 70's by Manitoba Hydro the project involved three main components:

- Channel excavations that included: 2-Mile Channel, 8-Mile Channel and Ominawin Channel to increase winter outflows from Lake Winnipeg;
- Jenpeg Generating Station and control structure to control flows from Lake Winnipeg into the Upper Nelson River; and
- A dam at the outlet of Kiskitto Lake to prevent water from backing up into the lake.

m metres.

massive rocks of any origin that are more or less homogeneous in texture or fabric displaying an absence of flow layering, foliation, cleavage, joints, fissility or thin bedding.

meander turn or winding of a stream.

median middle value in a distribution, above and below which lie an equal number of values.

Mesisols these are Organic soils (see Organic definition below) that are at a stage of decomposition intermediate between Fibrisols and Humisols. They occur on all types of peatland but are especially widespread in fens.

mitigation actions taken during the planning, design, construction and operation of works to reduce or avoid potential adverse effects.

***mode** of operation* method of operating a generating station for meeting electrical demands. The operation method, or mode, will determine the pattern of the outflows from the powerhouse.

modified run-of-river mode of operation that is based on modest flow changes that allows efficient generation, but is restricted so that the outflow pattern does not cause excessive downstream water level fluctuations. Generally the daily average outflow will be equal to the daily average inflow, therefore also limiting the forebay water level changes.

model tool used to help visualize something that cannot be directly observed.

monitoring any on-going process or program for measuring the actual effects of constructing or operating a development.

mudstone indurated mud having the texture and composition of shale, but lacking its fissility; a blocky fine-grained sedimentary rock in which the proportion of clay and silt are approximately equal.

MW (Megawatts) unit of power equal to one million watts. One megawatt is enough to power 50 average homes.

nearshore shallow underwater slope near to shore.

nearshore downcutting vertical erosion of the shallow underwater nearshore slope by wave action.

NFA Northern Flood Agreement; an agreement signed in 1977 by Manitoba Hydro, the governments of Canada and Manitoba, and five affected Cree Nations regarding the effects of the Churchill River Diversion and Lake Winnipeg Regulation.

numerical models mathematical models configured to simulate or replicate natural processes or phenomena.

operating rule written prescribed guide for implementing an operation action in regards to the effective management of hydroelectric facilities.

Organic soils of the Organic order are composed largely of organic materials. They include most of the soils commonly known as peat, muck, or bog and fen soils. Most organic soils are saturated with water for prolonged periods. These soils occur widely in poorly and very poorly drained depressions and level areas in regions of subhumid to perhumid climate and are derived from vegetation that grows in such sites.

Organic Cryosol these Cryosols (see Cryosols definition above) have developed primarily from organic material and are underlain by permafrost within 1 m of the surface.

outcrop	part of a geologic formation or structure that appears at the surface of the earth; also bedrock that is covered by surficial deposits such as alluvium.
outlet	natural opening at the downstream end of a lake; or a constructed opening in a structure, through which water can be freely discharged from a reservoir to the river for a particular purpose.
outwash	sand and gravel deposited by melt-water streams in front of the end moraine or the margin of an active glacier.
overburden	soil (including organic material) or loose material that overlies bedrock.
palsa bog	mounds of perennially peat and mineral soil, up to 5-m high, with a maximum diameter of 100 m. The surface is convex in shape and highly uneven. Collapse scar bogs may be found in association with palsa bogs. Fens commonly occur around palsa bogs.
parameters	any set of physical, chemical or biological properties whose values determine the characteristics or behaviour of a system.
peaking	mode of operation that is based on large flow changes that maximize on-peak generation, unrestricted outflow pattern may cause large downstream water level fluctuations.
peatland	type of ecosystem in which organic matter is produced faster than it is decomposed, resulting in the accumulation of partially decomposed vegetative material called peat; most extensive in northern regions, developing where drainage of water is blocked, precipitation is retained, and decomposition of organic matter is slowed.
peat plateau bog	composed of perennially frozen peat and are sharply defined. The surface sits about 1-m higher than unfrozen fen that surrounds it.

The surface is relatively flat, even and covers large areas. Peat plateau bogs appear to have developed under non-permafrost conditions and which subsequently became elevated and permanently frozen. Collapse scars are commonly found with peat plateau bogs. These bogs are common in areas of discontinuous permafrost.

permafrost permanently frozen ground.

phreatic surface the free surface or water table within a soil mass.

physiography description of the physical nature of objects, natural features and/or the description and origin of landforms.

planform shape of plan view.

plant axis center line, which defines the orientation and location of the associated plant structure. It is defined as a vertical plane or curved surface, appearing as a line in plan or cross section, to which horizontal dimensions can be referred.

plutonic pertaining to igneous rocks formed at great depth.

pocket cavity in the earth containing a deposit of material that is different than the surrounding material.

pollutants any substance, usually an unwanted by-product or waste, that is released into the environment as a result of (human) activities that alter the chemical, physical and biological characteristics of the environment. These substances may be found in any of the solid, liquid or gas phases.

ponding formation of a reservoir due to the damming of a river or creek; retention of water to replenish an existing reservoir.

pore pressure the pressure of water in a saturated soil.

post-CRD see existing flows.

potable water that meets drinking quality standards.

powerhouse building that encloses the generating equipment at a generating station.

Precambrian bedrock bedrock formed in the Precambrian era, which began with the consolidation of the earth's crust and ended approximately 4,000 million years ago.

profile sectional view of the change in water elevation, or river bed elevation, with distance, usually taken along the center line of a river reach.

project inflows simulated record of Wuskwatim Lake monthly inflows created from historical monthly system inflows (1912 to 1997) and current system operating rules. Assumed to represent future inflows for the Project.

project manager person who oversees the construction and all related aspects of the project.

Proterozoic more recent of two great divisions of the Precambrian Era.

radiative combined processes of emission, transmission, and absorption of radiant energy.

rated discharge capacity maximum power that a generator is designed to deliver without exceeding mechanical safety factors or allowable temperatures.

rating curve shows the relationship between discharge (flow) and river stage for a particular location on a river reach.

reach term used to describe sections of a river.

regression mathematical relationship between two or more correlated variables, which is derived from available data, and is used to predict values of one of the variables, when given values of the other(s).

rehabilitate to carry on or cause a process of rehabilitation.

rehabilitation restoring to a more normal state.

reservoir body of water impounded by a dam and in which water can be stored. Artificially impounded body of water. Any natural or artificial holding area used to store, regulate, or control water. Body of water, such as a natural or constructed lake, in which water is collected and stored for use. Dam design and reservoir operation utilize reservoir capacity and water surface elevation data.

reservoir capacity capacity of the reservoir, usually in millions of m^3. Dam design and reservoir operation utilises reservoir capacity and water surface elevation data.

riparian flow minimum, limiting flow, usually identified as an operating constraint, that has been established to minimise impacts on the aquatic environment in a river reach.

riprap layer of large stones, broken rock, boulders, or other suitable material generally placed in random fashion on the upstream and downstream faces of embankments, or other land surfaces to protect them from erosion or scour caused by current, waves, and/or ice action.

river management the management of river flows during construction of a Project within or near to a natural water body. This may entail various stages of diversion. See Stage I and II Diversion.

rock fill fill material typically consisting of excavated and crushed rock that is used to provide mass to a structure while protecting it from erosion.

RoW (Right-of-Way); area or strip of land cleared to accommodate a road or transmission line.

runoff portion of liquid (water) that does not percolate into the ground and is instead discharged into surface water bodies.

scour bed material removal caused by the eroding power of the flow.

sediment balance application of the principle of the conservation of matter to sediment processes.

sediment trap small cylindrical tube placed along the bottom of a water body to “trap” or capture a representative sample of deposited sediment.

service bay open area of the powerhouse where turbine and generator components are assembled during construction, and later, where maintenance and repairs are performed to major generating equipment.

shaping see modified run-of-river.

shore narrow strip of land in immediate contact with the sea, lake or river.

shear strength measure of the resistance of earth materials to be moved.

sinuous of a serpentine or wavy form.

soils natural medium for the growth of land plants; all unconsolidated materials above bedrock.

spillway structure that allows normal and/or flood flows to bypass the powerhouse in a manner that protects the structural integrity of the dam.

stage or water level; the elevation or vertical distance of the free water surface above a datum. If the lowest point of the channel section is chosen as datum, the stage is identical with the depth of flow. See datum.

Stage I Diversion the initial stage of diversion at Wuskwatim in which principle structures (powerhouse and spillway) are being constructed in the dry within the confines of a protective cofferdam structure.

Stage II Diversion the second stage of diversion at Wuskwatim in which the Main Dam is being constructed in the natural river channel at Taskinigup Falls, and the Burntwood River flows are being diverted through the completed spillway structure.

stage-discharge curve shows the relationship between discharge and river water elevation for a particular location on a river reach.

stage-storage curve shows the relationship between storage volume and water elevation for a particular lake or reservoir.

staging factors indicate the percentage of average ice staging that occurs during a specific winter month, based on the maximum winter ice staging; used to estimate average staging due to ice effects for the winter months.

steady-state under this condition, the flow remains constant for an entire study reach.

storage retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. See reservoir capacity.

storage volume reservoir capacity found between two reservoir levels. The active storage volume is normally usable for storage and regulation of reservoir inflows to meet established reservoir operating requirements. It extends from the full supply level (FSL) of the reservoir to the minimum operating reservoir level.

striae series of parallel straight lines, scratches or fine grooves on a rock surface by a geologic agent (e.g., glacier).

Suite collection of rocks from a single area generally representing related igneous rocks.

supercritical flow flow in a river normally located at a set of rapids/falls or a narrow channel where water velocity is high and is defined as rapid and shooting. High flow velocities result in a supercritical flow zone that becomes a hydraulic barrier through which the effect of the downstream disturbance or change cannot be translated further upstream; a flow zone where surface ripples from a disturbance cannot move farther upstream. (See Appendix 4A-1 Regimes of Flow for further explanation).

supracrustal above the Earth's crust.

surficial geology geology of surficial deposits, including soils; the term is sometimes applied to the study of bedrock at or near the earth's surface.

tailrace excavated channel or raceway that directs the water away from a turbine into the river channel.

tailwater water in the tailrace, or the level of this water.

tectonic deformation within the Earth's crust, and its consequent structural effects.

temporal pertaining to time.

terrestrial living on or in the ground, or related to the ground.

texture general physical appearance as shown by the size, shape and arrangement of the particles that make it up.

thalweg profile view of the lowest river bed elevation for successive river cross-sections, plotted with distance, along a river reach.

thermal plant generating station that uses coal or natural gas to create steam to drive a generator. Thermal plants are used at both Brandon and Selkirk, as well as a natural gas-fired simple-cycle combustion turbine at Brandon.

Threepoint Lake Ecodistrict subdivision in the Canadian Ecological Land Classification System hierarchy, which divides Canada's natural landscapes into 15 terrestrial Ecozones, which are then subdivided into 45 Ecoprovinces, 177 Ecoregions and 5,428 Ecodistricts. The Threepoint Lake Ecodistrict is 7,930 km^2; located in north-central Manitoba; lies within the glacial Lake Agassiz Basin; and the whole ecodistrict is part of the Nelson River drainage system.

toe point of intersection between the bottom of the slope of the downstream face of a set of falls or rapids, with the deeper river cross-section. The downstream extent of a set of falls or rapids; where the falls or rapids end.

topography general configuration of a land surface, including its relief and the position of its natural and man-made features.

Total Suspended Solids (TSS) portion of the total solids remaining in suspension (undissolved).

transient flow temporary, brief unsteady flow event, such would occur during the transition period of turning on or turning off powerhouse turbine units.

transmission electrical system used to transmit power from the generating station to customers.

tributary river or stream flowing into a larger river or stream.

turbine machine in a hydroelectric generating station which converts the energy of flowing water into rotary mechanical energy. This rotational energy is then transferred to the generator for conversion to electrical energy.

turbulence disturbed or agitated flow.

undulation wavy appearance.

ultramafic term applied to an igneous rock chiefly composed of mafic or dark-coloured minerals.

varved clay distinctly laminated lacustrine sediment (deposited in a body of still water within one year's time) consisting of clay-rich varves; also the upper, fine-grained "winter" layer of a glacial varve.

velocity speed of water measured in meters per second (m/s).

veneer thin layer or cover.

water level or stage**,** is the elevation or vertical distance of the free water surface above a datum. If the lowest point of the channel section is chosen as datum, the stage is identical with the depth of flow.

water regime description of water body (i.e., lake or river) with respect to water levels, flow rate, velocity, daily fluctuations, seasonal variations, etc.

water-washed refers to narrow river and downstream lake shoreline areas that are largely non to sparsely vegetated and that are periodically subjected to flooding, stream flow, wave action and/or ice-scouring under temporary high water level conditions. No eroded bank is observed and relatively minor near-shore erosion is inferred. This shoreline classification applies to upstream and downstream river reaches and downstream lakes mapped using low-level video coverage. The term applies to clay shorelines as well as non-eroding bedrock shorelines.

weathering destructive processes by which rocks are changed on exposure to atmospheric agents at or near the Earth's surface, with little or no transport of the loosened or altered material; the physical disintegration and chemical decomposition of rock that produce an *in-situ* mantle of waste and prepare sediments for transportation.

wind rose diagram showing yearly wind strengths for a locality.